ERGONOMIC STUDIES ON SELF PROPELLED BOOM SPRAYER

Dissertation

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
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DOCTOR OF PHILOSOPHY
in
FARM POWER AND MACHINERY
(Minor Subject: Computer Science and Engineering)

By

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CERTIFICATE I

This is to certify that the dissertation entitled, "**ERGONOMIC STUDIES ON SELF PROPELLED BOOM SPRAYER**" submitted for the degree of Ph.D., in the subject of **Farm Power and Machinery** (Minor subject: **Computer Science and Engineering**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Er. Naresh Kumar Chhuneja (L-2007-AE-44-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the dissertation entitled, "**ERGONOMIC STUDIES ON SELF PROPELLED BOOM SPRAYER**" submitted by **Er. Naresh Kumar Chhuneja** (Admission No. **L-2007-AE-44-D**) to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of Ph.D., in the subject of **Farm Power and Machinery** (Minor subject: **Computer Science and Engineering**) has been approved by the Student's Advisory Committee after an oral examination on the same.

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ABSTRACT

Based upon ergonomic considerations and stability against overturning, an operator's seat was developed to convert the boom sprayer into a riding type. Synthetic rubber based vibration isolators were developed and installed at engine mountings, base of handle bar, chassis-seat interfaces and handle grips of the boom sprayer. Studies were conducted under field conditions to determine the effect of provision of operator's seat with machine (M), provision of vibration isolators (V), forward speed (F) and subject (S) on vibrations, noise and physiological responses viz. heart rate (HR), volume of oxygen consumed (VO_2), overall discomfort rating (ODR) and body parts discomfort rating (BPDR). With the provision of vibration isolators (V_1), vibration acceleration were reduced by 0-13.9% at engine top, 59.4-74.0% at chassis, 73.5-86.5% at handle bar, 82.0-88.5% at handle, and 67.2-77.2% at seat base. ODR and BPDR of the operators were reduced by 43.0% and 25.7%, respectively with provision of vibration isolators on the boom sprayer. With the provision of vibration isolators (V_1), mean HR decreased from 99.4 to 89.0 beats/min and mean VO_2 from 778.9 to 514.6 ml/min; thereby leading to 51.6% reduction in human workload. Thus; the 'moderate work' for the boom sprayer without vibration isolators (V_0) was reduced to 'light work' category with the provision of vibration isolators (V_1). Based on the physiological parameters viz. HR and VO_2, it was concluded that there was a reduction in human workload by 9.5-12.7% with the provision of the operator's seat. The riding type (M_2) boom sprayer also reduced discomfort to the operator by 33.1% as compared to the walking type (M_1). All the dependent parameters increased significantly with increase in forward speed from 1.50 to 3.00 km/h of the sprayer. The sound pressure level was higher than safe limit of daily exposure of 8-h at forward speed of 2.25 and 3.00 km/h. Ergonomically it was concluded that a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed ranging between 1.50 and 3.00 km/h as the combination resulted in the lowest vibrations, light human workload and lowest discomfort. However, daily noise exposure to the subjects must be within safe limits as per standards.

Key Words: Ergonomics, vibrations, noise, physiological stress, discomfort, operator's seat, vibration isolators, self propelled boom sprayer.

Signature of Major Advisor **Signature of the Student**

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ਸਾਰ

ਚਾਲਕ ਸਮੇਤ ਵਿਓਂਤਬੰਦੀ ਅਤੇ ਸੰਤੁਲਨ ਦੇ ਆਧਾਰ ਨਾਲ, ਚਾਲਕ ਲਈ ਸੀਟ ਤਿਆਰ ਕਰਕੇ, ਬੂਮ ਸਪਰੇਅਰ ਨੂੰ ਬੈਠ ਕੇ ਚਲਾਉਣ ਯੋਗ ਬਣਾਇਆ ਗਿਆ। ਰਬੜ ਦੇ ਬਣੇ ਹੋਏ ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ ਤਿਆਰ ਕੀਤੇ ਗਏ ਅਤੇ ਉਨ੍ਹਾਂ ਨੂੰ ਇੰਜਨ ਦੇ ਥੱਲੇ, ਹੈਂਡਲ–ਛੜ ਦੇ ਆਧਾਰ, ਚੇਸੀ ਅਤੇ ਸੀਟ ਦੇ ਜੋੜਾਂ, ਅਤੇ ਹੈਂਡਲ ਦੀ ਪਕੜ–ਮੁੱਠੇ ਵਾਲੀ ਥਾਵਾਂ ਤੇ ਫਿਟ ਕਰ ਦਿੱਤਾ ਗਿਆ। ਖੇਤ ਵਿੱਚ ਕਾਮੇ ਦੀ ਸੀਟ, ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ, ਮਸ਼ੀਨ ਦੀ ਰਫਤਾਰ ਅਤੇ ਕਾਮਿਆਂ ਦਾ ਅਸਰ ਕੰਪਨ, ਸ਼ੋਰ–ਸ਼ਰਾਬਾ, ਸ਼ਾਰੀਰਕ ਪੈਮਾਨੇ ਜਿਵੇਂ ਕਿ ਦਿੱਲ ਦੀ ਧੜਕਨ, ਸਾਹ ਵਿੱਚ ਆਕਸੀਜ਼ਨ ਦੀ ਮਾਤਰਾ, ਸਮੁੱਚੀ ਬੇਆਰਾਮੀ ਅਤੇ ਵੱਖੋ–ਵੱਖਰੇ ਸਾਰੀਰਕ ਅੰਗਾਂ ਦੀ ਬੇਆਰਾਮੀ ਲਈ ਮਾਪਿਆ ਗਿਆ। ਰਬੜ ਦੇ ਬਣੇ ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ ਲਗਾਉਣ ਨਾਲ ਇੰਜਨ ਉਪਰ ਕੰਪਨ ਵਿੱਚ 0-13.9 %, ਚੇਸੀਸ ਉਪਰ 59.4–74.0 %, ਹੈਂਡਲ–ਛੜ ਉਪਰ 73.5–86.5 %, ਹੈਂਡਲ ਉਪਰ 82.0–88.5 %, ਅਤੇ ਸੀਟ ਦੇ ਥੱਲੇ 'ਤੇ 67.2–77.2 % ਕਮੀ ਦਰਜ ਕੀਤੀ ਗਈ। ਬੂਮ ਸਪਰੇਅਰ ਉੱਪਰ ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ ਲਗਾਉਣ ਕਰਕੇ ਸਮੁੱਚੀ ਬੇਆਰਾਮੀ ਵਿੱਚ 43.0 % ਅਤੇ ਸਾਰੀਰਕ ਅੰਗਾਂ ਦੀ ਬੇਆਰਾਮੀ ਵਿੱਚ 25.7 % ਕਮੀ ਦਰਜ਼ ਕੀਤੀ ਗਈ। ਇਸ ਦੇ ਨਾਲ–ਨਾਲ ਦਿਲ ਦੀ ਔਸਤ ਧੜਕਨ 99.4 ਤੋਂ ਘੱਟ ਕੇ 89.0 ਪ੍ਰਤੀ ਮਿੰਟ ਅਤੇ ਸਾਹ ਵਿੱਚ ਆਕਸੀਜ਼ਨ ਦੀ ਜਰੂਰਤ 778.9 ਤੋਂ ਘੱਟ ਕੇ 514.6 ਮਿਲੀਲਿਟਰ ਪ੍ਰਤੀ ਮਿੰਟ ਰਹਿ ਗਈ; ਜਿਸ ਕਰਕੇ ਚਾਲਕ ਦਾ ਕੰਮਭਾਰ 51.6 % ਘੱਟ ਗਿਆ। ਭਾਵ ਕਿ, ਬੂਮ ਸਪਰੇਅਰ ਉਪਰ ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ ਲਗਾਉਣ ਕਰਕੇ ਚਾਲਕ ਦਾ ਕੰਮਭਾਰ 'ਔਸਤ' ਦਰਜੇ ਤੋਂ ਘੱਟ ਕੇ 'ਹਲਕੇ ਕੰਮ' ਤੱਕ ਰਹਿ ਗਿਆ। ਦਿਲ ਦੀ ਧੜਕਨ ਅਤੇ ਸਾਹ ਵਿੱਚ ਆਕਸੀਜਨ ਦੀ ਮਾਤਰਾ ਦੀ ਮਿਨਤੀ ਤੋਂ ਇਹ ਪਤਾ ਲੱਗਿਆ ਕਿ ਮਸ਼ੀਨ ਪਿੱਛੇ ਤੁਰਨ ਦੀ ਸੂਰਤ ਦੇ ਮੁਕਾਬਲੇ ਸੀਟ ਉਪਰ ਬੈਠ ਕੇ ਕੰਮ ਕਰਨ ਨਾਲ ਚਾਲਕ ਦਾ ਕੰਮਭਾਰ 9.5–12.7 % ਘੱਟ ਗਿਆ। ਸੀਟ ਉਪਰ ਬੈਠ ਕੇ ਸਪਰੇਅਰ ਚਲਾਉਣ ਨਾਲ ਸਾਰੀਰਕ ਬੇਆਰਾਮੀ ਵੀ 33.1 % ਘੱਟ ਗਈ। ਮਸ਼ੀਨ ਦੀ ਰਫ਼ਤਾਰ, 1.50 ਤੋਂ 3.00 ਕਿਲੋਮੀਟਰ ਪ੍ਰਤੀ ਘੰਟਾ, ਵਧਾਉਣ ਨਾਲ ਸਾਰੇ ਪਰਾਧੀਨ ਮਾਪਦੰਡਾਂ ਵਿੱਚ ਕਾਫੀ ਵਾਧਾ ਦਰਜ਼ ਕੀਤਾ ਗਿਆ। 2.25 ਅਤੇ 3.00 ਕਿਲੋਮੀਟਰ ਪ੍ਰਤੀ ਘੰਟੇ ਦੀ ਰਫਤਾਰ ਵੇਲੇ ਮਸ਼ੀਨ ਦੀ ਆਵਾਜ 8 ਘੰਟੇ ਦੀ ਸੁਰਖਿਅਤ ਸਿਫਾਰਸ਼ ਵਾਲੇ ਦਰਜੇ ਤੋਂ ਘੱਟ ਦਰਜ ਕੀਤੀ ਗਈ। ਸਾਰੇ ਤਜਰਬਿਆਂ ਤੋਂ ਇਹ ਸਿੱਟਾ ਕੱਢਿਆ ਗਿਆ ਕਿ ਚਾਲਕ ਦੇ ਬੈਠ ਕੇ ਕੰਮ ਕਰਨ ਵਾਲਾ ਬੂਮ ਸਪਰੇਅਰ, ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ ਲਗਾ ਕੇ ਡੇਢ ਤੋਂ ਤਿੰਨ ਕਿਲੋਮੀਟਰ ਪ੍ਰਤੀ ਘੰਟੇ ਦੀ ਰਫਤਾਰ ਤੱਕ ਵਰਤਿਆ ਜਾ ਸਕਦਾ ਹੈ ਕਿਉਕਿ ਇਸ ਨਾਲ ਕੰਪਨ, ਚਾਲਕ ਦਾ ਕੰਮਭਾਰ ਅਤੇ ਸਾਰੀਰਕ ਬੇਆਰਾਮੀ ਸਭ ਤੋਂ ਘੱਟ ਸੀ। ਪਰੰਤੂ ਸ਼ੋਰ–ਸ਼ਰਾਬੇ ਦੀ ਸਿਫਾਰਸ਼ ਕੀਤੀ ਸੁਰਖਿਅਤ ਮਿਆਦ ਦਾ ਧਿਆਨ ਰੱਖਣਾ ਪਵੇਗਾ।

ਸ਼ਬਦ ਕੁੰਜੀ: ਚਾਲਕ ਸਮੇਤ ਵਿਓਂਤਬੰਦੀ, ਕੰਪਨ, ਸ਼ੋਰ–ਸ਼ਰਾਬਾ, ਸਾਰੀਰਕ ਥਕਾਵਟ, ਬੇਆਰਾਮੀ, ਚਾਲਕ ਸੀਟ, ਕੰਪਨ–ਘਟਾਓ ਯੰਤਰ, ਸਵੈ–ਚਾਲਤ ਬੂਮ ਸਪਰੇਅਰ।

ਸਲਾਹਕਾਰ ਦੇ ਦਸਤਖ਼ਤ **ਵਿਦਿਆਰਥੀ ਦੇ ਦਸਤਖ਼ਤ**

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%	:	per cent
<	:	less than
>	:	greater than
≥	:	greater than or equal to
≈	:	almost equal to
§	:	section
ANOVA	:	Analysis of Variance
Avg.	:	Average
BIS	:	Bureau of Indian Standards
BPDR	:	Body parts discomfort rating
C.D.(5%)	:	Coefficient of Differentiation at 5% level of confidence
C.V.	:	Coefficient of Variation
cal	:	calorie
cm	:	centimeter
CRD	:	Completely Randomized Design
d.f.	:	degrees of freedom
dB(A)	:	decibels acoustic
et al.	:	and others
F_1	:	Forward speed of 1.50 km/h
F_2	:	Forward speed of 2.25 km/h
F_3	:	Forward speed of 3.0 km/h
Fig.	:	Figure
F-ratio	:	Calculated value of F-test
GDP	:	Gross Domestic Product
h	:	hour
ha	:	hectare
HR	:	Heart Rate
HTV	:	Hand transmitted vibrations
Hz	:	Hertz
i.e.	:	that is
ISO	:	International Organization for Standardization
J	:	Joule
kg	:	kilo gram
kJ	:	kilo Joule
km	:	kilometer
kW	:	kilo Watt
l	:	liter
m	:	meter
M.S.	:	Mean Sum of Squares
M_1	:	Walk behind type boom sprayer
M_2	:	Riding type boom sprayer
min	:	minute
ml	:	milliliter
mm	:	millimeter
ºC	:	degree Centigrade
ºF	:	degree Fahrenheit
ODR	:	Overall discomfort rating
OSHA	:	Occupational Safety and Health Administration, USA

R	:	Respiratory quotient
r^2	:	coefficient of determination
RH	:	Relative Humidity
rms	:	root mean square
rpm	:	revolutions per minute
s	:	second
SPL	:	Sound Pressure Level
UTM	:	Universal Testing Machine
V_0	:	Vibration isolators not provided
V_1	:	Vibration isolators provided
VO_2	:	Volume of oxygen consumed
VCO_2	:	Volume of carbon dioxide exhaled
viz.	:	namely
WBV	:	Whole body vibrations
WHO	:	World Health Organization

Chapter I

INTRODUCTION

India has made impressive strides on the agricultural front since independence. India’s food-grain production has grown from 50.82 million tonnes in the year 1950-51 to 234.47 million tonnes in 2008-09 (Anonymous, 2010). The cultivated area increased from 97.32 million hectares in 1950-51 to 122.83 million hectares in 2008-09, the yield of food-grains increased from 522 to 1909 kg/hectare during the same period. This is a proud performance and speaks of commendable achievements in the Indian agriculture. Under the assumption of 3.5% growth in GDP (low income growth scenario), demand for food-grains is projected in the year 2020 at the level of 256 million tons comprising 112 million tons of rice, 82 million tons of wheat, 39 million tons of coarse grains, 22 million tons of pulses, etc (Singh, 2003). The agriculture sector recorded satisfactory growth due to improved technology, irrigation, inputs and pricing policies. An accelerated growth of mechanization is required in order to increase food production to keep pace with the rising population.

One of the problems affecting yield of crops is the weeds, and insect-pests; thus, necessitating their control. Application of weedicides and pesticides is one of the labour intensive operations in agriculture production. Presently manual knapsack sprayers are being used for plant protection. The output of these sprayers is low and non-uniform. Tractor operated sprayers are not suitable in wheat crop because of wide tyres compared to narrow crop-rows spacing. To solve the above problems, a self-propelled walk behind type boom sprayer with narrow wheels has been developed at Punjab Agricultural University, Ludhiana, India. The machine has an adjustable boom with 12 nozzles and can be used for spraying in wheat and vegetable crops. When operated at a forward speed of 2.25-2.50 km/h, its field capacity is 1.0-1.2 ha/h (Garg *et al*., 2004). The machine having a high field capacity has a potential scope for its adoption for custom hiring.

The ergonomic aspects of power sprayer are of great importance as the operator has to walk behind the machine for a distance of about 18 to 20 km in a day in field. Besides walking in field, stress due to mechanical vibrations, human workload, noise, etc. also affect performance of the operator. If ergonomic aspects are not given due consideration, the performance of the man-machine system will be poor and the effective working time will be reduced.

Mechanical vibrations have instantaneous and long term effects upon the human body. Kinds of effect depend upon the duration of exposure and the frequency of vibrations. In walk behind type machine, vibrations are transmitted to the operator through his hands. In case of a riding type, vibrations are transmitted to the operator through seat as whole body vibration (WBV) and through his hands as hand transmitted vibrations (HTV). Workers exposed to hand arm vibrations often experience aches and pains in upper limbs (Palmer *et al*., 2001). Current studies suggest that forceful, repetitive manual work, alongwith prolonged static loading and exposure to vibrations are established areas of risk (Buckle, 1997). The epidemiological literature provides substantive evidence of a relationship between exposure to factors in the work system and development of disorders. Vibration exposure to the hand often produces various disorders like, vascular neurological, musculoskeletal, articular and other effects. The term hand-arm vibration syndrome is used collectively for the different symptoms associated with manual work involving vibrating power tools. Daily exposure to hand arm vibrations over a period can cause permanent physical damage known as "White Finger Syndrome" or Raynaud's phenomenon of occupational origin. This begins with numbness and can lead to cold provoked blanching, cyanosis and even partial necrosis of the finger tip (Taylor, 1985). Vibration-related disturbances to the sensory system may present as a loss of sensation, or dexterity in the hand, or fingers, while musculoskeletal symptoms may include a reduced hand-grip strength (Wasserman and Taylor, 1991) and/or joint damage (Taylor, 1985). Exposure to whole body vibrations can cause back injury. Hence measurement and evaluation of vibrations are necessary for assessing operator's comfort and to suggest remedial measures for continuous operation of machine.

The noise produced by engines may cause discomfort, nervousness, tension, irritability and fatigue. Levels from 86 to 115 dBA can cause specific effects to the ear such as the damage of the corticells and can involve psychosomatic diseases (Cosa and Cosa, 1989). Noise also results in increase in the pulse rate & blood pressure and irregularities in heart rhythm.

With the introduction of modern technology, ergonomics becomes essential for its successful application. It is important to maintain a safe, healthy and productive environment for farm workers. For reliability of man-machine system, human operator and machine are to be considered in series – the failure of any one will result in failure of the system. The ultimate objective of the ergonomic studies is to optimize the man-machine-environment system to harness greater system efficiency. Having recognized that the social costs due to ill-health and injuries are real and substantial, the ergonomics as a scientific discipline can improve farming for socio-technical development. To achieve better efficiency of performance alongwith more human comfort, it is necessary to design and develop agricultural machinery keeping operator's capabilities and limitations into consideration. Ergonomic evaluation is necessary to assess the human energy expenditure in combination to man-machine system performance for a continuous work schedule of sufficient duration without suffering from excessive fatigue. The method which gives better field capacity, lower human energy cost, longer continuous work schedule with comfort and safety is recommended for agricultural operations.

The power tiller is being used in large numbers for tillage operations in Indian agriculture. Its engine acts as a source of vibrations; and hence, causes fatigue to its operator. The walk behind type power tillers have been successfully converted to riding type resulting in significantly reduced fatigue to the operators (Tiwari and Gite, 2000; Tiwari and Varshney, 2002; Tewari *et al.*, 2004; Tiwari *et al.*, 2005; Tiwari and Narang, 2006; Sam *et al.*, 2007). The synthetic rubber vibration isolators provided the simplest, inexpensive, and easy to adopt solution for control of vibrations and also noise (Mehta *et al.*, 1997; Sam and Kathirvel, 2006; Kathirvel *et al.*, 2007; Dewangan and Tewari, 2008; Sam and Kathirvel, 2009; Tewari and Dewangan, 2009; Dewangan and Tewari, 2009). Self propelled boom sprayer is a similar machine developed for chemical control of weeds. The developed sprayer is a walk behind type and has a mounted engine as its source of power, a water tank of 100 litres capacity and a reciprocating piston type spray pump. All these lead to a lot of vibrations and fatigue to the operator; thus, affect the performance of the man-machine system. No ergonomic study has been conducted on self propelled boom sprayer; hence, necessitating incorporation of seat and vibration isolators for their assessment from ergonomic point of view to improve its performance.

Keeping in view the above facts, the study was planned with the following objectives:

1. To develop a seat and vibration isolators for self propelled boom sprayer.
2. To study the effect of operational and design parameters of machine on vibrations, noise and physiological parameters of subjects.
3. To suggest the optimum man-machine parameters on the basis of results of study under objective-2.

Chapter II

REVIEW OF LITERATURE

The present ergonomic study on self propelled boom sprayer was conducted to develop a seat and vibration isolators and to determine their effect alongwith forward speed and subjects on physiological responses viz. heart rate, oxygen consumption, discomfort score; vibrations and noise. Measurement of physical work, their examination and correlation of human-expenditure with work output via physiological measurements has been the subject of much of the previous studies. Many studies have been conducted to determine these physiological responses in relation to self propelled agricultural machinery especially hand tractors and power tillers. Since these studies are related with the present one, their brief review has been included in this chapter.

2.1. Selection of Subjects

The subject (operator or worker) has an important role in ergonomic studies. The subjects must be medically fit and of a normal clinical state and ECG test (Seidel *et al.*, 1980). The subject should represent real user population in operation of the selected machinery. The subjects are selected on the basis of gender, age and weight. Generally male subjects are selected for conducting ergonomic studies on agricultural machinery in India. Gite *et al.* (2009) provided anthropometric and strength data of Indian agricultural workers for use in design and development of farm equipment.

2.1.1. Age of Subject

Deupree and Simon (1963) compared the reaction time and the movement time of group of elderly people (median age = 75 years) with a group of energetic young (median age = 20 years). It was found that the reaction time of the older group was 11 per cent slower and the movement time was 38 per cent slower.

Malhotra *et al.* (1966) reported that physical functions show some deterioration with age after 30 years; the strength, agility, arm and shoulder strength, and capacity for short bursts of activity. The aged, however, can be consoled by the encouraging comments of Muller (1953), who pointed that whereas maximum physical work capacity may drop with age, occupational work capacity (in many occupations) is not affected materially in modern industry. In part, this is due to the fact that modern industrial activities generally are less strenuous than in bygone days; in part this physical deterioration is compensated for by increased experience and skill.

The maximum force a muscle or group of muscles can exert depends upon the age. Grandjean (1982) stated that the peak of muscle strength for both men and women is reached between the age of 25 and 35 (Fig. 2.1). The workers aged between 50 and 60 years can exert only about 75-85 percent of muscular strength.

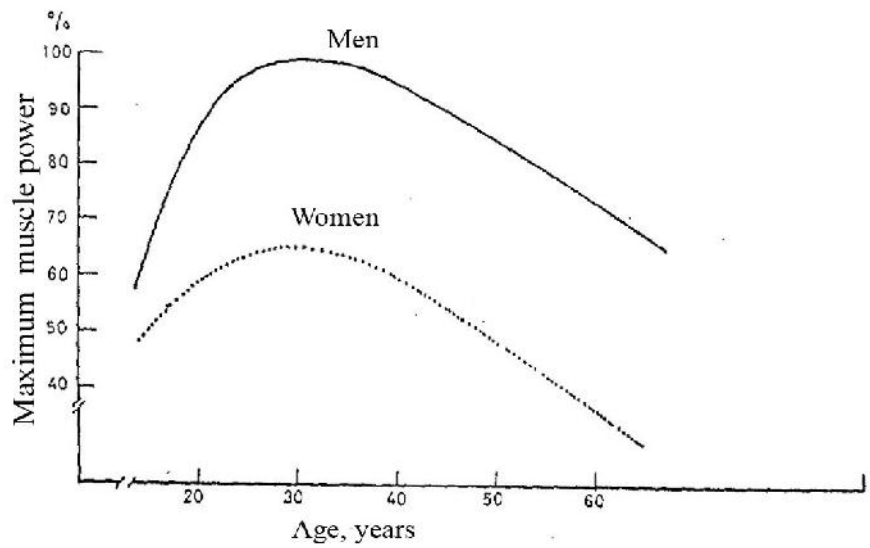

Fig 2.1. Muscle power with respect to age and sex (Grandjean, 1982).

Rodahl (1989) quoted the maximum heart rate declining with the age (in years). He defined HR_{max}, the maximum heart rate a normal person could be allowed during an experiment:

$$HR_{max} = 220 - age \qquad \text{------ (1)}$$

The volume of maximum oxygen consumption (VO_{2max}) is the oxygen consumption by the subject corresponding to HR_{max} achieved during an experiment. Care is to be taken for the subject so as not to cross HR_{max} i.e. the upper limit of heart rate allowed during an activity. The respiratory quotient (R), which is the ratio of volume of carbon dioxide (VCO_2) exhaled and volume of oxygen (VO_2) intake by the subject, is 1.10 at the level of VO_{2max}.

Mc Ardle *et al.* (1994) reported that the body functions generally improve rapidly during childhood and reach to the maximum level between 20-30 years of age. Thereafter, there is a gradual decline in functional capacity with advancing years.

Gite and Singh (1997) found that the maximum strength can be expected from the age group of 25 to 35 years. Nigg and Herzog (1999) reported that maximum muscle strength and the cross sectional area of muscle is greatest for the age group of 25 to 35 years.

2.1.2. Weight of Body

Body weight has great impact on all activities in which the worker has to move his body. Morrison and Harrington (1962) found that the ischial tuberosities (lower most projections of the pelvis) normally carry the weight of the upper part of the body and these projections spaced only 108 to 114 mm apart in the human adult and are capable of transmitting large force directly and uniformly into spinal column.

Griffin (1982) conducted study on sound and vibration and reported that both male and female subjects in seated posture, with more weight tend to be relatively less sensitive to low frequencies (less than 6.3 Hz) and more sensitive to high frequency of vertical vibration.

2.2. Physiological Responses

Physical activities stimulate certain physiological responses in human beings. These responses provided basis for human energy expenditure and fatigue. Weybrew (1967) gave the various measures for physiological and psychological stress and strain (Fig 2.2). When any work or activity is done, it gives physical exertion to the body and is characterized by high energy consumption and stress on the heart and lungs. So physiological response, in any work or operation is expressed in terms of cardio- respiratory response. The parameters measured are the heart rate and pulmonary ventilation rate or oxygen consumption rate. The heart rate indicates the total stress on the body.

2.2.1. Heart Rate

Le-Blanc (1957) reported a linear relationship between heart rate and the intensity of physical exercise. The price per unit of work (in physiological terms) goes up at an increasing rate with the rate of body movement (as in walking and running). This has been shown by heart rate during and after marching a 1600 meter course when 18 subjects marched at speeds ranging from 4.9 to 15.2 km/h. The increasing energy cost shoots up rather sharply at speed of 8.1 km/h and above. Besides, recovery time also increases markedly.

Brouha (1960) reported that physical fitness depended to a great extent on the circulatory capacity which in turn was closely related to pulse rate. He found that the fit as well as unfit subjects reached their maximum heart rate for maximal work. But the fit subject was able to perform work for longer duration before he reached that level then the unfit.

Morehouse and Miller (1963) stated that a starting period of 3-5 minutes is suitable for pulse rate to stabilize depending on the nature of exercise.

Brouha (1967) showed that the emotions and other physiological conditions also cause the heart rate to increase. Initially, the normal heart rate of the college students in an experimental study was found to be 82 and while waiting for their turn to run on treadmill, the normal heart rate rose to 125.

Tomlinson (1970) reported that the heart rate increases rapidly at the start of work and greatest increase takes place within first fifteen seconds of the exercise and then gradually becomes constant. In case of unduly heavy exercise, a secondary increase of pulse rate may also occur.

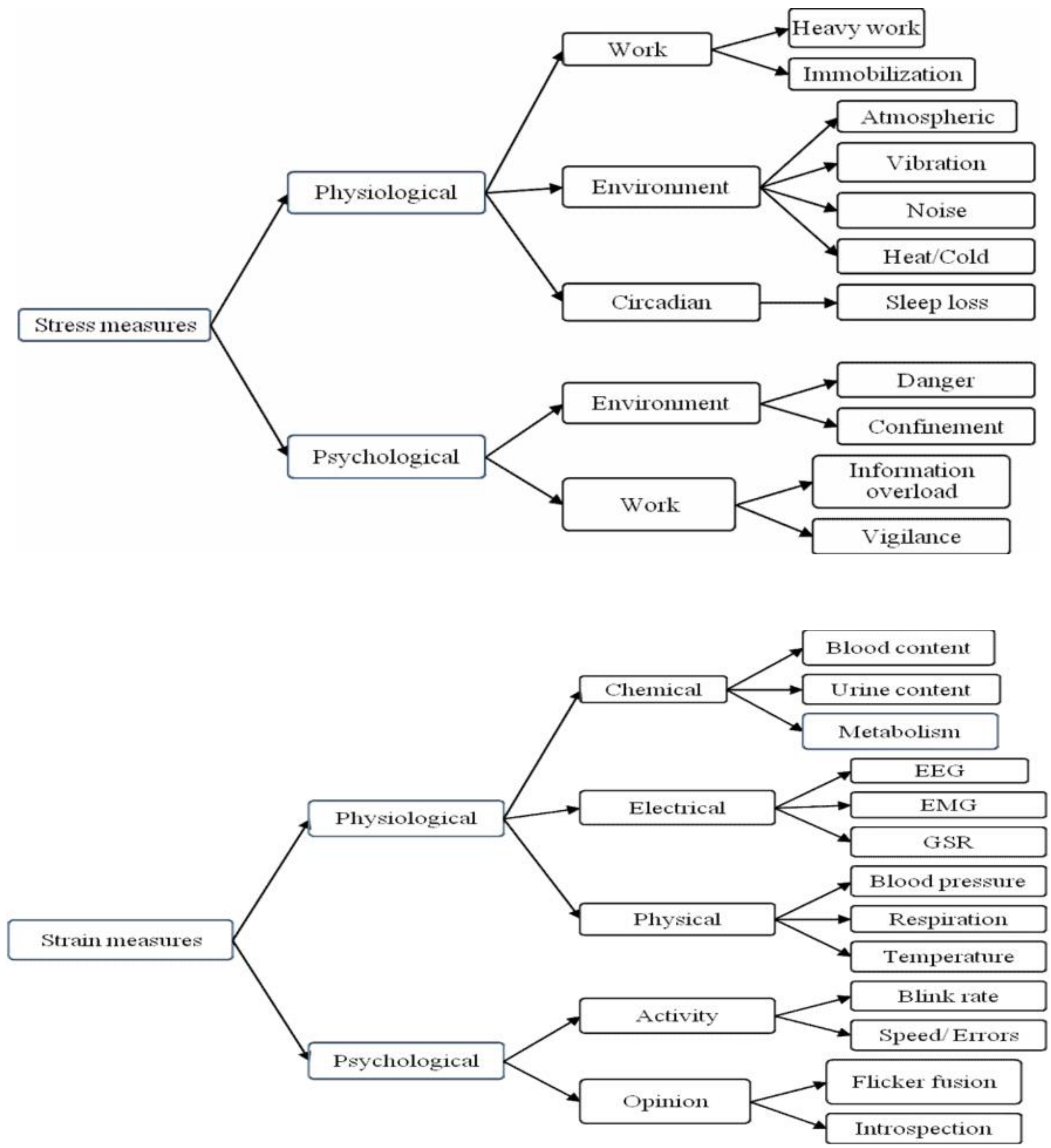

Fig.2.2. Stresses and strains in ergonomic studies (Weybrew, 1967).

Pawar (1978) conducted study on power tiller operator during seedbed preparation. He reported that the heart rate was in the range of 105 to 114 beats/min. The corresponding human energy requirement was in the range of 13.22 to 20.52 kJ/min. The heart rate was measured as an index of strain.

Sanchez *et al.* (1979) conducted study on effect of dynamic, static and combined work on heart rate and oxygen consumption. The dynamic work consisted of walking on a horizontal treadmill on four different speeds i.e. 0.56, 0.83, 1.11 and 1.39 m/s. The static work consisted of pushing against, pulling and holding 6, 9, 12, 18 and 24 kg weight. A significant difference in oxygen consumption and heart rate was observed for all the walking-pushing tests. Linear relationship was obtained between cardiac cost and load when walking at 0.56 or 0.83 m/s, with correlation coefficients statistically significant for pushing and pulling but not found significant for holding weight. It was concluded that when static work was combined with walking, the physiological cost varied with the type of static work.

Verma *et al.* (1979) compared two methods of indirect measurement of energy output at work viz. minute ventilation and heart recording. They evolved multiple linear regression equation for estimating energy expenditure from minute ventilation rate and heart rate during grade of sub maximal work on a bicycle ergometer for 55 human subjects involving 165 observations. The product moment correlation of minute ventilation and heart rate with energy expenditure were 0.74 and 0.59 respectively and multiple correlation coefficients between observed energy expenditure and both minute ventilation and heart rate was 0.8. It was concluded that the multiple correlation coefficient between observed energy expenditure and both minute ventilation and heart rate was a better predictor of energy expenditure than the use of either of the two variables singly.

Evans *et al.* (1983) conducted study on physiological response to load holding and load carriage on heart rate of the seven young male subjects. Experiments were carried out on 15, 20, 25, 30, and 40 kg load. It was found that heart rate increase (ΔHR) at exhaustion was linearly related to the load, and was greater when the load was carried rather than simply held. It happened because electromyography activity in the forearm flexor muscles increased when the load was carried and appeared in the form of marked fluctuations synchronous with stepping frequency. In the holding case the contractions are essentially static and isometric, whereas when the subject carries the load and the load undergoes vertical accelerations with respect to the subject's trunk, the contractions are dynamic and are alternately concentric and eccentric.

Datta *et al.* (1985) conducted study on the energy cost of pulling hand carts ('*thela*') by ten healthy subjects in the age group of 20-45 years. During experiments the environmental temperature varied between 31 to 33°C. The subject was to pull the unloaded hand cord (190 kg weight), then successively with loads of 185 and 370 kg. During pulling operation, the speed was maintained at 5 km/h. The pulmonary ventilation rate, heart rate and energy expenditure increased in an almost linear fashion with increasing work load. The mean heart rate at no load was 107 beats/min. The mean heart rate at 185 kg and 370 kg load was 133.7 and 155.5 beats/min, respectively. Energy expenditure and heart rates under different operational conditions showed that pulling a loaded cart represents very heavy work.

Mass *et al.* (1989) studied the validity of the use of heart rate in estimating oxygen consumption in static and in combined static/dynamic exercise. The experiment was conducted on eight healthy subjects. Heart rate and oxygen consumption of subjects were measured in weight holding task (static exercise) and weight carrying task (combined static and dynamic exercise with varying weight from 4 to 12 kg. From the test, they concluded that it was not accurate to use measured heart rate in static work for prediction of oxygen consumption in dynamic task. However in combined exercise i.e. static and dynamic work a simple dynamic task could accurately be used to predict oxygen consumption from measured heart rate while carrying small weights (4, 8 and 10 kg).

Tiwari and Gite (2000) studied physiological responses in operations by a 10.5 kW rotary power tiller. With seating attachment, the mean heart rate varied from 85.1 to 90.2 beats/min with increase in forward speed from 1.04 to 4.14 km/h. Without seating attachment, the heart rate varied from 90.3 to 134.0 beats/min with increase in forward speed from 1.06 to 4.16 km/h.

Tiwari and Gite (2002) carried out a study on physiological responses during rota-tilling and rota-puddling operations by a 6·7 kW rotary power tiller. Another set of experiments was conducted to measure the physiological responses while the operators walked alone on a puddled field. During the rota-tilling operation, the mean values of heart rate were 97, 103 and 110 beats/min at forward speeds of 0·30, 0·47 and 0·63 m/s, respectively. The corresponding values during rota-puddling operation were 101, 109 and 119 beats/min. Mean values of heart rate while the operators walked alone on puddled field were 99, 105 and 112 beats/min at the above forward speeds.

Tiwari *et al.* (2005) developed an operator's seat as an attachment to 6.7 kW power tiller. Mean heart rate varied from 81.7 to 87.6 beats/min with increase in forward speed from 0.28 to 0.62 m/s with the operator's seat. Without the operator's seat, the heart rate varied from 94.9 to 108.0 beats/min with increase in forward speed from 0.29 to 0.63 m/s.

Tiwari and Narang (2006) provided an operator's seat on power tiller for dry rota-tilling. Mean heart rate during operation of power tiller with and without operator's seat were 103.2 and

129.2 beats/min respectively. The corresponding increase in heart rate over resting values were 22 and 44.5 beats/min. Statistical analysis of data indicated that increase in heart rate (ΔHR) was significantly lower while operating power tiller with operator's seat than those without seat.

Dixit (2006) conducted ergonomic studies on agricultural workers performing selected farm operations in cotton crop. The heart rate varied between 96-111 beats/min while operating knapsack sprayer. Yadav and Pund (2007) developed a manually operated weeder and tested it ergonomically. The peak heart rate of the subjects was found to range from 142 to 150 beats per min. In case of heavy work and dense grass infested field, the rest pause of 14 min was required by the subjects to come to the normal heart rate. Narang (2010) developed and evaluated a revolving magazine type transplanting mechanism for vegetable nursery transplanter. The heart rate ranged between 80.71 and 91.95 beats/min and overall discomfort rate between 1 and 4 while feeding seedlings.

2.2.2. Oxygen Consumption (VO_2) and Pulmonary Ventilation Rate (PVR)

The oxygen consumption represents an individual capacity to utilize oxygen. It states that a point is reached where increase in work rate is no longer accompanied by increase in oxygen uptake and the individual is assumed to have reached her or his maximum level of oxygen uptake.

Durnin and Edwards (1955) found that the oxygen consumption of and individual was directly proportional to PVR for light and moderate exercise (PVR was normally less than 50 1/min). The relationship between PVR and oxygen consumption varied from individual to individual. So a separate regression line had to be determined for each individual. Karpovich (1966) also reported a linear relationship between PVR and oxygen consumption which are true not only during work but also during recovery period.

Singh (1972) conducted an experiment on various agricultural operations like spading, spraying and some manual methods of load transport to find out human energy requirements. He concluded that there is a linear relationship between PVR and intensity of physical exercise. In the tasks studied, spraying was least energy demanding with VO_2 not exceeding 0.71 l/min while for spading VO_2 requirement was 1.60 l/min. Pulling while facing the direction of travel demanded VO_2 of 2.14 l/min. Load carried in lap of hands at chest level demanded VO_2 of 1.81 l/min.

Astrand and Rodahl (1977) found that running on the treadmill at ≥ 3° inclination could bring the oxygen consumption to the maximum whereas running horizontally or at a slight inclination may result in somewhat lower VO_2 uptake. It was observed that higher oxygen uptake was obtained when running uphill as compared to that of bicycle ergometer. It was caused by the activation of a larger muscle mass during running uphill, since simultaneous work with both arm and legs did not increase maximal aerobic effect when compared to the work with legs only.

Saha *et al.* (1979) determined acceptable workloads for Indian workers. To determine it for sustained physical activity, five physically active young, healthy workers aged 20-24 years, were subjected to run on tread mill at different loads. It was found that acceptable work load for average workers was between 30 to 40 percent of individual's maximum aerobic power. The corresponding energy expenditure and heart rate were 18 kJ/min and 110 beats/min respectively. Energy expenditure rate (kcal/min) for male operators from heart rate (beats/min) response can be estimated using the formula mentioned below:

$$\text{Energy expenditure rate} = \{\text{Heart rate} - 66\} / (2.4 \times 4.187) \qquad \text{------ (2)}$$

Nag *et al.* (1980) conducted experiments on 13 agricultural workers performing thirty different operations like nursery sowing, water supply, transplanting, weeding, threshing, etc. during the actual working season. During these operations oxygen consumption varied from 28.6 to 41.5 cm^3/min kg with maximum of 34.8 cm^3/min kg. PVR varied from 14 to 41 liter/min only for water lifting, but bund trimming in dry land and pedal threshing operations were found as heaviest and jobs demanded more than 30 l/min of PVR. They concluded that 29 percent of total men were involved in light work, 64 percent in moderate work and only 6 percent in heavy work.

Jorgensen (1985) suggested the upper tolerance limit for continuous dynamic work at a constant work pace over an 8 hour working day without any changes in homoeostasis, to be 50% of VO_{2max} in trained subjects and 35% VO_{2max} in untrained subjects. Wu and Wang (2002) developed three maximum acceptable work time and physical load. Based on the models, they suggested upper limit of percent VO_{2max} for dynamic work lasting 12, 10, 8 and 4 h were 28.5, 31.0, 34.0 and 43.5% respectively. The results were similar to the recommendations proposed by Rodgers *et al.* (1986) who suggested 28.0, 30.5, 33.0 and 45.0 percent VO_{2max} for sustained workload limit of 12, 10, 8 and 4 h respectively.

Astrand and Rodhal (1986) suggested that there is a linear relationship between heart rate and oxygen consumption of the subject. The heart rate under standardized condition may be used as an index of oxygen uptake for a given task. By comparing the pulse rate obtained at different ergometer workloads with the pulse rate obtained during work, severity of the work could be estimated. It was recommended that the heart rate should be measured to assess the workload. However, it was pointed out that pulse rate may be significantly affected by other external factors like environment factors, work position, emotional stress, size of working muscle groups, static work components and stress and dehydration.

Verma (1994) developed nomograms based on cardio respiratory stress, body weight and time for 3.2 km run for predicting maximal aerobic power. If these nomograms are used, sophisticated laboratory facilities are not required for predicting the aerobic capacity.

Gite and Singh (1997) compared the activity of ergonomics in agricultural and allied activities in India. They summarized the findings of different scientists on maximum aerobic capacity. The maximum aerobic capacity (VO_2) of Indian male agricultural workers varied from 1.95 to 2.24 l/min.

Bot and Hollander (2000) investigated the heart rate (HR) response to oxygen uptake (VO_2) under varying non-steady state activities. Dynamic and static exercise engaging large and small muscle masses were studied in different experiments. Simultaneous heart rate and VO_2 measurement were made. Linear regression analyses revealed high correlation between heart rate and VO_2. It has been concluded that VO_2 may be estimated from individual Heart Rate-VO_2 regression lines for non-steady state exercise during both the interval test and field test.

Tiwari and Gite (2000) studied physiological responses in operations by a 10.5 kW rotary power tiller. The mean oxygen consumption rate (VO_2) varied from 0.32 to 0.43 l/min with increase in forward speed from 1.04 to 4.14 km/h with seating attachment. Without seating attachment the VO_2 varied from 0.42 to 0.77 l/min with increase in forward speed from 1.06 to 4.16 km/h.

Tiwari and Gite (2002) carried out a study on physiological responses during operations by a 6·7 kW rotary power tiller. During the rota-tilling operation, the mean values of oxygen consumption rate were 0·48, 0·58 and 0·63 l/min at forward speeds of 0·30, 0·47 and 0·63 m/s, respectively. The corresponding values during rota-puddling operation were 0·56, 0·70 and 0·86 l/min. Mean values of oxygen consumption rate while the operators walked alone on puddled field were 0·54, 0·63 and 0·75 l/min at the above forward speeds.

Tiwari *et al.* (2005) developed an operator's seat as an attachment to 6.7 kW power tiller. Mean oxygen consumption rate varied from 0.45 to 0.50 l/min with increase in forward speed from 0.28 to 0.62 m/s with the operator's seat. Without the operator's seat, oxygen consumption rate varied from 0.54 to 0.70 l/min with increase in forward speed from 0.29 to 0.63 m/s.

Sam *et al.* (2007) investigated physiological response of the subject while operating two power tillers with one as walking type (7.46 kW) and the other as riding type (8.95 kW). The selected operations included rotary tilling in untilled and tilled fields and transport on farm and bitumen roads. The forward speed of operation was 1.5-2.4 km/h and 3.5-5.0 km/h for field and transport operations respectively. For field operation with the walking type power tiller, the oxygen uptake in terms of the oxygen consumption rate (VO_{2max}) varied from 35.30 to 43.93

percent which was above the acceptable work load; whereas the values varied from 29.04 to 33.74 percent for the riding type power tiller and was within the acceptable workload. During transport mode, oxygen uptake in terms of VO_{2max} varied from 22.24 to 28.03 percent and the values were within the acceptable limit for both power tillers.

2.2.3. Effect of Environment on Physiological Response

Le Blanc (1957) studied four subjects at three levels of workload (15, 22 and 29 steps per minute on a 15 cm platform) for one hour at 42, 55, 70 and 80˚F. He found that heart rate is linear at all the levels of activity. The breakage of linear relationship beyond 80˚F shows the effect of heat stress.

Suggs and Splinter (1961) conducted study on the effect of environment on the allowable workload of man. A subject exposed to a mean radiant temperature of 158°F experienced a heart rate increase, due to the radiation, of 8 to 9 beats per minute above base values taken at a mean radiant temperature of 88°F, whether working or not. On the basis of subject's normal response to bicycle ergometer work, this increase was equal to a work load of 53.7 kg-m/min. It was also reported that at a low relative humidity (about 30%) the allowable workload was not affected by the temperature. Also at a moderate temperature (about 70°F), the allowable workload was also not affected by relative humidity. At temperature above this level, higher humidity depressed the allowable workload, whereas below this level it increased the allowable workload. It was specially mentioned that pulse rate and work out linearity was not disturbed under constant environmental conditions.

Gupta *et al.* (1977) studied the effect on metabolic responses during sub-maximal and maximal workload in dry and humid heat. It was reported that there was no significant increase in the heart rate with increase in the temperature (29 to 40 ^{0}C) and relative humidity (50 to 55%) for fixed workload of 600 kg-m/min (98.03 watt). But maximum oxygen consumption showed a significant fall in very hot and extremely hot conditions with greater fall in humid condition than in dry environment.

Thakur and Das (1978) investigated the effect of environment and modes of operation on rate and limitations of manual work output inside and outside the laboratory. Leg and hand cranking modes of operation were selected on the bicycle ergometer. PVR, heart rate and oxygen consumption rate were measured at various workloads. It was found that all the physiological parameters increased linearly with workload. They also found that subject felt uncomfortable and showed early sign of fatigue in hot condition than in cool condition. It was concluded that heart rate of 98 to 120 beats/min was more reliable physiological index for measurement of stress in environmental conditions for comparing the subjects at different modes of operation. The variation was found to be mainly due to temperature variation rather than subject variation.

2.2.4. Energy Cost of Physical Activities

Murrell (1965) presented the following formula for total amount of rest required for any given work activity, depending on its average energy cost.

$$R = \frac{T(K - S)}{K - 1.5} \qquad \text{------ (3)}$$

In which, R was rest required in minutes, T was total working time, K was average kilocalories per minute of work and S was kilocalories per minute adopted as standard. The value of 1.5 in denominator was an approximation of resting level in kilocalories per minute.

Saha *et al.* (1979) reported that acceptable work load for average young worker varies between 30 to 40 percent of an individual's maximum aerobic power under comfortable environmental conditions. The corresponding heart rate and energy expenditure were 110 beats/min and 18.0 kJ/min, respectively.

Samanta and Chatterjee (1981) investigated the physiological aspects of manual load lifting by Indian subjects. Major factors affecting the physiological load were identified as weight to be lifted, height to which it had to be lifted and the frequency at which the load was being lifted. It was found that most of these operations fell in unduly heavy category of workload.

Astrand and Rodahl (1986) classified the severity of work load in terms of oxygen uptake and heart rate (Table 2.1). It is used as a general guide line in view of the vast individual variations in ability to perform physical work.

Table 2.1. Work category and physiological response of individuals of age 20 to 30 years.

S. No	Work category	Physiological response	
		Oxygen consumption (l/min)	Heart rate (beats/min)
1	Light work	< 0.5	Up to 90
2	Moderate work	0.5 - 1.0	90-110
3	Heavy work	1.0-1.5	110-130
4	Very Heavy work	1.5-2.0	130-150
5	Extremely heavy work	> 2.0	150-170

*Source: Astrand and Rodahl, 1986

Terrier *et al.* (2001) studied the validity of activity monitors based on body acceleration measurement to assess the energy cost of the human locomotion. The body accelerations were recorded using tri-axial accelerometer attached to the low back. Large relative errors occurred when predicted VO_2 (from level walking) was compared with measured VO_2 for different inclines. It was concluded that without an external measurement of the slope, the standard method of analysis of body accelerations could not accurately predict the energy cost of uphill or downhill walking.

Walking alone on puddle field is very strenuous activity, which required about 87% to 96% of total energy expenditure during the rota-puddling operation (Tiwari and Gite, 2002). Singh and Kaul (1972) observed that walking behind the machine takes 16% to 25% during rota-tilling operation. They also pointed out that posture contributes 8.9% to 11.8% and vibration and noise contribute 4.6% to 7.2% of the total human energy demand for operating a hand tractor.

Energy expenditure rate for hand tractor operation depends on operations, design of hand tractor, inflation pressure, type of soil and operators (Kathirvel *et al.*, 1991). Tiwari and Gite (2000) found that rota-tilling with power tiller without seating attachment requires more human energy to the extent of 31-80% in comparison to power tiller with seating attachment without any significant increase in field capacity or reduction in fuel consumption. Tiwari and Gite (2002) found that the physiological response during rota-tilling and rota-puddling varied linearly with forward speed. The mean values for human energy expenditure were 10·02, 12·11 and 13·15 kJ/min during rota-tilling, 11·69, 14·62 and 17·96 kJ/min during rota-puddling and 11·28, 13·15 and 15·66 kJ/min during walking alone on puddled field at the forward speeds of 0·30, 0·47 and 0·63 m/s, respectively. The study indicated that rota-puddling involved higher energy expenditure to an extent of 17-37% as compared with rota-tilling for the above range of forward speeds. Walking alone on the puddled field was observed as a very strenuous activity, which required about 87-96% of total energy expenditure during the rota-puddling operation.

Tiwari *et al.* (2005) mention that human energy expenditure during operation of the power tiller varied from 9.40 to 10.44 kJ/min with the operator's seat and from 11.28 to 14.62 kJ/min without the operator's seat. It was observed that the attachment of an operator's seat to power tiller reduced human energy expenditure by 16.7-28.6%. On the basis of physiological responses, the rota-tilling operation by power tiller with and without operator's seat was classified as light and moderate work, respectively. Kathirvel *et al.* (1991); Tewari *et al.* (2004) also observed higher energy expenditure rate during rota-puddling operation.

Though the physiological cost in hand tractor operation is lower than the allowable work load, the walking behind hand tractor, high level vibration and noise are the main limiting factor for hand tractor operation. Tiwari and Gite (2006) concluded that duration of work bouts during rota-tilling operation by power tiller should not exceed 75 min especially during post-lunch period otherwise the operators may develop symptoms of physiological fatigue.

Sam *et al.* (2007) investigated physiological response of the subject while operating two power tillers with one as walking type (7.46 kW) and the other as riding type (8.95 kW). The selected operations included rotary tilling in untilled and tilled fields and transport on farm and bitumen roads. The forward speed of operation was 1.5-2.4 km/h and 3.5-5.0 km/h for field and transport operations respectively. For roto-tilling in an untilled field the energy cost of work varied from 17.13 to 20.09 kJ/min for the walking type and 13.95 to 15.43 kJ/min for riding type power tiller. In the tilled field the values varied from 15.70 to 18.23 kJ/min and 13.28 to 14.59 kJ/min, respectively. The operations were generally graded as "moderate work". The roto-tilling operation in an untilled field demanded 9.1-10.20% and 1-6% more energy for walking type and riding type power tillers, respectively than in a tilled field. Power tiller with seating attachment resulted in saving of 23-30% and 18-25% human energy requirement in untilled and tilled fields, respectively. In transport mode the energy cost of work was 10.17-11.12 kJ/min and 11.32-12.82 kJ/min with respective power tillers.

In order to reduce drudgery and improve comfort to the operators from walking behind the hand tractor several investigators (Sanyal and Datta, 1978; Mehta *et al.*, 1997; Tewari *et al.*, 2004; Tiwari *et al.*, 2005) modified machine for seating arrangement. Tewari *et al.* (2004) found that the transportation, rota-tilling and rota-puddling using a hand tractor in seated posture required about 25, 29 and 10% lower energy as compared to walking behind mode of operation.

2.3. Body Working Posture and Subjective Rating Scale

Body posture is one of the major factor which causes muscular fatigue and discomfort in the body. Uncomfortable body posture in different activities reduces work efficiency, capacity and safety of operator.

2.3.1. Working Posture

Posture may be defined as "the quasi static bio mechanic alignment" or in more simple terms "The configuration of body's head, trunk and limbs in space" (Haslegrave, 1994). Comfortable working posture is an essential requirement in all the efficient working systems. It is widely agreed that awkward working postures are the principle risk factor associated with muscular-skeletal injuries and disorders during occupational activities. Most of the manual field operations performed in developing countries demands complex and undesirable body posture.

Floyd and Roberts (1958) stated that the forearm should be approximately horizontal or sloping down slightly when performing most of the simple manual tasks, when the work surface is higher than the elbow. The need to keep the arm raised can generate stresses and strains, including those in the shoulder.

Vos (1973) conducted an experiment to find a physical load on different working posture while working near to and below ground level. The postures considered were bending, kneeling, squatting and sitting on low stool. Energy expenditure, heart rate and the increase in heart rate were recorded for five minute period. A remarkable increase in the workload in the bending position was observed when the working level was lower than the level of the feet. When the work was carried out at ground level, then squatting posture appeared the most suitable position.

Herberts *et al.* (1980) studied the importance of working level and shoulder joint position in manual task. They carried out experiment on localized muscle fatigue in three different working levels viz. shoulder level, the handle height at waist level and overhead level corresponding to three different degrees of flexion. Increase in localized muscle fatigue was noticed with the increase in the working level from waist to shoulder and overhead positions.

Laville (1985) showed that postural immobilization for period of several hours is poorly tolerated and has serious consequences. It explains the neck, shoulder and back pains frequently experienced in these situations. These consequences, combined with the constraints of speed and precision, make such jobs unsuitable for persons above a certain age.

Tewari and Geeta (2003) carried out an investigation to evaluate the work situation of female agricultural workers in India. Twenty four female subjects from different part of the region working in paddy fields were selected randomly for the study. Postures adopted by the workers while performing various operations involved in paddy cultivation were recorded.

Tewari *et al.* (2004) modified a walk behind type hand tractor to enable its operation in a seated position. Seating posture required about 25% lesser human energy in transportation, 29% in rota-tilling and 10% in rota-puddling as compared to walking behind. The work-related body pain was also reduced by 27% due to seating arrangement.

Tiwari and Gite (2006) conducted an experiment to study the influence of work-rest schedules on physical workload during power tiller operation. The study indicated that the work-rest schedules did influence the physiological and postural workload as evidenced by the differences in working heart rate and postural discomfort. Work schedules having smaller work bouts involved lower cardiac cost but subjectively felt more fatiguing on the basis of leg discomfort and upper arm discomfort. To avoid excessive postural discomfort the minimum duration of rest pauses should be of 15 min.

Sam and Kathirvel (2008) studied assessment of postural discomfort during walking type as well as riding type power tiller operation at different forward speeds. The overall discomfort rating and body parts discomfort score values were lower for the riding type power tiller than the walking type power tiller operation, which is indicative of the fact that the seating arrangement in the riding type power tiller reduced the discomfort due to walking. The majority of discomfort was experienced in the arm, leg, and shoulder region for all the subjects for the walking type power tiller, whereas the majority of discomfort was concentrated in the lower back, buttocks, and thigh region for the riding type power tiller.

2.3.2. Overall Discomfort Rating (ODR)

Borg (1962) developed a “category scale” for the rating of perceived exertions (RPE). The scale range from 6-20 (to match heart rate from 60 to 200 beats/min), with every second number anchored by verbal expression. In addition to this, a 15 point graded category scale was also developed to increase the linearity between the ratings and workload. Stamford and Noble (1974) developed a nine point scale and values obtained from this scale had been shown to correlate on the 15 point ‘Borg’ scale.

Borg (1982) developed a category-ratio (CR - 10) scale so that the best qualities of both the ratio and category could be integrated into one general psychophysical scale. In this scale, the numerical values range from 0 to 10. Verbal descriptors selected on the basis of quantitative semantics are associated with some, but not all, of the numeric values in the scale.

Table 2.2. Pain intensity score as a measure of overall discomfort rating (ODR)*.

Subjective feeling	ODR Score	Subjective feeling	ODR Score
Comfortable	0	Moderately painful	4
Uncomfortable	1	Highly painful	5-6
Pain starts	2	Very highly painful	7-9
Slightly painful	3	Extremely painful	10

*Source: Borg, 1982.

Gite (1991) carried out an experiment to know the postural discomfort experienced by the subjects while operating mould board plough with the different handle height. Overall discomfort was measured on eight point scale (0 - no discomfort, 8 - extreme discomfort).

Tiwari and Gite (2000) conducted study on power tiller with and without seating attachment. They reported that over all discomfort rating on a 10 point visual analogue discomfort scale varied from 1.0 to 3.5 for a power tiller with seating attachment and from 2.0 to 5.0 without seating attachment for an operation of 20 minutes duration

Tiwari and Gite (2002) studied physiological responses during operations by a 6·7 kW rotary power tiller. Overall discomfort ratings on a 10-point visual analogue discomfort scale for

15 min work duration were 1·5, 2·6 and 4·1 during rota-tilling, 3·3, 4·7 and 6·0 during rota-puddling and 3·4, 4·8 and 5·7 during walking alone on the puddled field at forward speeds 0·30, 0·47 and 0·63 m/s, respectively.

Tewari *et al.* (2004) compared work related body pain using Borg scale in a new seated position with a standard design of a hand tractor. Moderate to very high pain was reported in regions of the body except the head during various operations without the seat. Tiwari *et al.* (2005) quantified overall discomfort rating on a 10- point visual analogue discomfort scale in 15 minutes of rota-tilling operation. Mean overall discomfort rating varied from 0.5 to 1.5 with the operator's seat and from 1.5 to 3.0 without the operator's seat. It showed a linear relationship between overall discomfort rating and forward speed with and without the operator's seat. Tiwari and Narang (2006) provided an operator's seat on power tiller for dry rota-tilling. Mean values of overall discomfort ratings for an operating duration of 2 hours were 5 and 6.8 with and without operator's seat respectively. There was a significant difference in overall discomfort ratings at 5% level.

Dewangan and Tewari (2008) conducted an investigation to determine the work related body pain from the handle of the hand tractor to the operators under actual field conditions. The work related body pain was the maximum during the rota-tilling operation, followed by transportation and rota-puddling. Maximum pain to the level of 4.9, 3.7 and 3.3 (Borg, CR-10 scale) was observed at the wrist and 4.3, 3.5 and 2.6 at the hand during rota-tilling, rota-puddling and transportation operations, respectively.

2.3.3. Body Part Discomfort Rating (BPDR)

Corlett and Bishop (1976) developed a technique to record distribution of discomfort in body in the form of “overall discomfort rating” and “body part discomfort score”. To measure overall discomfort rating, a seven-point scale was developed with ‘extremely comfortable’ and ‘extremely uncomfortable’ marked at its left and right-hand ends, respectively. After completion of work subject was asked to indicate the point on the scale of current level of overall discomfort. To measure body part discomfort score, several numbered body diagram was produced. After operation, operators were asked to indicate on the diagram the body area, which was most painful. Having noted this, the next most painful areas were asked for, and so on.

Corlett *et al.* (1979) described a technique for recording whole body posture by making ten marks on a chart. This technique of posture targeting was tested on a group of 32 subjects and found that it was easy to learn, highly repeatable and accurate except where postures were held in short periods and not repeated.

Keyserling (1986) developed a method for analyzing and describing the posture of the trunk and shoulders. In this method videotape was used to create a permanent record of the job and personal computer was used to perform the clerical and time-keeping tasks associated with posture analysis. The classification system for standard postures of trunk and shoulder was used for analysis of videotapes. To perform analysis, the videotape was played back at the same speed as recorded i.e. posture analyst observes the job in simulated real time. After analysis, data was entered to the computer and then it generated posture profile for each joint i.e. trunk and both shoulder (left and right). This posture profile gave total time in each posture, average time in each posture, number of times the posture was entered and duration of the complete work cycle.

Legg and Mahanty (1985) compared five modes of carrying a load close to the trunk. During experiment subject was asked for any discomfort. The subject was asked to describe the extent of discomfort by giving a rating between 1 to 10 point scale (1-no discomfort, 10-extreme discomfort).

Lusted *et al.* (1994) developed a body area chart discomfort checklist. It was used to rate the discomfort under dynamic condition to identify body area feeling discomfort. One checklist was filled at the start of the experiment and second was filled after a long period sitting on seat. The ratings were then compared to estimate the level of discomfort.

Thompson and Eales (1994) compared utility of inclinometer and flexi curve for measurement of curvature of spine. These devices were compared by measuring the curvature of known curve whose angle of curvature at marked points has been calculated mathematically. The angle of curvature measured by flexi curve was close to the actual angle of curvature than that of the inclinometer. The additional advantages of the flexi-curve were observed as its cheap price, ease of use, better accuracy and better reliability.

Kumar *et al.* (2002) evaluated performance of manual weeders in respect of the area coverage, overall discomfort and body part discomfort. The higher capacity was observed in wheel hand hoe. The overall discomfort score i.e. “very tired” in all the cases was found. Body part discomfort score was 29.5, 26.22 and 23.22 for wheel hand hoe, crescent hoe and kasola respectively.

Dixit (2006) conducted ergonomic studies on agricultural workers performing selected farm operations in cotton crop. The overall discomfort rate varied between 2.93 and 4.50 while operating knapsack sprayer. The most painful body parts were reported as shoulder, trunk, legs, wrists and palms.

Tiwari and Narang (2006) provided an operator's seat on power tiller for dry rota-tilling. Mean values of body part discomfort scores for an operating duration of 2 hr were 67.3 and 99.97

with and without operator's seat respectively. There was a significant difference in body part discomfort scores at 5% level.

2.4. Effect of Vibration on Human Performance

The vibration is defined as oscillatory motion about a fixed point. A vibration is called periodic when the oscillation repeats itself. It affects the human performance. It is defined usually by its frequency, amplitude, velocity, acceleration and direction. It affects the whole body and its parts such as hands etc. Sanders and McCormick (1987) defined that the vibration is of two types. The body continues to vibrate at the same frequency over a considerable period of time, this is a sinusoidal motion. This is the first type of vibration and called periodic vibration. The other type of vibration is that of one time shocks and impacts called non-periodic vibrations.

Bawa and Kaul (1974) conducted study on knapsack power sprayer. They reported that the vibration levels transmitted to selected parts of the operator besides causing discomfort could be a source of long-term health hazards. Right hand was reported going numb and inactive and someone else had to help the subject to get sprayer off the shoulders after completion of the work.

Pawar (1978) conducted a study on power tiller and concluded that the vibrations observed at power tiller handle during field operation were considerable. The vertical acceleration recorded was to the extent of 2.366 - 3.467 g (1 g = 9.81 m/s^2) rms (root mean square value) and horizontal acceleration to the extent of 1.142 - 1.417 g at frequency of 125 Hz. Necessity was felt to reduce the transmission of vibrations to arm either by isolation from source or reduction in exposure time. It was concluded that excessive noise level, vibrations, uncomfortable bent posture were an important ergonomic shortcoming in the power tiller design.

Gupta (1979) conducted a study on power knapsacks sprayer and reported that the heart rate increased with the increase in vibration to the human body. The heart rate was influenced both by the frequency of vibration and pad thickness. The heart rate decreased as the frequency or pad thickness increased. Minimum vibration transmission was reported in transverse direction. At the head maximum vibrations were recorded in vertical direction and in the chest region in longitudinal direction. The range of frequencies studied was 40 to 80 Hz. The transmission of vibration decreased with increase in frequency. The maximum vibration was recorded in vertical direction and minimum in transverse direction.

Griffin *et al.* (1982) studied the effect of hand grip force on the transmission of vibration from the handle to the hand and found that an increase in grip force increased the vibration level transmitted to the handle.

Carsloo (1982) reviewed the effect of vibration on the skeleton, joints and muscles. The vibration damage took place mainly in the joints. Owing to the elasticity and plasticity of the skeleton, joints and muscles, the muscle-skeleton system was capable of absorbing and damping vibration without damage.

Guignard (1985) found that moderate to high magnitude of vertical vibration of about 2 to 20 Hz produced a cardiovascular response in which heart rate, respiration rate, pulmonary ventilation rate, oxygen up take, mean arterial blood pressure and cardiac output increased.

Mirbod *et al.* (1994) investigated hand-transmitted vibration levels (HTVLs) and the prevalence of vibration-induced white finger (VWF) in subjects operating various hand-held vibrating tools. The prevalence of VWF was in the range of 0.0-4.8% in subjects exposed to HTVLs between 1.1 to 2.5 m/s^2 and reached 9.6% in a group of workers exposed to HTVLs between 2.7-5.1 m/s^2.

Mehta *et al.* (1997) modified a walk behind type 7.5 kW rotary power tiller into a riding type. The operator's seat was developed on the basis of anthropometric data of Indian farm workers. It consisted of a trough type metal seat suspended on a single bent leaf spring, and two foot rests. A coil spring was provided between the seat trough and leaf spring to reduce high frequency vibrations. The rear depth control wheel assembly of the power tiller rotavator was replaced by a combined depth control and steering mechanism consisting of a threaded screw shaft with telescopic configuration. The seat angle was fixed at 15º to avoid any forward slippage of the seated operator. The position of the seat with respect to the power tiller could be adjusted such that the controls were within easy reach of the operator's hands. Power tiller ride vibration levels were measured at man-seat interface along three mutually perpendicular axes on four different terrains during the transport mode (with rotavator) and on three terrains during rota-tilling. Measurements were taken at five throttle settings to obtain a range of engine speeds and corresponding forward speeds. It was observed that equivalent acceleration levels increased as forward speed of travel increased under all operating conditions. Acceleration levels in the lateral axis were insignificant. There was no conclusive difference between measured acceleration levels on untilled and tilled fields during transport and rota-tilling. The measured ride vibration levels under different operating conditions were compared with the values specified under ISO 2631-1. The SUM (overall ride vibration value or vector sum) acceleration level varied from 0.6 to 1.4 m/s^2 during roto-tilling under different operating conditions and recommended that exposure time should not exceed 2.5 h. Increase in exposure time increased severe discomfort, injury and pain.

Measurement and evaluation of whole-body vibration was performed on the seats of popular riding agricultural machineries in Japan (Futatsuka *et al.*, 1998). Vector sum of frequency weighted acceleration for selected agricultural machines was measured between 0.414 and 1.628. Whole-body vibration on the seats of combine harvesters and wheel tractors exceeded exposure limits and the fatigue-decreased proficiency boundary limit of 8 hr and also shortened the reduced comfort boundary limits of ISO 2631:1985. Some combines, tractors and carriers had only less than one hour exposure duration as compared with the ISO 2631-1:1997.

Kumar *et al.* (1999) conducted survey on the effect of whole body vibration on the low back of tractor driving farmers in northern India. They concluded that the tractor driving farmers report backache more often than non-tractor driving farmers but no significant objective difference on clinical or magnetic resonance imaging evaluation were found between the two groups. Regular work related backache was more common among tractor driving farmers (40%) than among non-tractor driving farmers (18%). Anthropometrics evaluation showed abdominal girth and weight to be significantly higher in tractor driving farmers.

Ragni *et al.* (1999) studied vibration and noise of small implements for soil tillage. The results indicated that in 10% of the exposed population, vascular disorders of the hand (Vibration White Finger) can appear after three years of continues use of the machines, under usual working conditions.

Griefahn *et al.* (2000) proved that vertical vibrations solely affect the visual performance at the same frequency and magnitude. At large amplitudes of vibrations, speech can be modulated at the exposure frequency. The human movement control, especially the perception of the state of contraction and tension in the arm and leg muscles is especially distorted. The Fig.2.4 depicts the findings indicating the resonance occurring at various range of frequency of vibration.

Kromer and Grandjean (2000) concluded from the studies conducted for vertical oscillation applied to seated people that the most intense subjective sensitivity lies in the frequency range 4 to 8 Hz.

The International Standards Organization (ISO) specified method of measurement of vibrations as perceived by human beings. The ISO 5349-1 & 2: 2001 provides guidance for the evaluation of hand-transmitted vibration and daily exposure time (Anonymous, 2001 a & b); and the ISO 2631-1: 1997 defines whole body vibrations and limits of exposure (Anonymous, 1997a). The ISO 9996: 1996 classifies disturbance to human activity and performance due to mechanical vibration and shock (Anonymous, 1996). ISO 5805: 1997 defines vocabulary of human exposure to mechanical vibrations (Anonymous, 1997b). ISO 13090-1: 1998 explains guidance on safety aspects of tests and experiments with people regarding exposure to mechanical vibrations and repeated shocks (Anonymous, 1998). Another agency, British Standards Institution of United Kingdom, through BS 6841: 1987 explains details of measurement and evaluation of human exposure to whole body mechanical vibrations (Anonymous, 1987). Bureau of Indian Standards provides IS 13548: 1992 for the measurements of whole body vibrations for agricultural tractors and wheeled machinery (Anonymous, 1992).

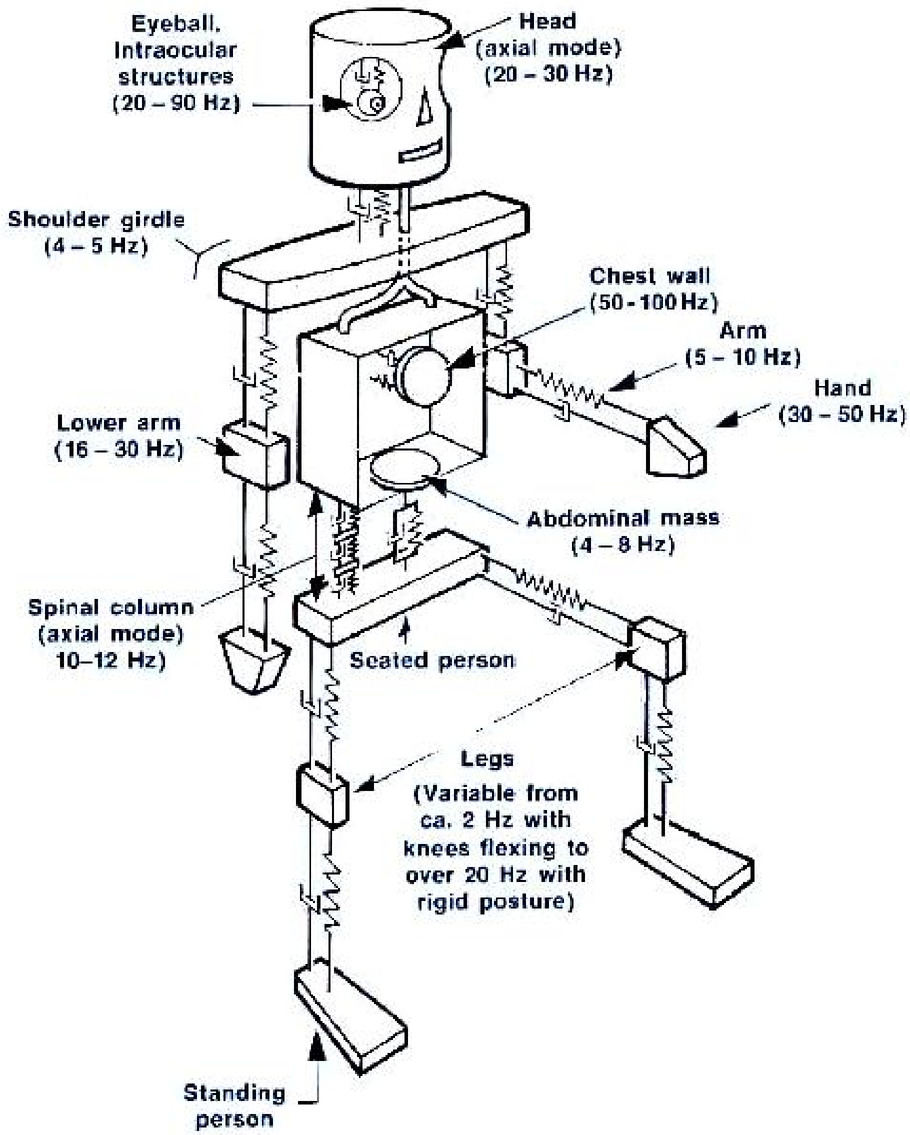

Fig.2.3. Resonance frequency ranges of various human-body sections.

ISO 10816-6 (Anonymous, 1995) contains recommendations for the assessment of vibrations of reciprocating machines like internal combustion engines. The measured quantities are the rms values of acceleration, velocity and displacement. They are picked up at the machine block in all three axes for a recommended frequency range between 2-1000 Hz. Table 2.4

provides vibration severity level and acceptance limits of vibration for different machine classes and their condition.

Table 2.3. Acceptance limits for vibration for different machine classes (ISO 10816-6:1995).

<table>
<tr><th rowspan="2">Vibration severity level</th><th colspan="3">Maximum Vibration RMS</th><th colspan="4">Machine Class*</th></tr>
<tr><th>Displacement μm</th><th>Velocity mm/s</th><th>Acceleration m/s²</th><th>Class I</th><th>Class II</th><th>Class III</th><th>Class IV</th></tr>
<tr><td>1.1</td><td>< 17.8</td><td>< 1.12</td><td>< 1.76</td><td rowspan="4">A/B**</td><td rowspan="5">A/B</td><td rowspan="6">A/B</td><td rowspan="7">A/B</td></tr>
<tr><td>1.8</td><td>< 28.3</td><td>< 1.78</td><td>< 2.79</td></tr>
<tr><td>2.8</td><td>< 44.8</td><td>< 2.82</td><td>< 4.42</td></tr>
<tr><td>4.5</td><td>< 71.0</td><td>< 4.46</td><td>< 7.01</td></tr>
<tr><td>7.1</td><td>< 113</td><td>< 7.07</td><td>< 11.1</td><td>C</td></tr>
<tr><td>11</td><td>< 178</td><td>< 11.1</td><td>< 17.6</td><td rowspan="7">D</td><td>C</td></tr>
<tr><td>18</td><td>< 283</td><td>< 17.8</td><td>< 27.9</td><td rowspan="6">D</td><td>C</td></tr>
<tr><td>28</td><td>< 448</td><td>< 28.2</td><td>< 44.2</td><td rowspan="5">D</td><td>C</td></tr>
<tr><td>45</td><td>< 710</td><td>< 44.6</td><td>< 70.1</td><td rowspan="4">D</td></tr>
<tr><td>71</td><td>< 1125</td><td>< 70.7</td><td>< 111</td></tr>
<tr><td>112</td><td>< 1784</td><td>< 112</td><td>< 176</td></tr>
<tr><td>180</td><td>> 1784</td><td>> 112</td><td>> 176</td></tr>
</table>

*The assessment classes have the following meaning:
Class I – individual components, integrally connected with complete machine (up to 15 kW)
Class II – Medium sized machines (15-75 kW)
Class III – Large prime movers on heavy, rigid foundations
Class IV – Large prime movers on relatively soft, lightweight Foundations
** Based on vibration severity level, the status of machine under observation is as follows:
A - New machines
B - Continuous running without restriction possible
C - Not suitable for continuous running, reduced operability until next scheduled maintenance
D - Too high vibration, damage to machine cannot be excluded

Mehta *et al.* (2000) conducted study on ride vibrations of tractor implement system. The measured vibration levels under different operating conditions were evaluated as per ISO 2631 and found that the SUM vibration levels increased as forward speed of travel increased under most of the operating conditions.

Muzzamil *et al.* (2004) conducted vibration studies on tractor drivers under varying ploughing conditions. He conducted test runs on tractor operators with and without farm equipment in wet and dry fields. The effect of farm equipments on vibration levels was significant but effect of field type was non-significant.

Tewari *et al.* (2004) modified a walk behind type hand tractor to enable its operation in a seated position. The location of the seat was decided on the basis of forces and reactions on the wheels in vertical direction. The seat pan was made strong enough to support the weight of an operator up to 80 kg. A leaf spring was used to support the seat and acted as a shock absorber. The dimensions of the seat were selected as per anthropometric data of male agricultural workers of the India. The vibration intensity in rms acceleration was observed as 45 m/s^2 without the seat and 20 m/s^2 with seat. Seating posture required about 25% lesser human energy in transportation, 29% in rota-tilling and 10% in rota-puddling as compared to walking behind. The work-related body pain was also reduced by 27% due to seating arrangement.

Dixit (2006) reported that vertical vibration on the handle of power weeder increased from 9.85 to 76.90 m/s^2 when throttle position increased from ideal to full. The vertical vibration at exhaust of engine was 20.4 m/s^2 at 4000 rpm and increased to 66.4 m/s^2 at 6000 rpm. The minimum vertical vibration was recorded on the frame (3.2 to 20.1 m/s^2).

Sam and Kathirvel (2006) conducted vibration studies on walking and riding type power tillers during roto-tilling in untilled & tilled fields and transportation on farm & bitumen roads. The results indicated that machine vibrations increased with increase in engine speed. The walking type power tiller showed higher hand transmitted vibrations (HTV) than the riding type during roto-tilling; whereas, riding type power tiller exhibited higher HTV and whole body vibration (WBV) during the transport mode. Roto-tilling in the untilled field resulted in 20% more HTV compared to tilled field. Vibration during transportation of power tiller attached to an empty trailer was significantly higher on the farm road than on the bitumen road, the increase being 32% for HTV and 8% for WBV. Exposure time for the power tiller operator was recommended not to exceed 4 h during roto-tilling and 8 h during transportation.

Kathirvel *et al.* (2007) measured vibration of walking and riding type power tillers at different locations in stationery condition, during roto-tilling in untilled and tilled soil and in transport mode on bitumen and farm roads. Comparing the acceleration at the different locations, the vibration at the top of the engine was highest followed by chassis, handle, root of handle bar and gear box for both walking and riding type power tillers. In stationary mode the increase in engine speed resulted in two fold increase in machine vibration at handle for both power tillers. Among the power tillers the vibration at handle was higher by 72.94 to 170 percent for the riding type power tiller. In field operation and transport mode the increase in forward speed of operation resulted in increased values of acceleration. The magnitude of vibration was higher at handle (40.50%) and seat (28.08%) in untilled field than tilled field. In transport mode farm road induced higher vibration than bitumen road. Among the power tillers the vibration induced in walking type power tiller was higher during field operation.

Dewangan and Tewari (2008) conducted an investigation to determine the transmission of vibration from the handle of the hand tractor to the operators under actual field conditions. The maximum transmissibility was observed during the rota-tilling operation with the mean values of 0.91, 0.47, 0.30 and 0.21 at the metacarpal, wrist, elbow and acromion, respectively. The corresponding values during transportation were 0.89, 0.44, 0.24 and 0.12 and during rota-puddling were 0.85, 0.43, 0.22 and 0.18.

Dewangan and Tewari (2009) measured and analyzed hand-transmitted vibration as per the guidelines of ISO 5349-2: 2001. Data were collected at three levels of forward speed, i.e. 1.11, 1.71 and 2.31 m/s during transportation and 0.30, 0.45 and 0.63 m/s during rota-tilling and rota-puddling. The vibration acceleration was significantly affected by axis of measurement, X_h-axis resulted more than 50% hand-arm vibration as compared to Y_h-axis and about 30% higher than Z_h-axis. The peak vibration acceleration was 5.52, 8.07 and 5.27 m/s^2 at the frequency of 31.5 Hz during transportation, rota-tilling and rota-puddling, respectively. Analysis of variance (ANOVA) indicated significant effect ($p < 0.01$) of forward speed of the hand tractor on hand-transmitted vibration during all the three modes of operation.

2.4.1. Protection from Vibration

A vibration isolator is a support, usually resilient connector, designed to attenuate the transmission of vibration in defined frequency range (Anonymous, 1990). A vibration isolator is considered to comprise a resilient element attached to a mounting plate at each end. Resilient elements include rubbers, elastomers, polymers, metal springs, corks, felts and air bags. Elastomeric, passive hydraulic, semi active and active engine mounts have been used for vibration isolation in the vehicle (Yu *et al.*, 2001). Elastomeric mounts are compact, cost-effective and maintenance free. Bonded elastomeric mounts are known to provide more consistent performance and longer life.

Elastomeric (or rubber) mounts have been used to isolate vehicle structure from engine vibration since the 1930s (Lord, 1930). Since then, much significant advancement has been made to improve the performance of the elastomeric mounts (Miller and Ahmadian, 1992). The discussion of detailed structural designs of these advancements is found in the literature (Schmitt and Leingang, 1976).

Bell and Bell (1994) stated that one of the most common sources of noise is vibrating machinery. The simplest and most straightforward solution to this problem is to provide some sort of mechanical isolation. The introduction of isolation is usually easy, inexpensive, and often completes solution to noise problem. The three major types of vibration isolators are metal springs, elastomeric mounts, and resilient pads. Metal springs are particularly applicable where heavy equipment is to be isolated. They withstand relatively large deflections and provide good low frequency isolation. Elastomeric isolators are more suited to small machines and relatively high excitations or forcing frequencies. The elastomeric medium can be easily molded into any size or shape, and a range of stiffness can be controlled over wide limits. The most common elastomeric materials in use are natural rubber, neoprene, butyl, silicon, and combinations of each. Vibrations isolation can also be achieved by using isolation pads consisting of natural or synthetic rubber, or blocks of cork, felt, fibrous glass and combinations thereof.

www.vibrationmounts.com in a technical section on vibration and shock control states that a good vibration mount functions as a time delay, temporary energy absorber and to some extent as an energy dissipater, or damper (Anonymous, 2008). The engineering design of a vibration mount consists in identifying the characteristics of the source of the vibration, the mechanical characteristics of the equipment and the determination of the mount characteristics, in order to achieve a specified degree of vibration reduction. The comparative properties of rubber and related materials are also given for selection as vibration isolator (Table 2.4).

Dong (1996) designed a vibration absorber for use on the handles of a walking tractor. The measured data indicated that the weighted acceleration in the direction of most severe vibration was reduced by 55.8% and the tolerable time period of daily exposure to handle vibration was increased by 126.4%.

Mead (1998) stated that vibration can be controlled by passive or active control methods. Passive control involves modification of the stiffness, mass and damping of the vibrating system to make the system less responsive to its vibratory environment. The modification may take the form of basic structural changes or addition of passive elements such as masses, springs, fluid dampers or damped rubbers. These elements simply react passively in opposition to the accelerations, deflections or velocities imposed upon them by the vibration. Active control systems, on the other hand, do require source of power to drive active devices to generate vibrations of such sign that vibration generated by initial exciting forces is nearly cancelled. Active control methods are necessarily more costly than passive methods.

Ying *et al.* (1998) designed an anti vibration device for walking tractor. The developed device could reduce vector sum of frequency-weighted accelerations up to 41.1% during stationary condition. The key element of the device is cylindrical rubber sheath (60 Shore) which was installed near the handle grip. Ragni (1994); Xu *et al*. (1995) inserted rubber sleeves along the pipe of the handle of hand tractor. Ragni (1994) observed vibration reduction up to 35% on an Italian make 4 kW walking tractor.

Table 2.4. Comparative properties of rubber and related materials.

SAE Abbreviation	**Butyl HR**	**Natural Rubber NR**	**Neoprene (Chloroprene) CR**	**Silicone SI**	**Styrene Butadiene (GR-S) SBR**	**Flouro-Elastomer (Viton) HK**
Cost relative to natural rubber	110%	100%	110%	850%	85%	2000%
Tensile of compounded stocks	2000 psi	3500 psi	3000 psi	800 psi	2500 psi	2000 psi
Durometer	40-75	30-90	30-90	45-85	40-90	50-90
Elongation	fair	excellent	excellent	fair	good	good
Aging	excellent	good	excellent	excellent	good	excellent
Heat aging	excellent	good	very good	excellent	good	excellent
Sunlight aging	good	poor	good	good	poor	excellent
Lubricating oil resistance	poor	poor	good	fair	poor	good
Aromatic oil resistance	poor	poor	fair	poor	poor	good
Animal-vegetable oils resistance	excellent	Fair	excellent	good	fair	good
Flame resistance	poor	poor	good	fair	poor	good
Tear resistance	good	good	good	poor	fair	fair
Abrasion resistance	good	excellent	excellent	poor	good	fair
Compression set resistance	fair	good	fair	fair	fair	good
Permeability to gases	very low	Fair	low	fair	fair	excellent
Dielectric strength	good	excellent	fair	good	excellent	good
Freedom from odor	good	excellent	good	fair	fair	fair
Maximum temperature (°F)	250	210	260	600	215	500
Minimum temperature (°F)	-50	-65	-50	-150	-60	-40

Source: www.vibrationmounts.com

Elimination of the vibration at source is the most effective solution for safety. Vibration is isolated at the source or it is arrested along the path of travel. Resilient materials, like foam rubber on the handle are used to reduce vibration at hand-handle interface (Bjoring *et al.*, 1999).

Sjoberg (2000) observed that the rubber characteristics, such as stiffness and damping, collected at large deformation, low frequency conditions might differ by several hundred per cent from the characteristics of actual working conditions under low amplitude and high frequency excitation. Richards and Singh (2001) observed that the behavior of rubber isolator depends on the type of excitation applied. Random excitation revealed non-linear behavior for two isolators under both single-dof and multi-dof configurations, however, linear behavior was observed under random for third isolator.

Balasankari (2002) carried out noise and vibration studies on two tractors (36.55 and 23.87 kW) for three implements (disc plough, cultivator and empty trailer on bitumen road). Vibration acceleration levels increased with forward speed of travel under all operating conditions. The hand transmitted vibrations were within the acceptable limit; hence, daily safe exposure time was 8 h. The noise levels of both the tractors were above the safe limit of 85 dB. By providing vibration isolator at seat, WBV were reduced by 12-42, 25-46 and 70-83 per cent for disc ploughing, cultivator operation and transport respectively. The WBV was reduced by 77.59-83.25 per cent after providing vibration isolators having key element of styrene butadiene rubber (SBR) at seat and at tractor-trailer hitch point.

Norton and Karczub (2003) stated that vibration control is not only important in minimizing structural vibrations and any associated fatigue, but also for noise control. Vibration control procedures generally involve either isolation of vibration forces, or the application of damping to the structure. Vibration isolation is the reduction of vibration transmission from one structure to another via some elastic device. The most commonly used vibration isolators include compression pads, metal springs, elastomeric mounts, air springs, and inertia blocks.

Sam and Kathirvel (2009) developed vibration isolators for engine mounting, handle bar and handle to reduce vibrations of power tiller transmitted to the hands. The key element of the vibration isolators was styrene butadiene rubber (SBR). The vibration isolators developed were of simple and easy to install. Further, installation of these isolators does not interfere in geometry characteristics of the power tillers. Combined effect of the three stages of vibration isolators was measured for vibration levels in walking and riding type power tillers at stationary condition. The results indicated that provision of vibration isolators reduced handle vibration by 50 to 60 percent. The effectiveness of vibration isolators in reducing the hand transmitted vibration (HTV) was also investigated during roto-tilling in untilled as well as tilled fields and in transport mode on farm and bitumen roads as per procedure in ISO standards. HTV was reduced from 4.55 m/s^2 to 3.18 m/s^2 for walking type whereas for riding type, it was reduced from 4.24 m/s^2 to 2.85 m/s^2 after incorporating vibration isolators during roto-tilling. Vibration transmitted to the hand was significantly reduced from 3.96 m/s^2 to 2.67 m/s^2 at 5 km/h in the transport mode of power tiller. The risk of vibration-induced white finger was prolonged from 5 years to 9 years in the case of roto-tilling at the forward speed of 2.4 km/h, 7 years to 11 years during transport at the forward speed of 5.0 km/h respectively for the 10% of operators if the power tiller is used 8 h/day.

Tewari and Dewangan (2009) installed a set of vibration isolators having styrene butadiene rubber (SBR) as its key element at engine mountings and handle of a hand tractor. These isolators were evaluated for their performance during various field operations of hand tractor. The results indicated that vibration acceleration was reduced by more than 50% after providing vibration isolators at engine mounting and handle. Provision of the vibration isolators reduced work related body pain on an average of 32%, 42%, 44%, 42%, 61% and 58% at hand, wrist, forearm, elbow, upper arm and shoulder, respectively.

2.5. Effect of Noise on Human Performance

Noise has physical, physiological and psychological forms. Physically it is a complex sound having little or no periodicity. Physiologically it is a signal that bears no information and whose intensity varies randomly with time. Psychologically it is any sound irrespective of wave which is unpleasant. The characteristics of noise can vary widely over an impulsive, intermittent or continuous and composed of low, high or mixed frequencies. Sound is a form of energy and we can measure its power, pressure etc. To accommodate the large range of pressure variations that human ear can sense, log scale is used. The SPL (Sound pressure level) is measured in decibels represented as dB.

$$SPL = 20 \log P_o/P_r \qquad \text{------ (4)}$$

Where, SPL is sound pressure level, P_o is root mean square (rms) acoustic pressure at point of consideration, and P_r is reference pressure (0.0002 n/m^2).

Barger *et al.* (1963) reported that more noise cause more human energy to perform a task. Noise decreases the quality and precision of work. Excessive noise gives some undesirable psychological reaction such as instability, nervousness and fatigue.

Huang and Suggs (1968) conducted study on tractor noise with the human performance and reported that tractor noise on full load was generally in the range of 101 to 109 dB(A) at operators ear level and was predominantly at low and medium frequency with a conventional muffler on the exhaust.

Bansal (1983) reported that in India the noise levels of agricultural machines like tractor, combine harvester and crop protection equipment ranged from 90 to 98 dB (A). The operators are exposed to these noise levels for duration more than 8 hours a day. Combustion in engine, cooling and other fans/ blowers are major sources of noise in agricultural machinery. The noise level for tractors ranged between 90-98 decibels acoustic dB(A), for threshers and combines 90-96 dB(A) and for power operated knapsack sprayer 93 dB(A). It was suggested that such noise producing machines should not be operated for more than 4 h/day.

Monnich (1985) re-examined 402 tractor drivers, already examined in 1974 for hearing loss and compared the result of hearing loss as indicated by group of an audiograms. Changes in machinery type and design were also compared. Graphs indicated the pattern of loss of hearing and the result showed that group of operations suffered a more severe hearing loss.

Gupta and Jain (1988) conducted the audiometric examination of 8 thresher operators, before and after a day of work to find out the TTS (Temporary Threshold Sluff) at frequencies 0.25, 0.5, 1, 2, 3, 4, 5 and 8 kHz on both the ears. It was found that TTS existed at almost all the frequencies and higher at higher frequencies.

Bansal and Dhir (1994) conducted study on the NIHL (Noise Induced Hearing Loss) among the operators belonging to some villages near Ludhiana District. They reported that the tractor noise contribute a lot to NIHL among the operators having 5-10 years exposure.

Gayatri (2000) observed that in addition to hearing damage, continuous noise can induce non-auditory physiological efforts. Noise pollution can interfere with speech communication, sleep, acoustic privacy and cause annoyance thus affecting human health, comfort and efficiency. Noise pollution also increases the heart rate. The World Health Organization (WHO) has recommended 75 dB as the explosive limit for industrial noise. The Bureau of Indian Standard (BIS) has recommended acceptable noise level in an industrial area between 45 to 60 dB.

Occupational Safety & Health Administration, USA has given a standard OSHA-1910.95 for occupational noise exposure. It mentions that effect of noise can be of three categories: Primary Effects, which includes noise-induced temporary threshold shift, noise-induced permanent threshold shift, acoustic trauma, and tinnitus; Effects on Communication and Performance, which may include isolation, annoyance, difficulty concentrating, absenteeism, and accidents; Other Effects, which may include stress, muscle tension, ulcers, increased blood pressure, and hypertension. It states that permissible sound level for 8 hrs duration of a day should be within 90 dB (Anonymous, 1971). As the sound level increases, the safe exposure duration of a worker decreases rapidly. There is a rule of thumb, which indicates that if the sound pressure level (SPL) exceeds by 5 dBA (decibels' Acoustic), the duration of exposure should be reduced to half. Above 115 dB sound level, it crosses the threshold of pains.

Table 2.5. Permissible daily noise exposure as per OSHA 1910.95.

Duration per day, hours	Sound level, dB(A)	Duration per day, hours	Sound level, dB(A)
8	90	1.5	102
6	92	1	105
4	95	0.5	110
3	97	0.25	115
2	100	--	> 115

IS 12207 (2004) recommended that maximum ambient noise emitted by the tractor and maximum noise at operator's ear level should not exceed 90 dB(A) for 8 h duration. The International Organization for Standardization (ISO) has considered the safe limit of exposure to noise for an eight hour working day to be 90 dB(A), for a 30 year working life (Bhattacharya 1999). Bureau of Indian Standards in IS 12180 (Anonymous, 1987; Anonymous, 2000a; Anonymous, 2000b) has provided guidelines and methodology of noise measurements during use of tractors and machinery for agriculture and forestry.

Dewangan *et al.* (2005) conducted an investigation to determine noise level for 18.7 and 26.1 kW tractors and 4.6 and 6.7 kW hand tractors during field operations with various implements. The sound pressure level (SPL) was 92 dB(A) for tractors and 94 dB(A) for hand tractors at operator's ear level. These levels were more than the safe exposure limits of noise for 8 hours work day recommended in various standards.

Dixit (2006) reported noise at operator's ear level varied from 80.6 to 95.48 dB(A) when power knapsack sprayer was operated at 4000-6000 rpm.

2.6. Salient Findings from the Review

The perusal of this chapter reveals that the human performance greatly affects the performance of man-machine system. The walk behind type power tillers and hand tractors have been successfully converted to riding type resulting in significantly reduced fatigue and discomfort to the operators. The synthetic rubber vibration isolators provided the simplest, inexpensive, and easy to adopt solution for control of vibrations and also noise. No ergonomic study has been conducted on self propelled walk behind boom sprayer; hence, necessitating incorporation of seat and vibration isolators for their assessment to improve performance from ergonomic point of view. Vibrations and noise can be measured as per respective standardized methodology. The physiological stress can be measured by recording more than one parameters viz. heart rate and oxygen consumption. To measure the discomfort to the operator, overall discomfort rating and body-part discomfort rating have been used by the researchers. However, experiment duration must be more than five minutes so as to let these responses stabilize.

Chapter III

MATERIAL AND METHODS

The present study on self propelled boom sprayer was carried out to develop a seat and vibration isolators and to study the effect of operational and design parameters of machine on vibrations, noise and physiological parameters of subjects. The dependent and independent variables, development of a seat and vibration isolators for boom sprayer, instruments used during the study and procedure followed for conducting the experiments have been discussed in detail in this chapter under the following headings:

1. Selection of dependent and independent variables
2. Parameters fixed for the study
3. Instruments used in the study
4. Brief description of self propelled boom sprayer
5. Modifications and refinements in self propelled boom sprayer
6. Measurement of variables by equipments
7. Methodology of research experiments
8. Statistical design of experiments.

3.1. Selection of Dependent and Independent Variables

3.1.1. Dependent Variables

Vibration, noise, heart rate, oxygen consumption, overall discomfort rating and body parts discomfort rating were selected to find the effect of independent variables.

3.1.1.1. Vibration

The self propelled boom sprayer has a mounted engine as its power source, a water tank of 100 litres capacity, and a reciprocating piston type spray pump. All these lead to a lot of vibrations, and hence fatigue to the operator; thus, affecting performance of the man-machine system. The vibrations may result in pain, discomfort, loss of sensation and vibration induced injury at hand arm region and also at back. The vibration could be expressed in terms of displacement, velocity or acceleration. The root mean square (rms) value of vibration acceleration, which is square root of mean value of square of the acceleration, was recorded during the experiments. The rms acceleration value is root relevant measure of amplitude because it takes the time history of the wave into account and gives a value directly related to energy content, and therefore the destructive abilities of the vibration.

3.1.1.2. Noise

The self propelled boom sprayer has a mounted engine which acts as not only a source of power but also associated vibrations and noise. The noise produced by engines may cause discomfort, nervousness, tension, irritability and fatigue. Levels from 86 to 115 dB(A) can cause specific effects to the ear. Noise also results in increase in heart rate, blood pressure and irregularities in heart rhythm. Incorporation of rubber based vibration isolators not only reduce vibration level but also help in reduction of noise generated. Keeping these facts in mind, noise was also selected as one of the dependent parameters for the study on the self propelled boom sprayer. However; it was measured as sound pressure level (SPL) in units of decibels acoustic, dB(A).

3.1.1.3. Heart Rate (HR)

Heart rate in terms of heart beats per minute was taken as one of the measures to assess the whole body physiological workload on the subjects operating the self propelled boom sprayer. Workload was determined by using subject characteristics' curves (HR versus workload) obtained through subject calibration on bicycle ergometer. It was chosen because it could be monitored continuously online with the help of computerized ambulatory metabolic measurement equipment without stopping the activity or disturbing the subject during experiment.

3.1.1.4. Oxygen Consumption (VO_2)

Oxygen consumption was another measure to assess the whole body fatigue. However, it was measured as volume of oxygen consumed per unit time, in units of millilitres per minute, through respiration by the subject. Subject characteristics' curves (VO_2 versus workload) obtained through subject calibration on bicycle ergometer were used to determine workload on the subjects operating the self propelled boom sprayer. It was chosen because oxygen consumption alongwith heart rate could be monitored continuously online with the help of computerized ambulatory metabolic measurement equipment.

3.1.1.5. Overall Discomfort Rating (ODR)

The discomfort is the body pain or fatigue arising as a result of working posture and excessive stress on muscles due to various physical activities performed by the subjects. For the assessment of ODR a category-ratio (CR-10) scale given by Borg (1982) was used. Pain intensity score used during the experiments are given in Table 2.2 (§ 2.3.2).

3.1.1.6. Body Part Discomfort Rating (BPDR)

The body part discomfort rating (BPDR) is a measure of localized discomfort which may restrict the duration of work depending upon the static load involved. The technique suggested by Corlett and Bishop (1976) was used to access BPDR. Each of the body regions was noted for intensity of pain/ fatigue, as per CR-10 scale, experienced by the subject after completion of experiment. BPDR was selected as one of the dependent parameters to assess localized body part discomfort due to operational and design parameters of self propelled boom sprayer by incorporating seat and vibration isolators.

The HR, VO_2, ODR and BPDR were used to assess the physiological stress and discomfort of the operator because a combination of these parameters gives better understanding of results than either of these variables used singly (Verma *et al.*, 1979).

3.1.2. Independent Variables

3.1.2.1. Provision of Operator's Seat with Machine (M)

The selected self propelled boom sprayer has no provision of seat and; thus, the operator has to walk behind the machine. At a recommended forward speed 2.25-2.50 km/h, the operator has to walk behind the machine for a distance of 18-20 km per day in field. Besides walking in field, stress due to mechanical vibrations, human workload, noise, etc. also affect performance of the operator. Therefore, boom sprayer was provided with a seat so as to enable the subject to operate it in sitting posture. Thus; walk behind type boom sprayer (M_1) was converted to a riding type (M_2) by provision of a seat for comparison on ergonomic aspects.

3.1.2.2. Provision of Vibration Isolators (V)

The self propelled boom sprayer has a mounted engine as its source of power, a water tank for storage of spray solution, and a reciprocating piston type spray pump. All these act as source of vibrations which has instantaneous and long term effects upon human body. With the objective of reduction in vibration transmission to the operator at hands and seat, vibration isolators having synthetic rubber as its key element were developed and mounted at various appropriate locations of machine. Thus; boom sprayer having no vibration isolators (V_0) was compared for dependent parameters with the same having provision of vibration isolators (V_1).

3.1.2.3. Forward Speed (F)

The engine acts as a source of vibration and noise, which is dependent on its rpm (i.e. forward speed) and affects the man-machine performance. Keeping the above consideration, three forward speeds of 1.50 (F_1), 2.25 (F_2) and 3.00 (F_3) km/h were selected for the study. As the boom sprayer has no provision of gears to vary forward speed, so engine throttle was the only option. It was noted that average rpm of engine was 1973, 2623 and 3546 at forward speed of 1.50, 2.25 and 3.00 km/h of the sprayer under field conditions.

3.1.2.4. Subject (S)

Three male subjects of different age groups and body dimensions were selected for the study. Anthropometric measurements of selected subjects were taken (Table 3.1.) as per Gite *et al.*, 2009.

Table 3.1. Anthropometric data and physiological characteristics of the selected subjects.

S. No.	Particulars	Subjects		
		S_1	S_2	S_3
1	Age, years	20	31	57
2	Weight, kg	57.5	52.0	66.0
3	Stature, cm	170.0	162.0	166.5
4	Vertical reach, cm	219.1	210.3	215.0
5	Vertical grip reach, cm	209.0	201.7	208.9
6	Eye height, cm	159.2	152.4	153.4
7	Acromial height, cm	144.8	136.0	142.4
8	Elbow height, cm	105.8	96.6	102.2
9	Knee height, cm	45.7	46.8	49.8
10	Sitting height, cm	85.5	83.8	84.7
11	Vertical grip reach Sitting, cm	126.7	116.8	121.7
12	Sitting eye height, cm	74.5	74.9	73.9
13	Sitting acromion height, cm	59.9	59.6	60.6
14	Sitting popliteal height, cm	40.4	40.8	39.4
15	Knee height sitting, cm	53.5	49.7	53.1
16	Thigh clearance height sitting, cm	15.2	13.8	18.0
17	Elbow rest height, cm	20.1	24.5	18.9
18	Coronoid fossa to hand length, cm	40.0	37.7	47.7
19	Buttock knee Length, cm	58.3	55.3	58.1
20	Hip breadth Sitting, cm	34.3	28.9	36.2
21	Elbow-elbow breadth sitting, cm	41.4	39.7	43.6
22	Functional leg length, cm	101.3	91.4	99.7
23	Thumb tip reach, cm	80.1	74.6	72.3
24	Shoulder grip length, cm	77.4	72.6	70.9
25	Elbow grip length, cm	36.1	32.6	36.5
26	Forearm hand length, cm	47.9	44.4	48.4
27	Grip diameter (Inside) , cm	6.0	6.0	6.3
28	Grip diameter (Outside) , cm	9.0	8.7	8.7
29	Grip span, cm	5.2	5.1	7.4
30	Maximum Grip Length, cm	10.6	10.1	11.2
31	Resting HR (beats/min)	72	90	75
32	Resting VO_2 (ml/min)	315	290	210
33	HR_{max} (beats/min)	200	189	163
34	$VO_{2\,max}$ (ml/min)	3268	3631	2153

Criteria for selection of the subjects included representation of the wide range of stature and weight, physical fitness, willingness to participate in the ergonomic experiments, experience in operation of agricultural machinery, and availability of the subjects during the entire period of the study. None of the selected subjects had a history of musculoskeletal or cardiovascular or respiratory problems or movement restrictions. All the three subjects preferred the use of their right hand. The major differences among the subjects were that of age and body-weight. The subject S_1 was young (20 years old) and the tallest (170.0 cm stature); the subject S_2 was of mediocre age (31 years) having stature of 162.0 cm; and the subject S_3 was comparatively an older person (aged 57 years) having stature of 166.5 cm. The body weight of subjects $S_{1,}$ S_2 and S_3 was 57.5, 52.0 and 66.0 kg, respectively. The anthropometric dimensions in standing and sitting posture were proportional to the stature of the selected subjects. The resting heart rate of subjects S_1, S_2 and S_3 was 72, 90 and 75 beats/min; respectively. While the HR_{max} for the subjects was calculated as per formula given by Rodahl, 1989 (see § 2.1.1); the corresponding values of VO_{2max} were observed as 3268, 3631 and 2153 ml/min for subjects $S_{1,}$ S_2 and $S_{3,}$ respectively.

A list of all the independent variables studied at different levels is given in Table 3.2. The subjects were used to study individual differences; and, the rest of three were machine parameters.

Table 3.2. Levels of independent variables and their respective notations.

S. No.	Independent variables and their levels	Notation
1	Provision of operator’s seat with machine (M)	
	i) Without operator’s seat i.e. walk behind type boom sprayer	M_1
	ii) With operator’s seat i.e. riding type boom sprayer	M_2
2	Provision of vibration isolators (V)	
	i) Vibration isolators not provided	V_0
	ii) Vibration isolators provided	V_1
3	Forward speed (F)	
	i) 1.50 km/h	F_1
	ii) 2.25 km/h	F_2
	iii) 3.00 km/h	F_3
4	Subject (S)	
	i) Aged 20 years	S_1
	ii) Aged 31 years	S_2
	iii) Aged 57 years	S_3

3.2. Fixed Parameters for the Study

3.2.1. Field Parameters

For the measurement of vibrations, noise and physiological parameters viz. HR, VO_2, ODR and BPDR, a field plot of size 75x25 meter was selected at the Research Farm of Department of Farm Machinery & Power Engineering, Punjab Agricultural University, Ludhiana. Guidelines as per ISO standards were followed to maintain and note down field and machine parameters. Along the length of field plot, flag marks were placed after leaving a 5 meter length needed for turning of machine at both the ends. Thus; an effective length of 65 meters of field plot was used for straight run of sprayer. The field was cleared from any crop residue and weeds, etc. The field was irrigated and ploughed repeatedly with disc harrow, cultivator and leveler so as to simulate field conditions for the operation of the boom sprayer. Soil samples were taken for testing from Soil Testing Laboratory of Department of Soils, Punjab Agricultural University, Ludhiana. The soil was reported as loamy-sand with 84.3% sand, 6.9% silt and 8.8% clay content. The average soil moisture content in the experimental plot was 14.6% (dry basis). The soil compaction measured as cone index values for depth upto 225 mm (at an interval of 25 mm) is given in Table 3.3 and presented in Fig. 3.1. Beyond 225 mm of soil depth, cone index could not be measured due to hard pan of soil.

Table 3.3. Soil cone index of experimental plot.

S. No.	Soil depth (mm)	Cone index (kPa)	
		Range	Average
1	0	0	0
2	25	0-34	5.14
3	50	32-582	313.86
4	75	361-2295	1087.43
5	100	824-3552	2016.86
6	125	1392-4130	2830.14
7	150	1903-4525	3302.29
8	175	2499-4841	3786.43
9	200	3027-4854	4124.71
10	225	3337-6086	4798.71

3.2.2. Machine Parameters

To conduct the field experiments on self propelled boom sprayer for measurement of vibrations, noise and physiological parameters of selected subjects, no weedicide/ chemical was used. Thus; the spray tank has only tap water. At the start of each experiment, the spray tank was filled to its capacity of 100 litres. As per guidelines in Standards, the tyres used during the study were new and of standard size i.e. tyre no. 5.00-8 at the front and tyre no. 3.50-8 at the rear. Recommended air pressure of 1.4 and 2.1 kg/cm^2 was maintained in the front and rear tyres of sprayer, respectively.

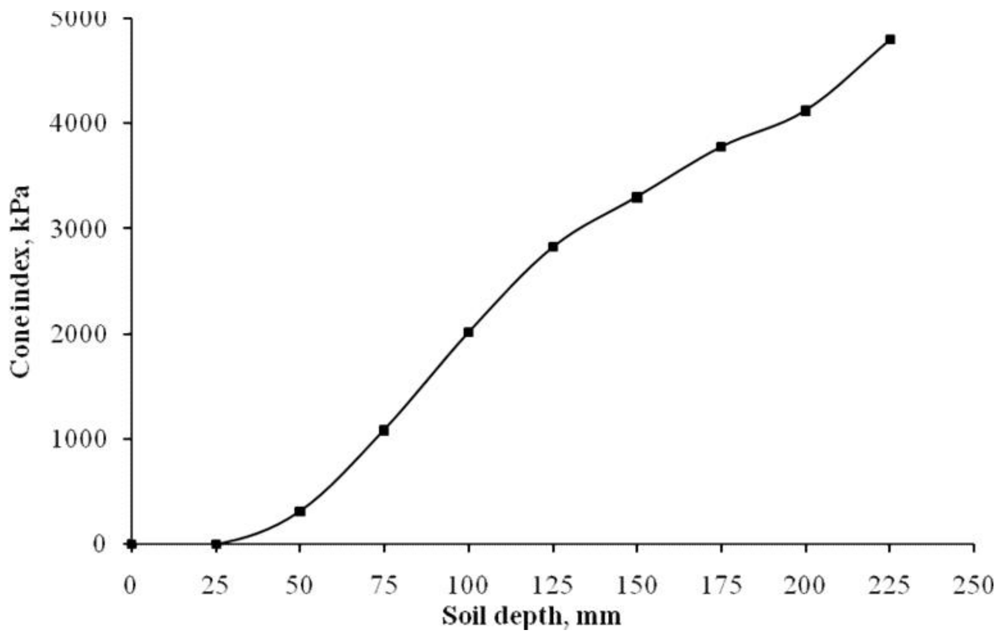

Fig. 3.1. Soil cone index of experimental plot.

3.2.3. Time Parameters

Duration of experiments for measurements of vibrations and noise was taken as one minute each as per standards. For the measurement of physiological parameters, the experiment duration was fixed as 15 minutes. This was due to the fact that at a recommended pump pressure of 2.5 kg/cm^2, the spray tank discharges within 15-20 minutes duration. An hour rest time was given to the subjects prior to start of field experiments. The variations in the ambient temperature (dry bulb basis), relative humidity and wind velocity during the experiments were 31-36ºC, 47-85% and 1.9-6.0 km/h, respectively. The average ambient temperature, relative humidity and wind velocity during experimental tests were observed as 34.2ºC, 71.1% and 4.3 km/h, respectively.

3.3. Instruments Used in the Study

3.3.1. Computerized Ambulatory Metabolic Measurement Equipment

Computerized ambulatory metabolic measurement equipment make COSMED, Italy model K4B2 was a portable, light weight, battery operated equipment used to measure heart rate (HR) and oxygen consumption (VO_2) under field condition. It had a portable unit which was fixed to the subject during the test by an anatomic harness. It contained O_2 and CO_2 analyzers, sampling pump, transmitter, barometric sensor and electronics. It was powered by rechargeable battery fixed to the back side of the harness. K4B2 was provided with a small display to show real time measurements. The equipment had an inbuilt memory to save data file for downloading on computer for further analysis. For online recording of data and its analysis, it had a receiver unit connected to a personal computer or laptop through the RS232 serial port. The data could be viewed online on the computer without any wired connection within a range of 800 meters of the portable unit mounted on the subject. The equipment also had a battery charger unit for simultaneous charging of 3 Nickel-Cadmium batteries and to supply power to the portable unit during the warm-up time. The equipment had inbuilt flow-meter and gas analyzers. The PC software, running on Windows, allowed the user to view data in tabular and graphic forms. The pulmonary function test provided data for 22 breath by breath parameters, 10 indirect calorimetric parameters, 6 lactate threshold and 2 O_2 kinetics parameters. The equipment is shown in Fig. 3.2 and its brief specifications are given in Appendix-A.

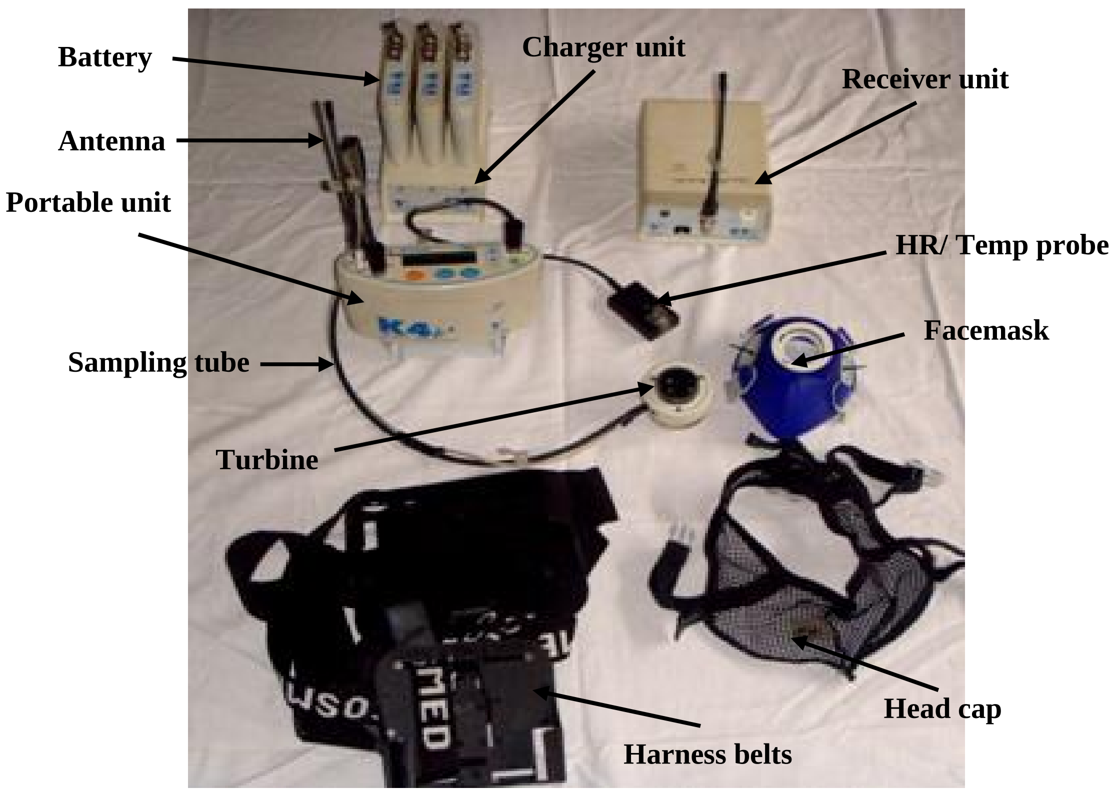

Fig. 3.2. Computerized ambulatory metabolic measurement equipment.

3.3.2. Portable Vibration Meter

A portable vibration meter of make Monitran, UK model VM110 was used for measurement of vibrations at specific locations of boom sprayer. The Monitran VM110 vibration meter was a battery powered portable instrument designed for use with an external accelerometer having a sensitivity of 10 mV/g. The equipment detected vibration signals via MTN/1100 accelerometer and displayed real time measurements on a small display. Measurements can be made in ‘g’ acceleration units (1g = 9.81 m/s^2), mm/s velocity units or μm displacement units via a selector switch. The vibration meter had RMS or Peak detection. Three measurement ranges were provided for maximum resolution together with a switch selectable low pass filter for reduction of broadband noise. Three measurement bandwidths available via a selector switch were 5, 10 and 20 kHz. Portable vibration meter used for the study is shown in Fig.3.3 and its brief specifications are mentioned in Appendix-A.

Fig. 3.3. Portable vibration meter for measurement of machine component vibrations.

3.3.3. Portable Sound Level Meter

A portable sound level meter of make CESVA Instruments, Spain model no. SC-20c was used for measurement of noise at operator’s ear level while operating the boom sprayer under field conditions. It was a type 1, battery powered sound level meter which measureed sound pressure level and was very easy to operate. It had a removable half inch condenser microphone, a wind shield, a display screen, selectable switches and RS232 for connection with PC. A selector switch was provided for frequency weighting A or C. The data could be stored in internal memory or a PC through RS232 data cable or could be noted down form display unit itself. Portable sound level meter is shown in Fig. 3.4 and its brief specifications are mentioned in Appendix-A.

Fig. 3.4. Portable sound level meter for measurement of noise.

3.3.4. Overall Discomfort Rating Scale

A category-ratio CR-10 scale (see §2.3.2) developed by Borg (1982) was used to observe pain/ fatigue intensity score as a measure of overall discomfort rating (ODR) of the subject after completion of field experiments. A wooden scale of about 70 cm length, having 10 digits marked on it at equal distance, was used (Fig. 3.5). A moveable pointer indicates rating of overall discomfort.

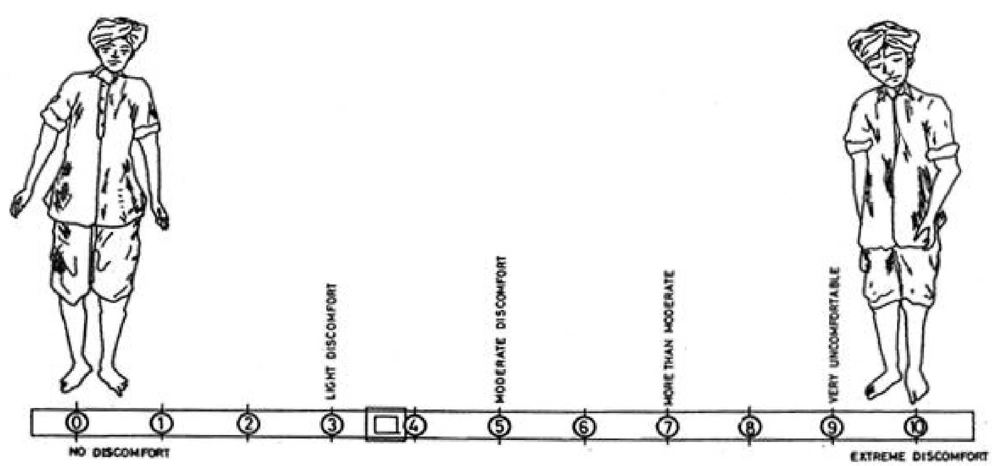

Fig. 3.5. Overall discomfort rating scale.

3.3.5. Body Part Discomfort Rating Chart

It was used to measure body part discomfort rating (BPDR) score. It was drawn on a drawing sheet showing body diagram divided into 27 numbers of regions on the basis of Corlett and Bishop (1976) technique alongwith CR-10 scale as per Borg (1982). Each of the body regions was noted for exertion as per CR-10 scale after completion of experiment in field for 15 minutes duration. Fig. 3.6 shows the body diagram chart used during the study.

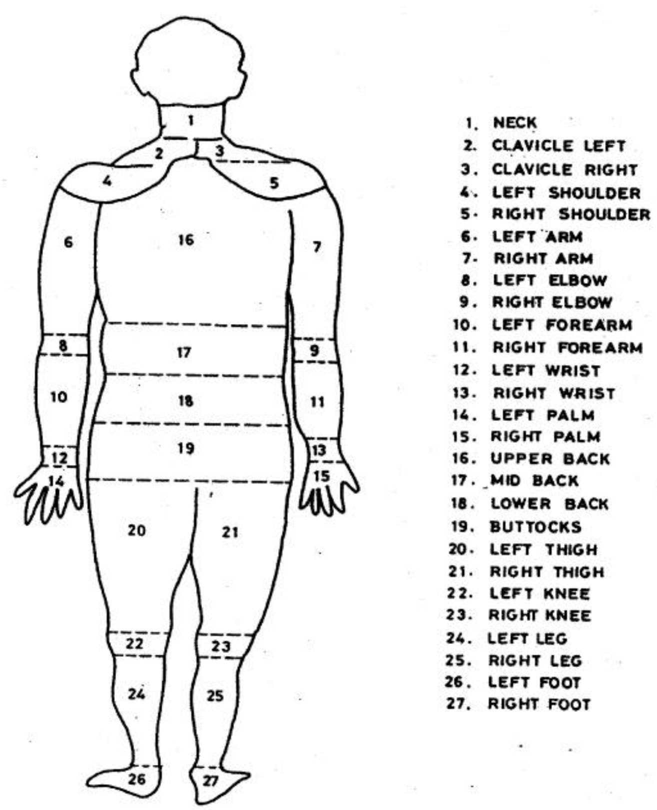

Fig. 3.6. Regions for evaluating body parts discomfort rating.

3.3.6. Bicycle Ergometer

Bicycle ergometer of make Ergoline GmBh, Germany model Ergoselect 100 was used for calibration of the subjects selected for the study. The selected bicycle ergometer was a digitally/ computer programmed equipment with rpm range of 30-130 and load upto 999 watts. Its braking load principle was based on computer controlled eddy current brakes with torque regulation, independent of pedal rpm. It had a digital display for real time monitoring of data. The seat and handle bar of the ergometer were adjustable as per need of the subject's anthropometry. Brief specifications of the bicycle ergometer are given in Appendix-A.

3.3.7. Anthropometer

A light weight, portable anthropometer (Fig. 3.7) of make Siber Hegner, Switzerland, was used for measurement of anthropometric dimensions of the subjects. The equipment consisted of followings:

i. An anthropometer in canvas bag for measurement of length 0-960 mm on one side and 0-2100 mm on opposite side,
ii. A base plate for anthropometer,
iii. Re-curved measuring branches for anthropometer,
iv. Matrin type sliding calipers for measuring length upto 200 mm and depth upto 50 mm,
v. A spreading caliper with rounded ends having a measuring range of 0-600 mm,
vi. A plastic tape of length 2000 mm,
vii. A spring type weighing balance having least count of 0.5 kg and a range of 0-130 kg for measuring body weight of the subject,
viii. An adjustable chair fabricated by using revolving stool for taking measurements in sitting posture.

Fig. 3.7. Anthropometer for measurements of body dimensions of the subjects.

3.3.8. Universal Testing Machine

A universal testing machine (UTM) of make Tinius Olsen, USA model no. 602 was used to observe static force-deformation characteristics during compression of vibration isolators. The UTM was computer programmable and had remote display and servo-control system. It can be used for load upto 1000 kN force. The UTM is shown in Fig. 3.8 and its brief specifications are given in Appendix-A.

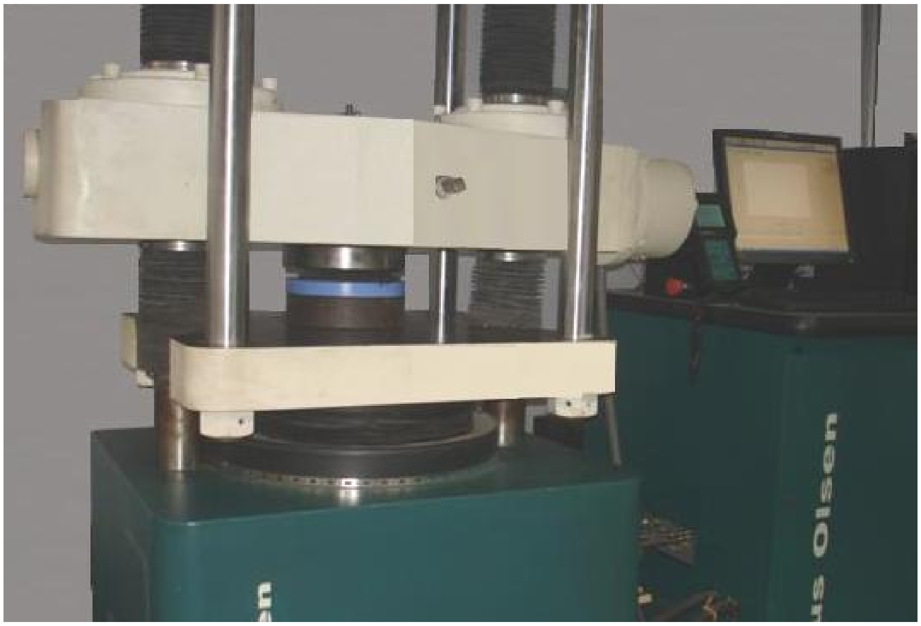

Fig. 3.8. Universal testing machine to study static force-deformation characteristics.

3.3.9. Cone Penetrometer

A cone penetrometer of make ICT International Pty Ltd., Australia model CP40II was used to measure resistance to penetration in soil. The instrument consisted of a data logger, load cell, a cone attached to a shaft and GPS. The data logger recorded cone index value of the load required for insertion of the cone through the soil as well as time, date and GPS coordinates. The logger plotted the cone index values against the depth. The data logger can display the measurements on screen and store the data in memory that can be downloaded to PC. Brief specifications of cone penetrometer are given in Appendix-A.

3.3.10. Digital Tachometer

A digital tachometer was used to measure rpm of engine of self propelled boom sprayer. The least count of tachometer was one rpm.

3.3.11. Stopwatch

An electronic stopwatch was used to measure time duration of experiments.

3.4. Brief Description of Self Propelled Boom Sprayer

A self propelled walk behind type boom sprayer developed by Garg *et al.* (2004) was used in the present study (Fig. 3.9). The machine consisted of a light weight power unit and a spray unit. The power unit had a 3.6 kW diesel engine which was replaced with a 5.4 kW diesel engine for converting the machine into a riding type. The sprayer was controlled by an operator through handle. Two narrow rubber wheels at the front were powered by engine through gears, chain and extension. The third wheel provided at rear acted as a supporting wheel. A spraying unit consisting of a tank of 100 litres capacity, reciprocating spray pressure pump, and a boom having 11 nozzles was provided with the machine. The nozzles spacing was fixed at 50 cm, but was adjustable to suit different crops. The spray boom was mounted through a canopy frame at the back of operator so as to provide safety to operator against weedicide health hazard. The sprayer covered a width of 6.70 meters in one pass. Brief specifications of self propelled boom sprayer are given in Appendix-B. Line sketches of walk behind type self propelled boom sprayer are shown in Figures 3.10 and 3.11. The machine had a field capacity of 1.0-1.2 ha/h when operated at recommended forward speed of 2.25-2.50 km/h. The pressure at spray pump has to be maintained at 2.5 kg/cm^2.

Fig. 3.9. A self propelled walk behind type boom sprayer.

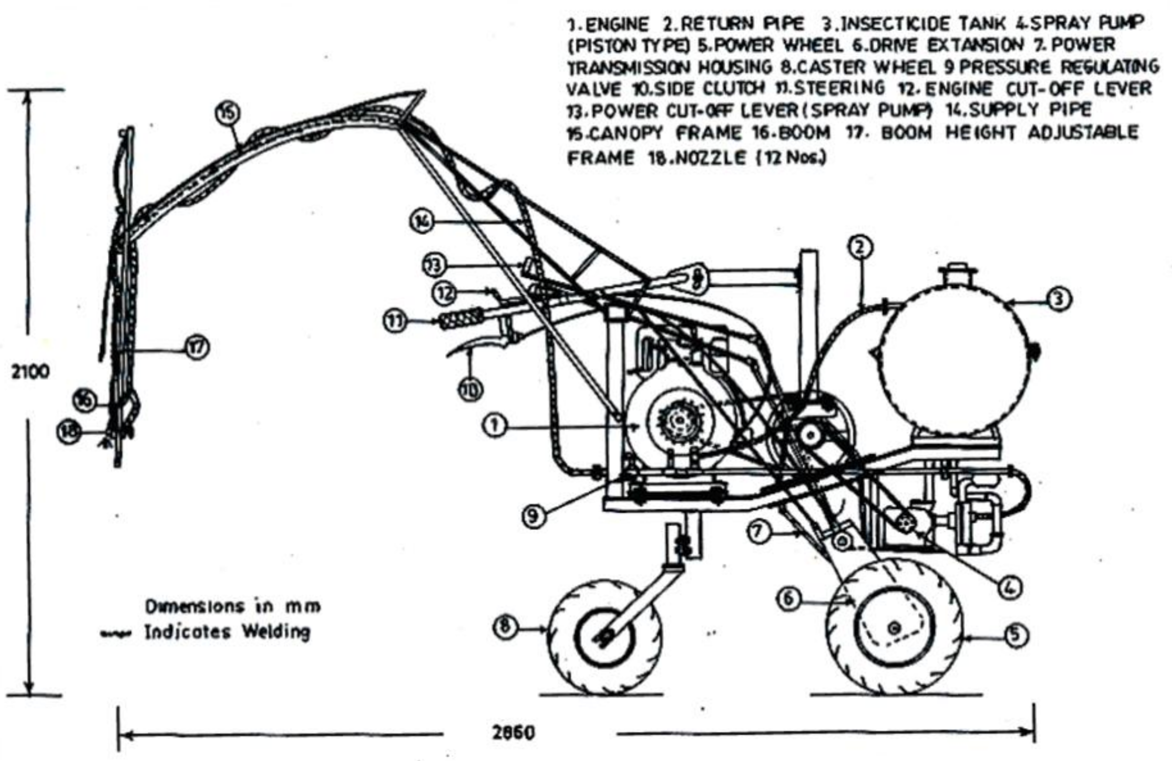

Fig. 3.10. Side view of walk behind type self propelled boom sprayer.

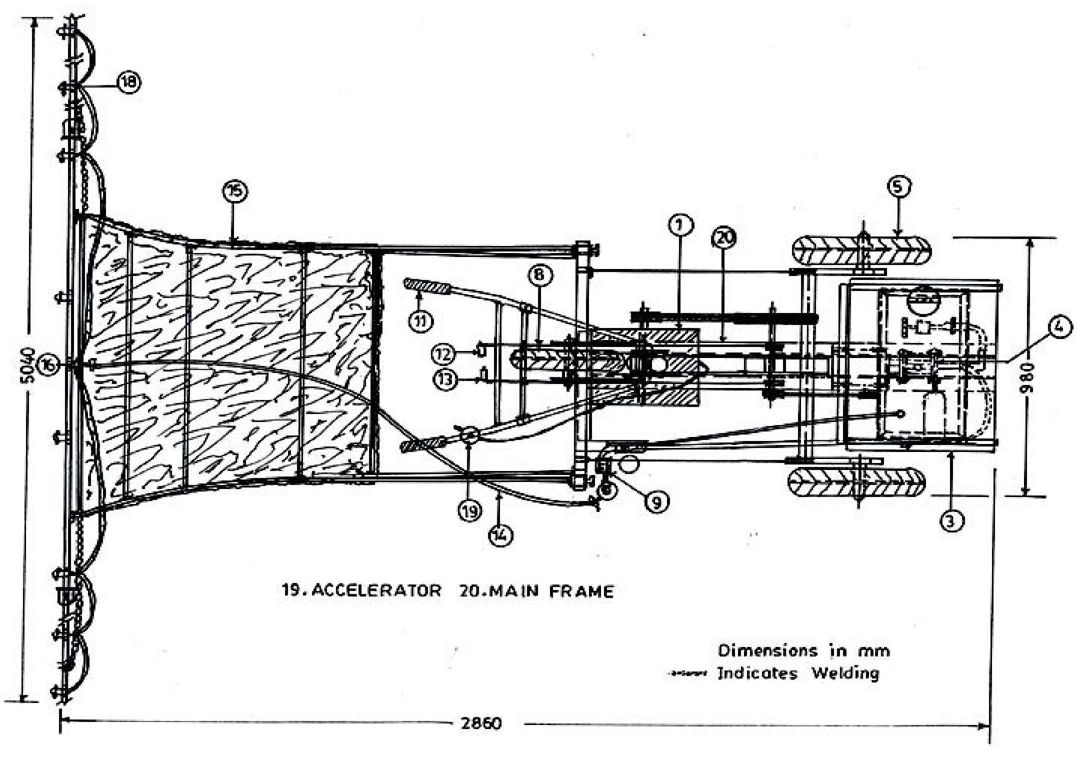

Fig. 3.11. Top view of walk behind type self propelled boom sprayer.

3.5. Modifications and Refinements in Self Propelled Boom Sprayer

3.5.1. Development of Operator's Seat

For converting a walk behind type boom sprayer into a riding type, an operators' seat has to be developed and placed between handle and spray boom. For study of comparative performance, existing boom sprayer has to be retained to the maximum possible level. Thus; a cantilever type provision of seat was the first choice. Considering criteria of easy and comfortable reach of controls to operator, distance between operators' seat and rear wheel was fixed as 0.77 m. However; stability of sprayer against overturning in vertical direction, which reaches at the most critical level when the spray tank gets emptied, has to be ensured. The methodology adopted by Mehta *et al.* (1997) and Tewari *et al.* (2004) for seat design was used as given under:

A free body diagram showing vertical forces and reactions of wheels on the sprayer with a cantilever type seat arrangement is given in Fig. 3.12.

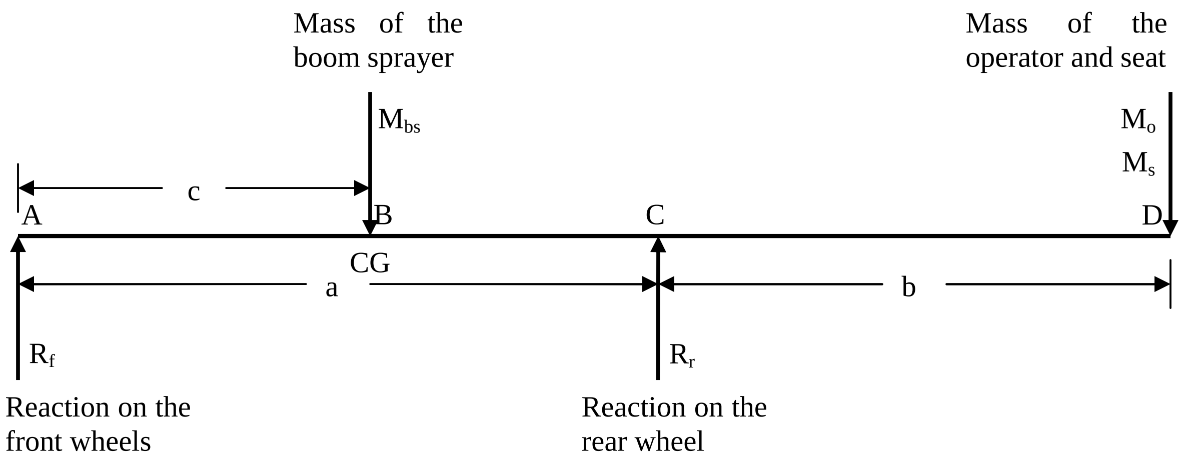

Fig. 3.12. Vertical forces and reactions on the sprayer with cantilever type seat arrangement.

Where,

M_{bs} = Mass of walk behind type boom sprayer with spray tank emptied, kg

M_o = The maximum mass of operator , kg

M_s = Mass of seat, kg

R_f = Reaction on the front wheels, kg

R_r = Reaction on the rear wheel, kg

a = Distance between front wheels and rear wheel, m

b = Distance between rear wheel and operators' seat, m

c = Distance between front wheels and centre of gravity (CG) of sprayer, m

The sum of the vertical forces is to be zero, i.e.

$$M_{bs} + M_o + M_s = R_f + R_r \qquad \text{----- (1)}$$

The sum of the moments about the front wheels is also zero, i.e.

$$M_{bs} \cdot c - R_r \cdot a + (M_o + M_s) \cdot (a + b) = 0 \qquad \text{----- (2)}$$

Rearranging equation (1) gives

$$R_r = M_{bs} + M_o + M_s - R_f \qquad \text{----- (3)}$$

Substituting R_r from equation (3) into equation (2) and rearranging gives

$$b = \frac{(M_{bs} - R_f) \cdot a - M_{bs} \cdot c}{(M_o + M_s)} \qquad \text{----- (4)}$$

For the worst condition, i.e. $R_f = 0$, the maximum distance b_{max} in meters of seat from the rear wheel is given as:

$$b_{max} = \frac{M_{bs} \cdot (a - c)}{(M_o + M_s)} \qquad \text{----- (5)}$$

Therefore, for a safe design against overturning of sprayer in vertical direction, equation (6) must be fulfilled, i.e.

$$b_{max} > b \qquad \text{-----(6)}$$

Substituting known values of M_{bs} of 192.5 kg, M_o of 100.0 kg, M_s of 40.0 kg, a of 1.025 m and c of 0.567 m in equation (5) yields a value for b_{max} of 0.63 meters, which doesn't satisfy equation (6) and is, hence, not safe. Thus; the cantilever type seat arrangement on walk behind boom sprayer was found to be not safe. Hence; rear wheel was shifted to location under the seat and provided support to it. The above procedure was repeated to check for stability, of sprayer having new arrangement, against overturning in vertical direction arrangement, when the spray tank get emptied.

A free body diagram showing vertical forces and reactions of wheels on the sprayer with a seat arrangement having rear wheel under it is given in Fig. 3.13.

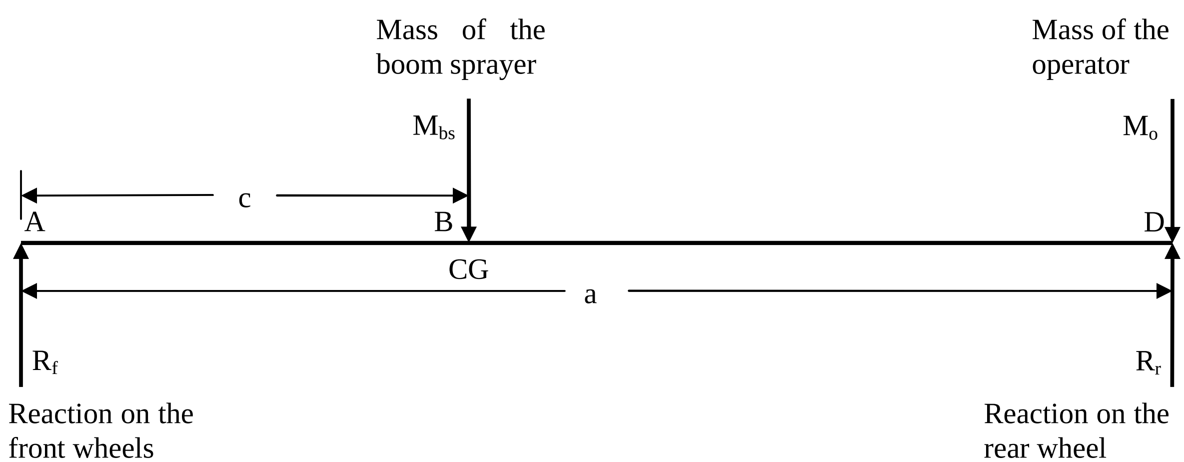

Fig. 3.13. Vertical forces and reactions on the sprayer with rear wheel placed under the seat.

Here, M_{bs}, M_o, R_f, R_r, a and c have the same meaning as already explained.

The sum of the vertical forces is to be zero, i.e.

$$M_{bs} + M_o = R_f + R_r \quad \text{----- (7)}$$

The sum of the moments about the front wheels is also zero, i.e.

$$M_{bs} \cdot c - R_r \cdot a + M_o \cdot a = 0 \quad \text{----- (8)}$$

Rearranging equation (7) gives

$$R_r = M_{bs} + M_o - R_f \quad \text{----- (9)}$$

Substituting R_r from equation (9) into equation (8) and rearranging gives

$$R_f = \frac{M_{bs}\,(a - c)}{a} \quad \text{----- (10)}$$

As values of M_{bs} or (a-c) can never be zero, therefore; it is not possible for reaction at the front wheels to be zero. Thus; necessary stability is achieved by placing the rear wheel under the operators' seat.

For converting walk behind type self propelled boom sprayer into a riding type, an operators' seat was developed and fabricated at Research Hall of the department. The developed riding type boom sprayer is shown in Fig. 3.14 and its side and top views are shown in Figures 3.15 and 3.16.

Fig. 3.14. Riding type self propelled boom sprayer.

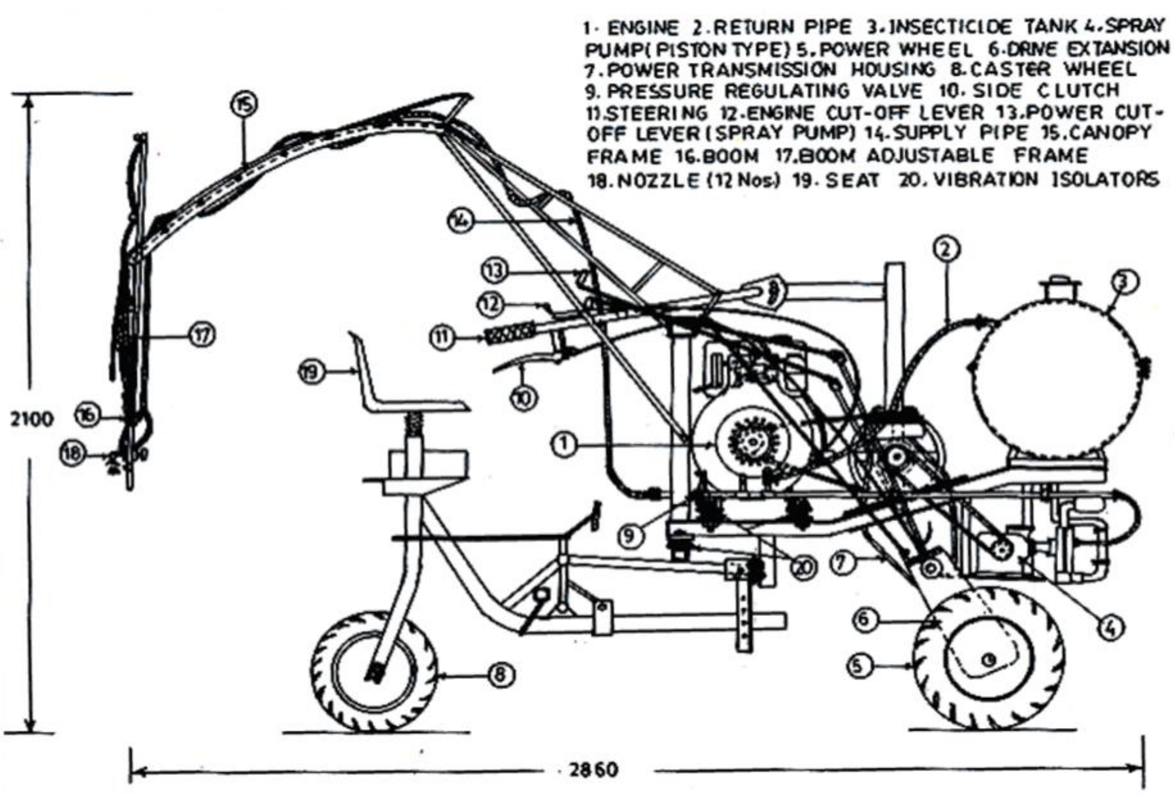

Fig. 3.15. Side view of riding type self propelled boom sprayer.

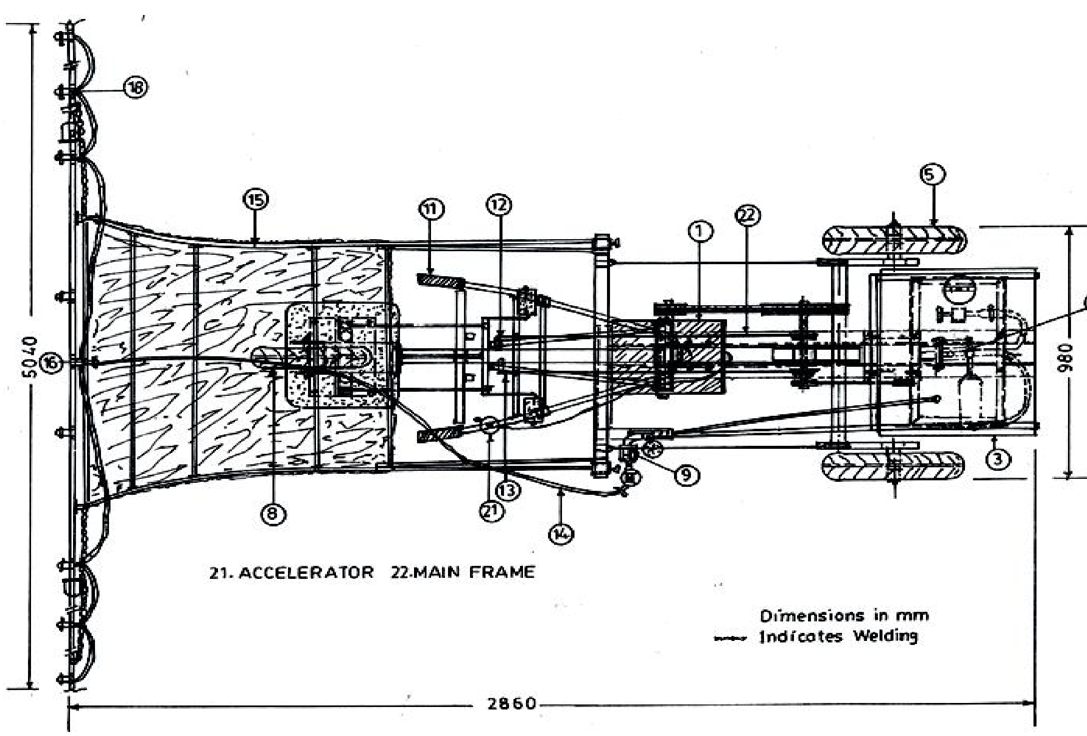

Fig. 3.16. Top view of riding type self propelled boom sprayer.

The trough type seat pan was made up of steel sheet of 2 mm thickness and was strong enough to support the weight of an operator. A metal spring mounting provided under the seat acted as a shock absorber. Foam cushion of 40 mm thickness was provided as an integral part of the seat. The dimensions of the seat (length 35 cm, width 40 cm, seat back height 26 cm) were selected as per the anthropometric data of male agricultural workers of India (Gite *et al.*, 2009). Provisions of necessary protections like back support and footrest were made so that the operator is not thrown out of the seat due to jerks and shocks. A support bar was provided near footrest for mounting and dismounting of operator on the seat. The footrest was placed with respect to seat as per functional leg length of operator. In designing the footrest, care was taken to ensure comfort in seated posture, the foot angle on the pedal varied between 15-35º and the ankle angle between 90-110º as prescribed by Sanders and McCormick (1987). The seat was located, between handle and spray boom, considering easy reach of controls to the operator. The seat placement with respect to handle of sprayer was fixed such that the arms of an operator were close to his body, upper arm was nearly vertical, and lower arm was nearly horizontal. The necessary adjustments in the seat structure was made so that the operator could comfortably control clutches, gear engaging lever, accelerator, spray pump engaging lever, etc. The power transmission from engine to driving wheel was strengthened by using double V-belt and pulley arrangement. The turning of riding type sprayer was accomplished by pedals at footrest instead of handle as in case of walk behind type. However, a steel bar was provided as restriction to avoid the excess turning for its safe operation. A turning radius of seven feet was achieved at inner wheel through the pedals at footrest. There was not any problem of maneuverability of machine in reference to operator's safety and comfort.

3.5.2. Development and Installation of Vibration Isolators

Vibration isolation is a phenomenon by which mechanical energy is converted into heat energy and would be dissipated in a vibratory system. The vibration has to be attenuated before reaching the handle and seat. For the present study, vibration isolators having synthetic rubber, Styrene Butadiene Rubber (SBR), as key element were used for reduction of transmission of vibrations generated by diesel engine to the handle and seat of self propelled boom sprayer. The Styrene Butadiene Rubber has a hardness of 50-55 Shore 'A' scale. The vibration isolation property of this material owes to its molecular structure. Millions of molecules are very closely packed and elastically trapped. During one cycle, the energy is absorbed and during the next cycle energy is released. These cycles are very fast and the material keeps on repeating the cycle. It is better than the metal spring in the sense that the arrangement of molecules in the structure is not as closely packed as in a rubber based isomer. The compression cycle is very slow in the metal spring; whereas, it is very fast in rubber-isomer. Thus; metal spring is good for low frequency isolation; and not for high frequency isolation. The selection of SBR for isolation of handle and seat owes to its properties of high compression characteristics and working under variable frequencies. Rubber based isomer, also known as elastomer, is being well adapted for use in shock isolation because of their high energy storage capacity and the convenience of moulding to any shape. However, the elastomer should not be continuously strained for more than 10-15% in compression and not more than 25-50% in shear.

Any system while actuating has its minimum and maximum compression limit. The isolator should have its signature in between these two limits. The isolator should also have some vibrating motion corresponding to the vibrating object. Here, the disturbing frequency is from the engine and opposite frequency is from the isolator. The main function of the isolator is to reduce the displacement/ velocity/ acceleration. The lesser the net resultant, better its characteristics are. Majority of isolators have damping in varying degree. Ratio of damping co-efficient to critical damping is a convenient reference for damping factor of that material. For the SBR it is 0.12; whereas, it is only 0.005 for steel springs. Damping would be effective only when the system functions at an equivalent natural frequency, as it tends to reduce the transmissibility. The properties of SBR material are given in Table 2.4. Moreover, the synthetic SBR rubber vibration isolators provided the simplest, inexpensive, and easy to adopt solution to designers, manufacturers and farmers, for their role in reduction of vibrations and also noise (see § 2.4 and § 2.5).

The synthetic rubber vibration isolators provided the simplest, inexpensive, and easy to adopt solution for control of vibrations and also noise (Mehta *et al.*, 1997; Sam and Kathirvel, 2006; Kathirvel *et al.*, 2007; Dewangan and Tewari, 2008; Sam and Kathirvel, 2009; Tewari and Dewangan, 2009; Dewangan and Tewari, 2009). Considering the above, synthetic rubber based isolators were selected and installed at four strategic locations of boom sprayer. The characteristics of the selected vibration isolators are given in Table 3.4. Dimensions of all the three types of vibration isolators were selected as per commercial availability in the market. These vibration isolators alongwith their line sketches are shown in Figures 3.17 to 3.22. The vibration isolators VI_1 and VI_2 have SBR embedded between two mild steel plates under high temperature and pressure.

Table 3.4. Characteristics of vibration isolators used in the study.

Isolator code	**Key material**	**Location of installation and nos.**	**Dimensions (mm)**		
			Length	**Width/ diameter**	**Thickness**
VI_1	Styrene butadiene rubber	Engine mountings (4)	52	45	28
VI_2	Styrene butadiene rubber	Base of handle bar (1), Chassis-seat interfaces (2)	140	58	9
VI_3	Foam rubber	Handle grips (2)	115	32	5

Fig. 3.17. Styrene butadiene rubber based vibration isolator VI_1.

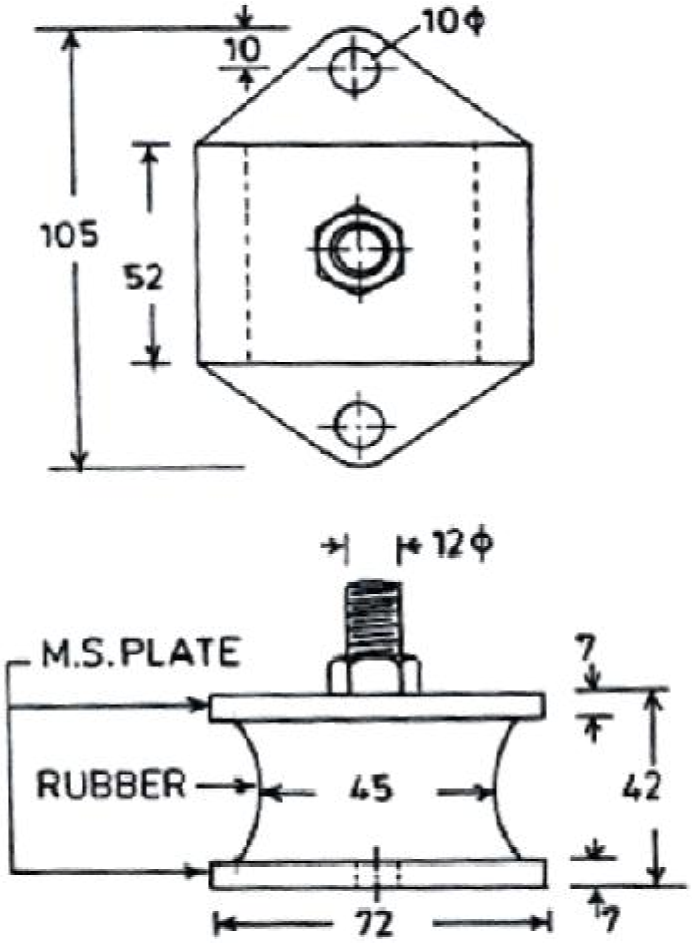

Fig. 3.18. Line sketches showing dimensions of vibration isolator VI_1.

Fig. 3.19. Styrene butadiene rubber based vibration isolator VI_2.

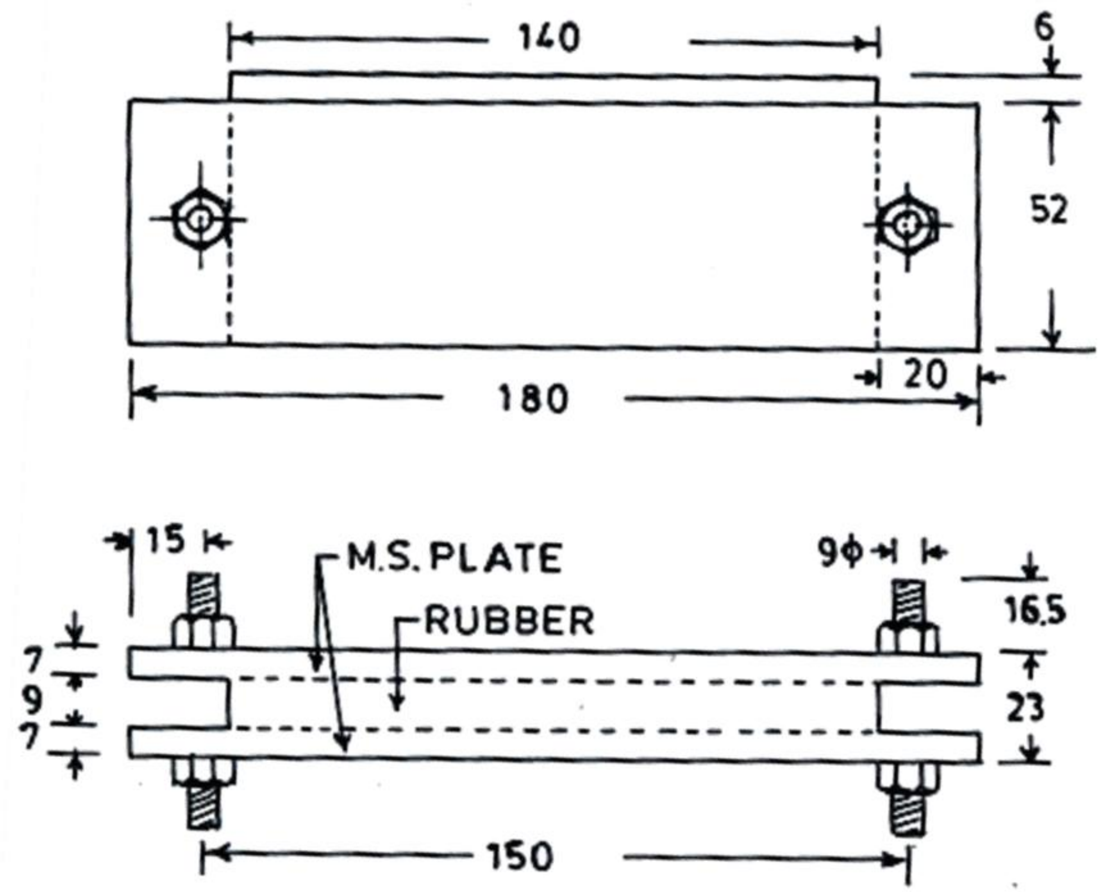

Fig. 3.20. Line sketches showing dimensions of vibration isolator VI_2.

Fig. 3.21. Foam rubber based vibration isolator VI_3.

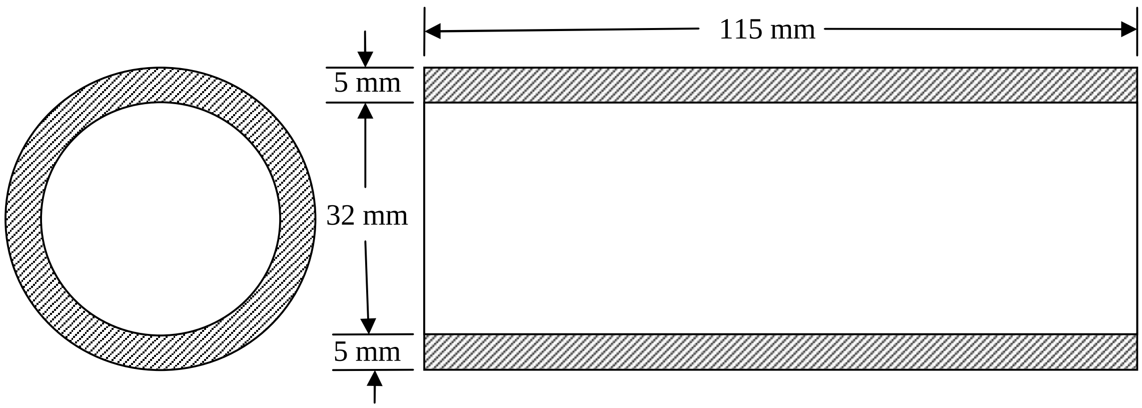

Fig. 3.22. Line sketches showing dimensions of vibration isolator VI_3.

Compression characteristics of synthetic rubber based vibration isolators VI_1 and VI_2 were determined using universal testing machine (UTM). The specimen was kept between the crosshead and the bottom plate fixture of UTM. Compression force was applied at a speed of 1.27 mm/min of crosshead. It was found that SBR based vibration isolators could be loaded upto the maximum compression force of 25 kN before failure. Static force-deformation characteristics were obtained for vibration isolators VI_1 and VI_2 under compression load upto 10 kN by the UTM. The load and deformation data was further calculated to stress and strain after considering their respective cross sectional area and thickness of isolator material. The vibration isolator VI_2 has more cross sectional area and less thickness as compared to VI_1 (Figures 3.18 and 3.20). The plots for static compression load versus deformation and corresponding stress versus strain are given in Figures 3.23 and 3.24. It was found that vibration isolator VI_1 deformed to much higher level as compared to vibration isolator VI_2 for all the levels of load recorded upto 10 kN. Strain in both the isolators VI_1 and VI_2 increased with increase in stress. Strain in vibration isolator VI_2 was almost same as compared to VI_1 at the start of the stress; however, it was significantly lower with further increase in stress.

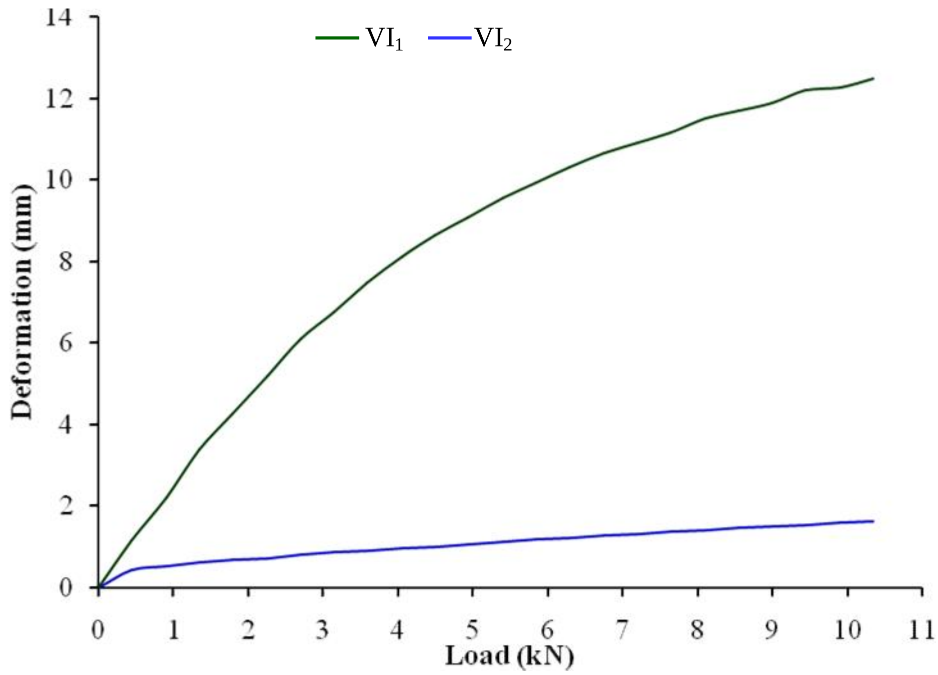

Fig. 3.23. Static compression force-deformation characteristics of vibration isolators.

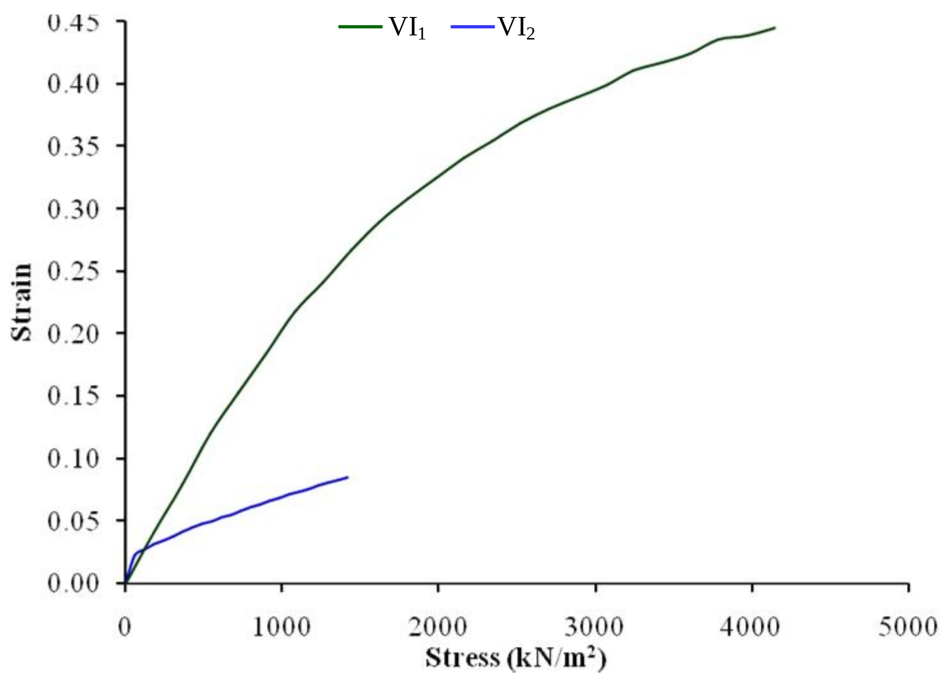

Fig. 3.24. Static compression stress-strain characteristics of vibration isolators.

Since engine is rigidly mounted on chassis of the existing self propelled boom sprayer; therefore, vibration arising from engine is transmitted without attenuation to handle grips through chassis and handle bar, and seat through chassis. In order to reduce the effect of engine vibration to the operator, four pieces of SBR based vibration isolator VI_1 were fixed between the engine and chassis. For this purpose, a base plate of size 420x200x12 mm was fabricated from mild steel. The vibration isolators VI_1 were fixed on the base plate with the help of nuts and bolts. The engine was mounted over the vibration isolators with another set of nuts and bolts as shown in Fig. 3.25. In order to reduce transmission of vibrations along the handle, the angular shaped handle bar was replaced with a fabricated 'L' shaped. One piece of SBR based vibration isolator VI_2 was fixed in horizontal direction at base of handle bar with the help of a base plate (Fig. 3.26). With the objective of reducing transmission of vibrations from chassis to the operators' seat, two pieces of SBR based vibration isolators VI_2 were fixed at chassis-seat interfaces (Fig. 3.27). While one of the two vibration isolators was fixed in horizontal direction, the other was in fixed in vertical direction. This arrangement was made to stop buckling of sprayer at chassis-seat interface due to its own weight. Two pieces of the handle grip VI_3 made of foam rubber were used for reduction of vibrations at hand-handle interfaces of operator and boom sprayer. The placement of handle grips is shown in Fig. 3.28.

Fig. 3.25. Placement of vibration isolators VI_1 under the engine base.

Fig. 3.26. Placement of vibration isolator VI_2 at the base of handle bar.

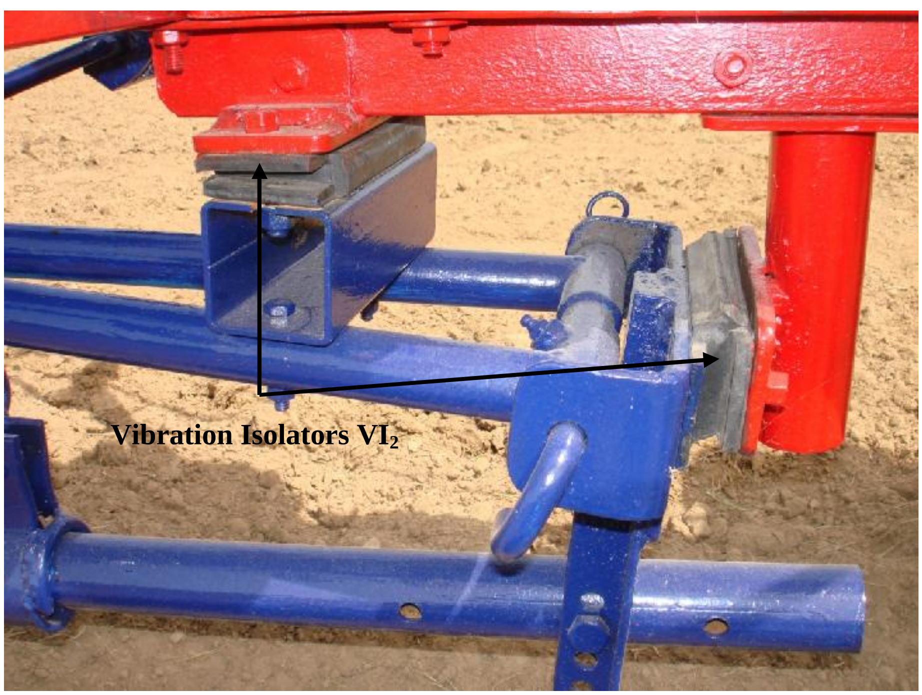

Fig. 3.27. Placement of vibration isolators VI_2 at the chassis-seat interfaces.

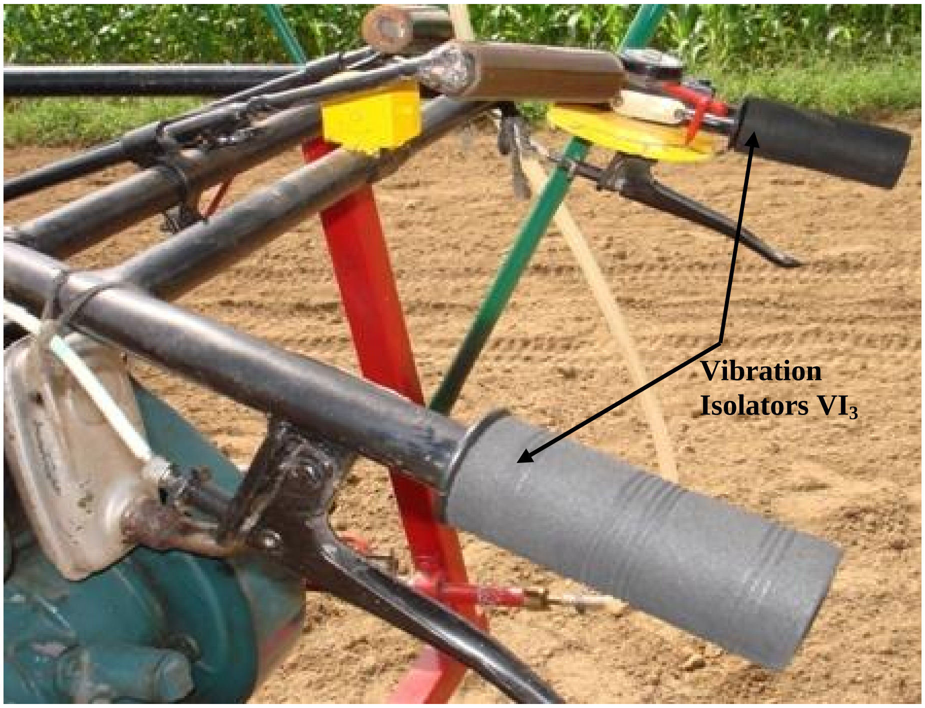

Fig. 3.28. Placement of vibration isolators VI_3 at the handle grips.

3.6. Measurement of Variables

3.6.1. Measurement of Heart Rate and Oxygen Consumption

Heart rate (HR) and oxygen consumption (VO_2) of the subjects were recorded with computerized ambulatory metabolic measurement equipment, K4B2. The procedure for measurement of variables with K4B2 is as given in subsequent sub-sections.

3.6.1.1. Setting up the Computerized Ambulatory Metabolic Measurement Equipment

Stepwise procedure for setting up the K4B2 is as follows:

i. Connect the portable unit (PU) with charged batteries.
ii. Switch on the PU and let it warm up for at least 30 minutes.
iii. Connect the PU with HR/ temperature probe, sampling tube, turbine and face mask, antenna cable and RS232 cable for PC connection.
iv. Connect the battery unit with antenna cable and antenna for signal transmission.
v. Through the PU control and display, set date, time, etc. as per instruction manual.
vi. Set turbine volume value at 3000 ml.
vii. Set room air values for O_2 at 20.93% and CO_2 at 0.03%.
viii. Set calibrated gas values for O_2 at 16.08% and CO_2 at 5.08% as per specified on supplied calibrated gas cylinder.

3.6.1.2. Calibration of Computerized Ambulatory Metabolic Measurement Equipment

The equipment is calibrated for four types of tests viz. room air calibration, reference gas calibration, delay calibration, and turbine calibration. The room air calibration forced by the equipment before every test, consists of sampling room air. It updates the baseline of the CO_2 analyzer and gain of the O_2 analyzer, in order to match the readings with predicted atmospheric values (20.93% for O_2 and 0.03% for CO_2). The reference gas calibration, recommended to be carried out daily, consists of sampling a gas with known composition (i.e. ≈16% for O_2 and ≈5% for CO_2) from a calibration cylinder, and updating the baseline and gain of the analyzers in order to match the readings with the predicted values. The delay calibration, recommended to be carried out at least once a week or whenever the sampling line is replaced, is necessary to measure accurately the time necessary for the gas sample to pass through the sampling line before being analyzed. The turbine calibration, recommended to be carried out quarterly, consists in measuring the volume of a 3 litres calibration syringe and in updating the gain of the flow meter in order to match the predicted value.

The stepwise procedure for calibration of K4B2 is as follows:

i. Set the transmission OFF through the PU control and display.
ii. Connect the PU to PC by serial port. Remove the sampling plug from the flow meter.
iii. Run the K4B2 software. Run the calibration program and choose **Room air** from the **Calibration** menu.
iv. The message "Room air calibration in progress …" appears and a graph shows in real time the O_2 and CO_2 calibration. At the end a message "Calibration done" appears and report is shown. Press **OK** to confirm the calibration.
v. Connect the high pressure tube between calibration unit and gas cylinder.
vi. Open the cylinder valve and set pressure at 4 bars.
vii. Run the calibration program and choose **Gas** from the **Calibration** menu.
viii. The message "Gas calibration in progress…" appears and a graph shows in seal time the O_2 and CO_2 calibration. The software first runs the room air calibration, so sampling line to cylinder output of calibration unit is connected only after the message "Sample reference gas…" is displayed. At the end the message "Calibration done" appears and report is shown. Press **OK** to confirm the calibration.
ix. Switch off the cylinder gas supply and remove the sampling line from calibrating unit.
x. Run the calibration program and choose **Delay** from the **Calibration** menu.
xi. The message "Gas calibration in progress …." appears and a graph shows in real time the O_2 and CO_2 calibration. The software first runs the room air calibration. At the end the message "Connect the sampling line to the flow meter and press OK to continue" appears.

xii. Connect the sampling line to the turbine and face mask and press **OK** to start breathing at a constant rate matching with the beep sound.

xiii. Continue breathing some cycles until the message "Calibration done" appears and a report is shown. Press **OK** to confirm the calibration.

xiv. Connect the facemask to the calibration syringe through the adapter.

xv. Choose **Turbine calibration** from the **calibration** menu.

xvi. When the data box appears, move the piston fully in and out for inspiratory and expiratory strokes in order to get values appearing on the display. Continue moving the syringe piston for more strokes until the message "Calibration done" appears. Press **OK** to store the values.

3.6.1.3. Measurements with Computerized Ambulatory Metabolic Measurement Equipment

Measurement of HR and VO_2 was done by K4B2 through the telemetry data transmission and receiver unit placed within a range of 800 meters of PU. Steps for measuring the variables in field are as listed below:

i. Disconnect the PU from the PC.

ii. Connect the receiver unit with receiving antenna, and PC through RS232.

iii. Go to K4B2 control panel and set **Transmission ON** through the **Settings** menu. Repeat the same on PC software.

iv. Choose the **Patients data** from the **Test** menu. Enter the patients ID number, age, height, weight and gender.

v. Through the K4B2 software in PC, enter the same patients data and ID.

vi. Fix the HR belt on chest of the subject.

vii. Fix the K4B2, battery and probes on subject with the help of harness belts, head-cap, and Velcro strips. The K4B2 unit is mounted on the belly, battery unit on the back, and the facemask is fitted over the face of the subject as shown in Fig. 3.29.

viii. Press **Enter** key on K4B2 and also the PC.

ix. Let the subject perform the assigned task. The data is displayed in tabulated form as well as graphically on PC in real time.

x. After completion of the task, press **Cancel** on K4B2. The message "Press enter to stop test" appears. Do as directed.

xi. Data is stored automatically both in K4B2 and PC memory.

Fig. 3.29. Positions for fixing of K4B2, facemask and battery on the subject.

xii. Remove the K4B2 equipment from the subject.

xiii. Repeat the steps numbered from (iv) to (xvii) to conduct experiment on other subject.

xiv. After the day's work, connect K4B2 to the PC through serial port.

xv. Choose **Receive test** from the **Test** menu of PC software.

xvi. Establish a link between patient's data of K4B2 and PC to start downloading the data. A status bar shows the data acquisition in progress. The downloaded file ensures that no data line is missing due to signal transmission lost during experiment.

xvii. Repeat the steps (xx) and (xxi) to download data files one by one on PC.

xviii. Convert the data files into Excel format for further analysis.

xix. Select **Erase memory** through **Memory functions** menu of K4B2 to free the memory available for the next day work.

xx. Charge the K4B2 batteries through battery charger to 100% for next day's work.

3.6.2. Measurements of Vibrations

A portable vibration meter of make Monitan model VM110 was used for measurement of vibrations at specific locations of boom sprayer. The procedure for measurement of vibrations is as given below:

i. Fit the PP3 type 9-V batteries at the slot provided in rear side of vibration meter.

ii. Connect the low noise coaxial cable of stud mounted accelerometer MTN/1100 with the connecting cable.

iii. Plug the 9-pin end of connecting cable into the socket above the display of vibration meter. The sensor plug is fixed firmly in place by two thumbscrews.

iv. Select the low pass filter at **5 kHz** of measurement bandwidth.

v. Select the parameter at **A**, i.e. acceleration measurement for vibrations.

vi. Connect the accelerometer at stud provided with fabricated fixture for measurement of vibration at pre-specified location and direction.

vii. Select the range switch at **2g**, where 'g' stands for 9.81 m/s^2.

viii. Switch **ON** the vibration meter and set it at **RMS** value.

ix. Note down the rms vibration acceleration reading at the display of vibration meter. If the reading exceeds the upper limit of range selected, the display shows "1". If such a display is shown, simply select the next higher range **20g** or **200g**, switch the vibration meter **OFF** and repeat steps (viii) and (ix).

3.6.3. Measurement of Noise

Noise was measured as sound pressure level (SPL) in terms of decibels acoustic dB(A) by a portable sound level meter. The procedure for measurement of noise by sound level meter is as follows:

i. Fit the 9-V battery at the slot provided in rear side of sound level meter.

ii. Connect the microphone by screwing it into position.

iii. Fit the wind shield to the microphone.

iv. Switch **ON** the power and let the warm up time of at least 30 seconds.

v. Select the frequency weighting switch at position marked **A**.

vi. Select the displaying switch at $\mathbf{L_s}$ position. L_s means rms value with a slow exponential averaging of 1 second, in decibels; and the value is displayed every second.

vii. Select the other displaying switch at $\mathbf{L_{eqT}}$ position. L_{eqT} means equivalent continuous sound pressure level i.e. the linear average of the square of the sound pressure during the time period of the measurement (from **Run** to **Stop**), in decibels. It is displayed every second.

$$L_{eqT} = 10 \,.\, \log \left\{ \frac{1}{T} \int_0^T \frac{p^2(t)}{p_0^2} \, dt \right\} \qquad \text{------ (11)}$$

viii. Set the timer at **1 minute** level. It is the length of time that a measurement lasts (from **Run** to **Stop**). It is shown in hours-minute-seconds format on the display. To display the **Timer,** press the button **Percentiles,** and while holding it down, press the button **Run/Stop**.

ix. Set the percentiles at $\mathbf{L_{90}}$ level. It is the level which has been exceeded the 90% of the measurement time, in decibels. To display the percentiles, press the button **Percentiles,** and while holding it down, press the button **Run/Stop.** The display first shows the **Timer** followed sequentially by the percentiles $\mathbf{L_{90}}$, $\mathbf{L_{50}}$ and $\mathbf{L_{10}}$.

x. Select the output switch at **PC OFF**.

xi. Place the sound level meter at pre-decided location near the sound producing machinery.

xii. Press the button **Run.** A new measurement begins and the results of previous measurement are lost.

xiii. At the end of 1 minute duration, press the button **Stop** which ends the measurement.

xiv. Note down the noise reading from the display.

xv. Repeat the experiment by repeating steps (xii) to (xiv).

3.7. Methodology of Research Experiments

The research experiments were conducted in four phases:

i. Subject calibration on bicycle ergometer.

ii. Field experiments on the boom sprayer for measurement of physiological parameter viz. HR, VO_2, ODR and BPDR.

iii. Field experiments on the boom sprayer for measurement of vibrations.

iv. Field experiments on the boom sprayer for measurement of noise.

3.7.1. Subject Calibration on Bicycle Ergometer

Steps involved, in sequence, in subject calibration on bicycle ergometer are as follows:

i. Subject was allowed to rest for the minimum of an hour prior to start of the experiment.

ii. Computerized ambulatory metabolic measurement equipment, K4B2, was setup, calibrated and prepared as in § 3.6.1 to measure HR and VO_2 of the subject before the start of the experiment.

iii. Power supply to the bicycle ergometer was switched **ON.**

iv. The **s**eat and handle bar of the ergometer was adjusted as per the subject's anthropometry.

v. The workload on the ergometer was set at 10 watts.

vi. The **Start** button on the control panel of the ergometer was pressed.

vii. Subject was asked to pedal the ergometer and to maintain rpm of about 50.

viii. Breath to breath HR and VO_2 readings were recorded continuously in real time by K4B2.

ix. At the end of every 5 minutes interval, without any break, the workload was increased by 10 watts. This was repeated upto a level of 70 watts.

x. The subject was asked to stop pedaling the ergometer after the recordings for a total of 35 minutes duration.

xi. From the data file, average HR and VO_2 values were recorded between 3^{rd} and 5^{th} minute duration at each of the workload levels from 10 to 70 watts.

xii. The same experiment in the given sequence was carried out on all the three selected subjects for 3 replications. Thus; a total of 9 experiments were conducted.

xiii. Workload versus average HR and VO_2 data was obtained from replicated experiments for each of the subject.

xiv. Linear regression lines of HR and on VO_2 on workload were fitted for each of the subjects. Fig. 3.30 shows the subject being calibrated on the bicycle ergometer.

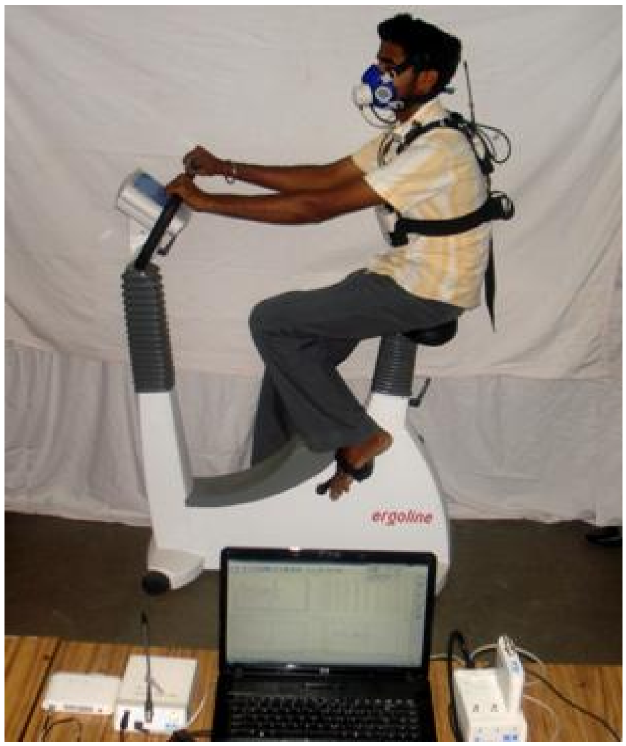

Fig. 3.30. Subject calibration on bicycle ergometer.

3.7.2. Field Experiments on Boom Sprayer for Measurement of Physiological Parameters

Since the self propelled boom sprayer did not have any provision of instrumentation to show the forward speed, it had to be set indirectly every time the experiment was conducted. Thus; a pointer was attached to the accelerator lever. A steel plate was fabricated and fixed below the pointer attached to the accelerator. The sprayer was run in the field and accelerator was adjusted to achieve a forward speed of 1.5 km/h. The position was marked on the steel plate fixed below the pointer attached with accelerator. The procedure was repeated for markings of 2.25 and 3.0 km/h forward speed of sprayer. Fig. 3.31 shows the provision to setup the forward speed of the boom sprayer.

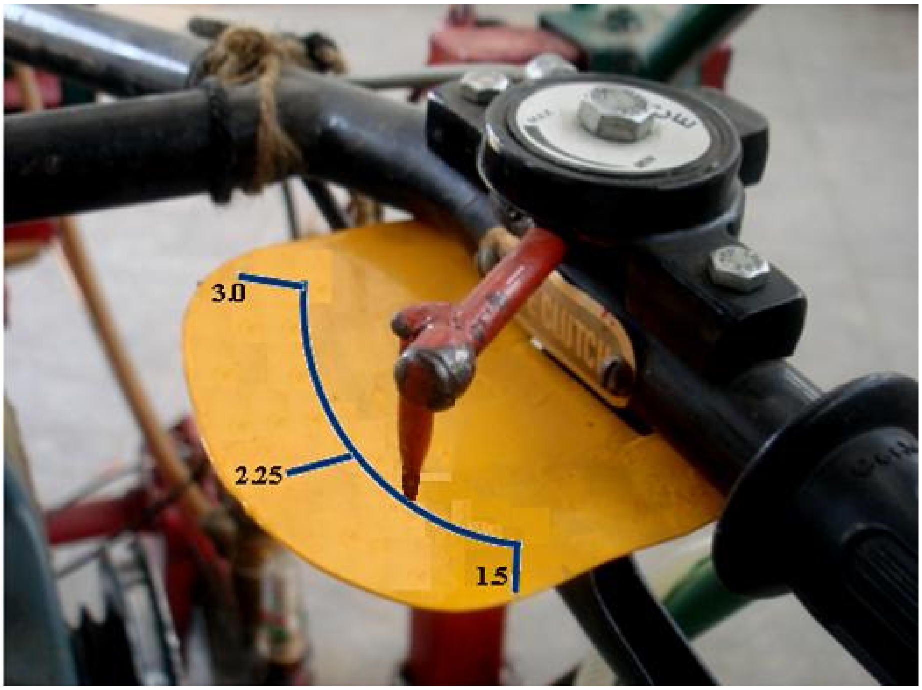

Fig. 3.31. Provision to setup the forward speed of boom sprayer.

Steps involved, in sequence, for measurement of physiological parameters viz. HR, VO_2, ODR and BPDR on the self propelled boom sprayer under simulated field conditions are as follows:

i. Subject was allowed to take about an hour rest before start of the experiment.

ii. Spray storage tank was filled upto top with the tap water.

iii. Sprayer engine was started and the machine was placed in field at the start line of the straight run.

iv. The machine was checked for any needful concerning nuts and bolts, leakage, diesel in tank, pressure of the spray pump @2.5 kg/cm^2, air pressure in tyres, etc.

v. Computerized ambulatory metabolic measurement equipment, K4B2 was setup, calibrated and prepared as in § 3.6.1 to measure HR and VO_2 of the subject before the start of experiment.

vi. Accelerator of the boom sprayer was set at pre-decided level of the forward speed.

vii. Spray pump gear lever was set at engaged position.

viii. Forward gear lever of the sprayer was engaged and the subject was asked to operate it for duration of 15 minutes.

ix. Side clutches were used by the subject while turning the sprayer in the field plot.

x. Breath to breath HR and VO_2 readings were recorded continuously in real time by K4B2.

xi. Subject was asked to stop the sprayer after 15 minutes of experiment duration.

xii. ODR and BPDR of the subject were recorded immediately after the end of experiment.

xiii. Data file of K4B2 was downloaded on PC and converted in Excel format.

xiv. Average HR and VO_2 readings were noted for 6^{th} to 15^{th} minutes of experiment duration.

xv. Three replications were conducted at each combination of the various levels of the independent variables (see Table 3.2). Thus; a total of 108 experiments were conducted on boom sprayer for measurement of physiological parameters under simulated field condition.

Figures 3.9 and 3.14 show the measurement of HR and VO_2 of subject working on walk behind type and riding type boom sprayer under simulated field condition.

3.7.3. Field Experiments on Boom Sprayer for Measurement of Vibrations

The magnitude of vibrations is dependent on location and direction of measurement. Any change in direction of measurement of vibrations leads to unrepresentative data. Because of the experiments to be conducted under field conditions, the accelerometer is to be mounted rigidly on the machine at pre-decided locations. Keeping the above in view, a stud mounted accelerometer was used with vibration meter for measuring vibrations of machine components. It was decided to measure vibrations along three mutually perpendicular directions viz. vertical, longitudinal and lateral (Fig.3.32). Therefore, cubical shaped fixtures of side 1.5 inches were developed and fabricated out of hollow mild steel bar. The cubical fixtures have studs of matching threads fixed on three adjacent sides (Fig. 3.33). These fixtures were welded horizontally at pre-decided locations viz. engine top, chassis, handle-bar, handle, and seat base, such that vibrations can be measured along three pre-decided directions (Fig.3.34).

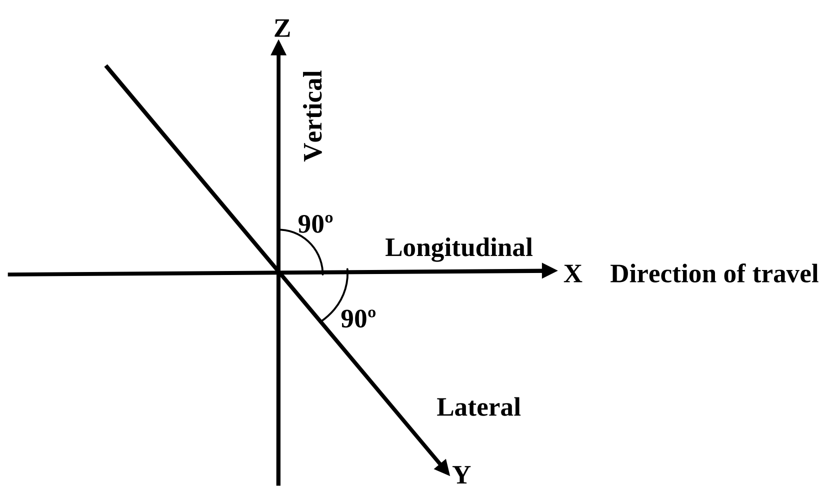

Fig. 3.32. Directions for measurement of vibrations.

Fig. 3.33. Fixture for measuring vibrations along three mutually perpendicular directions.

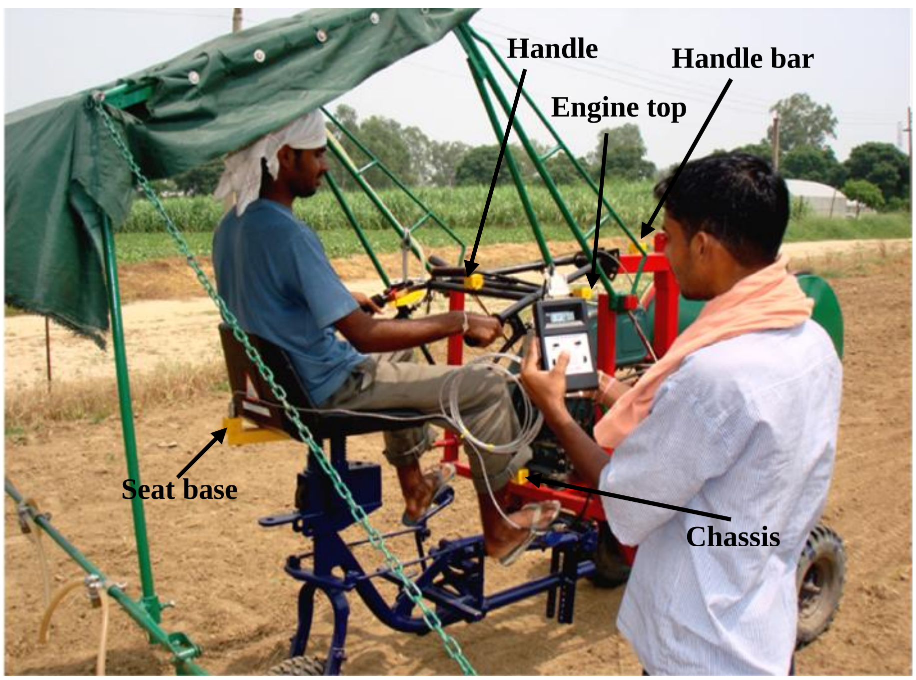

Fig. 3.34. Measurement of vibrations in vertical direction at seat base of boom sprayer.

Steps involved, in sequence, for measurement of vibrations of self propelled boom sprayer under simulated field conditions are as follows:

i. Spray storage tank was filled upto top with the tap water.
ii. Sprayer engine was started and the machine was placed in field at the start line of the straight run.
iii. The machine was checked for any needful concerning nuts and bolts, leakage, diesel in tank, pressure of the spray pump @ 2.5 kg/cm^2, air pressure of the tyres, etc.
iv. Accelerator of the boom sprayer was set at pre-decided level of the forward speed.
v. Spray pump gear lever was set at engaged position.
vi. Portable vibration meter was setup as discussed in § 3.6.2.
vii. Vibration accelerometer was mounted at stud provided with fixture for measurement of vibrations at pre-decided location and direction.
viii. Forward gear lever of the sprayer was engaged and the subject was asked to straight run it for duration of one minute.
ix. RMS acceleration was recorded from the display of vibration meter.
x. The experiment was repeated for measurement of vibrations in three directions i.e. vertical, longitudinal and lateral at five locations viz. engine top, chassis, handle bar, handle and seat base.
xi. The experiments were replicated thrice at each combination of the various levels of independent variables (see Table 3.2). Thus; a total of 1458 experiments were conducted on boom sprayer for measurement of vibrations.

Fig. 3.34 shows the measurement of vibrations in vertical direction at handle bar of the self propelled boom sprayer.

3.7.4. Field Experiments on Boom Sprayer for Measurement of Noise

Steps involved, in sequence, for measurement of noise of self propelled boom sprayer under simulated field conditions are as follows:

i. Spray storage tank was filled upto top with tap water.
ii. Machine was placed in the field at the start line of the straight run.
iii. It was confirmed that there is free acoustic area at least 20 meters around sprayer.
iv. Portable sound level meter was setup as discussed in § 3.6.3.
v. Sound level of background noise was measured.

vi. Sprayer engine was started and the machine was checked for any needful concerning nuts and bolts, leakage, diesel in tank, pressure of spray pump @ 2.5 kg/cm^2, air pressure of tyres, etc.

vii. Accelerator of boom sprayer was set at pre-decided level of forward speed.

viii. Spray pump gear lever was set at engaged position.

ix. Microphone of sound level meter was set horizontal, facing forward and at ear level of the subject.

x. Forward gear lever of the sprayer was engaged and the subject was asked to straight run it.

xi. After the speed and sound of machine has been stabilized, sound pressure level was recorded for duration of one minute.

xii. It was verified that the background noise was at least 10 dB lesser than recorded during field experiments.

xiii. The experiment was repeated three times. It was verified that the sound pressure level variation was not more than 3 dB during replications.

xiv. The experiments were conducted at each combination of the various levels of independent variables (see Table 3.2). Thus; a total of 108 experiments were conducted on boom sprayer for measurements of noise.

Fig. 3.35 shows the measurement of noise at operator's ear level.

Fig. 3.35. Measurement of noise at operator's ear level.

3.8. Statistical Design of Experiments

The data collected in the experiments was analyzed statistically. The regression coefficients of both the heart rate as well as oxygen consumption on workload were calculated for each of the three subjects separately. The correlation coefficients were also calculated to find coefficients of determination for each.

The development of the sprayer from walk behind type to riding type and also the provision of vibration isolators was tedious and time consuming. Therefore, all the experiments related to walk behind type boom sprayer were conducted at the start. These were followed by the experiments on sprayer after converting it into a riding type. This was followed by development of vibration isolators. The experiments were then repeated for riding type machine followed by walk behind type (both fitted with vibration isolators). Hence, the experiments were planned and analyzed in factorial in completely randomized design (Factorial in CRD) for the significance of difference, if any, among the factors at five per cent level of significance. The data of all the dependent variables were analyzed by using CPCS1 software.

Chapter IV

RESULTS AND DISCUSSION

The results of ergonomic studies on self propelled boom sprayer have been discussed in this chapter. While the subject calibration on bicycle ergometer was carried out to get subject characteristics' curves to find human workload on the subjects, field experiments on the boom sprayer were conducted for measurement of vibrations, noise and physiological parameters. The results obtained have been discussed under the following headings:

1. Subject characteristics
2. Effect of the independent variables on vibration
3. Effect of the independent variables on noise
4. Effect of the independent variables on physiological parameters
    i. Heart rate
    ii. Oxygen consumption
    iii. Overall discomfort rating
    iv. Body part discomfort rating
5. Optimum values of the independent variables
6. Effect of vibration exposure duration on isolator characteristics

4.1. Subject Characteristics

The data for subject characteristics of heart rate (HR) and oxygen consumption (VO_2) on workload is given in Table 4.1 and the corresponding curves are presented in Figures 4.1 and 4.2. These regression lines reveal that with increase in workload by one watt, there was an increase in HR by 0.59 beats/min and an increase in VO_2 *b*y 13.68 ml/min for the subject S_1. The corresponding increase in HR and VO_2 were 0.38 beats/min and 14.61 ml/min, respectively for subject S_2 and 0.74 beats/min and 16.48 ml/min, respectively for subject S_3. The correlation coefficients between workload and HR, and workload and VO_2 were also found to be very high. The coefficient of determination varied between 0.9742 and 0.9860 for workload versus HR curves, and between 0.9880 and 0.9960 for workload versus VO_2 curves for the selected three subjects.

The comparison of the regression coefficients of HR on workload reveal that the coefficient was the maximum for the subject S_3 which was due to his age factor. However, the regression coefficient of HR on workload was the minimum for the subject S_2 which was due to its resting HR value of 90 beats/min. The regression coefficient of VO_2 on workload was the maximum for the subject S_3 and the minimum for the subject S_1. However, the resting VO_2 was the maximum for the subject S_1 and the minimum for the subject S_3. This characteristic of VO_2 was due to age factor of the selected subjects, age being the minimum for the subject S_1 and the maximum for the subject S_3.

Table 4.1. Mean heart rate (HR) and oxygen consumption (VO_2) of selected subjects in relation to workload (W) on bicycle ergometer.

W (Watts)	Mean HR (beats/min)*			Mean VO_2 (ml/min)#		
	S_1	S_2	S_3	S_1	S_2	S_3
10	80.3	95.9	85.5	428.0	456.5	416.9
20	83.1	99.2	90.2	575.2	583.8	541.3
30	86.2	102.4	93.3	743.9	709.9	654.1
40	96.5	105.5	104.8	923.8	867.8	864.5
50	102.9	109.1	113.1	964.2	1009.9	1028.3
60	105.9	114.1	119.9	1143.9	1152.1	1159.1
70	114.9	119.6	128.5	1252.4	1341.6	1418.0

***Regression equation of HR (beats/min) on W (watts):**

i. **Subject S_1**
   $HR = 71.96 + 0.59\,W$ (Coefficient of determination, $r^2 = 0.9742$)
ii. **Subject S_2**
   $HR = 91.17 + 0.38\,W$ (Coefficient of determination, $r^2 = 0.9860$)
iii. **Subject S_3**
   $HR = 75.30 + 0.74\,W$ (Coefficient of determination, $r^2 = 0.9821$)

#Regression equation of VO_2 (ml/min) on W (watts):

i. **Subject S_1**
   $VO_2 = 314.36 + 13.68\,W$ (Coefficient of determination, $r^2 = 0.9880$)
ii. **Subject S_2**
   $VO_2 = 289.96 + 14.61\,W$ (Coefficient of determination, $r^2 = 0.9960$)
iii. **Subject S_3**
   $VO_2 = 209.87 + 16.48\,W$ (Coefficient of determination, $r^2 = 0.9880$)

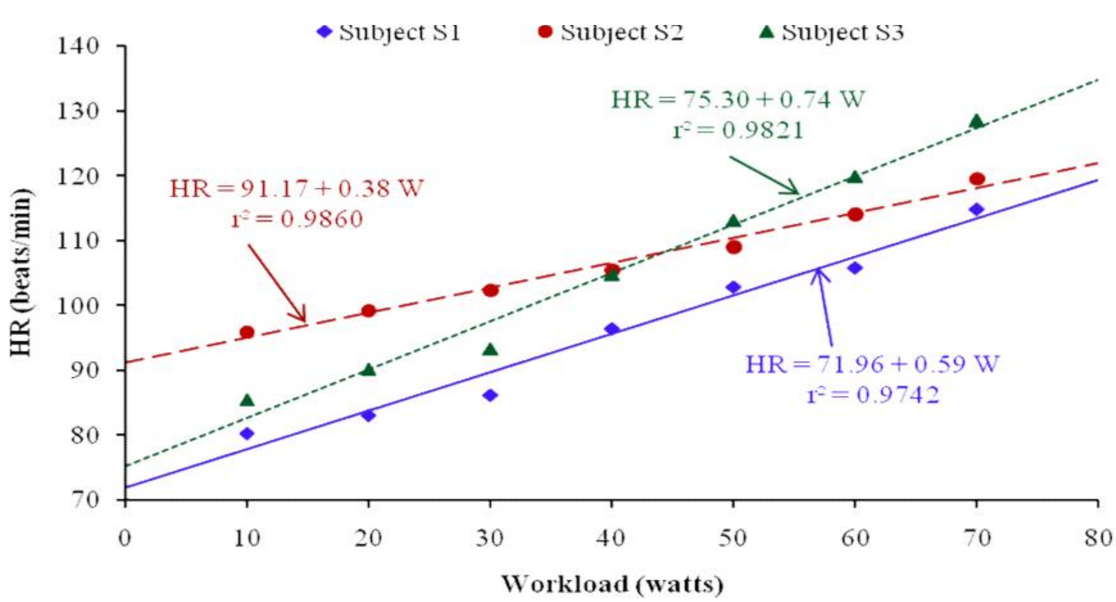

Fig. 4.1. Subject characteristics' curves between heart rate and workload.

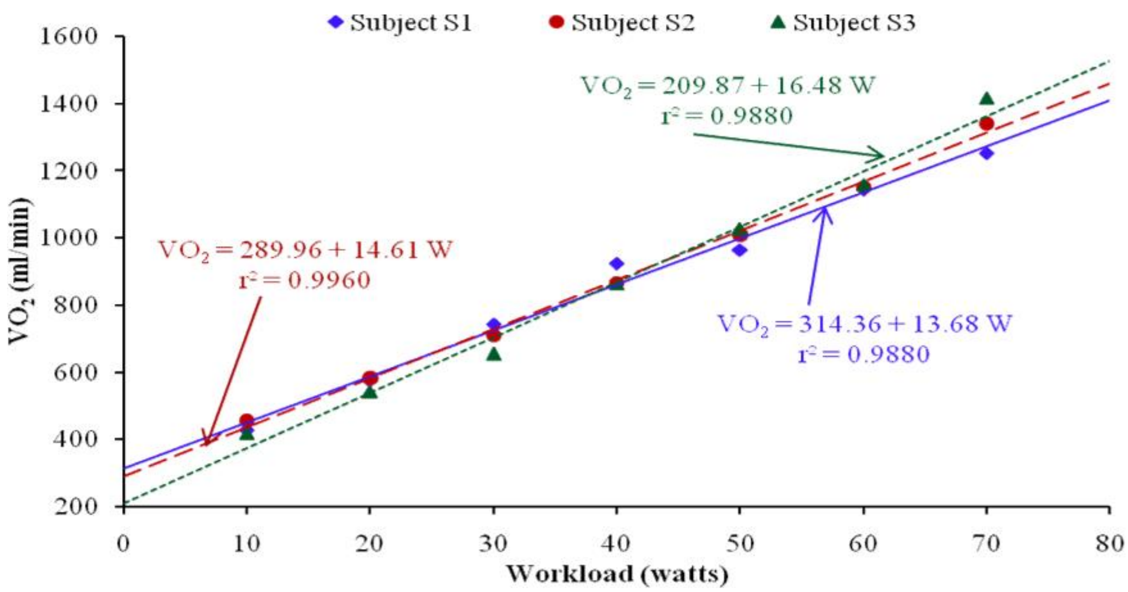

Fig. 4.2. Subject characteristics' curves between oxygen consumption and workload.

4.2. Effect of the Independent Variables on Vibration

Vibration was measured as rms acceleration in units of 'g' (1g = 9.81 m/s^2) at five locations of boom sprayer viz. engine top, chassis, handle bar, handle and seat base along three mutually perpendicular directions i.e. vertical, longitudinal and lateral at each.

4.2.1. Vibration Characteristics at Engine Top

4.2.1.1. Vibration Characteristics along Vertical Direction

The vibration characteristics along vertical direction at engine top of the boom sprayer have been given in Table 4.2 and its analysis of variance is presented in Table 4.3. The vibration characteristics are also shown graphically in Fig. 4.3. The mean values of vibration acceleration varied from 1.24 to 12.61 g m/s^2 among all the treatments and the differences were statistically significant (Critical Difference, C.D. = 0.572) at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 5.04 and 5.61 g m/s^2, respectively and were statistically different (C.D. = 0.135) at five per cent level of significance. The 11.3% increase in vibrations of M_2 over M_1 could be attributed to their weight and its distribution at wheels. Weight of riding type boom sprayer was 42 kg more than that of walk behind type. In addition, weight of operator was also supported at the seat of the riding type machine. The rear wheel of boom sprayer in case of walk behind type was under its engine, and was shifted to under the operator's seat in case of riding type; thus, resulting in redistribution of weight of machine and operator over a wider area.

Table 4.2. Response of vibration acceleration at engine top of self propelled boom sprayer.

S. No.	Treatment	RMS acceleration vibration (x g m/s^2)*											
		Vertical				Longitudinal				Lateral			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
1	$M_1V_0F_1S_1$	2.72	3.04	3.34	3.03	5.38	5.36	5.65	5.46	3.17	3.06	2.94	3.06
2	$M_1V_0F_1S_2$	3.17	2.80	2.97	2.98	5.39	5.04	5.25	5.23	3.40	3.09	3.22	3.24
3	$M_1V_0F_1S_3$	3.66	3.91	4.32	3.96	5.12	5.47	5.33	5.31	3.03	3.17	2.94	3.05
4	$M_1V_0F_2S_1$	7.12	7.06	6.88	7.02	6.89	6.94	7.03	6.95	3.20	3.04	2.90	3.05
5	$M_1V_0F_2S_2$	8.38	9.00	10.11	9.16	7.13	7.35	6.88	7.12	3.10	3.08	2.99	3.06
6	$M_1V_0F_2S_3$	8.11	7.64	8.23	7.99	6.82	6.94	7.06	6.94	3.10	3.33	2.92	3.12
7	$M_1V_0F_3S_1$	6.77	7.14	7.43	7.11	10.66	10.97	11.06	10.90	4.43	4.84	5.12	4.80
8	$M_1V_0F_3S_2$	5.43	5.97	5.34	5.58	9.90	9.59	9.95	9.81	4.55	5.03	4.76	4.78
9	$M_1V_0F_3S_3$	5.66	5.59	5.84	5.70	9.79	10.08	9.60	9.82	5.12	4.80	4.96	4.96
10	$M_1V_1F_1S_1$	1.98	2.12	2.06	2.05	2.94	2.78	2.72	2.81	1.36	1.41	1.31	1.36
11	$M_1V_1F_1S_2$	1.44	1.22	1.06	1.24	2.76	2.81	2.80	2.79	1.64	1.74	1.57	1.65
12	$M_1V_1F_1S_3$	2.28	2.42	2.55	2.42	4.55	4.83	4.76	4.71	2.30	2.62	2.77	2.56
13	$M_1V_1F_2S_1$	4.74	4.88	5.12	4.91	6.89	7.07	7.13	7.03	4.73	4.26	4.41	4.47
14	$M_1V_1F_2S_2$	4.94	4.78	4.58	4.77	6.58	6.69	6.75	6.67	4.11	4.69	4.41	4.40
15	$M_1V_1F_2S_3$	4.74	4.67	4.85	4.75	7.02	6.78	6.65	6.82	4.44	4.35	4.08	4.29
16	$M_1V_1F_3S_1$	5.95	6.35	6.41	6.24	7.81	8.04	8.01	7.95	6.42	6.93	7.07	6.81
17	$M_1V_1F_3S_2$	6.12	5.93	5.58	5.88	7.43	7.69	7.71	7.61	7.26	7.49	7.67	7.47
18	$M_1V_1F_3S_3$	5.77	6.12	5.97	5.95	7.68	7.55	7.98	7.74	7.67	6.85	7.45	7.32
19	$M_2V_0F_1S_1$	2.98	3.11	3.17	3.09	5.00	4.47	4.64	4.70	3.76	4.19	3.98	3.98
20	$M_2V_0F_1S_2$	2.84	3.03	2.97	2.95	5.10	4.91	4.98	5.00	3.68	3.82	4.01	3.84
21	$M_2V_0F_1S_3$	2.77	2.93	2.85	2.85	4.56	4.73	4.44	4.58	4.04	4.18	3.87	4.03
22	$M_2V_0F_2S_1$	5.05	4.87	5.17	5.03	5.83	5.93	5.71	5.82	3.35	3.42	4.02	3.60
23	$M_2V_0F_2S_2$	5.55	6.14	5.71	5.80	6.34	6.31	6.17	6.27	3.45	4.11	3.87	3.81
24	$M_2V_0F_2S_3$	5.20	5.48	4.67	5.12	6.67	7.29	7.01	6.99	3.65	3.75	3.81	3.74
25	$M_2V_0F_3S_1$	7.69	7.91	8.23	7.94	9.97	10.04	10.57	10.19	6.12	5.85	6.05	6.01
26	$M_2V_0F_3S_2$	8.02	9.33	8.51	8.62	9.99	10.21	10.55	10.25	5.16	5.43	5.38	5.32
27	$M_2V_0F_3S_3$	7.68	8.23	7.79	7.90	10.56	11.00	10.75	10.77	6.43	6.51	6.57	6.50
28	$M_2V_1F_1S_1$	1.97	2.36	2.54	2.29	4.46	4.62	4.76	4.61	1.78	1.94	2.09	1.94
29	$M_2V_1F_1S_2$	2.60	2.19	1.90	2.23	3.49	3.34	2.88	3.24	1.64	1.53	1.78	1.65
30	$M_2V_1F_1S_3$	1.77	2.12	2.01	1.97	2.93	2.79	3.05	2.92	2.15	1.97	2.01	2.04
31	$M_2V_1F_2S_1$	7.73	9.37	8.87	8.66	6.69	7.22	7.31	7.07	4.30	4.16	4.69	4.38
32	$M_2V_1F_2S_2$	5.31	4.76	5.12	5.06	7.68	7.34	6.99	7.34	3.60	3.82	4.17	3.86
33	$M_2V_1F_2S_3$	4.64	5.12	5.04	4.93	7.83	7.96	8.04	7.94	4.67	4.31	4.91	4.63
34	$M_2V_1F_3S_1$	13.49	11.96	12.39	12.61	9.43	9.51	9.53	9.49	5.92	6.19	6.17	6.09
35	$M_2V_1F_3S_2$	7.11	7.48	6.96	7.18	9.62	9.21	9.12	9.32	5.50	5.73	5.80	5.68
36	$M_2V_1F_3S_3$	6.49	7.05	6.88	6.81	7.25	7.80	8.12	7.72	4.97	5.20	5.00	5.06

*1 g = 9.81 m/s^2

Table 4.3. Analysis of variance for vibration acceleration measured along vertical direction at engine top of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)					
Provision of a seat with machine (M)			5.04 (M_1)	5.61 (M_2)	
Provision of vibration isolators (V)			5.66 (V_0)	5.00 (V_1)	
Forward speed (F)			2.59 (F_1)	6.10 (F_2)	7.29 (F_3)
Subject (S)			5.83 (S_1)	5.12 (S_2)	5.03 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	8.813	71.37	0.135	
V	1	11.768	95.30	0.135	
MV	1	23.473	190.09	0.191	
F	2	215.428	1744.62	0.165	
MF	2	24.298	196.77	0.234	
VF	2	6.268	50.76	0.234	
MVF	2	8.835	71.55	0.330	
S	2	6.961	56.38	0.165	
MS	2	7.095	57.46	0.234	
VS	2	10.800	87.47	0.234	
MVS	2	6.480	52.48	0.330	
FS	4	3.991	32.32	0.286	
MFS	4	1.482	12.00	0.405	
VFS	4	1.999	16.19	0.405	
MVFS	4	3.860	31.26	0.572	
Error	72	0.123			6.60

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 5.00 g m/s^2 in comparison to 5.66 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.135) at five per cent level. Thus; vibrations at engine top along vertical direction were reduced by 11.66% with the provision of vibration isolators. Vibrations were measured at the engine top which itself was a source of vibration. The vibration isolators at the engine mountings have no direct role in reduction of vibrations at the engine itself. However, the difference in vibration acceleration could be attributed to the fact that provision of synthetic rubber based vibration isolators at engine mountings resulted in absorption of external exciting force to the engine mass. In addition, vibration isolators at engine mountings also reduced shock caused by field contour to the engine.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.165) at five per cent level of significance. The vibration acceleration was observed as 2.59, 6.10 and 7.29 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend was due to the reason that increase in forward speed of the sprayer was directly related to increase in rpm of reciprocating type diesel engine.

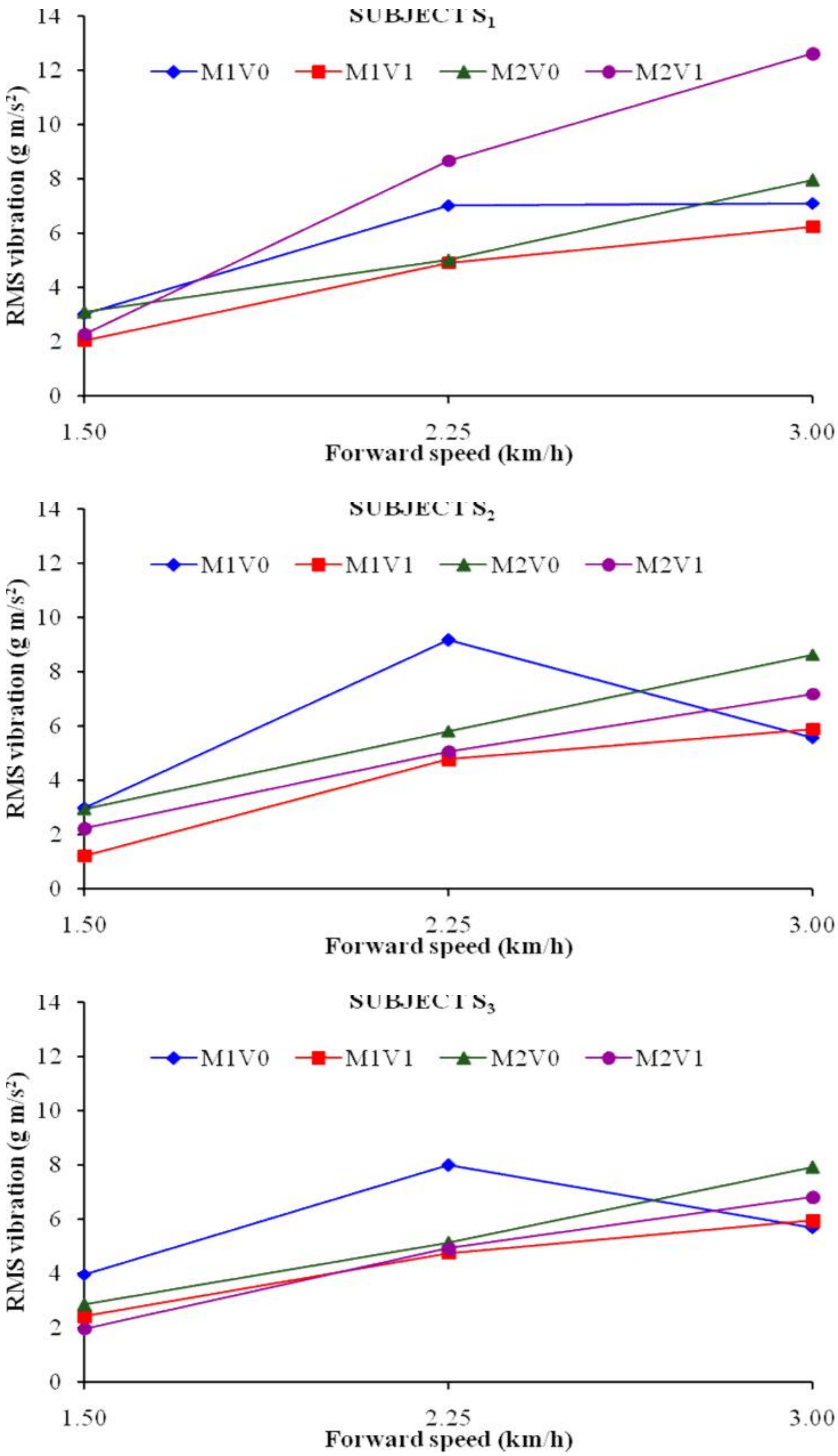

Fig. 4.3. Vibration acceleration along vertical direction at engine top of boom sprayer.

Vibration acceleration along vertical direction at engine top of boom sprayer was statistically at par (C.D. = 0.165) for the subjects S_2 (5.12 g m/s^2) and S_3 (5.03 g m/s^2). However, vibration in case of the subject S_1 was considerably higher (5.83 g m/s^2). The variation in this respect could be attributed to their individual characteristics viz. stature, weight and grip of handle while operation the boom sprayer.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. For all combinations of M and V, the vibration acceleration increased with increase in forward speed for all of the selected subjects.

4.2.1.2. Vibration Characteristics along Longitudinal Direction

The vibration characteristics along longitudinal direction at engine top of the boom sprayer have been given in Table 4.2 and its analysis of variance is presented in Table 4.4. The vibration characteristics are also shown graphically in Fig. 4.4. The mean values of vibration acceleration varied from 2.79 to 10.90 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.343) at five per cent level of significance.

Table 4.4. Analysis of variance for vibration acceleration measured along longitudinal direction at engine top of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	6.76 (M_1)	6.90 (M_2)	
Provision of vibration isolators (V)	7.34 (V_0)	6.32 (V_1)	
Forward speed (F)	4.28 (F_1)	6.91 (F_2)	9.30 (F_3)
Subject (S)	6.92 (S_1)	6.72 (S_2)	6.86 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	0.542	12.27	0.081	
V	1	27.988	632.94	0.081	
MV	1	6.003	135.75	0.114	
F	2	226.791	5128.80	0.099	
MF	2	1.840	41.61	0.140	
VF	2	15.260	345.09	0.140	
MVF	2	0.171	3.87	0.198	
S	2	0.365	8.25	0.099	
MS	2	0.419	9.48	0.140	
VS	2	0.209	4.72	0.140	
MVS	2	3.063	69.28	0.198	
FS	4	0.945	21.37	0.171	
MFS	4	1.779	40.23	0.242	
VFS	4	0.734	16.61	0.242	
MVFS	4	0.727	16.43	0.343	
Error	72	0.044			3.08

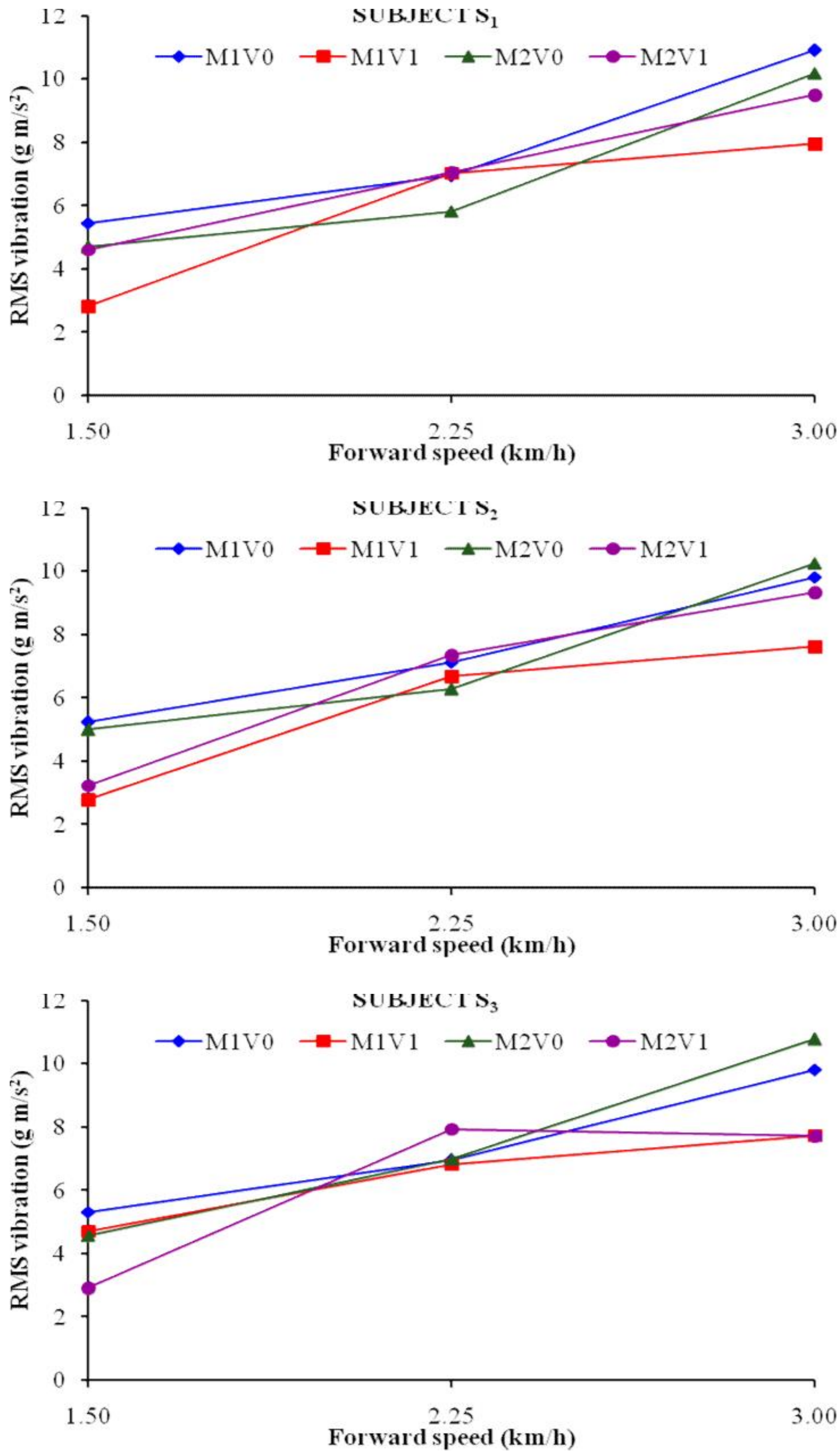

Fig. 4.4. Vibration acceleration along longitudinal direction at engine top of boom sprayer.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 6.76 and 6.90 g m/s^2, respectively and were statistically different (C.D. = 0.081) at five per cent level of significance. The reason for 2.1% increase in vibrations of M_2 over M_1 is as explained in §4.2.1.1.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 6.32 g m/s^2 in comparison to 7.34 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.081) at five per cent level. Thus; vibrations at engine top along longitudinal direction were reduced by 13.90% with the provision of vibration isolators. The reason, in this respect, is as already explained in §4.2.1.1.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.099) at five per cent level of significance. The vibration acceleration was observed as 4.28, 6.91 and 9.30 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend was due to direct relation between forward speed of the sprayer and rotational speed of reciprocating type diesel engine.

Vibration acceleration along longitudinal direction at engine top of boom sprayer was statistically at par (C.D. = 0.099) for the subjects S_1 (6.92 g m/s^2) and S_3 (6.86 g m/s^2). However, vibration in case of the subject S_2 was a little lower (6.72 g m/s^2). The variation in this respect could be attributed to their individual characteristics.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. The walk behind type boom sprayer (M_1) resulted in vibration acceleration statistically at par both for with (V_1) and without the provision of vibration isolators (V_0) at a forward speed of 2.25 km/h among all the subjects. The vibrations for a combination of M_1 with V_1 at forward speed of 1.50 and 3.00 km/h were, however, significantly lesser than M_1V_0 for all the subjects. Similarly for all the subjects, vibration acceleration was significantly lesser for a combination of M_2V_0 as compared to M_2V_1 at a forward speed of 2.25 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.1.3. Vibration Characteristics along Lateral Direction

The vibration characteristics along lateral direction at engine top of the boom sprayer have been given in Table 4.2 and its analysis of variance is presented in Table 4.5. The vibration characteristics are also shown graphically in Fig. 4.5. The mean values of vibration acceleration varied from 1.36 to 7.47 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.350) at five per cent level of significance.

Table 4.5. Analysis of variance for vibration acceleration measured along lateral direction at engine top of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	4.08 (M_1)	4.23 (M_2)	
Provision of vibration isolators (V)	4.11 (V_0)	4.20 (V_1)	
Forward speed (F)	2.70 (F_1)	3.87 (F_2)	5.90 (F_3)
Subject (S)	4.13 (S_1)	4.06 (S_2)	4.28 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	0.616	13.32	NS	
V	1	0.256	5.53	0.083	
MV	1	13.498	291.94	0.117	
F	2	94.471	2043.27	0.101	
MF	2	1.121	24.25	0.143	
VF	2	20.936	452.81	0.143	
MVF	2	2.755	59.59	0.202	
S	2	0.424	9.17	0.101	
MS	2	0.534	11.55	0.143	
VS	2	0.002	0.05	NS	
MVS	2	0.453	9.80	0.202	
FS	4	0.084	1.82	NS	
MFS	4	0.207	4.48	0.248	
VFS	4	0.702	15.19	0.248	
MVFS	4	0.380	8.22	0.350	
Error	72	0.046			5.17

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 4.08 and 4.23 g m/s^2, respectively. Though there was 3.7% increase in vibrations of M_2 over M_1, yet the difference was statistically non-significant at five per cent level of significance.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 4.20 g m/s^2 in comparison to 4.11 g m/s^2 for the sprayer without isolators (V_0) which was found to be statistically at par at five per cent level of significance.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.101) at five per cent level of significance. The vibration acceleration was observed as 2.70, 3.87 and 5.90 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend was due to increase in engine rpm.

Vibration acceleration along lateral direction at engine top of boom sprayer was statistically at par (C.D. = 0.101) for the subjects S_1 (4.13 g m/s^2) and S_2 (4.06 g m/s^2). However, vibration in case of the subject S_3 was a little higher (4.28 g m/s^2). The variation in this respect could be attributed to their individual characteristics.

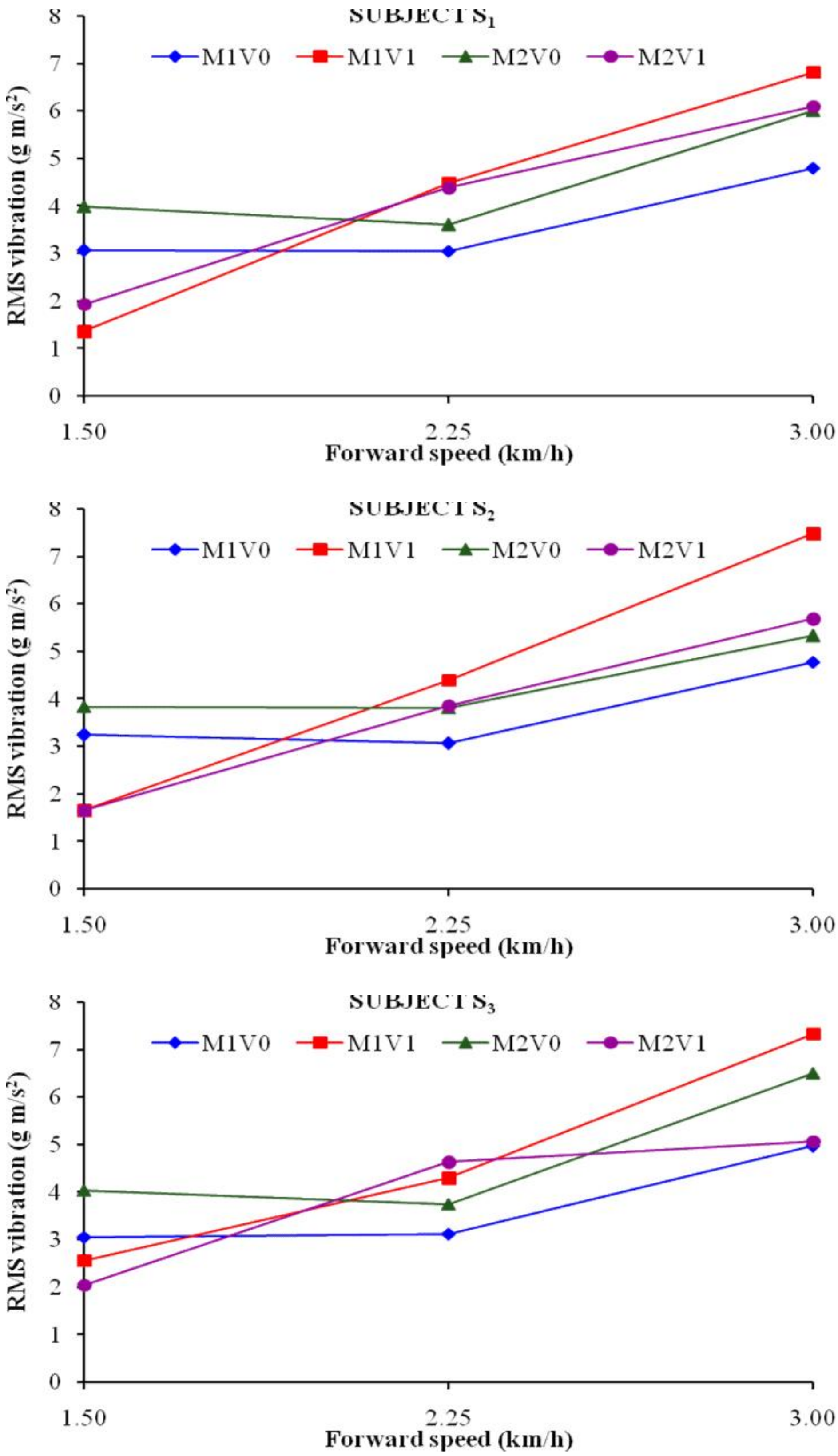

Fig. 4.5. Vibration acceleration along lateral direction at engine top of boom sprayer.

The interactions among various independent variables, except VS and FS, were also found to be statistically different at five per cent level of significance. The walk behind type boom sprayer (M_1) having provision of vibration isolators (V_1) resulted in higher vibration acceleration compared to that without vibration isolators (V_0) at the forward speeds of 2.25 and 3.00 km/h among all the subjects. The vibration for a combination of M_1 with V_1 at forward speed of 1.50 km/h was, however, significantly lesser than M_1V_0 for all the subjects. Similarly for all the subjects, vibration acceleration was significantly lesser for a combination of M_2V_0 as compared to M_2V_1 at a forward speed of 2.25 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.2. Vibration Characteristics at Chassis

4.2.2.1. Vibration Characteristics along Vertical Direction

The vibration characteristics along vertical direction at chassis of the boom sprayer have been given in Table 4.6 and its analysis of variance is presented in Table 4.7. The vibration characteristics are also shown graphically in Fig. 4.6. The mean values of vibration acceleration varied from 0.47 to 10.22 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.404) at five per cent level of significance.

Table 4.6. Response of vibration acceleration at chassis of self propelled boom sprayer.

S. No.	Treatment	RMS acceleration vibration (x g m/s^2)*											
		Vertical				Longitudinal				Lateral			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
1	$M_1V_0F_1S_1$	5.31	5.12	5.44	5.29	4.36	4.27	3.96	4.20	4.13	4.18	3.97	4.09
2	$M_1V_0F_1S_2$	5.24	5.22	4.80	5.09	4.08	3.87	4.04	4.00	3.80	3.61	4.09	3.83
3	$M_1V_0F_1S_3$	5.13	4.85	5.32	5.10	4.07	3.95	3.89	3.97	3.85	3.70	4.04	3.86
4	$M_1V_0F_2S_1$	5.81	5.66	5.91	5.79	4.76	4.53	4.66	4.65	4.98	5.18	5.24	5.13
5	$M_1V_0F_2S_2$	6.01	5.90	5.97	5.96	4.42	4.16	4.34	4.31	4.75	4.86	5.09	4.90
6	$M_1V_0F_2S_3$	5.85	5.76	5.66	5.76	4.20	4.39	4.61	4.40	4.95	5.10	5.14	5.06
7	$M_1V_0F_3S_1$	9.12	8.76	8.92	8.93	6.31	6.15	5.97	6.14	7.22	7.39	7.51	7.37
8	$M_1V_0F_3S_2$	8.72	9.83	10.16	9.57	7.17	6.99	7.47	7.21	8.19	7.52	7.81	7.84
9	$M_1V_0F_3S_3$	9.90	10.13	9.47	9.83	7.87	7.34	7.50	7.57	7.41	7.77	8.03	7.74
10	$M_1V_1F_1S_1$	0.50	0.58	0.66	0.58	0.60	0.54	0.78	0.64	0.38	0.42	0.44	0.41
11	$M_1V_1F_1S_2$	0.48	0.50	0.43	0.47	0.96	0.80	0.65	0.80	0.38	0.41	0.58	0.46
12	$M_1V_1F_1S_3$	0.87	1.01	0.91	0.93	0.51	0.60	0.89	0.67	0.33	0.38	0.44	0.38
13	$M_1V_1F_2S_1$	3.05	2.71	2.94	2.90	2.99	2.66	2.33	2.66	1.93	1.54	2.16	1.88
14	$M_1V_1F_2S_2$	2.19	3.01	3.15	2.78	2.15	2.44	2.74	2.44	1.86	1.94	2.21	2.00
15	$M_1V_1F_2S_3$	2.98	3.19	2.91	3.03	3.02	3.15	3.43	3.20	1.74	1.90	2.17	1.94
16	$M_1V_1F_3S_1$	5.81	6.11	5.95	5.96	4.87	4.12	4.44	4.48	2.81	3.15	3.33	3.10
17	$M_1V_1F_3S_2$	4.89	5.51	5.92	5.44	3.26	3.43	3.71	3.47	2.15	2.39	2.33	2.29
18	$M_1V_1F_3S_3$	4.02	4.27	4.37	4.22	3.97	4.02	4.22	4.07	2.48	2.81	3.05	2.78

19	$M_2V_0F_1S_1$	3.85	4.15	4.27	4.09	3.23	4.19	3.88	3.77	4.24	4.15	4.58	4.32
20	$M_2V_0F_1S_2$	4.27	4.22	3.98	4.16	3.14	2.72	3.11	2.99	4.20	4.32	4.16	4.23
21	$M_2V_0F_1S_3$	3.72	3.97	4.32	4.00	4.10	3.79	3.91	3.93	4.22	4.05	4.13	4.13
22	$M_2V_0F_2S_1$	5.54	5.37	5.61	5.51	3.60	4.22	4.01	3.94	4.83	4.57	5.05	4.82
23	$M_2V_0F_2S_2$	6.25	6.07	5.87	6.06	3.71	4.10	4.25	4.02	5.30	4.78	5.11	5.06
24	$M_2V_0F_2S_3$	6.04	5.38	5.74	5.72	3.83	4.22	4.38	4.14	4.80	4.64	5.02	4.82
25	$M_2V_0F_3S_1$	9.91	10.21	10.28	10.13	6.73	7.19	7.88	7.27	8.06	8.39	8.21	8.22
26	$M_2V_0F_3S_2$	10.27	9.92	10.14	10.11	7.71	7.98	8.04	7.91	7.97	8.79	8.61	8.46
27	$M_2V_0F_3S_3$	9.94	10.42	10.31	10.22	7.13	7.64	7.59	7.45	8.23	7.80	7.61	7.88
28	$M_2V_1F_1S_1$	0.96	1.02	0.73	0.90	0.99	0.84	0.78	0.87	0.26	0.24	0.28	0.26
29	$M_2V_1F_1S_2$	0.75	0.62	0.66	0.68	0.91	0.77	0.57	0.75	0.34	0.36	0.39	0.36
30	$M_2V_1F_1S_3$	0.93	0.89	0.71	0.84	0.44	0.45	0.57	0.49	0.43	0.53	0.38	0.45
31	$M_2V_1F_2S_1$	2.71	3.13	2.96	2.93	2.53	2.31	2.64	2.49	1.66	2.15	1.87	1.89
32	$M_2V_1F_2S_2$	3.12	3.01	2.97	3.03	1.51	2.09	2.34	1.98	1.74	2.19	2.27	2.07
33	$M_2V_1F_2S_3$	2.57	2.97	3.03	2.86	1.61	2.19	2.38	2.06	1.80	2.13	2.08	2.00
34	$M_2V_1F_3S_1$	2.24	2.48	2.56	2.43	1.60	2.12	2.54	2.09	1.45	1.66	1.70	1.60
35	$M_2V_1F_3S_2$	2.58	2.44	2.41	2.48	1.81	2.34	2.09	2.08	1.30	1.11	1.35	1.25
36	$M_2V_1F_3S_3$	3.09	2.91	2.77	2.92	1.76	2.25	2.04	2.02	1.40	1.14	1.53	1.36

*1 g = 9.81 m/s^2

Table 4.7. Analysis of variance for vibration acceleration measured along vertical direction at chassis of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	4.87 (M_1)	4.39 (M_2)	
Provision of vibration isolators (V)	6.74 (V_0)	2.52 (V_1)	
Forward speed (F)	2.68 (F_1)	4.36 (F_2)	6.85 (F_3)
Subject (S)	4.62 (S_1)	4.65 (S_2)	4.62 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	6.092	99.05	0.095	
V	1	480.701	7815.44	0.095	
MV	1	2.917	47.42	0.135	
F	2	158.945	2584.19	0.117	
MF	2	1.928	31.35	0.165	
VF	2	21.205	344.77	0.165	
MVF	2	12.540	203.88	0.233	
S	2	0.013	0.21	NS	
MS	2	0.085	1.38	NS	
VS	2	0.305	4.97	0.165	
MVS	2	0.282	4.58	0.233	
FS	4	0.086	1.40	NS	
MFS	4	0.292	4.75	0.286	
VFS	4	0.432	7.02	0.286	
MVFS	4	0.785	12.76	0.404	
Error	72	0.062			5.36

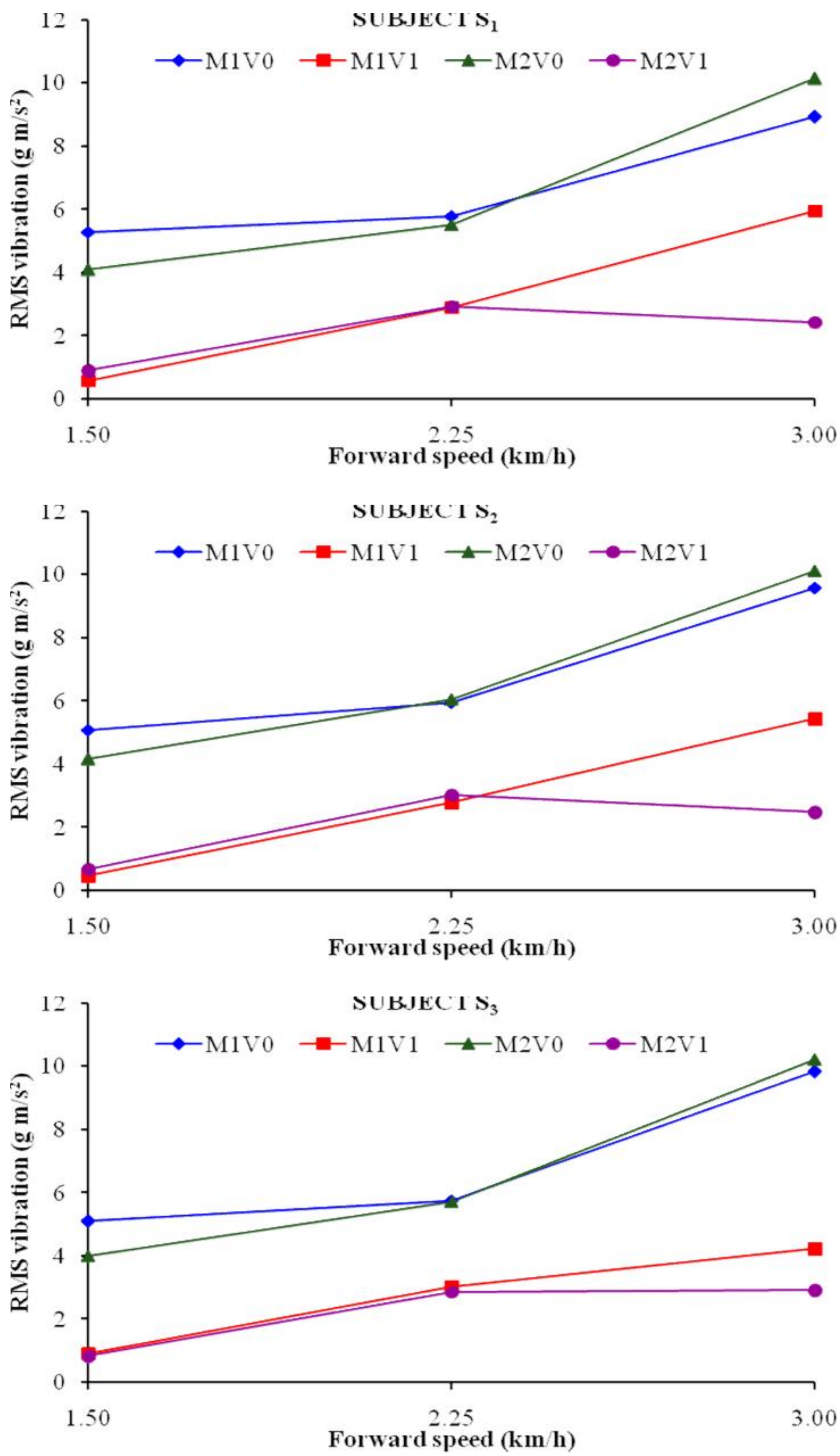

Fig. 4.6. Vibration acceleration along vertical direction at chassis of boom sprayer.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 4.87 and 4.39 g m/s^2, respectively and were statistically different (C.D. = 0.095) at five per cent level of significance. The 9.9% decrease in vibrations of M_2 over M_1, could be due to point of measurement on chassis being closer to centre of gravity of machine.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 2.52 g m/s^2 in comparison to 6.74 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.095) at five per cent level. Vibrations were measured at the chassis, which was isolated from the engine by four numbers of synthetic rubber based vibration isolators VI_1 at the engine mountings. These SBR vibration isolators reduced the transmission of vibrations originating from the reciprocating diesel engine to the chassis. Thus; vibrations at chassis along vertical direction were reduced by 62.61% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.117) at five per cent level of significance. The vibration acceleration was observed as 2.68, 4.36 and 6.85 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along vertical direction at chassis of boom sprayer was statistically at par for all the three selected subjects and varied between 4.62-4.65 g m/s^2.

The interactions among various independent variables, except MS and FS, were also found to be statistically different at five per cent level of significance. With increase in forward speed from 2.25 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.2.2. Vibration Characteristics along Longitudinal Direction

The vibration characteristics along longitudinal direction at chassis of the boom sprayer have been given in Table 4.6 and its analysis of variance is presented in Table 4.8. The vibration characteristics are also shown graphically in Fig. 4.7. The mean values of vibration acceleration varied from 0.49 to 7.91g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.439) at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 3.83 and 3.35 g m/s^2, respectively and were statistically different

(C.D. = 0.104) at five per cent level of significance. Thus; a decrease of 12.5% in vibrations of M_2 over M_1 were observed at chassis along longitudinal direction (see § 4.2.2.1).

Table 4.8. Analysis of variance for vibration acceleration measured along longitudinal direction at chassis of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	3.83 (M_1)	3.35 (M_2)	
Provision of vibration isolators (V)	5.10 (V_0)	2.07 (V_1)	
Forward speed (F)	2.26 (F_1)	3.36 (F_2)	5.15 (F_3)
Subject (S)	3.60 (S_1)	3.50 (S_2)	3.66 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	6.192	85.07	0.104	
V	1	248.612	3415.78	0.104	
MV	1	3.616	49.68	0.146	
F	2	76.576	1052.12	0.127	
MF	2	0.442	6.07	0.179	
VF	2	13.596	186.80	0.179	
MVF	2	5.596	76.89	0.254	
S	2	0.258	3.54	0.127	
MS	2	0.157	2.15	NS	
VS	2	0.404	5.55	0.179	
MVS	2	0.173	2.38	NS	
FS	4	0.208	2.86	0.220	
MFS	4	0.266	3.66	0.311	
VFS	4	0.779	10.70	0.311	
MVFS	4	0.508	6.98	0.439	
Error	72	0.073			7.52

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 2.07 g m/s^2 in comparison to 5.10 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.104) at five per cent level. The reason, in this respect, is as already discussed in §4.2.2.1. Thus; vibrations at chassis along longitudinal direction were reduced by 59.41% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.127) at five per cent level of significance. The vibration acceleration was observed as 2.26, 3.36 and 5.15 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

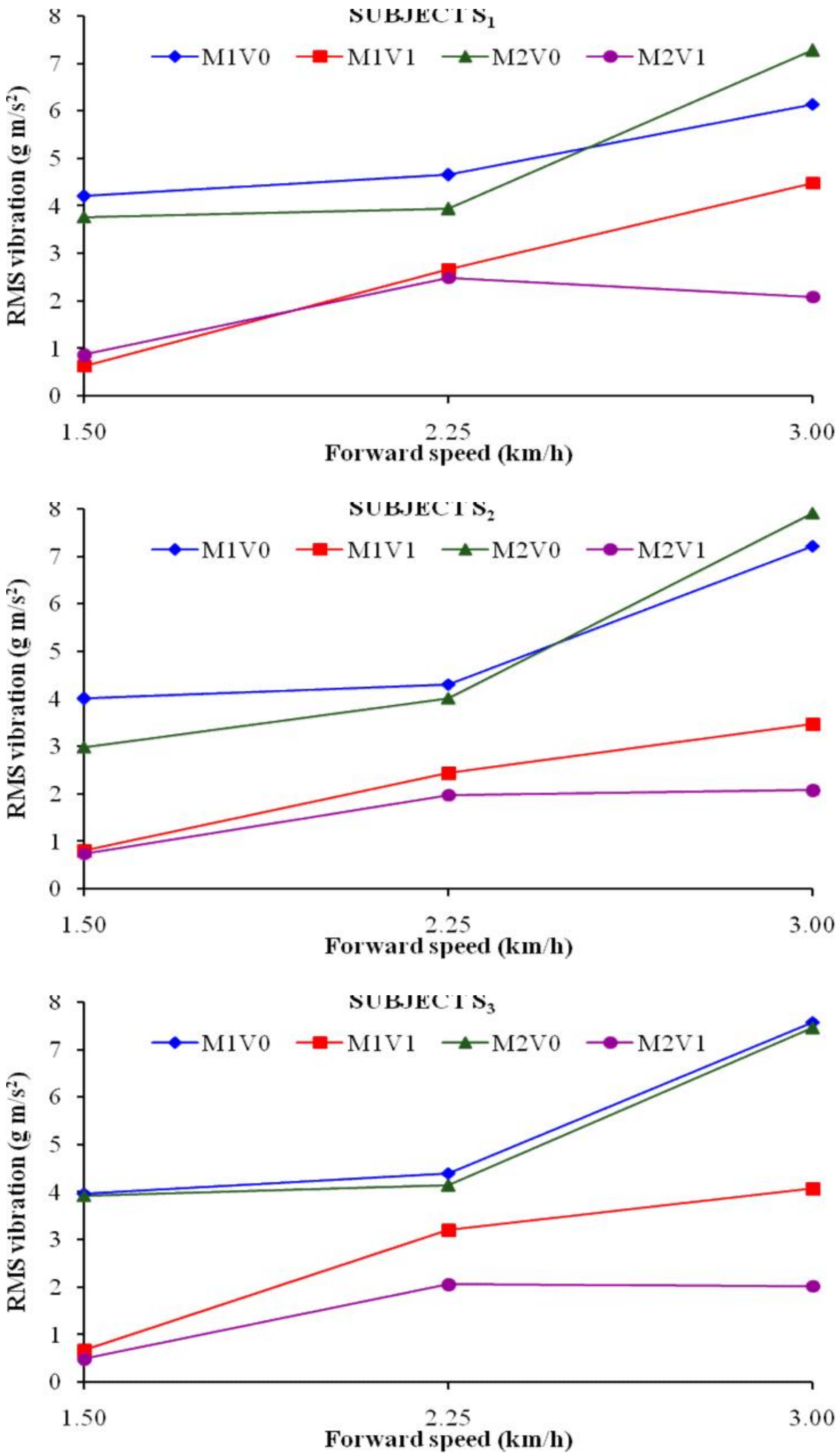

Fig. 4.7. Vibration acceleration along longitudinal direction at chassis of boom sprayer.

Vibration acceleration along longitudinal direction at chassis of the boom sprayer was statistically at par (C.D. = 0.127) for the subjects S_1 (3.60 g m/s^2) and S_2 (3.50 g m/s^2), and for the subjects S_1 (3.60 g m/s^2) and S_3 (3.66 g m/s^2). However, vibration in case of the subject S_2 (3.50 g m/s^2) was a little lower as compared to the same in case of the subject S_3 (3.66 g m/s^2). The variation in this respect could be attributed to their individual characteristics.

The interactions among various independent variables, except treatment combinations MS and MVS, were also found to be statistically different at five per cent level of significance. With increase in forward speed from 2.25 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. The reason for the above is as discussed in §4.2.2.1.

4.2.2.3. Vibration Characteristics along Lateral Direction

The vibration characteristics along lateral direction at chassis of the boom sprayer have been given in Table 4.6 and its analysis of variance is presented in Table 4.9. The vibration characteristics are also shown graphically in Fig. 4.8.

Table 4.9. Analysis of variance for vibration acceleration measured along lateral direction at chassis of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	3.62 (M_1)	3.51 (M_2)	
Provision of vibration isolators (V)	5.65 (V_0)	1.47 (V_1)	
Forward speed (F)	2.23 (F_1)	3.46 (F_2)	4.99 (F_3)
Subject (S)	3.59 (S_1)	3.56 (S_2)	3.53 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	0.296	6.89	0.080	
V	1	472.424	10986.15	0.080	
MV	1	3.094	71.94	0.113	
F	2	68.694	1597.47	0.098	
MF	2	0.611	14.21	0.138	
VF	2	19.926	463.37	0.138	
MVF	2	2.499	58.12	0.195	
S	2	0.031	0.71	NS	
MS	2	0.106	2.46	NS	
VS	2	0.120	2.78	NS	
MVS	2	0.062	1.44	NS	
FS	4	0.033	0.77	NS	
MFS	4	0.057	1.34	NS	
VFS	4	0.325	7.56	0.239	
MVFS	4	0.066	1.54	NS	
Error	72	0.043			5.82

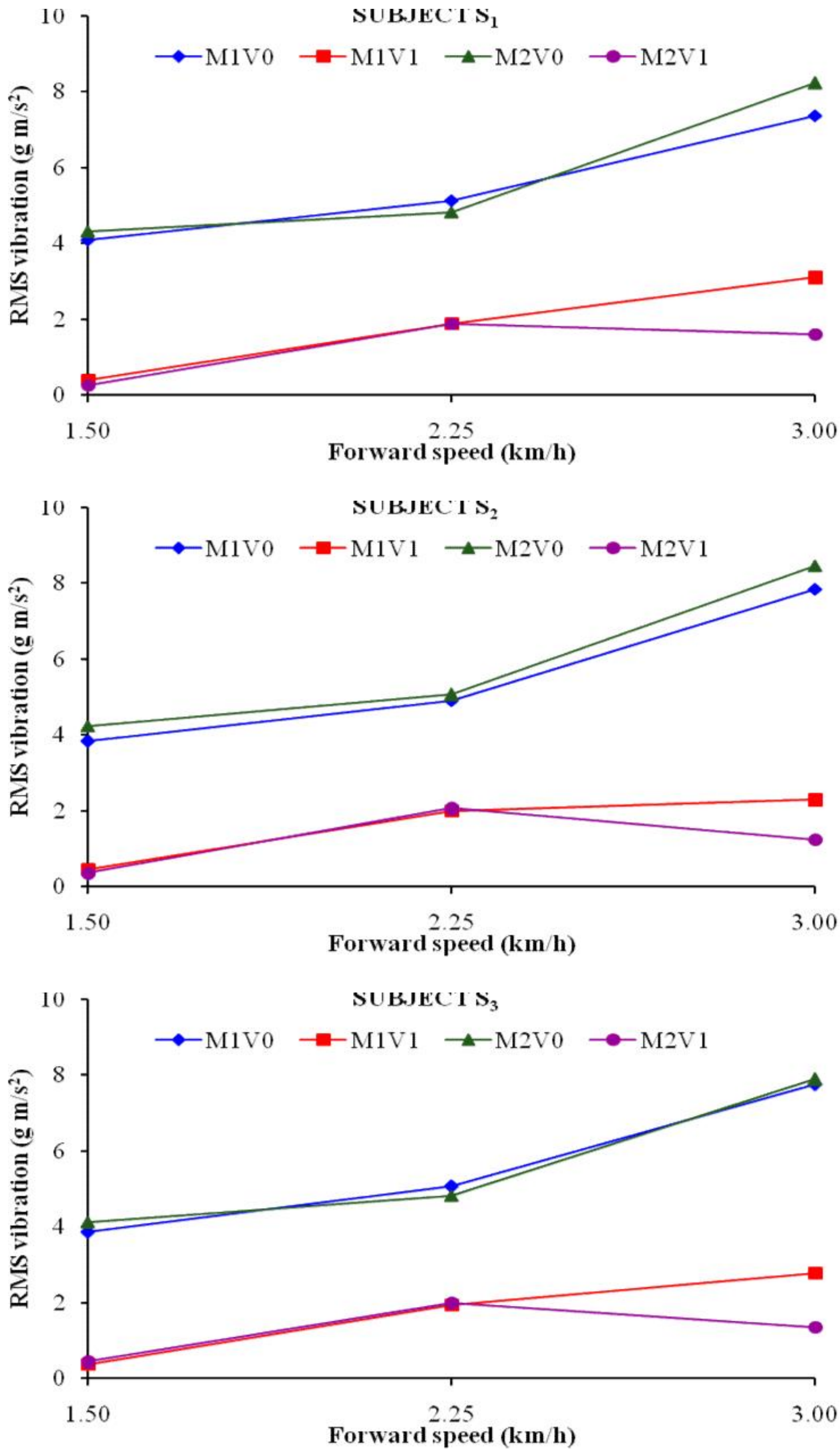

Fig. 4.8. Vibration acceleration along lateral direction at chassis of boom sprayer.

The mean values of vibration acceleration varied from 0.26 to 8.46 g m/s^2 among all the treatments and the differences were statistically non-significant at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 3.62 and 3.51 g m/s^2, respectively and were statistically different (C.D. = 0.080) at five per cent level of significance. Thus; a 3.0% decrease in vibrations of M_2 over M_1 were observed at chassis along lateral direction (see § 4.2.2.1).

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 1.47 g m/s^2 in comparison to 5.65 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.080) at five per cent level. The reason, in this respect, is as already discussed in §4.2.2.1. Thus; vibrations at chassis along lateral direction were reduced by 73.98% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.098) at five per cent level of significance. The vibration acceleration was observed as 2.23, 3.46 and 4.99 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along lateral direction at chassis of boom sprayer was statistically at par for all the three selected subjects and varied between 3.53-3.59 g m/s^2.

The interactions among various independent variables, except subjects, were also found to be statistically different at five per cent level of significance. With increase in forward speed from 2.25 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. The reason for the above is as discussed in §4.2.2.1.

4.2.3. Vibration Characteristics at Handle Bar

4.2.3.1. Vibration Characteristics along Vertical Direction

The vibration characteristics along vertical direction at handle bar of the boom sprayer have been given in Table 4.10 and its analysis of variance is presented in Table 4.11. The vibration characteristics are also shown graphically in Fig. 4.9. The mean values of vibration acceleration varied from 0.47 to 7.30 g m/s^2 among all the treatments and the differences were statistically non-significant at five per cent level of significance.

Table 4.10. Response of vibration acceleration at handle bar of self propelled boom sprayer.

S. No.	Treatment	RMS acceleration vibration (x g m/s²)*											
		Vertical				Longitudinal				Lateral			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
1	$M_1V_0F_1S_1$	2.57	2.52	2.45	2.51	2.37	2.62	2.56	2.52	1.99	2.01	2.11	2.04
2	$M_1V_0F_1S_2$	2.45	2.51	2.49	2.48	2.77	2.87	2.96	2.87	1.92	2.14	2.08	2.05
3	$M_1V_0F_1S_3$	2.26	2.31	2.39	2.32	2.42	2.40	2.46	2.43	1.97	1.93	2.01	1.97
4	$M_1V_0F_2S_1$	3.21	3.15	3.26	3.21	4.14	3.90	3.99	4.01	2.96	2.79	2.84	2.86
5	$M_1V_0F_2S_2$	3.17	3.08	3.26	3.17	3.99	4.22	4.06	4.09	2.97	3.05	2.80	2.94
6	$M_1V_0F_2S_3$	3.20	2.96	3.17	3.11	3.85	4.32	3.99	4.05	2.70	2.75	2.61	2.69
7	$M_1V_0F_3S_1$	6.33	5.92	6.11	6.12	9.57	9.31	9.76	9.55	5.42	5.59	5.57	5.53
8	$M_1V_0F_3S_2$	5.59	5.81	5.74	5.71	10.03	10.68	9.75	10.15	5.13	4.88	4.99	5.00
9	$M_1V_0F_3S_3$	5.86	6.17	5.74	5.92	10.42	9.88	9.65	9.98	5.05	4.88	4.76	4.90
10	$M_1V_1F_1S_1$	0.50	0.45	0.46	0.47	0.54	0.61	0.67	0.61	0.29	0.32	0.35	0.32
11	$M_1V_1F_1S_2$	0.47	0.54	0.49	0.50	0.66	0.75	0.81	0.74	0.33	0.36	0.41	0.37
12	$M_1V_1F_1S_3$	0.48	0.51	0.55	0.51	0.76	0.85	0.91	0.84	0.32	0.28	0.37	0.32
13	$M_1V_1F_2S_1$	1.01	1.17	0.99	1.06	0.72	0.79	0.83	0.78	0.76	0.65	0.86	0.76
14	$M_1V_1F_2S_2$	1.22	1.17	1.35	1.25	0.82	0.87	0.96	0.88	0.75	0.85	0.91	0.84
15	$M_1V_1F_2S_3$	1.14	1.37	1.30	1.27	0.66	0.81	0.59	0.69	0.71	0.67	0.61	0.66
16	$M_1V_1F_3S_1$	1.03	1.15	1.33	1.17	0.68	0.73	0.81	0.74	0.65	0.76	0.80	0.74
17	$M_1V_1F_3S_2$	1.37	1.20	1.11	1.23	0.73	0.86	0.97	0.85	0.65	0.58	0.71	0.65
18	$M_1V_1F_3S_3$	1.44	1.33	1.11	1.29	0.66	0.75	0.81	0.74	0.62	0.66	0.71	0.66
19	$M_2V_0F_1S_1$	2.40	2.19	2.17	2.25	2.42	2.37	2.20	2.33	2.37	2.19	2.56	2.37
20	$M_2V_0F_1S_2$	2.25	2.18	2.17	2.20	2.41	2.68	2.28	2.46	2.26	2.49	2.19	2.31
21	$M_2V_0F_1S_3$	2.24	2.31	2.37	2.31	2.49	2.62	2.68	2.60	2.14	2.29	2.55	2.33
22	$M_2V_0F_2S_1$	3.30	3.09	3.14	3.18	2.95	3.58	3.30	3.28	2.37	2.95	2.43	2.58
23	$M_2V_0F_2S_2$	2.99	3.11	3.24	3.11	3.03	3.29	2.97	3.10	2.66	2.42	2.38	2.49
24	$M_2V_0F_2S_3$	2.95	3.25	3.12	3.11	3.34	3.29	2.97	3.20	2.35	2.34	2.57	2.42
25	$M_2V_0F_3S_1$	6.98	7.13	7.80	7.30	11.57	10.88	11.27	11.24	5.81	5.71	5.60	5.71
26	$M_2V_0F_3S_2$	7.28	6.98	7.16	7.14	11.24	11.64	11.43	11.44	6.29	5.97	6.17	6.14
27	$M_2V_0F_3S_3$	7.12	6.32	7.28	6.91	10.71	11.09	11.31	11.04	6.12	5.95	5.82	5.96
28	$M_2V_1F_1S_1$	1.01	0.92	0.83	0.92	0.62	0.55	0.56	0.58	0.43	0.36	0.40	0.40
29	$M_2V_1F_1S_2$	0.61	0.54	0.70	0.62	0.56	0.55	0.60	0.57	0.44	0.52	0.62	0.53
30	$M_2V_1F_1S_3$	0.90	1.10	0.77	0.92	0.51	0.46	0.76	0.58	0.41	0.49	0.60	0.50
31	$M_2V_1F_2S_1$	1.47	1.18	1.31	1.32	0.74	0.86	0.76	0.79	0.77	0.92	1.14	0.94
32	$M_2V_1F_2S_2$	1.23	1.18	1.30	1.24	0.85	0.86	1.04	0.92	1.02	0.99	0.83	0.95
33	$M_2V_1F_2S_3$	1.12	1.36	0.83	1.10	0.59	0.60	0.72	0.64	0.91	1.04	1.33	1.09
34	$M_2V_1F_3S_1$	1.39	1.54	1.31	1.41	0.98	0.96	1.01	0.98	1.12	0.87	0.90	0.96
35	$M_2V_1F_3S_2$	1.56	1.43	1.63	1.54	0.88	1.03	1.10	1.00	1.06	0.83	0.77	0.89
36	$M_2V_1F_3S_3$	1.24	1.35	1.33	1.31	0.69	0.58	0.67	0.65	0.55	0.74	1.14	0.81

*1 g = 9.81 m/s²

Table 4.11. Analysis of variance for vibration acceleration measured along vertical direction at handle bar of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)					
Provision of a seat with machine (M)			2.41 (M_1)	2.66 (M_2)	
Provision of vibration isolators (V)			4.00 (V_0)	1.06 (V_1)	
Forward speed (F)			1.50 (F_1)	2.18 (F_2)	3.92 (F_3)
Subject (S)			2.58 (S_1)	2.52 (S_2)	2.51 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	1.748	65.54	0.063	
V	1	233.554	8754.59	0.063	
MV	1	0.143	5.38	0.089	
F	2	56.132	2104.07	0.077	
MF	2	1.315	49.27	0.109	
VF	2	34.366	1288.19	0.109	
MVF	2	1.369	51.30	0.154	
S	2	0.053	1.97	NS	
MS	2	0.024	0.91	NS	
VS	2	0.064	2.42	NS	
MVS	2	0.047	1.77	NS	
FS	4	0.023	0.85	NS	
MFS	4	0.087	3.26	0.188	
VFS	4	0.046	1.71	NS	
MVFS	4	0.010	0.39	NS	
Error	72	0.027			6.45

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 2.41 and 2.66 g m/s^2, respectively and were statistically different (C.D. = 0.063) at five per cent level of significance. The reason for 10.4% increase in vibrations of M_2 over M_1 is as explained in §4.2.1.1.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 1.06 g m/s^2 in comparison to 4.00 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.063) at five per cent level. Vibrations were measured at the handle bar, which is isolated from chassis by one number of SBR based vibration isolator VI_2 at the base of handle bar; and the chassis was further isolated from the engine by four numbers of SBR based vibration isolators VI_1 at the engine mountings. These SBR vibration isolators reduced the transmission of vibrations originating from the reciprocating diesel engine to the chassis, and further from chassis to handle bar. Thus; vibrations at handle bar along vertical direction were reduced by 73.50% with the provision of vibration isolators.

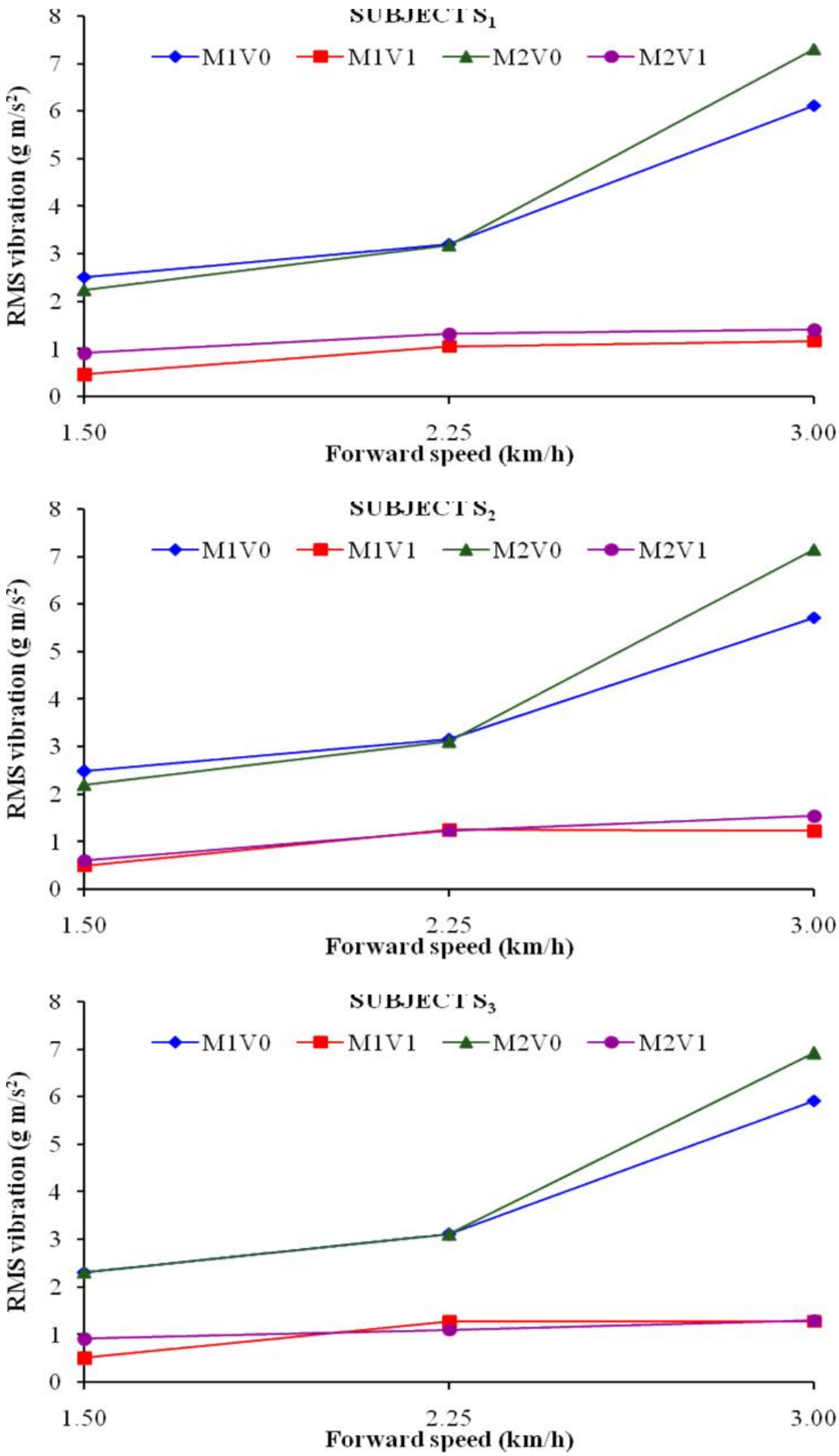

Fig. 4.9. Vibration acceleration along vertical direction at handle bar of boom sprayer.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.077) at five per cent level of significance. The vibration acceleration was observed as 1.50, 2.18 and 3.92 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along vertical direction at handle bar of boom sprayer was statistically at par for all the three selected subjects and varied between 2.51-2.58 g m/s^2.

The interactions among various independent variables, except subjects, were also found to be statistically different at five per cent level of significance. With increase in forward speed from 2.25 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. Vibration acceleration was statistically at par for M_1V_1 at forward speed of 2.25 and 3.00 km/h. However; a marginal increase in vibration acceleration was observed for M_2V_1 with increase in forward speed from 2.25 to 3.00 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.3.2. Vibration Characteristics along Longitudinal Direction

The vibration characteristics along longitudinal direction at handle bar of the boom sprayer have been given in Table 4.10 and its analysis of variance is presented in Table 4.12. The vibration characteristics are also shown graphically in Fig. 4.10. The mean values of vibration acceleration varied from 0.57 to 11.44 g m/s^2 among all the treatments and the differences were statistically non-significant at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 3.14 and 3.19 g m/s^2, respectively and were statistically not different at five per cent level of significance.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 0.75 g m/s^2 in comparison to 5.57 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.069) at five per cent level. The reason, in this respect, is as already discussed in §4.2.3.1. Thus; vibrations at handle bar along longitudinal direction were reduced by 86.54% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.084) at five per cent level of significance. The vibration acceleration was observed as 1.59, 2.20 and 5.70 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along longitudinal direction at handle bar of the boom sprayer was statistically at par (C.D. = 0.084) for the subjects S_1 and S_3 (3.12 g m/s^2). However, vibration in case of the subject S_2 (3.26 g m/s^2) was a little higher. The variation in this respect could be attributed to their individual characteristics.

Table 4.12. Analysis of variance for vibration acceleration measured along longitudinal direction at handle bar of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	3.14 (M_1)	3.19 (M_2)	
Provision of vibration isolators (V)	5.57 (V_0)	0.75 (V_1)	
Forward speed (F)	1.59 (F_1)	2.20 (F_2)	5.70 (F_3)
Subject (S)	3.12 (S_1)	3.26 (S_2)	3.12 (S_3)

ANOVA TABLE

Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	0.060	1.87	NS	
V	1	627.131	19459.03	0.069	
MV	1	0.119	3.70	NS	
F	2	176.648	5481.16	0.084	
MF	2	3.251	100.88	0.119	
VF	2	165.388	5131.78	0.119	
MVF	2	2.505	77.72	0.169	
S	2	0.229	7.12	0.084	
MS	2	0.095	2.94	NS	
VS	2	0.041	1.28	NS	
MVS	2	0.056	1.75	NS	
FS	4	0.060	1.88	NS	
MFS	4	0.072	2.22	NS	
VFS	4	0.075	2.31	NS	
MVFS	4	0.043	1.34	NS	
Error	72	0.032			5.67

The interactions among various independent variables, except subjects, were also found to be statistically different at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. However; response of vibration acceleration was statistically at par at forward speeds of 2.25 and 3.00 km/h. This trend may

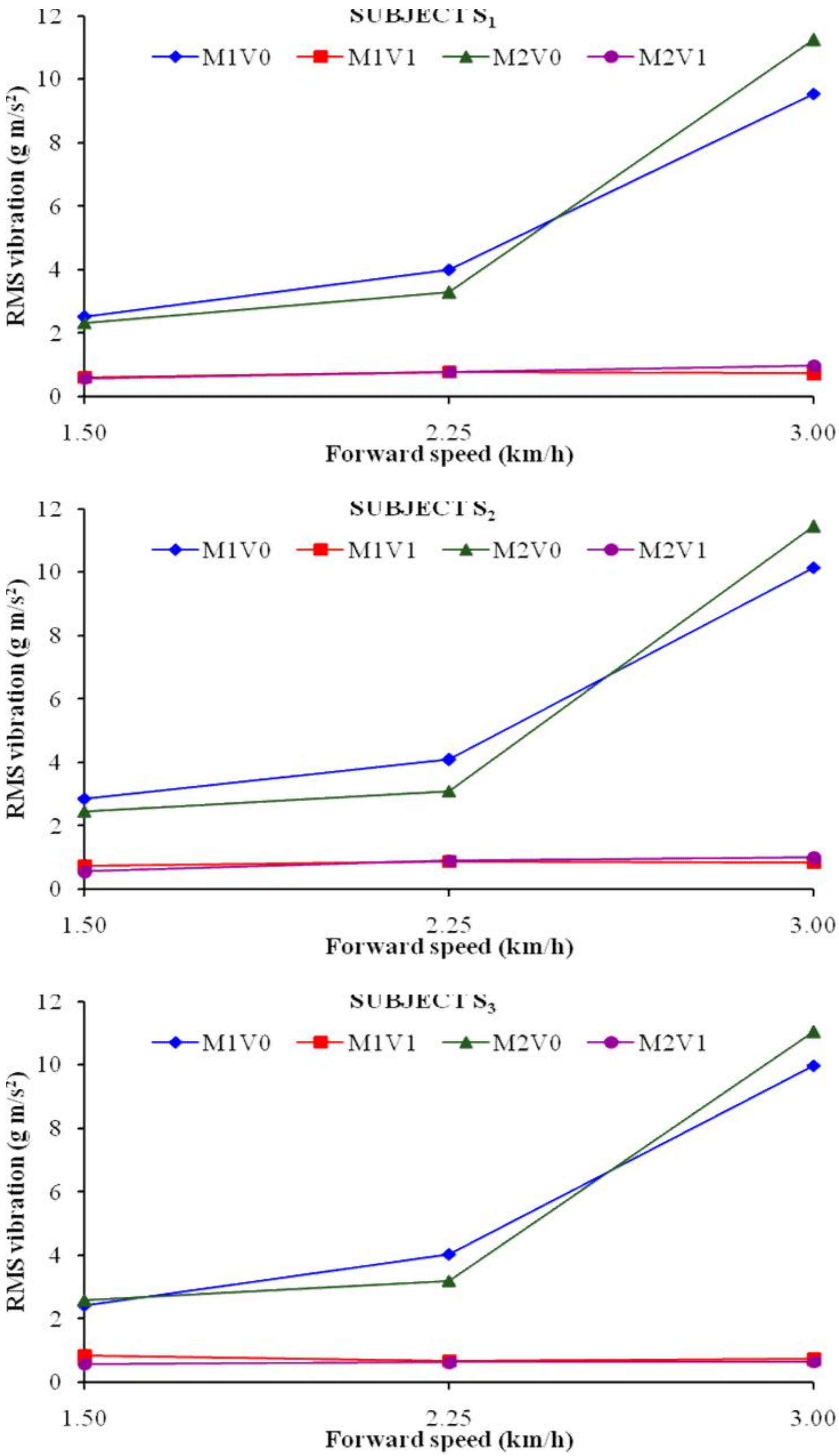

Fig.4.10. Vibration acceleration along longitudinal direction at handle bar of boom sprayer.

be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.3.3. Vibration Characteristics along Lateral Direction

The vibration characteristics along lateral direction at handle bar of the boom sprayer have been given in Table 4.10 and its analysis of variance is presented in Table 4.13. The vibration characteristics are also shown graphically in Fig. 4.11. The mean values of vibration acceleration varied from 0.32 to 6.14 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.223) at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 1.96 and 2.19 g m/s^2, respectively and were statistically different (C.D. = 0.053) at five per cent level of significance. The reason for 11.7% increase in vibrations of M_2 over M_1 is as explained in §4.2.1.1.

Table 4.13. Analysis of variance for vibration acceleration measured along lateral direction at handle bar of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	1.96 (M_1)	2.19 (M_2)	
Provision of vibration isolators (V)	3.46 (V_0)	0.69 (V_1)	
Forward speed (F)	1.29 (F_1)	1.77 (F_2)	3.16 (F_3)
Subject (S)	2.10 (S_1)	2.10 (S_2)	2.03 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	1.403	74.72	0.053	
V	1	207.528	11053.13	0.053	
MV	1	0.030	1.60	NS	
F	2	34.004	1811.07	0.064	
MF	2	0.671	35.75	0.091	
VF	2	26.533	1413.16	0.091	
MVF	2	0.790	42.06	0.129	
S	2	0.061	3.27	0.064	
MS	2	0.089	4.77	0.091	
VS	2	0.038	2.02	NS	
MVS	2	0.038	2.04	NS	
FS	4	0.018	0.97	NS	
MFS	4	0.083	4.42	0.158	
VFS	4	0.008	0.43	NS	
MVFS	4	0.103	5.48	0.223	
Error	72	0.019			6.61

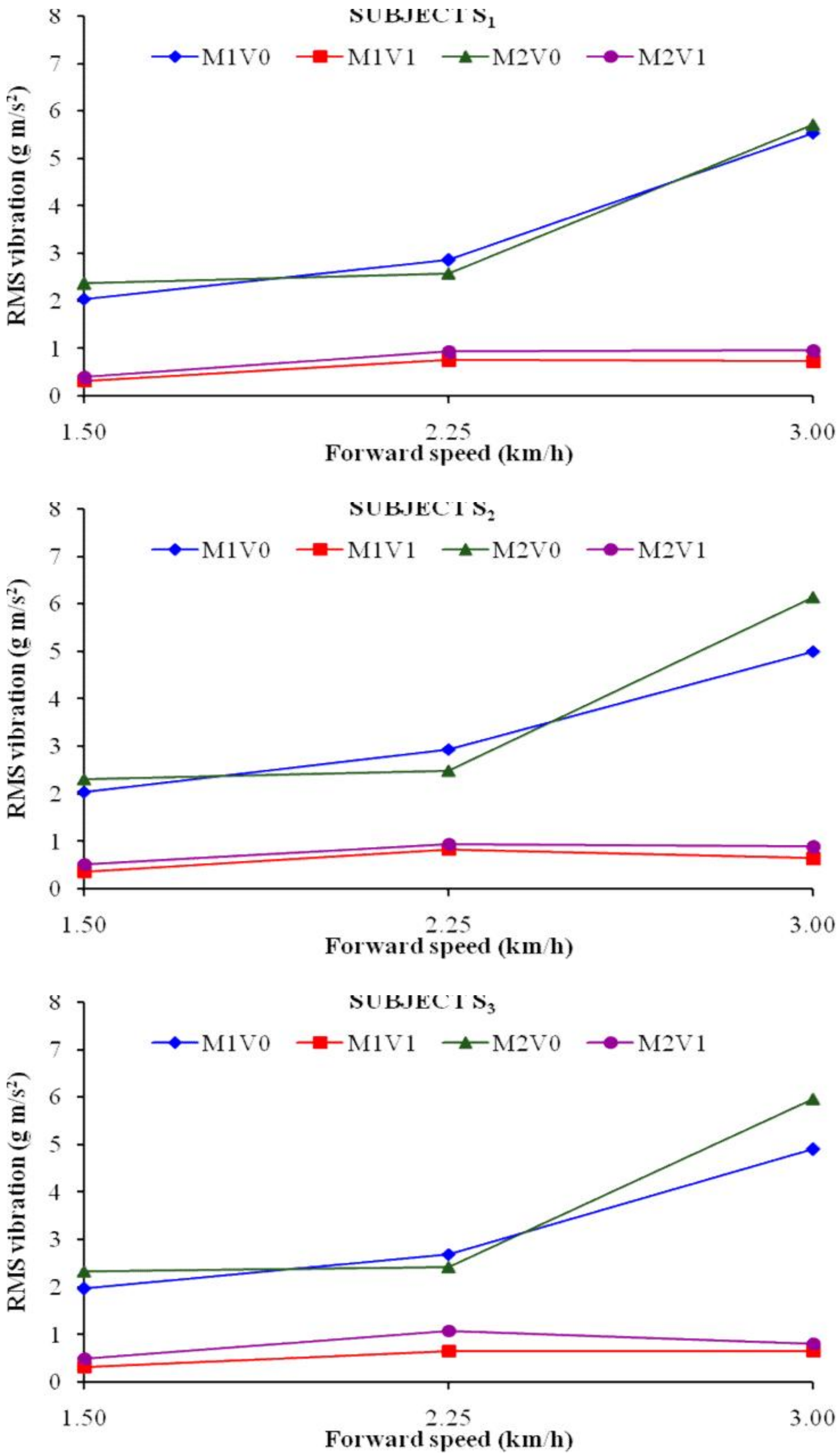

Fig. 4.11. Vibration acceleration along lateral direction at handle bar of boom sprayer.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 0.69 g m/s^2 in comparison to 3.46 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.053) at five per cent level. The reason, in this respect, is as already discussed in §4.2.3.1. Thus; vibrations at handle bar along lateral direction were reduced by 80.06% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.064) at five per cent level of significance. The vibration acceleration was observed as 1.29, 1.77 and 3.16 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along lateral direction at handle bar of the boom sprayer was statistically at par (C.D. = 0.064) for the subjects S_1 and S_2 (2.10 g m/s^2). However, vibration in case of the subject S_3 (2.03 g m/s^2) was a little lower. The variation in this respect could be attributed to their individual characteristics.

The interaction between variables M and V was found to be statistically non-significant at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. However; response of vibration acceleration was statistically at par at forward speeds of 2.25 and 3.00 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.4. Vibration Characteristics at Handle

4.2.4.1. Vibration Characteristics along Vertical Direction

The vibration characteristics along vertical direction at handle of the boom sprayer have been given in Table 4.14 and its analysis of variance is presented in Table 4.15. The vibration characteristics are also shown graphically in Fig. 4.12. The mean values of vibration acceleration varied from 0.51 to 17.25 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.459) at five per cent level of significance.

Table 4.14. Response of vibration acceleration at handle of self propelled boom sprayer.

S. No.	Treatment	RMS acceleration vibration (x g m/s^2)*											
		Vertical				Longitudinal				Lateral			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
1	$M_1V_0F_1S_1$	2.78	3.36	2.95	3.03	3.42	2.85	2.91	3.06	2.27	2.17	2.04	2.16
2	$M_1V_0F_1S_2$	2.73	2.69	2.65	2.69	2.93	3.12	3.37	3.14	2.14	2.33	2.44	2.30
3	$M_1V_0F_1S_3$	3.65	3.88	3.75	3.76	3.21	3.28	3.40	3.30	2.34	2.02	2.13	2.16
4	$M_1V_0F_2S_1$	4.10	3.75	4.27	4.04	4.32	4.47	4.52	4.44	2.66	3.01	2.82	2.83
5	$M_1V_0F_2S_2$	3.86	4.21	4.04	4.04	4.30	4.85	4.26	4.47	3.21	3.15	2.86	3.07
6	$M_1V_0F_2S_3$	4.35	4.63	4.22	4.40	4.59	4.76	4.61	4.65	2.82	3.01	2.94	2.92
7	$M_1V_0F_3S_1$	10.91	11.22	10.82	10.98	12.65	13.01	12.87	12.84	7.62	7.19	6.81	7.21
8	$M_1V_0F_3S_2$	10.68	11.33	10.65	10.89	12.36	13.04	12.71	12.70	6.92	7.07	6.73	6.91
9	$M_1V_0F_3S_3$	12.02	11.97	12.83	12.27	14.46	13.92	14.37	14.25	10.54	10.73	11.15	10.81
10	$M_1V_1F_1S_1$	0.49	0.52	0.60	0.54	0.54	0.51	0.58	0.54	0.39	0.32	0.46	0.39
11	$M_1V_1F_1S_2$	0.57	0.52	0.44	0.51	0.46	0.43	0.51	0.47	0.37	0.44	0.35	0.39
12	$M_1V_1F_1S_3$	0.55	0.62	0.57	0.58	0.55	0.61	0.63	0.60	0.38	0.35	0.46	0.40
13	$M_1V_1F_2S_1$	1.08	0.99	1.15	1.07	0.73	0.67	0.91	0.77	1.09	1.28	0.87	1.08
14	$M_1V_1F_2S_2$	1.17	1.04	1.24	1.15	0.76	0.87	0.99	0.87	0.87	0.99	1.10	0.99
15	$M_1V_1F_2S_3$	1.12	1.28	1.35	1.25	0.87	0.95	1.06	0.96	1.07	0.84	1.22	1.04
16	$M_1V_1F_3S_1$	1.11	1.27	0.87	1.08	0.77	0.87	0.94	0.86	0.85	0.75	1.02	0.87
17	$M_1V_1F_3S_2$	1.13	0.98	1.05	1.05	0.68	0.77	0.81	0.75	0.79	0.67	0.88	0.78
18	$M_1V_1F_3S_3$	1.15	1.03	0.98	1.05	0.84	0.78	0.92	0.85	0.86	0.91	1.07	0.95
19	$M_2V_0F_1S_1$	2.98	3.11	3.30	3.13	2.76	3.03	2.49	2.76	2.23	2.10	1.88	2.07
20	$M_2V_0F_1S_2$	3.11	2.75	2.88	2.91	2.88	3.03	3.17	3.03	1.95	1.88	2.04	1.96
21	$M_2V_0F_1S_3$	3.06	3.17	3.31	3.18	2.75	2.99	3.22	2.99	1.84	2.21	2.11	2.05
22	$M_2V_0F_2S_1$	4.98	4.40	5.16	4.85	4.82	4.23	5.02	4.69	4.04	4.45	4.36	4.28
23	$M_2V_0F_2S_2$	4.99	5.22	5.31	5.17	4.68	4.72	4.46	4.62	4.78	4.50	4.38	4.55
24	$M_2V_0F_2S_3$	4.29	4.52	5.01	4.61	4.69	4.85	5.50	5.01	4.96	4.18	4.37	4.50
25	$M_2V_0F_3S_1$	13.93	14.40	15.00	14.44	13.11	14.70	14.85	14.22	8.88	9.14	9.31	9.11
26	$M_2V_0F_3S_2$	13.31	14.41	15.02	14.25	14.09	14.22	14.63	14.31	9.54	9.71	9.82	9.69
27	$M_2V_0F_3S_3$	17.91	17.34	16.51	17.25	14.61	15.20	15.67	15.16	9.28	9.41	9.29	9.33
28	$M_2V_1F_1S_1$	0.82	0.78	0.97	0.86	0.67	0.77	0.80	0.75	0.44	0.52	0.37	0.44
29	$M_2V_1F_1S_2$	0.92	0.89	1.01	0.94	0.55	0.61	0.69	0.62	0.64	0.75	0.82	0.74
30	$M_2V_1F_1S_3$	0.62	0.56	0.71	0.63	0.59	0.76	0.67	0.67	0.77	0.56	0.85	0.73
31	$M_2V_1F_2S_1$	1.07	1.23	1.38	1.23	0.76	0.87	1.04	0.89	1.35	1.22	1.10	1.22
32	$M_2V_1F_2S_2$	1.19	1.35	1.25	1.26	0.78	1.06	0.90	0.91	1.11	1.22	1.43	1.25
33	$M_2V_1F_2S_3$	1.04	1.22	1.33	1.20	0.84	0.73	1.00	0.86	0.76	1.04	0.91	0.90
34	$M_2V_1F_3S_1$	1.55	1.80	1.78	1.71	1.08	1.25	1.33	1.22	1.30	1.76	1.47	1.51
35	$M_2V_1F_3S_2$	1.33	1.12	1.56	1.34	1.34	1.52	1.87	1.58	1.30	1.63	1.41	1.45
36	$M_2V_1F_3S_3$	1.06	1.11	0.83	1.00	0.62	0.72	1.12	0.82	0.86	0.78	0.62	0.75

*1 g = 9.81 m/s^2

Table 4.15. Analysis of variance for vibration acceleration measured along vertical direction at handle of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)					
Provision of a seat with machine (M)			3.58 (M_1)	4.44 (M_2)	
Provision of vibration isolators (V)			6.99 (V_0)	1.03 (V_1)	
Forward speed (F)			1.90 (F_1)	2.86 (F_2)	7.28 (F_3)
Subject (S)			3.91 (S_1)	3.85 (S_2)	4.27 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	20.185	254.28	0.108	
V	1	962.006	12119.05	0.108	
MV	1	11.649	146.76	0.153	
F	2	296.526	3735.54	0.132	
MF	2	10.666	134.37	0.187	
VF	2	258.932	3261.95	0.187	
MVF	2	9.753	122.87	0.265	
S	2	1.802	22.70	0.132	
MS	2	0.077	0.97	NS	
VS	2	2.929	36.90	0.187	
MVS	2	0.122	1.54	NS	
FS	4	0.995	12.53	0.229	
MFS	4	0.389	4.91	0.325	
VFS	4	1.642	20.68	0.325	
MVFS	4	0.561	7.06	0.459	
Error	72	0.079			7.03

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 3.58 and 4.44 g m/s^2, respectively and were statistically different (C.D. = 0.108) at five per cent level of significance. The reason for 24.0% increase in vibrations of M_2 over M_1 is as explained in §4.2.1.1.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 1.03 g m/s^2 in comparison to 6.99 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.108) at five per cent level. Vibrations were measured at the handle, which is isolated from chassis by one number of SBR based vibration isolator VI_2 at the base of handle bar; and the chassis was further isolated from the engine by four numbers of SBR based vibration isolators VI_1 at the engine mountings. These SBR vibration isolators reduced the transmission of vibrations originating from the reciprocating diesel engine to the chassis, and further from chassis to handle bar. Thus; vibrations at handle along vertical direction were reduced by 85.26% with the provision of vibration isolators. As measurement of vibrations at handle was before foam rubber based vibration isolator VI_3 provided at handle grips; therefore, a pair of vibration isolators VI_3 provided at handle grips played no role in vibration reduction during measurement of

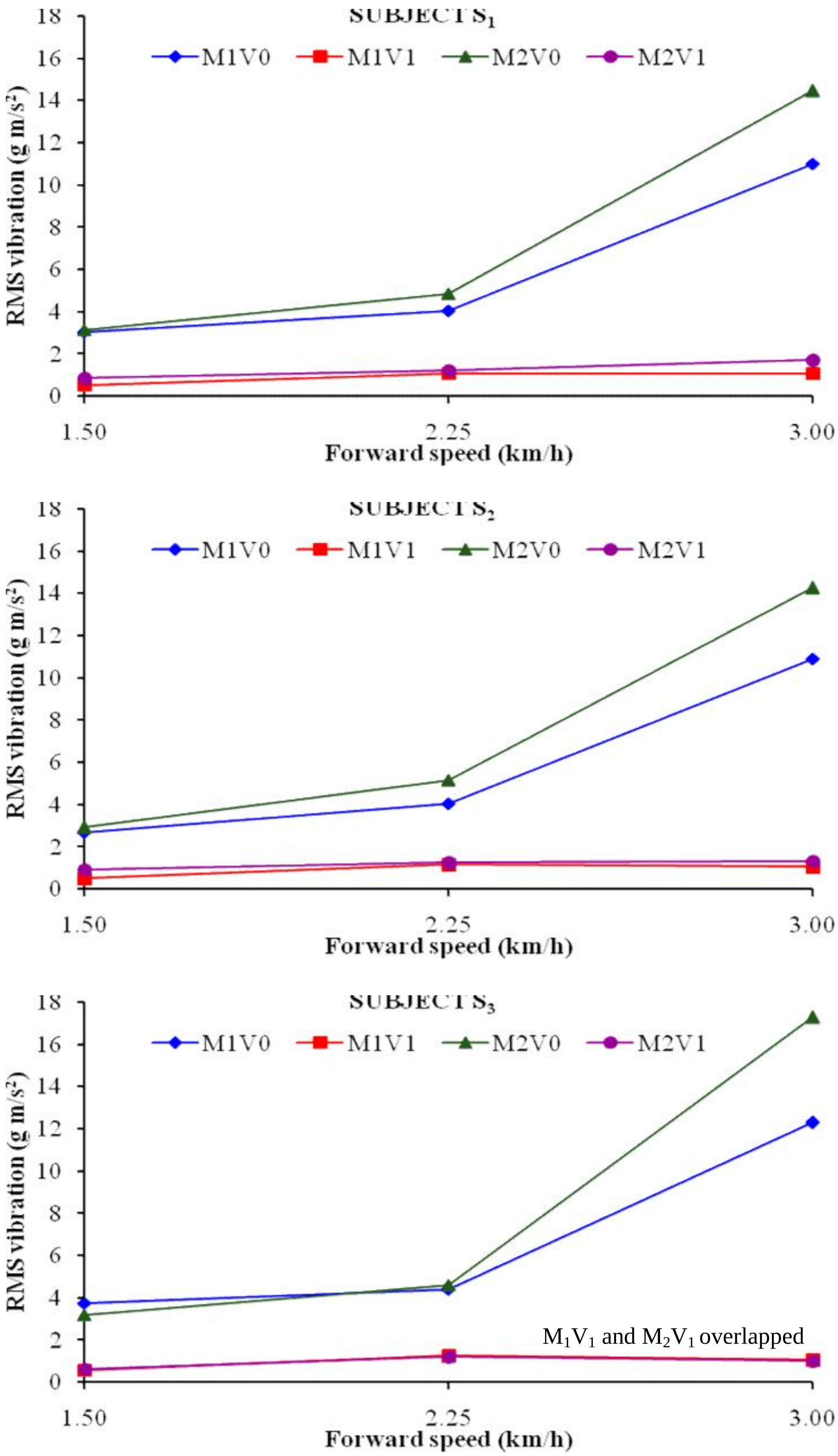

Fig. 4.12. Vibration acceleration along vertical direction at handle of boom sprayer.

vibrations at handle. However; these isolators VI_3 at handle grip might have provided extra comfort to the subject operating the boom sprayer.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.132) at five per cent level of significance. The vibration acceleration was observed as 1.90, 2.86 and 7.28 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along vertical direction at handle of the boom sprayer was statistically at par (C.D. = 0.132) for the subjects S_1 (3.91 g m/s^2) and S_2 (3.85 g m/s^2). However, vibration in case of the subject S_3 (4.27 g m/s^2) was significantly higher. The variation in this respect could be attributed to their individual characteristics.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 2.25 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. However; response of vibration acceleration was statistically at par at forward speeds of 2.25 and 3.00 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.4.2. Vibration Characteristics along Longitudinal Direction

The vibration characteristics along longitudinal direction at handle of the boom sprayer have been given in Table 4.14 and its analysis of variance is presented in Table 4.16. The vibration characteristics are also shown graphically in Fig. 4.13. The mean values of vibration acceleration varied from 0.47 to 15.16 g m/s^2 among all the treatments and the differences were statistically non-significant at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 3.86 and 4.17 g m/s^2, respectively and were statistically different (C.D. = 0.104) at five per cent level of significance. The reason for 8.0% increase in vibrations of M_2 over M_1 is as explained in §4.2.1.1.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 0.83 g m/s^2 in comparison to 7.20 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.104) at five per cent level. The difference, in this respect, is as explained in §4.2.4.1. Thus; vibrations at handle along longitudinal direction were reduced by 88.47% with the provision of vibration isolators.

Table 4.16. Analysis of variance for vibration acceleration measured along longitudinal direction at handle of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	3.86 (M_1)	4.17 (M_2)	
Provision of vibration isolators (V)	7.20 (V_0)	0.83 (V_1)	
Forward speed (F)	1.83 (F_1)	2.76 (F_2)	7.46 (F_3)
Subject (S)	3.92 (S_1)	3.96 (S_2)	4.18 (S_3)

ANOVA TABLE

Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	2.595	35.63	0.104	
V	1	1095.577	15041.14	0.104	
MV	1	0.437	6.00	0.147	
F	2	328.599	4511.33	0.127	
MF	2	1.989	27.31	0.179	
VF	2	292.015	4009.06	0.179	
MVF	2	0.948	13.02	0.254	
S	2	0.692	9.50	0.127	
MS	2	0.196	2.69	NS	
VS	2	1.068	14.66	0.179	
MVS	2	0.012	0.17	NS	
FS	4	0.150	2.06	NS	
MFS	4	0.138	1.89	NS	
VFS	4	0.595	8.17	0.311	
MVFS	4	0.019	0.26	NS	
Error	72	0.073			6.72

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.127) at five per cent level of significance. The vibration acceleration was observed as 1.83, 2.76 and 7.46 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along longitudinal direction at handle of the boom sprayer was statistically at par (C.D. = 0.127) for the subjects S_1 (3.92 g m/s^2) and S_2 (3.96 g m/s^2). However, vibration in case of the subject S_3 (4.18 g m/s^2) was significantly higher. The variation in this respect could be attributed to their individual characteristics.

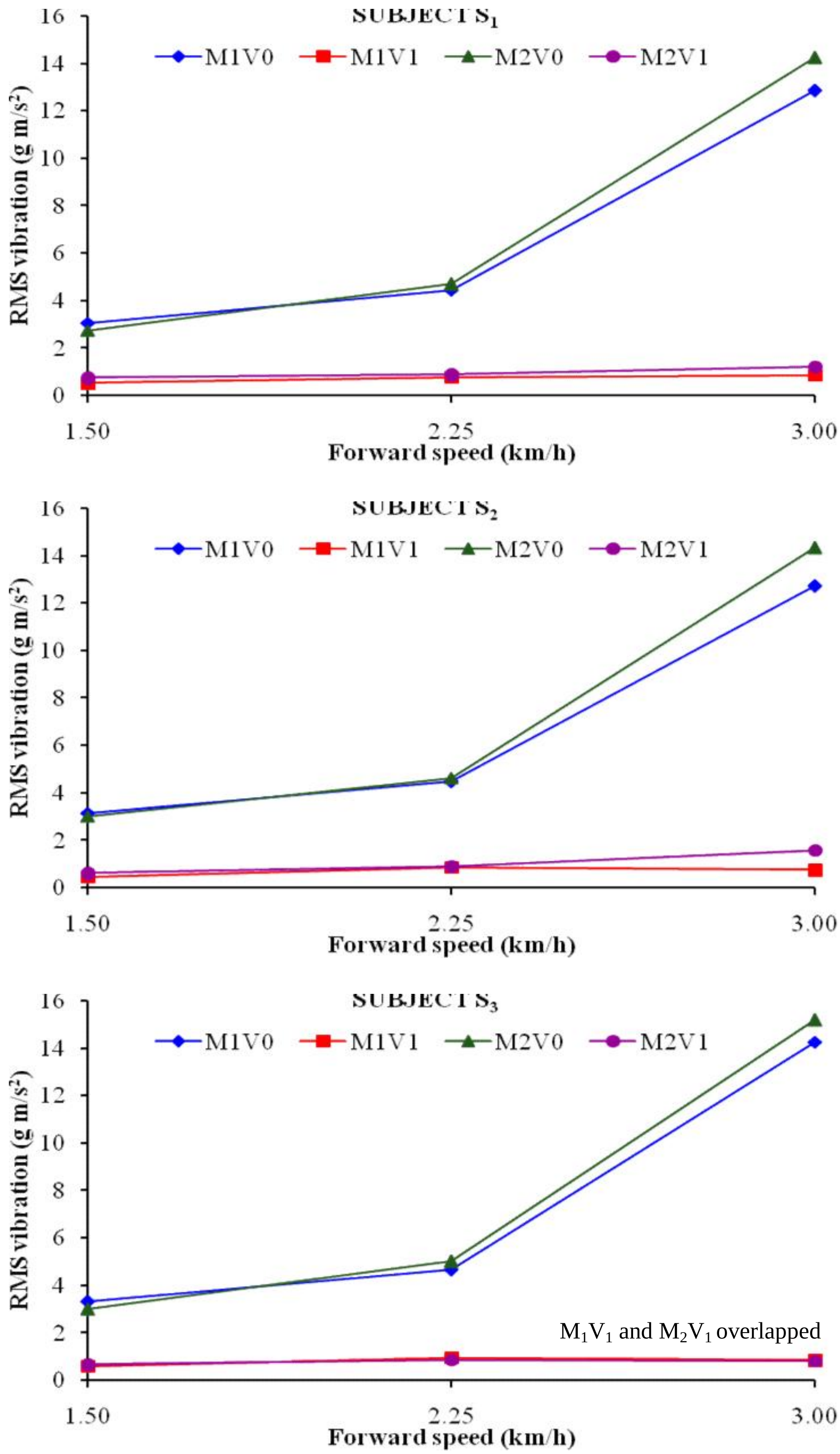

Fig. 4.13. Vibration acceleration along longitudinal direction at handle of boom sprayer.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 2.25 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. Response of vibration acceleration for M_1V_1 was statistically at par at forward speeds of 2.25 and 3.00 km/h. However; vibrations increased marginally when forward speed increased from 2.25 to 3.00 km/h for M_2V_1. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.4.3. Vibration Characteristics along Lateral Direction

The vibration characteristics along lateral direction at handle of the boom sprayer have been given in Table 4.14 and its analysis of variance is presented in Table 4.17. The vibration characteristics are also shown graphically in Fig. 4.14.

Table 4.17. Analysis of variance for vibration acceleration measured along lateral direction at handle of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of a seat with machine (M)	2.63 (M_1)	3.14 (M_2)	
Provision of vibration isolators (V)	4.88 (V_0)	0.88 (V_1)	
Forward speed (F)	1.32 (F_1)	2.39 (F_2)	4.95 (F_3)
Subject (S)	2.77 (S_1)	2.84 (S_2)	3.05 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	7.187	221.49	0.069	
V	1	432.480	13328.83	0.069	
MV	1	2.134	65.76	0.098	
F	2	125.270	3860.75	0.085	
MF	2	1.600	49.32	0.120	
VF	2	99.103	3054.32	0.120	
MVF	2	1.938	59.73	0.169	
S	2	0.760	23.43	0.085	
MS	2	1.888	58.19	0.120	
VS	2	1.715	52.87	0.120	
MVS	2	0.540	16.65	0.169	
FS	4	0.840	25.89	0.147	
MFS	4	1.874	57.75	0.207	
VFS	4	1.511	46.57	0.207	
MVFS	4	0.963	29.67	0.293	
Error	72	0.032			6.25

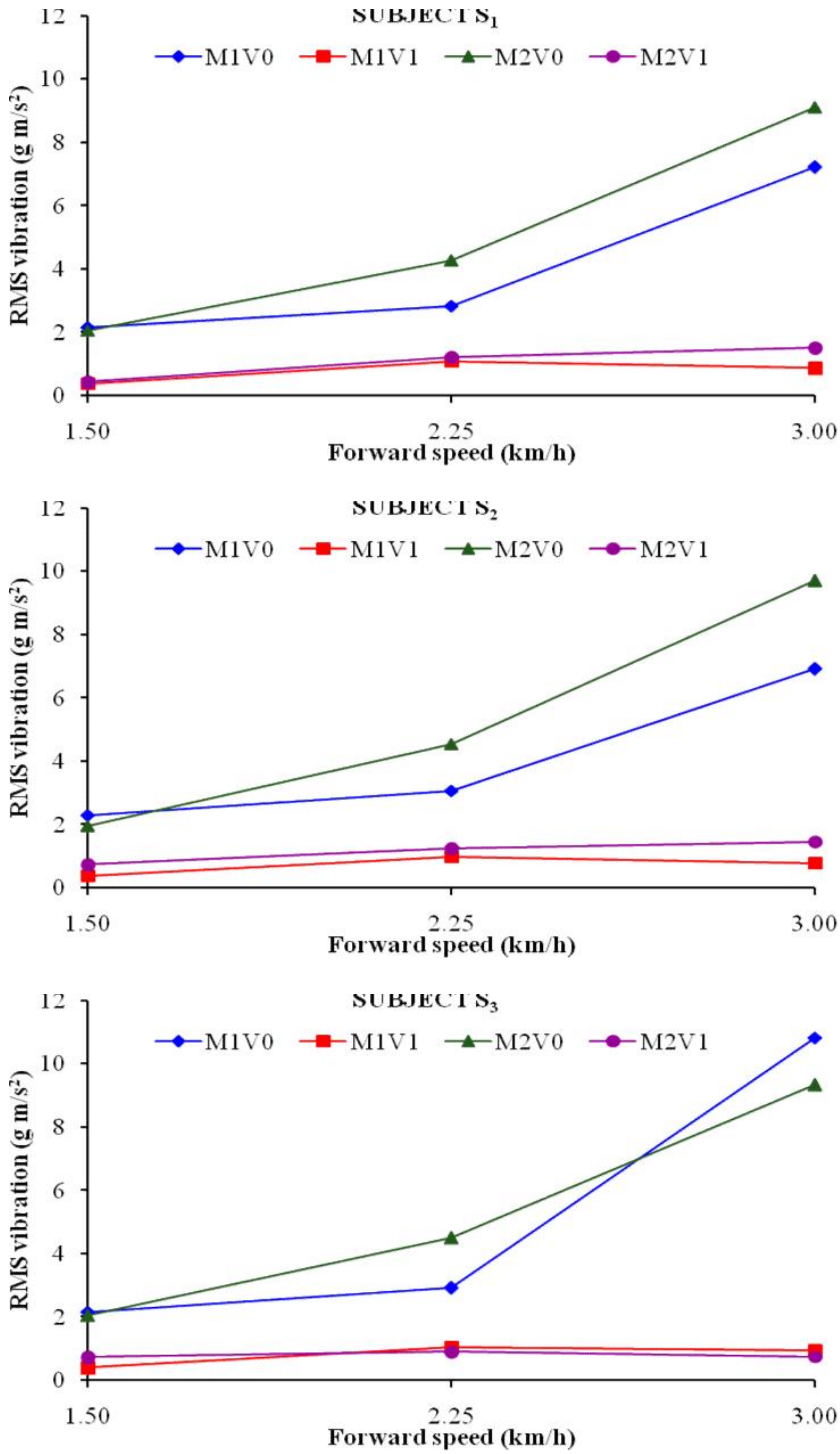

Fig. 4.14. Vibration acceleration along lateral direction at handle of boom sprayer.

The mean values of vibration acceleration varied from 0.39 to 10.81 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.293) at five per cent level of significance.

Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 2.63 and 3.14 g m/s^2, respectively and were statistically different (C.D. = 0.069) at five per cent level of significance. The reason for 19.4% increase in vibrations of M_2 over M_1 is as explained in §4.2.1.1.

The provision of vibration isolators (V_1) for boom sprayer resulted in vibration acceleration of 0.88 g m/s^2 in comparison to 4.88 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.069) at five per cent level. The reason, in this respect, is as already discussed in §4.2.4.1. Thus; vibrations at handle along lateral direction were reduced by 81.97% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.085) at five per cent level of significance. The vibration acceleration was observed as 1.32, 2.39 and 4.95 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along lateral direction at handle of the boom sprayer was statistically at par (C.D. = 0.085) for the subjects S_1 (2.77 g m/s^2) and S_2 (2.84 g m/s^2). However, vibration in case of the subject S_3 (3.05 g m/s^2) was marginally higher. The variation in this respect could be attributed to their individual characteristics.

The interactions among various independent variables were also found to be statistically significant at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. Vibration acceleration for M_1V_1 was marginally lower at forward speed of 3.00 km/h as compared to that at forward speed of 2.25 km/h. However; vibrations increased marginally when forward speed increased from 2.25 to 3.00 km/h for M_2V_1. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al.*, 2004).

4.2.5. Vibration Characteristics at Seat Base

4.2.5.1. Vibration Characteristics along Vertical Direction

The vibration characteristics along vertical direction at seat base of the boom sprayer have been given in Table 4.18 and its analysis of variance is presented in Table 4.19. The vibration characteristics are also shown graphically in Fig. 4.15. The mean values of vibration acceleration varied from 0.33 to 5.10 g m/s^2 among all the treatments and the differences were statistically significant (C.D. = 0.250) at five per cent level of significance. Measurement of vibration acceleration at seat base was possible only for the riding type (M_2) boom sprayer, which had an operators' seat provided for the subject operating the sprayer.

Table 4.18. Response of vibration acceleration at seat base of self propelled boom sprayer.

S. No.	Treatment	RMS acceleration vibration (x g m/s^2)*											
		Vertical				Longitudinal				Lateral			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
1	$M_2V_0F_1S_1$	1.25	1.41	1.74	1.47	1.02	0.99	1.05	1.02	0.87	0.95	1.20	1.01
2	$M_2V_0F_1S_2$	1.52	1.38	1.31	1.40	1.00	1.08	0.87	0.98	1.14	0.95	1.30	1.13
3	$M_2V_0F_1S_3$	1.38	1.51	1.48	1.46	1.23	1.62	1.57	1.47	0.85	0.90	1.01	0.92
4	$M_2V_0F_2S_1$	3.64	4.08	4.20	3.97	1.96	1.48	1.74	1.73	1.34	1.39	1.16	1.30
5	$M_2V_0F_2S_2$	3.86	4.07	4.13	4.02	1.85	1.64	1.77	1.75	1.32	1.13	1.05	1.17
6	$M_2V_0F_2S_3$	2.92	3.16	3.23	3.10	1.95	1.88	2.06	1.96	1.17	1.42	1.27	1.29
7	$M_2V_0F_3S_1$	5.14	5.32	4.84	5.10	2.29	2.30	2.15	2.25	1.46	1.37	1.52	1.45
8	$M_2V_0F_3S_2$	3.99	4.13	4.34	4.15	2.21	2.02	2.16	2.13	1.56	1.39	1.59	1.51
9	$M_2V_0F_3S_3$	4.38	4.91	4.54	4.61	2.54	2.55	2.48	2.52	1.46	1.38	1.57	1.47
10	$M_2V_1F_1S_1$	0.57	0.53	0.44	0.51	0.57	0.44	0.42	0.48	0.34	0.31	0.37	0.34
11	$M_2V_1F_1S_2$	0.45	0.46	0.52	0.48	0.40	0.44	0.47	0.44	0.52	0.46	0.54	0.51
12	$M_2V_1F_1S_3$	0.35	0.32	0.31	0.33	0.45	0.34	0.38	0.39	0.23	0.26	0.38	0.29
13	$M_2V_1F_2S_1$	0.94	0.90	0.87	0.90	0.42	0.52	0.58	0.51	0.39	0.44	0.35	0.39
14	$M_2V_1F_2S_2$	0.87	0.74	0.77	0.79	0.63	0.52	0.58	0.58	0.49	0.51	0.46	0.49
15	$M_2V_1F_2S_3$	0.88	0.84	0.76	0.83	0.70	0.47	0.64	0.60	0.29	0.35	0.44	0.36
16	$M_2V_1F_3S_1$	0.95	0.89	1.01	0.95	0.41	0.38	0.45	0.41	0.43	0.48	0.35	0.42
17	$M_2V_1F_3S_2$	1.14	1.01	0.97	1.04	0.44	0.39	0.43	0.42	0.50	0.44	0.52	0.49
18	$M_2V_1F_3S_3$	0.77	0.96	0.85	0.86	0.55	0.41	0.48	0.48	0.35	0.33	0.42	0.37

*1 g = 9.81 m/s^2

The provision of vibration isolators (V_1) for riding type boom sprayer (M_2) resulted in vibration acceleration of 0.74 g m/s^2 in comparison to 3.25 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.084) at five per cent level. Vibrations were measured at the seat base, which is isolated from chassis by two numbers of SBR based vibration isolator VI_2 at the chassis-seat interfaces – one in horizontal and another in vertical direction. The chassis was further isolated from the engine by four numbers of SBR based vibration isolators VI_1 at the engine mountings. These SBR vibration isolators reduced the transmission of vibrations originating from the reciprocating diesel engine to the chassis, and further from chassis to the seat base. Thus; vibrations at seat base along vertical direction were reduced by 77.23% with the provision of vibration isolators. As measurement of vibrations at seat was at its base, which was before foam cushion provided as an integral part of the operators' seat; therefore, foam cushion of the seat played no role in vibration reduction during measurement of vibrations at seat base. However; foam cushion of the seat might have provided extra comfort to the subject operating the boom sprayer.

Table 4.19. Analysis of variance for vibration acceleration measured along vertical direction at seat base of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)			
Provision of vibration isolators (V)	3.25 (V_0)	0.74 (V_1)	
Forward speed (F)	0.94 (F_1)	2.27 (F_2)	2.79 (F_3)
Subject (S)	2.15 (S_1)	1.98 (S_2)	1.86 (S_3)

ANOVA TABLE

Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
V	1	85.102	3716.29	0.084	
F	2	16.312	712.32	0.102	
VF	2	8.413	367.39	0.145	
S	2	0.375	16.40	0.102	
VS	2	0.156	6.79	0.145	
FS	4	0.173	7.55	0.177	
VFS	4	0.331	14.45	0.250	
Error	36	0.023			7.57

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.102) at five per cent level of significance. The vibration acceleration was observed as 0.94, 2.27 and 2.79 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Among the selected subjects, vibration acceleration along vertical direction at seat base of the boom sprayer was statistically different (C.D. = 0.102) at five per cent level of significance. Vibration was recorded as 2.15 g m/s^2 for the subjects S_1, 1.98 g m/s^2 for the subject S_2, and 1.86 g m/s^2 for the subject S_3. The variation in this respect could be attributed to their individual characteristics.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for M_2 boom sprayer without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all

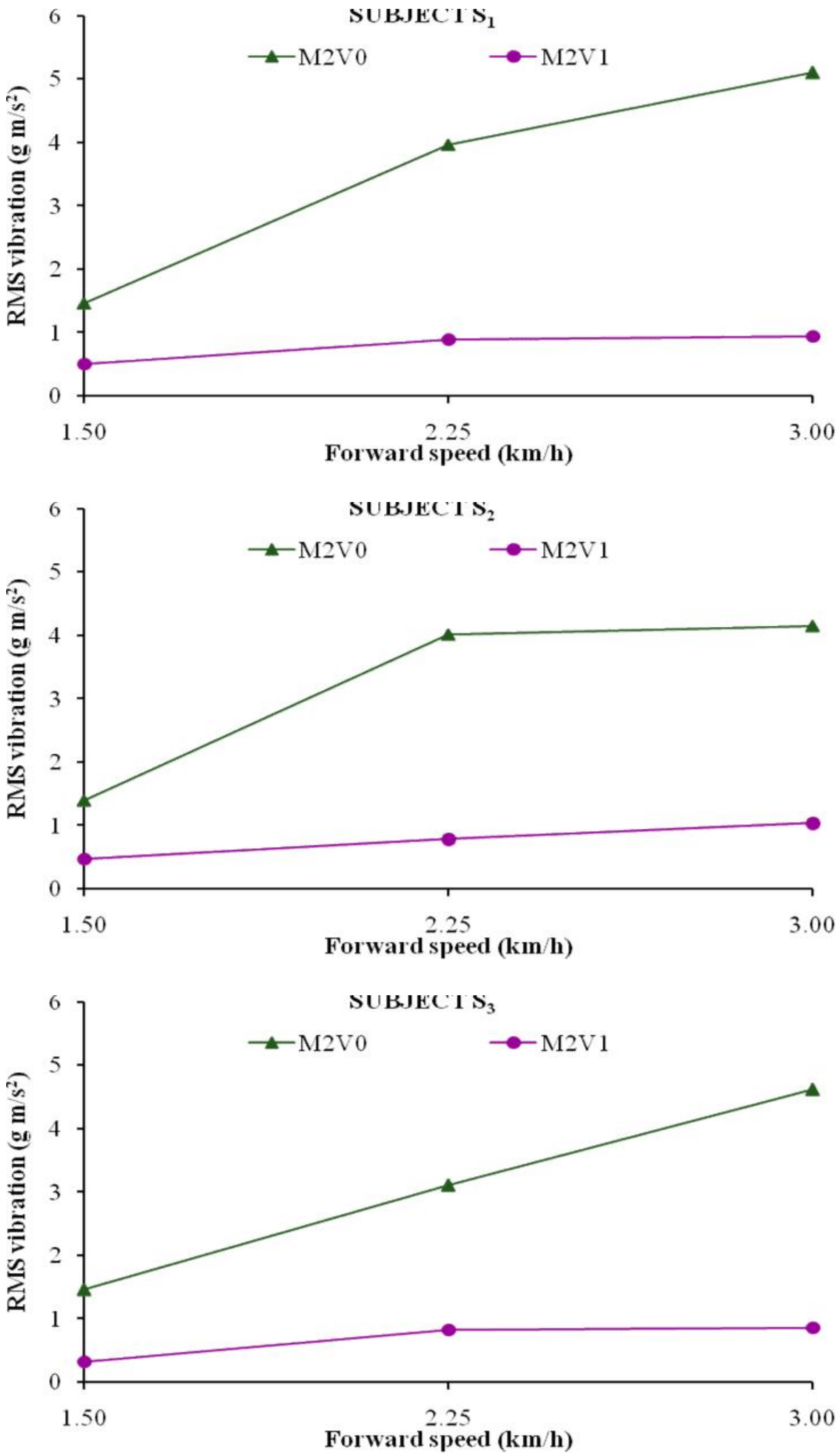

Fig. 4.15. Vibration acceleration along vertical direction at seat base of boom sprayer.

the subjects. The riding type (M_2) boom sprayer, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. However; response of vibration acceleration was statistically at par at forward speeds of 2.25 and 3.00 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.5.2. Vibration Characteristics along Longitudinal Direction

The vibration characteristics along longitudinal direction at seat base of the boom sprayer have been given in Table 4.18 and its analysis of variance is presented in Table 4.20. The vibration characteristics are also shown graphically in Fig. 4.16. The mean values of vibration acceleration varied from 0.39 to 2.52 g m/s^2 among all the treatments and the differences were statistically non-significant at five per cent level of significance.

Table 4.20. Analysis of variance for vibration acceleration measured along longitudinal direction at seat base of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)					
Provision of vibration isolators (V)			1.76 (V_0)	0.48 (V_1)	
Forward speed (F)			0.80 (F_1)	1.19 (F_2)	1.37 (F_3)
Subject (S)			1.07 (S_1)	1.05 (S_2)	1.24 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
V	1	22.106	2049.50	0.057	
F	2	1.540	142.81	0.070	
VF	2	1.459	135.26	0.099	
S	2	0.198	18.40	0.070	
VS	2	0.161	14.90	0.099	
FS	4	0.007	0.64	NS	
VFS	4	0.020	1.88	NS	
Error	36	0.011			9.29

The provision of vibration isolators (V_1) for riding type boom sprayer (M_2) resulted in vibration acceleration of 0.48 g m/s^2 in comparison to 1.76 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.057) at five per cent level. The difference, in this respect, is as explained in §4.2.5.1. Thus; vibrations at seat base along longitudinal direction were reduced by 72.73% with the provision of vibration isolators.

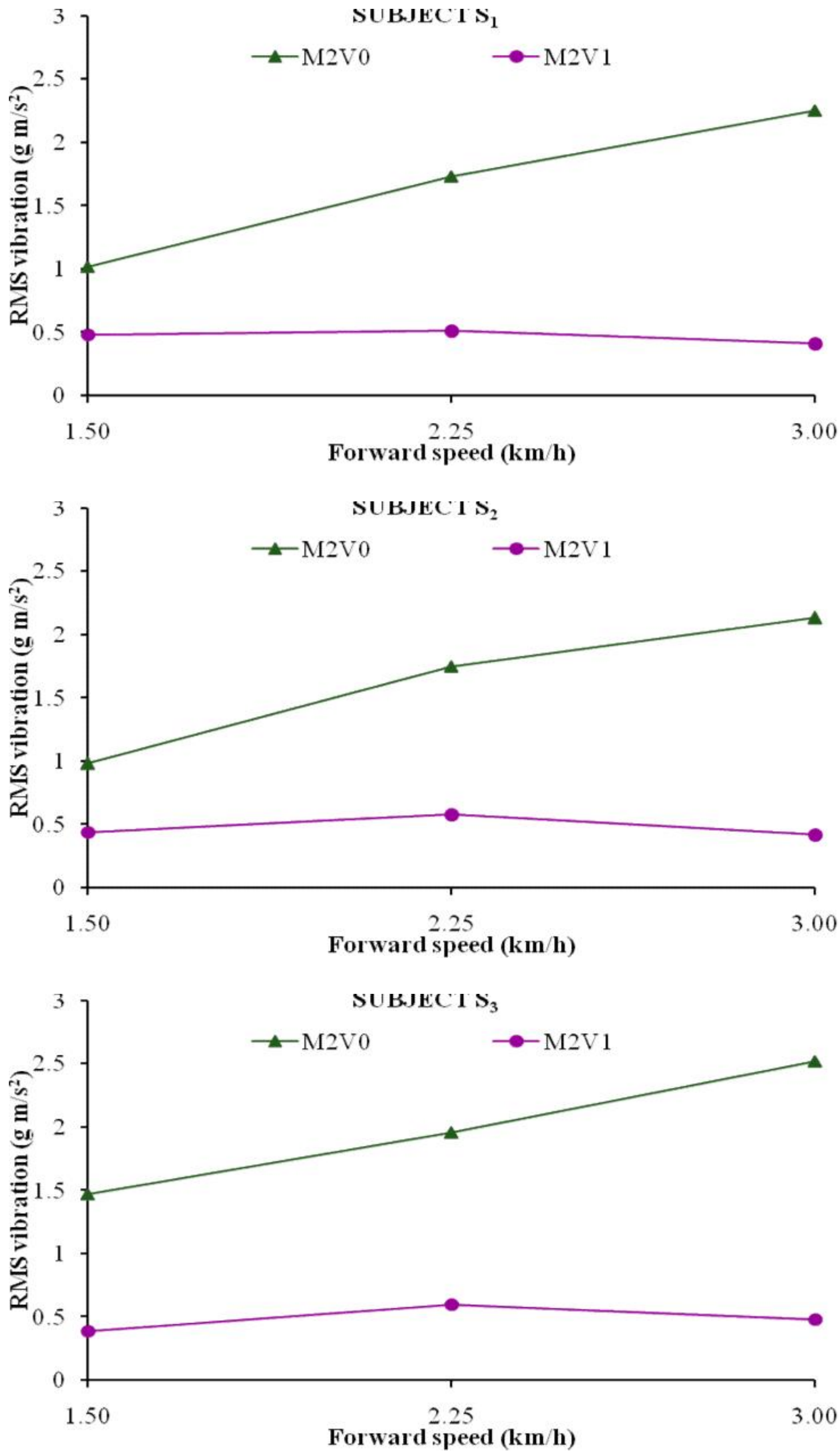

Fig. 4.16. Vibration acceleration along longitudinal direction at seat base of boom sprayer.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.070) at five per cent level of significance. The vibration acceleration was observed as 0.80, 1.19 and 1.37 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Vibration acceleration along longitudinal direction at seat base of the boom sprayer was statistically at par (C.D. = 0.070) for the subjects S_1 (1.07 g m/s^2) and S_2 (1.05 g m/s^2). However, vibration in case of the subject S_3 (1.24 g m/s^2) was significantly higher. The variation in this respect could be attributed to their individual characteristics.

The interactions between independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for M_2 boom sprayer without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. The riding type (M_2) boom sprayer, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. However; response of vibration acceleration was statistically at par at forward speeds of 1.50 and 3.00 km/h. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.5.3. Vibration Characteristics along Lateral Direction

The vibration characteristics along lateral direction at seat base of the boom sprayer have been given in Table 4.18 and its analysis of variance is presented in Table 4.21. The vibration characteristics are also shown graphically in Fig. 4.17. The mean values of vibration acceleration varied from 0.29 to 1.51 g m/s^2 among all the treatments and the differences were statistically non-significant at five per cent level of significance.

The provision of vibration isolators (V_1) for riding type boom sprayer (M_2) resulted in vibration acceleration of 0.41 g m/s^2 in comparison to 1.25 g m/s^2 for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.053) at five per cent level. The difference, in this respect, is as explained in §4.2.5.1. Thus; vibrations at seat base along lateral direction were reduced by 67.20% with the provision of vibration isolators.

The vibration acceleration increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.065) at five per cent level of significance. The vibration acceleration was observed as 0.70, 0.83 and 0.95 g m/s^2 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rotational speed of reciprocating type diesel engine.

Table 4.21. Analysis of variance for vibration acceleration measured along lateral direction at seat base of self propelled boom sprayer.

FACTOR MEANS (x g m/s^2)					
Provision of vibration isolators (V)			1.25 (V_0)	0.41 (V_1)	
Forward speed (F)			0.70 (F_1)	0.83 (F_2)	0.95 (F_3)
Subject (S)			0.82 (S_1)	0.88 (S_2)	0.78 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
V	1	9.601	1024.25	0.053	
F	2	0.287	30.57	0.065	
VF	2	0.192	20.52	0.093	
S	2	0.046	4.88	0.065	
VS	2	0.015	1.65	NS	
FS	4	0.019	2.00	NS	
VFS	4	0.008	0.85	NS	
Error	36	0.009			11.70

Vibration acceleration along lateral direction at seat base of the boom sprayer was statistically at par (C.D. = 0.065) between the subjects S_1 (0.82 g m/s^2) and S_2 (0.88 g m/s^2), and between the subjects S_1 (0.82 g m/s^2) and S_3 (0.78 g m/s^2). However, vibrations were significantly different between the subjects S_2 (0.88 g m/s^2) and S_3 (0.78 g m/s^2). The variation in this respect could be attributed to their individual characteristics.

The interactions between independent variables, except V and F, were found to be statistically non-significant at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, vibration acceleration increased significantly for M_2 boom sprayer without provision of vibration isolators (V_0). The riding type (M_2) boom sprayer, when provided with vibration isolators (V_1), responded vibration acceleration statistically at par for all the three selected forward speeds. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

4.2.6. Overall Response of Vibrations of Boom Sprayer

The vibration measurement of the boom sprayer was conducted along vertical, longitudinal and lateral direction each at engine top, chassis, handle bar, handle and seat base. Mean values of vibration acceleration for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be significantly different at each location except at handle bar along longitudinal direction.

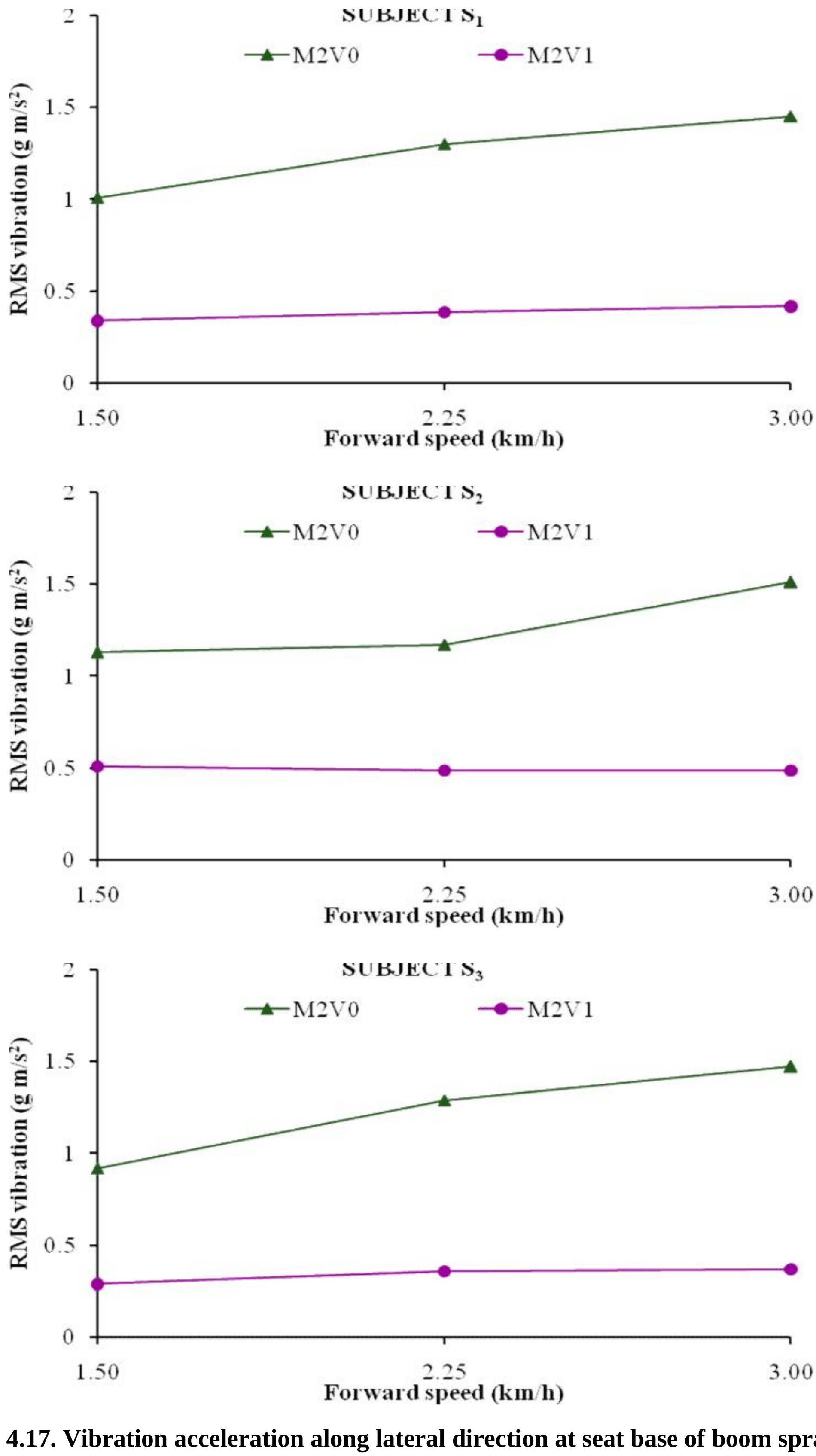

Fig. 4.17. Vibration acceleration along lateral direction at seat base of boom sprayer.

Vibrations for riding type boom sprayer (M_2) were significantly higher at engine top (2.1-11.3%), handle bar (1.6-11.7%) and handle (8.0-24.0%), but lower at chassis along all directions (3.0-12.5%). The difference, in this respect among the two types of machines, could be attributed to their weight and its distribution at wheels (see §4.2.1.1) and shift in CG (see § 4.2.2.1). Kathirvel *et al.* (2007) also reported increase in vibrations by 72.94-170 per cent for riding type power tiller.

The vibration acceleration increased significantly with increase in forward speed from 1.50 to 3.00 km/h of the sprayer. The observed trend due to increase in forward speed was directly related to increase in rpm of reciprocating type diesel engine. The finding was in line with as reported by Mehta *et al.* (2000); Dixit (2006). With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. Problem of frequent loosening of nuts and bolts or minor breakdown was observed at forward speeds of 2.25 and 3.00 km/h for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0). For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, vibration response, however, was more or less the same at all locations of measurement. This trend may be attributed to the dynamic vibration absorption characteristics of SBR based vibration isolators (Tewari *et al*., 2004).

The provision of vibration isolators (V_1) for boom sprayer resulted in significantly lesser vibration acceleration in comparison to the sprayer without isolators (V_0) at all the locations of measurement (see Table 4.22 and Fig. 4.18).

Table 4.22. Reduction in vibration acceleration with provision of vibration isolators.

Location of measurement	Mean RMS acceleration vibration (x g m/s^2)*								
	Vertical direction			Longitudinal direction			Lateral direction		
	V_0	V_1	Reduction (%)	V_0	V_1	Reduction (%)	V_0	V_1	Reduction (%)
Engine top	5.66	5.00	11.66	7.34	6.32	13.90	4.11	4.20	NS#
Chassis	6.74	2.52	62.61	5.10	2.07	59.41	5.65	1.47	73.98
Handle bar	4.00	1.06	73.50	5.57	0.75	86.54	3.46	0.69	80.06
Handle	6.99	1.03	85.26	7.20	0.83	88.47	4.88	0.88	81.97
Seat base	3.25	0.74	77.23	1.76	0.48	72.73	1.25	0.41	67.20

*1 g = 9.81 m/s^2

NS means statistically non-significant at 5% level of significance.

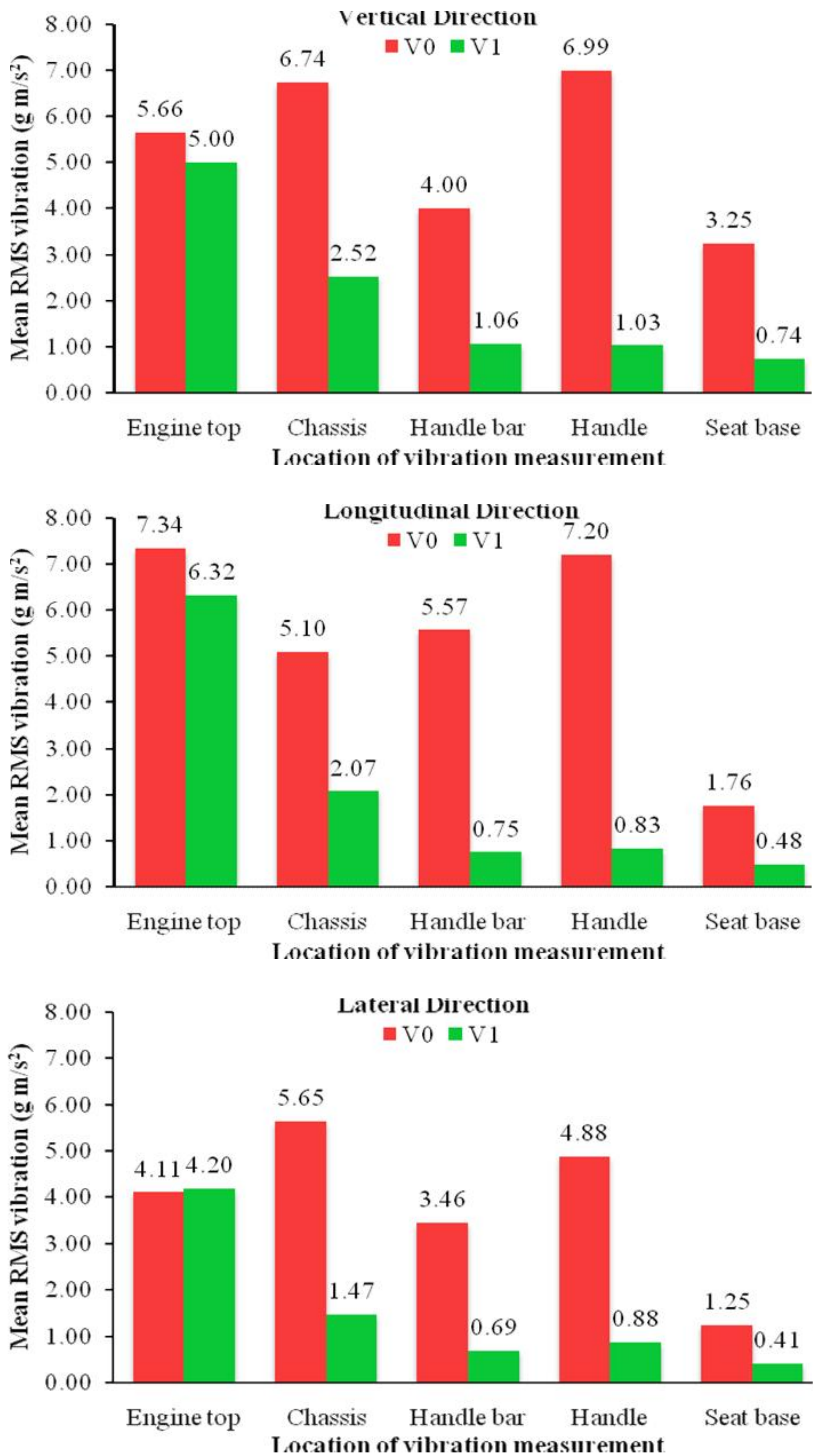

Fig. 4.18. Effect of provision of vibration isolators on vibration acceleration of boom sprayer.

With the provision of vibration isolators (V_1), vibration acceleration reduced by 11.66-13.90% at engine top, 59.41-73.98% at chassis, 73.50-86.54% at handle bar, 81.97-88.47% at handle, and 67.20-77.23% at seat base. The vibration isolators reduced the transmission of vibrations originating from the reciprocating diesel engine to other parts of the boom sprayer. Similar results have been reported by Ragni (1994); Xu *et al.* (1995); Dong (1996); Ying *et al.* (1998); Balasankari (2002); Tewari *et al.* (2004); Sam and Kathirvel (2009); Tewari and Dewangan (2009).

Vibration acceleration of boom sprayer without provision of vibration isolators (V_0) was much higher both in vertical as well as longitudinal direction as compared to lateral direction. The finding was in line with as reported by Pawar (1978); Gupta (1979); Dewangan and Tewari (2009). That was because of the diesel engine which had a vertical single cylinder arrangement. Also the spray pressure pump and power transmission of boom sprayer was along the longitudinal direction. However, with the provision of vibration isolators (V_1), the vibration response was the highest along vertical direction, followed by longitudinal and then lateral direction. Both the locations of vibration measurement at handle bar and handle had no difference in vibration transmission from the diesel engine. However; being a cantilever type arrangement of handle bar, and measurement at handle being at farther point from the handle base, vibrations measured at handle were much higher as compared to that at handle bar.

4.3. Effect of the Independent Variables on Noise

Noise was measured as slow exponential rms average of equivalent continuous sound pressure level in units of dB(A), decibels acoustic, at operators' right ear level. The noise data for various levels of independent parameters of the boom sprayer have been given in Table 4.23 and its analysis of variance is presented in Table 4.24. The same is also shown graphically in Fig. 4.19. The mean values of sound pressure level (SPL) varied from 85.6 to 101.2 dB(A) among all the treatments and the differences were statistically significant (C.D. = 0.438) at five per cent level of significance. The recorded noise level range was in line with as reported by the Bansal (1983); Dewangan *et al.* (2005).

Mean values of noise for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 95.59 and 94.30 dB(A), respectively and were statistically different (C.D. = 0.103) at five per cent level of significance. The difference, in this respect among the two types of machines, could be attributed to their weight (see §4.2.1.1).

Table 4.23. Noise level at operator's ear for various treatments of self propelled boom sprayer.

S. No.	Treatment	Sound pressure level (decibels acoustic)			
		R_1	R_2	R_3	Mean
1	$M_1V_0F_1S_1$	92.4	91.8	92.2	92.1
2	$M_1V_0F_1S_2$	94.7	94.6	94.6	94.6
3	$M_1V_0F_1S_3$	92.0	91.6	91.7	91.8
4	$M_1V_0F_2S_1$	96.3	96.2	96.3	96.3
5	$M_1V_0F_2S_2$	98.6	98.4	99.0	98.7
6	$M_1V_0F_2S_3$	95.2	95.5	95.4	95.4
7	$M_1V_0F_3S_1$	99.5	99.1	100.3	99.6
8	$M_1V_0F_3S_2$	101.3	101.2	101.2	101.2
9	$M_1V_0F_3S_3$	99.5	100.0	99.2	99.6
10	$M_1V_1F_1S_1$	85.7	85.6	85.6	85.6
11	$M_1V_1F_1S_2$	92.0	92.1	92.4	92.2
12	$M_1V_1F_1S_3$	86.6	86.5	86.0	86.4
13	$M_1V_1F_2S_1$	95.4	95.6	95.7	95.6
14	$M_1V_1F_2S_2$	97.0	97.1	96.8	97.0
15	$M_1V_1F_2S_3$	96.4	95.7	96.2	96.1
16	$M_1V_1F_3S_1$	99.3	99.6	99.2	99.4
17	$M_1V_1F_3S_2$	100.1	100.2	100.3	100.2
18	$M_1V_1F_3S_3$	98.9	99.2	99.1	99.1
19	$M_2V_0F_1S_1$	92.3	92.3	92.2	92.3
20	$M_2V_0F_1S_2$	91.3	91.4	91.3	91.3
21	$M_2V_0F_1S_3$	91.2	91.0	91.0	91.1
22	$M_2V_0F_2S_1$	94.7	94.8	94.8	94.8
23	$M_2V_0F_2S_2$	94.8	94.6	94.7	94.7
24	$M_2V_0F_2S_3$	95.2	95.1	95.2	95.2
25	$M_2V_0F_3S_1$	98.0	98.1	97.9	98.0
26	$M_2V_0F_3S_2$	98.4	98.4	98.4	98.4
27	$M_2V_0F_3S_3$	99.0	99.2	99.3	99.2
28	$M_2V_1F_1S_1$	88.8	89.4	89.9	89.4
29	$M_2V_1F_1S_2$	88.5	89.3	89.1	89.0
30	$M_2V_1F_1S_3$	89.5	88.5	88.6	88.9
31	$M_2V_1F_2S_1$	94.9	95.1	94.7	94.9
32	$M_2V_1F_2S_2$	94.6	94.6	94.7	94.6
33	$M_2V_1F_2S_3$	93.5	94.4	94.2	94.0
34	$M_2V_1F_3S_1$	97.3	97.4	97.0	97.2
35	$M_2V_1F_3S_2$	97.9	97.5	97.4	97.6
36	$M_2V_1F_3S_3$	97.1	97.1	96.6	96.9

Table 4.24. Analysis of variance for noise level at operator's ear for various treatments of self propelled boom sprayer.

FACTOR MEANS (decibels acoustic)					
Provision of a seat with machine (M)			95.59 (M_1)	94.30 (M_2)	
Provision of vibration isolators (V)			95.79 (V_0)	94.11 (V_1)	
Forward speed (F)			90.38 (F_1)	95.59 (F_2)	98.87 (F_3)
Subject (S)			94.59 (S_1)	95.79 (S_2)	94.46 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	45.456	628.38	0.103	
V	1	76.049	1051.29	0.103	
MV	1	2.322	32.10	0.146	
F	2	659.524	9117.19	0.126	
MF	2	8.994	124.33	0.179	
VF	2	26.476	366.00	0.179	
MVF	2	5.284	73.04	0.253	
S	2	19.524	269.90	0.127	
MS	2	20.494	283.31	0.179	
VS	2	0.420	5.81	0.179	
MVS	2	1.284	17.74	0.253	
FS	4	2.231	30.84	0.219	
MFS	4	3.913	54.09	0.310	
VFS	4	2.227	30.79	0.310	
MVFS	4	2.386	32.98	0.438	
Error	72	0.072			0.28

The provision of vibration isolators (V_1) for the boom sprayer resulted in noise of 94.11 dB(A) in comparison to 95.79 dB(A) for the sprayer without isolators (V_0) which was found to be significantly different (C.D = 0.103) at five per cent level. Noise at operators' ear level was, therefore, marginally lesser, by 1.68 dB(A), with the provision of vibration isolators due to reduction in fretting sound because of lesser vibrations.

The noise level increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.126) at five per cent level of significance. Noise was observed as 90.38, 95.59 and 98.87 dB(A) at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in rpm of reciprocating type diesel engine (Dewangan *et al.*, 2005; Dixit, 2006). The SPL at an operator's ear level was more than that corresponding to the recommended allowable exposure as per ISO and OSHA criteria for 8-h of operation. Therefore operating both the walking type (M_1) as well as riding type (M_2) boom sprayers is sufficient to cause both temporary and permanent noise induced hearing loss to the operator. The safe daily exposure of the operator as per standards is 8-h at 1.50, 4-h at 2.25, and 2-h at 3.00 km/h of forward speed.

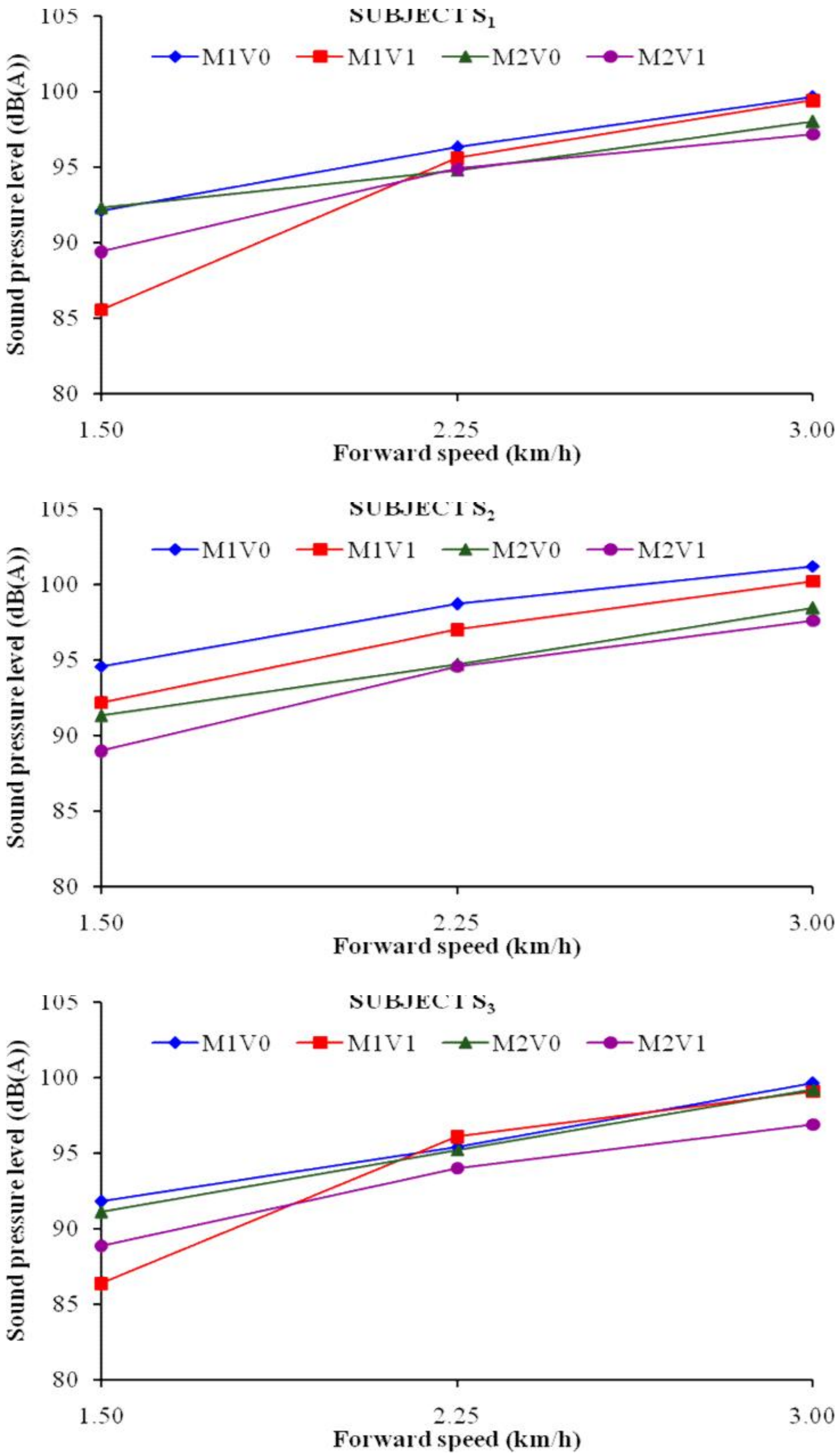

Fig. 4.19. Noise level for various treatments of self propelled boom sprayer.

Among the selected subjects, noise level of the boom sprayer was statistically different (C.D. = 0.126) at five per cent level of significance. Noise level was recorded as 94.59 dB(A) for the subject S_1, 95.79 dB(A) for the subject S_2, and 94.46 dB(A) for the subject S_3. The variation in this respect could be attributed to their individual characteristics.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 1.50 to 2.25 km/h, increase in noise level was much higher as compared to the same with increase in forward speed from 2.25 to 3.00 km/h/. Tewari *et al*. (2004); Dewangan *et al.* (2005) have also reported similar trend of noise level with increase in engine speed.

In the present study, the exhaust of the diesel engine was located at its rear (towards operator) and had a small bend to emit gases towards right side. The noise reduction may also be achieved by suitable exhaust silencer or through use of personal means of protection viz. ear muffs (Ragni *et al*., 1999).

4.4. Effect of the Independent Variables on Physiological Parameters

4.4.1. Heart Rate

Heart rate (HR) was taken as a measure to assess the whole body fatigue and measured as heart-beats per minute. The results of the effect of the independent variables on the HR and corresponding human workload for the boom sprayer have been given in Table 4.25 and its analysis of variance is presented in Table 4.26. The same is also shown graphically in Figures 4.20 and 4.21. Workload (W) in watts was calculated by using subject characteristics' curves of HR on W (see §4.1 for details). The mean values of HR varied between 79.8 and 112.3 beats/min among all the treatments and the differences were statistically non-significant at five per cent level of significance.

Mean values of HR for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 95.19 and 93.15 beats/min, respectively and were statistically different (C.D. = 0.631) at five per cent level of significance. Mean values of workload corresponding to HR for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 27.5 and 24.0 watts, respectively. Thus; there was a reduction in human workload by 12.73% with the provision of the operator's seat. This was mainly because the riding type boom sprayer eliminated the walking of operator behind the sprayer in field. However, turning of the riding type sprayer has to be performed with the foot pedal instead of handle; thus, reducing extent of achieved benefit. The finding was in line with the similar studies performed by Sanyal and Datta (1978); Mehta *et al.* (1997); Tewari *et al.* (2004); Tiwari and Gite (2000); Tiwari *et al.* (2005); Tiwari and Narang (2006); Sam *et al.* (2007).

Table 4.25. Response of heart rate, oxygen consumption and corresponding workloads for various treatments of self propelled boom sprayer.

S. No.	Treatment	HR (beats/min)				VO_2 (ml/min)				Workload (watts) corresponding to	
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean	HR	VO_2
1	$M_1V_0F_1S_1$	86.1	88.0	86.7	86.9	637.7	682.5	648.2	656.1	25.4	25.0
2	$M_1V_0F_1S_2$	101.4	98.5	100.3	100.1	644.8	564.0	618.2	609.0	23.4	21.8
3	$M_1V_0F_1S_3$	92.6	95.1	96.8	94.8	595.2	665.5	649.7	636.8	26.4	25.9
4	$M_1V_0F_2S_1$	89.8	86.1	89.4	88.4	715.4	645.2	703.8	688.1	27.9	27.3
5	$M_1V_0F_2S_2$	102.5	102.9	104.6	103.3	724.5	736.9	779.3	746.9	32.0	31.3
6	$M_1V_0F_2S_3$	104.6	104.8	103.8	104.4	812.5	868.7	853.9	845.0	39.3	38.5
7	$M_1V_0F_3S_1$	100.8	105.1	102.6	102.8	943.8	1035.4	978.3	985.8	52.3	49.1
8	$M_1V_0F_3S_2$	110.4	112.6	113.9	112.3	1023.5	1082.6	1061.7	1055.9	55.6	52.4
9	$M_1V_0F_3S_3$	109.7	114.9	112.1	112.2	968.4	1082.7	1035.2	1028.8	49.9	49.7
10	$M_1V_1F_1S_1$	80.9	81.2	79.4	80.5	477.6	534.1	465.4	492.4	14.5	13.0
11	$M_1V_1F_1S_2$	96.8	97.6	98.3	97.6	522.6	549.7	568.2	546.8	16.8	17.6
12	$M_1V_1F_1S_3$	82.7	86.5	85.4	84.9	420.5	426.3	468.1	438.3	12.9	13.9
13	$M_1V_1F_2S_1$	83.5	83.9	85.4	84.3	492.0	496.7	539.7	509.5	20.9	14.3
14	$M_1V_1F_2S_2$	98.5	98.1	95.4	97.3	601.8	571.6	552.3	575.2	16.2	19.5
15	$M_1V_1F_2S_3$	90.5	90.1	93.9	91.5	516.8	549.2	578.0	548.0	21.9	20.5
16	$M_1V_1F_3S_1$	86.2	84.5	86.0	85.6	578.2	590.5	604.1	590.9	23.1	20.2
17	$M_1V_1F_3S_2$	96.9	98.2	99.6	98.2	543.6	512.5	599.4	551.8	18.6	17.9
18	$M_1V_1F_3S_3$	87.2	88.1	89.5	88.3	458.8	472.6	490.5	474.0	17.5	16.0
19	$M_2V_0F_1S_1$	83.8	81.5	84.6	83.3	568.3	531.8	614.8	571.6	19.2	18.8
20	$M_2V_0F_1S_2$	98.4	99.6	102.1	100.0	596.4	649.1	702.8	649.4	23.3	24.6
21	$M_2V_0F_1S_3$	93.4	93.7	95.8	94.3	608.3	629.5	678.4	638.7	25.7	26.0
22	$M_2V_0F_2S_1$	84.9	86.7	88.0	86.5	615.8	652.7	683.3	650.6	24.7	24.6
23	$M_2V_0F_2S_2$	103.7	105.1	104.9	104.6	737.2	799.6	762.6	766.5	35.3	32.6
24	$M_2V_0F_2S_3$	99.5	103.4	103.8	102.2	737.5	792.1	838.5	789.4	36.4	35.2
25	$M_2V_0F_3S_1$	92.4	96.1	96.8	95.1	792.5	834.5	866.9	831.3	39.2	37.8
26	$M_2V_0F_3S_2$	106.5	106.8	108.3	107.2	874.3	882.9	916.2	891.1	42.2	41.1
27	$M_2V_0F_3S_3$	108.4	108.2	113.6	110.1	934.8	939.3	1060.9	978.3	47.0	46.6
28	$M_2V_1F_1S_1$	80.2	77.6	81.5	79.8	468.0	502.1	511.4	493.8	13.2	13.1
29	$M_2V_1F_1S_2$	95.4	95.9	98.3	96.5	451.8	495.2	468.1	471.7	14.1	12.4
30	$M_2V_1F_1S_3$	85	82.9	83.1	83.7	398.5	412.5	445.8	418.9	11.3	12.7
31	$M_2V_1F_2S_1$	84.5	81.5	82.9	83.0	610.5	572.8	561.7	581.7	18.7	19.5
32	$M_2V_1F_2S_2$	99.2	98.5	96.8	98.2	564.9	567.2	599.6	577.2	18.4	19.7
33	$M_2V_1F_2S_3$	85.8	87.6	88.9	87.4	436.2	509.1	473.4	472.9	16.4	16.0
34	$M_2V_1F_3S_1$	82.5	80.3	83.1	82.0	562.9	516.5	559.2	546.2	17.0	16.9
35	$M_2V_1F_3S_2$	96.1	97.9	98.6	97.5	564.2	552.4	536.7	551.1	16.7	17.9
36	$M_2V_1F_3S_3$	84	86.7	85.2	85.3	409.4	423.1	435.8	422.8	13.5	12.9

Table 4.26. Analysis of variance for heart rate for various treatments of self propelled boom sprayer.

FACTOR MEANS (beats/min)					
Provision of a seat with machine (M)			95.19 (M_1)	93.15 (M_2)	
Provision of vibration isolators (V)			99.37 (V_0)	88.97 (V_1)	
Forward speed (F)			90.20 (F_1)	94.26 (F_2)	98.05 (F_3)
Subject (S)			86.51 (S_1)	101.07 (S_2)	94.93 (S_3)
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	113.072	41.83	0.631	
V	1	2922.701	1081.23	0.631	
MV	1	3.965	1.47	NS	
F	2	555.351	205.45	0.773	
MF	2	18.631	6.89	1.093	
VF	2	314.427	116.32	1.093	
MVF	2	6.073	2.25	NS	
S	2	1922.962	711.38	0.773	
MS	2	12.409	4.59	1.093	
VS	2	226.650	83.85	1.093	
MVS	2	7.906	2.92	NS	
FS	4	29.443	10.89	1.339	
MFS	4	5.879	2.17	NS	
VFS	4	11.809	4.38	1.894	
MVFS	4	1.582	0.59	NS	
Error	72	2.703			1.75

The provision of vibration isolators (V_1) for the boom sprayer resulted in HR of 88.97 beats/min in comparison to 99.37 beats/min for the sprayer without isolators (V_0) which was found to be significantly different (C.D. = 0.631) at five per cent level. Thus; vibration isolators reduced the workload of the operators by 51.6% and provided more comfort due to reduction of vibrations transmitted from engine to the operator (see §4.2.6 for details). Gupta (1979); Guingard (1985); Balasankari (2002); Tewari *et al.* (2004); Tewari and Dewangan (2009) have also observed reduction in physiological workload after provision of vibration isolators.

The HR increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.773) at five per cent level of significance. Mean values of HR were observed as 90.20, 94.26 and 98.05 beats/min at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in stress on operator during sprayer operation. The increase in stress on operator was due to increase in workload, especially in case of walk behind boom sprayer, and also due to increase in vibrations associated with speed of engine (Tiwari and Gite, 2000; Tiwari and Gite, 2002; Tiwari *et al*., 2005; Dixit, 2006).

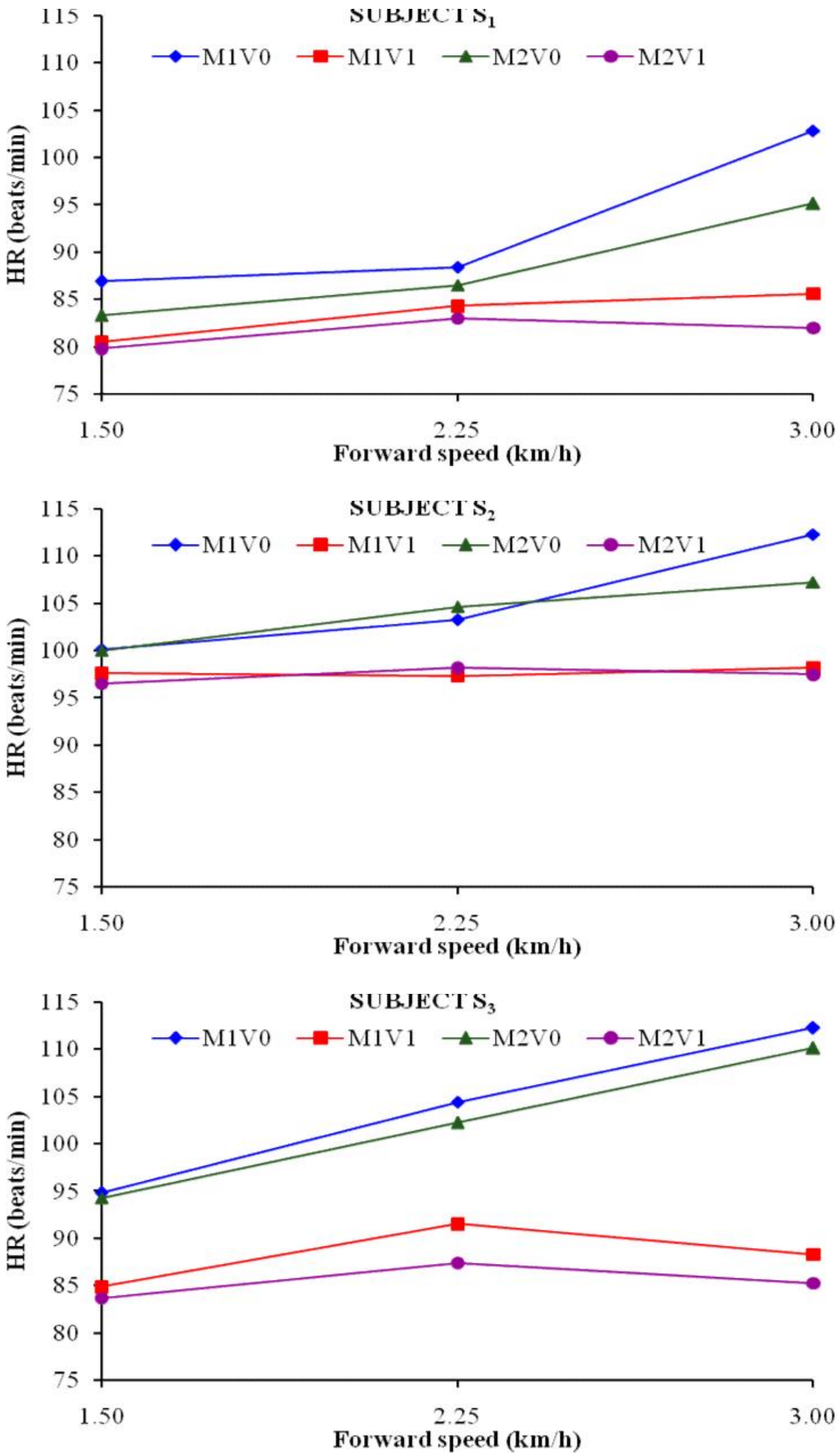

Fig. 4.20. Heart rate response of subjects for various treatments of boom sprayer.

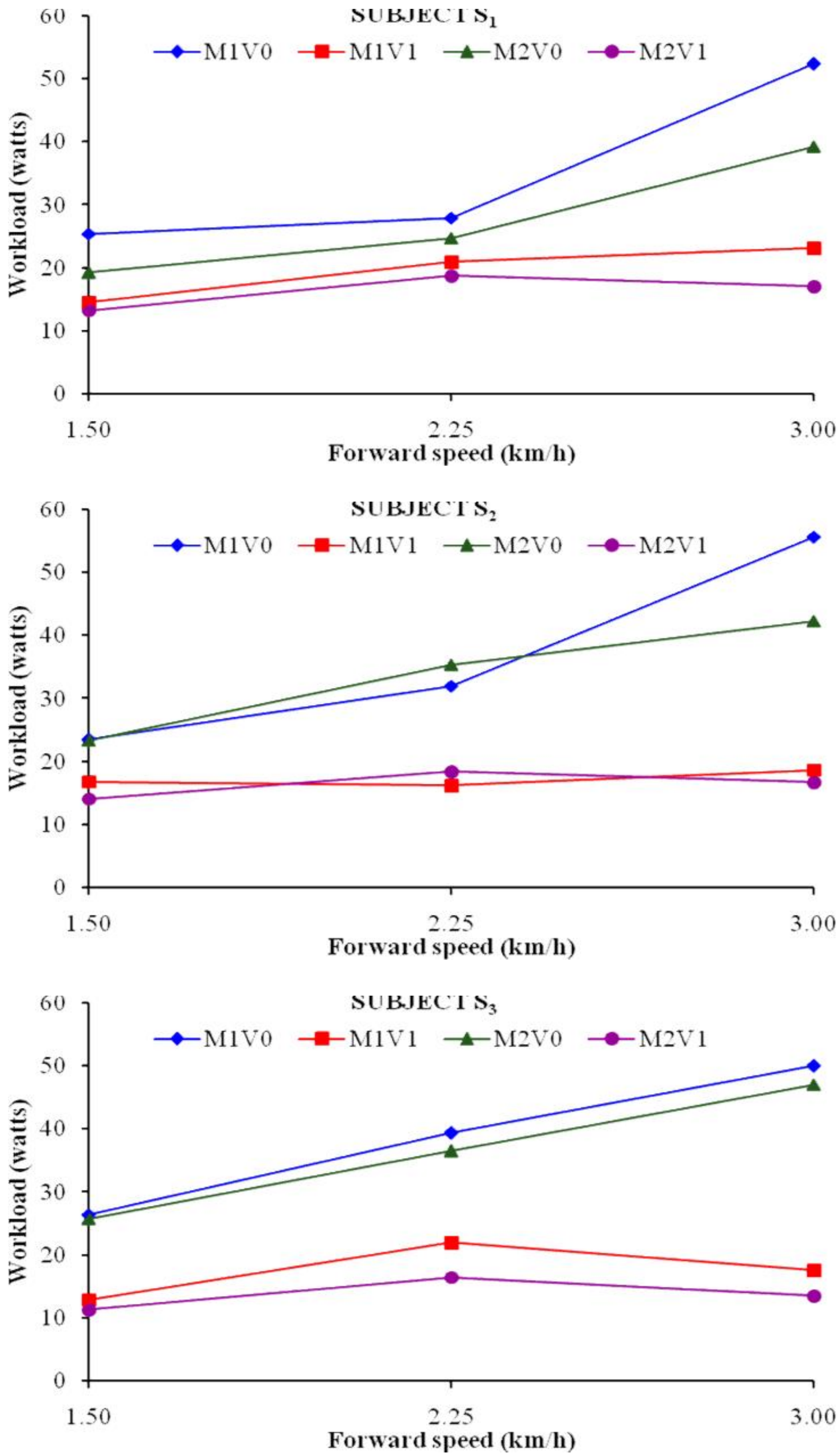

Fig. 4.21. Workload corresponding to heart rate for various treatments of boom sprayer.

The HR varied between 79.8 and 102.8, between 96.5 and 112.3, and between 83.7 and 112.2 beats per minute for the subjects S_1, S_2 and S_3, respectively at all combinations of independent parameters. The variation in HR among the subjects was due to their individual characteristics (§4.1). It was found that workload corresponding to HR varied from 13.2 to 52.3 with a mean of 24.7 watts for the subject S_1, from 14.1 to 55.6 with a mean of 26.1 watts for the subject S_2, and from 11.3 to 49.9 with a mean of 26.5 watts for the subject S_3 (Fig. 4.21). The workload on the subject S_1 was less due to his young age (20 years). Workload on the subjects S_2 (aged 31 years) and S_3 (aged 57 years) was about the same. The reason could be explained through findings of Malhotra *et al.* (1966); Mc Ardle *et al.* (1994); Gite and Singh (1997); Nigg and Herzog (1999).

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in HR and corresponding workload was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher HR and workload with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, HR, and workload, however, responded more or less at the same level. This may be attributed to the vibration characteristics of isolators provided to boom sprayer (§4.2.6). As per the classification of Astrand and Rodahl (1986), the physical work falls in the category of light to moderate work (see (§2.2.4 for details). The moderate work for the boom sprayer without vibration isolators (V_0) was improved to light work category with the provision of vibration isolators (V_1). The riding type (M_2) boom sprayer also provided more comfort to the operator as compared to the walking type (M_1). Thus; a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combination resulted in the lowest workload (light work).

4.4.2. Oxygen Consumption

Volume of oxygen consumption (VO_2) was another measure to assess the whole body fatigue and measured as rate of oxygen consumed through respiration by the subject in units of milli-litres per minute. The results of the effect of the independent variables on the VO_2 and corresponding human workload for the boom sprayer have been given in Table 4.25 and its analysis of variance is presented in Table 4.27. The same is also shown graphically in Figures 4.22 and 4.23. Workload (W) in watts was calculated by using subject characteristics' curves of VO_2 on W (see §4.1 for details).

The mean values of VO_2 varied between 418.9 and 1055.9 ml/min among all the treatments and the differences were statistically significant (C.D. = 56.1) at five per cent level of significance.

Table 4.27. Analysis of variance for oxygen consumption for various treatments of self propelled boom sprayer.

FACTOR MEANS (ml/min)			
Provision of a seat with machine (M)	665.53 (M_1)	627.96 (M_2)	
Provision of vibration isolators (V)	778.86 (V_0)	514.63 (V_1)	
Forward speed (F)	551.98 (F_1)	645.92 (F_2)	742.34 (F_3)
Subject (S)	633.18 (S_1)	666.07 (S_2)	640.99 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	38088.0	32.11	13.223	
V	1	1885171.0	1589.30	13.223	
MV	1	7252.5	6.11	18.700	
F	2	326169.3	274.98	16.195	
MF	2	11130.2	9.38	22.903	
VF	2	212849.3	179.44	22.903	
MVF	2	6677.8	5.63	32.390	
S	2	10626.2	8.96	16.195	
MS	2	413.8	0.35	NS	
VS	2	62872.5	53.00	22.903	
MVS	2	8375.5	7.06	32.390	
FS	4	5377.5	4.53	28.050	
MFS	4	4320.7	3.64	39.669	
VFS	4	3351.8	2.83	39.669	
MVFS	4	4326.9	3.65	56.101	
Error	72	1186.2			5.33

Mean values of VO_2 for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 665.5 and 628.0 ml/min, respectively and were statistically different (C.D. = 13.2) at five per cent level of significance. Mean values of workload corresponding to VO_2 for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 26.3 and 23.8 watts, respectively. Thus; there was a reduction in human workload by 9.51% with the provision of the operator's seat. The reason for the above has already been explained in §4.4.1. The finding was in line with the similar studies performed by Sanyal and Datta (1978); Mehta *et al.* (1997); Tewari *et al.* (2004); Tiwari and Gite (2000); Tiwari *et al.* (2005); Tiwari and Narang (2006); Sam *et al.* (2007).

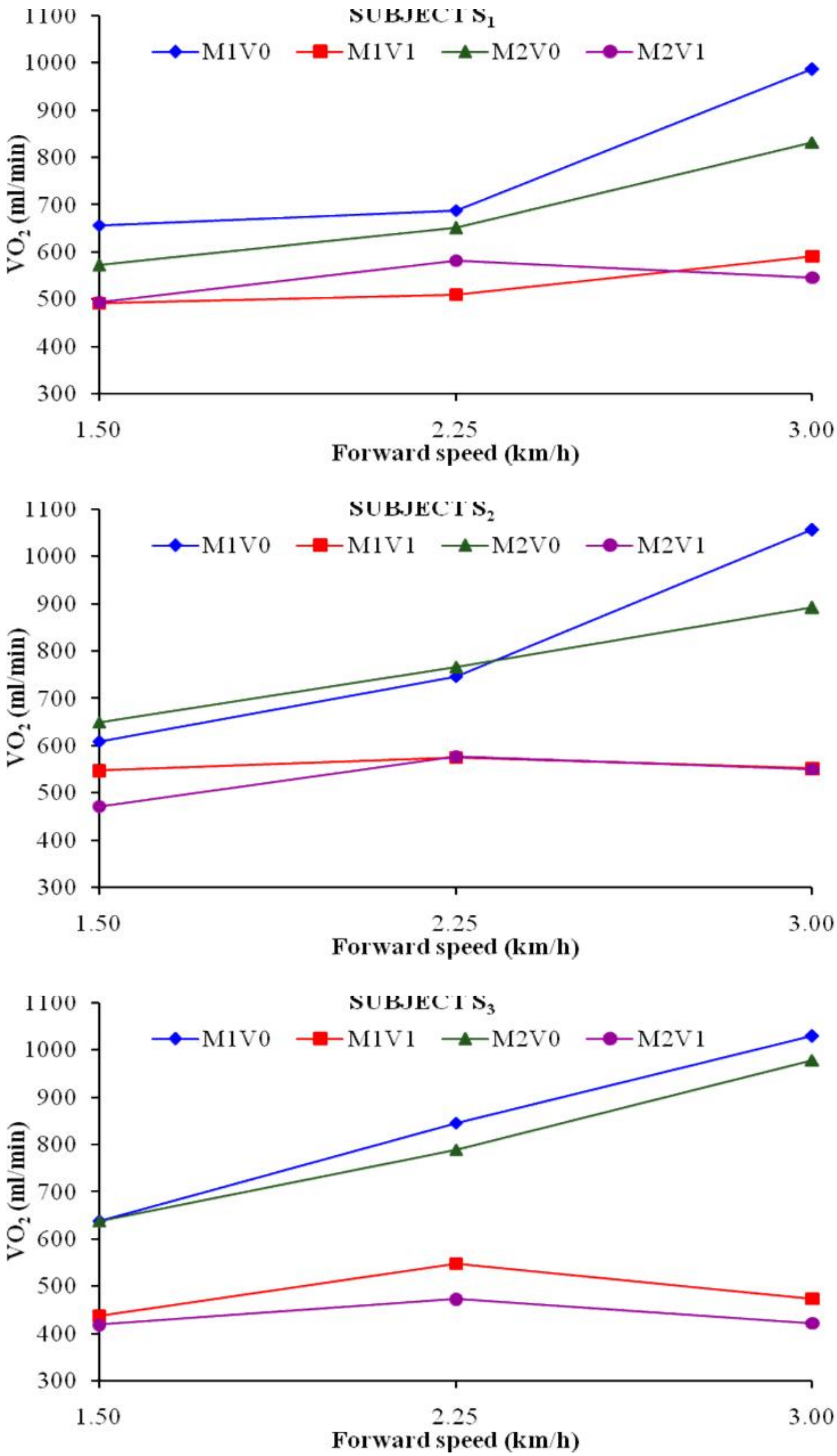

Fig. 4.22. Oxygen consumption response of subjects for various treatments of boom sprayer.

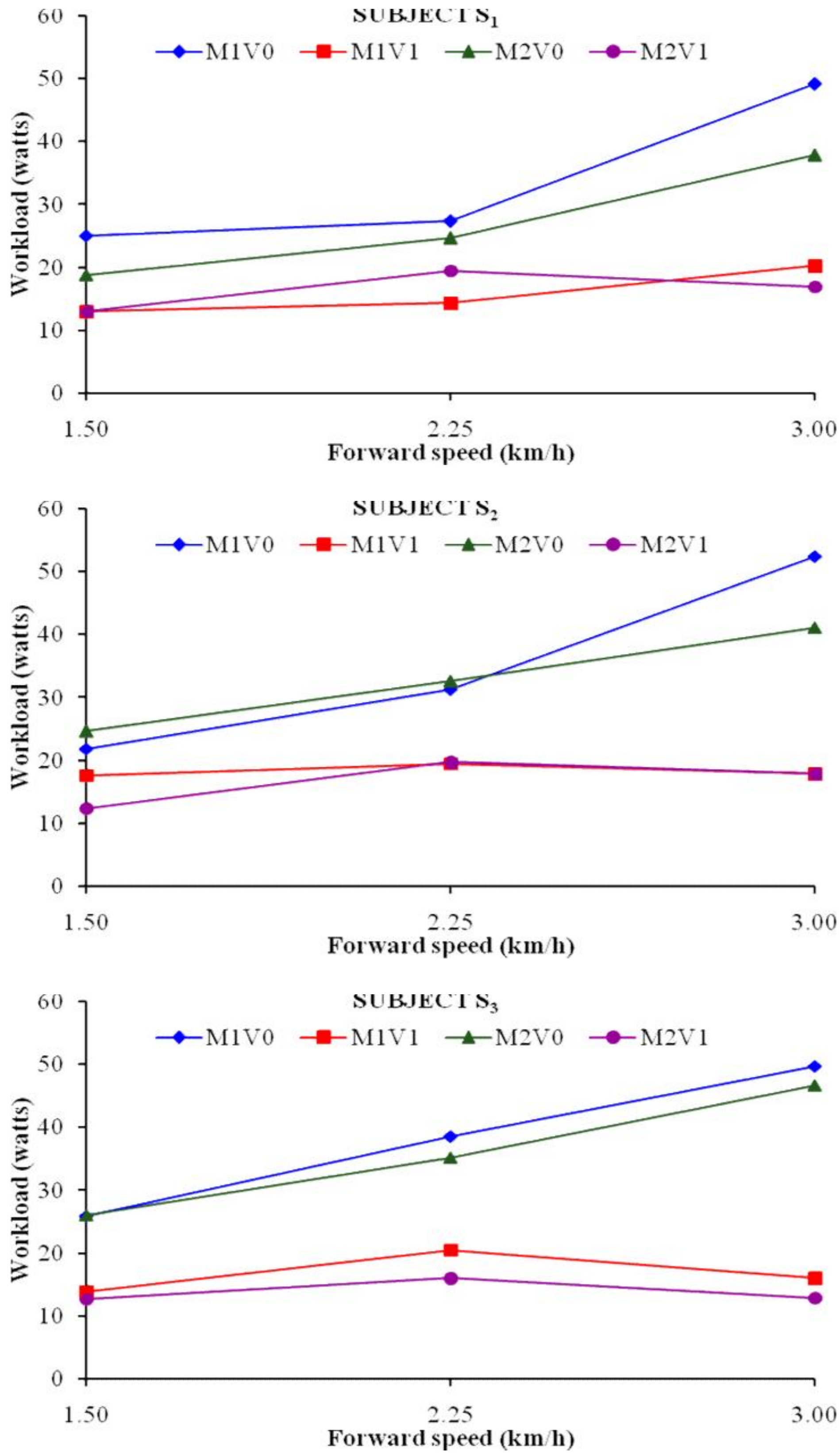

Fig. 4.23. Workload corresponding to oxygen consumption for various treatments of boom sprayer.

The provision of vibration isolators (V_1) for the boom sprayer resulted in VO_2 of 514.6 ml/min in comparison to 778.9 ml/min for the sprayer without isolators (V_0) which was found to be significantly different (C.D. = 13.2) at five per cent level. Thus; vibration isolators reduced the workload of the operators by 51.8% and provided more comfort due to reduction of vibrations transmitted from engine to the operator (see §4.2.6 for details). Gupta (1979); Guingard (1985); Balasankari (2002); Tewari *et al.* (2004); Tewari and Dewangan (2009) have also observed reduction in physiological workload after provision of vibration isolators.

The VO_2 increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 16.2) at five per cent level of significance. Mean values of VO_2 were observed as 552.0, 645.9 and 742.3 ml/min at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in stress on operator during sprayer operation. The increase in stress on operator was due to increase in workload, especially in case of walk behind boom sprayer, and also due to increase in vibrations associated with speed of engine (Tiwari and Gite, 2000; Tiwari and Gite, 2002; Tiwari *et al.*, 2005; Dixit, 2006).

The VO_2 varied between 492.4 and 985.8, between 471.7 and 1055.9, and between 418.9 and 1028.8 ml/min for the subjects S_1, S_2 and S_3, respectively at all combinations of independent parameters. The variation in VO_2 among the subjects was due to their individual characteristics (§4.1). It was found that workload corresponding to VO_2 varied from 13.0 to 49.1 with a mean of 23.3 watts for the subject S_1, from 12.4 to 52.4 with a mean of 25.7 watts for the subject S_2, and from 12.7 to 49.7 with a mean of 26.2 watts for the subject S_3 (Fig. 4.23). The workload on the subject S_1 was less due to his young age (20 years). Workload on the subjects S_2 (aged 31 years) and S_3 (aged 57 years) was about the same. The reason could be explained through findings of Malhotra *et al.* (1966); Mc Ardle *et al.* (1994); Gite and Singh (1997); Nigg and Herzog (1999).

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. With increase in forward speed from 1.50 to 3.00 km/h, increase in VO_2 and corresponding workload was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1) among all the subjects. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded significantly higher VO_2 and workload with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, VO_2 and workload, however, decreased. This may be attributed to the vibration characteristics of isolators provided to boom sprayer (§4.2.6). As per the classification of Astrand and Rodahl (1986), the physical work falls in the category of light to moderate work (see (§2.2.4 for details). The moderate work for the boom sprayer without vibration isolators (V_0) was improved to light work category with the provision of vibration isolators (V_1). The riding type (M_2) boom sprayer also provided more comfort to the operator as compared to the walking type (M_1). Thus; a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combination resulted in the lowest workload (light work). The results obtained through measurement of VO_2 were also observed to be in line with the measured HR (see §4.4.1 for details).

4.4.3. Overall Discomfort Rating

Overall discomfort rate (ODR) was used as a measure to assess the body discomfort arising as a result of working posture due to activity performed by the subject and measured as category-ratio (CR-10) scale given by Borg (1982). The results of the effect of the independent variables on the ODR have been given in Table 4.28 and its analysis of variance is presented in Table 4.29. The same is also shown graphically in Fig. 4.24. The mean values of ODR varied between 1.0 and 5.0 among all the treatments and the differences were statistically significant (C.D. = 0.222) at five per cent level of significance.

Mean values of ODR for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 3.15 and 3.13, respectively and were statistically non-significant at five per cent level of significance. As per the Borg (1982), pain intensity score; thus, falls in the category of ‘slightly painful’ (see §2.3.2 for details). Since ODR may be taken as a measure of overall body discomfort due to work being performed, it may be concluded that there was no reduction in overall discomfort to the operator with the provision of the operator’s seat. The result obtained was in contradiction with the findings of Tiwari and Gite (2000); Tewari *et al.* (2004); Tiwari *et al.* (2005); Tiwari and Narang (2006); Sam and Kathirvel (2008). The reason for the above could be duration of experiment (15 minutes); which was fixed so as the spray tank of boom sprayer discharges within 15-20 minutes when operated at a recommended spray pressure of 2.5 kg/cm^2.

The provision of vibration isolators (V_1) for the boom sprayer resulted in ODR of 2.28 in comparison to 4.00 for the sprayer without isolators (V_0) which was found to be significantly different (C.D. = 0.05) at five per cent level. Thus; vibration isolators reduced the overall discomfort of the operators by 43.0% and provided more comfort due to reduction of vibrations transmitted from engine to the operator (see §4.2.6 for details). Balasankari (2002); Tewari *et al.* (2004); Sam and Kathirvel (2008); Tewari and Dewangan (2009) have also observed similar results.

Table 4.28. Discomfort ratings of subjects for various treatments of self propelled boom sprayer.

S. No.	Treatment	Overall discomfort rating				Body part discomfort rating			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
1	$M_1V_0F_1S_1$	3	3	3	3.0	55	53	51	53.0
2	$M_1V_0F_1S_2$	3	3	3	3.0	64	68	61	64.3
3	$M_1V_0F_1S_3$	3	3	3	3.0	65	64	59	62.7
4	$M_1V_0F_2S_1$	4	4	4	4.0	74	72	68	71.3
5	$M_1V_0F_2S_2$	4	4	4	4.0	63	71	66	66.7
6	$M_1V_0F_2S_3$	4	4	4	4.0	84	76	71	77.0
7	$M_1V_0F_3S_1$	5	5	5	5.0	87	90	86	87.7
8	$M_1V_0F_3S_2$	5	5	5	5.0	91	93	89	91.0
9	$M_1V_0F_3S_3$	5	5	5	5.0	108	102	102	104.0
10	$M_1V_1F_1S_1$	1	1	1	1.0	45	45	42	44.0
11	$M_1V_1F_1S_2$	2	2	2	2.0	45	45	43	44.3
12	$M_1V_1F_1S_3$	1	1	1	1.0	49	53	52	51.3
13	$M_1V_1F_2S_1$	2	2	2	2.0	53	50	52	51.7
14	$M_1V_1F_2S_2$	3	3	3	3.0	59	55	55	56.3
15	$M_1V_1F_2S_3$	2	2	1	1.7	65	63	64	64.0
16	$M_1V_1F_3S_1$	3	3	3	3.0	65	67	64	65.3
17	$M_1V_1F_3S_2$	4	4	4	4.0	63	61	66	63.3
18	$M_1V_1F_3S_3$	3	3	3	3.0	68	66	67	67.0
19	$M_2V_0F_1S_1$	3	3	3	3.0	36	38	35	36.3
20	$M_2V_0F_1S_2$	3	3	3	3.0	35	34	35	34.7
21	$M_2V_0F_1S_3$	3	3	3	3.0	44	39	40	41.0
22	$M_2V_0F_2S_1$	4	4	4	4.0	42	44	46	44.0
23	$M_2V_0F_2S_2$	4	4	4	4.0	40	44	45	43.0
24	$M_2V_0F_2S_3$	4	4	4	4.0	52	52	48	50.7
25	$M_2V_0F_3S_1$	5	5	5	5.0	67	68	67	67.3
26	$M_2V_0F_3S_2$	5	5	5	5.0	74	74	71	73.0
27	$M_2V_0F_3S_3$	5	5	5	5.0	67	67	68	67.3
28	$M_2V_1F_1S_1$	1	1	1	1.0	29	33	32	31.3
29	$M_2V_1F_1S_2$	2	1	1	1.3	37	35	33	35.0
30	$M_2V_1F_1S_3$	2	2	2	2.0	33	31	33	32.3
31	$M_2V_1F_2S_1$	2	2	2	2.0	31	27	34	30.7
32	$M_2V_1F_2S_2$	2	2	2	2.0	39	35	36	36.7
33	$M_2V_1F_2S_3$	2	2	2	2.0	41	35	40	38.7
34	$M_2V_1F_3S_1$	3	3	3	3.0	47	44	47	46.0
35	$M_2V_1F_3S_2$	4	4	4	4.0	43	41	46	43.3
36	$M_2V_1F_3S_3$	3	3	3	3.0	39	43	44	42.0

Table 4.29. Analysis of variance for overall discomfort rating for various treatments of self propelled boom sprayer.

FACTOR MEANS					
Provision of a seat with machine (M)		3.15 (M_1)	3.13 (M_2)		
Provision of vibration isolators (V)		4.00 (V_0)	2.28 (V_1)		
Forward speed (F)		2.19 (F_1)	3.06 (F_2)	4.17 (F_3)	
Subject (S)		3.00 (S_1)	3.36 (S_2)	3.06 (S_3)	
ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	0.009	0.50	NS	
V	1	80.083	4324.51	0.052	
MV	1	0.009	0.50	NS	
F	2	35.194	1900.51	0.064	
MF	2	0.065	3.50	0.090	
VF	2	0.194	10.50	0.090	
MVF	2	0.0.648	3.50	0.128	
S	2	1.361	73.50	0.064	
MS	2	0.565	30.50	0.090	
VS	2	1.361	73.50	0.090	
MVS	2	0.565	30.50	0.128	
FS	4	0.181	9.75	0.111	
MFS	4	0.162	8.75	0.157	
VFS	4	0.181	9.75	0.157	
MVFS	4	0.162	8.75	0.222	
Error	72	0.019			4.34

The ODR increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 0.06) at five per cent level of significance. Mean values of ODR were observed as 2.19, 3.06 and 4.17 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in stress on operator during sprayer operation; which was due to increase in workload, especially in case of walk behind boom sprayer, and also due to increase in vibrations associated with speed of engine. Tiwari and Gite (2000); Tiwari and Gite (2002); Tewari *et al.* (2004); Sam and Kathirvel (2008) have also observed similar results.

The ODR was statistically at par (C.D. = 0.06) for the subjects S_1 (3.00) and S_3 (3.06). However, ODR in case of the subject S_2 (3.36) was significantly higher. The variation in this respect could be attributed to their individual characteristics.

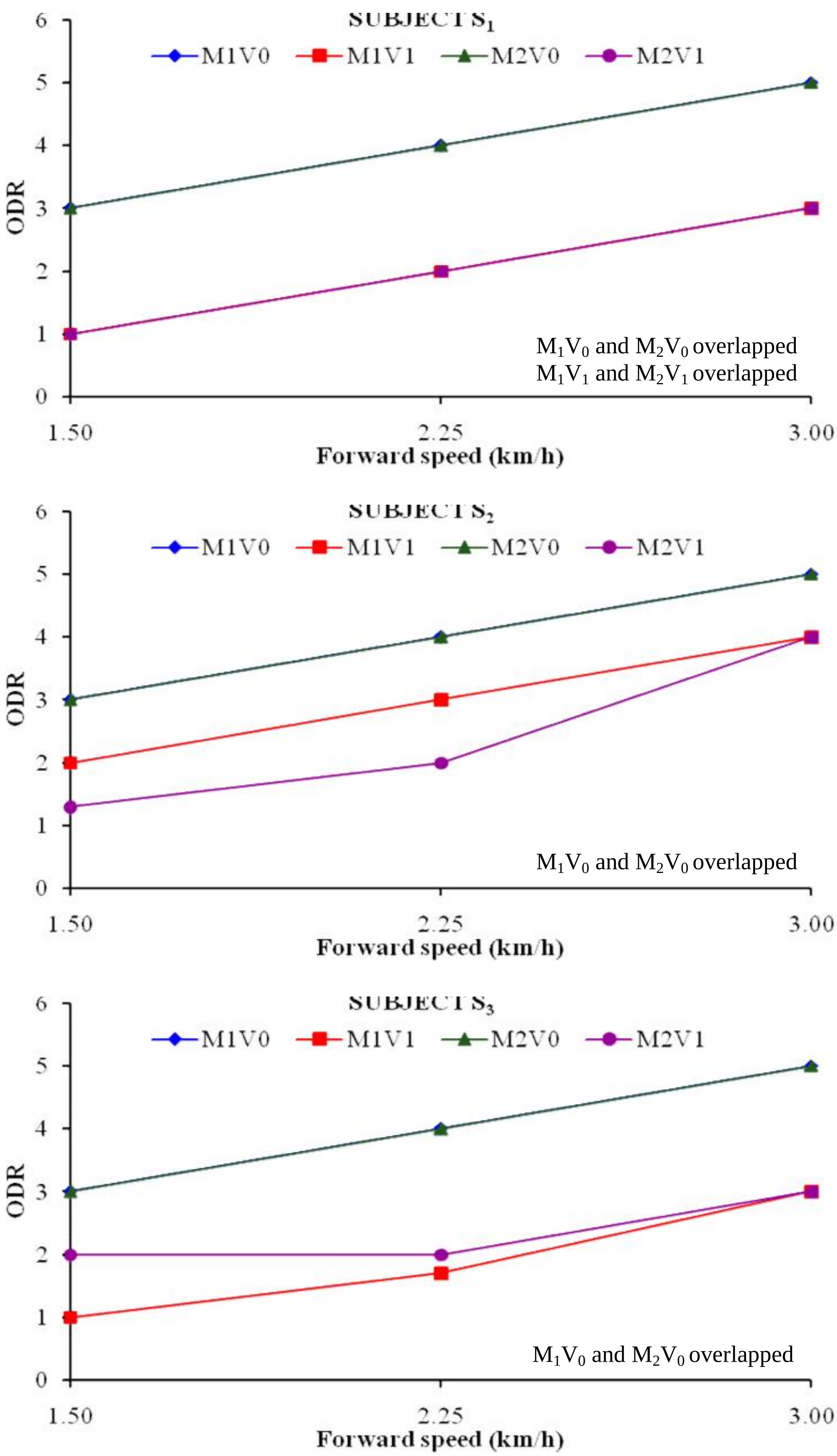

Fig. 4.24. Overall discomfort rating by subjects for various treatments of boom sprayer.

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. The 'moderately painful' subjective feeling for the boom sprayer without vibration isolators (V_0) was improved to 'pain starts' feeling with the provision of vibration isolators (V_1). Thus; a boom sprayer (walk behind or riding type) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combinations resulted in the 'slightly painful' subjective feeling category.

4.4.4. Body Part Discomfort Rating

Body part discomfort rate (BPDR) was used as a measure to assess the localized discomfort arising as a result of working posture due to activity performed by the subject. The results of the effect of the independent variables on the BPDR have been given in Table 4.28 and its analysis of variance is presented in Table 4.30. The same is also shown graphically in Fig. 4.25. The mean values of BPDR varied between 30.7 and 104.0 among all the treatments and the differences were statistically significant (C.D. = 4.08) at five per cent level of significance.

Table 4.30. Analysis of variance for body part discomfort rating for various treatments of self propelled boom sprayer.

FACTOR MEANS			
Provision of a seat with machine (M)	65.83 (M_1)	44.07 (M_2)	
Provision of vibration isolators (V)	63.06 (V_0)	46.85 (V_1)	
Forward speed (F)	44.19 (F_1)	52.56 (F_2)	68.11 (F_3)
Subject (S)	52.39 (S_1)	54.31 (S_2)	58.17 (S_3)

ANOVA TABLE					
Source	d.f.	M.S.	F-Ratio	C.D. (5%)	C.V.
M	1	12783.530	2042.33	0.961	
V	1	7089.083	1132.57	0.961	
MV	1	200.139	31.97	1.358	
F	2	5303.333	847.28	1.176	
MF	2	88.139	14.08	1.664	
VF	2	847.083	135.33	1.664	
MVF	2	21.334	3.41	2.353	
S	2	311.778	49.81	1.176	
MS	2	103.639	16.56	1.664	
VS	2	19.750	3.16	1.664	
MVS	2	7.722	1.23	NS	
FS	4	28.319	4.52	2.038	
MFS	4	34.250	5.47	2.882	
VFS	4	54.417	8.69	2.882	
MVFS	4	54.458	8.70	4.075	
Error	72	6.259			4.55

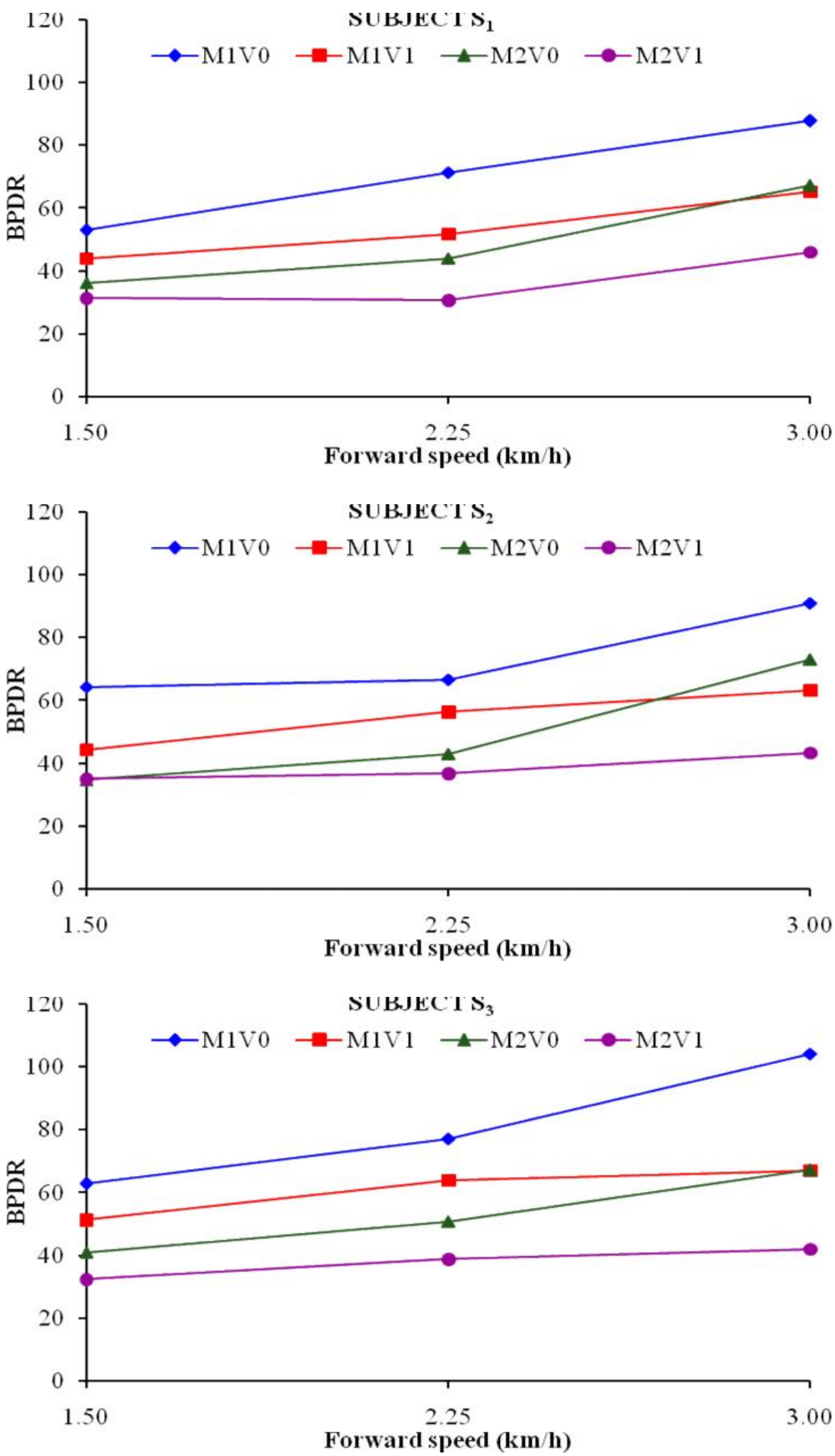

Fig. 4.25. Body part discomfort rating by subjects for various treatments of boom sprayer.

Mean values of BPDR for the walking type (M_1) and the riding type (M_2) boom sprayers were found to be 65.83 and 44.07, respectively and were statistically significant (C.D. = 0.96) at five per cent level of significance. Thus; it may be concluded that there was 33.05% reduction in body part discomfort to the operator with the provision of the operator's seat. The main reason for discomfort to subject was walking behind the sprayer, and turning by application of human-force through shoulder and arm regions in case of walk behind type (M_1) boom sprayer. The walking of subject behind the sprayer was completely eliminated due to provision of seat for riding type boom sprayer (M_2). Also, its turning has to be accomplished by foot-pedals at the footrest and the body weight of the operator could not help in turning of boom sprayer provided with the seat (M_2). Thus; the majority of discomfort was experienced in the thigh, leg, arm and shoulder regions for all the subjects for the walking type boom sprayer (M_1); whereas, the majority of discomfort was in the back, buttocks, thigh and leg regions for the riding type boom sprayer (M_2). The result obtained was in line with the finding of Tewari *et al.* (2004); Tiwari and Narang (2006); Sam and Kathirvel (2008).

The provision of vibration isolators (V_1) for the boom sprayer resulted in BPDR of 46.85 in comparison to 63.06 for the sprayer without isolators (V_0) which was found to be significantly different (C.D. = 0.96) at five per cent level. Thus; vibration isolators reduced the body part discomfort of the operators by 25.71% due to reduction of vibrations transmitted from engine to the operator (see §4.2.6 for details). Balasankari (2002); Tewari *et al.* (2004); Sam and Kathirvel (2008); Tewari and Dewangan (2009) have also observed similar results.

The BPDR increased with increase in forward speed of the sprayer and was found to be statistically different (C.D. = 1.18) at five per cent level of significance. Mean values of BPDR were observed as 44.19, 52.56 and 68.11 at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The observed trend due to increase in forward speed was directly related to increase in discomfort on operator due to increase in workload, especially in case of walk behind boom sprayer, and also due to increase in vibrations associated with speed of engine. Tiwari and Gite (2000); Tiwari and Gite (2002); Tewari *et al.* (2004); Sam and Kathirvel (2008) have also observed similar results.

The BPDR among the subjects was statistically different (C.D. = 1.18) at five per cent level of confidence. BPDR was observed as 52.39 for the subject S_1, 54.31 for the subject S_2 and 58.17 for the subject S_3. The variation in this respect could be attributed to their individual characteristics, especially the age factor (Malhotra *et al.*, 1996).

The interactions among various independent variables were also found to be statistically different at five per cent level of significance. The riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combinations resulted in low score of BPDR (30-46).

4.5. Optimum Values of the Independent Variables

All the independent parameters clearly depicted the vibrations, noise, and physiological responses of the subjects operating the self propelled boom sprayer. Characteristics of vibrations (§4.2) and noise (§4.3) were found to support the results obtained for the heart rate (§4.4.1), oxygen consumption (§4.4.2), overall discomfort rate (§4.4.3) and body part discomfort rate (§4.4.4). The effect of various treatments on all the physiological parameters viz. HR, VO_2, ODR and BPDR were almost similar. The optimum values of the various levels of independent variables arrived at from the results of the ergonomic studies on self propelled boom sprayer has been summarized in Table 4.31.

Table 4.31. Optimum levels of the independent variables.

Dependent variable	Provision of seat with machine	Provision of vibration isolators	Forward speed	Combination of independent variables*
Vibration	M_1	V_1	F_1	$M_1V_1F_1$, $M_1V_1F_2$, $M_1V_1F_3$, $M_2V_1F_1$, $M_2V_1F_2$, $M_2V_1F_3$
Noise	M_2	V_1	F_1	$M_1V_1F_1$, $M_2V_1F_1$
Heart rate	M_2	V_1	F_1	$M_2V_1F_1$, $M_2V_1F_2$, $M_2V_1F_3$
Oxygen consumption	M_2	V_1	F_1	$M_2V_1F_1$, $M_2V_1F_2$, $M_2V_1F_3$
Overall discomfort rating	M_1, M_2	V_1	F_1	$M_1V_1F_1$, $M_1V_1F_2$, $M_1V_1F_3$, $M_2V_1F_1$, $M_2V_1F_2$, $M_2V_1F_3$
Body part discomfort rating	M_2	V_1	F_1	$M_2V_1F_1$, $M_2V_1F_2$, $M_2V_1F_3$

*M_1 - Without operator's seat i.e. walk behind type boom sprayer
M_2 - With operator's seat i.e. riding type boom sprayer
V_1 - Vibration isolators provided
F_1 - Forward speed of 1.50 km/h
F_2 - Forward speed of 2.25 km/h
F_3 - Forward speed of 3.00 km/h

Vibrations at handle for riding type boom sprayer (M_2) were significantly higher (by 8.0-24.0%) than that observed for the walking type (M_1). The difference, in this respect among the two types of machines, could be attributed to their weight and its distribution at wheels. Weight of riding type boom sprayer was 42 kg more than that of walk behind type. In addition, weight of operator was also supported at the seat of the riding type machine. The rear wheel of boom sprayer in case of walk behind type was under its engine, and was shifted to under the operator's seat in case of riding type; thus, resulting in redistribution of weight of machine and operator over a wider area. Noise for the riding type (M_2) was lower than walking type (M_1) boom sprayer by about 1.5 dB(A). Based on the physiological parameters viz. HR and VO_2, it was concluded that there was a reduction in human workload by 9.51-12.73% with the provision of the operator's seat. The riding type (M_2) boom sprayer also reduced discomfort to the operator by 33.05% as compared to the walking type (M_1). This was mainly because the riding type boom sprayer eliminated the walking of operator behind the sprayer in field. However, turning of the riding type sprayer has to be performed with the foot pedal instead of handle; thus, reducing extent of achieved benefit.

With the provision of vibration isolators (V_1), vibration acceleration reduced by 11.66-13.90% at engine top, 59.41-73.98% at chassis, 73.50-86.54% at handle bar, 81.97-88.47% at handle, and 67.20-77.23% at seat base. The vibration isolators reduced the transmission of vibrations originating from the reciprocating diesel engine to the boom sprayer. Noise at operators' ear level was lesser, by 1.68 dB(A), with the provision of vibration isolators due to reduction in fretting sound because of lesser vibrations. As evident from the response of HR and VO_2, provision of vibration isolators reduced the workload of the operators by 51% and provided more comfort due to reduction of vibrations transmitted from engine to the operator. ODR and BPDR of the operators were reduced by 43.0% and 25.71%, respectively with provision of vibration isolators to the boom sprayer.

The vibration acceleration increased significantly with increase in forward speed from 1.50 to 3.00 km/h of the sprayer. The observed trend due to increase in forward speed was directly related to increase in rpm of reciprocating type diesel engine. With increase in forward speed from 1.50 to 3.00 km/h, increase in vibration acceleration was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1). Problem of frequent loosening of nuts and bolts or minor breakdown was observed at forward speeds of 2.25 and 3.00 km/h for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0). For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, vibration response; however, was more or less the same at all locations of measurement.

The noise level increased significantly with increase in forward speed of the sprayer. Noise was observed as 90.38, 95.59 and 98.87 dB(A) at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The corresponding safe daily exposure of the operator as per standards is 8-h at 1.50, 4-h at 2.25, and 2-h at 3.00 km/h of forward speed. With increase in forward speed from 1.50 to 2.25 km/h, increase in noise level was much higher as compared to the same with increase in forward speed from 2.25 to 3.00 km/h.

The physiological parameters viz. HR, VO_2, ODR and BPDR also increased significantly with increase in forward speed of the sprayer. The observed trend due to increase in forward speed was directly related to increase in stress on operator during sprayer operation; which was due to increase in workload, especially in case of walk behind boom sprayer, and also due to increase in vibrations associated with speed of engine. With increase in forward speed from 1.50 to 3.00 km/h, increase in HR, VO_2 and corresponding workload was much higher for both the M_1 as well as M_2 boom sprayers without provision of vibration isolators (V_0) as compared to the same with provision of vibration isolators (V_1). For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher HR, VO_2 and workload with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, HR, VO_2 and workload, however, responded more or less at the same level.

As per the classification of Astrand and Rodahl (1986), the physical work falls in the category of light to moderate work. The moderate work for the boom sprayer without vibration isolators (V_0) was improved to light work category with the provision of vibration isolators (V_1). The riding type (M_2) boom sprayer also provided more comfort to the operator as compared to the walking type (M_1). Thus; a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combination resulted in the lowest workload (light work). The ‘moderately painful’ (ODR = 4) subjective feeling for the boom sprayer without vibration isolators (V_0) was improved to ‘pain starts’ (ODR = 2) feeling with the provision of vibration isolators (V_1). Thus; a boom sprayer (walk behind or riding type) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combinations resulted in the ‘slightly painful’ (ODR = 3) subjective feeling category. The riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combinations resulted in low score of BPDR ranging between 30 and 46.

It may thus be summarized that from ergonomic point, a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed ranging between 1.50 and 3.00 km/h. Selecting a high forward speed of boom sprayer could improve the field capacity; however, daily noise exposure has to be reduced within safe limits as per standards. Alternatively, noise reduction has to be achieved by suitable exhaust silencer or through use of personal means of protection like ear muffs.

4.6. Effect of vibration exposure duration on isolator characteristics

The vibration isolator VI_1 was further tested for its characteristics in response to vibration exposure duration upto 100 h. The isolator was fitted at engine mounting of the sprayer and exposed to vibrations of different durations. Thereafter exposed isolators were tested on UTM for stiffness characteristics. The stiffness of a material represents its ability to resist deformation and is commonly characterized by slope of linear region of a stress-strain curve. Stiffness can be used to estimate both the natural frequency and isolation effectiveness of a lightly damped isolation system. Stiffness can be represented as:

$$K_s = \frac{dL}{dX} \qquad \text{----- (12)}$$

Where,

K_s = Stiffness constant

dL = Change in compression load, kN

dX = Change in deformation, mm

The data for load-deformation characteristics corresponding to vibration exposure duration is given Table 4.32 and presented in Figures 4.26 and 4.27.

Table 4.32. Load-deformation characteristics of VI_1 for different vibration exposure durations.

Load, kN	**Deformation (mm) for different vibration exposure duration**				
	0 h	**25 h**	**50 h**	**75 h**	**100 h**
0.00	0.00	0.00	0.00	0.00	0.00
0.45	1.17	0.60	1.40	1.40	1.58
0.90	2.21	1.65	2.52	2.73	2.85
1.35	3.38	2.63	3.50	3.85	4.05
1.80	4.29	3.60	4.34	4.76	5.10
2.25	5.20	4.50	5.25	5.74	6.00
2.70	6.11	5.48	5.95	6.51	6.90
3.15	6.76	6.08	6.58	7.28	7.65
3.60	7.48	6.83	7.28	7.98	8.40
4.05	8.13	7.50	7.91	8.54	9.00
4.50	8.65	8.03	8.54	9.10	9.60
4.95	9.10	8.55	9.03	9.59	10.20
5.40	9.56	9.00	9.52	10.08	10.58
5.85	9.95	9.45	9.94	10.50	11.10
6.30	10.34	9.90	10.36	10.92	11.48
6.75	10.66	10.28	10.71	11.27	11.85
7.20	10.92	10.65	11.06	11.62	12.23
7.65	11.18	10.95	11.41	11.97	12.53
8.10	11.51	11.25	11.76	12.32	12.90

8.55	11.70	11.55	12.04	12.60	13.20
9.00	11.90	11.78	12.32	12.88	13.43
9.45	12.21	12.08	12.60	13.09	13.65
9.90	12.29	12.30	12.81	13.30	13.88
10.35	12.48	12.53	13.02	13.51	14.10
Stiffness (kN/mm)	0.83	0.83	0.79	0.77	0.73

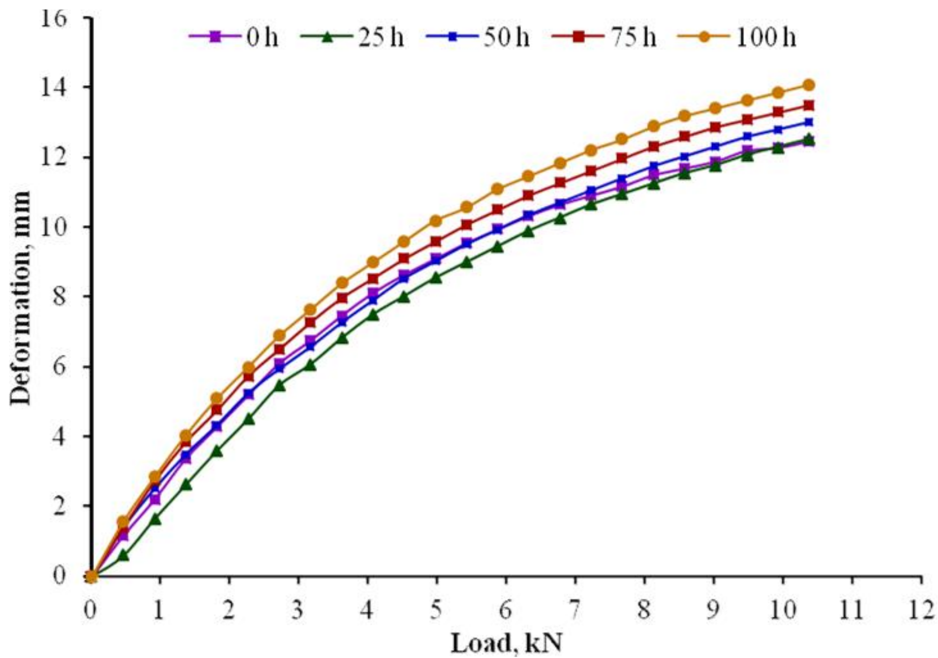

Fig. 4.26. Load-deformation characteristics of VI_1 for different vibration exposure durations.

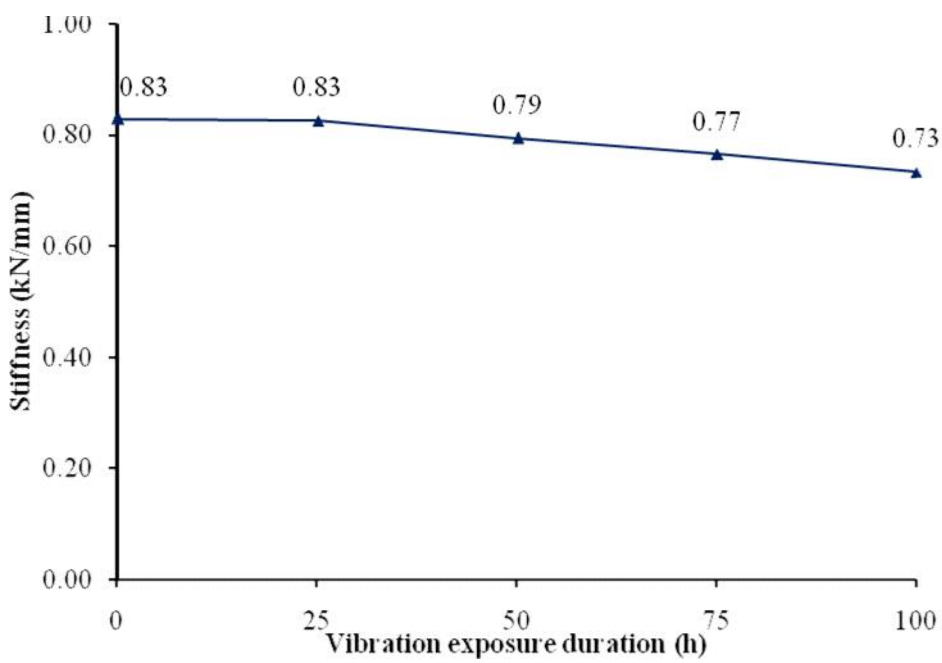

Fig. 4.27. Stiffness characteristics of VI_1 for different vibration exposure durations.

The stiffness of vibration isolator VI_1 decreased with increase in vibration exposure duration (Fig. 4.27). It indicated that vibrations will increase with increase in exposure duration. A stage shall come when vibrations will exceed tolerance limits. It is possible that at that time vibration isolators may still not physically fail or break. However; replacement of vibration isolators may be required, due to fatigue of material, as its vibrations reduction performance may not be as per desired. Thus; further investigation is needed to study effect of vibration exposure duration for its full functional life.

SUMMARY

Self propelled walk behind type boom sprayer with narrow wheels is an important machine for control of weeds. When operated at a forward speed of 2.25-2.50 km/h, its field capacity is 1.0-1.2 ha/h; thus, has a potential scope for its adoption for custom hiring. The ergonomic aspects of boom sprayer are of great importance as the operator has to walk behind the machine for a distance of about 18 to 20 km in a day in field. Besides walking, stress due to mechanical vibrations, workload, noise, etc. also affect performance of the operator. Based upon ergonomic considerations and stability against overturning, an operator's seat was developed to convert the boom sprayer into a riding type. Synthetic rubber based vibration isolators were developed and installed at engine mountings, base of handle bar, chassis-seat interfaces and handle grips of the boom sprayer for reduction in vibrations being transmitted to the operator.

Studies were conducted under simulated field conditions to determine the effect of provision of operator's seat with machine (M), provision of vibration isolators (V), forward speed (F) and subject (S) on vibrations, noise and physiological responses viz. heart rate (HR), volume of oxygen consumed (VO_2), overall discomfort rating (ODR) and body parts discomfort rating (BPDR). Vibrations were measured as rms acceleration in units of 'g' m/s^2 (1 g = 9.81 m/s^2) in three mutually perpendicular directions viz. vertical, longitudinal and lateral at five locations viz. engine top, chassis, handle bar, handle and seat base. Noise was measured as sound pressure level in units of decibels acoustic, dB(A), at the operator's ear level. Heart rate and oxygen consumption were measured by using computerized ambulatory metabolic measurement equipment to assess the whole body fatigue to the operator. ODR and BPDR were measured to assess discomfort to operator by using technique given by Borg (1982), and Corlett and Bishop (1976), respectively. The subjects were calibrated on bicycle ergometer to get subject characteristics curves to find human workload on the subjects. Duration of field experiments for measurements of vibrations and noise was taken as one minute each. For the measurement of physiological parameters, the experiment duration was fixed as 15 minutes. An hour rest time was given to the subjects prior to start of field experiments.

On the basis of results obtained, the following conclusions were drawn:

1. Based upon ergonomic considerations and stability against overturning, an operator's seat was developed to convert the boom sprayer into a riding type

2. Synthetic rubber based vibration isolators were developed and installed at engine mountings, base of handle bar, chassis-seat interfaces and handle grips of the boom sprayer.
3. With the provision of vibration isolators (V_1), vibration acceleration reduced by 11.66-13.90% at engine top, 59.41-73.98% at chassis, 73.50-86.54% at handle bar, 81.97-88.47% at handle, and 67.20-77.23% at seat base.
4. The vibration acceleration increased significantly with increase in forward speed from 1.50 to 3.00 km/h of the sprayer. The observed trend due to increase in forward speed was directly related to increase in rpm of reciprocating type diesel engine.
5. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher vibration acceleration with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, vibration response, however, was more or less the same at all locations of measurement.
6. The provision of vibration isolators (V_1) for the boom sprayer resulted in noise of 94.11 dB(A) in comparison to 95.79 dB(A) for the sprayer without isolators (V_0). Thus; noise at operators' ear level was lesser by 1.68 dB(A) with the provision of vibration isolators due to reduction in fretting sound because of lesser vibrations.
7. Noise was observed as 90.38, 95.59 and 98.87 dB(A) at forward speed of 1.50, 2.25 and 3.00 km/h, respectively. The safe limit of daily exposure of the operator as per standards is 8-h at 1.50, 4-h at 2.25, and 2-h at 3.00 km/h of forward speed.
8. Based on the physiological parameters viz. HR and VO_2, it was concluded that there was a reduction in human workload by 9.51-12.73% with the provision of the operator's seat. The riding type (M_2) boom sprayer also reduced discomfort to the operator by 33.05% as compared to the walking type (M_1). This was mainly because the riding type boom sprayer eliminated the walking of operator behind the sprayer in field. However, turning of the riding type sprayer has to be performed with the foot pedal instead of handle; thus, reducing extent of achieved benefit.
9. The provision of vibration isolators (V_1) for the boom sprayer resulted in HR of 88.97 beats/min in comparison to 99.37 beats/min for the sprayer without isolators (V_0). Also, provision of vibration isolators (V_1) for the boom sprayer resulted in VO_2 of 514.6 ml/min in comparison to 778.9 ml/min for the sprayer without isolators (V_0). Thus; vibration isolators reduced the workload of the operators by 51% and provided more comfort due to reduction of vibrations transmitted from engine to the operator.

10. ODR and BPDR of the operators were reduced by 43.0% and 25.71%, respectively with provision of vibration isolators to the boom sprayer.
11. Workload corresponding to HR varied from 13.2 to 52.3 with a mean of 24.7 watts for the subject S_1, from 14.1 to 55.6 with a mean of 26.1 watts for the subject S_2, and from 11.3 to 49.9 with a mean of 26.5 watts for the subject S_3.
12. Workload corresponding to VO_2 varied from 13.0 to 49.1 with a mean of 23.3 watts for the subject S_1, from 12.4 to 52.4 with a mean of 25.7 watts for the subject S_2, and from 12.7 to 49.7 with a mean of 26.2 watts for the subject S_3.
13. For both the walk behind type (M_1) as well as riding type (M_2) boom sprayers, when provided with vibration isolators (V_1), responded marginally higher HR, VO_2 and workload with increase in forward speed from 1.50 to 2.25 km/h. With further increase in forward speed from 2.25 to 3.00 km/h, HR, VO_2 and workload, however, responded more or less at the same level.
14. As per the classification of Astrand and Rodahl (1986), the physical work falls in the category of light to moderate work. The moderate work for the boom sprayer without vibration isolators (V_0) was improved to light work category with the provision of vibration isolators (V_1). The riding type (M_2) boom sprayer also provided more comfort to the operator as compared to the walking type (M_1). Thus; a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combination resulted in the lowest workload (light work).
15. The ‘moderately painful’ (ODR = 4) subjective feeling for the boom sprayer without vibration isolators (V_0) was improved to ‘pain starts’ (ODR = 2) feeling with the provision of vibration isolators (V_1).
16. The riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed varying between 1.50 to 3.00 km/h as the combinations resulted in low score of BPDR ranging between 30 and 46.
17. Ergonomically it was concluded that a riding type boom sprayer (M_2) provided with vibration isolators (V_1) could be used at any of the forward speed ranging between 1.50 and 3.00 km/h. However, daily noise exposure has to be reduced within safe limits as per standards.

SUGGESTIONS FOR FUTURE WORK

1. The experiments should be carried out for more number of subjects of different anthropometric dimensions and age to optimize the values of various operational parameters of the self propelled boom sprayer.
2. The experiments need to be conducted to study effect of duration of vibrations exposure on vibration characteristics of synthetic rubber based vibration isolators.
3. There is need to reduce level of noise of engine with suitable exhaust silencer or muffler so as to reduce it within safe limits as prescribed by the standards.

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APPENDIX - A

SPECIFICATIONS OF INSTRUMENTS USED IN THE STUDY

1. COMPUTERIZED AMBULATORY METABOLIC MEASUREMENT EQUIPMENT

Make	Cosmed, Italy
Model	K4B2
Portable Unit	
Memory	16,000 breaths
Display	LCD 2 lines x 16 characters
Keyboard	Waterproof, 6 keys
Power supply	Ni-MH rechargeable batteries 3 hours endurance
Thermometer	0-50°C
Barometer	53-106 kPa
Dimensions PU	170x55x100 mm
Dimensions battery	120x20x80 mm
Weight	400g
Receiver Unit	
Transmission range	800 meters
Battery	4 x 1.5V AA
Dimension	170 x 48 x 90 mm
Weight	550 g
PC interface	RS 232
Battery charger Unit	
Power supply	120V - 240V
Power consumption	25W
Flow meter	
Type	Bidirectional digital turbine of diameter 28 mm
Flow Range	0.03-20 l/s
Accuracy	± 2%
Resistance	<0.7 cm H_2O s/l @ 12 l/s
Ventilation Range	0-300 litres x min
Oxygen Sensor (O_2)	
Response time	<150 ms
Range	7-24% O_2
Accuracy	±0.02% O_2
Carbon Dioxide Sensor (CO_2)	
Response time	<150 ms
Range	0-8%
Accuracy	±0.01%
Power Supply	
Voltage	100V-240V ±10%; 50/60Hz
Power consumption	60W
Environmental Sensors	
Temperature	0-50°C
Barometer	400-800 mm Hg
Humidity	0-100%

2. PORTABLE VIBRATION METER

Make	Monitran, UK
Model	VM110
Measurement ranges	
Acceleration	2-200 g m/s^2
Velocity	20-2000 mm/s
Displacement	20-2000 µm
Frequency range	
Upper frequency	Selectable low pass filter of 5kHz, 10kHz, 20kHz
Lower frequency	Acceleration 5Hz, velocity 10Hz, displacement 15Hz
Detector	
Switch selectable	RMS, Peak
Accuracy	
Acceleration	1.5% RMS – 3% Peak
Velocity	2.5% RMS – 4% Peak
Displacement	3.5% RMS – 5% Peak
Accelerometer	
Standard sensitivity	100 mV/g ± 10% nominal at 80 Hz
Frequency response	2 Hz to 10 Hz ± 5% (-3 dB at 0.8 Hz)
Mounted base resonance	18 kHz (nominal)
Isolation	Base isolation
Dynamic range	± 80g
Transverse sensitivity	Less than 5%
Electrical noise	0.1 mg maximum
Current range	0.5 mA to 8 mA
Temperature range	-55 to 140ºC
Bias voltage	12 V DC (nominal)
Case material	Stainless steel
Cable	Integral stainless steel over braided PTFE
Cable length	5 meters
Mounting torque	8 Nm
Weight	110 g (nominal)
Inputs (from accelerometer)	
Input voltage	10mV/g
Output	
DC	200mV at FSD as displayed on the meter
Power	
Battery	2 x PP3 type batteries
Battery life	Approximately 15 hours

3. PORTABLE SOUND LEVEL METER

Make	CESVA Instruments, Spain
Model	SC-20c
Measurement ranges	
Operating range of indicator	0-137 dB
Primary range	50-137 dB
Frequency weightings	A or C

Integrator	
Linearity range	110 dB
Pulse range	65 dB
Response time for steady input signal	2 s
Fixed integration times	1 minute and 1 second
DC output	
Sensitivity	10 mV/dB
Upper limit	1.4 V (140 dB)
Maximum error	± 4 mV (± 0.4 dB with regard to the display value)
Microphone	
Type	½" condenser microphone model no. CESVA C-130
Polarization	200 V
Nominal capacitance	22.5 pF
Nominal sensitivity	17.5 mV/Pa ± 0.5 dB under reference conditions
Effect of windscreen	< 1 dB for frequencies < 10 kHz < 3 dB for frequencies <12.5 kHz
Reference conditions	
Type of sound field	Free field
Reference direction	Perpendicular to the microphone's diaphragm
Reference sound pressure	94 dB
Reference frequency	1 kHz
Reference temperature	20ºC
Relative humidity	65%
Atmospheric pressure	1013 mbar
Warm up time	
Warm up time	30seconds
Influence of temperature	
Operating range	-10 to +50ºC
Maximum error	0.5 dB (-10 to +50ºC)
Influence of humidity	
Operating range	30 to 90%
Maximum error	0.5 dB (30%<RH<90%, 40ºC and 1 kHz)
Power	
Battery	One 9V battery type 6LF22
Battery life	Approximately 15 hours (Lithium)
Size and weight	
Dimensions	301x82x19 mm
Weight	545 g (without battery), 600 g (with battery)

4. BICYCLE ERGOMETER

Make	Ergoline GmBh, Germany
Model	Ergoselect 100
Type	Modular ergometer system
Operation mode	Continuous operation
Power supply	100-240 V, 50-60 Hz
Power rating	Maximum 60 VA
Braking principle	Computer controlled eddy current brakes with torque regulation
Load range	Up to 999 watts, pedal speed independent
Rpm range	30-130

Load increments	5 W manual, 1 W or multiple via program
Maximum deviation of load	±3 W in range of 20-100 W, ±3% in range 100-999 W
Maximum allowed subject's weight	150 kg
Adjustments for anthropometry	Seat, handlebar
Output data	LCD display, PC
Interfaces	Set/ actual load, HR, BP, speed
Weight	64 kgs
Dimensions (W x L)	460 x 900 mm
Height	900-1350 mm
Width of handlebar	575 mm
Calibration	Via software on keyboard/ PC with 8 kg calibration weight

5. UNIVERSAL TESTING MACHINE

Make	Tinius Olsen, USA
Model	No. 602 remote display and controller
Power supply	415 V, 50 Hz, 3 phase
Capacity	1000 kN / 100000 kgf
Stroke	229 mm
Testing speed	0-76 mm/min
Adjustable crosshead speed	305 mm/min
Loadframe dimensions	864 x 660 x 2289 mm
Machine weight	4490 kg
Display	PC and printer

6. CONE PENETROMETER

Make	ICT International Pty Ltd, Australia
Model	CP40II
Maximum small cone index	5600 kPa, 75 kg
Maximum large cone index	2200 kPa, 75 kg
Resolution	0.03 kg
Maximum insertion depth	750 mm
Interval spacing	10, 15, 20, 25 mm
Memory capacity	2047 insertions
Operating temperature	-10 to 60ºC
Operating humidity	60% RH
Baud rate/ download speed	9600 bps
Screen resolution	160 x 128 pixels
Conforms to standards	ASAE S313.3 feb99
Battery life	3000 mAh
Small cone size	Diameter 12.83 mm, area 130 mm^2
Large cone size	Diameter 20.27 mm, area 323 mm^2
Shaft diameter	9.53 mm
Weight	3.9 kg
Dimensions	560 x 1073 x 130 mm

APPENDIX - B

SPECIFICATIONS OF SELF PROPELLED BOOM SPRAYER

Type of machine	Self propelled
Power source	5.4 kW diesel engine
Engine rated rpm	3000
Engine make	M/s Greaves Cotton Ltd., Aurangabad, Maharashtra, India
Engine model	Greaves engine model no. 1080
Engine weight	75 kg
Machine suitability	Spraying in wheat, paddy and vegetable crops
Ground clearance	50 cm
Boom height, cm	60-130 (adjustable)
No. of nozzles on the boom	11
Spacing between nozzles	50 cm (adjustable)
Swath width	670 cm
Tread width	90-105 cm (adjustable)
Tank capacity	100 litres
Spray pump pressure	2.5 kg/cm^2
Spray discharge	270 l/ha
Tank refilling time	25-35 min/ha
Forward speed	2.25-2.50 km/h
Field capacity	1.0-1.2 ha/h
Front tyres	5.00-8, 2 in nos., 1.4 kg/cm^2
Rear tyre	3.50-8, 1 in no., 2.1 kg/cm^2
Walk behind type sprayer	
Weight of machine	192.5 kg (spray tank empty)
Distance between front and rear wheels	102.5 cm
Distance between rear wheel and spray boom	150 cm
Distance of CG from front wheels	0.567 m (spray tank empty), 0.346 (spray tank full)
Riding type sprayer	
Weight of machine	235 kg (spray tank empty)
Distance between front and rear wheels	179 cm
Distance between rear wheel and spray boom	73.5 cm
Distance of CG from front wheels (without operator)	0.701 m (spray tank empty), 0.411 (spray tank full)
Distance of CG from front wheels (with operator of 60 kg body weight sitting on operator's seat)	1.158 m (spray tank empty), 0.732 (spray tank full)

VITA

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OGPA	:	3.69/4.00 (81.2%)

Master's degree

University and year of award	:	Punjab Agricultural University, Ludhiana, 1995
OGPA	:	3.92/4.00 (83.0%)

Ph.D.

OCPA	:	8.36/10.00 (83.6%)
Title of Master's Thesis	:	Ergonomic Studies on Semi-Automatic Rota-Drum Sugarcane Planter.

Awards/Distinctions/ Publications

Research papers presented in conferences	:	10
Research papers published	:	9
Book chapters	:	6
Extension articles	:	39
Recommendations	:	4