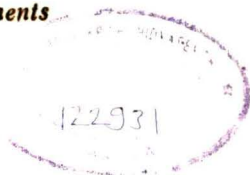


ERGONOMICAL STUDIES ON MANUAL KNAPSACK SPRAYER

THESIS

*Submitted to the
Punjabrao Krishi Vidyapeeth, Akola
in partial fulfilment of the requirements
for the degree of*

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H01



**MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING
(FARM POWER AND MACHINERY)**

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled "ERGONOMICAL STUDIES ON MANUAL KNAPSACK SPRAYER" or part thereof has not been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any University or Scientific Organisation. The sources of materials used and all assistance received during the course of investigation have been duly acknowledged.

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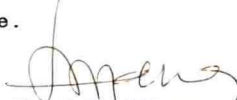



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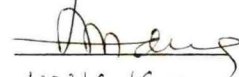
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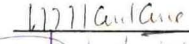

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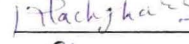

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Akola

Date:


(M.J. HANDE)

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
I.	INTRODUCTION	1
1.1	General	1
1.2	Spraying Equipment	2
1.3	Types of Sprayers	2
1.4	Lever Operated Knapsack Sprayer	3
1.5	Ergonomics	5
1.6	Benefits of Ergonomic Research	6
1.7	Ergonomic Evaluation of LOK Sprayers	7
1.8	Need for Ergonomics Design Improvement in LOK Sprayers	8
1.9	Objectives	8
II.	REVIEW OF LITERATURE	11
2.1	LOK Sprayer	11
2.2	Performance Evaluation of LOK Sprayer	12
2.3	Ergonomics Evaluation of LOK Sprayer	13
2.4	Tank Capacities and Weights of Sprayer	16
2.5	Location and Type of Pump	16
2.6	Pump Parameters	17
2.6.1	Pump size	17
2.6.2	Stroke length	18
2.6.3	Number of strokes per minute	18
2.7	Range of Handle Movement	19
2.8	Strap Attachments	19

2.9	Maximum Force Exertable by Arm Movement	20
2.10	Anthropometric Data for LOK Sprayers Design	22
2.11	Parameters for Ergonomics Evaluation	22
2.11.1	Heart rate	22
2.11.2	Oxygen consumption	24
2.11.3	Postural discomfort	25
2.12	Acceptable Work Load	26
III.	THEORETICAL CONSIDERATIONS	28
3.1	Spraying Operation	28
3.2	Mechanics of LOK sprayers	29
3.3	Use of Anthropometry in Design	34
3.4	Human Dody	35
3.5	Parameters for Estimation of Work Load	36
3.5.1	Oxygen uptake	36
3.5.2	Heart rate	37
3.5.3	Postural discomfort	37
3.6	Muscular Effort in Handle Operation	38
IV	MATERIALS AND METHODS	40
4.1	Place of Study	40
4.2	Spray Studies	40
4.3	Preliminary Trials	41
4.3.1	Procedure for determination of number of strokes ₂ required to build and maintain 3 kg/cm ² pressures	41
4.3.2	Procedure for discharge Vs pressure relationship	43

4.3.3	Procedure for finding volumetric efficiency	43
4.4	Optimization of Frequency of Handle Operation and Range of Handle Movement (Experiment-1)	44
4.4.1	Experimental set-up	44
4.4.2	Experimental details	45
4.4.3	Subjects	46
4.4.4	Measurements	46
4.4.5	Procedure	47
4.5	Optimization of Number of Strokes Per Minute	49
4.5.1	Short duration trials (Experiment-2)	49
4.5.1.1	Experimental set-up	49
4.5.1.2	Experiment details	49
4.5.1.3	Procedure	50
4.5.2	Long duration trials (Experiment-3)	51
4.5.2.1	Experimental set-up	51
4.5.2.2	Experiment details	51
4.6	Measurement of Maximum Strength in Elbow Flexion and Extension (Experiment-4)	52
4.6.1	Experimental set-up	52
4.6.2	Instrumentation	53
4.6.3	Procedure	53
4.7	Computer Programming	54
4.8	Fabrication of Modified Prototypes	56
4.9	Ergonomical Evaluation of Sprayer Units	57
4.9.1	Preliminary trials	57

4.9.2	Measurement of effort	58
4.9.2.1	Effort measurement by mounting the sprayer on a test bench	58
4.9.2.2	Effort measurement by mounting sprayer on operators back	60
4.9.3	Measurement of physiological cost of sprayer operation	61
4.9.3.1	Procedure	61
4.9.4	Test for assessment of postural discomfort during continuous operation of LOK sprayer for 2-hours	64
4.9.4.1	Procedure	64
4.9.4.2	Procedure for recording overall discomfort rating	65
4.9.4.3	Procedure for recording body part discomfort score	66
4.9.4.4	Walking trials	67
4.9.5	Ergonomic score	67
4.9.5.1	Criteria for evaluation	67
4.9.5.2	Procedure for calculation of score	68
V.	RESULTS AND DISCUSSION	70
5.1	Preliminary Trials	70
5.1.1	Pressure Vs number of stroke relationship	70
5.1.2	Discharge Vs pressure relationship	70
5.2	Optimization of Frequency of Handle Operation and Range of Handle Movement	72
5.3	Optimization of Frequency of Handle Operation for Constant Work Load	83
5.3.1	Short duration (10-minute) trials	83
5.3.2	Long duration (30-minute) trials	88

5.4	Maximum Strength in Elbow Extension and Flexion	90
5.5	Sprayers Pump Design with Computer Programming	94
5.6	Ergonomical Evaluation	94
5.7	Sprayer Comparison	110
VI.	SUMMARY AND CONCLUSIONS	113
VII.	SUGGESTIONS FOR FUTURE WORK	118
	BIBLIOGRAPHY	119
	APPENDIX-I	127
	APPENDIX-II	130
	APPENDIX-III	141
	APPENDIX-IV	199

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
4.1	LOK sprayers selected for study	41
4.2	Parameters selected for generation of data through computer programme	55
4.3	Possible combinations for the fabrication of modified prototype	56
4.4	Pump parameters selected for the fabrication of two modified prototypes	57
5.1	Number of strokes required to build different pressures in three types of LOK sprayers	71
5.2	Number of strokes required to maintain different pressures in three types of LOK sprayers	71
5.3	Discharge (cc/min) at different pressure in three types of LOK sprayers	72
5.4	Effect of four frequencies of handle operation in four ranges of handle movement on heart rate (RCB design)	74
5.5	Effect of four frequencies of handle operation in four ranges of handle movement on heart rate difference (RCB design)	76
5.6	Effect of four frequencies of handle operation in four ranges of handle movement on job severity rating (RCB design)	77
5.7	Statistical analysis of heart rate data given in Table 5.4	79
5.8	Statistical analysis of heart rate difference (Δ HR) given in Table 5.5	80
5.9	Statistical analysis of job severity rating given in Table 5.6	82

5.10	Effect of frequencies of handle operation (for constant work load) on heart rate of the subjects (Expt. 2)	84
5.11	Statistical analysis of data in Table 5.10	84
5.12	Effect of frequencies of handle operation on heart rate difference (Δ HR)	86
5.13	Statistical analysis of data from Table 5.12	86
5.14	Effect of frequencies of handle operation on job severity rating (Expt. 2)	87
5.15	Statistical analysis of data from Table 5.14	87
5.16	Data of job severity rating of five subjects for 30-minute duration trials	89
5.17	Statistical analysis of data from Table 5.16	89
5.18	Data of job severity rating for 10-minute and 30-minute duration trials	90
5.19	Data of maximum muscular strength in kgf for five subjects in extension and flexion (Expt. 4)	91
5.20	Statistical analysis of data from Table 5.19 for elbow extension	92
5.21	Statistical analysis of data from Table 5.19 for elbow flexion	93
5.22	Preliminary trials of modified sprayer, 12-litre capacity	97
5.23	Muscular effort required in handle operation of modified (12. l capacity) sprayer	98
5.24	Measurement of physiological cost of modified sprayer operation	99

5.25	Data on assessment of postural discomfort during spraying operation of modified sprayer	100
5.26	Ergonomics score of modified (12, 1 capacity) sprayer	101
5.27	Preliminary trials of Aspee Napsak (SRP-50), 16 l capacity sprayer	105
5.28	Muscular effort required in handle operation of Aspee Napsak sprayer	106
5.29	Physiological cost of operation of Aspee Napsak (SRP-50, 16 l capacity) sprayer	107
5.30	Data on assessment of postural discomfort during spraying operating of Aspee Napsak (SRP-50, 16 l capacity) sprayer	108
5.31	Ergonomics score of Aspee Napsak (SRP-50 16, 1 capacity) sprayer	109
5.32	Comparison of modified sprayer with the commonly used sprayer (Aspee Napsak)	111
5.33	Body part discomfort scores for the operation of existing and modified LOK sprayers according to Corlett and Bishop (1976) technique	112

LIST OF FIGURES

FIGURE NO.	TITLE	AFTER PAGE
1.1	Some typical LOK sprayers	4
2.1	Nomenclature of arm and hand movement	20
3.1	Mechanics of LOK sprayer	30
3.2	Metabolic processes which take place during muscular work	35
3.3	Conversion of nutrients into heat and mechanical energy in the human body	36
4.1 (a)	Mechanical setup for simulation of effort application in LOK sprayer	44
4.1 (b)	Plan and side view of the mechanical setup for simulation of effort application in LOK sprayer	44
4.2 (a)	Calibration of setup using dead weight	47
4.2 (b)	Calibration of setup using load cell and polyrite recorder unit	47
4.3	Experiment-1 for determination of optimum frequency and range of handle movement-Measurement of heart rate	48
4.4	Experiment-1, for determination of optimum frequency and range of handle movement-Assessment of job severity rating	48
4.5	Mechanical setup for simulation of effort application for constant work load in LOK sprayer	49
4.6	Calibration of setup using load cell and polyrite recorder unit (Expt.2)	50
4.7	Experiment-2 for optimization of frequency of handle operation-Measurement of heart rate	51

4.8	Experiment-2, for optimization of frequency of handle operation-Assessment of job severity rating	51
4.9 (a)	Plan and side view of the muscular strength application setup	53
4.9 (b)	Setup along with polyrite recorder unit for measurement of muscular strength	53
4.10	Calibration of load cell using dead load	53
4.11	Subject applying maximum muscular strength on the handle	54
4.12	Pump unit of modified sprayer (24 strokes/min)	57
4.13	Pump unit of modified sprayer (18 strokes/min)	57
4.14	Preliminary trials of modified sprayers Unit	58
4.14 (a)	Modified sprayer mounted on test rig	58
4.14 (b)	Measurement of number of strokes/min required to maintain 3 (± 10 per cent) kg/cm^2 pressure	58
4.14 (c)	Measurement of discharge at 3 (± 10 per cent) kg/cm^2 nozzle pressure for one minute	58
4.15	Physiological cost of operation of sprayers	63
4.16	Postural discomfort trials of sprayers	65
4.17	Recording of severity rating after each fill	66
4.18	Body regions for assessing postural discomfort (using Corlett and Bishop [1976] scale) in the operation of a lever operated knapsack sprayer	66

4.19	Assessment of intensity level of pain in different body part regions	66
4.20	Walking trial for assessment of postural discomfort and body part discomfort scores for 2-hour	67
5.1	Effect of frequencies of handle operation on range of handle movements for heart rate and job severity rating	73
5.2	Effect of frequency of handle operation (for constant work load) on heart rate, Δ HR and job severity rating for 10-minute trial	88
5.3	Maximum muscular strength in elbow extension and flexion at seven positions of elbow angles	93
5.4	Theoretical relationship between swept volume and number of strokes per min required to maintain 3 kg/cm ² pressure	94

ABBREVIATION USED

Abbreviations	Description
A.R.I.	Aspee Research Institute
A.W.A.	Acceptable work load
B.P.	Body parts
B.P.D.S.	Body part discomfort score
B.I.S	Bureau of Indian Standard
cc/min	Cubic centimetre per minute
°C	Degree centigrade
cm	Centimetre
C.I.A.E.	Central Institute of Agricultural Engineering
E.C.G.	Electro-Cardio Graphy
F.P.M.	Farm Power and Machinery
F	Frequency
h	hour
HR	Heart rate
ΔHR	Incremental heart rate over rest
ISAE	Indian Society of Agricultural Engineer's
kcal	Kilocalories
kg	Kilogramme
kgf	Kilogramme force
kgf/cm ²	Kilogramme force per centimeter square
kJ	Kilojoule
km/h	kilometer per hour

l	Litre
l/min	Litre per minute
LOK	Lever Operated Knapsack
max	Maximum
min	Minute
mm	Millimetre
μm	Micrometre
NASA	National Aeronautics and Space Administration
No. or no	Number
O ₂	Oxygen
ODR	Overall discomfort rating
P.K.V.	Punjabrao Krishi Vidyapeeth
RNAM	Regional Network for Agricultural Machinery
s	Second
S.D.	Standard Deviation
\dot{V}_E	Total air uptake
\dot{V}_{O_2}	Oxygen uptake min^{-1}

CHAPTER I

INTRODUCTION

1.1 General

Spraying is one of the important operations in crop production. Insects and pests are predominant factors responsible for reduction in the crop yield. The need for chemical application arises from man's desire to protect his crop from attacks of various pests and diseases. The increased use of fertilizers and irrigation facilities resulted in higher incidence of pest, weeds and diseases making these high yielding varieties less remunerative. This necessitated plant protection measures in large scale.

It is estimated that in Indian agriculture, the annual loss due to weeds, insects and diseases amounts to be about Rs.500 crores (Pradhan, 1983). Prior to 1860's man had a little knowledge regarding chemicals for control of plant pests. In 1860, parisgreen diluted with lime was applied by means of a box with wire screen bottom on a loosely woven cloth bag for the control of Colorado potato beetle (Bindra and Singh, 1971). The first large scale use of sprayer for fungicide application to vineyards was reported in France during late 1880's (Fisher and Deutsch, 1985; Matthews, 1982). The National Council of Applied Economic Research (1967) carried out benefit-cost analysis of pesticide

treatment. Chattopadhyay (1980) reviewed various studies and stated that the benefit-cost ratio's of pesticide treatment were 3 to 7.2 for food crops, 2.8 to 4.7 for vegetables, 2 to 13.5 for cotton, 3.4 to 14.0 for sugarcane and 1.4 to 44 for oilseeds. In general, savings due to plant protection measures have been estimated to vary from 5 to 15 per cent of production.

1.2 Spraying Equipment

For proper pest management, it is necessary to use an efficient equipment for securing uniform deposit of a pesticide on the target substrate without any wastage of the material in the least time and with the minimum labour. In our country, at present, there are over 60 firms manufacturing about 2.5 lakh sprayers of different types annually and the total sprayer population is estimated at about 15 lakhs (ISAE, 1984; Patel, 1989; Pandya, 1990).

1.3 Types of Sprayers

The main function of a sprayer is to atomize the spray fluid which may be a solution, an emulsion or a suspension into small droplets (500 μm) and eject the same with some force for distributing it properly. There are many types of sprayers. However, they can be grouped in the

following four categories on the basis of energy employed to atomize and apply the spray fluid:

- i) Hydraulic energy sprayers
- ii) Gaseous energy sprayers
- iii) Centrifugal energy sprayers
- iv) Kinetic energy sprayers

Among these types, the hydraulic energy sprayers are the most widely used because considerable flexibility can be achieved by interchanging the tips in a standard nozzle body to provide a wide range of outputs and spray patterns at low cost (Matthews, 1982). These sprayers may be manually operated or power operated.

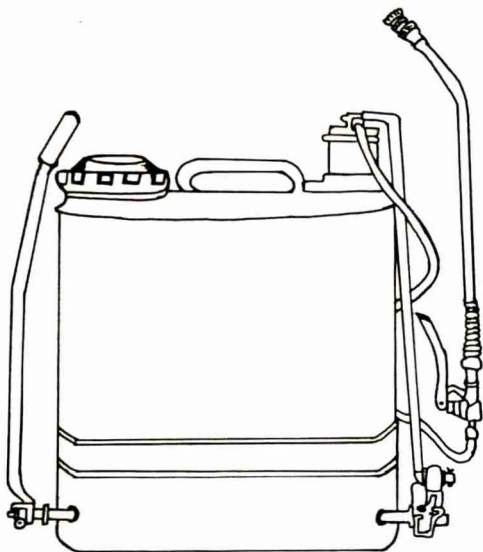
1.4 Lever Operated Knapsack Sprayer

Even though there is remarkably a wide range of spraying machinery to protect crops, the fact remains that the lever operated knapsack (LOK) sprayer is the most commonly used sprayer by Indian farmers for application of pesticides and other agricultural chemicals. Of all different types of sprayers in the country, 90 per cent are of this type. A hydraulic energy sprayer - LOK - type is a versatile equipment and with appropriate fittings, it can apply herbicides, insecticides, fungicides as well as other compounds. It is useful for applying small or large amounts

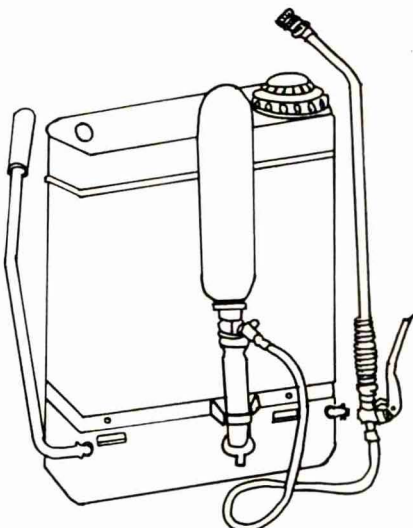
of chemicals to areas, strips, spots, or individual targets. Persons with a wide range of physique can use these sprayers. A LOK sprayer costs about Rs.700 (1992 price) and if regularly maintained it can be used for 5 to 7 years. The Bureau of Indian Standards have formulated a Standard (IS:3906 {Part-I}-1982) and laid down specifications for hand operated knapsack sprayer-piston type.

According to location of lever, LOK sprayers may be over arm lever or underarm lever type. Depending upon the type of pump, these may be piston pump or diaphragm pump type. According to the location of pump those may be internal pump type or external pump type.

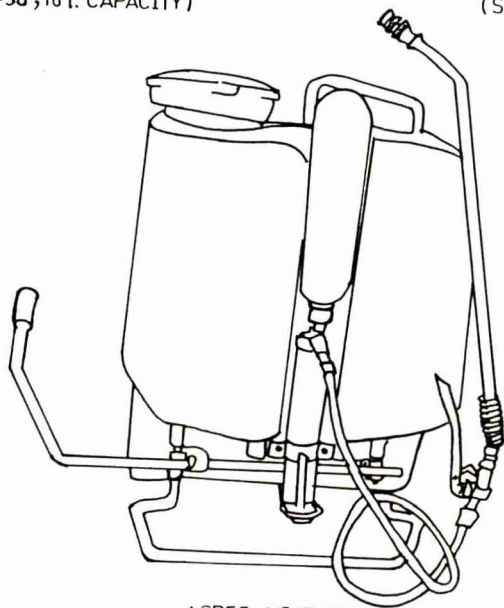
A lever operated knapsack sprayer consists of a tank which will stand erect on the ground and when in use fit comfortably on operators' back like a knapsack, a hand operated pump, a pressure chamber and a lance with on-off tap or trigger valve and one or more nozzles. Some typical LOK sprayers are shown in Fig.1.1. After the spray liquid is filled in the tank, the sprayer is lifted and secured to operators' back with carrying straps. The operator holds the pump actuating lever in one hand and the lance in other hand. He moves the lever in a vertical pumping motion and this movement runs the pump which propels liquid past a one way valve into a pressure chamber. Air is trapped in upper part



ASPEE NAPSAK
(SRP-50, 16 l. CAPACITY)



ASPEE HI-FLO
(SRP-55, 12 l. CAPACITY)



ASPEE HI-TECH
(SRP-60, 16 l. CAPACITY)

FIG. 1.1: SOME TYPICAL LOK SPRAYER.

of the pressure chamber and compressed as liquid is forced into the chamber. A hose connects pressure chamber and lance. When operator opens the control valve, the compressed air force the liquid from the pressure chamber to the lance and it comes out through the nozzle into atmosphere as a spray (Bindra and Singh, 1971).

1.5 Ergonomics

Ergonomics is the scientific study of the relationship between man and his working environment. The term environment covers not only the ambient environment in which he may work but also his tools and materials, his method of work and the organization of his work. In man-machine system the man plays very important role. Therefore it is necessary to study the sprayer from ergonomics point of view. Ergonomics aims to help the workers to work at levels economically acceptable to the employer while enjoying, at the same time, a high standard of physiological and emotional well-being. Ergonomics can be referred to as the external triangle between efficiency, comfort and health.

During the period of World War II a rapid development in the military field took place. Equipment became very complex and operating speed too high. Due to these the men were subjected to such stress that they either

failed to get best out of the equipment or suffered complex operational breakdown. It thus became essential to study more about limitations and capacities of men and extensive programmes of research were undertaken. This interdisciplinary field of research was named as 'Ergonomics' (Ergos-work, nomos-natural laws). Earlier, ergonomics was limited to industrial field only but now it has spread to all fields including agriculture. In our country, there has been some work in ergonomics related to industries but in agriculture it is still a new concept.

1.6 Benefits of Ergonomics Research

Earlier ergonomics served mainly to increase efficiency and thereby productivity. However, now the following objectives more closely define the benefits to be gained by ergonomics research (Grandjean, 1982).

- i) Fitting the demands of work to the efficiency of man in order to reduce stress.
- ii) Designing machines equipment and installations so that they can be operated with great efficiency, accuracy and safety.
- iii) Working out proportions and conditions of the work place to ensure correct body posture.

- iv) Adapting to environment, lighting, air conditioning, noise etc. to suit the man's physical requirements.

In brief, the ergonomics helps to heighten the quality of life in work conditions and thus promotes health and wellbeing of workers.

1.7 Ergonomic Evaluation of LOK Sprayer

The lever operated knapsack sprayer is a manually operated equipment. Therefore its work performance depends not only on the equipment but also on the worker operating it. If ergonomic aspects are not given due attention the man-equipment system performance will be poor resulting in lower work output over a longer period. Gite and Yadav (1982) have given data for some manually operated equipment and mentioned that the man equipment system performance was about one half that of the equipment performance. This was because workers had to take rest for a long time, sometime equal to that of working time during the day. Another aspect is that of worker's health. Due to adoption of improper postures and excessive movements or heavy demand on workers biological system, the equipment operation may cause clinical/anatomical disorders and in long run will affect the worker's health (Astrand and Rodhal, 1977).

1.8 Need for Ergonomic Design Improvement in LOK Sprayers

While operating the LOK sprayer, the body is in awkward posture. In that posture head and neck of the operator fall forward to counter-balance the weight of the sprayer. Also the straps of the sprayer cut deep into shoulder muscles and severe discomfort is felt in the clavicle and shoulder regions. Also the excessive up and down movement of operating lever and improper positioning of the pivot point in relation to shoulder and elbow point of operator cause undue fatigue in upper limb muscles. Many times the force requirement in lever movement is also quite high. To get better efficiency of man-equipment system, it is necessary that the sprayer matches to the capabilities and limitations of the operator. Hence the study was carried out with the following specific objectives.

Objectives

1. To study the basic principles of the lever operated knapsack sprayer commonly used by farmers.
2. To determine optimum number of strokes and comfortable range of handle movement based on ergonomical consideration.
3. Establishment of optimum design of lever operated knapsack sprayer with the help of computer programming.

4. Fabrication and testing of the modified sprayer and its comparison with the commonly used unit.

This study was undertaken on optimization of frequency of handle operation and ranges of handle movement for human comfort. The experiment one with four ranges of frequency of handle operation and four ranges of handle movement were studied. For this 16 combination each trials were of 6 minute duration and a rest of 6 minutes was given between two trials. The data recorded for each trials were heart rate at rest, heart^{rate} at work and job severity rating. The experiment 2 and 3 were conducted for optimization of frequency of handle operation by keeping workdone constant and range of handle movement constant to 30° upward and 30° downward with horizontal. The experiment (No-2) was of short duration (i.e. 10-minute) for six ranges of frequencies i.e. 6, 12, 18, 24, 30 and 36 strokes/min. Based on the result of experiment (No.2) the experiment (No.3) was conducted for 30-minute duration trial (i.e. mostly time required to complete the fill of sprayer). For this experiment only job severity rating data was collected. All these experiment was carried out for five subject.

The experiment (No.4) was carried out to study the maximum muscular strength exerted by subject by right hand at seven different elbow angles for elbow extension and flexion

i.e. 60, 70, 80, 90, 100, 110 and 120 degree keeping upper arm vertical. Based on these studies two pump units were fabricated for 18 and 24 strokes/mi. and fitted to 12 litre capacity tank. The modified sprayer with 24 strokes/min along with commonly used ASPEE NAPSAC were ergonomically tested for preliminary trials, effort required for handle operation, physiological cost of operation and postural discomfort. Based on the data the modified sprayer was better than the commonly used ASPEE NAPSAC sprayer.

CHAPTER II

REVIEW OF LITERATURE

The review of relevant work related to the ergonomics of sprayers carried out by various researchers are presented in this chapter. The reviews of researches presented in this chapter are, ergonomics evaluation of Lok sprayers, various components of sprayers, and various parameters for ergonomics evaluation viz. heart rate, oxygen consumption and postural discomfort.

2.1 LOK Sprayer

LOK sprayers are commonly used to apply pesticides or other agricultural chemicals for protection of crops or plants from insects and pests. Sprayer development followed two basic paths i.e. small operator carried units, and large machines that required a cart, wagon or motorised vehicle for transport. One of the first large scale use of LOK sprayers involved fungicide application to vineyards in France during the late 1880's. The emergence and development of blow moulding man-made material in recent years has made a major change in construction of LOK sprayers. Due to this technique lighter and chemically resistant plastic models became available. Some attention has also been paid to construction of unit with curved tanks or which include some sort of back(lumber) brace, both aimed at making LOK

sprayers more comfortable to carry and operator. Another technological trend involves more firms fitting LOK sprayers with nozzles suitable for herbicide application as a standard accessory (Fisher and Deutsch, 1985).

2.2 Performance Evaluation of LOK Sprayers

Early work in the field of sprayer evaluation was concerned with equipment for vector control. Hall (quoted by Matthews, 1985) suggested test procedures and test rig for assessing the basic material strength and durability of compression and stir-up pump sprayers. Subsequently Matthew's(1969) developed a test rig for simulated field use of lever operated sprayers. The testing procedures of lever operated sprayers was reviewed at different centres (Sastry, 1971). Bindra (1971) and Ramarao (1971) also dealt with testing standards and test procedure for plant protection equipments.

Sutherland (1979) outlined format of specification for comparative evaluation of lever operated and motorised knapsack sprayers. This format could be used either as an absolute standard or as a means of comparing machines. For the LOK sprayers, the format was in two parts, Part-I covered dimensions, construction and performance and Part-II covered structural strength and durability. A scoring system was

suggested which was based on the criteria such as efficiency, suitability, safety, comfortable operation, strength, repairs etc. Results of the farmers surveys and discussions with them was the basis for giving the scores points. Based on this study Sutherland (1987) formulated a procedure for comparative evaluation of knapsack sprayers. Matthews and Thornhill (1989) suggested checklist and procedure for evaluation of lever operated knapsack sprayers.

The Bureau of Indian Standards have formulated a standard specifying methods for testign of manually operated knapsack sprayers (BSI, 1982). Regional Network for Agricultural Machinery (RNAM) has also broughtout the test code and procedure for hand operated sprayers (RNAM, 1983). However, all these test codes mainly deals with mechanical testing of sprayers and very little importance has been given to ergonomic aspects.

2.3 Ergonomics Evaluation of LOK Sprayers

There have been few efforts earlier related to ergonomics evaluation of sprayers. Singh and Kaul (1972) reported energy expenditure of manual knapsack sprayer as 0.49 l/min. The spraying operation was found equivalent at 118.14 kg m/min of mechanical work on bicycle ergometer. Backache as well as stiffening of neck was reported by the

subjects. Nag et al. (1980) studied the physiological workload of spraying operation. The heart rate and oxygen consumption were found to be 125.5 beats/min and 0.653 l/min., respectively. Fisher and Deutsch (1985) highlighted the problems and suggested ways to evaluate the sprayer from ergonomics view point. Ghugare (1989) carried out the ergonomical studies on operation of LOK sprayer. The mean heart rate, oxygen uptake and energy expenditure were found to be 94.6 beat/min, 0.45 l/min and 9.48 kJ/min, respectively. The mean overall discomfort ratings were 3.4, 5.0 and 5.7 on an eight point discomfort scale (0 = no discomfort, 7 = extreme discomfort) and the mean body part discomfort scores were 65.8, 93.8 and 89.1 at the end of 1st, 2nd and 3rd fill of sprayer, respectively. The maximum discomfort was experienced at the left clavicle region followed by lower back, neck, left thigh and right clavicle. He also studied 18 body dimensions and shape of back and data were collected for 10 subjects. Based on the data generated in this project, a draft test code and procedure for ergonomical evaluation of LOK sprayers was formulated by Gite and Pandya (1999). Phadke (1990) carried out a study on four different types of knapsack sprayers to validate this test code. He found that effort required in downward (pressure) stroke for operation of four sprayers, were 6.10, 6.56, 5.32 and 11.15 kgf for HI-Tech, LOK, Hi-Flo and Napsack

sprayers respectively, whereas the corresponding values in upward (idle) stroke were 1.28, 2.24, 0.45 and 3.17 kgf. The mean heart rate (beats/min) during sprayer operation were 88.4, 93.0, 91.3 and 94.2 for Hi-Tech, LOK, Hi-flo and Napsack sprayers, respectively whereas the corresponding increase in heart rate over walking (Δ HR) were 10.15, 11.6, 9.8 and 14.6 beats/min. The mean oxygen uptake (l/min) during sprayer operation was 0.38, 0.37, 0.33 and 0.43 and corresponding values of increase in oxygen uptake over walking (VO_2) were 0.15, 0.16, 0.13 and 0.22 l/min for Hi-Tech, LOK, Hi-Flo and Napsack sprayers. The mean overall discomfort rating (ODR) reported were 5.5, 4.9, 4.0 and 6.5 and mean body part discomfort scores (BPDS) were 109, 75, 56 and 129 for HI-Tech, LOK, Hi-Flo and Napsack sprayers, respectively and the increase in ODR over walking (Δ ODR) and increase in BPDS over walking (Δ BPDS) were 3.8, 3.1, 2.2, and 4.8 and 89, 53, 34 and 107, respectively. The ergonomics scores calculated for four sprayers were 78.1, 69.5, 61.6 and 50.7 respectively for four sprayers. Meshram (1991) carried out the study on design improvement in LOK sprayers for better ergonomical performance. The pump design was modified by him to reduce the effort required in handle operation of sprayer from 7.75 kgf to 5.97 and 4.33 kgf in two models for the desired mechanical performance.

2.4 Tank Capacities and Weights of Sprayers

In LOK sprayer operation, a worker has to carry the sprayer in rucksack mode. The WHO (1964) specified that the capacity of the tank should be between 7.5 and 15 litres. The weight of sprayer when empty but equipped for operation should not exceed 6.8 kg. Matthews (1979) suggested that the usual capacity of the tank should be about 15 litres so that the total weight of sprayer is not too excessive to be carried by the operator. The Indian Standards IS-3906 Part-I (1982) specified tank capacities as 10, 14, 16 or 18 litres. Thornhill (1982) reported that operator will get tired while carrying an excessive weight particularly in hot weather. So the empty machine should be as light as possible with good capacity weight ratio i.e. liquid capacity (litres) divided by the empty weight (kg) and this should range considerably from 2 to 4 l/kg. As per BIS-3906 Part I (1982), the empty weight of sprayer should not exceed 9kg. Garg (1990) has suggested tank capacities as 10 l for low volume and 12 to 16 litres for medium volume sprayers. Phadke (1990) suggested tank capacities between 10 or 12 litres to reduce postural discomfort of the operator.

2.5 Location and Type of Pump

The location and type of pump has a regional preference and traditions. In South East Asia, for example

over the shoulder lever type pumps are more popular than the underarm type found elsewhere. It is also a matter of individual preference and convenience. The OTS - over the shoulder - lever position allows an operator to easily switch from right to left hand pumping and to move through tall closely spaced plants more readily than an underarm lever. However the long curved OTS lever arm can be a inconvenient during filling, emptying, and transporting a LOK sprayer. Also an OTS configuration usually operates only piston pumps and may not be suitable for diaphragm pumps. A piston pump (positive displacement) usually produces more output than a diaphragm pump, but the later often requires less energy for operation and maintenance. Diaphragm pumps generally resist wear better than piston pumps when using wetttable powders (Fisher and Deutsch, 1985).

2.6 Pump Parameters

2.6.1 Pump size

The pressure fluctuation is dependant upon the capacity of pressure chamber. For uniform spray, pressure fluctuations should be minimum. IS-3906 (Part I): 1982, specifies that the pressure chamber shall have a minimum capacity of eight times the piston displacement. In commercial models of LOK sprayers the pressure chamber

generally varies from 500 to 1000 cc. As per IS-3906 (1982), for piston type knapsack sprayer, the inner diameter of pump cylinder should not be more than 5.5 cm and the thickness and height of the piston shall not be less than 0.25 mm and 13 mm, respectively. Garg (1990) recommended reduction of piston displacement and increase in pump operating speed as the pressure chambers used in LOK sprayers are of smaller capacities.

2.6.2 Stroke length

As per the Indian Standard (IS:3906 Part I-1982), stroke is the maximum travel of the piston rod in one direction when the handle moves from the maximum upward to the maximum downward position. For a complete stroke, Sutherland (1979) specified lever movement at handle grip as 30 cm to 40 cm.

2.6.3 Number of strokes per minute

There is no research data available about the optimum frequency of handle operation for pump of LOK sprayer. The operating frequency depends upon the working pressure, piston displacement, volumetric efficiency and desired discharge (i.e. type of nozzle used). Sutherland (1979) reported the pumping rate as 12 to 28 strokes per minute in different LOK sprayers. Garg (1990) reported that

the pump was operated at a speed range of 25 to 35 cycles per minute in the field, and therefore, a pump speed of 30 cycles per minute should be specified for conducting various tests viz. pressure development test, discharge rate, volumetric efficiency and endurance test, on manually operated sprayers.

2.7 Range of Handle Movement

There is no data available about the optimum range of handle movements. As per IS-3906: Part-I (1982) the handle movement should be 35° upward to 35° downward (i.e. total of 70° or less) of a horizontal plane passing through the centre line of the handle pivot.

2.8 Strap Attachments

Strap attachment location influences sprayer balance and comfort. Upper ends of the straps should be attached near the sprayer top. Those should be wide enough to evenly distribute the sprayers load on operator's shoulders. If possible strips should be padded at shoulder contact points. It should be possible to easily secure the straps at the skirt of the sprayer (Fisher and Deutsch, 1985). As per IS-3906: Part-I (1982) two straps of not less than 80 cm in length and 3.87 cm in width is to be provided

and there should be provision for adjustment of length of each strap.

2.9 Maximum Force Exertable by Arm Movement

In the LOK sprayer operation, the operator applies push-pull force for moving the lever in downward - upward stroke. Principle limb movement involved in the LOK sprayer operation are flexion and extension of arm, involved joint being elbow, and supination and pronation of palm involving wrist (Fig. 2.1.). The push is applied in extension mode while the pull in flexion mode.

Morehouse (1959) gave the maximum elbow flexion and extension strength as 27 kgf and 9 kgf respectively. Caldwell (1962) measured the maximum force of arm extension at five elbow angles at 25° intervals between 60° and 160°. It was found that the strength of the response was influenced by the elbow angle. The subject was told to push as hard as he could on the handle and to reach maximum output in about 3 sec. It was found that there was no appreciable difference between the force measured at 110°, 135° and 160° of elbow angle. The mean strength was 17.4, at 60° elbow angle and increased to 22.4 kgf at 110° elbow angle. Kroemer (1970) suggested strength tests duration as less than 10 seconds to avoid muscular fatigue.

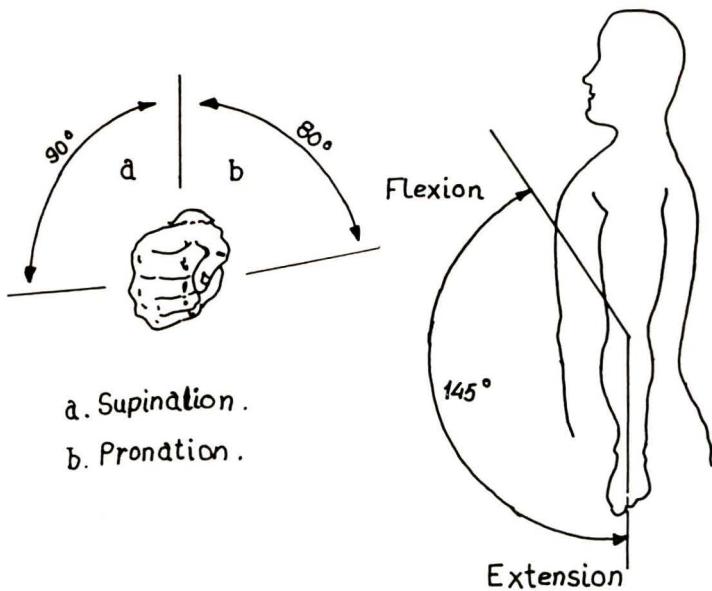


FIG.2.1 : NOMENCLATURE OF ARM AND HAND MOVEMENT

Murrell (1979) mentioned that the strength of flexion was almost one and half times that of the extension. Kroemer and Marras (1981) studied the male and female subjects and found that maximum strength in elbow flexion were 34.2kgf and 14.4kgf, respectively. Legg and Pateman (1984) suggested that average values of maximum flexion and extension of elbow for eleven male subjects as 26.7 kgf and 17.7 kgf for right hand and 27.6 kgf and 18.0 kgf for left hand, respectively. Sato and Ohashi (1989) studied the relationship between the force level of sustained isometric contraction and the time until two indices of muscular fatigue was compared for the right elbow flexion between 6 young women and 6 men. The strength of the maximum voluntary contraction (MVC) measured at the wrist with the elbow at right angle was significantly greater in men (26.7 ± 3.5 kgf) than in women (16.3 ± 2.3 kgf). Seki (1990) studied isometric muscle strength of elbow flexion, elbow extension and hand grip. The speed of exertion of muscle strength was also determined by the subject, except that he had to finish each trial within 5 to 10 seconds and he had reported that

- 1) Elbow Flexion : Maximum strength of right arm 22.1 kgf and of left arm 17.6 kgf
- 2) Elbow extension : Right arm 13.7 kgf left arm 12.9 kgf

Kumar (1991) conducted study to determine arm strength values for isometric and isokinetic effort around the human trunk. Subjects were instructed to build gradually to their maximal strength within the first two seconds and maintain for another three seconds for isometric trials. A rest period of atleast two minutes was allowed to ensure recovery and lack of fatigue.

2.10 Anthropometric Data for LOK Sprayer Design

There are few studies available which give information about selected body dimensions of Indian agricultural workers. These studies have been summarised by Gite and Yadav (1985) and data on 14 body dimension i.e. mean, 5 percentile value, and 95 percentile value have been given. Ghugare (1989) studied the shape and size of back of 10 workers and suggested improvement in the tank shape of sprayers.

2.11 Parameters for Ergonomic Evaluation

2.11.1 Heart rate

Heart rate data are used to estimate the workload imposed on the subject due to various operations. Increase in heart rate is considered as a reliable index of the amount of energy expended by an individual performing a task.

Leblanc (1957) mentioned that the work and recovery of pulse rate of human beings exercising at different levels of activity have shown to be value of judging the intensity and duration of work performed. Since the heart rate is directly affected by circulatory change, its use as an index of fatigue resulting from muscular activity, was also suggested by him. Suggs and Splinter (1958) used this index as a basis of comparing the relative difficulty of several farm tasks. Burger (1969) reported that use of heart rate for workload estimation had the primary advantage of simplicity and quickness of measurement. However heart rate is influenced by many other factors than the task intensity alone. Heart rate increase considerably in general and regional dynamic activity, in static muscular load, during heat exposure and under emotional stresses from work. Sengupta et al. (1979) reported that there was no significant difference in heart rate at light workload (having HR below 90 beats/min) when compared at 22°C and 30°C temperature.

The resting heart rate does not normally give any information over and above that provided by the work test. At low levels of physical activity there may be some variation in resting heart rate data due to emotional stress etc. Therefore, this data is not given much importance during ergonomics trials (Astrand and Rodahl, (1977). When

work is started from resting condition, heart rate immediately increases and approaches to equilibrium with the task within a relatively short time. For light to moderate tasks, equilibrium is reached in 3 minute or even earlier. In any case after 4 to 5 minutes of work, the heart rate generally reaches the steady state. In such conditions, the minute heart rate readings will not differ by more than 5 beats/ min (Astrand and Rodahl, 1977).

2.11.2 Oxygen consumption

The heart rate serves as an index of stress on worker whereas the oxygen consumption is supposed to be the absolute measure of work load. Various aspects of oxygen consumption as a measure of work load have been dealt with by Astrand and Rodahl (1977), Brouha (1960) and Consolazio et al. (1963).

Oxygen uptake is extensively used to determine the energy cost of different human activities. In field studies the classical method was to collect the expired air in Douglas bag, measure it and analyse the samples for oxygen concentration. With the development of portable devices for measuring of expired air volume and oxygen content, it has become easier to measure oxygen uptake in various operations. Harrison et al. (1982) carried out studies on Morgan oxylog

and concluded that this equipment was sufficiently accurate for reliable determination of oxygen consumption under field conditions.

Measurement of oxygen consumption or heart rate may be used to evaluate heavy work loads involving a substantial proportion of the body's muscles but may not be sensitive enough to evaluate the local fatigue of small muscle groups (Bush et al., 1988).

2.11.3 Postural discomfort

Bad postures and probable sites of pain or other symptoms were studied by Van Wely (1970). According to him, stooped position of work may cause pain in lumber region and erector spinae muscles. Any such inconvenient work postures result in muscular pain. Corlett and Bishop (1976) suggested a technique for assessing the postural discomfort. With the help of this technique, they could successfully study the effect of improvement in posture on performance of subjects with spot welding machines. De and Sen (1986) used this technique for assessing postural discomfort during ploughing operation in paddy fields. Yu and Keyserling (1989) modified this technique slightly and used it for evaluations of new work seat for industrial sewing operations. Many other research workers have also used the Corlett and Bishop (1976)

technique as such or with modification for assessing postural discomfort in operations of various machines. Ghugare (1989) used this technique to assess postural discomfort during operation of a 16 l capacity LOK sprayer and found that mean overall discomfort ratings were 3.4, 5.0 and 5.7 on an eight point scale (0 = no discomfort, 7 = extreme discomfort) and the mean body part discomfort scores were 65.84, 93.86 and 89.16 at the end of 1st, 2nd and 3rd fill respectively during the 3-hour continuous operation of sprayer. Phadke (1990) also used this technique to assess postural discomfort during operation of LOK sprayers.

2.12 Acceptable Work Load (AWL concept)

'AWL' represents that level of physical activity which can be sustained by an individual in an 8-hour working day in a physiologically steady state and which will not cause fatigue or discomfort. It is expressed in terms of relative load i.e. per cent of maximum aerobic power ($\dot{V}O_2$ max) spent performing a particular task. Michael (1961) and Bink (1962) (quoted by Grandjean, 1982) and Lehman (1962) have reported 33 per cent of $\dot{V}O_2$ maximum as AWL. Astrand (1956, 1960), Wyndham et al. (1962) and Christensen (1963) (all quoted by Samanta et al. 1967) fixed this limit as much higher as 50 per cent of $\dot{V}O_2$ maximum. Suggs and Splinter (1961) set the limits of heart rate, ventilation rate and

oxygen consumption as 110 beats/min., 2.5 l/min and 0.5 l/min, respectively for a working day of 8-hour. Brouha (1960) has recommended that industrial workers should not exceed an average heart rate of 110 beats/min over an 8 hour working shift. The study of Saha et al. (1979) has indicated that 35 per cent of $\dot{V}O_2$ max could perhaps be reasonably considered as the AWL. The energy expenditure and the corresponding heart rate at this level of work were around 18 kJ/min and 110 beats/min respectively.

The above is a brief review of various factors involved in the present study.

CHAPTER III

THEORETICAL CONSIDERATIONS

The theoretical consideration which were involved in this study are presented in this chapter under the following heads.

1. Spraying operation
2. Mechanics of LOK sprayer
3. Use of Anthropometry in design
4. Human body
5. Parameters for estimation of work-load
6. Muscular effect in handle operation

3.1 Spraying Operation

Operation of a lever operated knapsack sprayer involves the following activities :

- i) Opening the cap, filling water and chemical mixture in sprayer tank and replacing the cap tightly.
- ii) Lifting the sprayer, mounting it on back and securing it with straps.
- iii) Walking in the field at a speed of 2-3 km/hour.

- iv) Carrying the load of the sprayer (which may be about 5 to 25 kg at starting and 5 to 7 kg at the end of the operation) depending upon the tank capacity and type of sprayer.
- v) Operating the lever by one hand at necessary stroke frequency (5 to 20 per min. to maintain 300 kPa pressure in the tank).
- vi) Holding the lance in another hand, keeping the trigger pressed by palm grip (if there is no lock to it) and directing the spray at desired locations.
- vii) Unfastening the straps and taking the sprayer down from back after completion of spraying.

3.2 Mechanics of LOK Sprayer

The mechanics of LOK sprayer given by Meshram (1991) as follows:

In a lever operated knapsack sprayer with water filled in the tank, initially the pressure chamber is occupied by air at atmospheric pressure. During the suction stroke certain volume of liquid is drawn through the valve into the pump cylinder. With the return of the lever (working or pressure stroke) liquid in the pump cylinder is forced past

another valve into the pressure chamber. The suction valve between the pump and tank is closed during this operation to prevent return of the liquid back into the tank. Air is trapped in upper portion of the pressure chamber and compressed as liquid is forced into the chamber. Thus in each stroke certain volume of water is drawn into the pressure chamber reducing the volume of air inside the chamber and increasing the air pressure inside it. (Fig. 3.1).

Equation of State of Air

For perfect gas the equation of state can be written as $PV = RT$

Where,

P = Pressure, V = Specific volume

T = Absolute temp., R = Gas constant

In actual behaviour of air very closely approximates the perfect gas under most conditions and may, with good accuracy, be represented by the above equation of state.

Compression and expansion of air takes place according to various laws of thermodynamics. A constant temperature is characterised by Boyle's law.

$$PV = RT = \text{CONST}$$

- R_L - LENGTH OF OPERATING HANDLE
- R_S - LENGTH OF CRANK ARM
- L - STROKE LENGTH
- D - CYLINDER DIAMETER (INSIDE)
- F_H - FORCE ON OPERATING HANDLE

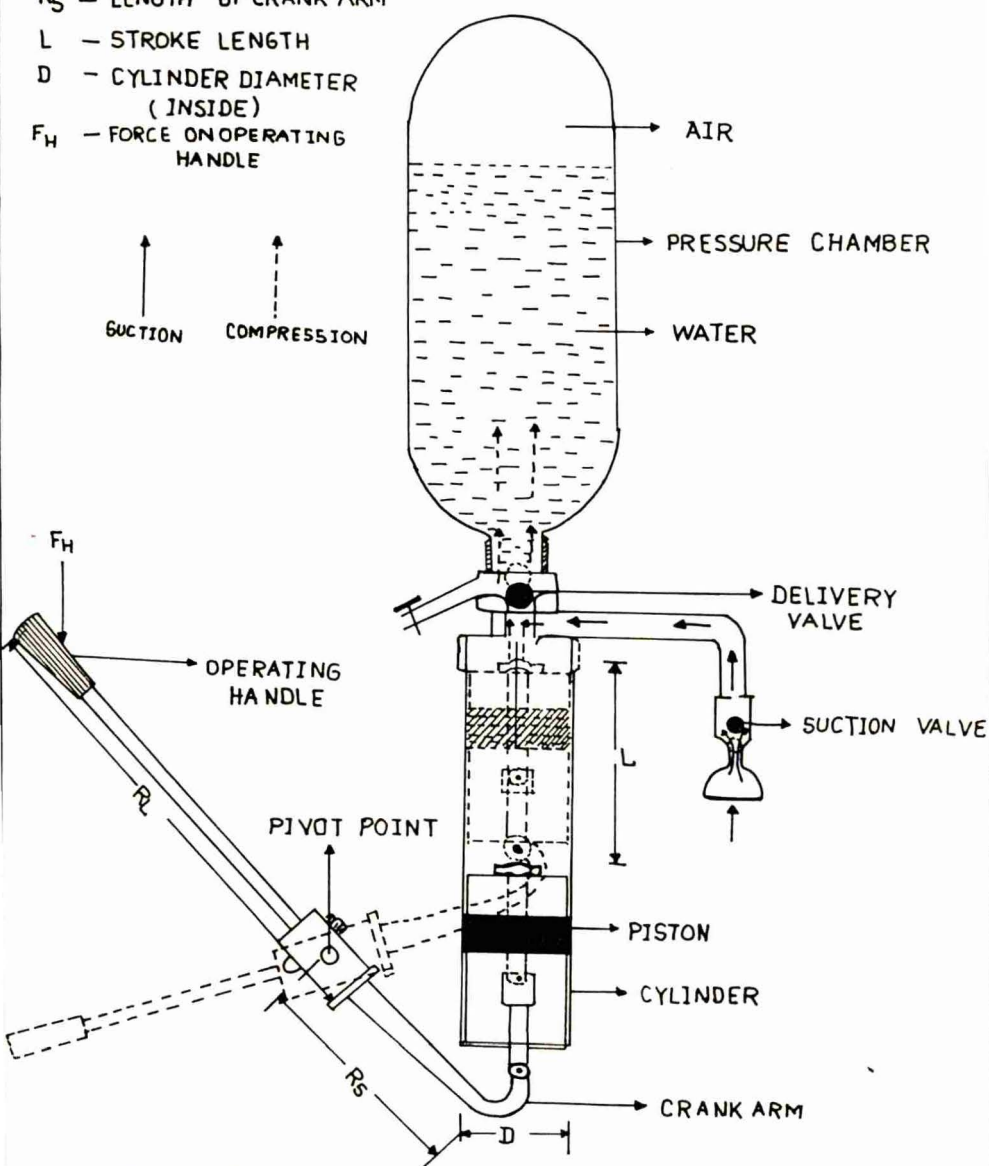
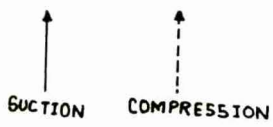


FIGURE 3-1 MECHANICS OF LOK SPRAYER

For a given mass of air a specific volume can be replaced by the volume of air.

Let us consider

V_t = Volume of pressure chamber, cc

P_{atm} = atmospheric pressure, kg/cm^2

V_s = swept volume, cc

now according to Boyle's Law

$$V_t \times P_{atm} = V_D \times P_D \dots\dots (1)$$

After one stroke a volume of liquid equal to the swept volume of pump is forced into the pressure chamber.

Hence,

$$(V_t - V_s \times E_{fv}) \times P_{b1} = V_t \times P_{atm} \dots (2)$$

Where,

E_{fv} = Volumetric efficiency of pump

P_{b1} = Pressure after one stroke, kg/cm^2

After another stroke again certain volume of liquid equal to swept volume of pump is forced inside the pressure chamber reducing volume of air and increasing its pressure inside the pressure chamber.

So

$$([V_t - V_s \times E_{fv}] - V_s \times E_{fv}) \times P_{b2} = V_t \times P_{atm} \dots (3)$$

It will continue till $P_{bi} = P_D$, ($I = 1, 2, 3 \dots\dots$)

$$\text{Now } V_s = \frac{22}{7} \times \frac{1}{4} \times D \times D \times L \dots\dots\dots (4)$$

Where,

V_s = Swept volume of pump, cc

D = Inside diameter of cylinder, cm

L = Stroke length, cm

$$\text{and } V_D \times P_D = V_N \times P_N \dots\dots\dots (5)$$

Where,

V_N = Volume of air inside pressure chamber at any stroke, cc

P_N = Pressure of air inside pressure chamber at any stroke, kg/cm^2

$$\text{Now } V_N \times (V_D + Q - V_s) \times P_N$$

Where,

Q = Discharge in a stroke, ml

Let us consider the small fraction of the stroke

$$V_N = (V_D + dQ - dV_s) \times E_{fv} \dots\dots\dots (6)$$

$$\text{Here } dV_s = \frac{22}{7} \times \frac{1}{4} \times D \times D \times dt. \quad (dt = \text{delta } t)$$

Let N = Number of strokes per minute

Time for one stroke = $1/N$ minute

$$dt = \frac{1}{N} \times 20$$

$$dV_s = dt \times N \times L/C$$

$$dV_s = \frac{1}{N} \times N \times L/N \times 20 \times C$$

$$dV_s = L/20 \times C$$

Where,

- C = ratio of time for one working stroke to total cycle time
 = 0.5 when time for one working stroke and idle stroke in same

Now from equation (5)

$$PN = VD \times PD / VN \quad \dots\dots \quad (7)$$

$$\text{Now } FP = PN \times 22/7 \times 1/4 \times D \times D \quad \dots\dots \quad (8)$$

Where,

- FP = Force on the piston, kgf
 PN = Pressure on the piston, kg/cm^2
 D = Diameter of piston, cm

Now taking the reaction at point A

$$FH \times RL = FP \times RS \quad \dots\dots \quad (9)$$

Where,

- FH = Force on the operating handle, kgf
 FP = Force on the piston, kgf
 RL = Length of operating handle, cm
 Rs = Length of small crank arm, cm
 FH = $FP \times RS / RL \quad \dots\dots \quad (10)$

With the help of equation (10) the force required to operate the handle can be calculated for any given combination of pump parameters.

3.3 Use of Anthropometry in Design

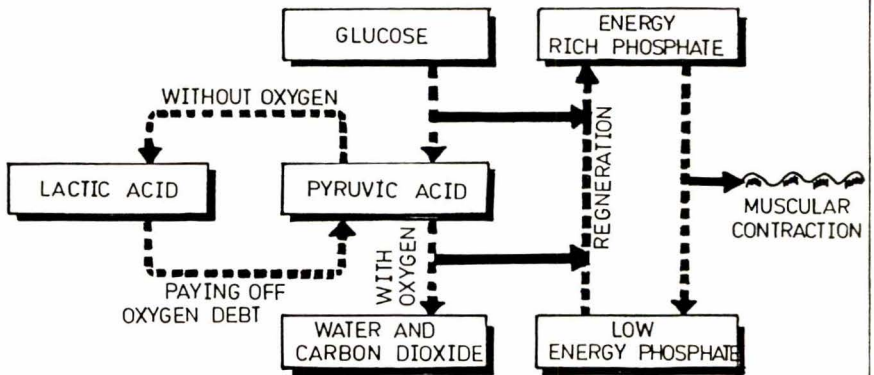
The design of all equipment have to be considered in relation to both the size of individuals who are going to use it and the movement which they can make with difficulty or strain. Individuals vary greatly in size from dwarf to gaints. On the other hand limits imposed on movement by the joints and tendons show much less variability. It is, therefore necessary to have some information about the body measurements of population who is likely to use the equipments. This systematic measurement of body dimensions using specialised instruments is known as Anthropometry.

The anthropometric data are generally processed to get mean, standard deviation and 5th and 95th percentile values. Ideally, an equipment should be made adjustable to suit the work population and for this purpose the percentile are more important than mean. But while adjustment of this kind can be provided in some things, many times it is not possible or economical. When equipment is non-adjustable, the designer has to choose limiting dimensions suitable for user population. For instance if reach is involved the 5th percentile value is used. If head room or leg room is to be designed then the 95th percentile value is used. Generally 5th to 95th percentile population is considered while designing an equipment. Only those measurements which may

constitute an impairment of life and safety, should be suited to users between the 1st and 99th percentile.

3.4 Human Body

The bony skeleton of human body is a framework made-up of 206 bones and the remainder of body is built upon it, in order that the bones which form the lever system, are able to do useful work, they are hinged together at the joints by smooth cartilage to minimize the friction. The forces which operate these levers are produced by muscles. Human body has widely distributed muscular system which together make-up approximately 40 per cent of the total body weight. Muscles have a property of contraction a process in which a chemical reaction takes place changing energy rich phosphate compound into low energy stage (Fig. 3.2). The energy thus liberated is used for various body activities and external work. Using glucose, fat, proteins available in the muscles the low energy phosphate compounds are continuously converted back to high energy state so that the reserve of energy remains undiminished. This process may be aerobic or anaerobic depending upon the availability of oxygen in the cell. In absence of oxygen skeletal muscles can work only for a short period of 40 sec. If the efforts has the duration of one minute, about half of the maximum potential energy release is aerobic. With five minutes of activity 80



— ENERGY FLOW

- - - CHEMICAL REACTION

FIG 3.2: METABOLIC PROCESS

per cent is oxygen dependent and over one hour of work 90 per cent of metabolism is aerobic (Astrand and Rodhal, 1977, Levay, 1974; Grandjean, 1982).

3.5 Parameter for Estimation of Work-load

In human body the supply of oxygen and nutrients to various muscles and the removal of carbon dioxide depend upon the precise integration of respiratory and cardio-vascular functions. When a person does a muscular work, oxygen uptake as well as heart rate increases to meet the additional demands. The increase in these parameters is related to energy spent in doing the work.

3.5.1 Oxygen uptake

Human body is like an engine in which food stuff is oxidised and energy is liberated in form of heat (Fig.3.3). Part of this heat is used to maintain the body mechanism and the rest is utilised for doing work. As the energy provided by the food stuff can be liberated and used only as a result of oxidation, which ultimately depends on the supply of oxygen from air, the measurement of oxygen uptake of body gives the energy expenditure.

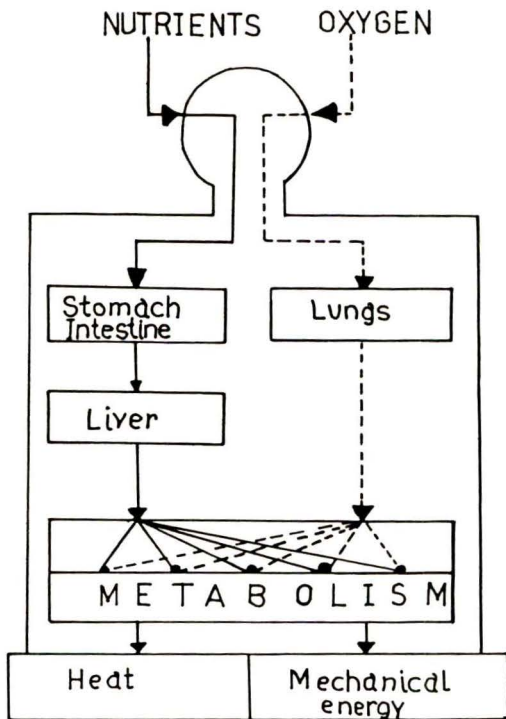


Figure:3.3 CONVERSION OF NUTRIENTS INTO HEAT AND MECHANICAL ENERGY IN THE HUMAN BODY

3.5.2 Heart rate

Heart rate is the number of ventricular beats per minute as counted from the record of electrocardiogram or blood pressure curves being 40 to 80 beats per minute. The heart rate gives the good measurement of work load as well as degree of strain during continuous work load. Use of heart rate for work load estimation has the primary advantage of simplicity and quickness of measurement. However, it is influenced by many other factors than the task intensity alone. Heart rate increases considerably by dynamic muscular activity, in static muscular load, during heat exposure and under emotional stresses from work. Therefore, great care has to be taken while interpreting the heart rate data. Thus oxygen consumption is a measure of workload whereas heart rate serves as an index of stress on the worker.

3.5.3 Postural discomfort

Posture is recognised as an important aspect of work loading because awkward posture when adopted for long period cause bodily damage and ill health. In LOK sprayer operation worker has to carry the sprayer in rucksack mode. Here the arms are free from work, however shoulders are constantly pulled back and body is in stooped posture. The straps of the sprayer cut into neck muscles. He also has to

assume posture different from normal standing posture. Thus changes occur in the centre of gravity which may result in temporary discomfort of different parts of body. Any change in centre of gravity from body will result in extra work being done by muscles which maintain posture as well as centre of gravity.

Load carrying involve some amount of static work due to static contraction of muscles. During static effort the flow of blood is constricted in proportion to the force exerted resulting in muscular fatigue. The static work performed depends on the extent and degree of muscular contraction and varies with the quantity of load and mode of carrying. A technique involving larger group of muscles and large support area will involve less muscular fatigue.

Postural discomfort is a concept used to assess muscular fatigue. The measure of it would be levels of discomfort judged on a psychophysical scale. The accurate discomfort felt by the operator would be a summation of all the individual sensations felt by different muscle group.

3.6 Muscular Effort in Handle Operation

When any form of body activity calls for a considerable expenditure of effort, it is necessary to design the activity properly so that the fatigue to the operator is

minimum. Static as well as excessive load on muscles lead to painful fatigue. In sprayer operation a worker has to move the handle with one hand in upward and downward direction. The frequency of this operation may vary from 6 to 30 strokes per minute depending upon sprayer and thus it has a considerable effect on comfort of the operator.

CHAPTER IV

MATERIALS AND METHODS

4.1 Place of Study

The study was carried out at two places viz. ASPEE Research Institute, Bombay from 5th Jan. 1992 to 16th Jan. 1992 and 10th April to 18th April, 1992 and the Central Institute of Agricultural Engineering, Bhopal from 17th Jan. to 4th April and 20th April to 20th May, 1992.

4.2 Sprayers Studied

As the study was pertaining to lever operated knapsack sprayers, three different models of LOK sprayers mentioned in Table 4.1 were selected for preliminary study. These models were chosen to represent the type of available LOK sprayers in the country. The three units were dismantled and reassembled to study their working principles and constructional features. Detailed technical specifications of the three units were obtained from the manufacturer. These specifications were verified during dismantling and reassembling. Dimensions of components were measured using dial calliper, meter scale and measuring tape. The measurement of upward and downward angle of operating handle with horizontal were made with the help of abney level. The detailed technical specifications of these three units are given in Appendix-I.

Table 4.1 LOK sprayer selected for study

Sprayer	Code number	Capacity Litres
ASPEE Napsack sprayer	SRP-50	16
ASPEE Hi-tech sprayer	SRP-60	16
ASPEE Hiflo sprayer	SRP-55	12

4.3 Preliminary Trials

After the verification of specifications of the three sprayers, preliminary trials were conducted for each test sprayer to find out number of strokes required to create and maintain a pressure of 2 kg/cm^2 , 3 kg/cm^2 and 4 kg/cm^2 , discharge per minute and volumetric efficiency at these three pressures. These tests were conducted as per the procedure specified by Gite and Pandya (1989).

4.3.1 Procedure for determination of no. of strokes required to build and maintain the pressures of 2 kg/cm^2 , 3 kg/cm^2 and 4 kg/cm^2

This test was carried out by mounting the test sprayers rigidly on a work bench with the help of suitable clamps.

- i) The sprayer was rigidly mounted on the test rig with the help of suitable clamps in such a way that its operating handle could be operated in desired direction. The 'Napsak' 'Hitech' and 'Hiflo' sprayers were operated in right hand lever position.

- ii) The sprayer was filled to its full capacity. A pressure gauge of range 0 to 7 kg/cm² (0 to 100 psi) was fitted in the discharge line just before the trigger.

- iii) The handle was operated manually to obtain 2 kg/cm² pressure and the number of strokes required to build this pressure were obtained. Then the spray was started and the lever was operated to maintain a pressure of 2 kg/cm² (\pm 10 per cent) and the number of strokes required to maintain 2 kg/cm² (\pm 10 per cent) pressure for one minute were obtained. Five such readings were taken and the data were averaged to get the number of stroke required to create and maintain 2 kg/cm² pressure.

These trials were repeated for 3 kg/cm² and 4 kg/cm² pressures also. The test was carried out for three sprayers given in Table 4.1.

4.3.2 Procedure for discharge Vs pressure relationship

This test was carried out as per the procedure specified in IS: 10134-1982 (Methods of test for manually operated sprayers). Each sprayer was fitted with a pressure gauge as mentioned in section 4.3.1. The sprayer was mounted on the test rig and filled to its full capacity with clean water. A person operated the lever to maintain the desired pressure, and discharge was measured at the nozzle for one minute into a measuring cylinder of one litre capacity. Five such readings were taken and the data were averaged to get the mean value. These trials were carried out for three pressures i.e. 2,3 and 4 kg/cm² and for three sprayers.

4.3.3 Procedure for finding volumetric efficiency

To measure the volumetric efficiency, the sprayer was mounted on a test rig which was operating at a stroke frequency of 16 cycles/min. The outlet value of delivery line was adjusted such that the pressure of 3 kg/cm² was maintained. The discharge in 10 strokes was collected and measured in a measuring cylinder of one litre capacity. The procedure was repeated five times and an average of these readings was taken. Volumetric efficiency of the pump was calculated by dividing the volume of water collected in 10 strokes with theoretical swept volume in 10 strokes.

4.4 Optimization of Frequency of Handle Operation and Range of Handle Movement (Experiment - 1)

4.4.1 Experimental set-up

A set-up for mechanical simulation of effort application in LOK sprayer was developed by Gite and Pandey (1992) and the same was adopted for carrying out these studies. The mechanical set-up is shown in Fig. 4.1 (a) and 4.1 (b). The set-up consists of a strong frame work of M.S. angles of size 45 x 45 x 5 mm. An angle of 35 x 35 x 5 mm with bush fitted at its centre was used as a horizontal shaft and it can be moved up and down vertically. At one end, there was arrangement to attach loads to get the required effort at the centre of handle. With a proper linkage arrangement a modified handle was fitted to the lever at another end. Again with a proper linkage the lever was attached to the dash pot, so that the modified handle can return to its original place without any effort. The modified handle was also having a suitable arrangement to fit the load cell so that the effort applied at handle can be measured. There was arrangement to restrict the range of handle movement so that the required angle can be adjusted. Provision was also made to adjust the elbow height of operator with respect to handle.

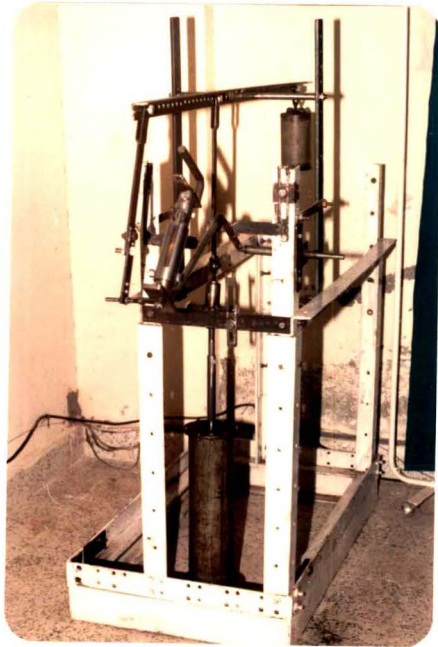
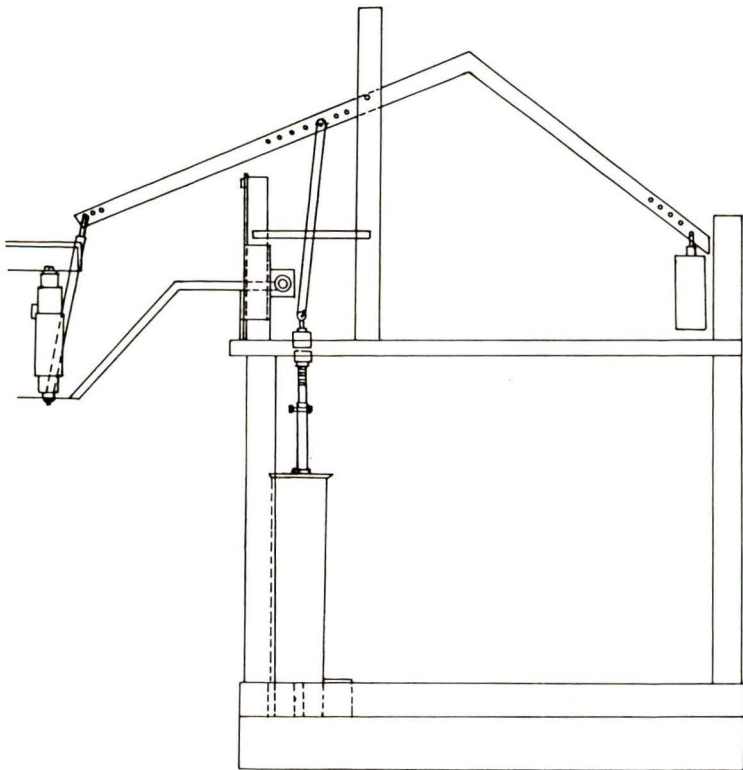
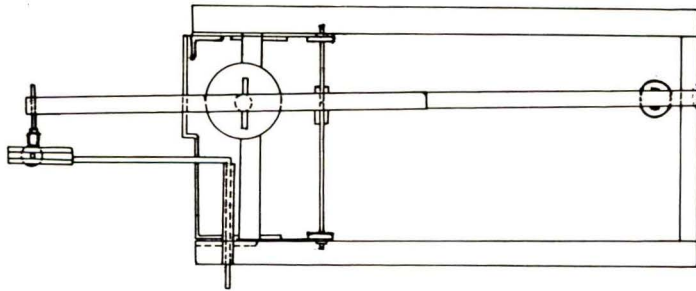


Fig. 4.1 (a) Mechanical setup for simulation of effort application in LOK sprayer



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FIG. 4.1 (b) : PLAN AND SIDE VIEW OF THE MECHANICAL SETUP FOR SIMULATION OF EFFORT APPLICATION IN LOK SPRAYER.

4.4.2 Experimental details

For optimization of frequency of handle operation and range of handle movement four frequencies of handle operation and four ranges of handle movements were selected. They were as follows.

Four frequencies of handle operation

	Notation	Stroke/min
1	N ₁	6
2	N ₂	12
3	N ₃	18
4	N ₄	24

Four ranges of handle movements

	Notation	Upward Angle degrees	Downward Angle degrees	Total Angle, degrees
1	M ₁	45	15	60
2	M ₂	40	20	60
3	M ₃	35	25	60
4	M ₄	30	30	60

The total range of handle movement was 60 degrees. The total treatment combinations were $4 \times 4 = 16$. Thus 16

trials were carried out on the mechanical set-up in a set. Each trial was of 6 minutes duration and 6 minutes of rest was given between the two trials. These trials were conducted for 8 kgf handle effort.

4.4.3 Subjects

Five male subjects were used for study on the mechanical setup. All the subjects were right handed and the setup was also having the lever which could be operated by right handed operators. Their mean age, stature and body weight were 32.8 (± 7.39) years, 160.70 (± 2.79) cm, and 50.10 (± 4.53) kg, respectively. All the subjects were conversant with the sprayer and spraying operation. The subjects were also provided opportunity to get conversant with the mechanical setup.

4.4.4 Measurements

For optimization of range of handle movement and frequency of handle operation, short term trials of 6 minutes duration were carried out. The objectives of these trials was to study the heart rate and job severity of the subjects while operating the mechanical setup. For measurement of heart rate continuously during the work, the UNI-INSTA E.C.G. telemetry system was used. It had a range of 30 meters. The detailed information about the equipment is

given in Appendix II. For job severity rating a 0-10 point scale was prepared and used for the study (0 = no discomfort, 10 = extremely severe job causing extreme discomfort). Arrangement was made such that the effort required at the handle was 18 kgf at the rate of 24 strokes/min. Generally, in the first minute of work itself, the subjects expressed inability to continue the work and this rating was considered as 10 on the rating scale.

4.4.5 Procedure

These trials were conducted in the laboratory with five subjects. Their mean age, stature and body weight were 32.8 (± 7.39) year, 160.70 (± 2.79) cm and 50.1 (± 4.53) kg. All the trials were carried out from 9.30 AM to 2.00 PM. During the experiments, the mean ambient conditions were thermally comfortable with air temperature of 22.2 (± 0.95) $^{\circ}$ C, relative humidity of 49.1 (± 5.95) percent and air velocity less than 1 m/s. The calibration of effort required in handle operation was done as shown in Fig.4.2.

The subjects were given information about the experimental requirements so as to enlist their full cooperation. From these 16 combinations lots were drawn to select the sequence of trials. The subjects were asked to drive the bicycle ergometer for 10 minutes to get warmed up

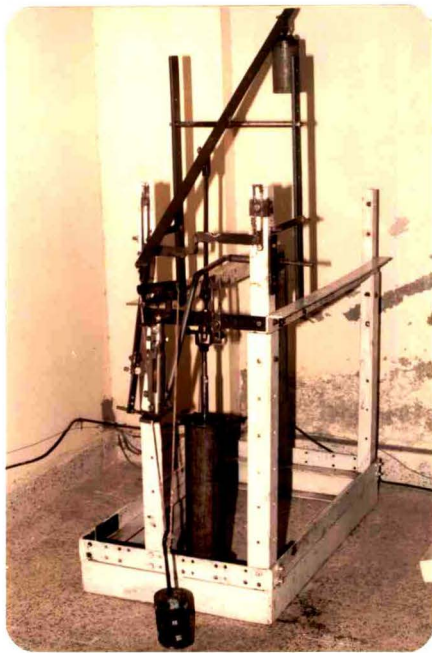


Fig. 4.2 (a) Calibration of setup using dead weight

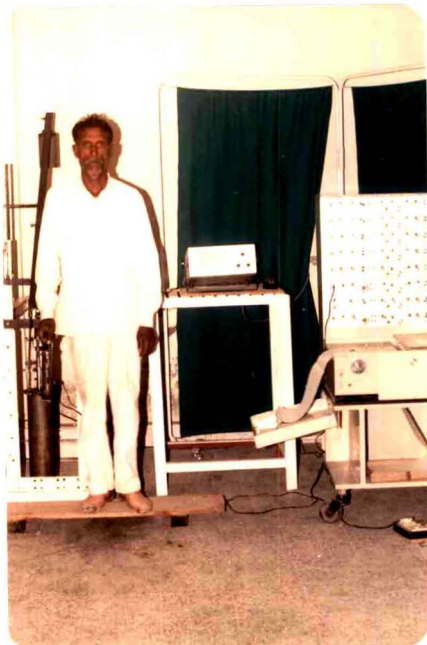


Fig. 4.2 (b) Calibration of setup using load cell and polyrite recorder unit

so as to avoid erratic variations in heart rate. After the subject had rested for 10 minutes, he was made ready for the experiment by fitting the E.C.G. telemetry transmitter with electrodes. After five minutes of rest the resting heart rate of the subject (while sitting on stool) and in standing position were noted. Then for a particular treatment the range of handle movement was adjusted with a suitable arrangement provided on the setup. The subject was then asked to stand with the setup and to hold the handle at the centre. The subject was asked to operate the handle at a specified frequency. A technician was guiding the subject in maintaining the required frequency of handle operation (Fig. 4.3). Each trial was of a 6-minute duration and observation on heart rate was taken from fourth minute of work to sixth minute of work. E.C.G. telemetry system was giving instantaneous heart rate average over previous 10 seconds. Therefore, for heart rate, in each minute about 30 to 40 readings were noted and their average was taken to calculate the heart rate for that particular minute. After the completion of each trial the subject was asked about the job severity rating (on 0-10 points scale) (Fig. 4.4). The subject was given a rest of 6 minutes and the next trial was carried out. Three replications were carried out on separate days for each of five subjects.



Fig. 4.3 Experiment-1 for determination of optimum frequency and range of handle movement-Measurement of heart rate



Fig. 4.4 Experiment-1, for determination of optimum frequency and range of handle movement-Assessment of job severity rating

4.5 Optimization of Number of Strokes Per Minute

4.5.1 Short duration trials (Experiment-2)

4.5.1.1 Experimental setup

In this experiment for optimization of number of strokes per minutes the experimental setup mentioned earlier was used with little modifications. The horizontal lever to which the weight was attached was given a bend of 52° with horizontal toward the end where weight was attached. This was done so as to get the effort required in handle operation less at the start of the stroke and the desired effort at the end of the stroke. The experimental setup used for the study is as shown in Fig. 4.5.

4.5.1.2 Experimental details

For optimization of number of strokes per minute six frequencies of handle operations were studied keeping the range of handle movement constant i.e. 30 degree upward and 30 degree downward. In this study, work done by the subject were kept constant i.e. the product of number of stroke per minute and effort required for handle operation was 72. The product was kept constant to 72 as generally this was the figure worked out from the data of commonly used sprayers

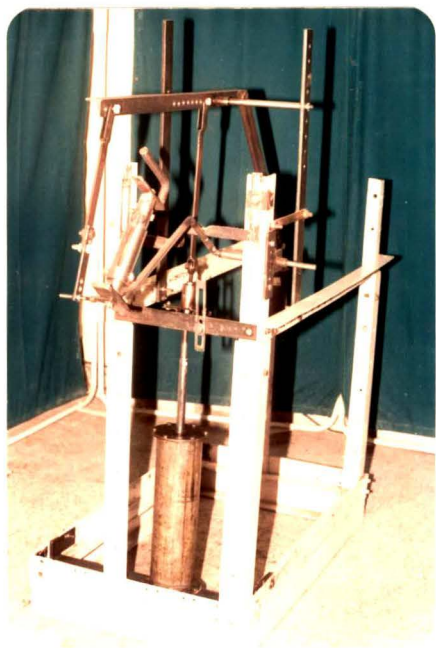


Fig. 4.5 Mechanical setup for simulation of effort application for constant work load in LOK sprayer

The combinations selected for the study were :

Sr. No.	Notation	Stroke/min.	Effort required for handle operation, kgf	Product of stroke/min x effort
1.	N ₁	6	12.0	72
2.	N ₂	12	6.0	72
3.	N ₃	18	4.0	72
4.	N ₄	24	3.0	72
5.	N ₅	30	2.4	72
6.	N ₆	36	2.0	72

4.5.1.3 Procedure

These trials were conducted in the laboratory with the same five subjects used in the experiment one. All the trials were carried out from 9.30 AM to 2.00 PM. During the experiments, the mean ambient conditions were thermally comfortable with air temperature of 27.35°C (± 1.8) relative humidity of 51.28 (± 8.09) per cent and air velocity less than 1 m/sec.

The subjects were given information about the experimental requirements so as to enlist their full cooperation. The calibration of the setup for required force was done as shown in Fig. 4.6. Lots were drawn to select the

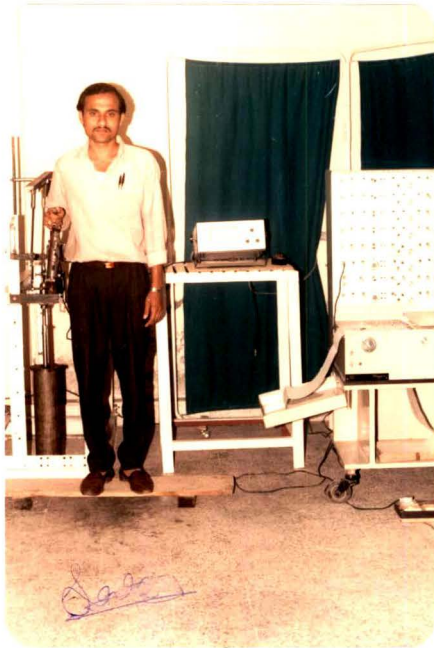


Fig. 4.6 Calibration of setup using load cell and polyrite recorder unit (Expt.2)

sequence of trials. The subject was asked to drive the bicycle ergometer for warming up. After the subject had rested for 10 min., he was made ready for the experiment by fitting the ECG telemetry transmitter with electrodes. After 5 minutes of rest, the resting heart rate of the subject (while sitting on stool) was noted. Then the subject was asked to operate the handle for a particular frequency (Fig.4.7). Each trial was of a 10 minutes duration and 10 minutes rest was given between the two trials. The heart rate data were collected from fifth minute of work to the 10th minute of work. After completion of each trial the job severity rating was asked and noted (on 0-10 points scale). (Fig. 4.8). For each subject two such replications were carried out on separate days.

4.5.2 Long duration trials (Experiment-3)

4.5.2.1 Experimental setup

In this experiment for optimization of number of strokes per minute the same experimental setup was used as described in 4.5.1.1.

4.5.2.2 Experiment details

For optimization of number of strokes per minute four frequencies of handle operation were studied keeping



Fig. 4.7 Experiment-2 for optimization of frequency of handle operation- Measurement of heart rate



Fig. 4.8 Experiment-2. for optimization of frequency of handle operation-Assessment of job severity rating

the range of handle movement constant i.e. 30 degree upward and 30 degree downward. The frequency of handle operation selected for the study were :

Sr.No.	Notation	Strokes/min
1	N ₂	12
2	N ₃	18
3	N ₄	24
4	N ₅	30

The trials were of 30 minutes duration and a rest of one hour was given between two trials. These trials were conducted in the laboratory with the same give subjects. In this experiment only data of job severity rating were collected at the end of each trial. Only one replication was carried out in this study for each of five subjects.

4.6 Measurement of Maximum Strength in Elbow Flexion and Extension (Experiment-4)

4.6.1 Experimental setup

A mechanical setup was fabricated to study the maximum muscular force which could be exerted in elbow flexion and extension. The setup consisted of mild steel angles (50 x 50 x 5 mm) size fixed rigidly to the wall as

shown in Fig. 4.9. A hollow cylinder with a semi circular disc welded to it was fixed to the angle with the help of nut and bolts so that the elbow height of the subject can be adjusted with respect to handle height of the setup. The modified handle was fixed in the hollow cylinder with a proper arrangement to fix the load cell.

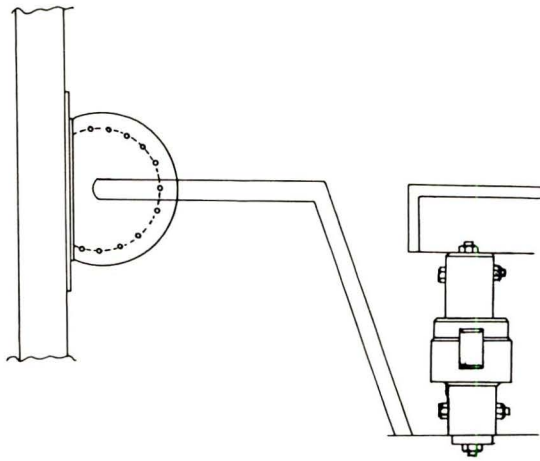
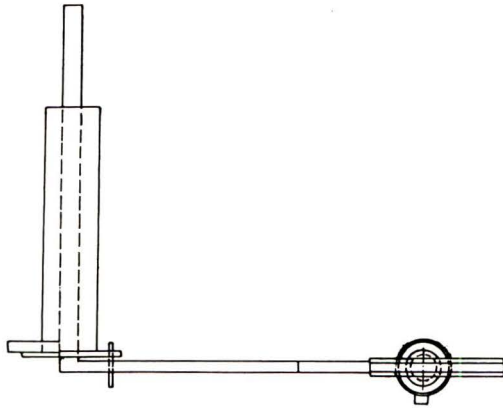
4.6.2 Instrumentation

For measurements of maximum muscular force exerted by subject in elbow flexion and extension, a load cell was fixed to the modified handle and for recording of the force, the Polyrite recorder unit was used. The details of these instruments are given in Appendix II.

4.6.3 Procedure

Data on the maximum muscular force exerted in elbow flexion and extension were collected for seven positions of elbow angles i.e. 60,70, 80, 90,100, 110 and 120 degrees. While measuring and applying the force, the upper arm was kept vertical and only muscular force was exerted. The subjects were asked not to use body weight to apply the force on the handle. Calibration of the load cell was done as shown in Fig. 4.10.

The subjects were given information about the experimental requirement so as to enlist their full



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FIG. 4.9 (a) : PLAN AND SIDE VIEW OF THE MUSCULAR STRENGTH APPLICATION SETUP.

cooperation, and they were explained about the method of applying the force on the handle. The elbow height of the subject was adjusted so as to get the desired angle by keeping the upper arm vertical. Then the subject was asked to exert the maximum force and to maintain it for the 3 sec. (Kroemer, 1970) as shown in Fig. 4.11. Then a rest of 2 minutes was given between the two replications and a rest of 5 minutes was given between the two treatments. The maximum muscular force exerted was recorded on the Polyrite recorder chart. The same five subjects were used for study as in previous experiments. Three such replications were carried out and the mean force exerted in elbow flexion and extension were found out at seven different positions of elbow angle. Then the data were statistically analysed using RCBD design to know the significance and non-significance of the collected data.

4.7 Computer Programming

A computer programme based on the mechanics of LOK sprayer as given by Meshram (1991) was used to know the effect of different pump parameters viz. pressure chamber volume, piston diameter and stroke length on the muscular effort required in handle operation. For this purpose a personal computer PCL PC/XT having 64 KB main boards,



Fig. 4.9 (b) Setup along with polyrite recorder unit for measurement of muscular strength



Fig. 4.10 Calibration of load cell using dead load

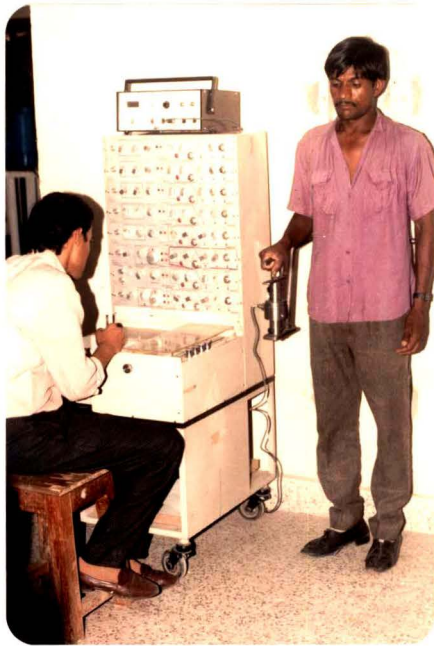


Fig. 4.11 Subject applying maximum muscular strength on the handle muscular

RAM expandable to 640 KB, ROM expansion slots (5 full size, 3 half size) and 360 KB 5 1/4 inch floppy disc drive was used.

Using the computer programme the data on 1080 combinations were generated. The following parameters with their specifications given in Table 4.2 were used for the study.

Table 4.2: Parameters selected for generation of data through computer programme

Sr. No.	Volume of pressure chamber, CC	Diameter of piston, cm	Stroke length cm	Ratio of time for one working stroke to total cycle time
1.	500	1.75	2.0	0.1
2.	600	2.50	3.0	0.3
3.	700	3.25	4.0	0.5
4.	800	4.00	5.0	0.7
5.	900	4.75	6.0	0.9
6.	1000	5.50	7.0	-

The parameters which were kept constant had the following values :

Length of small crank arm (Rs)	= 6.0 cm
Length of large crank arm (RL)	= 49.0 cm
Nozzle discharge (Q)	= 450 cc/min.
Atmospheric pressure (Patm)	= 1 kg/cm ²

Minimum nozzle pressure (PD)	=	3.8 kg/cm ²
Volumetric efficiency of pump (EFv)	=	0.90

4.8 Fabrication of Modified Prototypes

For the fabrication of modified prototypes, five pump combinations were selected from 1080 combinations for which data on effort were generated through computer programme and the same are given below (Table 4.3).

Table 4.3: Possible combinations for the fabrication of modified prototype

Sr.No	Particular	I	II	III	IV	V
1.	Volume of pressure chamber, cc	500	500	500	500	500
2.	Piston diameter, cm	2.5	2.5	2.5	2.5	2.5
3.	Stroke length, cm	3.5	4.3	5.7	6.5	7.0
4.	Swept volume, CC	17.17	21.09	27.07	31.89	34.34
5.	No.of stroke required to create 300 kPa pressure	24.0	20.0	15.0	14.0	13.0
6.	No.of strokes required to maintain 300 kPa pressure (\pm 10 per cent)	30.0	24.0	18.0	16.0	15.0
7.	Force required for handle operation (estimated) kgf	2.7	2.7	2.7	2.7	2.7

Two pump units with the dimensions given in Table 4.4 were fabricated (Fig. 12 and Fig. 13). These two pump units were fitted to the two separate sprayer tanks of 12 litre capacity. The detailed specifications of these two fabricated prototypes are given below.

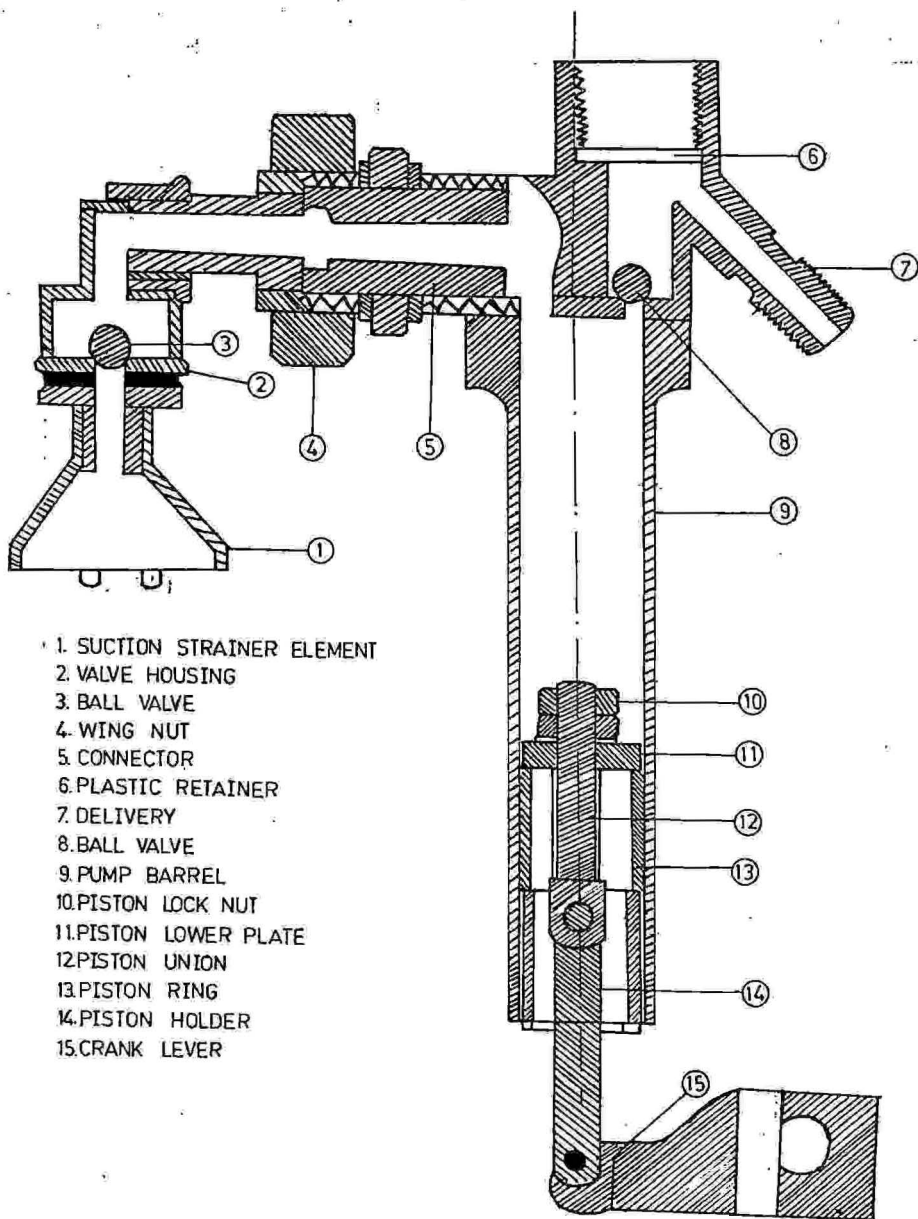
Table 4.4: Pump parameters selected for the fabrication of two modified prototypes

Sr.No.	Particulars	I	II
1.	Volume of pressure chamber, cc	500	500
2.	Piston diameter, cm	2.5	2.5
3.	Stroke length, cm	4.3	5.7
4.	Swept volume, cc	15.0	20.0
5.	No. of strokes/min required to maintain 300 kPa pressure	24.0	18.0
6.	Calculated effort required for operation of handle in downward stroke, kgf	2.7	2.7

4.9 Ergonomical Evaluation of Sprayer Units

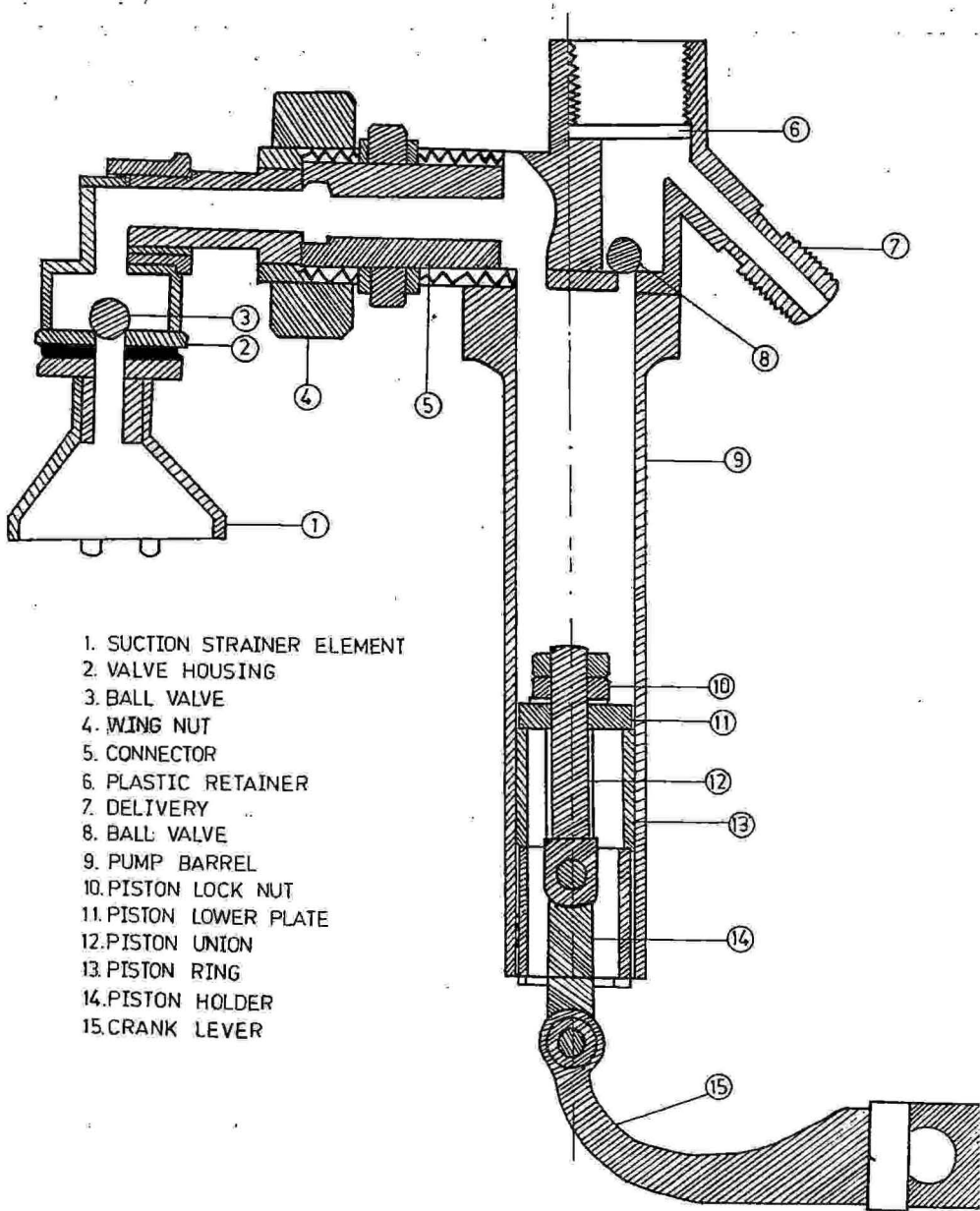
4.9.1 Preliminary trials

After the fabrication and assembling of modified prototypes, the units were tested for leakage and proper operation. Then preliminary tests were carried out on the prototypes alongwith one existing model of Aspee Napsak



1. SUCTION STRAINER ELEMENT
2. VALVE HOUSING
3. BALL VALVE
4. WING NUT
5. CONNECTOR
6. PLASTIC RETAINER
7. DELIVERY
8. BALL VALVE
9. PUMP BARREL
10. PISTON LOCK NUT
11. PISTON LOWER PLATE
12. PISTON UNION
13. PISTON RING
14. PISTON HOLDER
15. CRANK LEVER

FIG. 4.12 : PUMP UNIT OF MODIFIED SPRAYER (24 strokes/min.).



1. SUCTION STRAINER ELEMENT
2. VALVE HOUSING
3. BALL VALVE
4. WING NUT
5. CONNECTOR
6. PLASTIC RETAINER
7. DELIVERY
8. BALL VALVE
9. PUMP BARREL
10. PISTON LOCK NUT
11. PISTON LOWER PLATE
12. PISTON UNION
13. PISTON RING
14. PISTON HOLDER
15. CRANK LEVER

FIG. 4.13 : PUMP UNIT OF MODIFIED SPRAYER (18 strokes / min.)

(SRP-50), 16 litre capacity (as it is the commonly used sprayer by farmers) to find out number of strokes required to create and maintain a pressure of 300 kPa, discharge per minute and volumetric efficiency. The procedure mentioned by Phadke (1990) were followed for these sprayers (Fig. 4.14). Due to non availability of time ergonomic evaluation of only one modified sprayer (Unit-I) alongwith an existing unit of ASPEE Napsak sprayer was carried out using the procedure suggested by Phadke (1990)

4.9.2 Measurement of effort

4.9.2.1 Effort measurement by mounting the sprayer on a test bench

The instruments used for the measurement of effort in upward and downward stroke during sprayer operation were a load cell which was fitted to modified handle for individual sprayer and the Polyrite recorder unit.

Procedure

- i) The modified handle was fitted to the sprayer
- ii) The load cell was fitted to the modified operating handle at the place of handle grip and connected to the Polyrite recorder unit through strain indicator.

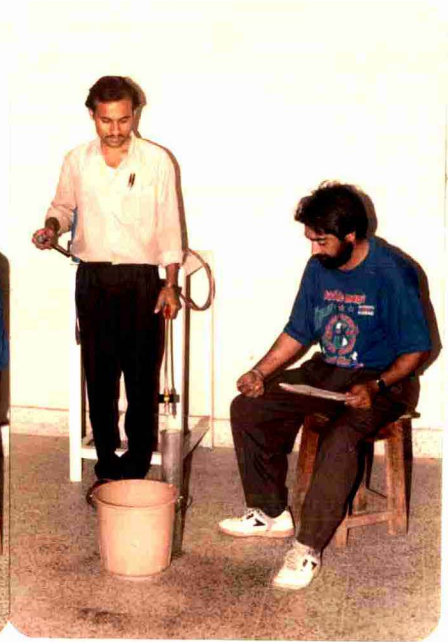


Fig. 4.14 (a) Modified sprayer mounted on test rig
Fig. 4.14 (b) Measurement of number of strokes/min required to maintain $3 (\pm 10 \text{ per cent})$ kg/cm^2 pressure
Fig. 4.14 (c) Measurement of discharge at $3 (\pm 10 \text{ per cent})$ kg/cm^2 nozzle pressure for one minute
Fig. 4.14 Preliminary trials of modified sprayers unit

- iii) The load cell was calibrated using a dead weight of 10 kg.
- iv) A pressure gauge of 0 to 7 kg/cm² was fitted to the delivery line just before the nozzle.
- v) The sprayer was rigidly mounted on a test bench in such a way that its handle could be operated in the direction it was designed for operation.
- vi) The sprayer was filled to its full capacity with clean water.
- vii) The operator was asked to build-up pressure of 300 kPa. Spray was started and the handle was operated with necessary stroke frequency to maintain a pressure of 300 kPa (\pm 10 per cent) in standing posture.
- viii) Reading of force required in upward and downward stroke of operating handle were recorded for 2 minutes duration
- ix) Three such replications were carried out and the mean values of effort required in upward and downward stroke of sprayer operation for each subjects were found out.

- x) The same procedure was repeated for the modified prototype and mean values of effort required in downward and upward strokes during operation of this prototypes was found out.

4.9.2.2 Effort measurement by mounting the sprayer on operator's back

The instruments used for the measurement of effort in upward and down strokes during sprayer operation and subject used for the study were same as mentioned in section 4.9.1

Subjects :

Five physically sound subjects who participated in previous experiments were used for this study. Before starting the actual experiment on effort measurement, all the five subjects were familiarised with the operation of sprayers particularly about the method of maintain the operating pressure during operation. They were also told about the purpose of study to ensure full cooperation.

Procedure

The steps mentioned in the procedure given in the section 4.9.2.1 were same from I to IV. The sprayer was properly mounted on operator's back in standing posture, then

all the steps from VI to x were same for the measurement of effort in downward and upward stroke during operation of sprayers.

4.9.3 Measurement of physiological cost of sprayer operation

Trials were carried out to know the physiological cost of sprayer operation of the modified unit and the Aspee Napsak(SRP-50) unit. The purpose of these trials was to study the heart rate and energy expenditure of the worker while operating the sprayer. For measurement of heart rate during work, the UNI-INSTA ECG telemetry system was used. It had a range of 30 metres. Oxygen consumption and ventilation rates were measured using Morgan Oxylog. The detailed information about these equipment is given in Appendix-II.

4.9.3.1 Procedure

These trials were conducted in the laboratory with five subjects who participated in other experiments. During the experiments, the mean ambient condition was thermally comfortable with air temperature of $33.7 (\pm 2.37)^{\circ}\text{C}$ relative humidity of $58.2 (\pm 4.8)\%$ and air velocity less than 1 m/s.

- 1) Each trial was of 15 minutes duration (5 minutes walking + 10 minutes spraying).

- 2) A laboratory space of 10 mx 3 m was used for carrying out the experiment
- 3) The subject was given the information about the purpose of the study so as to ensure his full cooperation.
- 4) A suitable pressure gauge (0-700 kPa range) was fitted in the lance and necessary arrangement was made to maintain nozzle height at 50 cm level from ground.
- 5) Before starting the actual trials, the subject was asked to mount the sprayer on his back and to carry out spraying operation for 30 minutes. This was done for warming up of the subject. The subject was explained about pressure maintenance technique and maintenance of nozzle height so that he was totally familiarised with the spraying operation. Then a 30-minute rest was given after this period.
- 6) The subject was made ready by fitting him electrodes and telemetry system and Morgan Oxylog to measure heart rate and oxygen uptake of the subject during trials.

- 7) The sprayer was filled with clean water to its full capacity (less the water equivalent to weight of instruments i.e. 3 kg)
- 8) The subject was clamed for 2 minutes in sitting posture and data on heart rate and oxygen uptake of rest condition for one minute were noted.
- 9) The subject was asked to walk at a speed of 2.5 km/h. Heart rate and oxygen uptake data of 4th and 5th minute of walking were noted and the average heart rate and oxygen uptake of walking were noted. The Fig. 4.15 shows the measurement of heart rate and oxygen consumption during walking.
- 10) The sprayer was mounted on the operator's back in standing posture
- 11) The operator was asked to walk at a speed of 2.5 km/h. and to operate the sprayer with necessary stroke frequency to maintain a pressure of 300 kPa during operation. While walking, the lance was held such that the nozzle height as 50 cm from ground level (Fig. 4.15).

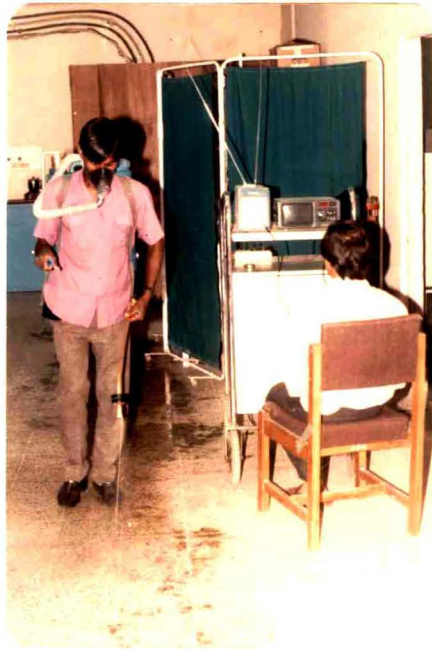


Fig. 4.15

Physiological cost of operation of sprayers

- 12) The data for heart rate and oxygen uptake of 5th to 10th minute of spraying work were noted and the average heart rate and oxygen uptake were found out.
- 13) The sprayer was dismantled after 10 minute spraying trial and the subject was given a rest of 10 minutes.
- 14) The same procedure was repeated three times to get the three sets of reading for each of five subjects.

4.9.4 Test for assessment of postural discomfort during continuous operation of LOK sprayers for 2 hours

4.9.4.1 Procedure

Trials on 2-hour duration each were carried out with five subjects to find the postural discomfort during continuous operation of LOK sprayers. A plot just outside the laboratory having 20 m length was used for these trials. The trials were carried out from 9.30 AM to 11.30 AM each day. During the experiment the mean ambient conditions were as follows air temperature $36.5 (+2.33)^{\circ}\text{C}$, relative humidity of 34.4 (± 6.7) per cent and air velocity between 1.2 to 1.5 m/s.

During the 2 h period the subjects were not given any rest. However he was allowed a short break for personal needs if necessary. During the trials, water for filling the sprayer was made available at one end of the plot. A suitable pressure gauge was connected in the lance near the nozzle and also arrangement was made to keep the nozzle height to 50 cm from ground level. The subject was asked to fill the sprayer with clean water to its full capacity and mount the sprayer himself on his back. An initial pressure of 300 kPa was created before start of the trial. Then the discharge was started and operator was asked to operate the sprayer with necessary frequency to maintain a pressure of 300 kPa (± 10 per cent). During operations, a walking speed of 2.5 km/h, and the nozzle height of 50 cm was maintained by the subject (Fig. 4.16). After all the liquid in the tank was sprayed the subject came back to the end where water was kept. He dismantled the sprayer and repeated the above procedure till the trial time of 2 h was over. The time for each fill, for mounting and filling were noted.

Data on overall discomfort rating and body part discomfort score was recorded as per procedure given below.

4.9.4.2 Procedure for recording overall discomfort rating

- a) The overall discomfort rating were obtained with an eight point psychophysical rating scale (0 = no



Fig. 4.16 Postural discomfort trials of sprayers

discomfort, 7 = extreme discomfort) which was an adaptation of Corlett and Bishop (1976) technique.

- b) A scale of 70 cm in length having 0 to 7 digits, marked on it equidistantly was used. It had a movable pointer to indicate the rating.
- c) At the end of each fill, the subject was asked to indicate the overall discomfort rating on the scale. The last reading was taken at the end of 2 hour work period (Fig. 4.17).

4.9.4.3 Procedure for recording body part discomfort score

- a) To measure localised discomfort, Corlett and Bishop (1976) technique was used.
- b) The body was divided in 27 regions as shown in Fig. 4.18 and discomfort scores were collected using Corlett and Bishop (1976) technique. In this technique, the subject was asked first to indicate the regions which were most painful. Having noted these, the next most painful area were asked for and so on until no further areas were reported by him. The number of different groups of body part which were identified before "No Discomfort" was reported represented the number of intensity level of pain experienced (Fig.4.19).



Fig. 4.17 Recording of severity rating after each fill

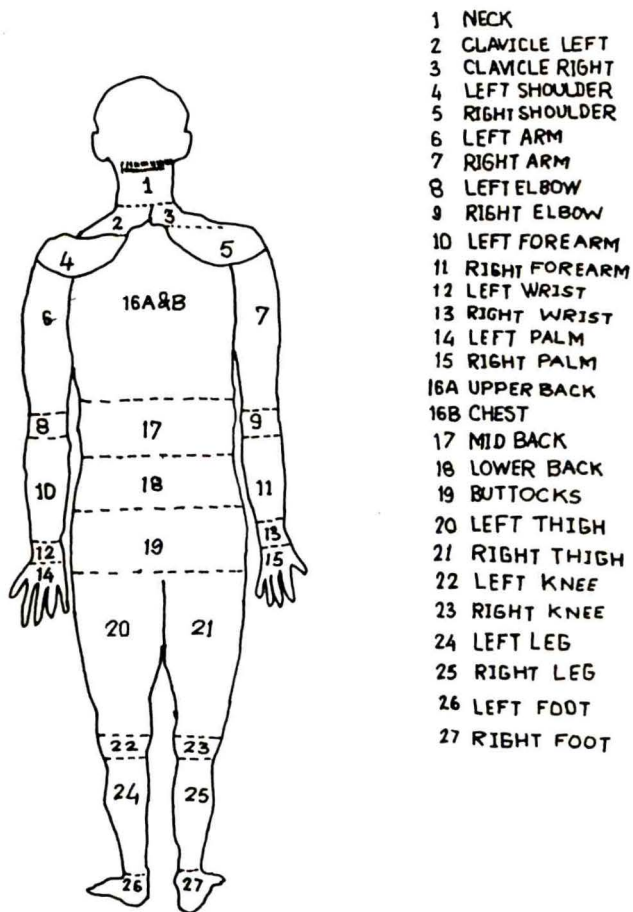


FIG. 4.18: BODY REGIONS FOR ASSESSING POSTURAL DISCOMFORT (USING CORLETT AND BISHOP (1976) SCALE) IN THE OPERATION OF A LEVER OPERATED KNAPSACK SPRAYER



Fig. 4.19

Assessment of intensity level of pain in different body part regions

The overall discomfort ratings given by each of five subjects were added and averaged to get the mean rating. For assessing localised discomfort scores totals were added and averaged to get the mean value.

4.9.4.4 Walking trials

Walking trials of all the subjects were conducted for 2 hours duration (Fig.4.20) to find out postural discomfort due to walking alone. The subject was asked to follow the schedule of their trials during sprayer operation. They were asked to walk during the spraying period and were allowed to stand during the refilling period.

4.9.5 Ergonomics score

4.9.5.1 Criteria for evaluation

The sprayers were evaluated on the following criteria.

- a) Heart rate (HR)
Increase in heart rate (ΔHR) over walking was calculated.
- b) Oxygen uptake ($\dot{V}O_2$)
Increase in oxygen uptake ($\Delta \dot{V}O_2$) over walking was calculated.



Fig. 4.20

Walking trial for assessment of postural discomfort and body part discomfort scores for 2-hour

c) Overall discomfort rating (ODR)

Increase in ODR (ΔODR) over walking was calculated.

d) Body part discomfort score (BPDS)

Increase in BPDS ($\Delta BPDS$) over walking was calculated.

e) Effort required

The muscular effort required in handle operation was considered.

4.9.5.2 Procedure for calculation of score

For calculation purpose, a total score of 100 points was considered as follows :

i) Heart rate (beats/min) If	$\Delta HR = 0$	-	20 points
	$\Delta HR = 70$	-	0 point
ii) Oxygen uptake (l/min)	$\dot{\Delta V}O_2 = 0$	-	20 points
	$\dot{\Delta V}O_2 = 1.2$	-	0 point
iii) Overall discomfort rating (ODR)	$\Delta ODR = 0$	-	20 points
	$\Delta ODR = 5.5$	-	0 point
iv) Body part discomfort score (BPDS)	$\Delta BPDS = 0$	-	20 points
	$\Delta BPDS = 150$	-	0 point

v) Muscular effort (kgf)	FH = 0	-	20 points
(force required in handle operation)	FH = 18	-	0 point

Points were calculated using mean value of five subjects and were added to get the final score out of 100 points, for the Aspee Knapsack as well as modified unit.

NOTE :

A sprayer scoring 100 or near 100 will indicate that the unit can be operated continuously for 8 hours (with normal rest breaks) and there is no fatigue to the operator. This is equivalent to a person walking without any load at 2.5 kmph.

A sprayer scoring 0 or near to 0 will indicate that the unit involves extreme drudgery and operator has to stop the work very early due to excessive muscular stress (may be within 5-10 minutes) or physiological limitations.

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 Preliminary Trials

As mentioned earlier, preliminary trials were carried out on three models of LOK sprayers as per procedure specified by Gite and Pandya (1989). The results of the same are presented below :

5.1.1 Pressure Vs number of stroke relationship

The number of strokes required to build up and maintain 2, 3 and 4 kg/cm² pressure for three different models of LOK sprayers are presented in Tables 5.1 and 5.2, respectively. The data differs from sprayer to sprayer due to variation in size of pressure chamber, pump unit and swept volume. The Napsak, Hi-tech and Hiflo models required 8, 11 and 11 strokes, respectively to build up a pressure of 3 kg/cm². The number of strokes required to maintain a pressure of 3 kgf/cm² were 8, 10 and 9 respectively for these sprayers.

5.1.2 Discharge Vs pressure relationship

The nozzle type used for the study was NMD/SA 60 450. The discharge obtained at three different pressures for these three sprayers are presented in Table 5.3.

Table 5.1: Number of strokes* required to build different pressures in three types of LOK sprayers

Sr. No.	LOK sprayers	Pressure kg/cm ²		
		2	3	4
		No. of strokes		
1.	Aspee Napsak sprayer (SRP-50, 16 l capacity)	7	8	9
2.	Aspee Hi-Tech sprayer (SRP-60, 16 l capacity)	10	11	12
3.	Aspee Hi-Flow sprayer (SRP-55, 12 l capacity)	10	11	12

* Average of five readings

Table 5.2: Number of strokes* required to maintain different pressures in three types of LOK sprayers

Sr. No.	LOK sprayers	Pressure kg/cm ²		
		2	3	4
		No. of strokes		
1.	Aspee Napsak sprayer (SRP-50, 16 l capacity)	6	8	9
2.	Aspee Hi-Tech sprayer (SRP-60, 16 l capacity)	8	10	11
3.	Aspee Hi-Flow sprayer (SRP-55, 12 l capacity)	7	9	10

* Average of five readings

Table 5.3: Discharge * (cc/min) at different pressures in three types of LOK sprayers

Sr. No.	LOK sprayers	(unit: cc/min)		
		Pressure kg/cm ²		
		2	3	4
		Discharge		
1.	Aspee Napsak sprayer (SRP-50, 16 l capacity)	395	455	550
2.	Aspee Hi-Tech sprayer (SRP-60, 16 l capacity)	390	444	532
3.	Aspee Hi-Flow sprayer (SRP-55, 12 l capacity)	400	448	540

* Average of five readings

The volumetric efficiencies of Napsak, Hi-tech and Hi-Flo sprayer were 87.4, 91.7 and 90.8 per cent respectively.

5.2 Optimization of Frequency of Handle Operation and Range of Handle Movement

The experiment was conducted as per the procedure mentioned in section 4.4 on the mechanical simulation setup to study the heart rate and job severity rating for 16 treatment combinations. The replicationwise data are given in Appendix-III and the mean values of three replications are given in Table 5.4, 5.5 and 5.6. The statistical analysis was carried out using Randomized Complete Block Design and the same is given in Table 5.7, 5.8 and 5.9 for heart rate

data, heart rate difference data and job severity rating data respectively. Fig. 5.1 shows the mean heart rate at work along with severity rating plotted against four frequencies of handle operation. The effect of range of handle movement is also shown in the figure.

It can be seen that the mean heart rate was 82.41 beats/min in N_1 treatment and increased to 85.38, 87.51 and 89.83 in N_2 , N_3 and N_4 treatments respectively. This was due to increase in work done as the handle frequency was increased. Similar was the pattern in case of ΔHR and job severity rating. The mean HR (beats/min) values were 11.84, 14.99, 17.18 and 20.75 and the job severity ratings were 1.88, 3.01, 4.11 and 5.17 for N_1 , N_2 , N_3 and N_4 treatments, respectively. Statistical analysis (Table 5.7, 5.8 and 5.9) also showed significant effect of the handle frequency on these parameters at $p = 0.05$ as well as $p = 0.01$.

The data about the effect of range of handle movement are also given in Table 5.7, 5.8 and 5.9. The mean values of heart rate (beats/min) at work were 87.51, 86.46, 85.82 and 85.34 for M_1 , M_2 , M_3 and M_4 treatments. The corresponding values of heart rate difference (ΔHR) were 16.98, 16.19, 15.80 and 15.80 beat/min. The job severity rating given by the subject for these four treatment were

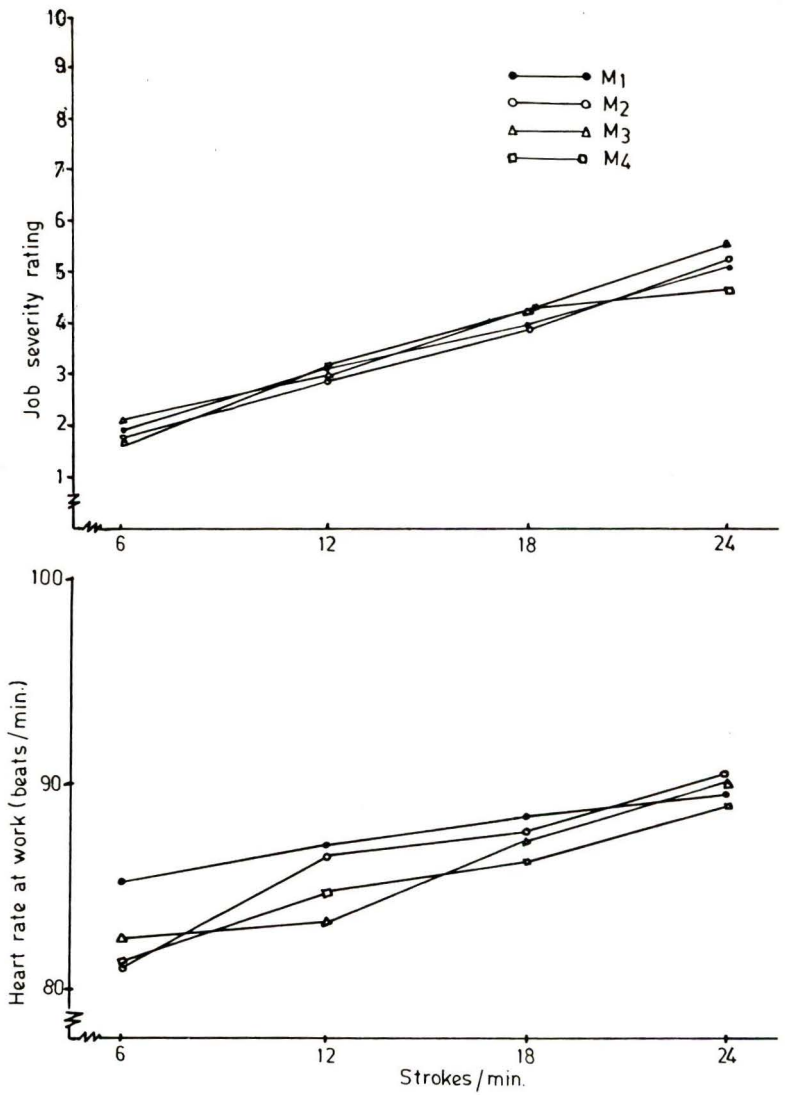


FIG. 5.1 : EFFECT OF FREQUENCIES OF HANDLE OPERATION ON RANGES OF HANDLE MOVEMENT FOR HEART RATE AND JOB SEVERITY RATING.

3.52, 3.47, 3.75 and 3.43, respectively. Thus the M_4 (30° upward and 30° downward with horizontal axis of handle) treatment had the lowest value of the heart rate, heart rate difference and job severity rating. However, the difference in the four treatment in range of handle movement were not significant at $p = 0.05$.

Table 5.4 Effect of four frequencies of handle operation in four ranges of handle movement on heart rate (RCB design)

Range of movement	Heart rate, beats/min					Treatment Total (T)	Mean
	Subjects						
	S_1	S_2	S_3	S_4	S_5		
N_1							
M_1	78.9	94.8	69.9	88.4	93.7	425.5	85.10
M_2	76.9	89.1	67.0	83.9	87.5	404.4	80.88
M_3	78.8	90.1	67.1	86.0	88.9	411.7	82.34
M_4	77.9	83.9	70.9	81.2	92.6	406.5	81.30
	312.4	357.7	274.9	340.4	362.7	1648.1	
N_2							
M_1	82.9	96.0	71.7	88.2	95.7	434.5	86.90
M_2	78.3	101.0	74.1	86.6	93.1	433.1	86.82
M_3	80.9	89.5	67.9	88.2	89.7	416.2	83.24
M_4	80.9	91.4	69.2	90.6	91.7	423.8	84.76
	323.0	377.9	282.9	353.6	370.2	1707.6	

Table 5.4 contd.

		N ₃					
M ₁	82.9	94.2	76.2	94.1	94.3	441.7	88.34
M ₂	82.7	94.4	72.5	92.3	97.5	439.4	87.86
M ₃	82.6	95.1	73.1	89.2	97.6	437.6	87.52
M ₄	82.6	102.1	69.7	83.6	93.4	431.4	86.28
		330.8	385.8	291.5	359.2	382.8	1750.1
		N ₄					
M ₁	84.8	100.2	75.3	90.3	97.8	448.4	89.68
M ₂	82.8	105.5	74.5	91.1	98.5	452.4	90.48
M ₃	86.4	99.5	73.1	93.6	98.2	450.8	90.16
M ₄	83.8	101.3	73.1	88.7	98.1	445.0	89.00
		337.8	406.5	296.0	363.7	392.6	1796.6
Frequency Total							
(R)	1304.0	1527.9	1145.3	1416.9	1508.3		
Grand total						6902.4	

Table 5.5 Effect of four frequencies of handle operation in four ranges of handle movement on heart rate difference (RCB design)

Range of movement	Heart rate, beats/min					Treatment Total (T)	Mean
	Subjects						
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁							
M ₁	12.6	18.8	7.7	12.0	16.3	67.4	13.48
M ₂	7.8	17.6	7.6	8.1	16.0	57.1	11.42
M ₃	10.9	14.7	5.9	11.3	14.9	57.7	11.54
M ₄	10.6	14.4	7.8	8.9	12.9	54.6	10.92
	41.9	65.5	29.0	40.3	60.1	236.8	
N ₂							
M ₁	13.6	24.9	9.9	11.2	17.8	77.4	15.48
M ₂	11.7	23.8	10.7	14.3	17.7	78.2	15.64
M ₃	13.5	20.1	9.9	11.8	14.5	69.8	13.96
M ₄	11.5	19.6	10.8	16.2	16.4	74.5	14.9
	50.3	88.4	41.3	53.5	66.4	299.9	
N ₃							
M ₁	17.3	25.5	10.2	15.2	22.5	90.7	18.14
M ₂	13.2	22.4	11.3	14.0	21.1	82.0	16.4
M ₃	14.2	23.5	13.4	13.1	20.2	84.4	16.88
M ₄	12.7	26.9	12.9	13.9	20.2	86.6	17.32
	57.4	98.3	47.8	56.2	84.0	343.87	

Table contd.

	N ₄						
M ₁	14.3	28.8	16.5	18.6	25.9	104.1	20.82
M ₂	18.7	31.6	15.6	19.9	20.8	106.6	21.32
M ₃	20.0	28.3	12.4	19.1	24.3	104.1	20.82
M ₄	14.9	130.6	13.3	19.6	21.9	100.3	20.06
	67.9	119.3	57.8	77.2	92.9	415.1	
Frequency Total (R)	217.5	371.5	175.9	227.2	303.4		
Grand total							1295.5

Table 5.6 Effect of four frequencies of handle operation in four ranges of handle movement on job severity rating (RCB design)

Range of movement	Severity rating					Treatment Total (T)	Mean
	Subjects						
	S ₁	S ₂	S ₃	S ₄	S ₅		
	N ₁						
M ₁	1.3	1.0	2.7	2.7	1.7	9.4	1.88
M ₂	2.0	1.0	1.7	2.0	2.3	9.0	1.80
M ₃	2.0	1.3	2.0	2.7	2.7	10.7	2.14
M ₄	2.3	1.3	1.3	2.3	1.3	8.5	1.70
	7.6	4.6	7.7	9.7	8.0	37.6	

Table contd.

	N ₂						
M ₁	3.0	2.7	3.7	3.0	3.0	15.4	3.08
M ₂	3.0	2.3	2.7	3.3	3.0	14.3	2.86
M ₃	2.3	3.0	3.0	3.0	3.7	15.0	3.0
M ₄	2.7	3.0	3.7	2.7	3.3	15.4	3.08
	11.0	11.0	13.1	12.0	13.0	60.1	

	N ₃						
M ₁	4.7	4.3	3.0	3.7	4.3	20.4	4.0
M ₂	3.3	3.7	5.0	3.3	4.3	19.6	3.92
M ₃	5.0	4.3	4.7	4.0	3.3	21.3	4.26
M ₄	4.7	4.3	4.3	4.3	3.7	21.3	4.26
	17.7	16.6	17.0	15.3	15.6	82.2	

	N ₄						
M ₁	4.3	5.3	5.3	5.0	5.7	25.6	5.12
M ₂	6.0	5.3	4.7	4.7	5.7	26.4	5.28
M ₃	6.3	5.7	5.0	4.7	6.3	28.0	5.60
M ₄	4.7	5.0	4.7	5.0	4.0	23.4	4.68
	21.3	21.3	19.7	19.4	21.7	103.4	

Frequency							
Total (R)	57.6	53.5	57.3	56.4	58.3		
Grand total						283.3	

Table 5.7: Statistical analysis of heart rate data given in Table 5.4

The frequency x range table of totals

Range of movement	Heart rate beats/min (A x B)				Range Total (B)	Mean
	Frequency of handle operation					
	N ₁	N ₂	N ₃	N ₄		
M ₁	425.5	434.5	441.7	448.4	1750.1	87.51
M ₂	404.4	433.1	439.4	452.4	1729.3	86.47
M ₃	411.7	416.2	437.6	450.8	1716.3	85.82
M ₄	406.5	423.8	431.4	445.0	1706.7	85.34
Frequency Total (A)	1648.1	1707.6	1750.1	1796.6	6902.4	
Mean	82.41	85.38	87.51	89.83		

Analysis of variance of data for 4 x 4 factorial experiment in RCB design

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	6284.74	1571.19	230.04	2.52	3.65
Treatment	15	714.61	47.64	6.98	1.83	2.36
Frequency (A)	3	598.58	194.53	29.21	2.76	4.13
Range (B)	3	52.88	17.63	2.58	2.76	4.13
A x B	9	63.15	7.02	1.03	2.04	2.72
Error	60	409.76	6.83			
	79	7409.11				
C.D. (5%) for frequency	=	1.652776				
C.D. (5%) for movement	=	1.652776				
C.D. (5%) for Interaction	=	3.305557				

Summary of heart rate data

Range of movement	Frequency				Mean (Beats/min)
	N ₁	N ₂	N ₃	N ₄	
M ₁	85.1	86.90	88.34	89.68	87.51
M ₂	80.88	86.82	87.86	90.48	86.46
M ₃	82.34	83.24	87.52	90.16	85.82
M ₄	81.30	84.76	86.28	89.0	85.34
Mean	82.41	85.38	87.51	89.83	
Range of movement	-				Not significant
Frequency C.D. at 5%	-				1.65 beats/min

Table 5.8: Statistical analysis of heart rate difference (Δ HR) given in Table 5.5

The frequency x range table of totals

Range of movement	Heart rate difference beats/min (A x B)				Range Total (B)	Mean
	Frequency of handle operation					
	N ₁	N ₂	N ₃	N ₄		
M ₁	67.4	77.4	90.7	104.1	339.6	16.98
M ₂	57.1	78.2	82.0	106.6	323.9	16.19
M ₃	57.7	69.8	84.4	104.1	316.0	15.8
M ₄	54.6	74.5	86.6	100.3	316.0	15.8
Frequency Total(A)	236.8	299.9	343.7	415.1	1295.5	
Mean	11.84	14.99	17.18	20.75		

Analysis of variance of data for 4 x 4 factorial experiment in RCB design

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	1516.66	379.17	98.74	2.52	3.65
Treatment	15	883.52	58.90	15.33	1.83	2.36
Frequency (A)	3	843.59	281.19	73.22	2.76	4.13
Range (B)	3	18.56	6.18	1.61	2.76	4.13
A x B	9	21.37	2.37	0.61	2.04	2.72
Error	60	230.25	3.84			
	79	2630.43				

C.D. (5%) for frequency = 1.238983

C.D. (5%) for movement = 1.238983

C.D. (5%) for Interaction = 2.477965

Summary of heart rate different data

(Beats/min)

Range of movement	Frequency				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	13.48	15.48	18.14	20.82	16.98
M ₂	11.42	15.64	16.4	21.32	16.19
M ₃	11.54	13.96	16.88	20.82	15.8
M ₄	10.92	14.9	17.32	20.06	15.8
Mean	11.84	14.99	17.18	20.75	

Range of movement - Not significant

Frequency C.D. at 5% - 1.24 beats/min

Table 5.9: Statistical analysis of job severity rating given in Table 5.6

The frequency x range table of totals

Range of movement	Severity rating (A x B)				Range Total (B)	Mean
	Frequency of handle operation					
	N ₁	N ₂	N ₃	N ₄		
M ₁	9.4	15.4	20.0	25.6	70.4	3.52
M ₂	9.0	14.3	19.6	26.4	69.3	3.47
M ₃	10.7	15.0	21.3	28.0	75.0	3.75
M ₄	8.5	15.4	21.3	23.4	68.6	3.43
Frequency Total (A)	37.6	60.1	82.2	103.4	283.3	
Mean	1.88	3.0	4.11	5.17		

Analysis of variance of data for 4 x 4 factorial experiment in RCB design

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	0.90	0.23	0.70	2.52	3.65
Treatment	15	123.83	8.25	25.78	1.83	2.36
Frequency (A)	3	120.47	40.15	125.48	2.76	4.13
Range (B)	3	1.25	0.41	1.30	2.76	4.13
A x B	9	2.11	0.23	0.73	2.04	2.72
Error	60	19.39	0.32			
	79	144.12				
C.D. (5%) for frequency	=	0.3595199				
C.D. (5%) for movement	=	0.3595199				
C.D. (5%) for Interaction	=	0.7190398				

Summary data of job severity rating

Range of movement	Frequency				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	1.88	3.08	4.0	5.12	3.52
M ₂	1.80	2.86	3.92	5.28	3.47
M ₃	2.14	3.0	4.26	5.60	3.75
M ₄	1.70	3.08	4.26	4.68	3.43
Mean	1.88	3.01	4.11	5.17	

Range of movement - Not significant
 Frequency C.D. at 5% - 0.36

5.3 Optimization of Frequency of Handle Operation for Constant Workload

5.3.1 Short duration (10 minutes) trials

From the data of experiment 1, no conclusion could be drawn about the optimum frequency of handle operation. Therefore, another study (Experiment-2) was carried out for this purpose as given in section 4.5.1. Here the range of handle movement was kept constant as 30° upward and 30° downward from horizontal; keeping the work done constant, the effect of handle frequency on heart rate, heart rate difference and job severity rating was observed. The data for two replications along with statistical analysis given is Appendix III.

Table 5.10: Effect of frequency of handle operation (for constant work load) on heart rate of the subjects (Expt. 2)

Treatment	(beats/min)					Total	Mean
	Subjects						
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁	81.4	88.1	70.7	89.1	90.1	419.4	83.88
N ₂	79.4	85.7	69.2	90.8	90.4	415.5	83.10
N ₃	81.1	86.5	69.8	85.8	84.4	407.6	81.52
N ₄	80.5	85.7	67.9	87.3	87.7	409.1	81.82
N ₅	80.2	87.6	67.8	89.3	87.5	412.4	82.48
N ₆	81.2	87.6	68.2	89.2	91.4	417.6	83.52
Total	483.8	521.2	413.6	531.5	531.5	2481.6	

(Data is mean of two replications)

Table 5.11: Statistical analysis of data in Table 5.10

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	1682.27	420.56	203.17	2.87	4.43
Treatment	5	22.19	4.44	2.14	2.71	4.10
Error	20	41.47	2.07			

C.D. at 5% level = 1.89 beats/min

Table 5.10 gives the heart rate data (mean of two replications). The lowest heart rate (81.52 beats/min) was observed for N_3 and the highest value (83.88 beats/min) was for N_1 treatment. Thus all the values were very close with each other and therefore statistically no significance was observed at $p = 0.05$ (Table 5.11).

The data on heart rate difference are given in Table 5.12. The lowest difference was observed for N_3 treatment (10.72 beats/min) and the highest (15.18 beats/min) for N_1 treatment. Statistical analysis (Table 5.13) showed significant effect on handle frequency on heart rate difference (ΔHR). The treatment N_3 and N_4 were at par. But N_3 was significantly better than N_1 , N_2 , N_5 and N_6 treatments. Where N_4 was significantly better than N_1 and N_6 treatment considering the HR data.

The data on job severity rating as given in Table 5.14. The treatment N_3 has the minimum rating (1.0) whereas N_1 had the maximum rating (3.9). Statistical analysis (Table 5.15) showed significance effect of handle frequency on job severity rating. The treatment N_3 , N_4 and N_5 were at par and significantly better than N_1 , N_2 and N_6 treatments. At the lower frequency the effort required was higher and therefore subject felt the job strenuous. At higher frequency (36 strokes/min) though the effort was very low (2 kgf) the subject experienced muscular fatigue and gave higher rating.

Table 5.12: Effect of frequencies of handle operation (for constant work load) on heart rate difference of the subjects (Expt. 2)

Treatment	(beats/min)					Total	Mean
	Subjects						
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁	11.8	20.6	12.7	14.5	16.3	75.9	15.18
N ₂	11.1	16.7	9.6	11.8	12.1	61.3	12.26
N ₃	11.8	14.4	7.5	9.5	10.4	53.6	10.72
N ₄	10.4	17.3	8.9	11.2	11.1	58.9	11.78
N ₅	12.5	16.6	8.0	12.0	13.5	62.5	12.5
N ₆	12.3	20.1	10.1	13.4	14.0	69.9	13.98
Total	69.9	105.6	56.8	72.4	77.4	382.1	

(Data is mean of two replications)

Table 5.13: Statistical analysis of data in Table 5.12

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	216.0	54.0	48.64	2.87	4.43
Treatment	5	63.9	12.78	11.51	2.71	4.10
Error	20	22.35	1.11			

C.D. at 5% level = 1.39 beats/min

Table 5.14: Effect of frequencies of handle operation (for constant work load) on job severity rating of the subjects (Expt. 2)

Treatment	Subjects					Total	Mean
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁	4.0	3.5	3.0	4.5	4.5	19.5	3.9
N ₂	2.5	1.5	2.0	2.0	2.0	10.0	2.0
N ₃	1.0	1.0	1.0	1.0	1.0	5.0	1.0
N ₄	1.0	1.0	1.5	1.0	1.0	5.5	1.1
N ₅	1.0	1.0	1.0	1.5	1.5	6.0	1.2
N ₆	2.5	2.5	2.5	2.5	3.0	13.0	2.6
Total	12.0	10.5	11.0	12.5	13.0	59.0	

(Data is mean of two replications)

Table 5.15: Statistical analysis of data in Table 5.14

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	0.72	0.18	1.8	2.87	4.43
Treatment	5	32.07	6.41	64.1	2.71	4.10
Error	20	2.18	0.10			

C.D. at 5% level = 0.42

Fig. 5.2 shows the effect of handle frequency on data of heart rate at work, HR and job severity rating together. N_3 from this figure and statistical analysis (Table 5.11, 5.13 and 5.15), the handle frequency of N_3 and N_4 (i.e. 18 and 24 strokes/min) can be considered as the optimum one for LOK sprayer operation.

5.3.2 Long duration (30-minute) trials

Experiment-3 was conducted as per the procedure in section 4.5.2 to confirm and support the findings of experiment 2. Generally, a sprayer fill lasts for about 30 minutes and therefore, the trial duration was kept as 30 minutes. As N_1 and N_6 were clearly identified as very strenuous, the experiment was carried out with only for four treatment i.e. N_2 , N_3 , N_4 and N_5 . As the workload is light to moderate the heart rate pattern was likely to remain same and, therefore data on only job severity rating was noted in this experiment. As this was long duration trials only one replication was carried out for each of five subjects.

Table 5.16 gives the data on job severity rating for different handle frequencies. The subjects gave lowest rating of 2.2 for N_4 treatment followed by 2.6 for N_3 and N_5 treatment. The treatment N_2 was felt strenuous and had the rating of 4.0. The statistical analysis (Table 5.17) showed that the treatments N_3 , N_4 and N_5 were at par but significantly better than N_2 treatment.

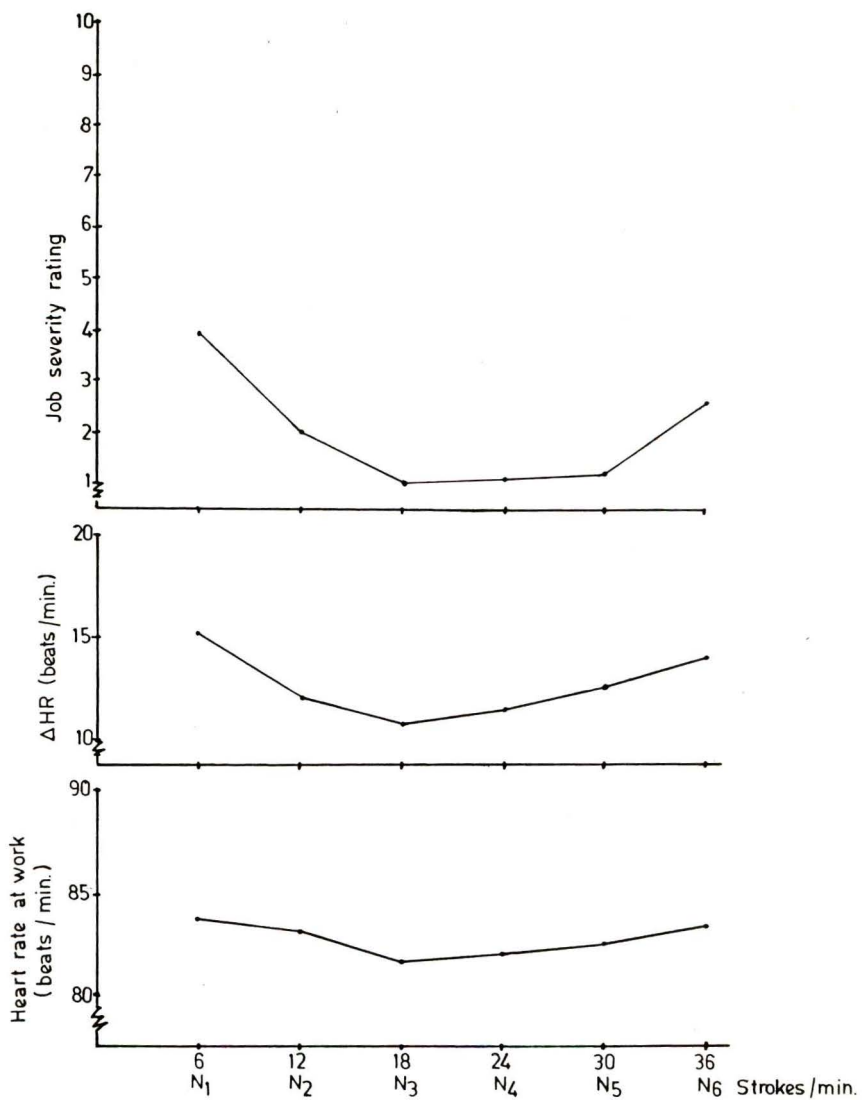


FIG. 5.2: EFFECT OF FREQUENCY OF HANDLE OPERATION (FOR CONSTANT WORK LOAD) ON HEART RATE, Δ HR AND JOB SEVERITY RATING FOR 10-MINUTE TRIAL.

Table 5.16: Data of job severity rating of five subjects for 30 minutes duration trials (Expt.3)

Treatment	Subjects					Total	Mean
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₂	3	4	4	5	5	20	4
N ₃	2	3	3	3	2	13	2.6
N ₄	2	2	2	2	3	11	2.2
N ₅	1	3	3	2	4	13	2.6
Total	8	12	12	12	13	57	

Table 5.17: Statistical analysis of data in Table 5.16

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	3.8	0.95	2.11	3.26	5.41
Treatment	3	9.35	3.11	6.91	3.49	5.95
Error	12	5.4	0.45			

C.D. at 5% level = 0.92

The rating in these trials were higher than these of 10 minute duration trials due to the increased muscular fatigue experienced by the subject. However; the pattern of rating was similar (Table 5.18).

Table 5.18: Data of job severity rating* for 10 minute and 30 minute duration trials

Sr.No.	Treatment	Job severity rating	
		10 minutes duration trials	30 minutes duration trials
1.	N ₂	2.0	4.0
2.	N ₃	1.0	2.6
3.	N ₄	1.1	2.2
4.	N ₅	1.2	2.6

* Mean of five subjects

5.4 Maximum Strength in Elbow Extension and Flexion

This experiment (No.4) was carried out on the setup shown in Fig. 4.9. The maximum muscular effort exerted in elbow extension and flexion was studied at seven positions of elbow angles i.e. 60, 70, 80, 90, 100, 110 and 120 degrees keeping the upper arm vertical. The maximum muscular effort was applied and kept constant for 3 seconds. The data is presented in Table 5.19 and statistical analysis in Table 5.20 and 5.21, respectively.

Table 5.19: Data of maximum muscular strength in kgf for five subjects in elbow extension and flexion (Expt. 4)

Sr. No.	Elbow position degree	Extension kgf					Mean	Flexion kgf					Mean
		S ₁	S ₂	S ₃	S ₄	S ₅		S ₁	S ₂	S ₃	S ₄	S ₅	
1	60	7.66 (0.57)	10.66 (1.15)	11.66 (1.52)	9.33 (1.15)	7.0 (1.0)	9.26 (1.15)	9.66 (1.15)	14.66 (1.15)	14.0 (0.0)	12.0 (0.0)	12.0 (0.0)	12.46 (0.14)
2	70	9.33 (0.57)	11.33 (2.30)	10.0 (1.0)	11.66 (0.57)	8.66 (1.15)	10.19 (1.18)	10.0 (0.0)	15.0 (1.0)	14.66 (0.57)	14.0 (2.0)	9.33 (1.15)	12.59 (0.94)
3	80	10.66 (1.15)	16.0 (2.0)	10.0 (0.0)	12.33 (1.52)	8.33 (0.57)	11.46 (1.31)	11.33 (1.15)	17.33 (1.15)	15.33 (0.57)	13.66 (2.30)	16.0 (2.0)	14.73 (1.50)
4	90	10.0 (0.0)	22.0 (3.40)	9.0 (1.0)	11.0 (1.0)	9.0 (0.0)	12.2 (1.82)	14.0 (0.0)	18.66 (1.15)	17.66 (0.57)	16.66 (2.30)	18.00 (2.0)	16.99 (1.50)
5	100	9.66 (0.57)	20.0 (0.0)	10.0 (0.0)	12.0 (1.0)	8.66 (0.57)	12.06 (0.43)	18.0 (0.0)	22.66 (1.15)	17.66 (0.57)	19.44 (1.15)	14.0 (1.73)	19.33 (1.15)
6	110	9.66 (0.57)	19.33 (1.52)	9.0 (1.0)	16.0 (0.0)	9.66 (1.15)	12.73 (0.85)	19.66 (3.5)	32.0 (2.0)	19.0 (1.0)	30.66 (1.15)	19.66 (1.52)	24.19 (1.83)
7	120	9.33 (1.15)	16.0 (0.0)	9.33 (1.15)	15.66 (1.0)	10.0 (0.0)	12.06 (0.77)	28.33 (0.52)	24.66 (4.61)	18.0 (0.0)	34.66 (1.15)	20.66 (1.15)	25.26 (2.10)

Mean of three replications

() Standard deviation

Table 5.20: Statistical analysis of data from Table 5.19 for elbow extension

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	280.29	70.07	14.35	2.78	4.22
Treatment	6	46.33	7.72	1.58	2.51	3.67
Error	24	117.18	4.88			

C.D. at 5% level = 2.88

Table 5.21: Statistical analysis of data from Table 5.19 for elbow flexion

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	148.15	37.03	3.06	2.78	4.22
Treatment	6	824.08	137.34	11.35	2.51	3.67
Error	24	290.58	12.10			

C.D. at 5% level = 4.54

The maximum muscular effort exerted in elbow extension was 9.26 (± 1.15) kgf at 60° elbow angle and increased to 12.73 (± 0.85) kgf at 110° elbow angle. However, almost statistically the strength difference in extension at these elbow angles were found to be non-significant. The

maximum muscular effort exerted in elbow flexion was 12.46 (\pm 0.14) kgf at 60° elbow angle and increased to 25.26 (\pm 2.10) kgf at 120° elbow angle. The muscular strength continuously increased from 60° to 120° elbow angles. The strength at flexion increased regularly as the arm was strengthened until the elbow angle reached to 120° but the strengthen in elbow extension decreased beyond the 110° elbow angle. Sato and Ohashi (1989) reported the strength of the maximal voluntary contraction (MVC) measured at the wrist with elbow at right angle as 26.7 (\pm 3.5) kgf in men and 16.3 (\pm 2.3) kgf in women. Seki (1990) found isometric muscle strength of elbow flexion and elbow extension. The maximal strength of the right arm for elbow flexion was 14.3 to 22.1 (Mean \pm S.D. 17.0 \pm 2.4) kgf and left arm 12.8 to 17.6 (15.3 \pm 1.7) kgf and for elbow extension for right arm 6.4 to 13.7 kgf and for left arm 6.7 to 12.9kgf. From the data of Morehouse (1959), Caldwell (1962), Murrell (1975) and Ghugare (1989) suggested the maximum strength of elbow flexion and extension as 27.0 kgf and 18 kgf respectively.

The present study gave the maximum strength in elbow extension and flexion as 12.73 kgf and 25.26 kgf, respectively (Fig. 5.3).

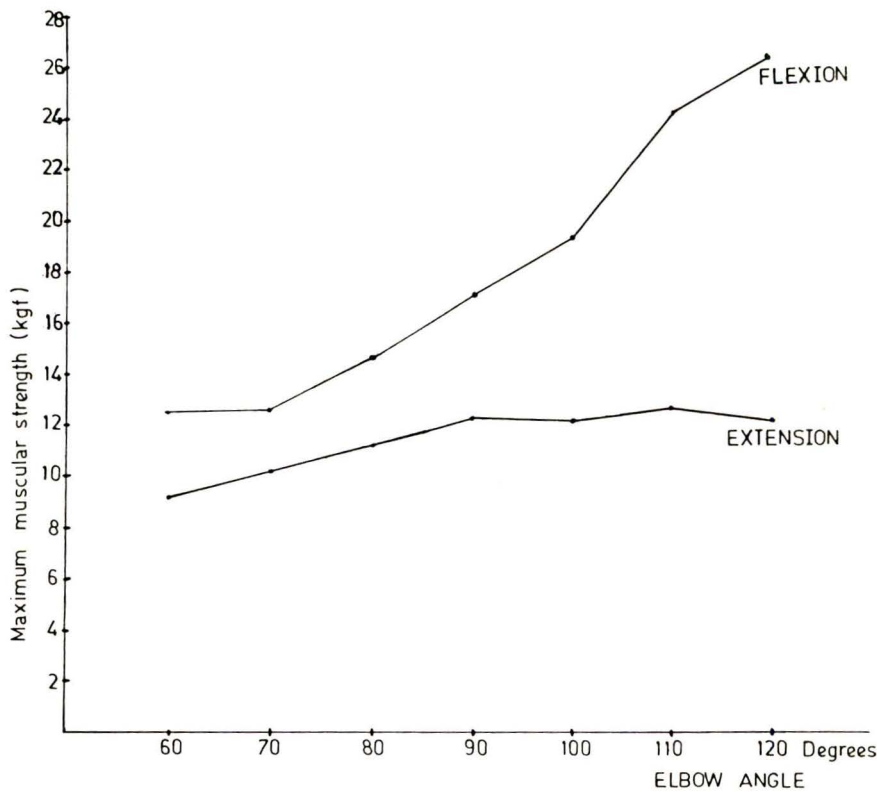


FIG. 5.3 : MAXIMUM MUSCULAR STRENGTH IN ELBOW EXTENSION AND FLEXION AT SEVEN POSITIONS OF ELBOW ANGLE .

5.5 Sprayer Pump Design with Computer Programming

As mentioned in section 4.7, data on 216 combination of piston diameter, stroke length, and volume of pressure chamber were generated using the computer programme given in Appendix IV. Fig. 5.4 shows the plot of handle frequency (no. of strokes/min) against swept volume for 450 ml/min discharge and 0.90 volumetric efficiency. Based on the data of earlier experiments (No.1, 2 and 3) swept volume was decided for 18 and 24 strokes/min. The values of swept volume were 27.07 and 21.09 cc, respectively.

According to Wely (1970) dynamic effort of a repetitive nature should not exceed 30 per cent of the maximum. Accordingly the muscular effort in handle operation of sprayer should not exceed $0.30 \times 12.73 = 3.82$ kgf while selecting the pump parameters this limit was kept into consideration. The diameter of piston was decided as 2.5 cm and stroke length was decided as 5.7cm and 4.3 cm for sprayers having 18 and 24 strokes/min, respectively.

5.6 Ergonomics Evaluation

As given in section 4.9 ergonomic evaluation of modified unit and one existing unit was carried out. Tables 5.22, 5.23, 5.24 and 5.25 gives data for modified sprayer on preliminary trials, muscular effort requirement trials,

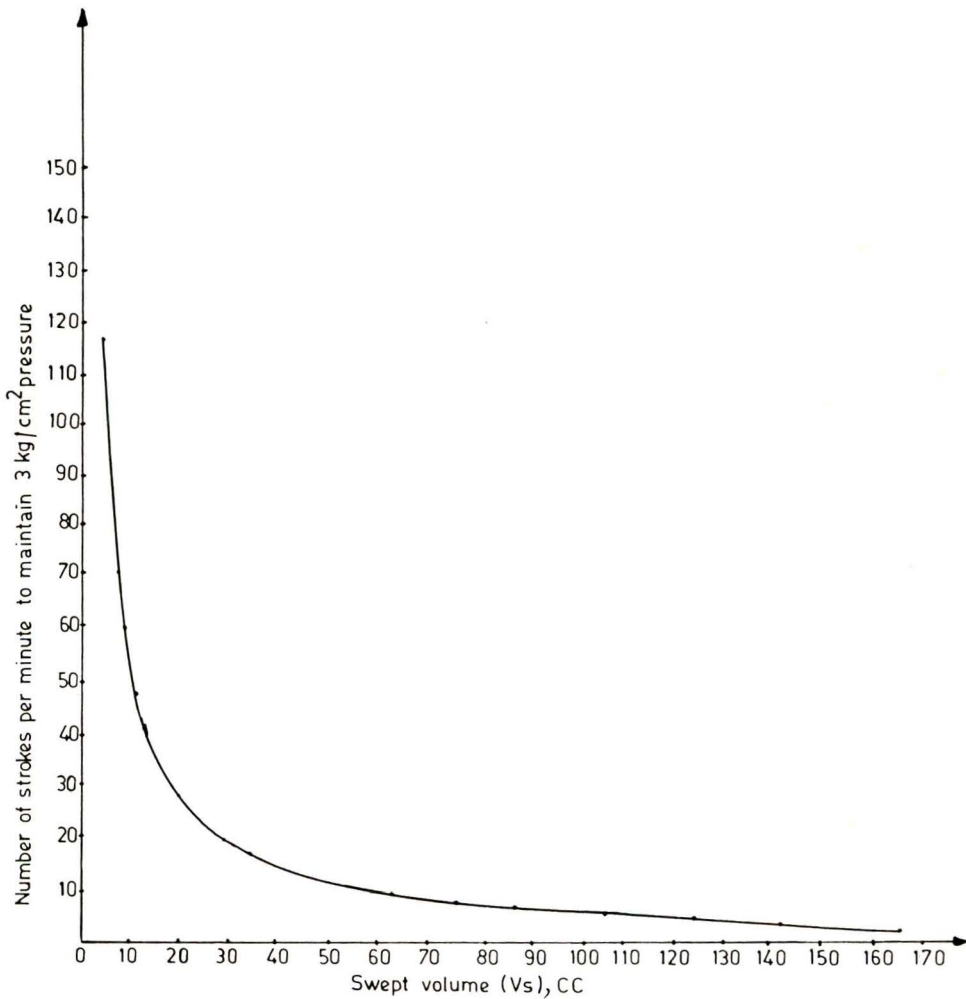


FIG. 5.4 : THEORETICAL RELATIONSHIP BETWEEN SWEEPED VOLUME AND NUMBER OF STROKES PER MINUTE REQUIRED TO MAINTAIN 3 KG/CM² PRESSURE.

physiological cost trials and postural discomfort trials. The ergonomic score calculated from these data for the modified sprayer is given in Table 5.26.

Specification of modified sprayer

Particulars	Measurements
1. Type of sprayer	Fabricated at ARI, Bombay
2. Normal working pressure, kg/cm^2	3.0
3. Overall dimension	
i) Length, mm	135
ii) Width, mm	320
iii) Height, mm	330
iv) Tank capacity, l	12
5. Weight of sprayer, kg	
i) Without water, kg	5.2
ii) With water, kg	17.2
6. Inside diameter of cylinder, mm	25
7. Stroke length, mm	43
8. Volume of pressure chamber, cc	500
9. Length of operating lever arm, mm	490
10. Length of crank arm, mm	45
11. Type of agitator	-
12. Area of filler hole, cm^2	70.88

13. Type of nozzle	Duromist NMD/S A 60 450
14. Length of lance mm	610
15. Weight of lance + nozzle, kg	0.25
16. Length of hose, mm	1100
17. Material of construction	
i) Tank	High density polythelene
ii) Pressure chamber	Brass
iii) Pump cylinder	Brass
iv) Piston	High density polythelene
v) Lance	Brass
vi) Nozzle	Brass
vii) Straps	Cotton
18. Width of straps, mm	38
19. Normal position of operating lever	Right
20. Whether there is provision to change position of handle (right or left)	Yes
21. Movement of operating lever	
i) Upward stroke, degree	30
ii) Downward stroke, degree	30
22. Number of strokes required to operate sprayer at 3 kg/cm ² pressure	
i) To create, no.	18
ii) To maintain, no.	24

Table 5.22: Preliminary trials of modified sprayer,
12 litre capacity

Particulars	Replications			Mean	S.D.
	1	2	3		
A) Pressure development and maintenance test					
i) No. of strokes required for create pressure of 300 kPa	18	18	18	18	0.0
ii) No. of strokes required to maintain a pressure of 300 kPa (± 10 per cent)	23.5	24	24	23.83	0.28
B) Discharge test					
i) Discharge (cc/min) at a pressure of 300 kPa (± 10 per cent)	445	445	445	445	0.0
ii) Pressure (kPa) variation range	2.70 to 3.20	2.60 to 3.30	2.70 to 3.30	2.70 to 3.30	
C) Volumetric efficiency test					
i) Discharge in 10 working strokes at 300 kPa (± 10 per cent) pressure, ml	190	195	190	191.67	2.88
ii) Volumetric efficiency per cent	90.00	92.37	90.00	90.97	1.36

Table 5.23: Muscular effort required in handle operation of modified (12, 1 capacity) sprayer

A) In rigid mounting

(Effort in kgf)

Stroke	Replication			Mean (S.D.)
	1	2	3	
a) Pressure stroke (Downward)	2.50	2.39	2.34	2.41 (0.08)
b) Suction stroke (Upward)	0.80	0.87	0.81	0.82 (0.04)

B) With sprayer mounted on subject's back

Sr. Subject No.	Replication						Mean S.D.	
	1		2		3		Down	Up
	Down	Up	Down	Up	Down	Up		
1. BK	3.29	0.90	2.94	0.86	3.25	1.02	3.16 (0.19)	0.92 (0.08)
2. MJ	3.48	0.78	3.92	0.80	3.82	1.07	3.74 (0.23)	0.88 (0.16)
3. HS	2.67	0.81	2.41	1.0	2.49	0.69	2.52 (0.13)	0.83 (0.15)
4. CR	3.0	1.11	3.30	1.52	2.99	1.62	3.09 (0.18)	1.41 (2.7)
5. AS	2.91	1.51	2.94	1.40	2.93	0.98	2.93 (0.02)	1.17 (0.29)
Mean	3.07	1.02	3.10	1.04	3.09	1.08	3.08	1.04
S.D.	0.32	0.30	0.55	0.28	0.48	0.34	0.44	0.24

Location of trials : Inside laboratory

Table 5.24: Measurement of physiological cost of modified sprayer operation
Heart rate (HR) and oxygen uptake (\dot{V}_{O_2}) data

Sr. No.	Sub-ject	Trial	HR (beats/min)			\dot{V}_{O_2} (l/min)		
			Rest	Walking	Work	Rest	Walking	Work
1.	BK	I	73.33	81.34	92.15	0.12	0.33	0.39
		II	71.42	80.37	90.48	0.14	0.28	0.35
		III	70.95	79.34	89.57	0.16	0.27	0.34
	Mean	71.9	80.35	90.73	0.14	0.29	0.36	
	S.D.	1.17	1.46	1.31	0.02	0.03	0.03	
2.	MJ	I	81.65	87.26	96.33	0.14	0.33	0.40
		II	79.85	86.20	97.78	0.13	0.30	0.38
		III	79.34	85.78	96.48	0.14	0.30	0.37
	Mean	80.28	86.41	96.86	0.14	0.31	0.38	
	S.D.	2.61	2.10	2.03	0.05	0.02	0.02	
3.	HS	I	61.81	66.13	74.89	0.08	0.17	0.23
		II	60.23	64.82	73.02	0.08	0.17	0.23
		III	60.51	64.35	73.09	0.08	0.18	0.23
	Mean	60.85	65.1	73.67	0.08	0.17	0.23	
	S.D.	1.26	1.29	1.25	0.0	0.05	0.00	
4.	CR	I	79.72	86.69	92.98	0.12	0.21	0.27
		II	77.89	83.87	91.79	0.08	0.20	0.25
		III	76.05	82.76	92.26	0.07	0.17	0.24
	Mean	77.89	84.44	92.34	0.09	0.19	0.25	
	S.D.	1.34	1.27	1.14	0.03	0.02	0.01	
5.	AS	I	82.10	87.46	95.80	0.08	0.23	0.33
		II	81.62	86.70	96.71	0.14	0.25	0.37
		III	-	-	-	-	-	-
	Mean	81.86	87.08	96.26	0.11	0.24	0.35	
	S.D.	1.41	1.65	1.41	0.04	0.03	0.03	
Mean	74.56	80.68	89.97	0.11	0.24	0.31		
S.D.	8.54	9.09	9.47	0.03	0.06	0.06		

a) Location : Inside laboratory

b) Hours of day when test were conducted : 10 A.M. to 12.0 Noon

c) Ambient condition (1) Temperature- 35°C (2) RH-54.17%
(3) Air velocity- 0.8 m/sec.

Table 5.25: Data on assesment of postural discomfort during spraying operation of modified sprayer

Sr. No.	Subject		ODR		BPDS*	
			Walking	Spraying	Walking	Spraying
1.	BK	After fill				
		I	0.6	2		
		II	1.0	2		
		III	1.5	3		
		2-hour	1.75	5	18.64	53.0
2.	MJ	After fill				
		I	0.7	1		
		II	1.0	2		
		III	1.50	4		
		2-hour	2.0	5	20.0	75.0
3.	HS	After fill				
		I	0.5	2		
		II	0.8	3		
		III	1.0	4		
		2-hour	1.5	5	20.0	81.0
4.	CR	After fill				
		I	0.6	2		
		II	1.2	3		
		III	1.5	4		
		2-hour	2.0	5	23.98	57.0
5.	AS	After fill				
		I	0.5	1		
		II	1.0	2		
		III	1.75	3		
		2-hour	2.0	4	18.64	72.0
Mean (after 2-hour)			1.85	4.8	20.25	67.6
S.D.			0.22	0.44	2.19	12.03

* - BPDS was calculated after 2-hour operation of walking and spraying

Table 5.26: Ergonomics score of modified (12 l capacity) sprayer

Sr. No.	Criterion	Maximum points	Points given (based on data)	Remarks
1.	Heart rate (HR)	20	17.3	
2.	Oxygen uptake (V_{O_2})	20	18.8	
3.	Overall discomfort rating (ODR)	20	9.3	
4.	Body part discomfort score total (BPDS)	20	13.7	
5.	Muscular effort (force required in handle operation)	20	16.6	
Points		100	75.7	

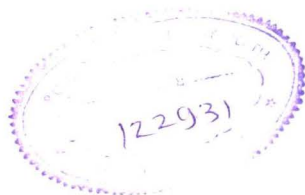


Table 5.27, 5.28, 5.29 and 5.30 gives data for Aspee Napsak sprayer on preliminary trials, muscular effort requirement trials, physiological cost trials and postural discomfort trials, respectively. The ergonomic score calculated from these data for Aspee Napsak sprayer is as given in Table 5.31.

Specification of ASPEE NAPSAK

Particulars	Measurements
1. Type of sprayer	LOK
2. i) Make	ASPEE NAPSAK
ii) Manufacturer	ASPEE
iii) Model	SRP-50
iv) Market price	Rs. 650/-
3. Normal working pressure, kg/cm^2	3.0
4. Overall dimension	
i) Length, mm	170
ii) Width, mm	360
iii) Height, mm	317
5. Tank capacity, l	16
6. Weight of sprayer, kg	
i) Without water, kg	5.8
ii) With water, kg	21.8
7. Inside diameter of cylinder, mm	43
8. Stroke length, mm	
i) Maximum, mm	59
ii) Normal, mm	41.9
9. Volume of pressure chamber, cc	690
10. Length of operating lever arm, mm	435
11. Length of crank arm, mm	69
12. Type of agitator	Mechanical

13. Area of filler hole, cm^2	70.88
14. Type of nozzle	Duromist NMD/S A 60 450
15. Length of lance mm	610
16. Weight of lance + nozzle, kg	0.25
17. Length of hose, mm	1100
18. Material of construction	
i) Tank	High density polythelene
ii) Pressure chamber	Brass
iii) Pump cylinder	Brass
iv) Piston	Rubber
v) Lance	Brass
vi) Nozzle	Brass
vii) Straps	Cotton
19. Normal position of operating lever	Right
20. Whether there is provision to change position of handle (right or left)	Yes
21. Movement of operating lever	
i) Upward stroke, degree	25
ii) Downward stroke, degree	37
22. Number of strokes required to operate sprayer at 3 kg/cm^2 pressure	
i) To create, no.	8
ii) To maintain, no.	8

Table 5.27: Preliminary trials of Aspee Napsak (SRP-50),
16 litre capacity

Particulars	Replications			Mean	S.D.
	1	2	3		
A) Pressure development and maintenance test					
i) No. of strokes required to create pressure of 300 kPa	8	8	8	8	0.0
ii) No. of strokes required to maintain a pressure of 300 kPa (± 10 per cent)	8	8	8	8	0.0
B) Discharge test					
i) Discharge (cc/min) at a pressure of 300 kPa (± 10 per cent)	455	460	460	458.33	2.88
ii) Pressure (kPa) variation range	2.90 to 3.20	2.90 to 3.20	2.90 to 3.20	2.90 to 3.20	
C) Volumetric efficiency test					
i) Discharge in 10 working strokes at 300 kPa (± 10 per cent) pressure, ml	545	540	540	540.66	2.88
ii) Volumetric efficiency per cent	89.40	88.58	88.56	88.85	0.47

Table 5.28: Muscular effort required in handle operation of Aspee Napsak SRP-50 (16 l capacity) sprayer

A) In rigid mounting

(Effort in kgf)

Stroke	Replication			Mean (S.D.)
	1	2	3	
a) Pressure stroke (Downward)	12.25	11.8	13.10	12.38 (0.66)
b) Suction stroke (Upward)	2.74	3.0	2.60	2.78 (0.20)

B) With sprayer mounted on subject's back

Sr. No.	Subject	Replication						Mean S.D.	
		1		2		3		Down	Up
		Down	Up	Down	Up	Down	Up		
1.	BK	12.02	2.10	11.62	2.86	12.19	2.60	11.94 (0.29)	2.52 (0.38)
2.	MJ	11.58	3.50	11.90	3.05	12.55	2.65	12.01 (0.49)	3.07 (0.43)
3.	HS	12.76	3.60	12.10	4.34	12.47	4.13	12.44 (0.33)	4.02 (0.38)
4.	CR	9.73	3.38	10.5	2.74	10.55	2.78	10.26 (0.46)	2.97 (0.36)
5.	AS	14.24	3.26	13.19	4.13	13.77	2.61	13.73 (0.52)	3.33 (0.76)
Mean		12.06	3.17	11.86	3.42	12.31	2.95	12.08	3.18
S.D.		1.65	0.61	0.97	0.75	1.15	0.66	1.24	0.55

Location of trials : Inside laboratory

Table 5.29: Measurement of physiological cost of Aspee Napsak (SRP-50, 16 l capacity) sprayer operation Heart rate (HR) and oxygen uptake (\dot{V}_{O_2}) data

Sr. No.	Sub-ject	Trial	HR (beats/min)			\dot{V}_{O_2} (l/min)		
			Rest	Walking	Work	Rest	Walking	Work
1.	BK	I	72.21	80.52	94.20	0.08	0.19	0.34
		II	72.20	81.27	92.90	0.05	0.17	0.27
		III	72.0	80.90	91.64	0.03	0.17	0.29
		Mean	72.13	80.92	92.91	0.05	0.18	0.30
		S.D.	1.24	1.32	1.40	0.03	0.02	0.03
2.	MJ	I	72.68	84.92	99.23	0.15	0.20	0.32
		II	69.5	78.37	93.52	0.08	0.17	0.31
		III	69.56	76.96	91.89	0.08	0.17	0.31
		Mean	69.91	80.08	94.88	0.10	0.18	0.31
		S.D.	1.93	2.36	2.26	0.04	0.01	0.01
3.	HS	I	60.19	67.74	75.01	0.10	0.28	0.36
		II	59.20	63.12	74.82	0.12	0.17	0.36
		III	57.62	62.88	74.21	0.14	0.27	0.36
		Mean	59.00	64.55	74.68	0.12	0.24	0.36
		S.D.	1.15	1.60	1.66	0.02	0.06	0.02
4.	CR	I	73.57	78.77	90.36	0.08	0.19	0.29
		II	71.75	78.44	88.14	0.08	0.17	0.28
		III	70.80	78.24	88.73	0.08	0.17	0.28
		Mean	71.71	78.48	89.08	0.08	0.18	0.28
		S.D.	1.62	1.45	1.82	0.0	0.01	0.03
5.	AS	I	79.24	88.93	97.41	0.08	0.20	0.32
		II	77.62	87.36	97.62	0.08	0.19	0.33
		III	77.47	85.86	95.89	0.08	0.18	0.34
		Mean	78.11	87.38	96.97	0.08	0.19	0.33
		S.D.	1.49	1.82	1.72	0.0	0.01	0.01
	Mean	70.17	78.28	89.70	0.09	0.19	0.32	
	S.D.	6.96	8.39	8.88	0.03	0.03	0.03	

a) Location : Inside laboratory

b) Hours of day when test were conducted : 10 A.M. to 12.0 Noon

c) Ambient condition (1) Temperature- $33^{\circ}\text{C}(\pm 2.15)$

(2) RH-51.6(± 15.54) %

(3) Air velocity- 0.9 m/sec.

Table 5.30: Data on assesement of postural discomfort during spraying operation of Aspee Napsak (SRP-50,16 l capacity)

Sr. Subject No.			ODR		BPDS*	
			Walking	Spraying	Walking	Spraying
1. BK	After fill					
	I	1.0	5.0			
	II	1.5	6.0			
	2-hour	1.75	6.5	18.64	80.5	
2. MJ	After fill					
	I	1.0	4.0			
	II	1.5	5.0			
	2-hour	2.0	6.5	20.0	88.20	
3. HS	After fill					
	I	0.8	2.0			
	II	1.0	5.0			
	2-hour	1.5	6.5	20.0	104.0	
4. CR	After fill					
	I	1.2	4.0			
	II	1.5	5.0			
	2-hour	2.0	6.5	23.98	124.0	
5. AS	After fill					
	I	1.0	3.0			
	II	1.75	5.0			
	2-hour	2.0	6.5	18.64	103.0	
Mean (after 2-hour)			1.85	6.5	20.52	99.94
S.D.			0.22	0.0	2.19	16.74

* - BPDS was calculated after 2-hour operation of walking and spraying

Table 5.31: Ergonomics score of Aspee Napsak (SRP-50, 16 l capacity) sprayer

Sr. No.	Criterion	Maximum points	Points given (based on data)	Remarks
1.	Heart rate (HR)	20	16.7	
2.	Oxygen uptake (\dot{V}_{O_2})	20	18.0	
3.	Overall discomfort rating (ODR)	20	3.0	
4.	Body part discomfort score total (BPDS)	20	9.4	
5.	Muscular effort (force required in handle operation)	20	6.6	
Points		100	53.7	

5.7 Sprayer Comparison

Table 5.32 shows the comparison of modified unit with a commonly used sprayer (ASPEE Napsak). It can be seen that the modified unit required only 3.08 kgf force for handle operation as against 12.08 kgf in ASPEE Napsak model. The physiological cost as well as postural discomfort were also less in case of modified sprayer. Therefore the ergonomics score for modified sprayer was 75.7 as against 53.7 for the ASPEE Napsak sprayer. Though the capacity was less i.e. 12 l instead of 16 l in existing sprayer, the field efficiencies were obtained to be same for both the sprayer.

Table 5.33 gives regionwise discomfort scores for 27 body parts for operation of these two sprayer. It may be seen that the discomfort was less in all the body region in case of modified sprayer.

Table 5.32: Comparison of modified sprayer with the commonly used sprayer (Aspee Napsak)

Sr.No.	Particulars	Commonly used sprayer ASPEE NAPSAK	Modified sprayer
i)	Code	SRP-50	MS ₁
ii)	Tank capacity, l	16	12
iii)	Empty weight, kg	5.8	5.2
iv)	Operating frequency, (Strokes/min)	8	24
v)	Muscular effort requirement in handle operation, kgf		
	a) Pressure stroke	12.08	3.08
	b) Suction stroke	3.18	1.04
vi)	Physiological cost of operation		
	a) Heart rate (HR), beats/min	89.70	89.97
	b) Δ HR (beats/min) over walking	11.42	9.29
	c) Oxygen consumption (\dot{V}_{O_2}) l/min	0.32	0.31
	d) $\Delta\dot{V}_{O_2}$, l/min over walking	0.12	0.07
vii)	Postural discomfort during operation		
	a) Overall discomfort rating (ODR)	6.5	4.8
	b) Δ ODR over walking	4.65	2.95
	c) Body part discomfort score (BPDS)	99.94	67.6
	d) Δ BPDS over walking	79.69	47.35
viii)	Ergonomics score	53.7	75.7
ix)	Field efficiency, per cent (for 2-h trials)	87.0	88.0

Table 5.33: Body part discomfort scores for the operation existing and modified LOK sprayers according to Corlett and Bishop (1976) technique

Sr.No.	Body part	Aspee Napsak sprayer	Mofidied sprayer
1.	Neck	5.27	3.8
2.	Clavicle left	7.0	5.0
3.	Clavicle right	7.0	5.0
4.	Left shoulder	4.64	5.0
5.	Right shoulder	6.25	5.0
6.	Left arm	2.2	2.4
7.	Right arm	4.14	3.8
8.	Left elbow	1.8	1.8
9.	Right elbow	2.85	2.2
10.	Left forearm	3.97	2.4
11.	Right forearm	3.54	2.8
12.	Left wrist	4.52	1.2
13.	Right wrist	1.55	1.4
14.	Left palm	1.93	3.0
15.	Right palm	5.05	3.2
16A.	Upper back	4.49	2.2
16B.	Chest	2.31	0.2
17.	Mid back	5.42	3.2
18.	Lower back	3.28	2.4
19.	Buttocks	0.0	0.0
20.	Left thigh	2.2	1.6
21.	Right thigh	2.2	1.6
22.	Left knee	2.16	1.2
23.	Right knee	2.16	1.4
24.	Left leg	5.72	2.0
25.	Right leg	5.72	2.0
26.	Left foot	1.2	0.8
27.	Right foot	1.2	0.8

CHAPTER VI

SUMMARY AND CONCLUSIONS

Spraying is one of the important operation in crop production. Use of sprayers for crop production dates back to 1880's. At present there are various types of sprayers in use. In our country more than 60 firms manufactures about 2.5 lakh of sprayers each year, 90 per cent of them being lever operated knapsack sprayers (LOK sprayers). The LOK sprayer uses hydraulic energy and is very versatile. There are different types of LOK sprayer. However, LOK sprayers with piston pump having under arm lever is the most common type. The sprayer consist of a tank, a hand operated pump, a pressure chamber, a lance with an on-off trigger value and a nozzle. The worker operate the lever with one hand and holds the lance in other hand directing the spray on required surface. It costs about Rs. 700 and its life is 5 to 7 years with proper maintenances.

The LOK sprayer is a manually operated equipment and therefore its performance depends on both, the equipment and the operator. Hence, due consideration to ergonomics aspects in sprayer design and operation will help in increasing the man equipment system efficiency and also in minimizing the discomfort in sprayer operation. The study reported here included experiments for optimization of

frequency of handle operation and range of handle movement for better ergonomical performance. Fabrication of a modified prototype and its comparison with a existing commonly used sprayer has also been reported here.

For the study on optimization of frequency of handle operation and range of handle movement, a mechanical simulation setup was used. the four frequencies of handle operation studied were 6, 12, 18 and 24 strokes/min. The four range of handle movement studied were $+45^{\circ}$ and -15° , $+40^{\circ}$ and -20° , $+35^{\circ}$ and -25° and $+30^{\circ}$ and -30° (from horizontal). The effort to be applied at handle was 8 kgf for all of these trial. Another experiment (No.2) was carried out for optimization of frequency of handle operation. Here the work done per unit time was kept constant and six frequencies of handle operation were studied i.e. 6, 12, 18, 24, 30 and 36 strokes/min. After analysis of the data of this experiment, the experiment-3 was conducted to compare the four handle frequencies in long duration (30-minute) trials. The frequencies studied were 12, 18, 24 and 30 strokes/min. Another study (Experiment-4) was carried out to measure maximum muscular strength of the subjects in elbow extension and flexion at seven different elbow angles i.e. 60° , 70° , 80° , 90° , 100° , 110° and 120° .

In these experiment the heart rate was measured using UNI-INSTA ECG telemetry system were as oxygen uptake was measured using Morgan Oxylog. The job severity rating was assessed by using ten point psychophysical rating scale (10-extremely heavy work). The muscular strength was measured using New Engineering make load cell and polyrite recorder unit.

Using a computer programme of LOK sprayer mechanics and the data obtained in these experiments two pump units were fabricated and fitted to a 12 l capacity tank. The only one (24 strokes/min) modified prototype was ergonomically evaluated along with one commonly used sprayer (Aspee Napsak). The parameters of ergonomical evaluation were preliminary trials, effort required to operate the sprayer, physiological cost of sprayer operation and postural discomfort experienced by the subject in sprayer operation. All these studies were carried out with five male subjects. The ergonomic score for modified as well as existing sprayer was calculated from the data collected in the study.

The conclusions drawn from the study are as follows:

- 1) In the study on mechanical simulation set up, the mean heart rate at work increased with the increase in handle

frequency the values being 82.4, 85.4, 87.5 and 89.8 beats/min, respectively. The corresponding job severity rating as given by the subjects were 1.88, 3.01, 4.11 and 5.17 for these four handle frequencies. The effect of handle frequency on heart rate and job severity rating were statistically significant at $p = 0.05$. However, the effect of range of handle movement was not significant. The heart rate at work at four ranges of handle movement i.e. 45° upward and 15° downward, 40° upward and 20° downward, 35° upward and 25° downward and 30° upward and 30° downward from horizontal, were 87.5, 86.5, 85.8 and 85.3 beats/min, respectively. The corresponding job severity rating were 3.52, 3.47, 3.75 and 3.43, respectively.

2) In the studies carried out on mechanical simulation setup keeping the workload and range of movement constant, the heart rate at work were 83.9, 83.1, 81.5, 81.8, 82.5 and 83.5 beats/min for 6, 12, 18, 24, 30 and 36 strokes/min. of handle frequency, respectively. The corresponding values of severity ratings were 3.9, 2.0, 1.0, 1.1, 1.2 and 2.6. Long duration trials (30-minute) carried out on the setup confirmed the pattern of results obtained in above short duration (10-minute) trials. These studies have shown that the handle frequencies of 18 and 24 strokes/min was the optimum one for LOK sprayer operation.

3) The maximum strengths in elbow extension and flexion were found to be 12.73 kgf and 25.26 kgf, respectively.

4) The modified sprayer (12 l capacity) required 3.08 kgf force for handle operation whereas the Napsak model (16 l capacity) required 12.08 kgf force. The physiological cost as well as postural discomfort were also less in modified sprayer. Therefore, the ergonomics score of modified sprayer was 75.7 as against 53.7 for the Napsak model.

CHAPTER VII

SUGGESTIONS FOR FUTURE WORK

The studies are required to make on the following points from ergonomics point of view.

1) A shape of human back and shape of tank so as to distribute the weight of tank partially on the back. This will help to reduce the total weight coming on shoulder muscles.

2) The effect of the use of different widths of straps and use of the wrist belt and use of shoulder cushion pad and back cushion pads studies may be carried out.

3) Measurements of reactions due to the location of the cylinder being on right side or left side and cylinder being located centrally. The effect of cylinder being located centrally in tank or outside should also be studied.

4) It is also required to optimize different levels and components for the operation of piston considering man-machine system.

5) From biomechanics point of view, the hand grip of the operating handle should be such that, for most of time the hand would be in straight line with forearm. A study to design this type of spraying handle may also be undertaken.

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APPENDIX I

SPECIFICATIONS OF THREE LOK SPRAYERS

Particulars	Measurements		
	ASPEE NAPSAK	ASPEE HI-TECH	ASPEE HI-FLO
1. Type of sprayer	LOK	LOK	LOK
2. i) Make	ASPEE NAPSAK	ASPEE HITECH	ASPEE HIFLO
ii) Manufacturer	ASPEE	ASPEE	ASPEE
iii) Model	SRP-50	SRP-60	SRP-55
iv) Market Price	Rs.650/-	Rs.640/-	Rs.560/-
3. Normal working pressure, kg/cm ²	3	3	3
4. Overall dimension			
i) Length, mm	170	204	135
ii) Width, mm	360	362	320
iii) Height, mm	317	325	330
5. Tank capacity, l	16	16	12
6. Weight of Sprayer			
i) Without water, kg	5.8	5.3	4.8
ii) with water, kg	21.8	21.8	16.8
7. Inside diameter of cylinders, mm	43	36	36.5

8. Stroke length, mm			
i) Maximum	59	60	58.5
ii) Normal	41.9	-	-
9. Volume of pressure chamber, cc	690	900	900
10. Length of operating lever, mm	435	480	480
11. Length of crank arm, mm	69	79	61
12. Type of agitator	Machanical	-	-
13. Area of filler hole cm ²	70.88	95.0	70.88
14. Type of nozzle	Duromist NMD/S 60A 450		
15. Length of lance, mm	610	610	610
16. Weight of lance + nozzle, kg	0.25	0.25	0.25
17. Length of hose, mm	1100	1100	1100
18. Material of Construction			
i) Tank	High density Polythelene		
ii) Pressure chamber	Brass	High Density Polythelene	
iii) Pump cylinders	Brass	Brass	Brass

iv) Piston	Rubber	High Density Polytheline	
v) Lance	Brass	Brass	Brass
vi) Nozzle	Brass	Brass	Brass
vii) Straps	Cotton	Cotton	Cotton
19. Normal position of operating lever	Right	Right	Right
20. Whether there is provision to change position of handle (Right or Left)	Yes	Yes	Yes
21. Movement of operating lever			
i) Upward stroke, degree	25	16	36
ii) Downward storke, degree	37	32	28
22. Number of strokes required to operate sprayer at 300 kPa pressure.			
i) To create, no.	8	11	11
ii) To maintain, no.	8	10	9

APPENDIX II

A) UNI-INSTA E.C.G. Telemetry System.

UNI-INSTA E.C.G. Telemetry System was used to measure the heart rate of the subject during the work on mechanical setup without disruption. The system is manufactured by M/s. Electronical Ltd., Indore.

It consist of telemetry encorder and decoder. The encoder is a small size light weitht battery operated and can be easily kept in subject pocket or hooked to the belt of the subject. It's size is 138 mm x 74 mm x 38 mm and weight about 450 gms. It works at 100 MHz and remains in hight tuned stage upto a distance of 30 meters.

The decoder decodes the signals and give on E.C.G. output which can be seen on E.C.G. monitor 230 Volts, A.C. supply.

In this system heart rate can be read on a monitor or can be recorded on the electro cardiograph. This is the best method available and used now a days for a measurement of heard rate of the subject during work. It's cost is Rs.60,000/-.

Specifications of Telemetry

ENCODER :

Transmitting frequency	: 100 MHz
Working range	: 25 meters
Leads	: Bipolar Cable (placement of electrodes decoder the PQRS complexes)
Input Signal level Acceptable	: Maximum 10 MV
Modulation	: Doubly frequency modulated.
C.M.R.R.	: Better than 1:5000
Size	: 138 mm X 74 mm X 38 mm
Weight	: 450 gms.
Power	: 1.5 volt cell x 4 nos.
Optional	: 1.2 volts x 5 nos. rechargeable.

DECODER:

Demodulation	: Double frequency demodulating circuit.
Out signal level	: Equivalent of input signal amplitude.
Tuning	: Adjustable around 100 MHz.
Size	: 126mm X 176mm X 340mm
Weight	: 2.950 kg.
Battery life	: 4 to 6 hours.

(B) POLYRITE RECORDER

The 'POLYRITE' Recorder is a highly sensitive oscillograph capable of simultaneously recording signals in different modes from many sources. Polyrite Recorders can be used by the medical professionals for the recording of Bio-electirc Potentials, in aerospace technology for recording telemetered informations, in industry for recording of servo amplifier performance all type of viberation pick-up and recording of temperature etc. The flexibility resuring out of modules construcion of the polyrite allows a wide variety of physical phenomena to be recorded simultaneously.

SPECIFICATIONS

- a. Input connector : Standard 5 pin 'Polyrite' connector
- b. Input : Differential capacitor coupled or direct.
- c. Input impedance : 20 Mohms at AC
20 Mohms at DC
2 Kohms at Bridge
- d. Maximum Sensitivity : With polyrite pen recorder, the maximum sensitivity is 5 uv/cm pen deflection. At the bridge position of input selector the max. sensitivity is 2 uv/cm. At GSR setting the maximum sensitivity is 100 ohms per cm. (Model 201 only)
- e. Attenuator position : 10, 20, 50 uv/cm .1, .2, .5, 1, 2, 5, 10, 20 mV/cm.
- f. Cal adjust : Fine continuous adjustment in between each attenuator step.
- g. Noise (Typical) : 2 uv peak to peak referred to input.
- h. C M R R : Better than 100, 000.1
- i. Frequency response (at pen) : 100% at DC, down 3 db at 75Hz.
- j. 1/2 AMP HI frequency : Upper frequency of the pen can be adjusted to give half amplitude frequency responses at 75, 35, 15, 3, 0.5 and 0.1 Hz.
- k. Time constants : 0.03, 0.1, 0.3 and 1 secs.
- l. 50 Hz cutoff : Provided

- m. Calibration : Voltages are provided for each position of the sensitivity control.
- n. Balance controls : Consist of a coarse 10 mV per step switch, a 10-turn potentiometer with 1 mV per turn, and a balance voltage reversing switch. At the bridge position of the input selector the balance controls are connected as a variable resistance across one arm of the bridge and a fixed resistance across the adjacent arm. Accuracy of balance voltage is $\pm 20\%$ maximum balance voltage is -110 mV and +110 mV derived from a mercury battery which is not referred to ground.
- o. GSR Control : The changes in skin resistance commonly known as GSR on PGR may be recorded with this amplifier. With the input of the amplifier set of GSR, a 5 microampere constant current is passed through the electrodes.
- p. Outputs : Jacks are provided for monitoring on CRO's etc. Signals identical in wave form to those recorded by the pens. Jacks are also provided for checking the calibration and balance voltages.
- q. Baseline : Adjustable over entire 4 cm. chart range.

(C) Nova-Tech. Force Transducer

Range : 0 to 100 kg.

The F 201 range of force transducer is used for tension and compression studies. It consists of a precision machined cylinder operating as the strain element. Bonded foil strain gauges are mounted on the cylinder in a compensating bridge network. The load cell is designed to produce the optimum amount of measuring element strain relating to total signal output of high linearity and low hysteresis. The transducer is cylindrical and extremely compact. It has female and male threads and can be easily fitted as a force - rod link in a measuring system. Swivelling ball rod ends are also available.

Specifications:

1. Manufacturer's Name : Nova Tech Measurements Ltd., England
2. Load Cell type : F 201 T
3. Input resistance : 418 ohms
4. Load cell supply : 10 volts
5. Insulation resistance: 500 Mohms, 50 volts
6. Shunt calibration : 100 Kohms; 8.742 Mvolts, 131 kg
7. MV/V rated load : 1.333
8. Zero balance : 0.004 mV

(D) Universal load Cell

Make : New Engineering
 Cap : 0 to 100 kg.
 Tension compression type.

(E) MORGAN OXYLOG

For measurement of oxygen consumptions and pulmonary ventilation rate, oxylog was used, this equipment is manufactured by M/s.P.K. Morgon Ltd., Charter, Kent, U.K.

The oxylog combines all three functions in one instant 18.5 cm wide, 8.2 cm deep and 21.5 cm tall weighing 2.5 kg in its leather case. It provide a digital display of cumulative oxygen consumption during the preceding minutes. Inspired volume is measured by means of a turbine flow meter mounted in a mask fitting with appropriate valves and air temperature also registered. The expired air is conveyed to the instrument properly by corrugated tube which also supports the flow meter cable. The inspired expired oxygen partial pressure difference is obtained by a sampling system which first obtain a dynamic sample of mixed expired air. Past two stable polarographic oxygen sensors. Suitable circuits thus calculate oxygen consumption with atleast a first-order correction for changes in barometric pressure temperature and on assumption of 50 percent relative humidity in the inspired air. The oxylog is suitable for ventilation volumes of 6-80 lpm, 0.25 - 3.00 lpm oxygen consumption. It is powered by internal rechargeable batteries with an endurance of upto 24 hours.

The oxylog is one of the only two instruments currently available which are both portable and able to measure O_2 consumption directly. But it is lighter and cheaper and is intended to be worn by the person on whom measurements are being made.

It is very essential that oxylog is switched on 30 minutes before use.

Specifications of Oxylog

Measurement Range	: 25 - 3 liters oxygen per minute.
Flow transducer	: Turbine type flowmeter attached to face mask to measure inspiratory volume in range 6 - 80 l/min. ventilation.
Oxygen Sensors	: Beckman polarographic oxygen sensors part No.148375.
Batteries	: + 5 volt supply off NCC 120 - 5 volt supply off NCC 24
Fuse	: 2 amp. 20 mm
Drying Tubes	: Drying Agent 20 - 40 mesh. Indicating drierite (calcium sulphate anhydrous)
Mask	: Type protector safety
Output Indication	: 1. Total oxygen display Maximum reading 999.9 liters Resolution 0.1 liters. 2. Minute oxygen Maximum reading 3 liters/min Resolution 0.01 liters/min. 3. Total ventilation display. Maximum reading 99999 liters. resolution 1 liter. 4. Minute ventilation. Maximum 80 liters/min. Resolution 1 liter. Not corrected for S.T.P.D.
Recorder output	: 1. 3 V positive pulse 30 msec long every 0.1 litre of oxygen. 2. Minute oxygen output 1 volt liter/min. 3. 3 V positive pulse 30 msec wide every 1 liter of ventilation.

Setting of Oxylog

This should be carried out in well ventilated surroundings.

1. Switch on the instrument and wait one minute for it to settle.
2. Check that drying tubes are not exhausted.
3. Check the battery voltages.
4. Remove the sample connector from the 'MASK' drying tube.
5. Switch selector switch to "AIR SET".
6. Run pump for two minutes by pressing "Pump run" button on the control panel. Check that the readings on the selector display is stable.
7. Adjust the "AIR SET" control (on the control panel) until the selector display shows the barometric pressure reading in millimeters of mercury.

NOTE : During calibration the sensor is measuring the partial pressure of oxygen in atmosphere. Setting the output to read barometric pressure is for operational convenience. The OXYLOG is not affected by changes in barometric pressure during use.

8. Switch the selector switch to "MASK SET".
9. Run the pump until the reading on the selector display is stable.

10. Adjust the "MASK SET" control on the control panel until the selector display shows the barometric pressure reading.
11. Switch to "AIR SET" and check the reading.
12. Switch the selector switch to Po_2 Diff. The reading should be 00.00 if not, adjust "MASK SET" on control panel to obtain this reading.
13. Replace the pipe from the sample outlet on "MASK" drying tube.

APPENDIX III (A)

Data of heart rate at rest of five subjects for I-replication
Expt. No.1 (Beats/min)

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	65.82 (2.17)	78.90 (2.15)	64.5 (1.68)	80.4 (1.39)	71.65 (1.92)	72.25 (1.86)
N ₁ M ₂	73.2 (1.76)	69.16 (2.70)	62.73 (2.03)	83.76 (2.24)	68.24 (1.55)	71.41 (2.05)
N ₁ M ₃	67.94 (1.39)	71.37 (2.37)	64.26 (1.81)	69.64 (1.69)	66.95 (3.45)	67.93 (2.14)
N ₁ M ₄	70.18 (2.49)	65.84 (2.25)	65.61 (1.64)	75.04 (2.65)	68.34 (1.65)	69.00 (2.13)
N ₂ M ₁	67.16 (1.10)	65.38 (3.65)	63.42 (1.03)	78.85 (1.10)	66.21 (1.29)	68.20 (1.63)
N ₂ M ₂	66.26 (1.09)	75.31 (2.50)	61.47 (1.60)	71.40 (1.89)	75.15 (1.30)	69.91 (1.87)
N ₂ M ₃	67.47 (1.78)	64.98 (1.37)	63.5 (2.40)	83.47 (1.27)	78.22 (1.69)	71.52 (1.70)
N ₂ M ₄	72.70 (1.59)	66.04 (2.75)	60.27 (2.02)	77.93 (1.59)	72.97 (1.53)	69.98 (1.89)
N ₃ M ₁	64.0 (2.12)	66.33 (1.74)	63.24 (2.55)	83.91 (2.73)	65.75 (1.52)	68.64 (2.13)
N ₃ M ₂	61.97 (2.06)	64.51 (2.55)	60.29 (2.64)	73.51 (1.88)	68.97 (1.98)	65.85 (2.22)
N ₃ M ₄	76.34 (1.69)	72.86 (2.19)	59.88 (2.22)	66.00 (2.64)	68.35 (1.53)	68.68 (2.05)
N ₄ M ₁	69.68 (2.74)	65.44 (1.79)	63.21 (1.98)	68.86 (2.12)	69.86 (3.48)	67.41 (2.92)
N ₄ M ₂	64.18 (1.57)	77.03 (5.41)	60.45 (1.53)	67.39 (1.55)	65.03 (2.09)	66.81 (2.43)
N ₄ M ₃	67.78 (1.36)	63.0 (2.83)	65.88 (1.31)	78.59 (1.17)	64.95 (1.73)	68.04 (1.68)
N ₄ M ₄	65.62 (2.05)	64.43 (1.56)	60.83 (1.59)	68.97 (1.20)	76.69 (2.31)	67.30 (1.93)

* Figures in parenthesis indicate standard deviations.

Data of heart rate of five subjects at work for different treatment combination for I-replication (Expt-1)

Treatment	(Beats/Min)					
	S ₁	S ₂	Subjects S ₃	S ₄	S ₅	Mean
N ₁ M ₁	79.30 (2.41)	96.15 (4.16)	73.63 (2.13)	93.13 (2.35)	89.74 (2.72)	86.39 (2.75)
N ₁ M ₂	78.29 (2.57)	87.08 (3.05)	70.74 (1.40)	90.56 (2.34)	84.03 (5.02)	82.14 (2.97)
N ₁ M ₃	76.84 (1.78)	88.97 (4.33)	69.68 (2.85)	79.87 (2.20)	81.46 (4.75)	79.36 (3.18)
N ₁ M ₄	80.93 (1.99)	81.16 (5.23)	74.47 (1.83)	82.88 (2.64)	81.98 (5.84)	80.28 (3.5)
N ₂ M ₁	78.30 (1.92)	91.25 (3.46)	74.24 (2.02)	89.86 (2.22)	90.01 (3.66)	84.73 (2.65)
N ₂ M ₂	76.69 (1.75)	102.85 (2.67)	73.32 (3.02)	83.45 (1.80)	93.65 (3.37)	85.99 (2.52)
N ₂ M ₃	81.86 (1.83)	86.43 (4.30)	73.29 (1.31)	94.66 (2.16)	90.93 (2.17)	85.43 (2.32)
N ₂ M ₄	79.35 (1.42)	94.26 (3.90)	72.78 (2.50)	94.05 (1.84)	87.09 (2.73)	85.50 (2.47)
N ₃ M ₁	81.02 (1.34)	95.66 (1.81)	75.03 (3.15)	94.96 (2.19)	95.50 (3.30)	88.43 (2.43)
N ₃ M ₂	79.58 (1.83)	94.58 (2.32)	73.43 (1.97)	95.72 (1.28)	96.91 (3.85)	88.04 (2.25)

Table contd.

N_3M_3	81.55 (1.30)	97.82 (4.09)	72.64 (2.34)	85.27 (1.70)	93.06 (2.57)	86.06 (2.4)
N_3M_4	81.68 (1.37)	104.16 (2.99)	73.12 (2.86)	84.21 (1.48)	90.74 (2.20)	86.78 (2.18)
N_4M_1	83.93 (1.60)	103.88 (2.86)	78.62 (1.43)	87.0 (1.61)	103.17 (3.24)	91.32 (2.14)
N_4M_2	83.64 (1.21)	121.12 (2.30)	76.75 (2.45)	87.45 (1.64)	92.10 (3.29)	92.21 (2.17)
N_4M_3	85.74 (1.72)	102.28 (4.27)	82.90 (2.31)	97.96 (1.60)	100.31 (1.92)	93.83 (2.36)
N_4M_4	78.64 (1.63)	102.42 (2.83)	76.64 (1.65)	88.43 (1.81)	99.27 (2.45)	89.08 (2.07)

* Figures in brackets indicate standard deviation.

Difference of Heart rate (Δ HR) at rest and work for five subjects for I-replication. (Expt - 1)

Treatment	(beats/min)					Mean
	S ₁	S ₂	Subjects S ₃	S ₄	S ₅	
N ₁ M ₁	13.48	17.25	9.13	12.73	18.09	14.13
N ₁ M ₂	5.09	17.92	8.01	6.8	15.79	10.72
N ₁ M ₃	8.9	17.6	5.42	10.23	15.01	11.43
N ₁ M ₄	10.75	15.32	8.86	7.84	13.64	11.28
N ₂ M ₁	11.14	25.87	10.82	11.01	23.8	16.52
N ₂ M ₂	10.43	27.54	11.85	12.05	18.5	16.07
N ₂ M ₃	14.39	21.45	9.79	11.19	12.71	13.90
N ₂ M ₄	6.65	28.22	12.51	16.12	14.12	15.52
N ₃ M ₁	17.02	29.33	11.79	11.05	29.75	19.78
N ₃ M ₂	11.51	28.56	13.92	16.2	21.77	18.39
N ₃ M ₃	19.58	33.31	12.35	11.76	24.09	20.21
N ₃ M ₄	5.34	31.3	13.24	18.21	22.39	18.09
N ₄ M ₁	14.25	38.44	15.41	18.14	33.49	23.94
N ₄ M ₂	19.46	44.09	16.3	20.06	27.07	25.39
N ₄ M ₃	17.46	39.28	17.02	19.37	35.36	25.79
N ₄ M ₄	13.02	37.99	15.81	19.46	22.58	21.77

Job severity rating of five subjects on 0-10
scale for I-replication (Expt.-1).

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	1	1	3	4	2	2.2
N ₁ M ₂	1	1	2	2	3	1.8
N ₁ M ₃	2	2	3	4	3	2.8
N ₁ M ₄	2	1	2	3	2	2.0
N ₂ M ₁	3	3	5	4	5	3.8
N ₂ M ₂	2	3	4	5	3	3.4
N ₂ M ₃	1	3	3	3	4	2.8
N ₂ M ₄	2	3	4	3	4	3.2
N ₃ M ₁	4	5	4	3	5	4.2
N ₃ M ₂	4	4	6	3	5	4.4
N ₃ M ₃	5	4	7	4	3	4.6
N ₃ M ₄	4	5	5	5	4	4.6
N ₄ M ₁	5	6	6	5	8	6.0
N ₄ M ₂	6	6	6	5	7	6.0
N ₄ M ₃	5	6	4	4	9	5.6
N ₄ M ₄	3	4	5	5	2	3.8

Effect of four frequencies of handle operation in four range of handle movement in RCB design for heart rate in I-replication (Expt.-1) statistical analysis

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
	N ₁					
M ₁	79.3	96.2	73.6	93.1	89.7	431.9
M ₂	78.3	87.1	70.7	90.6	84.0	410.7
M ₃	76.8	88.9	69.7	79.9	81.5	396.8
M ₄	80.9	81.2	74.5	82.9	81.9	401.4
	315.3	353.4	288.5	346.5	337.1	1640.8
	N ₂					
M ₁	78.3	91.3	74.2	89.9	90.0	423.7
M ₂	76.7	102.9	73.3	83.5	93.7	430.1
M ₃	81.9	86.4	73.3	94.7	90.9	427.2
M ₄	79.3	94.3	72.8	94.1	87.1	427.6
	316.2	374.9	293.6	362.2	361.7	1708.6
	N ₃					
M ₁	81.0	95.7	75.0	94.9	95.5	442.1
M ₂	79.6	94.6	73.4	95.7	96.9	440.2
M ₃	81.6	97.8	72.6	85.3	93.1	430.4
M ₄	81.7	104.2	73.1	84.2	90.7	433.9
	323.9	392.3	294.1	360.1	376.2	1746.6

Table contd.

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
			N ₄			
M ₁	83.9	103.9	78.6	87.0	103.2	456.6
M ₂	83.6	121.1	76.8	87.5	92.1	461.1
M ₃	85.7	102.3	82.9	97.9	100.3	469.1
M ₄	78.6	102.4	76.6	88.4	99.3	445.3
	331.8	429.7	314.9	360.8	394.9	1832.1
Frequency Total (R)	1287.2	1550.3	1191.1	1429.6	1469.6	6928.1

The frequency x range table of totals

Range	Heart rate (Beats/min)				Range Total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	431.9	423.7	442.1	456.6	1754.3	87.71
M ₂	410.7	430.1	440.2	461.1	1742.1	87.10
M ₃	396.8	427.2	430.4	469.1	1723.5	86.17
M ₄	401.4	427.6	433.9	445.3	1708.2	85.41
Frequency Total (A)	1640.8	1708.6	1746.6	1832.1	6928.1	
(Medn)	(82.04)	(85.43)	(87.3)	(91.60)		

Analysis of variance of data for 4 x 4
factorial experiment in RCB design.

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5 %	1%
Subject	4	5230.08	1307.52	54.48	2.52	3.65
Treatment	15	1181.69	78.77	3.28	1.83	2.36
Frequency (A)	3	954.90	318.30	13.26	2.76	4.13
Range (B)	3	61.89	20.63	0.85	2.76	4.13
A x B	9	164.9	18.32	0.76	2.04	2.72
Error	60	1440.5	24.00			
	79	7852.27				

C.D. (5%) For frequency = 3.098992

C.D. (5%) For range of movement = 3.09899

C.D. at interaction = 6.197984

Effect of four frequencies of handle operation in four ranges of handle movement in RCB design for heart rate difference 1st replication (Expt.-1).

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁						
M ₁	13.5	17.3	9.1	12.7	18.1	70.7
M ₂	5.1	17.9	8.0	6.8	15.8	53.6
M ₃	8.9	17.6	5.4	10.2	15.0	57.1
M ₄	10.8	15.3	8.9	7.8	13.6	56.4
	38.3	68.1	31.4	37.5	62.5	237.8
N ₂						
M ₁	11.1	25.9	10.8	11.0	23.8	82.6
M ₂	10.4	27.5	11.9	12.0	18.5	80.3
M ₃	14.4	21.5	9.8	11.2	12.7	69.6
M ₄	6.7	28.2	12.5	16.1	14.1	77.6
	42.6	103.1	45.0	50.3	69.1	310.1
N ₃						
M ₁	17.0	29.3	11.8	11.0	29.8	98.9
M ₂	11.5	28.6	13.9	16.2	21.8	92.0
M ₃	19.6	33.3	12.4	11.8	24.1	101.2
M ₄	5.3	31.3	13.2	18.2	22.4	90.4
	53.4	122.5	51.3	57.2	98.1	382.5

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
			N ₄			
M ₁	14.3	38.4	15.4	18.1	33.5	119.7
M ₂	19.5	44.1	16.3	20.1	27.1	127.1
M ₃	17.5	39.3	17.0	19.4	35.4	128.6
M ₄	13.0	37.9	15.8	19.5	22.6	108.8
	64.3	159.7	64.5	77.1	118.6	484.2
Frequency Total (R)	198.6	453.4	192.2	222.1	348.3	1414.6

The frequency x range table of total trials

Range	Heart rate (Beats/min)				Range total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	70.7	82.6	98.9	119.7	371.9	18.59
M ₂	53.6	80.3	92.0	127.10	353.0	17.65
M ₃	57.1	69.6	101.2	128.6	356.5	17.83
M ₄	56.4	77.6	90.4	108.8	333.2	16.66
Frequency Total (A)	237.8	310.1	382.5	484.2	1414.6	
Mean	(11.89)	(15.51)	(19.13)	(24.21)		

Analysis of variance of data for 4 x 4
factorial experiment in RCB design.

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabuler F	
					5 %	1%
Subject	4	3273.56	818.39	55.54	2.52	3.65
Treatement	15	1779.6	118.64	8.05	1.83	2.36
Frequency (A)	3	1659.67	553.22	37.58	2.76	4.13
Range (B)	3	37.99	12.66	0.86	2.76	4.13
A x B	9	81.94	9.10	0.61	2.04	2.72
Error	60	883.72	14.72			
	79	5936.88				

C.D. (5%) For frequency = 2.425008

C.D. (5%) For range of movement = 2.425008

C.D. at interaction = 4.850016

Effect of four frequencies of handle operation in four ranges of handle movement in RCB design for severity rating 1st replication (Expt.-1).

Range of Movement	Severity Rating					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
	N ₁					
M ₁	1	1	3	4	2	11
M ₂	1	1	2	2	3	9
M ₃	2	2	3	4	3	14
M ₄	2	1	2	3	2	10
	6	5	10	13	10	44
	N ₂					
M ₁	3	3	5	4	5	20
M ₂	2	3	4	5	3	17
M ₃	1	3	3	3	4	14
M ₄	2	3	4	3	4	16
	8	12	16	15	16	67
	N ₃					
M ₁	4	5	4	3	5	21
M ₂	4	4	6	3	5	22
M ₃	5	4	7	4	3	23
M ₄	4	5	5	5	4	23
	17	18	22	15	17	89

Table contd.

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
			N ₄			
M ₁	5	6	6	5	8	30
M ₂	6	6	6	5	7	30
M ₃	5	6	6	4	9	30
M ₄	5	4	4	5	2	18
	19	22	22	19	26	108
Frequency Total (R)	50	57	70	62	69	308

The frequency x range table of totals

Range	Severity Rating (AB)				Range total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	11	20	21	30	82	4.1
M ₂	9	17	22	30	78	3.9
M ₃	14	14	23	30	81	4.05
M ₄	10	16	23	18	67	3.35
Total	44	67	89	108	308	
Mean	(2.2)	(3.35)	(4.45)	(5.4)		

Analysis of variance of data for 4 x 4
factorial experiment in RCB design.

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5 %	1%
Subject	4	17.57	4.39	4.48	2.52	3.65
Treatment	15	143.4	9.56	9.75	1.83	2.56
Frequency (A)	(3)	114.7	38.23	39.01	2.76	4.13
Range (B)	(3)	7.1	2.36	2.41	2.76	4.13
A x B	(9)	21.6	2.4	2.44	2.04	2.72
Error	60	59.23	0.98			
79						

C.D. (5%) For frequency = 0.6260

C.D. (5%) For range of movement = 0.6260

C.D. at interaction = 1.252

Data of heart rate at rest of five subjects for 2nd replication - Expt. No.1 (Beats/min)

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	67.86 (1.61)	75.84 (2.33)	55.86 (1.26)	74.32 (1.14)	78.5 (1.94)	70.47 (1.65)
N ₁ M ₂	66.31 (1.86)	72.84 (2.53)	52.68 (1.31)	71.25 (1.18)	74.36 (2.21)	67.54 (1.81)
N ₁ M ₃	64.67 (1.20)	78.20 (2.32)	52.39 (1.79)	76.02 (1.20)	77.47 (1.62)	69.75 (1.62)
N ₁ M ₄	63.27 (1.10)	72.38 (2.90)	62.44 (2.96)	69.89 (1.36)	86.32 (1.79)	70.86 (2.01)
N ₂ M ₁	73.75 (2.36)	70.62 (2.11)	58.09 (2.21)	69.54 (1.06)	82.17 (2.63)	70.83 (2.07)
N ₂ M ₂	64.24 (1.04)	79.07 (2.29)	62.09 (1.18)	74.89 (1.55)	78.51 (1.24)	71.76 (1.46)
N ₂ M ₃	66.48 (1.76)	67.09 (1.90)	54.10 (1.65)	70.46 (1.94)	74.58 (1.05)	66.54 (1.66)
N ₂ M ₄	63.5 (1.40)	73.82 (2.91)	56.20 (1.79)	73.85 (1.09)	80.62 (1.15)	69.59 (1.67)
N ₃ M ₁	64.15 (1.47)	66.92 (3.33)	67.88 (1.50)	74.75 (1.29)	77.28 (1.59)	70.19 (1.83)
N ₃ M ₂	67.48 (1.73)	74.18 (2.17)	58.4 (1.88)	73.82 (1.53)	77.68 (1.38)	70.31 (1.73)
N ₃ M ₃	76.63 (2.26)	73.93 (1.66)	61.37 (1.57)	74.4 (0.98)	79.21 (1.57)	73.10 (1.60)
N ₃ M ₄	65.88 (1.51)	78.54 (4.20)	54.62 (1.13)	69.82 (0.83)	73.4 (2.58)	68.45 (2.05)
N ₄ M ₁	67.54 (1.09)	73.05 (1.98)	57.0 (1.50)	75.71 (1.93)	73.25 (1.70)	69.31 (1.54)
N ₄ M ₂	61.73 (1.98)	71.96 (2.70)	60.73 (1.77)	71.47 (1.20)	84.35 (1.39)	70.10 (1.80)
N ₄ M ₃	64.10 (0.92)	75.74 (1.99)	52.61 (1.13)	69.58 (1.39)	74.51 (1.92)	67.30 (1.46)
N ₄ M ₄	70.85 (2.24)	68.87 (3.04)	53.63 (1.32)	69.24 (1.01)	77.61 (1.46)	68.04 (1.81)

Data of heart rate at rest of five subjects for 2nd
 replication - Expt. No.1 (Beats/min)

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	81.43 (2.36)	97.81 (3.53)	62.12 (2.24)	87.07 (2.27)	95.91 (2.04)	84.86 (2.48)
N ₁ M ₂	75.54 (2.1)	90.54 (2.54)	59.86 (2.82)	80.93 (1.33)	86.45 (1.67)	78.66 (2.09)
N ₁ M ₃	79.52 (2.17)	89.6 (3.27)	58.77 (1.92)	90.98 (2.64)	90.24 (1.78)	81.82 (2.34)
N ₁ M ₄	75.30 (2.92)	85.31 (3.59)	69.92 (1.81)	79.92 (1.24)	97.96 (3.24)	81.68 (2.46)
N ₂ M ₁	87.12 (2.30)	104.25 (2.52)	67.89 (2.11)	81.48 (1.25)	97.75 (2.04)	87.69 (2.04)
N ₂ M ₂	76.68 (1.95)	99.47 (2.20)	74.53 (1.75)	93.38 (1.67)	94.63 (2.68)	87.73 (2.05)
N ₂ M ₃	81.59 (1.8)	92.74 (2.61)	62.1 (2.10)	81.02 (1.23)	86.20 (1.76)	80.73 (1.90)
N ₂ M ₄	79.68 (2.72)	90.21 (3.06)	66.25 (1.81)	90.69 (1.45)	97.19 (2.50)	84.80 (2.30)
N ₃ M ₁	83.21 (1.92)	95.23 (3.83)	75.25 (2.26)	92.46 (1.43)	93.66 (1.97)	87.99 (2.38)
N ₃ M ₂	81.58 (1.59)	92.80 (2.89)	69.62 (1.26)	85.45 (1.15)	100.18 (2.21)	85.92 (1.82)
N ₃ M ₃	87.92 (2.01)	95.78 (2.52)	74.42 (1.27)	93.76 (1.50)	98.74 (1.77)	90.12 (1.87)
N ₃ M ₄	82.62 (1.70)	102.59 (2.52)	66.41 (2.05)	80.84 (1.42)	95.16 (2.52)	85.56 (2.03)
N ₄ M ₁	82.8 (1.60)	99.74 (1.82)	73.19 (1.97)	95.69 (2.26)	97.46 (2.09)	89.77 (1.94)
N ₄ M ₂	81.62 (1.18)	98.28 (2.78)	73.97 (1.84)	94.81 (1.41)	99.52 (1.68)	89.64 (1.77)
N ₄ M ₃	87.80 (1.54)	100.97 (3.21)	62.62 (2.46)	87.58 (1.08)	96.27 (2.29)	87.04 (2.11)
N ₄ M ₄	88.80 (1.95)	97.88 (2.28)	67.56 (2.0)	85.59 (1.19)	99.58 (1.92)	87.88 (1.86)

Difference of heart rate (Δ HR) at rest and work for five subjects for 2nd replication (Expt.-1)

Treatment	(Beats/min)					Mean
	S ₁	S ₂	Subjects S ₃	S ₄	S ₅	
N ₁ M ₁	13.57	21.97	6.26	12.75	17.41	10.91
N ₁ M ₂	9.23	17.7	7.18	9.86	12.09	11.17
N ₁ M ₃	14.85	11.4	6.38	14.96	12.77	12.07
N ₁ M ₄	12.03	12.93	7.48	10.03	11.64	10.82
N ₂ M ₁	13.68	33.63	9.8	11.94	15.58	16.92
N ₂ M ₂	12.44	20.4	12.44	18.49	16.12	15.97
N ₂ M ₃	15.11	25.65	8.0	10.56	11.62	14.18
N ₂ M ₄	16.36	16.39	10.05	16.84	16.57	15.23
N ₃ M ₁	19.06	28.31	7.37	17.89	16.38	17.80
N ₃ M ₂	14.1	18.62	11.28	11.62	22.5	15.61
N ₃ M ₃	11.29	21.85	13.05	19.36	19.53	17.01
N ₃ M ₄	16.74	24.05	11.99	11.02	21.76	17.11
N ₄ M ₁	15.26	26.69	16.19	19.98	24.21	20.46
N ₄ M ₂	19.89	26.32	13.24	23.34	15.17	19.54
N ₄ M ₃	23.7	25.23	10.01	18.0	21.76	19.74
N ₄ M ₄	17.95	29.01	13.93	16.35	21.97	19.89

Discomfort rating of five subject on 0-10 scale for 2nd replication (Expt.-1)

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	2	1	4	2	2	2.2
N ₁ M ₂	2	1	2	2	2	1.8
N ₁ M ₃	3	1	2	2	2	2.0
N ₁ M ₄	3	2	1	2	1	1.8
N ₂ M ₁	3	3	3	3	2	2.8
N ₂ M ₂	3	2	1	2	3	2.2
N ₂ M ₃	3	3	3	3	3	3.0
N ₂ M ₄	4	3	5	2	3	3.4
N ₃ M ₁	5	4	2	5	3	3.8
N ₃ M ₂	3	4	4	3	4	3.6
N ₃ M ₃	4	5	3	3	3	3.6
N ₃ M ₄	4	4	4	4	3	3.8
N ₄ M ₁	4	5	5	5	4	4.8
N ₄ M ₂	7	5	3	5	5	5.0
N ₄ M ₃	8	6	4	5	5	5.6
N ₄ M ₄	5	6	5	5	5	5.2

Effect of four frequencies of handle operation in four ranges of handle movement in RCB design for 2nd replication heart rate (Expt.-1).

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁						
M ₁	81.4	97.8	62.10	87.1	95.9	424.3
M ₂	75.5	90.5	59.90	80.9	96.5	393.3
M ₃	79.5	89.6	58.8	90.9	90.2	409.0
M ₄	75.3	85.3	69.9	79.9	97.9	408.3
	311.7	363.2	250.7	338.8	370.5	1634.9
N ₂						
M ₁	87.1	104.3	67.9	81.5	97.8	438.6
M ₂	76.7	99.5	74.5	93.4	94.6	438.7
M ₃	81.6	92.7	62.1	81.0	86.2	403.6
M ₄	79.7	90.2	66.3	90.7	97.20	424.1
	325.1	386.7	270.8	346.6	375.8	1705.0
N ₃						
M ₁	83.2	95.2	75.3	92.6	93.7	440.0
M ₂	81.00	92.8	69.6	85.4	100.2	429.6
M ₃	87.90	95.8	74.4	93.8	98.7	450.6
M ₄	82.6	102.6	66.4	80.8	95.2	427.6
	335.3	386.4	285.7	352.6	387.8	1747.8

Table contd.

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
			N ₄			
M ₁	82.8	99.7	73.2	95.7	97.5	448.9
M ₂	81.6	98.3	73.9	94.8	99.5	448.1
M ₃	87.8	100.9	62.6	87.6	96.3	435.2
M ₄	88.8	97.9	67.6	85.6	99.6	439.5
	341.00	396.9	277.3	363.7	392.9	1771.8
Frequency Total (R)	1313.1	1533.2	1084.5	1401.7	1527.00	6859.5

The frequency x range table of total trials

Range of movement	Heart rate, beats/min (AB)				Range total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	424.3	438.6	440	448.9	1751.8	87.59
M ₂	393.3	438.7	429.6	448.1	1709.7	85.48
M ₃	409.0	403.6	450.6	435.2	1698.4	84.92
M ₄	408.3	424.1	427.6	439.5	1699.5	84.97
Total	1634.9	1705.0	1747.8	1771.8	6859.5	
Mean	(81.47)	(85.25)	(87.39)	(88.58)	(88.58)	

Analysis of variance of data for 4 x 4
factorial experiment in RCB design.

Source of variance	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5 %	1%
Subject	4	8583.62	2140.90	127.81	2.52	3.65
Treatment	15	878.56	58.57	3.49	1.83	2.36
Frequency (A)	3	540.90	180.3	10.76	2.76	4.13
Range (B)	3	77.75	25.91	1.54	2.76	4.13
A x B	9	259.91	28.87	1.72	2.04	2.72
Error	60	1005.37	16.75			
	79	10447.55				

C.D. at (5%) frequency = 2.591273

C.D. at (5%) range = 2.591273

Interaction = 5.183146

Effect of four frequencies of handle operation in four ranges of handle movement in RCB design for Δ HR replication II (Expt.-1).

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁						
M ₁	13.6	21.9	6.3	12.8	13.4	68.0
M ₂	9.2	17.7	7.2	9.7	20.2	64.0
M ₃	14.9	11.4	6.4	14.9	17.2	64.8
M ₄	12.0	12.9	7.5	10.0	13.5	55.9
	49.7	63.9	27.4	47.4	64.3	252.7
N ₂						
M ₁	13.7	33.6	9.8	11.9	13.9	82.7
M ₂	12.4	20.4	12.4	18.5	18.5	82.2
M ₃	15.1	25.7	8.0	10.6	19.3	78.7
M ₄	16.4	16.4	10.0	16.8	18.6	78.3
	57.6	96.1	40.3	57.8	70.3	322.1
N ₃						
M ₁	19.1	28.3	7.4	17.5	21.4	93.7
M ₂	14.1	18.6	11.2	11.6	19.1	74.6
M ₃	11.3	21.9	13.1	19.4	16.9	82.6
M ₄	16.7	24.1	11.9	11.0	16.6	80.3
	61.2	92.9	43.6	59.5	74.0	331.2

Table contd.

Range of Movement	Heart rate beats/min					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
			N ₄			
M ₁	15.3	26.7	16.9	19.9	20.1	98.9
M ₂	19.9	26.3	13.2	23.3	20.3	103.0
M ₃	23.7	25.2	10.0	18.0	15.7	92.6
M ₄	17.9	29.0	13.9	16.4	21.3	98.5
	76.8	107.2	54	77.6	77.4	393
Frequency Total (R)	245.3	360.1	165.3	242.3	286	1299

The frequency x range table of total trials

Range of movement	Hart rate, beats/min (AB)				Range total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	68.0	82.9	93.7	98.9	343.5	17.17
M ₂	64.0	82.2	74.6	103.0	323.8	16.19
M ₃	64.8	78.7	82.6	92.6	318.7	15.93
M ₄	55.9	78.3	80.3	98.5	313	15.65
Total	252.7	322.1	331.2	393	1299	
Mean	(12.63)	(16.10)	(16.56)	(19.65)		

Analysis of variance of data for 4 x 4
factorial experiment in RCB design.

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5 %	1%
Subject	4	1262.07	315.51	27.41	2.52	3.65
Treatment	15	563.60	37.57	3.26	1.83	2.36
Frequency (A)	(3)	494.89	164.96	14.33	2.76	4.13
Range (B)	(3)	26.35	8.78	0.76	2.76	4.13
A x B	(9)	42.36	4.70	0.40	2.04	2.72
Error	60	690.92	11.51			
	79	2516.59				

C.D. (5%) frequency = 2.143568

Interaction = 4.287136

Effect of four frequencies of handle operation in four range of handle movement in RCB design on Severity rating replication-II (Expt.-1).

Range of Movement	Severity Rating					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁						
M ₁	2	1	4	2	2	11
M ₂	2	1	2	2	2	9
M ₃	3	1	2	2	2	10
M ₄	3	2	1	2	1	9
	10	5	9	8	7	39
N ₂						
M ₁	3	3	3	3	2	14
M ₂	3	2	1	2	3	11
M ₃	3	3	3	3	3	15
M ₄	4	3	5	2	3	17
	13	11	12	10	11	57
N ₃						
M ₁	5	4	2	5	3	19
M ₂	3	4	4	3	4	18
M ₃	4	5	3	3	3	18
M ₄	4	4	4	4	3	19
	16	17	13	15	13	74

Table contd.

Range of Movement	Severity rating					Treatment Total (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
			N ₄			
M ₁	4	5	5	5	4	23
M ₂	7	5	3	5	5	25
M ₃	8	6	4	5	5	28
M ₄	5	6	5	5	5	26
	24	22	17	20	19	102
Frequency Total (R)	63	55	51	53	50	272

The frequency x range table of total trials

Range of movement	Severity Rating (AB)				Range Total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	11	14	19	23	67	3.35
M ₂	9	11	18	25	63	3.15
M ₃	10	15	18	28	71	3.55
M ₄	9	17	19	26	71	3.55
Total	39	57	74	102	272	
Mean	(1.95)	(2.85)	(3.7)	(5.1)		

Analysis of variance of data for 4 x 4
factorial experiment in RCB design.

Source of variance	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5 %	1%
Subject	4	6.7	1.67	2.32	2.52	3.65
Treatment	15	114.8	7.65	10.62	1.83	2.36
Frequency (A)	3	107.7	35.9	49.86	2.76	4.13
Range (B)	3	2.2	0.73	1.01	2.76	4.13
A x B	9	4.9	0.54	0.75	2.04	2.72
Error	60	43.7	0.72			
	79	165.2				

C.D. (5%) for frequency = .5397531

C.D. at (5%) for Range of movement = .5397531

Interaction = 1.079506

Data of heart rate of 3rd replication at rest of five subjects
(Expt. -1) (Beats/min)

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	65.47 (2.20)	72.65 (2.53)	66.23 (1.05)	74.4 (3.02)	82.15 (1.27)	72.18 (2.01)
N ₁ M ₂	67.76 (1.07)	72.37 (1.92)	62.75 (0.96)	72.3 (1.93)	71.89 (1.35)	69.41 (1.45)
N ₁ M ₃	70.85 (0.83)	76.49 (1.93)	67.0 (1.01)	81.34 (1.41)	77.73 (1.74)	74.68 (1.38)
N ₁ M ₄	68.58 (1.23)	70.30 (2.34)	61.22 (1.03)	72.79 (1.43)	84.39 (0.99)	71.45 (1.43)
N ₂ M ₁	67.6 (1.21)	77.36 (1.69)	63.93 (1.20)	82.59 (2.21)	85.55 (1.13)	75.40 (1.49)
N ₂ M ₂	69.62 (0.91)	77.34 (1.82)	66.72 (1.22)	70.68 (1.29)	72.5 (1.43)	71.37 (1.33)
N ₂ M ₃	68.38 (1.05)	76.31 (2.07)	56.33 (0.95)	75.47 (1.65)	72.57 (1.61)	69.81 (1.47)
N ₂ M ₄	72.43 (1.07)	75.52 (2.42)	58.35 (1.03)	71.35 (1.76)	72.2 (1.23)	69.97 (1.51)
N ₃ M ₁	68.52 (1.33)	72.89 (2.10)	67.02 (1.40)	77.45 (2.46)	72.3 (1.36)	71.63 (1.73)
N ₃ M ₂	72.94 (1.12)	75.74 (3.43)	65.89 (1.30)	81.67 (1.71)	76.34 (1.52)	74.51 (1.82)
N ₃ M ₃	66.5 (1.27)	76.21 (1.87)	57.37 (1.41)	80.55 (1.38)	83.97 (0.81)	72.92 (1.35)
N ₃ M ₄	67.70 (1.66)	74.22 (2.44)	56.34 (1.33)	73.05 (1.66)	83.59 (1.51)	70.98 (1.72)
N ₄ M ₁	74.14 (1.26)	75.69 (2.59)	56.80 (1.63)	70.27 (1.38)	72.95 (1.56)	69.97 (1.70)
N ₄ M ₂	66.36 (1.12)	72.81 (1.10)	55.41 (1.59)	74.69 (2.06)	83.47 (1.42)	70.54 (1.46)
N ₄ M ₃	66.75 (1.37)	74.75 (2.25)	63.63 (1.64)	75.38 (2.46)	82.29 (1.33)	72.56 (1.81)
N ₄ M ₄	70.40 (1.40)	78.77 (2.17)	65.0 (1.03)	80.68 (1.78)	74.14 (1.13)	73.79 (1.50)

Data of heart rate at work of 3rd replication (Expt.-1)
(Beats/min)

Subject/ Treatment	S ₁	S ₂	S ₃	S ₄	S ₅	Mean
N ₁ M ₁	76.2 (2.31)	89.89 (3.20)	73.87 (1.14)	85.0 (2.48)	95.52 (1.94)	84.1 (2.21)
N ₁ M ₂	76.73 (2.38)	89.63 (3.3)	70.42 (2.22)	80.18 (2.18)	92.13 (1.58)	81.8 (2.33)
N ₁ M ₃	79.84 (2.25)	91.64 (2.45)	72.97 (1.31)	90.09 (2.46)	94.93 (2.39)	85.86 (2.17)
N ₁ M ₄	77.64 (1.61)	85.3 (2.71)	68.36 (1.82)	80.90 (2.89)	97.91 (2.67)	82.02 (2.34)
N ₂ M ₁	83.44 (1.16)	92.50 (2.23)	73.02 (1.55)	93.23 (1.44)	99.45 (1.73)	88.32 (1.62)
N ₂ M ₂	81.71 (1.75)	100.75 (2.32)	74.42 (1.70)	83.11 (1.50)	91.0 (1.73)	86.2 (1.62)
N ₂ M ₃	79.36 (1.47)	89.44 (2.27)	68.44 (1.58)	89.06 (1.38)	91.85 (1.60)	83.64 (1.66)
N ₂ M ₄	83.77 (1.6)	89.71 (2.18)	68.45 (1.11)	86.98 (2.03)	90.83 (1.44)	83.94 (1.67)
N ₃ M ₁	84.32 (1.19)	91.79 (2.66)	78.34 (1.6)	94.56 (1.69)	93.74 (1.68)	88.56 (1.76)
N ₃ M ₂	86.90 (1.33)	95.77 (2.07)	74.55 (1.27)	95.86 (1.24)	95.43 (1.97)	89.72 (1.58)
N ₃ M ₃	78.28 (1.30)	91.67 (1.67)	72.10 (1.68)	88.62 (1.39)	100.94 (1.73)	86.32 (1.55)
N ₃ M ₄	83.62 (1.14)	99.54 (1.91)	69.65 (2.07)	85.70 (1.55)	100.15 (2.25)	87.74 (1.78)
N ₄ M ₁	87.53 (1.56)	97.04 (2.18)	73.95 (1.72)	88.09 (1.73)	93.0 (1.56)	87.9 (1.75)
N ₄ M ₂	83.17 (1.10)	97.14 (2.63)	72.76 (1.67)	91.04 (2.09)	103.73 (2.07)	89.56 (1.91)
N ₄ M ₃	85.69 (1.62)	95.21 (1.96)	73.85 (1.59)	95.28 (1.56)	98.0 (2.22)	89.62 (1.79)
N ₄ M ₄	83.99 (1.99)	103.49 (1.77)	75.11 (1.57)	92.12 (1.64)	95.45 (1.55)	90.02 (1.70)

Difference of heart rate at rest and work of subjects for 3rd replication (Expt.-1)

Treatment	(Beats/min)					Mean
	S ₁	S ₂	Subjects S ₃	S ₄	S ₅	
N ₁ M ₁	10.73	17.24	7.64	10.6	13.37	11.9
N ₁ M ₂	8.97	12.26	7.67	7.88	20.24	12.4
N ₁ M ₃	8.99	15.15	5.97	8.75	17.2	11.2
N ₁ M ₄	9.06	15.0	7.14	8.11	13.52	10.56
N ₂ M ₁	15.84	15.14	0.09	10.64	13.9	12.9
N ₂ M ₂	12.09	23.41	7.7	12.43	18.5	14.82
N ₂ M ₃	10.98	13.13	12.11	13.59	19.28	13.8
N ₂ M ₄	11.34	14.19	9.92	15.63	18.63	13.92
N ₃ M ₁	15.8	18.9	11.41	17.11	21.44	16.92
N ₃ M ₂	13.96	20.03	8.66	14.19	19.09	15.18
N ₃ M ₃	11.78	15.46	14.73	8.07	16.97	13.4
N ₃ M ₄	15.92	15.32	13.31	12.71	16.56	16.76
N ₄ M ₁	13.39	21.35	17.15	17.82	20.05	17.98
N ₄ M ₂	16.81	24.33	17.35	16.35	20.26	19.04
N ₄ M ₃	18.94	20.46	10.22	19.9	15.71	17.04
N ₄ M ₄	13.59	24.72	10.11	21.84	21.31	18.5

Job severity rating as given by subjects on 0-10 scale
for 3rd replication (Expt.-1)

Treatment	Subjects					Mean
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁ M ₁	1	1	1	2	1	1.2
N ₁ M ₂	3	1	1	2	2	1.8
N ₁ M ₃	1	1	1	2	3	1.6
N ₁ M ₄	2	1	1	2	1	1.4
N ₂ M ₁	3	2	3	2	2	2.4
N ₂ M ₂	4	2	3	3	3	3.0
N ₂ M ₃	3	3	3	3	4	3.2
N ₂ M ₄	2	3	2	3	3	2.6
N ₃ M ₁	5	4	3	3	5	4.0
N ₃ M ₂	3	3	5	4	4	3.8
N ₃ M ₃	6	4	4	5	4	4.6
N ₃ M ₄	6	4	4	4	4	4.4
N ₄ M ₁	4	5	5	5	5	4.8
N ₄ M ₂	5	5	5	4	5	4.8
N ₄ M ₃	6	5	5	5	5	5.2
N ₄ M ₄	6	5	5	5	5	5.2

Effect of four frequencies of handle operation in four range of handle movement in a RCB design replication-III (Expt. 1))

Range of movement	Heart rate, beats/min					Total treatment (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
	N ₁					
M ₁	76.2	89.9	73.9	85.0	95.5	420.5
M ₂	76.7	89.6	70.40	80.2	92.1	409.0
M ₃	79.8	91.6	72.9	90.1	94.9	429.3
M ₄	77.6	85.3	68.4	80.9	97.9	410.1
	310.3	356.4	285.6	336.2	380.4	1668.9
	N ₂					
M ₁	83.4	92.5	73.0	93.2	99.5	441.6
M ₂	81.7	100.8	74.1	83.1	91.0	431.0
M ₃	79.4	89.4	68.4	89.1	91.9	418.2
M ₄	83.8	89.7	68.5	86.9	90.8	419.7
	328.3	372.4	284.3	352.3	373.2	1710.5
	N ₃					
M ₁	84.3	91.8	78.4	94.6	93.7	442.8
M ₂	86.9	95.8	74.6	95.9	95.4	448.6
M ₃	78.3	91.7	72.1	88.6	100.9	431.6
M ₄	83.6	99.5	69.6	85.8	100.2	438.7
	333.1	378.8	294.7	364.0	390.2	1761.7

Table contd.

	N ₄					
M ₁	87.5	97.0	73.9	88.1	93.0	439.5
M ₂	83.2	97.1	72.8	91.0	103.7	447.8
M ₃	85.7	95.2	73.9	95.3	98.0	448.1
M ₄	83.9	103.5	75.1	92.1	95.5	450.1
	340.3	392.8	295.7	366.5	390.2	1785.5
Frequency Total (R)	1312.0	1500.4	1160.3	1419.9	1534.0	6926.6

The frequency x range table of total trials

Range	Heart rate, beats/min. (AB)				Range Total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	420.5	441.6	442.8	439.5	1744.4	87.22
M ₂	409.0	431.0	448.6	447.8	1736.4	86.82
M ₃	429.3	418.2	431.6	448.1	1727.2	86.36
M ₄	410.1	419.7	438.7	450.1	1718.6	85.93
Frequency Total (A)	1668.9	1710.5	1761.7	1785.5	6926.6	
Mean	(83.44)	(85.52)	(88.08)	(89.27)		

Analysis of variance of data from 4 x 4 factorial
experiment in RCB design

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	5784.67	1446.16	131.35	2.52	3.65
Treatment	15	579.94	38.66	(3.51)	1.83	2.36
Frequency (A)	(3)	409.39	136.46	12.39	2.76	4.13
Range (B)	(3)	18.76	6.25	0.56	2.76	4.13
A x B	(9)	151.79	16.86	1.53	2.04	2.72
Error	60	660.63	11.01			
	79	7025.24				
C.D. (5%) for frequency	-			2.114533		
C.D. (5%) for movement	-			2.114533		
C.D. (5%) for interaction	-			4.229066		

Effect of four range of frequencies of handle operation in four range of handle movement in a RCB design for Δ HHR replication-III (Expt. 1)

Range of movement	Heart rate, beats/min					Total treatment (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
N ₁						
M ₁	10.70	17.24	7.69	10.6	13.4	59.5
M ₂	8.90	17.30	7.7	7.9	20.2	62.0
M ₃	8.90	15.20	5.9	8.8	17.2	56.0
M ₄	9.10	15.0	7.1	8.1	13.5	52.8
	37.6	64.7	28.3	35.4	64.3	230.3
N ₂						
M ₁	15.80	15.10	9.1	10.6	13.9	64.5
M ₂	12.10	23.40	7.7	12.4	18.5	74.1
M ₃	10.90	13.10	12.1	13.6	14.3	69.0
M ₄	11.30	14.10	9.9	15.6	18.6	69.6
	50.1	65.8	38.8	52.2	70.3	277.2
N ₃						
M ₁	15.8	18.9	14.4	17.1	21.4	84.6
M ₂	13.90	20.0	8.7	14.2	19.1	75.9
M ₃	11.80	15.5	14.7	8.1	16.9	67.0
M ₄	15.90	25.3	13.3	12.7	16.6	83.8
	57.4	79.7	48.1	52.1	74	311.3

Table contd.

	N ₄					
M ₁	13.40	21.4	17.2	17.8	20.1	89.9
M ₂	16.80	24.3	17.4	16.4	20.3	95.2
M ₃	18.9	20.5	10.2	19.9	15.7	85.2
M ₄	13.6	24.7	10.1	22.8	21.3	92.5
	62.7	90.9	54.9	76.9	77.4	362.8
Frequency Total (R)	207.8	301.1	170.1	216.6	286.0	1181.6

The frequency x range table of total trials

Range	Heart rate, beats/min. (AB)				Range Total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	59.5	64.5	84.6	89.9	298.5	14.92
M ₂	62.0	74.1	75.9	95.2	307.2	15.36
M ₃	56.0	69.0	67.0	85.2	277.2	13.86
M ₄	52.8	69.6	83.8	92.5	298.7	14.93
Frequency Total (A)	230.3	277.2	311.3	362.8	1181.6	
Mean	(11.51)	(13.86)	(15.56)	(18.14)		

Analysis of variance of data from 4 x 4 factorial
experiment in RCB design

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	765.74	191.43	25.90	2.52	33.65
Treatment	15	538.58	35.90	4.85	1.83	2.36
Frequency (A)	(3)	468.24	156.08	21.12	2.76	4.13
Range (B)	(3)	24.55	8.18	1.10	2.76	4.13
A x B	(9)	45.79	5.08	0.68	2.04	2.72
Error	60	443.67	7.39			

C.D. (5%) for frequency		=		1.719814		
C.D. (5%) for interaction		=		3.43.9628		

Effect of four frequencies of handle operation in four range of handle movement in a RCB design for severity rating replication-III (Expt.1)

Range of movement	Severity Rating					Total treatment (T)
	S ₁	S ₂	S ₃	S ₄	S ₅	
	N ₁					
M ₁	1	1	1	2	1	6
M ₂	3	1	1	2	2	9
M ₃	1	1	1	2	3	8
M ₄	2	1	1	2	1	7
	7	4	4	8	7	30
	N ₂					
M ₁	3	2	3	2	2	12
M ₂	4	2	3	3	3	15
M ₃	3	3	3	3	4	16
M ₄	2	3	2	3	3	13
	12	10	11	11	12	56
	N ₃					
M ₁	5	4	3	3	5	20
M ₂	3	3	5	4	4	19
M ₃	6	4	4	5	4	23
M ₄	6	4	4	4	4	22
	20	15	16	16	17	84

Table contd.

	N ₄					
M ₁	4	5	5	5	5	24
M ₂	5	5	5	4	5	24
M ₃	6	5	5	5	5	26
M ₄	6	5	5	5	5	26
	21	20	20	19	20	100
Frequency Total (R)	60	49	51	54	56	270

The frequency x range table of total trials

Range	Severity Rating (AB)				Range Total (B)	Mean
	N ₁	N ₂	N ₃	N ₄		
M ₁	6	12	20	24	62	3.1
M ₂	9	15	19	24	67	3.35
M ₃	8	16	23	26	73	3.65
M ₄	7	13	22	26	68	3.4
Frequency Total (A)	30	56	84	100	270	
Mean	(1.5)	(2.8)	(4.2)	(5.0)		

Analysis of variance of data from 4 x 4 factorial
experiment in RCB design

Source of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	4.62	1.15	2.81	2.52	3.65
Treatment	15	149.15	9.94	24.2	1.83	2.86
Frequency (A)	(3)	143.35	47.78	116.53	2.76	4.13
Range (B)	(3)	3.05	1.01	2.46	2.76	4.13
A x B	(9)	2.75	0.30	0.73	2.04	2.72
Error	60	24.98	0.41			
	79	178.75				

C.D. (5%) for frequency = 4.080439

C.D. (5%) for interaction = 8.160878

Data of average heart rate of five subjects in first replication at work (Expt -1)

Range	Heart rate (beats/min)				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	86.38	84.73	88.43	91.32	87.71
M ₂	82.14	85.99	88.04	92.21	87.10
M ₃	79.36	85.43	86.06	93.83	86.17
M ₄	80.28	85.50	86.78	89.08	85.41
Mean	82.04	85.43	87.3	91.60	

Data of average heart rate of five subjects in second replication at work (Expt -1)

Range	Heart rate (beats/min)				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	84.86	87.69	87.99	89.77	87.50
M ₂	78.66	87.73	85.92	89.64	85.48
M ₃	81.82	80.73	90.12	87.04	84.92
M ₄	81.68	84.80	85.56	87.88	84.97

Data of average heart rate of five subjects in third replication at work (Expt -1)

Range	Heart rate (beats/min)				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	84.1	88.32	88.56	87.9	87.22
M ₂	81.86	86.23	89.72	89.56	86.82
M ₃	85.86	83.64	86.32	89.62	86.36
M ₄	82.02	83.94	87.74	90.02	85.93
Mean	83.44	85.52	88.08	89.27	

Data of average heart rate difference of work and rest
(Δ HR) of five subjects for first replication (Expt-1)

Range	Frequency				Mean
	N_1	N_2	N_3	N_4	
M_1	14.14	16.52	19.78	23.94	18.59
M_2	10.72	16.06	18.42	25.42	17.65
M_3	11.42	13.92	20.24	25.72	17.83
M_4	11.28	15.52	18.08	21.76	16.66
Mean	11.89	15.51	19.13	24.21	

Data of average heart rate difference of work and rest
(Δ HR) of five subjects for 2nd replication (Expt-1)

Range	Frequency				Mean
	N_1	N_2	N_3	N_4	
M_1	13.6	16.58	18.74	19.78	17.17
M_2	12.82	16.44	14.92	20.62	16.19
M_3	12.96	15.74	16.52	18.52	15.93
M_4	11.18	15.66	16.06	19.76	15.65
Mean	12.63	16.10	16.56	19.65	

Data of average heart rate difference of work and rest
(Δ HR) of five subjects for 3rd replication (Expt-1)

Range	Frequency				Mean
	N_1	N_2	N_3	N_4	
M_1	11.9	12.9	16.92	17.98	14.92
M_2	12.4	14.82	15.18	19.04	15.36
M_3	11.22	13.82	13.44	17.04	13.86
M_4	10.56	13.92	16.76	18.5	14.93
Mean	11.51	13.86	15.56	18.14	

Data of average job severity rating of five subjects
for first replication (Expt-1)

Range	Frequency				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	2.2	4.0	4.2	6.0	4.1
M ₂	1.8	3.4	4.4	6.0	3.9
M ₃	2.8	2.8	4.6	6.0	4.1
M ₄	2.0	3.2	4.6	3.6	3.35
Mean	2.2	3.35	4.45	5.4	

Data of average job severity rating of five subjects
for 2nd replication (Expt-1)

Range	Frequency				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	2.2	2.8	3.8	4.6	3.35
M ₂	1.8	2.2	3.6	5.0	3.15
M ₃	2.0	3.0	3.6	5.6	3.55
M ₄	1.8	3.4	3.8	5.2	3.55
Mean	1.95	2.85	3.7	5.1	

Data of average job severity rating of five subjects
for 3rd replication (Expt-1)

Range	Frequency				Mean
	N ₁	N ₂	N ₃	N ₄	
M ₁	1.2	2.4	4.0	4.8	3.1
M ₂	1.8	3.0	3.8	4.8	3.35
M ₃	1.6	3.2	4.6	5.2	3.65
M ₄	1.4	2.6	4.4	5.2	3.40
Mean	1.5	2.8	4.2	5.0	

Data of heart rate (beats/min) at rest of five subjects for first and second replication with mean of two replications (Expt.2)

Treatment	S ₁			S ₂			S ₃			S ₄			S ₅		
	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean
H ₁	68.45 (1.69)	70.76 (1.13)	69.60 (1.41)	69.31 (2.58)	65.55 (1.40)	67.43 (2.03)	56.32 (1.61)	59.60 (1.49)	57.96 (1.53)	73.30 (1.80)	75.98 (1.70)	74.64 (1.75)	77.25 (2.18)	70.25 (2.07)	73.75 (2.13)
H ₂	68.14 (1.40)	68.41 (1.24)	68.27 (1.41)	72.30 (2.92)	65.63 (2.11)	68.96 (2.51)	59.09 (1.47)	59.92 (1.89)	59.50 (1.68)	77.62 (1.41)	80.28 (1.0)	78.95 (1.21)	81.35 (1.24)	75.06 (1.33)	78.20 (1.29)
H ₃	67.44 (1.91)	71.11 (1.38)	69.27 (1.63)	78.73 (1.79)	65.35 (2.07)	72.04 (1.93)	62.36 (1.20)	62.21 (1.71)	62.28 (1.46)	74.91 (1.41)	77.63 (1.69)	76.27 (1.55)	79.23 (1.62)	68.73 (2.18)	73.98 (1.9)
H ₄	71.10 (2.09)	69.0 (1.10)	70.05 (1.59)	71.84 (3.29)	64.83 (1.90)	68.33 (2.59)	56.5 (1.60)	61.58 (2.33)	59.04 (1.97)	75.75 (1.42)	76.21 (1.24)	75.98 (1.33)	78.93 (1.90)	74.21 (1.31)	76.57 (1.61)
H ₅	67.28 (1.52)	68.03 (1.11)	67.65 (1.31)	77.44 (1.86)	64.77 (2.28)	71.10 (2.07)	58.30 (1.78)	61.30 (1.26)	59.8 (1.32)	76.15 (1.10)	78.44 (1.18)	77.29 (1.14)	79.48 (1.02)	68.43 (1.81)	73.95 (1.42)
H ₆	67.62 (1.81)	70.27 (0.98)	68.94 (1.39)	70.29 (1.44)	64.40 (1.04)	67.44 (1.52)	54.82 (1.98)	61.29 (1.61)	58.05 (1.79)	75.03 (1.46)	76.58 (1.16)	75.80 (1.31)	80.40 (1.28)	74.29 (1.23)	77.34 (1.26)

S.D. Figures in brackets indicate Standard Deviation

Data of heart rate (beats/min) at work for five subjects for first and second replication with mean of two replications (Expt. 2)

Treatment	S ₁			S ₂			S ₃			S ₄			S ₅		
	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean
H ₁	79.73 (2.63)	83.13 (2.10)	81.43 (2.37)	88.04 (3.56)	88.06 (2.63)	88.65 (3.11)	67.92 (2.51)	73.36 (2.57)	70.67 (2.54)	85.30 (2.46)	92.91 (2.10)	89.10 (2.29)	92.36 (2.68)	87.65 (3.37)	90.05 (3.03)
H ₂	78.68 (1.66)	80.87 (1.52)	79.37 (1.59)	87.26 (2.64)	84.04 (2.60)	85.65 (2.62)	67.74 (2.45)	70.56 (1.86)	69.15 (2.16)	89.16 (2.17)	92.43 (1.59)	90.75 (1.88)	93.18 (1.98)	87.46 (2.89)	90.38 (2.44)
H ₃	81.27 (1.88)	80.83 (1.40)	81.05 (1.64)	91.00 (2.7)	81.93 (2.63)	86.46 (2.67)	69.28 (2.65)	78.25 (1.42)	69.76 (2.04)	83.33 (1.87)	88.25 (1.56)	85.79 (1.72)	90.13 (2.12)	78.71 (1.77)	84.4 (1.95)
H ₄	80.47 (1.87)	80.37 (1.68)	80.45 (1.78)	88.59 (2.16)	82.67 (2.64)	85.65 (2.4)	65.75 (1.67)	70.12 (1.80)	67.93 (1.74)	86.65 (2.16)	87.75 (1.79)	87.27 (1.98)	90.18 (2.13)	85.17 (1.79)	87.57 (1.96)
H ₅	80.82 (1.56)	79.48 (1.53)	80.15 (1.55)	92.39 (2.21)	82.82 (2.72)	87.60 (2.47)	65.93 (2.03)	69.72 (1.56)	67.82 (1.79)	87.52 (2.04)	91.09 (1.81)	89.30 (1.93)	93.08 (1.76)	81.88 (2.11)	87.48 (1.94)
H ₆	79.89 (1.56)	82.54 (1.24)	81.21 (1.40)	87.93 (2.61)	87.19 (2.25)	87.56 (2.43)	63.78 (2.23)	72.45 (1.79)	68.16 (2.01)	86.92 (1.90)	91.54 (1.93)	89.23 (1.94)	94.79 (2.21)	87.90 (2.04)	91.35 (2.13)

Data of heart rate difference (beats/min) at rest and work) of five subjects on 1st and 2nd replication (Expt. 2)

Treatment	S ₁			S ₂			S ₃			S ₄			S ₅		
	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean
N ₁	11.28	12.37	11.82	18.73	22.51	20.62	11.6	13.76	12.68	12.0	16.93	14.46	15.11	17.4	16.25
N ₂	10.54	11.66	11.1	14.96	18.41	16.68	8.65	10.64	9.64	11.54	12.15	11.84	11.83	12.4	12.11
N ₃	13.83	9.72	11.77	12.27	16.58	14.42	6.92	8.04	7.48	8.42	10.62	9.52	10.9	9.98	10.44
N ₄	9.37	11.37	10.37	16.75	17.84	17.29	9.25	8.54	8.89	10.9	11.54	11.22	11.25	10.96	11.10
N ₅	13.54	11.45	12.49	14.95	18.05	16.5	7.63	8.42	8.02	11.37	12.65	12.01	13.60	13.45	13.52
N ₆	12.27	12.27	12.27	17.64	22.59	20.11	8.96	11.16	10.06	11.89	14.96	13.42	14.39	13.61	14.0

Job severity rating of five subjects for first and second replication on 0-10 point scale (Expt. 2)

Treatment	S ₁			S ₂			S ₃			S ₄			S ₅		
	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean	R ₁	R ₂	Mean
H ₁	4	4	4	3	4	3.5	3	3	3	4	5	4.5	4	5	4.5
H ₂	3	2	2.5	1	2	1.5	2	2	2	2	2	2	2	2	2
H ₃	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H ₄	1	1	1	1	1	1	2	1	1.5	1	1	1	1	1	1
H ₅	1	1	1	1	1	1	1	1	1	1	2	1.5	1	2	1.5
H ₆	2	3	2.5	2	3	2.5	2	3	2.5	2	3	2.5	3	3	3

Analysis of Data in Replication-I
 Effect of frequencies of handle operation in handle movement
 for first replication (Expt. 2)

Treatment	Heart rate (Beat/min)					Total	Mean
	S ₁	S ₂	Subjects S ₃	S ₄	S ₅		
N ₁	79.7	88.0	67.9	85.3	92.4	413.3	82.66
N ₂	78.7	87.3	67.7	89.2	93.2	416.1	83.22
N ₃	81.3	91.0	69.3	83.3	90.1	415	83.0
N ₄	80.5	88.6	65.8	86.7	90.2	411.8	82.36
N ₅	80.8	92.4	65.9	87.5	93.1	419.7	83.94
N ₆	79.9	87.9	63.8	86.9	94.8	413.3	82.66
Total	480.9	535.2	400.4	518.9	553.8	2489.2	
Mean	80.15	89.2	66.73	86.48	92.3		

Analysis of Variance

Degree of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	2458.72	614.68	167.94	2.87	4.43
Treatment	5	7.84	1.56	0.42	2.71	4.10
Error	20	73.16	3.66			

C.D. at 5% level: 2.52

Effect of frequencies of handle frequency in constant work load for heart rate difference (Expt-2)

Treatment	Heart rate difference (Beat/min)					Total	Mean
	Subjects						
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁	11.3	18.7	11.6	12.0	15.1	68.73	13.74
N ₂	10.5	14.9	8.7	11.5	11.8	57.41	11.48
N ₃	13.8	12.3	6.9	8.4	10.9	52.3	10.46
N ₄	9.4	16.8	9.3	10.9	11.3	57.78	11.54
N ₅	13.5	14.9	7.6	11.4	13.6	61.0	12.2
N ₆	12.3	17.6	8.9	11.9	14.4	65.1	13.02
Total	70.8	95.2	53	66.1	77.1	362.2	
Mean	11.8	15.87	8.83	11.02	12.85		

Analysis of Variance

Degree of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	160	40.0	18.09	2.87	4.43
Treatment	5	34.65	6.93	3.13	2.71	4.10
Error	20	44.25	2.21			

C.D. at 5% level: 1.96 beats/min

Effect of frequencies of handle operation in constant work load for job severity replication I (Expt-2)

Treatment	Job severity rating					Total	Mean
	S ₁	S ₂	Subjects				
			S ₃	S ₄	S ₅		
N ₁	4	3	3	4	4	18	3.6
N ₂	3	1	2	2	2	10	2.0
N ₃	1	1	1	1	1	5	1.0
N ₄	1	1	2	1	1	6	1.2
N ₅	1	1	1	1	1	5	1.0
N ₆	2	2	2	2	3	11	2.2
Total	12.0	9.00	10	11.0	12	55	
Mean	2.0	1.50	1.86	1.83	2.0		

Analysis of Variance

Degree of variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	1.0	0.25	1.32	2.87	4.43
Treatment	5	25.37	5.07	26.68	2.71	4.10
Error	20	3.8	0.19			

C.D. at 5% level: 0.58

Effect of frequencies of handle operation for constant work load at for heart rate at work for second replication (Expt.2)

Treatment	Heart rate (Beat/min)					Total	Mean
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁	83.1	88.1	73.4	92.9	87.7	425.2	85.04
N ₂	80.1	84.0	70.6	92.4	87.5	414.6	82.92
N ₃	80.8	81.9	70.3	88.3	78.7	400.0	80.0
N ₄	80.4	82.7	70.1	87.8	85.2	406.2	81.24
N ₅	79.5	82.8	69.7	91.1	81.9	405.0	81.0
N ₆	82.5	87.2	72.5	91.5	87.9	421.6	84.32
Total	486.4	506.70	426.6	544	508.9	2472.6	
Mean	81.06	84.45	71.1	90.66	84.81		

Statistical Analysis

Source of variation	Degree of Freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	1247.08	311.77	128.83	2.87	4.43
Treatment	5	99.95	19.99	8.26	2.71	4.10
Error	20	48.4	2.42			

C.D. at 5% level = 2.05 beats/min

Effect of frequencies of handle operation for constant work load on heart rate difference for second replication (Expt-2)

Treatment	Heart rate (Beat/min)					Total	Mean
	S ₁	S ₂	Subjects S ₃	S ₄	S ₅		
N ₁	12.4	22.5	13.8	16.9	17.4	83.0	16.6
N ₂	11.7	18.4	10.6	12.2	12.4	65.3	13.06
N ₃	9.7	16.6	8.0	10.6	9.9	54.8	10.96
N ₄	11.4	17.8	8.59	11.5	10.9	60.1	12.02
N ₅	11.5	18.1	8.4	12.7	13.5	64.2	12.84
N ₆	12.3	22.6	11.2	14.9	13.6	74.6	14.92
Total	69	116	60.5	78.8	77.7	402	
Mean	11.5	19.33	10.08	13.13	12.95		

Statistical Analysis

Source of variation	Degree of Freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	300.53	75.13	74.38	2.87	4.43
Treatment	5	104.19	20.83	20.62	2.71	4.10
Error	20	20.26	1.01			

C.D. at 5% level = 1.33

Effect of frequencies of handle operation for constant work load on job severity rating for second replication (Expt-2)

Treatment	Job severity rating					Total	Mean
	Subjects						
	S ₁	S ₂	S ₃	S ₄	S ₅		
N ₁	4	4	3	5	5	21	4.2
N ₂	2	2	2	2	2	10	2.0
N ₃	1	1	1	1	1	5	1.0
N ₄	1	1	1	1	1	5	1.0
N ₅	1	1	1	2	2	7	1.4
N ₆	3	3	3	3	3	15	3.0
Total	12	12	11	14	14	63	
Mean	2.0	2.0	1.83	2.33	2.33		

Statistical Analysis

Source of variation	Degree of Freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Subject	4	1.2	0.3	2.14	2.87	4.43
Treatment	5	40.7	8.14	58.14	2.71	4.10
Error	20	2.8	0.14			

C.D. at 5% level = 0.49

Body part discomfort data after 2 hours continuous operation of modified Hi-Flo (12 litre capacity) sprayer

Subject Bk

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	2	11	10	1	20	
	3,5	14	17	16A	21	
	7,4	15		24,25		

Subject MJ

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	2	6	1,7	12,16A	20	
	3	10	11,13	24,25,	21	
	4	-	15,17	26,27,	22	
	5	14	8,9	18	23,16B	

Subject HS

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	1	6	10	20	24	
	2	7	11	21	25	
	3	8	12	22		
	4	9	13	23		
	5	17,18	14,15			
		16A				

Table contd.

Subject CR

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	1,2	17	7	6	16A	
	3,4	18	11	14	20	
	5		15	24	21	
				25	22,27	
					23	
				26		

Subject AS

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	2,3,4,5	1,7,9	15,20,	16A,6	12,11	
			21,22,	8,10	13,26	
			23,24,	14,17,	27	
			25	18		

Body part discomfort data after 2 hours continuous operation of Aspee Napsak (SRP-60, 16 litre capacity) LOK sprayer

Subject BK

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	2,3 24,25, 5	1,16A, 9,10, 14,15	7,17, 11	13,16B		

Subject MJ

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	2,3 15	1,5, 17,10, 12,24, 25	4,16A, 7,11	16B,22, 23	18,14,	

Subject HS

Body part	2,3, 17	1,16A, 12,15	4,5, 20,21, 24,25	7,18,	16B,6 8,9	10,11 22,23	14
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Subject CR

Body part	2,3 4,5, 24,25	18,7, 9,11, 15	6,17, 10,12, 26,27	16A,1	16B	20,21, 22,23,	14
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Subject AS

Body part	2,3 4,5	12,13, 17	1,8, 18	20,21, 22,23, 24,25	16A,6 7	11,10	14, 15, 26, 27, 16B
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Overall discomfort rating for 2 hours continuous walking

S.No.	Subject	Ist Fill	2nd Fill	3rd Fill	4th Fill
1.	BK	0.6	1.0	1.5	1.75
2.	MJ	0.7	1.0	1.5	2.0
3.	HS	0.5	0.8	1.0	1.5
4.	CR	0.6	1.2	1.5	2.0
5.	AS	0.5	1.0	1.75	2.0
	Mean	0.58	1.0	1.45	1.85
	S.D.	(0.08)	(0.14)	(0.27)	(0.22)

Body part discomfort score after 2 hours continuous walking

Subject BK

	Intensity level of pain					
	I	II	III	IV	V	VI
Body part	24	26	20			
	25	27	21			
			22			
			23			

Subject MJ

Body part	24	22	20	26		
	25	23	21	27		

Subject HS

Body part	24	26	22	20		
	25	27	23	21		

Subject CR

Body part	20	22	26			
	21					
	24	23	27			
	25					

Subject AS

Body part	24	26	20			
			21			
	25	27	22			
			23			

APPENDIX IV (A)

Computer Programme for Individual Combination

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90 INPUT "title=";A$:LPRINT "Machineof";A$:LPRINT :LPRINT
100 INPUT "Volume of pressure chamber,cc";VT:LPRINT "Volume of pressure chamber
,cc=";VT
110 INPUT "Diameter of piston ,cm=";D:LPRINT "Diameter of piston ,cm=";D
120 INPUT "STROKELENGTH OF PISTON , CM ";L:LPRINT "Stroke length of piston ,cm
";L
130 INPUT "Small crank arm ,cm";RS:LPRINT "small crankarm,cm=";RS
140 INPUT "large crank arm, cm ";RL:LPRINT "LARGE CRANK ARM, CM=";RL
150 INPUT "ratio of pressure stroke time to cycle time ";C:LPRINT "Ratio of pres
ssure stroke time to cycle time=";C
160 INPUT "Nozzle discharge, cc/min.";Q:LPRINT "Nozzle discharge,cc/min=";Q
170 INPUT "crank speed, cycle/min.";N:LPRINT "crank speed, cycle/min=";N
180 INPUT "minimum nozzle pressure, kg/cm square";PD:LPRINT "minimum nozzle pres
sure, kg/cm sq.=";PD
205 LPRINT "Stroke";TAB(15);"Pressure";LPRINT
210 VS=0:DIFF=VT-VS:FOR I=1 TO 550
220 VS=3.1415*D*D*L*EFV/4:DIFF=DIFF-VS
230 PBI=VT*PDM/DIFF
240 IF PBI>PD THEN 260
245 LPRINT I,PBI
250 NEXT I:LPRINT:LPRINT
260 VD=VT*PDM/PBI:LPRINT "Volume at pressure";PBI="";VD
270 LPRINT I;VD;PBI
280 VS=3.1415*D*D*L*EFV/4
290 NT=(VT-(VT*PDM/PD))/VS
300 LPRINT "No. of strokes required to create the given pressure=";NI
310 VD1=VT*PDM/PD:LPRINT "Volume at pressure";PD;"=";VD1
320 FOR K=1 TO 50:LPRINT "=";:NEXT K:LPRINT :LPRINT
330 LPRINT "Time";TAB(10);"Instantaneous";TAB(25);"Instantaneous";TAB(40);"FORCE
ON OPER."
340 LPRINT "Increment";TAB(10);"Pressure";TAB(25);"Volume";TAB(40);"Handle"
350 FOR K=1 TO 50:LPRINT "=";:NEXT K:LPRINT :LPRINT
360 DT=1/(20*N):DL=DT*L*N/C:DVS=3.1415*D*D*DL*EFV/4
370 FOR I=1 TO 2:DVS=31415*D*D*DL*EFV/4:FOR I=1 TO 20:T=1*DT
380 IF T>(C*20*DT)AND T<=(20*DT)THEN DVS=0
390 IF T>20*DT*(1+C) AND T<=(40*DT)THEN DV=0
400 VM=VD+Q*DT-DVS:PM=PS*VD/VM
410 FP=PM*3.1415*D*D/4:FB=PP*RS/RL
420 IF T>20*C*DT AND T<=20*DTTHEN FM=0
430 LPRINT I;TAB(10);PM;TAB(25);VM;TAB(40);FM
440 VD=VM-PD-PM
450 NEXT I
460 NEXT II
470 FOR F=1 TO 45:LPRINT "=";:NEXT K:LPRINT :LPRINT :LPRINT
480 END

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Computer Programme for Generating Effort data for Z16
Combination of three pump parameters of Lok Sprayer

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50 WIDTH="16":I=1:J=1:K=1
80 DIM VT(6),L(6),D(1),C(1)
90 INPUT "title *":AS:LPRINT TAB(35);CHR$(27);CHR$(14)"Machines of ".AS:LPRINT
LPRINT
92 FOR I1 = 1 TO 6:READ VT(I1):NEXT I1:FOR I2=1 TO 6:READ D(I2):NEXT I2:FOR I3=1
TO 6:READ L(I3):FOR I4=1 TO 5:READ C(I4):NEXT I4
93 DATA 500,600,800,900,1000,1.75,2.5,3.25,4.4,7.5,5.5,,2.3,4,5,6,7, 1, 3, 5, 7,
9
100 INPUT "Volume of pressure chamber,cc *":VT:LPRINT "Volume of pressure
110 INPUT "diameter of piston ,cm *":D:LPRINT " Diameter of piston ,cm *": D
120 INPUT " STROKE LENGTH OF PISTON,CM *":L:LPRINT "Stroke length of piston . cm
*":L
130 RS = 8.600001 : LPRINT "Small crank arm,cm *":R:TAB(60);
140 RL= 49:LPRINT "Large crank arm, cm *":RL
160 Q = 450 LPRINT "Nozzle discharge, cc/min *":Q:TAB(60);
180 P=3 LPRINT "Minimum nozzle pressure , kg/cm sq. =":PD
190 PATH = "LPRINT "ATMOSPHERIC PRESURE , KGCM SQ. =":PMT :TAB(60)
200 EPV = .9 LPRINT " Volumic efficiency of piston =":EPV
201 FOR K3=1 TO 150 :LPRINT "-*";:NEXT K3:LPRINT :LPRINT
202 LPRINT "Volume";TAB (10) : "Dia of *":TAV (17) : "Stroke *":TAB(25) : "Idle";
TAB(31) : " Chamber Vol & press . at *":TAB (57) : "NO. of *":TAB(77) : "Cycles/*";
203 FOR J3=1 TO 6:LPRINT VT(J2);:FOR J3=1 TO 6 LPRINT TAB(10);D(J3);:FOR J4=1 T
O 6:LPRINT TAB(18);L(J4);:FOR J5=1 TO 5:LPRINT TAB(25);C(J5);
204 LPRINT "Pressure *":TAB(17) : "Stroke *":TAB(25) : "Idle *":TAB(31) : "Chamber vol. &
press. at *":NO. OF *":TAV(67) : " VOLUME AT *":TAB(77) : "CYCLES/*":TAB (87) : "TIME *":
TAV (115) : "SWEEP *";
205 LPRINT TAB(1256) : "Volume"
206 LPRINT " Chamber *":TAB(18) : "Piston *":TAB(30) : "Stroke *":TAB(38) : "Volume *":TAB(
47) : "Pressure *":TAB(57) : "Rad. *":TAB(67) : "Pressure TAB(77) : "REQUIRED *":TAB(87) : "E
MENT *":TAB(93) : "PRESSURE *":TAB(104) : "VOLUME *":TAB(115) : "HMADLE *":TAB(125) : "CC"
207 FOR K3=1 TO 150:LPRINT "-*";:NEXT K3:LPRINT:LPRINT:LPRINT
215 VS=0:DIFF=VT(J2)-VS:FOR I=1 TO 550
220 VS=3.1415*D(J3)*D(J3)*L(J4)*EFV/4:DIFF=DIFF+VS:M=Q/VS
230 PB1=VT(J2)*PATM/DIFF:VS1=VS/EFV:RVTS=VT(J2)/VS1
240 IF PB>PD THEN 260
250 NEXT I
260 VD=VT(J2)*PATM/PB1
270 LPRINT TAB(31);I:TAB(37);VD:TAB(47);PB1;
280 VS=3.1415*D(J3)*D(J3)*L(J4)*EFV/4
290 M1=(V1(J2)-(VT(J2)-(VT(J2)*PATM/PD1))/VS
300 LPRINT TAB(57);M1;
310 VD1=VT(J2)*PASTM/PD:LPRINT TAB(67);VD1;
315 LPRINT TAB(77);M;
360 DT=1/(20*M):DL=DT*L(J4)*M/C(J5):DVS=3.1415*D(J3)*D(J3)*DL*EFV/4
370 FOR I1=1 TO 2:FJMAX=0:DVS=3.1415*D(J3)*D(J3)*DL*EFV/4:FOR I=1 TO 20:T=I*DT
380 IF T>(C(J5)*20*DT)AND T<=(20*DT)THEN DVS=0
390 IF T>20*DT*(1+C(J5))AND T<=(40*DT)THEN DV=0
400 VN=VD1+Q*DT-DVS:PN=PD*VD1/VN
410 PP=PN*3.1415*D(J3)*D(J3)/4:PH=PP*RS/RL
415 IF I=1 THEN LPRINT TAB(87);I:TAB(93);PN:TAB(104);VN:TAB(115);PH
417 IF PHMAX>PH THEN 420
418 I6=1:PN8=PN:VN8=VN:PHMAX=PH
420 IF T>20*(C(J5)*DT)AND T<=20*DT THEN PH=0
440 VD1=VN:PD=PN
445 Q=20.5*70.5*PI
450 NEXT I
455 LPRINT TAB(87);I6:TAB(93);PN8:TAB(104);VN8:TAB(115);PHMAX:TAB(125);VS1:TAB(1
35);RVTS
460 NEXT J5:LPRINT:LPRINT:NEXT J4:LPRINT:LPRINT:NEXT J3:LPRINT:LPRINT:NEXT J2
470 FOR K=1 TO 150:LPRINT "-*";:NEXT K:LPRINT:LPRINT:LPRINT
480 END

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