DESIGN AND DEVELOPMENT OF CUTTING MECHANISM OF FLAIL MOWER

Dissertation submitted to the

Marathwada Agriculture University, Parbhani

For the Degree of

Master of Technology
In Agricultural Engineering
In
Farm Power and Machinery

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2007

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I, here by Declare that the dissertation or

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(Mr. Dhadve P.K.)

Place : **Parbhani**

Date : 24 / 12 /2007

Dedicated to

my beloved

Parents,

Brother

&

Sisters

Dr.R.G.Nadre

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CERTIFICATE -I

This is to certify that the dissertation entitled **"Design and Development of Cutting Mechanism of Flail Mower"** submitted to Marathwada Agriculture University, Parbhani in partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agril. Engineering)** in **Farm Power and Machinery** embodied the results of the bonafied study carried by **Mr. Dhadve Prashant Kishanrao** under my guidance and supervision. I also certify that the dissertation has not been previously submitted by him for the award of Degree or Diploma of any University or Institute.

Place : Parbhani.
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CERTIFICATE -II

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ACKNOWLEDGEMENT

With immense pleasure, I express my deepest sense of gratitude and intrinsic affection to Dr.R.G.Nadre, Associate Dean and Principal, Head of the Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Marathwada Agricultural University, Parbhani. Without his sustained enthusiastic interest and constructive criticism, constant encouragement from time to time during the entire period of project work this work would not have materialized. His kind co-operative nature and sympathetic attitude during the course of present work would remain a source of encouragement forever in my life.

I am also grateful to Prof. Mrs. S.N. Solanki, Prof. P. A.Munde, Assistant Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, M.A.U., Parbhani. And also grateful to Prof. B.A. kadam, Professor Incharge, College of Horticulture, M.A.U., Parbhani and Prof. H.W.Awari, Assistant Professor, Department of Agricultural Engineering, College of Agriculture, M.A.U., Parbhani.

I also thankful to Mr.Kapse U.N., Mr.Chavan B.L.,Mr.Sadawarte Sanjay, Mr. Ranbawle, Mr. Mane, Mr. Ambhore, Mr. Shelke, and Mr. Panchal for their valuable assistant during project work.

I am also thankful to shri.Bhattacharya sab of Department of Farm Machinery and Power, C.A.E.T., M.A.U. Parbhani for their timely help rendered during the conduct of research work.

I am deeply obliged to all the authors past and present whose literature has been cited

My personal thanks are due to my friends Mr.Bakle A.P., Mr.Rathod R.K., Mr.Hingole P.B., Mr.More A.K., Mr.Wankhede S.J.,Mr.Mukade V.T., Mr.Bhange V.M., Mr.Kulkarni V.P.,Mr.Magar A.P., Mr.Raut D.V., Mr.Shaikh L.J., Mr. Jamadar S.S. for their constant encouragement for project work.

I extend my special thanks to my special friend and my well wisher for giving me support and being close to me during the project work.

Lastly, I should not forget to express my independence and gratitude to my parents due to whom only I am at this stage.

One uses the choicest words to measure the boundless love for someone. I find no such measure in adequate quantity for all that my respectful parents have done for me. The words with me are insufficient to express the feelings of my heart to acknowledge them for their difficult job of educating me in all comforts without which this work would not have seen the light of the day at all.

While traveling on this path of education many hands pushed me forth learned hearts put me on the right track enlightened by their knowledge and experience. I ever rest thanks to all if them.

Finally I owe my sincere thanks to all those whom I might have forgotten due to my short come.

(Dhadve P.K.)

Place : Parbhani

Date : 24/12/2007

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LIST OF SYMBOLS

Agril. /Agric.	-	Agricultural
ASAE	-	American Society of Agricultural Engineering
bet^n	-	Between
C/S	-	Cross section
cm	-	Centimeter
cm^2	-	Centimeter square
cm^3 /cc	-	Centimeter cube
d.b.	-	dry basis
Deptt.	-	Department
dia	-	diameter
Dr.	-	Doctor
EFC	-	Effective field capacity
Engg. / engg.	-	Engineering
et al.	-	and all
etc	-	etceteras
e.g.	-	Example
F.E.	-	Field Efficiency
f.s.	-	Factor of safety
Fig.	-	Figure
gm	-	gram
ha	-	Hectare
ha	-	hectare
hp	-	Horse power
hr	-	hour
i.e.	-	that is
ISAE	-	Indian Society of Agricultural Engineers
J	-	Journal
kg	-	Kilogram
kg-m	-	kilogram meter
kg-cm	-	kilogram centimeter
Kg-cm^2	-	Kilogram-centimeter square
km	-	Kilometer
KN	-	Kilo-Newton
Kw	-	Kilo watt
L	-	liter
l	-	liter
l/hr	-	Liter/hour
m	-	Meter
M.A.U.	-	Marathwada Agriculture University
M.S.	-	Mild Steel

mins	-	minutes
m/min	-	Meter per minute
m/s	-	Meter per second
m^2	-	Meter square
m^3	-	Meter cube
mm	-	mili meter
MPa	-	Mega Pascal
N-mm	-	Newton-mili meter
N/mm^2	-	Newton-mili meter square
Prof.	-	Professor
PTO	-	Power Take Off
rad	-	radian
resp.	-	respectively
rpm	-	Revolutions per minute
Rs.	-	Rupees
Sci.	-	Science
Sec	-	Second
Sr.No.	-	Serial number
SWCE	-	Soil and Water Conservation Engineering
Tech	-	Technology
TFC	-	Theoretical field capacity
viz.	-	Namely
Wt	-	Weight
%	-	Per cent
&	-	and
θ	-	Angle
$^{\circ}$	-	Degree

INTRODUCTION

Chapter I

INTRODUCTION

In India, ever since human beings first attempted the cultivation of plants, they have had to fight the invasion by weeds into areas chosen for crops. Some unwanted plants later were found to have virtues not originally suspected and so were removed from the category of weeds and taken under cultivation. But still thousands of land is categorized under pastureland due to lack of cheaper mechanical weed control techniques.

Because, for various reasons, weeds interfere with man's activities, many ways have been developed for suppressing or eliminating them. These methods vary with the nature of the weed itself, the means at hand for disposal, and the relation of the method to the environment. Mechanical weed control, in any event, has become a highly specialized activity employing thousands of trained persons. Universities and agricultural colleges teach courses in mechanical weed control, and industry provides the necessary technology. Governmental workers and private individuals are engaged daily in the practice of mechanical weed control because the growing of food and fiber crops depends on it for current levels of production. The many reasons for controlling weeds become more complex with the increasing development of technology.

In case of cutting of weeds, a system of forces acts upon the material in such a manner as to cause to fail in shear. This shear failure is almost invariably accompanied by some deformation in bending and compression, which increases the amount of work, required for the cutting operation. An impact cutter has a single, high-speed cutting element and relies primarily upon the inertia of the material being cut to furnish the opposing force required for shear. The impact cutting principle is applied in an implement named **FLAIL MOWER**. The flail mower has knives rotating in vertical planes parallel with the direction of travel. The flail mower includes a cutting member which contains a cutting head named flail knives. The cutting head defines a cutting edge which acts upon material to be comminuted during operation of the rotary impact mechanism. The cutting edge is made wear-resistant by having affixed thereto a plural number of wear-resistant parts made of mild steel metal.

An alternative to the more common rotary mower is a Flail mower. Flails do a better job of cutting shrubs and weedy material of the pastureland. The horizontal rotor shaft has many pairs of swinging knives that pulverize vegetation and breakup woody stems. Because the knives are mounted on clevises of flange on rotor shaft, they are free to rebound if they cannot shear some weedy materials on first strike, and thus protect themselves from damage. The vegetation tends to be cut and recut and is scattered uniformly under mower hood. The “V" belt drives the rotor shaft. All these attributes make flails ideal for mowing weeds and general brush clearing operations.

The weeds grown on, the land which turns into uncultivable land or pastureland, along the farm roadsides and in the bunds which needs periodical cleaning is the major problem faced by the farmers in India. The commercially available units for mowing or grass cutting are costing heavily. Hence considering the need for development of effective and economic weed management practices, a research work was carried out in year 2006-07 entitled "Design and development of cutting mechanism of flail mower" with the following prime objectives,

- To design cutting mechanism of flail mower
- To develop walking type flail mower
- To evaluate performance of cutting mechanism of walking type flail mower.

REVIEW OF LITERATURE

Chapter II

REVIEW OF LITERATURE

Review of research work carried out by various investigators on various parameters related to mower. But the concept of flail mower is not yet studied in detail, very little work has been published in response of flail mower mechanism studies and presented in this chapter.

Review of literature presented is categorized as follows.

1) Power required for cutting weeds
2) Power transmission for mowers
3) Blade requirement for mowers
4) General studies related to mowers.
5) Different references from internet

2.1 Power required for cutting weeds

Chancellor (1958) studied the effect of velocity on cutting. It observed that the velocity in the range of 175.26 to 518.26 cm per sec. had no significant effect on force or energy requirement. The energy values at these speeds were of the same magnitude as energy values obtained at a speed of 2.54 cm when all the factors were same.

Dutta, A.C.; Chakravorty, A.K. and Gupta, C.P. (1969) found out the maximum shear stress offered by a crop at a peripheral velocity of knife was higher than 160 m/min.

Nagpal and Aggrawal (1973) while working with energy requirement in a chaff cutter observed that cutting energy vary with moisture content. Energy decrease with increase in moisture content, some observations with cross-sectional area 112.50 cm^2 at 76.5 percent moisture content energy required was 335 kg-cm while it decreased to 328 at 88.5 percent moisture content. Further, at 93.5 percent moisture content it was 288 kg-cm.

Siteki (1986) states that the cutting resistances of younger plants significantly lower than the older plants, also the specific cutting energy increased with the stem diameter.

Mimura, K; Yamada, T. (1990) reported a comparative study of the power requirement of down cutting and up cutting flail mowers in Japan. Power required for cutting small diameter (up to 20cm) white oak (Quercus serrata) trees using stirrup shaped cutting blades of the down cutting type was 40 to 50% greater than that for the up cutting type. No difference found between down and up cutting power requirements for brush cutting when tested on bamboo grass (Pleioblastus chino). However, under the same conditions, bamboo grass used 20 to 30% more power than that required for cutting Sasa kurilensis, apparently because the cutting blades clogged with finely cut pieces of bamboo grass, so increasing resistance. Specifications of prime mover and mowers were used and details of tests undertaken in two stands in the Numata National Forest.

Tuck, C.R.; O'Dogherty, M.J.; Baker, D.E. and Gale, G.E. (1991) evaluated laboratory studies of the effectiveness of rotary cutting mechanisms when cutting single and groups of grass stems were undertaken. The effect of using static stem supports or ledger plates with clearances of up to 5 mm from the cutting blade was investigated. The effectiveness of cutting with single-toothed and plain discs was examined also. The effect of clamping the tops of grass stems was examined for both types of mechanism. A number of mechanism design parameters were investigated and cutting efficacy was assessed by measuring the stubble length of individual stems, together with the number of stems, which were uncut, pulled out of the holder or broken at their base. The critical speed, which is the minimum required for efficient cutting, was also assessed. The use of ledger plates, above and below the cutting blade, resulted in lower critical cutting speeds than for conventional impact cutting when cutting single stems. For groups of stems, however, the critical speeds when using static elements did not differ significantly from those required for impact cutting. Clamping the tops of the stems resulted in very low critical cutting speeds (5 m/s or less). Critical cutting speed was reduced to below 35 m/s by increasing ledger plate length and by utilizing the whole of the blade length during cutting. Lower cutting speeds were also achieved by using a combination of ledger plate and blade angles, which retained stems within the cutting area of the mechanism.

Copland, T. (1993) described briefly the history of rotary shear grass cutting. The principles involved in cutting plant material and the influence of mower knife geometry on cutting are discussed. A project was set up to combine the main advantages of rotary and finger bar mowers, with main objective of reducing energy requirement for mowing, and the developed prototype is described. A mathematical model was used to predict mower-cutting quality and was verified in field tests. It was found that low cutting powers could be achieved, uniform stubble height could be obtained, high spot work rates were possible and machine maintenance was comparable to that of other mowers.

Komarizade, M.H. (2002) studied on energy requirement of hay mowers. In order to evaluate energy consumption of hay mowers, performance of four types of mowers including self-propelled cutter bar mower (binder mower), Integral cutter bar mower, disc mower and drum type mower were studied. The main components of the consumed energy were the machine, fuel and labour energies. Results showed that disc mower with 455.76 Mj/ha and binder mower with 120.86 Mj/ha consumed the highest and lowest rates of energy, respectively. Although there were no significant differences between the tractor mounted mowers, the drum type mower with 422.73 Mj/ha and binder mower with 120.86 Mj/ha consumed the highest and lowest rates of energy, respectively. Although there were no significant differences between the tractor mounted mowers, the drum type mower with 422.73 Mj/ha appeared to have the lowest consumption in comparison with the two other types. Fuel energy showed to have the highest amount among other items of energy; this included 83.4 to 88.5% total energy used by tractor-mounted mowers. Machine energy consumption was directly affected by effective field time. For example among the tractor mounted mowers, the cutter bar mower in spite of its lowest weight had the highest machine energy consumption due to its poor field capacity, likewise, the drum type mower with the highest weight, showed the lowest consumption due to its higher field capacity. Machine energy came out to be between 10.87 and 15.5% total energy for tractor mowers. The measured labour energy appeared to be very low in comparison with the other part of energies. Total energy consumed per hectare per one meter of operating width was 86.32 Mj for binder mower,187.88 Mj (the lowest) and 284.85 Mj (the highest) for drum type and rotary disc type, respectively.

Erokhin, M.N.; Belov, M.I.; Sudnik, Y.A. (2003) carried out theoretical studies on rotary cutting units as found in forage-harvesters and self-propelled or trailed mowers (i.e. with vertical axis of rotation and intended for mowing tall grass). A test rig was developed (layout illustrated) for high-speed cutting, and results are shown in graphs and compared with the theoretical findings. The results indicate that the regime of work of rotary cutters must be capable of being regulated. And the most convenient way of achieving this is by changing the advance speed v, according to the law **v = cR** omega, where R is the distance from axis of rotation of the rotor to the furthest part of the blade; omega is angular velocity of rotor (in rad/s) and c is v/R omega..

Purwantana, B.; Horio, H.; Shoji, K.; Kawamura, T. (2003) studied a flail-type rotary cultivator is efficacious for swampy land preparation, grass cutting and topsoil treatment. The cutting characteristics of the cultivator were studied in the laboratory to determine the energy requirement for cutting grass stems. The cutting speed was significantly effective in the cutting process. The specific energy required decreased by approximately 58% when the cutting speed increased from 10 to 25 m/s. Effective cutting was achieved at cutting speeds of over 20 m/s. The bent angle of the knife did not significantly affect the specific cutting energy, although less energy was required at bent angles between 90 and 102 degrees. The specific energy required was less when the grass stems inclined towards the machine and when cutting a single stem rather than a bunch of stems. The effect of the number of stems in a bunch on the specific energy decreased as the cutting speed increased.

2.2 Power transmission for mowers

Patnaik (1982) stated that the power requirement increased with increase of rotor speed. He further concluded that the power requirement decrease with the increase of forward speed.

Ambujam *et al* (1984) designed and developed a rotary paddy weeder powered by a knapsack type 1 KW spark ignition engine. The machine had a operational depth of 70mm with 80 per cent weeding efficiency. The effective field capacity of the machine was 0.022 ha/hr. The average fuel consumption was 0.86 lit/hr.

Singh, R.D. and Ingle, G.S.(1987) studies were conducted on a straight rotary tiller tine to evaluate specific energy requirement during operation under laboratory conditions and a mathematical modes was developed to predict the specific energy requirement in up cut and down cut modes. Input values were 0.05, 0.075, 0.1 & 0.125m depth of operation, 0.093, 0.143, 0.217 and 0.385m/s linear speeds and 148, 212, 328 and 432 rpm rotor speeds. Specific energy found to increase linearly with the increase of the speed of rotovator and to decrease with the increase of linear speed of the machine.

Fawoll (1988) evaluated three models of shoulder suspended, hand guided rotary power weeders in comparison with hand slashing of weeks. The power weeders were operated by 1.86, 1.49 and 1.12 Kw gasoline engines. The carrying weights of three machines ranged from 5.4 to 10 kg with overall lengths of 1600 to 1700 mm. A rigid shaft rotating in a pipe shield by a centrifugal clutch transmitted power from the engine to a saw type rotary cutter. Out of three models the 1.49 Kw machine had better performance in terms of both field capacity and weeding cost.

Guzel, et.al.(1990) studied the properties of rotary cutter for cotton i.e. peripheral velocity, impact energy, free cutting curves, cutting points and cutting forces in laboratory and under field conditions. Energy consumption of the blade was 240 to 289kg-m and power requirement was 1.74hp at 540rpm. Maximum and minimum blade velocities were 46.97 to 51.87m/s and 33.64 to 36.52m/s resp.

Rotz and Mutitar (1992) worked on rotary power requirement for harvesting and handling equipment. A model and parameters were developed for predicting average rotary power requirements for 32 major harvesting and handling machines. Typical power requirement parameters were determined along with an expected range of variation due to differences in machine design, machine condition and crop characteristics.

Victor and Verma (2003) studied on power operated rotary weeder for wetland paddy. He concluded that, the introduction of efficient weeding aids and equipments for weed control seems highly necessary to minimize time consumption, labour requirement and cost. As consequence, a prototype power operated rotary weeder for weeding in wetland rice cultivation was designed, developed. A 0.5 HP petrol driven engine was used for power weeder with a reduction gearbox. The power transmission from engine to traction wheel and to the cutting unit was provided by means of a belt, pulley and chain, sprocket. For cutting the 4 L-shaped standard blades were used on the hub, and in turn fitted on rotary shaft. Two big traction wheels were used to make the operation smooth. A gauge wheel was provided for depth adjustment of the cutting unit. With 200 mm spacing, the field capacity of the machine varied between 0.04-0.06 ha/h with field efficiency of 71%. The weeding efficiency of the machine was 90.5%.

Celik, A (2006) concluded that the engine power should be at least 25% greater than the power required by the mower, to overcome changes of forward speed, forage density and ground topography conditions in the field.

2.3 Blade requirement for mowers

Steward (1928) carried out the research on cutting ensilage by using different horsepower motors. It observed that the sharpness affected to the power requirements. A blade having a leading edge thickness less than 0.0127 cm required 35 per cent less energy.

Prince, R.P.; Wheeler, W.C. and Fisher, D.A. (1958) studied the cutting process and concluded that the effect of dullness of knife, more pronounced with smaller diameter stems. The energy requirement found out for 0.1524 to 2794 cm diameter stems by using dull, medium and sharp knife. It observed that the energy required for cutting 0.1524 cm diameter stem was 0.32 kg/m, 0.25 kg/m and 0.08 kg/m with dull, medium and sharp blade knives respectively.

Johnson et al. (1984) derived equation governing the motion of a horizontal rotary mower with a free-swinging blade and estimate the forces acting on the blade, which was made for the horizontal motion when the free-swinging blade subjected to a shock load. Empirical equations for the maximum longitudinal force as a function of blade parameters developed for use in design.

Klenin et al. (1985) concluded that as the angle decreases and sharpness increases the cutting ability of the knife increases.

O'Dogherty and Gale (1986) studied the cutting process with blades, which had edges ranging from very sharp to an edge radius a 1.5 mm. The sharp blade (below 1 mm radius) showed maximum specific energy of only 82 MJ per mm, which implied effective cutting. The blunt blade (1 and 1.5 mm radius) showed specific energies ranging up to 155 MJ per mm.

US Patent Issued on January 28, 2003, published that a double knife stubble-cutting machine was provided for cutting stubble after a harvesting action into three separate pieces including a standing stubble piece and two cut pieces. The device comprises a frame having a center section and a pair of wing sections with the wing sections being pivotal about a horizontal axis upwardly to a transport position. The frame defines a tool bar across the full width of the frame which carries a pair of sickle knife support bars downwardly of the tool bar and arranged so that one sickle knife is forwardly of and upwardly of the second sickle knife. Both knives are open and free from support elements between the knives so that the cut material could discard back to the ground after cutting without any transverse movement or blockage. The harvesting action therefore allows the minimum amount of straw to be taken by the combine harvester so that the standing stubble element is cut into three pieces of equal length. Twisting the support beam adjust the space in between the cutter knives.

2.4 General studies related to mowers

McRandal and McNulty (1980) had studied the mechanical properties of ryegrass and concluded that, all the mechanical properties of ryegrass were independent of shear velocity except the stem resistance of penetration.

Handler, F. (1994) studied on implements for maintaining fallow grassland. Flail mowers are the most commonly used implements in Austria for maintaining fallow grassland. Power requirement, chop quality and performance characteristics of five flail mowers were compared. All showed superior chopping ability and output than rotary mowers and rotary cultivators.

Kogut, S. (1994) showed the effect of field inclination angles from 3 to 13.5 degrees on the operational efficiency was investigated in the Bieszczady mountain region for the following machines: rotary mowers, self-propelled mowers, raking tedders, pick-up balers, field choppers, forage harvesters, self-loading trailers, sheaf-binders and combine harvesters. The slope angle showed significant adverse effect on the operational efficiency, however no linear relationships were observed (P=0.05). Within the examined inclination range, 2 points per degree of slope angle lowered the average operational efficiency of the machines under favorable weather conditions.

Khadem, S-M-R (1996) explained that more than 80% of the farms in Iran fall into the 'small farm' category. The reaper, as a small harvesting machine, has become one of the major implements for mechanization of such farms. Reapers are either self-propelled or tractor mounted in Iran, where the production of small engines has not gained the proper momentum. The latter design seems more feasible considering the fact that tractors are available in almost all farming areas. By searching through literature, a proper reaper design and a popular mower selected to be combining for the present work. Such a dual-purpose machine could used for forage harvesting if the reaper attachment was dismounted. The reaper attachment was functionally designed and fabricated. During workshop and field tests, in addition to faultfinding and remedy, a special curved plate delivery mechanism was designed and manufactured. The results of field tests showed that conveying of material is not possible by this mechanism. In the field test the machine performance was evaluated according to a completely randomized block design. The plant population was taken as the variable while the yield losses of plots were compared. It was found that the yield losses were well within the acceptable range.

Tajuddin, A. (1996) studied modification and testing of a power tiller rotovator for flail mowing. A power tiller operated rotovator was modified as flail mower. The speed of rotovator shaft was increased from 255 to 1137 rev/min, the rotary blades were replaced with 6mm size, and 25mm pitch mild steel chains of 280mm length with a flat cutting element at the tip. The modified machine was evaluated for lawn mowing and parthenium cutting operations. The cost of conversion was Rs.1060/-. Maximum cutting efficiency of 97% was achieved at 1100 rev/min rotor speed and 1.60 km/h forward speed. Average effective field capacity of the machine was 0.05 ha/h with average field efficiency of 56.3%.

Loo, L-van (1997) analyzed the experience of users of rotary mowers in Germany. An analysis is made of 396 replies to a questionnaire inquiring in Germany on the use of rotary mowers since 1990. The analysis covers makes of mower (10 different makes, the main ones being Kuhn, Krone and Class), type (front or rear mounted or trailed, disc or drum), area mown per annum, knife replacement, quality of work and degree of satisfaction with the mower. The degree of satisfaction was greatest among users of Kuhn mowers.)

Chattopadhyay, P.S. and Pandey, K.P. (2001) studied an experimental model of the flail-type forage harvester was fabricated to study the effect of flail tip speed, knife rake angle and bevel angle on conveying of chopped forage sorghum (*S. bicolor*) through a 90° deflector elbow under laboratory conditions. The exit air velocity from the chute outlet and static pressure head created at the blower outlet were measured. The exit velocity of the chopped forage and the corresponding throw distance were determined considering the aerodynamic properties of the chopped forage material. The knife bevel angle did not have a significant effect on the throw distance of the chopped forage material. The exit air velocity from the chute outlet increased logarithmically as the flail tip speed was increased from 20 to 60 m/s and it decreased linearly as the knife rake angle was increased from 20 to 60°. The static pressure head created by the rotating flails at the blower outlet (chute inlet) increased exponentially as the flail tip speed was increased, and decreased linearly when the knife rake angle was increased.

Fanigliulo, R.; Vassalini, G.; Fedrizzi, M. (2003) conducted study to determine the working characteristics of two mowers manufactures by Gianni Ferrari (Turbo 1 and Turbo 4) in the context of the certification activities conducted by ISMEA-ENAMA. The self-propelled mowers, designated as machinery A and machinery B, are the professional ride on machinery designed for cutting and collecting grass and transporting and dumping it. It was found that both self-propelled mowers, in one single transit in cutting and collecting grass, performed excellent work in terms of quantity as quality. Both mowers turn out to be easy to use and to manage in maneuvering. From the point of view of quality of work, the best results were by machinery A, both in terms specific trial conditions and in light of reduced forward speed during work. Because of its higher work capacity, machinery B was more suitable on large surfaces and especially on hilly ground or steep slopes.

Miyahara, S.; Tosaki, K.; Ichikawa, T.; Kuromi, K. (2003) studied on development of walking type mower for ridges of paddy fields-mowing devices and performance. They stated that bush cutter is the most popular for mechanical weeding on ridges of paddy fields. However, there is the problem of low work efficiency and unstable work posture by using bush cutter caused heavy work load. Then, we developed the new self propelled walking type mower, which could mow the top and one slope surface of a ridge simultaneously. The mower has mowing devices, which at the mowing width for the top surface was 30cm. In addition, that for a slope surface was possible to adjust within the range from 30 to 70cm. Its traveling unit has two-wheel drive system with front wheel steering mechanism, which could work and move stable on the ridge. As the test results, the mower worked smoothly and the work efficiency by the mower was approximately two times that of weeding by a bush cutter, when the width of top surface was 45cm and the widths of slopes were 70 and 30cm.

2.5 Different references from internet

Few flail mowers of different types such as power tiller operated, tractor operated, hydraulic operated and diesel engine operated with different designs, power transmission systems, with different cutting mechanism and performance reviewed for literature cited are;

Hermes Flail Mower

An alternative to the more common rotary mower is a Flail mower. Flails do a better job of cutting trash and woody material. The horizontal rotor shaft has many pairs of swinging knives that pulverize vegetation and breakup woody stems.

Fig. 2.1 Hermes Flail Mower

Because the knives are mounted on clevises, they are free to rebound if they cannot penetrate some materials on first strike and thus protect themselves from damage. The vegetation tends to be cut and recut and is scattered uniformly under mower hood. The rubber "V" belt that drives the rotor also acts to protect the gear box from shocks should a rock or other hard obstacle be struck. All these attributes make flails ideal for mowing crop residues like corn stalks, light pruning as in vineyards and cane fruit plantings and general brush clearing operations. Models from 24" to 39" are suitable for 12 Hp and higher walking tractors.

SMWA Flail mower

Fig. 2.2 SMWA Flail Mower

Flail mower is an ideal mower for general mowing duties. It mows the grass and branches up to 5 cm [2 inch] in diameter. It is mounted on tractors from 14 to 41 Kw (20 - 55 HP). The mower has 3 point linkage Cat 1 and has 2 position hitch mounting to give 17 cm [7 inch] offset.

For the reduction of speed, it has provided with 540 rpm gearbox with freewheel. Also it is provided with full width rear roller with height adjustment. It has adjustable rear hood to adjust the degree of mowing and the power requirement. The rotor with hammers or optional Y-flails with or without shackles are used for the cutting unit. Optional hydraulic sweeper for pulling pruned material into the line of the mower.

BRAHMA power operated Flail Mower

Cut heavier material at a faster ground speed than other mowers. The mower is made for cutting heavy grass and light brush with less hassle, the Brahma flail mower is built stronger and has more power than other side mount mowers in its class.

Fig. 2.3 BRAHMA Flail Mower

The mowing heads have been designed for faster cutting in heavy-duty situations making the Brahma the first choice for any roadside vegetation maintenance job. High speed flail mowing head is available in 5' and 6.5' widths and furnished with 8 oz. heavy duty flail knives providing a smooth, finished cut. Rotary mowing head is available in 60" width and with its deep deck permits better air flow and easier discharge. Powerful tilt and lift controlling cylinders are a minimum of 3-1/2" bore and 1-1/2" rod and both use double lip "U" cup seals. Front-mounted 17 gallon hydraulic tank provides higher efficiency by running cooler and using less hydraulic oil. Both flail and rotary heads feature 30" lift height, Mower is operated by a single one-touch joystick control. Flail head features an over 50% horsepower increase above competitive flails.

Power Rotary Weeder

A 8.38 hp diesel engine operates the weeder. The engine power is transmitted to ground wheels through V-belt

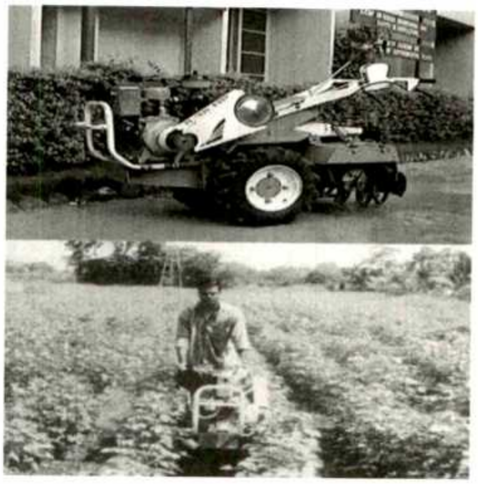


Fig. 2.4 Power Rotary weeder

pulley. A tail wheel is provided at the rear to maintain the operating depth. Weeding is done by the rotary weeding attachment. The rotary weeder consists of three rows of discs mounted with 6 numbers of curved blades in opposite directions alternatively in each disc.

These blades when rotating enable cutting and mulching the soil. The width of coverage of the rotary tiller is 500 mm and the depth of operation can be adjusted to weed and mulch the soil in the cropped field.

Type	:	Self propelled
Power requirement	:	8.38 hp Diesel engine
Overall dimensions	:	2400 x 1750 x 1100 mm
Weight	:	200 Kg
Capacity	:	1 - 1.2 ha per day

Power Tiller operated Lawn Mower (TNAU)

The cylindrical lawn mower attachment to power tiller consists of 750 mm width and 235 mm diameter cylinder fitted with 12 numbers of helical steel blades on its periphery. A horizontal ledger plate with a concave groove is provided beneath the cylinder. The rotating cylinder and the stationary ledger plate are fitted in a frame, which in turn is attached to the power transmission case and rotary driving shaft support arms.

The power is transmitted from the power tiller rotary drive shaft to the cylinder shaft through chain and sprocket. A tail wheel is provided for controlling the height of cut. The unit is attached to the power tiller rotary hitch bracket assembly of the transmission case and the rear portion of the unit derives support from the power tiller handle through two support arms. During the operation in the field, the grass is cut when it is passed through the clearance between the rotating cylinder and the ledger plate and the cut grass is blown off. A shield is provided to protect the operator against throwing of cut grasses and stones.

Fig. 2.5 Power Tiller operated Lawn Mower

Type	:	Mounted type
Power requirement	:	8 -10 hp power tiller
Overall dimensions	:	400 x 636 x 1665 mm
Weight	:	79 kg
Capacity	:	0.8 ha per day

Lawn / Shrub Mowing attachment to Power Weeder

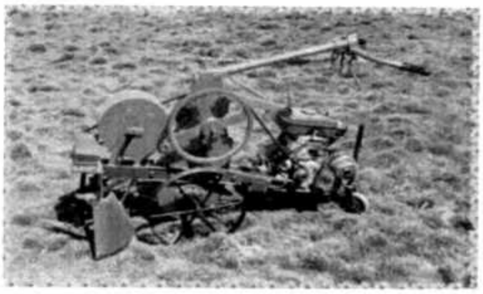


Fig. 2.6 Lawn / Shrub Mowing attachment to Power Weeder

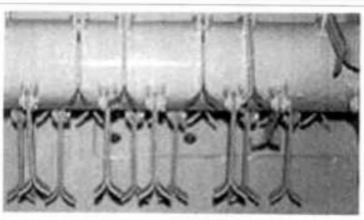
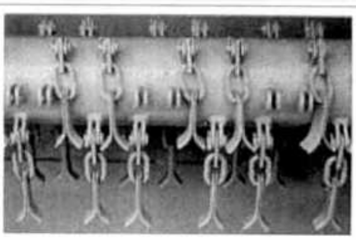
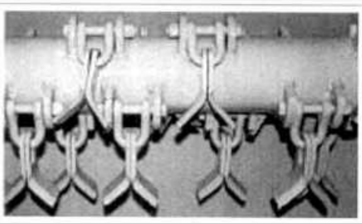
The weeds and grasses grown along the farm roadsides and in the bunds which needs periodical cleaning is the major problem faced by the farmers. Moreover, these grasses and weeds are not to be uprooted fully to ensure and prevent soil loss due to rain and wind. Similar aspect prevails in the landscaping process also like lawns. The commercially available units for lawn mowing and grass cutting are costing heavily. Two curved and sharpened high carbon steel blades of total length 38cm are mounted on a vertical shaft. A 3 hp petrol start kerosene run engine powers the self propelled traction unit and the lawn mower. The power is taken from the gearbox through v-belt pulley and through a 90° conversion gearbox. The speed conversion ratio from the engine to the blades is 16:10. The traction wheel is replaced with 18" diameter and 1.5"thick 6-spoked rigid wheel for easy maneuverability. The front and backsides of the blades are covered with rubber and metal sheets respectively as a precaution to avoid the stones throwing away by the blades during operation. Width of coverage of the unit is 450 mm and the height of cut is 25 mm.

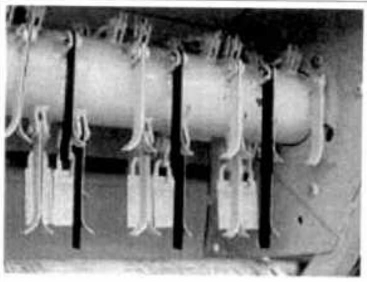
Type	:	Self propelled
Power requirement	:	3 hp petrol / kerosene engine and an operator
Capacity	:	400 to 500 m^2 per hour for a single pass

The machine is capable of cutting grasses on the farm roadsides and mowing lawns.

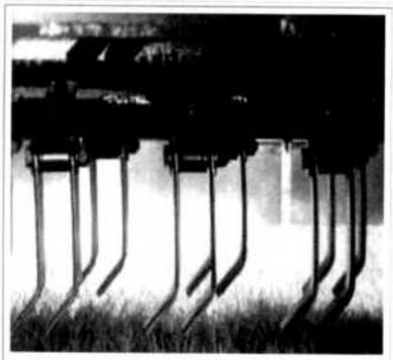
Different designs of flail blades

Flail mowers are suited to both commercial and professional applications. There are varying blade designs available for different applications and most models in the range can be fitted with any of the blades.

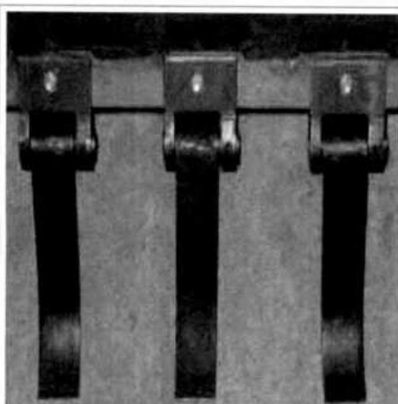
	**Standard 2mm grass flails** closely spaced back to back knives for superb finish on regularly maintained grass
	**3mm heavy duty grass flails** are 50% heavier for longer services life and better performance in rough conditions
	**6mm heavy duty flails** are recommended for contract work, e.g. verges, rides, braken etc



Verti-cutting scarifying knives can be fitted in conjunction with, or in lieu of the 2mm grass fails. These precision knives will penetrate into the turf and remove dead grass, moss, etc. and also stem any lateral growth which will in turn stimulate the growth of fresh, healthy grass.



Sukup has developed a new system for mounting the L-knives to the rotor. The self-cleaning mounting approach eliminates build-up between the knives and gives twice the cutting area due to the spacing of the knives. This unique mounting system also creates an overlap of blades, giving double coverage and creating a finer cut. L-knives are available heat treated or hard faced.



Sukup 1800 Shredders are also available with cupped knives. The vacuum created by the cupped knives lifts flattened material into the rotor for a more complete and uniform cut. Cupped knives are required for windrowing.

DESIGN CONSIDERATIONS

Chapter III

DESIGN CONSIDERATIONS

The principle of working of the flail mower is to cut the weed by swinging action of the flail knives above the ground surface without damaging the flail knives when it strikes an immovable object such as rock, stone or the like. The cutting of weeds takes place due to impact and shearing action.

Until now, no work has been done on diesel engine mounted flail mower. Following are the various parts of flail mower to be designed carefully.

3.1 CUTTING UNIT

The "Y" shaped cutting edge has been sharpened for easy cutting and fixed at an optimum angle of inclination of 120^0 to it's vertical axis. The cutting blade has also been used as an inclined plane to perform cutting the weeds efficiently. Design aspect of cutting unit consists of following considerations.

3.1.1 Design of flail knives

In order to cut the weeds, the peripheral speed of flail knives is calculated by the formula,

$$V_k = \frac{S \times n}{30}$$

Where,

V_k = flail knife speed, m/s

S = Length of stroke, m

n = rotor speed, rpm

3.1.2 Design of Byte length

The byte length for the Flail knives was calculated as follows,

$$\textbf{Byte length, mm} = \frac{V_k \times \pi \times D}{V_m}$$

Where,

V_k = speed of flail knives, m/s

D = outer diameter of the flange, mm

V_m = revolutions of the rotor shaft, rpm

3.1.3 Determination of number of blades

The number of blades was calculated by using the expression,

$$Z = \frac{2 \times \pi \times h}{S \times \lambda - 2A}$$

where,

Z = number of blades

h = maximum depth of operation, m

S = byte length, m

A = blade thickness, m

λ = speed rate $\Rightarrow \lambda = \frac{V_k}{V_t}$

V_k = cutting speed, m/s

V_t = forward speed, m/s

3.1.4 Power requirement for cutting

The horsepower required to cut the weed can be found out with the help of formula,

$$H_p = \frac{F_t \times V_k}{75}$$

Where,

F_t = tangential force, m/s

V_k = peripheral speed of flail knife, m/sec.

3.2 POWER TRANSMISSION UNIT

To achieve desired transmission of power, V-belt drive is used. V-belt drive comprises design of pulleys and design of belt.

3.2.1 Design of Pulleys

1) Velocity ratio

Velocity ratio is calculated by the formula,

$$\text{Velocity ratio} = \frac{\text{RPM of input shaft}}{\text{RPM of output shaft}}$$

2) Diameter of pulley

From recommended diameters of pulleys, we selected the diameters of the driving and driven pulleys by velocity ratio.

$$\text{Diameter of driven driver pulley} = \text{Velocity ratio} \times \text{Diameter of pulley.}$$

3) **Center distance of pulleys**

The center distance can be calculated from the formula,

$$C = \frac{b + \sqrt{b^2 - 32\,(D_L - D_S)^2}}{16}$$

Where,

$b = 4L_s - 6.28(D_L + D_S)$, mm

L_S = standard belt length, mm

4) **Speed ratio**

The speed ratio of the drive is computed by

$$\text{Speed ratio} = \frac{n_S}{n_L}$$

Where,

n_s = number of revolutions of the small pulley, rpm

n_L = number of revolutions of the large pulley, rpm

3.2.2 Design of belt

For the transmission of the power, open belt is used.

1) **Length of belt**

The approximate belt length for the two-pulley drive is calculated by using the formula,

$$L = 2C + \frac{\pi}{2}(D_L + D_S) + \frac{(D_L - D_S)^2}{4C}$$

Where,

L = length of the belt, mm

C = distance between centers of pulleys, mm

D_L = pitch diameter of the large pulley, mm

D_S = pitch diameter of the small pulley, mm

2) Belt speed

The belt speed is computed as,

$$V = \frac{\pi \text{ x } D_S \text{ x } n_S}{1000}$$

Where,

D_s = diameter of the small pulley, mm

n_s = number of revolutions of the small pulley, rpm

3) Ratio of tensions

Tensions on the belt is calculated by the formula,

$$\frac{T_1}{T_2} = e^{\mu\theta / \sin \alpha /2}$$

Where,

T_1 = tension in the tight side, Kg

T_2 = tension in the slack side, Kg

μ = Coefficient of friction = 0.2 t0 0.3

θ = angle of wrap

α = groove angle (let $\alpha = 40^0$)

θ = for large pulley = $180 + 2\sin^{-1} [(r_1 - r_2)/ C]$

θ = for small pulley = $180 - 2\sin^{-1} [(r_1 - r_2)/ C]$

Where,

C = Center to center distance between the shafts.

The pulley, which governs the design is one with smaller value of ratio of tension. Therefore, smaller diameter pulley will govern the design.

4) Power transmitted by V-belt

Horsepower transmitted by the V-belt is calculated by the formula,

$$\text{Horsepower transmitted, } P = \frac{(T_1 - T_2)\,V}{75}$$

Where,

T_1 = tension on the tight side, Kg

T_2 = tension on the slack side, Kg

V = belt speed, m/s

3.2.3 Design of solid shaft

Shaft diameter is calculated by the formula,

$$d = \sqrt[3]{\frac{16\,T}{\pi} \times T_s}$$

Where

d = diameter of solid shaft, mm

T = torque transmitted by the shaft, N-mm

T_s = allowable shear stress, N/mm^2

3.3 Design of Bearing

As compared to load and bending, the rotor shafts are under greater stress. Since the exerting pressure is more for the shafts, Pedestal bearings should be used.

3.3.1 Diameter of Pedestal

Diameter of Pedestal should be decided from the diameter of rotor shaft and solid shaft used.

3.3.2 Bearing Length

The values commonly adopted for Pedestal bearings can be selected from table 9-5.1, (pandya and Shah, Page No.463)*.

Adopted suitable I/d ratio according to bearing pressure, type of power transmission, revolutions per minute, etc.

3.3.3 Bearing pressure

Bearing pressure is calculated by the following formula,

$$\text{Bearing pressure, } P = \frac{\text{Force}}{\text{Area}}$$

On each bearing, Force = R / 2

The maximum value of bearing pressure should be within the limit.

The maximum permissible unit pressure is given by,

$$P = \frac{Z\,N}{475 \times 10^6} \times (d / c)^2 \times [\, 1 / (d + 1)]$$

Where,

P = maximum permissible bearing pressure, kg / cm2

Z = absolute viscosity of a lubrication in centipoises

N = speed of Pedestal, rpm

D = diameter of Pedestal, cm

c = clearance (difference between diameter of bushing and diameter of Pedestal)

l = length of bearing, cm

c / d = clearance ratio.

3.4 Design considerations of frame

Design of frame is mainly guided by the moment caused by rotating action of cutting weeds of the flail mower. Moment due to rotating cutting force is supported by the frame.

Allowable moments of section can be calculated as,

$$\frac{M}{I} = \frac{F}{y} \quad \text{or} \quad M = \frac{F}{y \times I} = F \times Z$$

Where,

M = allowable moments of resistance of section

I = moment of inertia about neutral axis

F = permissible stress in the frame material

y = depth of neutral axis from extreme end

Z = modulus of section

If allowable moment of resistance of frame > moment due to cutting of weeds then the design is suitable.

* --Ref. Book of Machine Design by Pandya and Shah, 13th Edition.

MATERIALS AND METHODS

Chapter IV

MATERIAL AND METHODS

This chapter deals with the experimental details, material used and methods followed during the course of investigation. Any type of machine or mechanism require the number of elements which are so designed that they withstand safely against the forces to which they are subjected. The analysis of the forces involves the design of machine parts, so that they can perform their function without failure or undue distortions. The project work was conducted in the Workshop of Farm Machinery and Power of College of Agricultural Engineering and Technology, Marathwada Agriculture University, Parbhani. All dimensions of the flail mower were selected to be as small as possible to minimize the amount of material used. This chapter includes the points that are described below.

4.1 SELECTION OF MATERIAL

Design of machine was carried out and the material required for its fabrication was used as per the availability in the market. The available material was used as per the requirements, concerning the function, stressing and the life of the component. In order to reduce the cost of manufacturing, the material used was not so expensive.

4.1.1 Mild Steel

Mild steel is known as soft metal, having less than 0.25% of carbon, able to withstand with the loads that will occur against machine elements, its lower cost, easy availability, it is mostly used in order to reduce the cost of agricultural machines. Hence, for the fabrication of the machine, mild steel was used.

4.2 Fabrication of the Flail mower

A due attention was provided on the following design aspects while designing and fabrication of flail mower.

1) Cutting unit
2) Support frame
3) Power unit
4) Power transmission unit
5) Handle
6) Transporting unit

4.3 CUTTING UNIT

Cutting unit consists of rotary gang, which is divided into following different parts.

4.3.1 Flail Knives

Flail knives used, were curved blades with sharpened edges. The flail knife blade was made of mild steel flats. The flail knife blade were hardened and tempered to suitable hardness for longer service life of the cutting edge. The flail knives were rotated by rotating the shaft with the v-belt drive from the engine. The flail knives operated by striking the cutting edges on the weeds. The tall weeds up to 240mm heights were cut by swinging action of the flail knives at revolutions of 1500 per minute. The cutting edge was hardened and tempered to suitable hardness to resist wear and abrasion. The cutting end of the flail knives strikes the grass stems

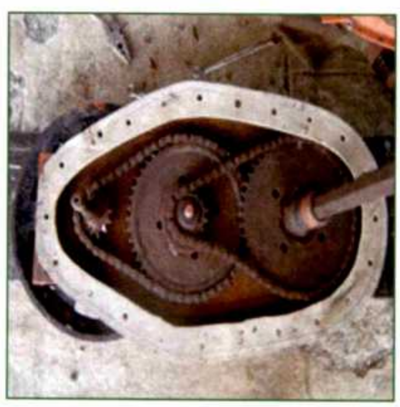
Rotor Gang

Diesel engine

Flail knives with flange

Power transmission from engine

Gear Box



Power transmission from gear box

Support wheel

Ground wheel

Plate 1 : Different Parts of Flail mower

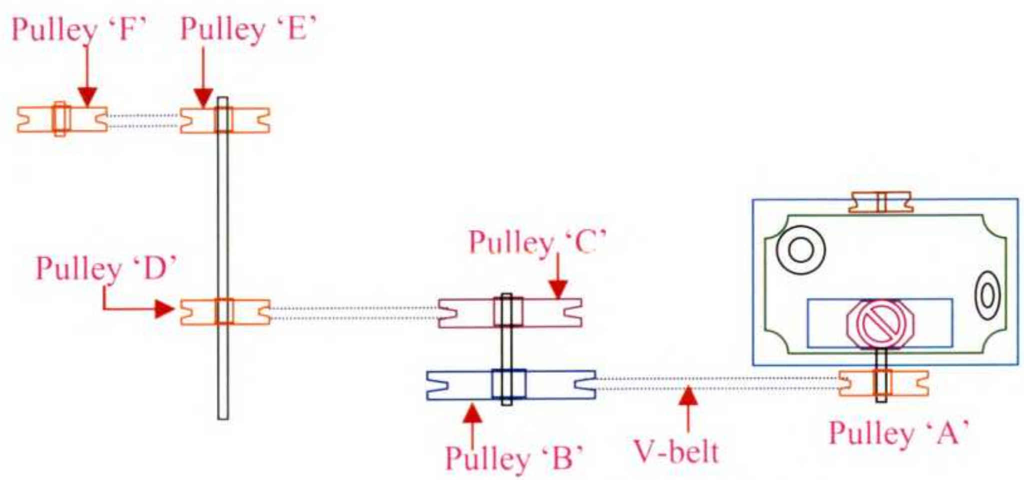


Fig.No.4.1 : Power transmission system of flail

and cutting takes place due to impact and shearing action. With the scythe, it is possible to cut an area of the about 990mm wide.

The flail knife and flange attachment was secured by an appropriate self locking nut and bolts in such a manner that will permit the flail knives to be rotated by the drive rotor shaft. The flail knives were mounted to apertures on the flanges, which thereby permit the flail knives to freely pivot about a vertical axis. The centrifugal forces cause each of the flail knives to pivot outwardly and thereby cut the weed. The free pivot arrangement of mount for flail knives minimizes damage to the blades in the event the blades strike an immoveable object such as a rock, stone or the like. In that instance, the flail knife will be forced backwards away from the immovable object and thereby cushion the blow against the blade. The use of the cutter flail knife post for mounting of the knives thereby provides improved performance of the cutting operation.

4.3.2 Flanges

Flang or circular metal plates were used for structural component for the flail knives. In order to mount the flail knives, flanges were used. Flanges were made of 10mm thick mild steel metal sheet. The flanges have three consecutive holes having an angle of 120^0 to its axis for the attachment of flail knives. The hole diameter was of 12mm each.

4.3.3 Self-locking nut and bolt

Self-locking nut and bolts were used for fastening flail knives permanently or semi-permanently. The use of nut and bolts provides easy assembly and disassembly of the joint. The flail knives were attached to the flanges with the help of self-locking nut and bolts in order to avoid unlocking or breaking of nut and bolts while

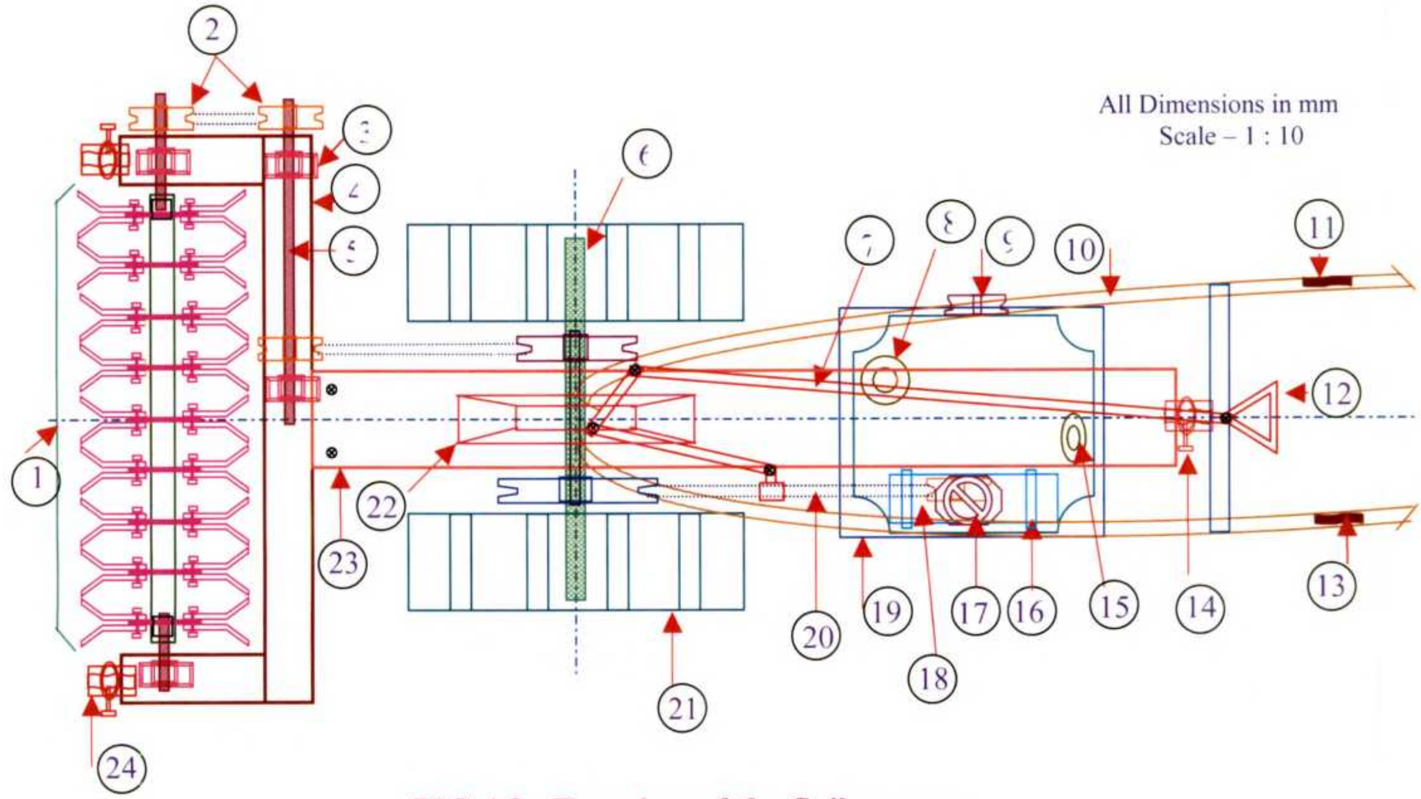


FIG.4.2 : Top view of the flail mower

1. Rotor Gang
2. Pulleys
3. Pedestal Bearing
4. Semi-rectangular square frame
5. Solid shaft
6. Hexagonal shaft
7. Engage-disengage lever shaft
8. Air cleaner
9. Engine Flywheel
10. Handle
11. Accelerator
12. Engage-disengage lever
13. Clutch
14. Back Support wheel
15. Engine exhaust
16. Fuel tank
17. Fuel tank Lid
18. Engine pulley
19. Diesel engine
20. V-belt
21. Ground wheel
22. Gear box
23. Base support Frame
24. Transporting Wheels

it is rotating in speed. The standard length and diameter of self-locking nut and bolts of 31.75mm and 10mm resp. were used.

4.3.4 Rotor shaft

Rotor Shaft was used to mount the flanges with flail knives. It receives power from the engine and drives the rotor gang. The torque required to rotate the shaft was calculated as mentioned in the previous chapter. The hollow rotor shaft which was used, had the nominal outer diameter of 62mm and the inner diameter of 59mm and thickness of 3mm.

The solid shaft was used to mount the parallel pulleys for the transmission of power from engine to the rotor gang. The solid shaft used had diameter of 25mm and length of 755mm for the adjustment of pulley.

4.4 SUPPORT FRAME

Support frame is comprises of semi rectangular square frame, base frame, Pedestal bearings and height adjustable wheels and are discussed below.

4.4.1 Semi rectangular Square Frame

Semi rectangular square frame was the main support for the rotor gang. The rotor gang was mounted with the help of pedestal bearings and the pedestal bearings were supported onto the frame. The frame was made of channels having size of 75 x 75 x 5mm welded in such a manner it forms square frame.

4.4.2 Base frame

From the economic point of view, to reduce the cost of machine, it was suggested to make use of the reaper frame. It was clear that the frame was able to bear the load of diesel engine due to the ground wheel based on hexagonal axle. The base frame was made from mild steel channel 1070 x 70 x 6 mm making square arms of frame.

4.4.3 Pedestal Bearings

In order to provide support for the shaft and for shaft alignment, Pedestal bearings were used. Pedestal bearings were mounted on adequate supports so that accurate alignment was maintained in order to keep in mind misalignment may cause shaft or bearing failure.

4.4.4 Height adjustable wheels

In order to adjust the height of machine, the height adjustable wheels were provided to the machine in accordance with required cut of weeds. Two wheels were given to the front arms of the semi rectangular square frame and one wheel was given to the back end of the base frame. The height of weeds ranges from 10mm to 244mm may cut efficiently, so that the wheels are provided. Diameter of wheel used was 152mm and width of wheel was 40mm.

4.5 POWER UNIT

Power to the machine is provided with the help of power generated from the Lombardini diesel engine.

4.5.1 Lombardini Engine

6hp Lombardini engine was used for power requirement for the design and development of cutting mechanism of flail mower. It has direct injection and combustion system. It has 6hp maximum output with low noise level and stability. Tank capacity is about 4liters. Its structure is compact and size is small. It has given manual recoil system for starting the engine.

4.6 POWER TRANSMISSION UNIT

Transmission of power for the flail mower was carried out by the v-belt drive and is discussed below.

4.6.1 V-Belt

V-belt having B type cross section was used to transmit motion and power between two shafts, the cross section of which was shaped roughly like a regular trapezoid outlined by the base, sides and top of the belt. V-belt drives were used for transmitting motion and power to shafts with short center distances and operated with small pulley diameters. V-belt used for transmission of motion and power from various pulleys are of 500mm, 380mm and 250mm. The top width of the belt was 16mm and the height of V-belt was 10mm.

4.6.2 V-Pulley

V-Pulley was a wheel with one or more grooved rims used to transmit motion and power by means of one or more V-belts. V-belt pulleys having B type cross section of various pitch diameters ranging between 115mm to 180mm are used. The heights of the pulley groove h_g, are 15mm and groove angles, were in between 34 to 38^0 . The top widths of pulley groove, were ranging between 16.2 to 16.5mm were used. The different diameter sizes 305mm, 254mm, 102mm pulleys were used for the transmission of motion and power.

4.6.3 Chain and sprocket drive box

In order to reduce the time of fabrication and cost of machine, it was suggested that the use of chain and sprocket drive box of reaper was used for the flail mower. Numbers of teeth of big sprocket were 47 and numbers of teeth of small sprocket were 14.

The sprocket of the drive box was attached directly to the hexagonal axle of the ground wheel.

4.7 HANDLE

The handle was made of 20mm outside diameter mild steel pipes. The handle was provided for the ease of driving the flail mower by walking behind the mower. Handle was very useful in turning the flail mower at headlands.

4.7.1 Engage-disengage lever

A lever was provided to the handle called engage-disengage lever. As the name indicates, it was used for engaging or disengaging the power transmission from engine to the ground wheel and rotor gang respectively. It engages the transmission of power through the v-belt with the help of the idler pulley.

4.7.2 Accelerator

Accelerator was used to increase or decrease the speed of machine. It was fixed at the right hand side to the handle for the ease of operator to increase or decrease the forward speed of machine.

4.7.3 Cut-off lever

Cut-off lever was used to cut the supply of fuel to the engine by which engine stops completely. It was fixed at the left hand side to the handle for the ease of operator to stop the engine completely.

4.8 TRANSPORTING UNIT

Transport unit composed of ground wheels and axle.

4.8.1 Ground wheel

Ground wheels were provided to the machine in order to ease of transport the machine and also for balancing the support of the machine. Ground wheels of 490mm diameter and 260mm width were used. The both ground wheels were placed at a distance of 215mm from each other.

4.8.2 Hexagonal Axle

Hexagonal axle was used to mount the ground wheels at a distance of 215mm from each other. The length of axle was 750mm. The axle provides support to the chain and sprocket drive box and transmits power to the ground wheels.

4.9 PERFORMANCE EVALUATION OF FLAIL MOWER

The laboratory tests and field tests of the flail mower were taken at Workshop of Farm Machinery and Power of College of Agricultural Engineering and Technology, Marathwada Agriculture University, Parbhani and at three different test plots viz. Plot I, Plot II and Plot III selected in Marathwada Agriculture University, Parbhani. The details about tests are mentioned below.

A) LABORATORY TEST

Laboratory test was carried out at the Workshop of Farm Machinery and Power, College of Agricultural Engineering and Technology, Marathwada Agriculture University, Parbhani. During laboratory test, the different parameters were observed carefully and described as below. The observations and measurements of machine were categorized into following units.

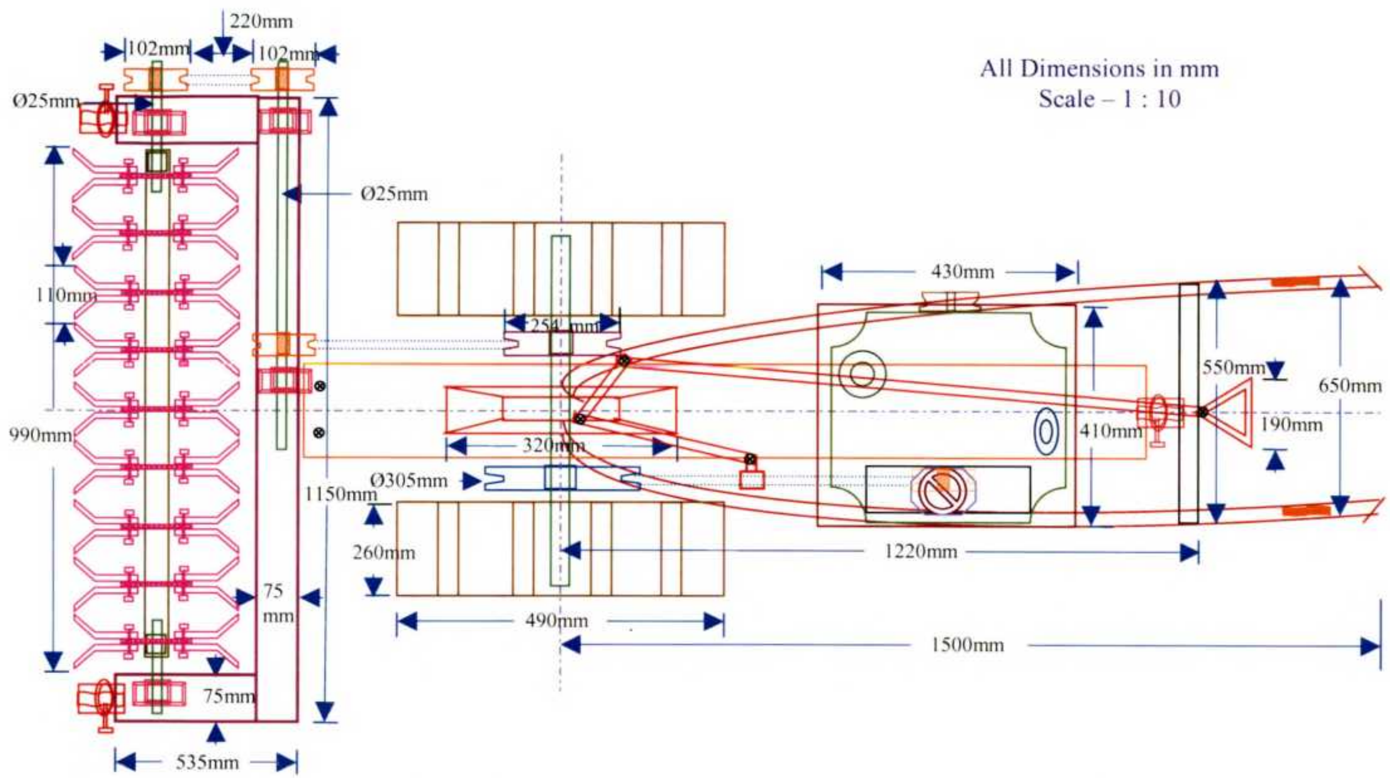


FIG.4.3 : Top view of the flail mower with overall dimensions

4.9.1 MEASUREMENT OF CUTTING UNIT

A) Flail knife Specifications

Width, mm	30
Thickness, mm	5
Height, mm	130
Angle of inclination, ^{0}	120^0
Bite length, mm	10
Total number of flail knives	54
Weight of each flail knife, gm	350
Total weight of flail knives, gm	18900
Number of flail knives on each flange, pairs	3
Spacing between two flail knives of a single pair, mm	10
Overlapping distance of each pair, mm	100
Stroke length of flail knife, mm	584
Radial height of flail knife, mm	186
Circumference made by flail knives, mm	1169
Flail knife speed, m/s	29.2
Effective cutting width of pair of flail knives, mm	110
Overall cutting width by flail knives, mm	990
Mean cutting height of weeds, mm	12.67

B) Flange Dimensions

Outer diameter, mm	152
Inner diameter, mm	62
Thickness, mm	10
Total number of flange on rotor shaft	9
Weight of each flange, gm	1100
Total weight of flange, gm	9900
Spacing between each flange, mm	100
Distance between outer radius and inner radius, mm	45
Circumference of flange, mm	478
Distance of flail knives on circumference of flange, mm	159
Angle between mounting of flail knives, o	120
Diameter of hole on flange, mm	10
Radial distance of hole from axis, mm	66

C) Self-locking nut and bolt

Standard diameter of nut, mm	10
Standard length of nut, mm	31.75
Type of bolt thread	Fine thread
Type of bolt shape	Hexagonal type

All Dimensions in mm
Scale – 1 : 10

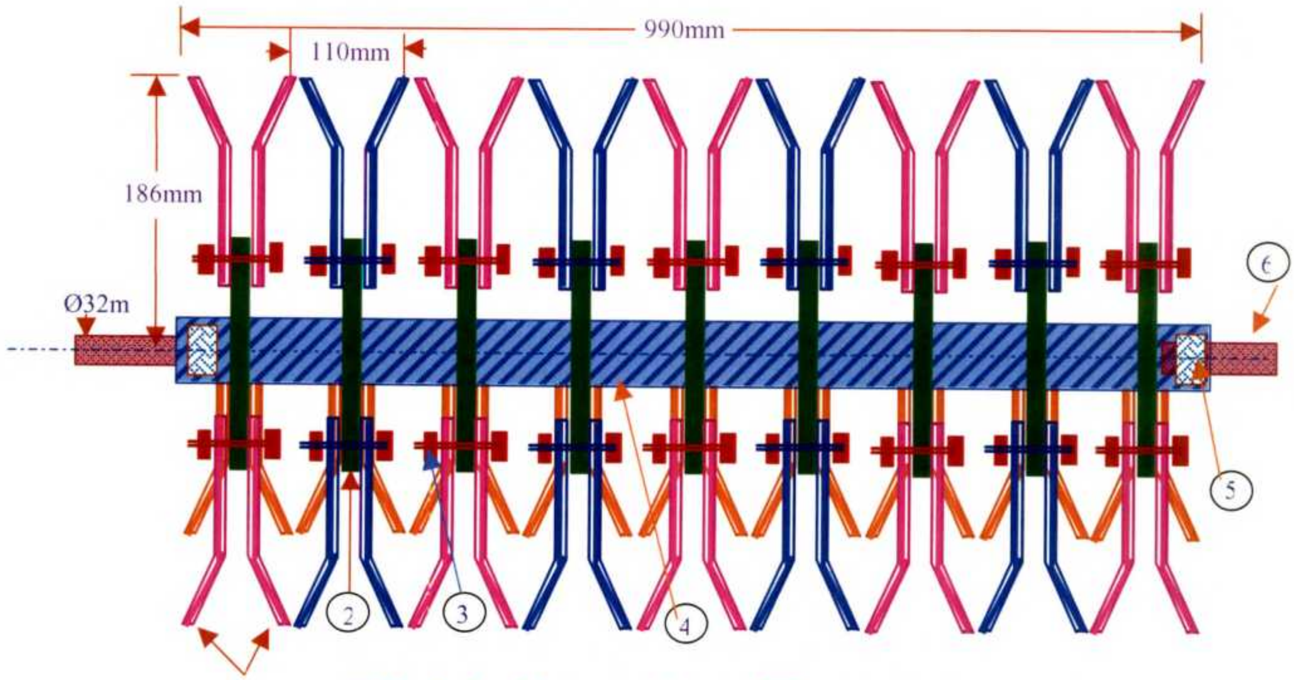


FIG.4.4 : Front view of Rotor Gang

Sr. No.	Description	Dimensions (mm)	Sr. No	Description	Dimensions (mm)
1	**Flail knives**		5	**Bush**	
	Height	186		Diameter	59
	Width	30		Width	30
	Thickness	5	6	**Solid shaft**	
2	**Flange**			Diameter	32
	Outer diameter	152		Length	70
	Inner diameter	62			
	Thickness	10			
3	**Self-locking nut and bolts**				
	Length	31.75			
	Diameter	10			
4	**Rotor shaft**				
	Outer diameter	62			
	Inner diameter	59			
	Length	3			

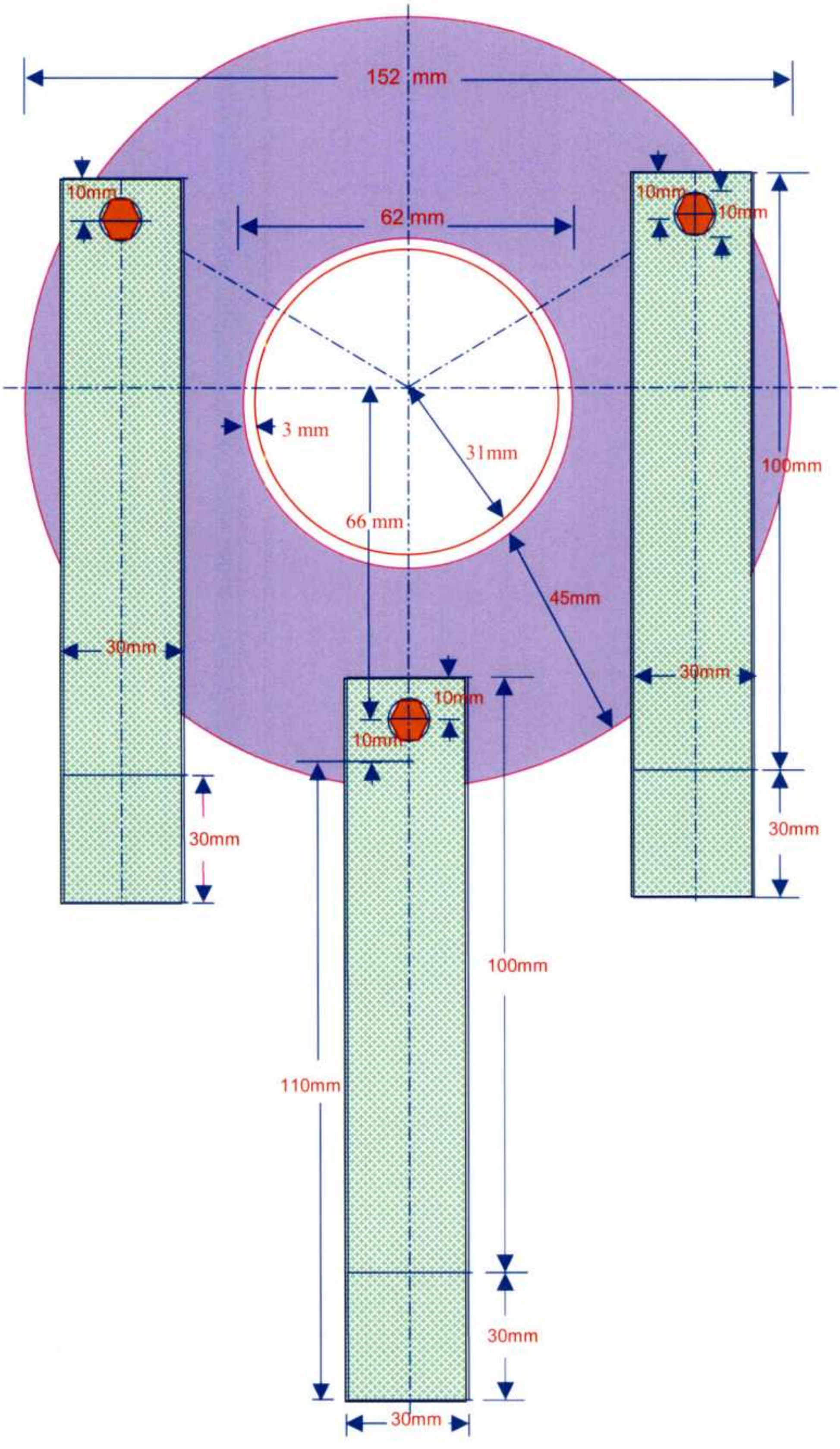


FIG 4.5 : Side view of Flange with three pairs on flail knives

D) Rotor shaft

Hollow rotor shaft specifications	
Outer diameter, mm	62
Inner diameter, mm	59
Thickness of shaft, mm	3
Length of rotor shaft, mm	1000
Solid shaft specifications	
Diameter of connector solid shaft, mm	32
Length of each connector solid shaft, mm	70
Diameter of transmission solid shaft, mm	25
Length of transmission solid shaft, mm	755

4.9.2 MEASUREMENT OF SUPPORT FRAME

A) Semi rectangular Square Frame

Outer length of frame, mm	1150
Inner length of frame, mm	1000
Outer width of frame, mm	535
Inner width of frame, mm	460
Width of square arms of frame, mm	75
Height of square arms of frame, mm	75

B) Base frame specifications

Overall Length, mm	1070
Width of square shape of frame, mm	70
Height of square shape of frame, mm	70
Ground clearance, mm	260

C) Specifications of Pedestal bearing

Inner diameter, mm	25	32
Length of base, mm	140	140
Height, mm	70	70

D) Specifications of Height adjustable wheels

Diameter of wheels, mm	152
Width of wheels, mm	40
Total adjustable height, mm	240

4.9.3 MEASUREMENT OF POWER UNIT

A) Lombardini Engine

Particulars	Remarks
Make	Greaves Pvt. Ltd.
Brand	Lombardini Diesel Engine
Model	Greaves Model 1523
Engine Type	Single cylinder, four stroke, air cooled, diesel engine
Rated RPM	1800rpm
Hp	6 hp
Overall length, mm	430mm
Overall width, mm	410mm
Overall height, mm	510mm
Starting system	Manual rope coil system
Fuel tank capacity, lit	4
Fuel consumption per working hour, lit	1.074

4.9.4 MEASUREMENT OF POWER TRANSMISSION UNIT

A) V-Belt

Type of belt	"B" type
Length of belt 'X', m	1.1
Length of belt 'Y', m	0.98
Length of belt 'Z', m	0.75
Top width of belt, mm	16
Height of belt, mm	10

B) V-Pulley

Diameter of pulley 'A', mm	102
Diameter of pulley 'B', mm	305
Diameter of pulley 'C', mm	254
Diameter of pulley 'D', mm	102
Diameter of pulley 'E', mm	102
Diameter of pulley 'F', mm	102

C) Chain and sprocket drive box

Number of teeth of small sprocket	14
Number of teethes of large sprocket	47
Speed ratio	1 : 3.35
Revolutions transferred to ground wheel, rpm	179

4.9.5 Measurement of output power

Output power at the rotor gang was calculated by the idle speed and high speed of the rotor shaft and torque as per the formula,

$$P_o = \frac{T \times N}{974}$$

Where,

P_o = output power, kW

T = shaft torque, kg-m

N = shaft speed, rpm

4.9.6 Adjustment of cutting height

At height of 10mm from the ground surface, the flail knives were adjusted so that the cutting of weeds took place above the ground surface. It has the facility to adjust the height of cut upto 240mm in case tall weeds were present in the field.

4.9.7 Power transmission system

Power transmitted by the engine to the machine was checked. The tensions on the belt were also checked. The number of revolutions at pulley of rotor gang and the number of revolutions of the driver pulley was measured with the help of contact type tachometer.

4.10 FIELD TEST

Field test was carried out in order to confirm the adaptability of the flail mower to practical conditions in the field. The practical field test was conducted in three plots, the area of each plot being the same as 20m x 10m as per recommended by RNAM Test Codes (1983).

4.10.1 Location and condition of the field

The experimental test plot was located at the residential quarters sector, SWCE Research Plot and Cotton research plot of Marathwada Agriculture University which was located about 3kms east of Parbhani town. It was located at the altitude of 409m above the mean sea level at the intersection of $19^{0}16'$ north latitude and $76^{0}47'$ longitude. The test plot was the pastureland on which weeds were grown previously at unique height of 181mm, 203mm and 237mm in Plot I, Plot II and Plot III.

4.10.2 Collection of basic data

Basic data was collected from the test plot and described as below.

A) Measurement of average height of weeds

The height of weeds in the test plot was measured by selecting the ten weeds randomly throughout the test plot.

B) Measurement of average thickness of weeds

The thickness of the weeds in the test plot was measured by selecting the ten weeds randomly throughout the test plot.

C) Measurement of intensity of weeds

Count of weeds in the net plot/m^2 were recorded. At the corner of the test plot, the area of 1m x 1m selected and counted the number of weeds present in that area.

4.9.3 Field parameters that are taken in field test

During field test, some parameters were noted and described as below.

I) Theoretical field capacity

Theoretical field capacity was calculated by using the following formula,

$$T.F.C = \frac{\text{Width (m) x Speed (km/hr)}}{10}$$

II) Effective field capacity

Flail mower was operated in the test plot continuously for the specified time. The area covered during the test was calculated. The effective field capacity was then calculated by formula,

$$E.F.C. = \frac{\text{Area covered (ha)}}{\text{Time required (hr)}}$$

III) Field efficiency

Field efficiency was calculated by the formula,

$$F.E. (\%) = \frac{E.F.C.}{T.F.C.} \times 100$$

4.9.4 Machine parameters that were taken during field test

During field teat, some parameters of the machine were noted carefully. They were as follows.

a) Speed of operation

Two poles A and B are placed at the outside corners, 20m apart to the long boundary of the test plot. On the opposite side, two poles C and D are also placed in a similar position, 20m apart so that all four poles form corners of a rectangle, parallel to at least one long side of the test plot. The speed will be calculated from the time required for the machine to travel the distance of 20m between the poles A and B.

b) Time of turning the machine

Time required to turn the machine was calculated when it completes the distance of 20m and when it begins the other end of 20m.

c) Actual operating time

Actual operating time was the time required to complete the cutting of weeds of 20m x 10m test plot including speed of operation and time required to turn the machine.

d) Fuel consumption

The following simple method is often used for the fuel consumption test. The tank was filled to full capacity before the test. Amount of refueling after the test was the fuel consumption for the test. It was kept in mind that when filling up the tank, careful attention paid to keep the tank horizontal and not to leave empty space in the tank. After the test, the amount of fuel refueled was calculated with the help of measuring cylinder.

e) Effective cutting width

The effective cutting width of the machine was the actual width of cut of the flail knives including overlapping of flail knives. It was measured with the help of measuring tape after cutting of weeds taken place.

f) Weeding efficiency

The mowing efficiency was calculated from the number of weeds before mowing and the number of weeds after mowing in the net plot/m^2.

4.10 Instruments used and their specifications

Different instruments were used for different measurements of machine parts and other also were described below.

1) Tachometer

The contact type tachometer was used to measure the revolutions of pulleys and rotor shaft.

2) Measuring tape

Measuring tape was used to measure the distance of plots, effective width of cut, height of weeds and all required dimensions of the machine.

3) Stop watch

Stop watch was used to calculate the time required for the operation of machine.

4) Vernier caliper

Vernier caliper was used to measure the dimensions of different small parts of the machine.

5) Measuring cylinder

Measuring cylinder was used to measure the amount of fuel to calculate the fuel consumption of the machine.

RESULT AND DISCUSSION

Chapter V

RESULTS AND DISCUSSION

In this chapter, the design of flail mower and its performance analysis is presented. The performance of the flail mower under different field conditions such as height of weeds, intensity of weeds, cutting height of weeds and speed of operation are discussed.

5.1 Working of flail mower

The 6hp Lombardini diesel engine started by recoiling the rope manually. When the engine starts, the power is transmitted from the engine pulley 'A' to the parallel pulley 'B' through v-belt when engage–disengage lever is move down. The power from pulley 'B' receives the pulley 'C' being both mounted on same shaft and it transmits the power further to pulley 'D' and pulley 'E' those were mounted on the same shaft as shown in Fig.5.1. The pulley 'E' transmits the power to pulley 'F' through v-belt. The pulley 'F' rotates the rotor shaft along the direction of travel. When the rotor shaft rotates, the flail knives mounted on flanges also rotates with respect to rotor shaft and cutting of weeds takes place. The weeds having height more than 180mm were also cuts efficiently.

5.2 Experimental details

The performance evaluation of flail mower was tested on three plots viz. Plot I, Plot II and Plot III. The size of plot was taken as 20 x 10m for all the test plots. The developed flail mower was operated in the test plot and observations were taken for each strip of (20 x1m) test plots. The detail calculations were described in Appendices.

5.2.1 Machine parameters

Machine parameters that were taken into considerations to evaluate the field performance of flail mower and are presented in table 5.1

Table 5.1 Machine parameters

Particulars	**Remarks**
Make	Greaves Pvt.Ltd.
Brand	Lombardini Diesel Engine
Model	Greaves Model 1523
Power, hp	6
Engine Type	Single cylinder, four stroke, air cooled, diesel engine
Rated RPM	1800
Combustion system	Direct injection
Cooling system	Air cooled
Starting system	Manual rope coil system
Fuel tank capacity, ltr	4
Fuel consumption per working hour, l/hr	1.074
Rated width of machine, m	1.11
Effective working width, mm	990
Max. speed of machine, km/hr	1.54
Max. working height of machine, mm	240

Plate 2 : Pictorial Views of Flail mower

5.2.2 Field condition of test plots

Different test plots having different field conditions were selected for evaluating the field performance of flail mower and the details of test plots were discussed in table 5.2

Table 5.2 Field condition

Particulars	Plot I	Plot II	Plot III
Test plot size, m	20 x 10	20 x 10	20 x 10
Area of test plot, m^2	200	200	200
Kind of plot	Flat, dense	Flat, dense	Flat, highly dense
Location of plot	Residential Quarters sector	SWCE Research Field	Cotton Research Field
Type of soil	Black cotton soil	Black cotton soil	Black cotton soil
Average height of weeds, mm	181	203	237
Intensity of weeds per m^2	395	416	448

From table 5.2, the Plot I, Plot II and Plot III having size of 20 x 10m each as per RNAM Test codes 1983. The Plot I and Plot II was flat and dense having average height of weeds and intensity of weeds as 181mm, 203 mm and $395/m^2$, $416/m^2$ resp. And the Plot III was flat and highly dense having average height of weeds and intensity of weeds as 237 mm and $448/m^2$ resp.

Plate 3 : Measurement of test plot

Plate 4 : Height measurement of weeds

Plate 5 : Weed condition in selected test plots before mowing

Table 5.3 Field evaluation of Plot I

Particulars	I	II	III	Mean
Test plot size, m	**20 x 10**	**20 x 10**	**20 x 10**	**20 x 10**
Area of test plot, m^2	200	200	200	200
Average height of weeds, mm	179	181	183	181
Intensity of weeds per m^2	373	398	414	395
Cutting height of weeds, mm	9	10	11	10
Total No. of strips (1 x 20m) to cover the area of plot	10	10	10	10
Time taken to cover total strips of test plot, sec	470	484	486	480
Total number of turns of headlands	9	9	9	9
Time lost owing to turning headlands, sec	36	36	36	36
Total time required to cover the test plot, mins	8.43	8.66	8.71	8.60
Speed of operation, km/hr	1.548	1.482	1.410	1.480
Theoretical field capacity, ha/hr	0.154	0.148	0.141	0.147
Effective field capacity, ha/hr	0.142	0.133	0.125	0.133
Field efficiency, %	92.20	89.86	88.65	90.24
Weeding efficiency, %	93.83	87.93	85.74	89.16
Fuel consumed to complete test plot, ltr	0.101	0.158	0.140	0.123
Fuel consumption per working hour, l/hr	0.721	0.888	0.965	0.858
Actual area covered per hour, ha	1.10	1.02	0.971	1.03

Table 5.4 Field evaluation of Plot II

Particulars	I	II	III	Mean
Test plot size, m	20 x 10	20 x 10	20 x 10	20 x 10
Area of test plot, m^2	200	200	200	200
Average height of weeds, mm	198	202	209	203
Intensity of weeds per m^2	402	410	436	416
Cutting height of weeds, mm	10	13	16	13
Total No. of strips (1 x 20m) to cover the area of plot	10	10	10	10
Time taken to cover total strips of test plot, sec	510	536	544	530
Total number of turns of headlands	9	9	9	9
Time lost owing to turning headlands, sec	36	45	54	45
Total time required to cover the test plot, mins	9.10	9.68	9.96	9.58
Speed of operation, km/hr	1.494	1.423	1.380	1.432
Theoretical field capacity, ha/hr	0.149	0.142	0.138	0.143
Effective field capacity, ha/hr	0.132	0.124	0.120	0.125
Field efficiency, %	88.59	87.32	86.69	87.53
Weeding efficiency, %	96.07	94.58	91.17	93.94
Fuel consumed to complete test plot, ltr	0.123	0.167	0.192	0.160
Fuel consumption per working hour, l/hr	0.814	1.037	1.156	1.002
Actual area covered per hour, ha	0.980	0.880	0.831	0.897

Table 5.5 Field evaluation of Plot III

Particulars	I	II	III	Mean
Test plot size, m	20 x 10	20 x 10	20 x 10	20 x 10
Area of test plot, m^2	200	200	200	200
Average height of weeds, mm	228	239	244	237
Intensity of weeds per m^2	430	454	460	448
Cutting height of weeds, mm	15	16	17	15
Total No. of strips (1 x 20m) to cover the area of plot	10	10	10	10
Time taken to cover total strips of test plot, sec	570	595	605	590
Total number of turns of headlands	9	9	9	9
Time lost owing to turning headlands, sec	45	54	60	54
Total time required to cover the test plot, mins	10.25	10.81	11.08	10.71
Speed of operation, km/hr	1.381	1.360	1.340	1.360
Theoretical field capacity, ha/hr	0.138	0.136	0.134	0.136
Effective field capacity, ha/hr	0.117	0.111	0.108	0.112
Field efficiency, %	84.78	81.61	80.59	82.32
Weeding efficiency, %	97.20	94.71	93.47	95.12
Fuel consumed to complete test plot, ltr	0.198	0.240	0.296	0.244
Fuel consumption per working hour, l/hr	1.159	1.332	1.602	1.364
Actual area covered per hour, ha	0.807	0.760	0.725	0.764

Plate 6 : Flail mower working in test plots

Plate 7 : Cutting of weeds by the flail knives

Plate 8 : Turning at headlands

Table 5.6 Mean of field evaluation of test plots

Particulars	Plot I	Plot II	Plot III
Test plot size, m	20 x 10	20 x 10	20 x 10
Area of test plot, m^2	200	200	200
Average height of weeds, mm	181	203	237
Intensity of weeds per m^2	395	416	448
Cutting height of weeds, mm	10	13	15
Total No. of strips (1 x 20m) to cover the area of plot	10	10	10
Time taken to cover total strips of test plot, sec	480	530	590
Total number of turns of headlands	9	9	9
Time lost owing to turning headlands, sec	36	45	54
Total time required to cover the test plot, mins	8.60	9.58	10.71
Speed of operation, km/hr	1.480	1.432	1.360
Theoretical field capacity, ha/hr	0.147	0.143	0.136
Effective field capacity, ha/hr	0.133	0.125	0.112
Field efficiency, %	90.24	87.53	82.32
Weeding efficiency, %	89.16	93.94	95.12
Fuel consumed to complete test plot, ltr	0.123	0.160	0.244
Fuel consumption per working hour, l/hr	0.858	1.002	1.364
Actual area covered per hour, ha	1.03	0.897	0.764

Plate 9 : Test Plot I after mowing completed

Plate 10 : 14mm stem diameter weed cuts cleanly

Plate 11 : Test Plot III after mowing completed

5.8 Field evaluation of flail mower

The results of field tests are given in table 5.3, table 5.4 and table 5.5. The summary of the performance of field tests of flail mower for different test plots is presented in table 5.6. From the table 5.6, following observations regarding the different performance parameters of flail mower are given.

5.8.1 Height of weeds

The average height of weeds was found to be 181mm, 203mm and 237mm for test Plot I, Plot II and Plot III resp. For test Plot III, the height of weeds was found to be maximum as compared to test Plot I and Plot II.

5.8.2 Intensity of weeds

From table 5.6, it is observed that intensity of weed was maximum in test Plot III ie. 448 per m^2 and minimum for test Plot I ie.395 per m^2. It is also seen that when the intensity of weeds is more, the rotor gang is choked due to wrapping of heightened weeds around the rotor shaft at the end of bearing support.

5.8.3 Cutting height of weeds

From table 5.6, cutting height varies with height of weed. It is observed that as the height of weed increases, the cutting height of weed also increases. The adjustments can be made for cutting of weed from 10-20mm from the ground level.

5.8.4 Speed of operation

The speed of operation was 1.48 km/hr, 1.432 km/hr and 1.36 km/hr for test plot I, plot II and plot III resp. The kind of plot I and plot II was flat, dense and plot III was flat, highly dense, so that the speed of operation is minimum for plot III as compared to plot I and plot II. It is found that the intensity of weeds affects the speed of operation. For less intensity of weeds, the speed of operation is more and vice versa.

5.8.5 Time requirement

It is found that the time required to cover the test plot is inversely proportional to the speed of operation. As the speed of operation is more, the time required to cover the test plot is less. The maximum time required to cover the plot is 11.08mins for test Plot III at the speed of 1.34km/hr and minimum time required to cover the plot is 8.43mins for test Plot I at the speed of 1.548km/hr.

5.8.6 Field efficiency

It is found that the values of field efficiency for different test plots were in the range of 92.20 per cent to 80.59 per cent and the average field efficiency was found to be 88.69 per cent. The field efficiency decreases as the speed of operation decreases. The maximum field efficiency of 92.20 per cent was obtained at a speed of 1.548km/hr for which weeding efficiency was found to be 93.83 per cent for plot I and the minimum field efficiency of 92.20 per cent was obtained at a speed of 1.34 km/hr for which weeding efficiency was found to be 93.47per cent

5.8.7 Weeding efficiency

It is found that the speed of operation is directly proportional to the weeding efficiency. As the speed of operation decreases, the weeding efficiency also decreases. The maximum weeding efficiency of 95.12 per cent is obtained in test Plot III when the speed of operation was 1.360km/hr and the minimum weeding efficiency of 89.16 per cent is obtained when the speed of operation was 1.480km/hr.

5.8.8 Fuel consumption

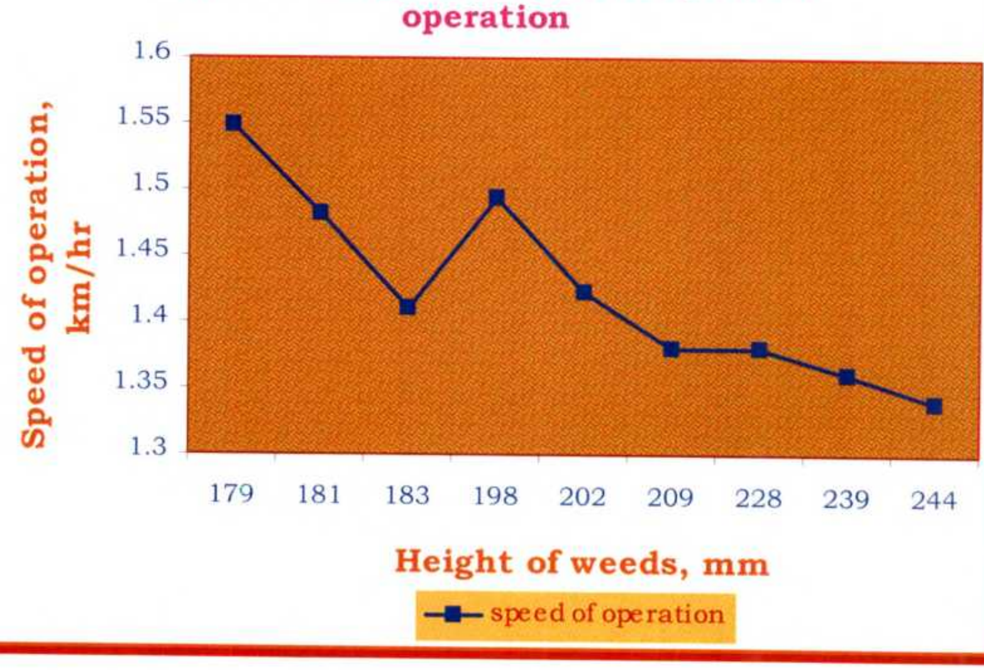
Fuel consumption per working hour was 0.858 l/hr, 1.002 l/hr and 1.364 l/hr for Plot I, Plot II and Plot III resp. It is found that as the speed of operation decreases, the amount of fuel consumption increases. The fuel consumption by engine increases when the load is transfers onto the engine.

5.9 Effect of operational parameters on weeding

5.9.1 Effect of height of weeds on speed of operation

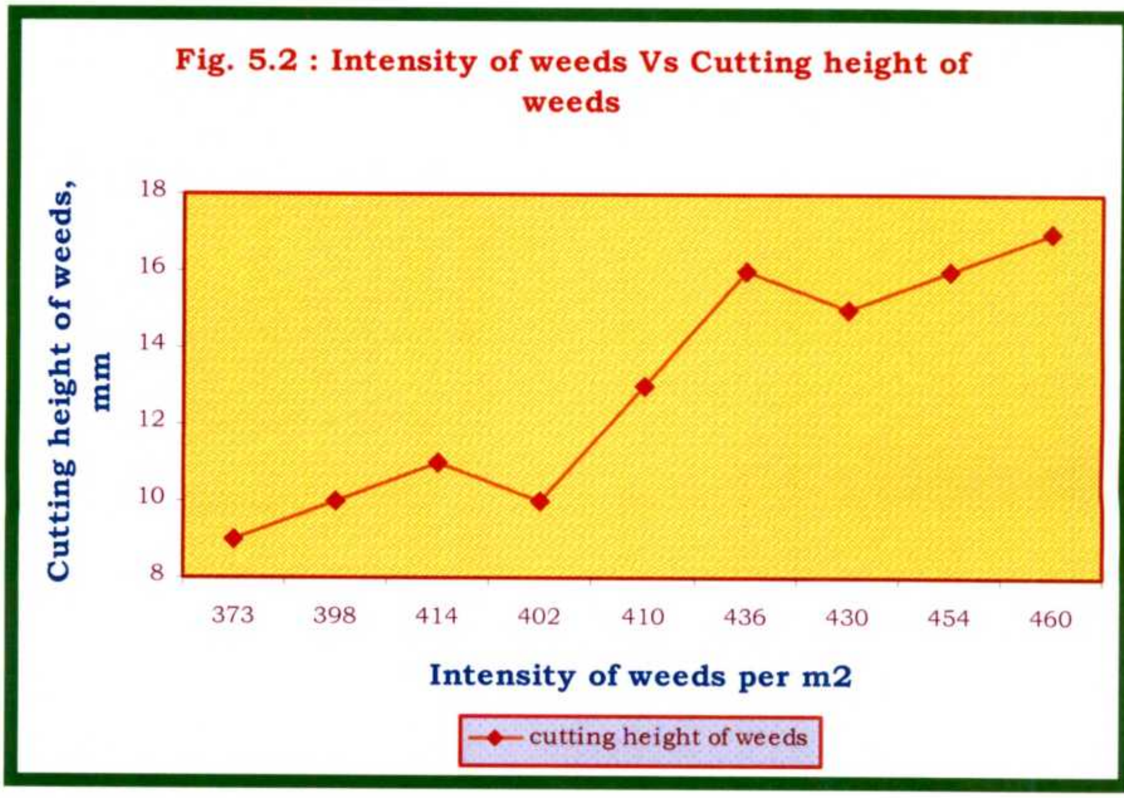
The effect of height of weeds on speed of operation is presented in Fig.5.1. From the Fig.5.1, it is seen that as the height of weeds is increases, the speed of operation decreases. There is decrease in speed of operation from 1.548km/hr to 1.340km/hr when the height of weeds increases from 179mm to 244mm resp.

Fig.5.1 : Height of weeds Vs Speed of operation



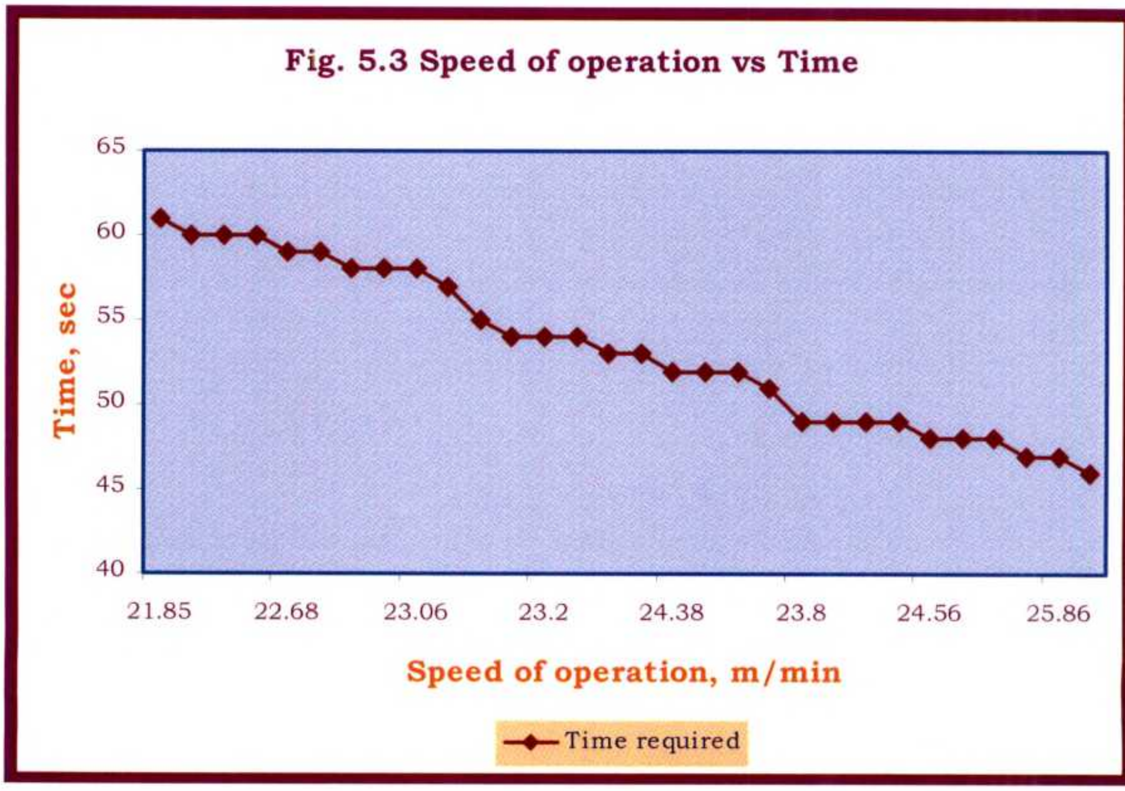
5.9.2 Effect of intensity of weeds on cutting height

The effect of intensity of weeds on cutting height of weeds is shown in Fig.5.2. From Fig.5.2, it is seen that as the intensity of weeds is more, the cutting height of weeds is more. The cutting height of weeds increases from 9mm to 17mm when the intensity of weeds increases from 373 per m^2 to 460 per m^2 resp.



5.9.3 Effect of speed of operation on time requirement

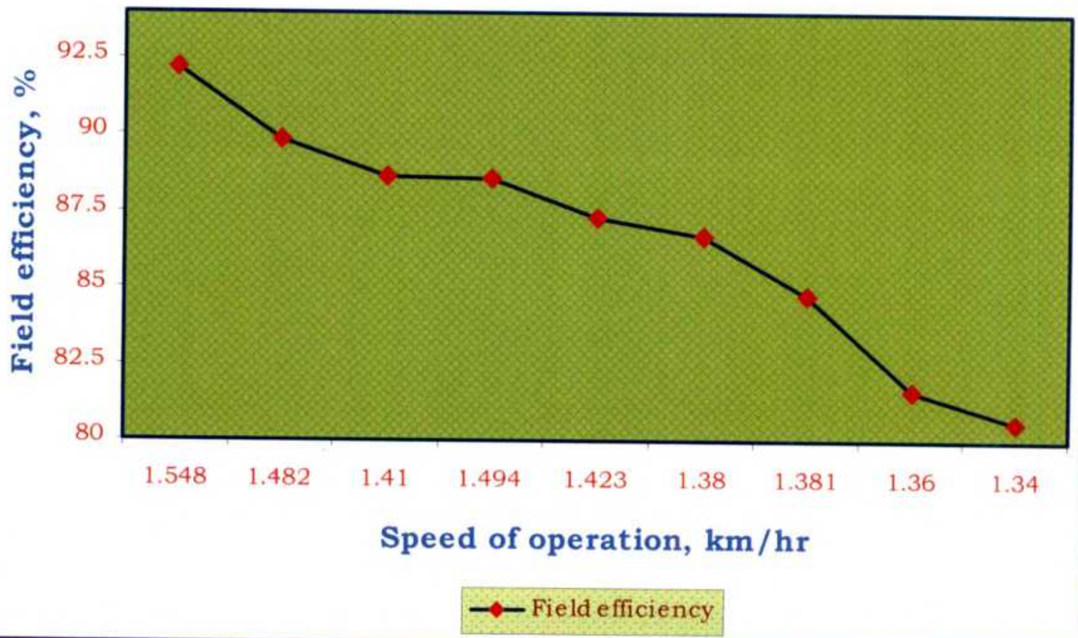
Different parameter such as height of weeds, intensity of weeds etc. affects the speed of operation, which affects the time requirement. The effect of speed of operation on time requirement is shown in Fig.5.3. It is seen that from the Fig.5.3, as the speed of operation decreases, the time required to cover the test plot increases. The speed of operation decreases from 1.548km/hr to 1.340km/hr for which time required to cover the plots increases from 8.4mins to 11.08mins resp.



5.9.4 Effect of speed of operation on field efficiency

Fig.5.4 gives the relationship between the speed of operation and field efficiency. It is found that the speed of operation is directly proportional to the field efficiency. As the speed of operation decreases, the field efficiency also decreases. The speed of operation decreases from 1.548km/hr to 1.340km/hr for which the field efficiency decreases from 92.20 per cent to 80.59 per cent.

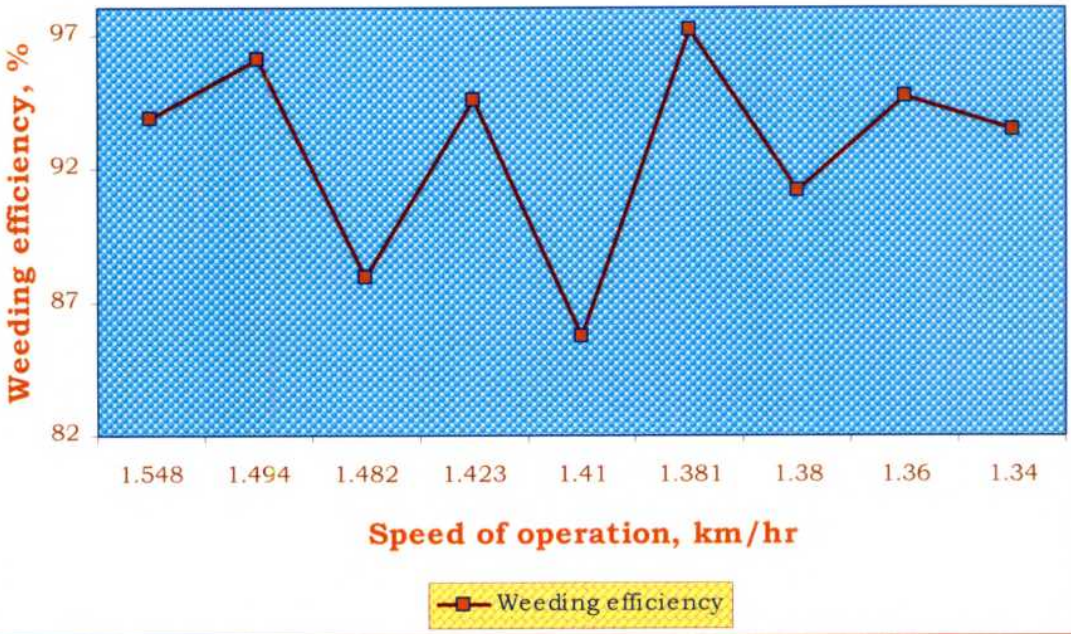
Fig. 5.4 : Speed of operation Vs Field efficiency



5.9.5 Effect of speed of operation on weeding efficiency

The effect of speed of operation is shown in Fig.5.5. The Fig.5.5, shows that the weeding efficiency increases as the speed of operation decreases. Weeding efficiency is maximum 95.12 per cent at the speed of operation of 1.360km/hr and is minimum 89.16 per cent at the speed of operation of 1.480km/hr.

Fig. 5.5 : Speed of operation Vs Weeding efficiency



5.9.6 Effect of speed of operation on fuel consumption

Fig.5.6 gives the relationship between speed of operation and weeding efficiency. From Fig.5.6, it is found that the fuel consumption increases when the speed of operation decreases and the speed of operation decreases when engine suffer more load on it. The maximum fuel consumption per working hour is 1.602ltrs when the speed of operation was 1.340km/hr and the minimum fuel consumption per working hour is 0.721ltr when the speed of operation is 1.548km/hr.

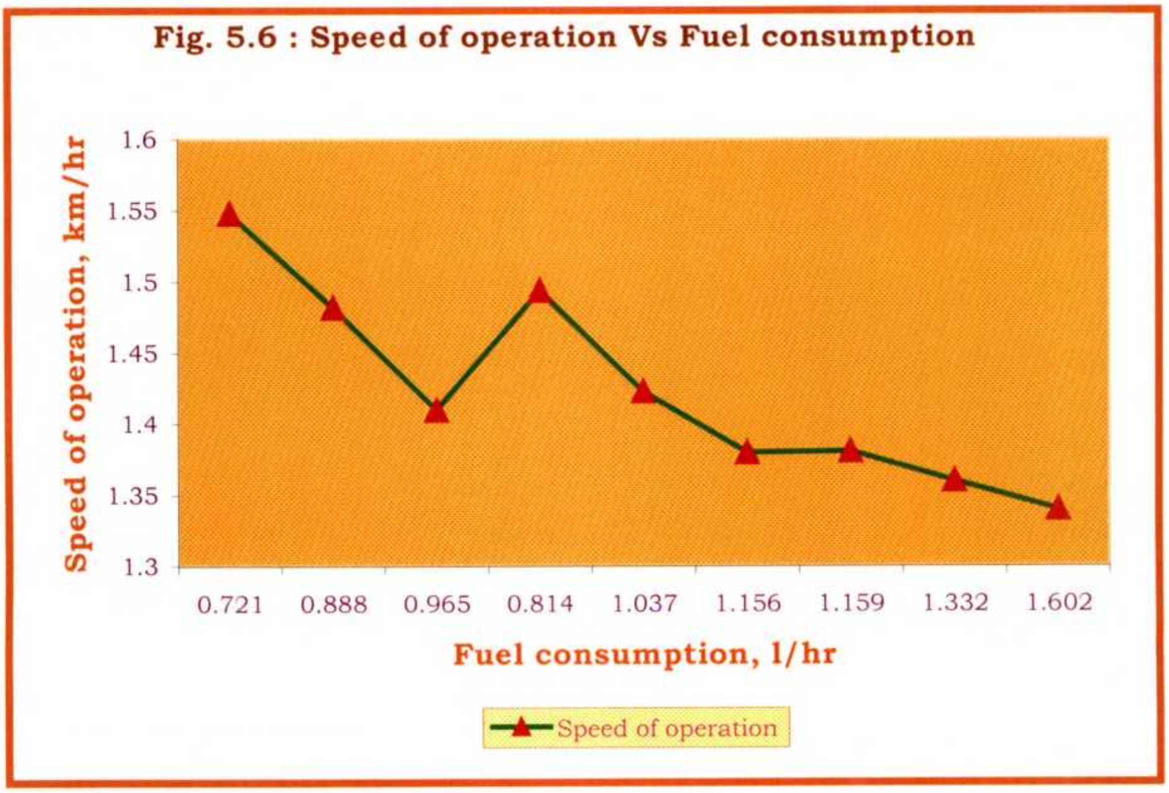


Fig. 5.6 : Speed of operation Vs Fuel consumption
Speed of operation, km/hr
1.6
1.55
1.5
1.45
1.4
1.35
1.3
0.721
0.888
0.965
0.814
1.037
1.156
1.159
1.332
1.602
Fuel consumption, l/hr
Speed of operation

SUMMARY AND CONCLUSION

Chapter VI

SUMMARY AND CONCLUSION

6.1 Summary

Research project **"Design and development of cutting mechanism of flail mower"** was taken up with the following objectives;

- To design cutting mechanism of flail mower
- To develop walking type flail mower
- To evaluate performance of cutting mechanism of walking type flail mower.

After the trials were taken in the selected three plots viz. Plot I, Plot II and Plot III of different conditions, time required to cover the plots were noted as 8.43 mins, 9.58 mins and 10.71 mins resp.

Total time lost owing to turning headlands in the test plots were noted 36 secs, 45 secs and 54 secs resp. Travel speed of machine were noted as 1.48 km/hr,1.432 km/hr and 1.360 km/hr. And also, fuel consumption by the engine were noted as 0.858 l/hr, 0.1002 l/hr and 0.1364 l/hr resp.

Based on the results discussed in chapter "Results and Discussion", the following conclusions were taken.

6.2 Conclusions

1) The flail mower is able to cut weeds of height from 15 to 240mm above ground level at a cutting height of 10mm to 20mm resp.
2) It is able to cut a wide variety of weeds from thin-dense portion to thick-dense portion, tough stalks, cleanly and without choking.
3) The cutting parts of the mower were protected from rocks, stones etc. and are capable of cutting through occasional mounds of soil without damage.
4) The forward speed of the machine should be selected by considering weed intensity to avoid choking on the cutting unit.
5) The forward speed of the machine is comparatively higher than the speed of operator.
6) For weeding dense and tall weeds, the width of the flail knife gang should upto 900mm.
7) The material used for the flail knife should be more hardened to avoid blunting of flail knives.
8) The size of transmission unit parts should be minimized in order to minimize power losses.
9) The highly dense weed plots should not divert the load on engine.
10) For that plots, the engine power should be at least 5-10% greater than the power required by the mower to overcome changes of forward speed, weed intensity and ground topography conditions in the field.

LITERATURE CITED

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APPENDICES

APPENDIX –I

1. Calculations for design of cutting unit

1.1 Calculations for peripheral speed of flail knives

The peripheral speed of flail knives is calculated by the formula,

$$V_k = \frac{S \times n}{30}$$

Where,

V_k = flail knife speed, m/s

S = Length of stroke, m = 584mm

n = rotor speed, rpm = 1500rpm

Therefore,

$$V_k = \frac{584 \times 1500}{1000 \times 30}$$

$$\mathbf{V_k = 1752\ m/min}$$

$$\mathbf{V_k = 29.2\ m/s}$$

1.2 Calculation of Torque available to flail knives

Torque available to flail knives is calculated by the formula,

$$T = \frac{Hp \times 4500}{2\pi N}$$

$$= \frac{6 \times 4500}{2 \times 3.142 \times 1500}$$

$$\mathbf{T = 2.86\ kg\text{-}m}$$

1.3 Calculation of Tangential force available at flail knives

Tangential force available at flail knives is calculated by the formula,

$$\mathbf{F_t} = \frac{\textbf{Torque (kg-m)}}{\textbf{Radius of flail knives (m)}}$$

$$= \frac{2.86}{0.186}$$

$$\mathbf{F_t = 15.37\ kg}$$

1.4 Calculations for power requirement for cutting of weed

The power requirement for cutting of weeds is calculated by the formula,

$$\mathbf{Hp = \frac{F_t \times V_k}{75}}$$

Where,

F_t = tangential force, kg

V_k = peripheral speed of flail knife, m/s.

$$Hp = \frac{15.37 \times 29.2}{75}$$

$$= 5.98$$

$$\mathbf{Hp = 6\ hp}$$

1.5 Determination of Byte length

The byte length for the Flail knives was calculated as follows.

$$\textbf{Byte length, mm} = \frac{V_k \times \pi \times D}{V_m}$$

Where,

V_k = Speed of flail knives, m/s

D = Outer diameter of the flange, mm

V_m = revolutions of the rotor shaft, rpm

$$\text{Byte length} = \frac{29.2 \times 3.142 \times 152}{1500}$$

Byte length = 9.29 mm = 10 mm

1.6 Determination of number of blades

The number of blades was calculated by using the expression.

$$Z = \frac{2 \times \pi \times h}{S \times \lambda - 2A}$$

where,

Z = number of blades

h = maximum depth of operation, m

S = byte length, m

A = blade thickness, m

λ = speed rate $\Rightarrow \lambda = \frac{V_k}{V_t}$

V_k = cutting speed, m/s

V_t = forward speed, m/s

Speed rate,

$$\lambda = \frac{V_k}{V_t}$$

$$= 29.2 \; / \; 26.1$$

$$\boldsymbol{\lambda = 1.118}$$

Therefore,

$$Z = \frac{2 \times \pi \times h}{S \times \lambda - 2A}$$

$$Z = \frac{2 \times 3.142 \times 0.01}{0.01 \times 1.118 \; - 2 \times 0.005}$$

$$Z = 53.94$$

$$\mathbf{Z = 54}$$

1.7 Cross-sectional area of a flail knife

The cross-sectional area of a flail knife is calculated by the formula,

$$\mathbf{A = h\,(2b + 2l)}$$

$$= 5\,(2 \times 30 + 2 \times 150)$$

$$\mathbf{A = 1800mm^2}$$

The total surface area of flail knife

$$\mathbf{A' = 2(lb + bh + hl)}$$

$$= 2\,(\,150 \times 30 + 30 \times 5 + 5 \times 150)$$

$$\mathbf{A' = 10800\ mm^2}$$

APPENDIX –II

2. POWER TRANSMISSION UNIT

Power transmission unit comprises the following design Aspects

2.1 Design of pulleys

1) Velocity ratio

Velocity ratio is calculated by the formula,

$$\text{Velocity ratio} = \frac{\text{RPM of input shaft}}{\text{RPM of output shaft}}$$

Number of revolutions of engine pulley (A) = 1800rpm

(rated rpm of engine pulley)

Let us consider 1/3rd revolutions of rated rpm requires for the driven pulley (B),

$$= 1800 \times 1/3$$

$$= \mathbf{600}$$

By formula,

$$\text{Velocity ratio} = \frac{\text{Number of revolutions of engine pulley (A)}}{\text{Number of revolutions required for driven pulley (B)}}$$

$$= 1800 / 600$$

$$= \mathbf{3 : 1}$$

2) Diameter of driven pulley (B)

$$\text{Diameter of driven pulley (B)} = \text{Velocity ratio (B)} \times \text{Diameter of driving pulley (B)}$$

$$= \frac{3}{1} \times 10.16$$

$= \mathbf{30.48cm}$

3) **Speed ratio**

$$\text{Speed ratio} = \frac{\text{Number of revolutions of small pulley (A)}}{\text{Number of revolutions large pulley (B)}}$$

$= 1800 / 600$

$= \mathbf{3 : 1}$

Both the pulleys, pulley B and pulley C are mounted on the same shaft, the number of revolutions of both the pulleys B and C are same. ie. 600rpm

Let us consider the revolutions of driven pulley (D) = 1500rpm

4) **Velocity ratio**

$$\text{Velocity ratio} = \frac{\text{RPM of input shaft}}{\text{RPM of output shaft}}$$

$= 600 / 1500$

$= \mathbf{1 : 2.5}$

5) **Diameter of driven pulley (D)**

$$\text{Diameter of driven pulley (D)} = \text{Velocity ratio} \times \text{Diameter of driving pulley (C) (cm)}$$

$= 1 / 2.5 \times 25.40$

$= \mathbf{10.16cm}$

Both the pulleys, pulley D and pulley E are mounted on the same shaft, the number of revolutions of both the pulleys D and E are same. ie. 1500rpm

Let us consider the revolutions of driven pulley (E) = 1500rpm

6) Velocity ratio

$$\text{Velocity ratio} = \frac{\text{RPM of input shaft}}{\text{RPM of output shaft}}$$

= 1500 / 1500

= 1 : 1

7) Diameter of driven pulley (E)

$$\text{Diameter of driven pulley (E)} = \text{Velocity ratio} \times \text{Diameter of driving pulley (D) (cm)}$$

= 1 / 1 x 10.16

= 10.16cm

The pulley (E) drives the pulley (F).

Let us consider the revolutions of driven pulley (F) = 1500rpm

8) Velocity ratio

$$\text{Velocity ratio} = \frac{\text{RPM of input shaft}}{\text{RPM of output shaft}}$$

= 1500 / 1500

= 1 : 1

9) Diameter of driven pulley (F)

$$\text{Diameter of driven pulley (F)} = \text{Velocity ratio} \times \text{Diameter of driving pulley (E) (cm)}$$

= 1 / 1 x 10.16

= 10.16cm

APPENDIX - III

3 Calculations for power transmission belt

3.1 Design of belt

For the transmission of the power, open belt is used.

Length of belt 'X' (bet^{n} Pulley A and B)

The approximate belt length for the two-pulley drive is calculated by using the formula,

$$L = 2C + \frac{\pi}{2}(D_L + D_s) + \frac{(D_L - D_s)^2}{4C}$$

Where,

L = length of the belt, mm

C = distance between centers of pulleys, mm

D_L = pitch diameter of the large pulley, mm

D_S = pitch diameter of the small pulley, mm

$$L = 2C + \frac{\pi}{2}(D_L + D_s) + \frac{(D_L - D_s)^2}{4C}$$

$$L = 2 \times 500 + \frac{3.142}{2}(472 + 157) + \frac{(472 - 157)^2}{4 \times 500}$$

$$= 1000 + 988.1 + 49.61$$

L = 1137.77mm

Similarly,

Length of belt 'Y' (bet^n Pulley C and D) and length of belt 'Z' (bet^n Pulley E and F) was calculated as 98.68mm and 74.94mm resp.

3.2 Belt speed

Belt speed between different pulleys are calculated as below,

1) Belt speed between pulley A and B is calculated by the formula,

$$V = \frac{\pi \times D_s \times n_s}{1000}$$

Where,

D_s = diameter of the small pulley, mm

n_s = number of revolutions of the small pulley, rpm

$$V = 3.142 \times 101.6 \times 1800 / 1000$$

$$= 574.6 m/min$$

$$V = 575 m/min$$

$$\mathbf{V = 9.58\ m/s}$$

2) Belt speed between pulley D and E is calculated as,

$$V = 3.142 \times 254 \times 1500 / 1000$$

$$V = 1197.10 m/min$$

$$V = 1197 m/min$$

$$\mathbf{V = 19.95 m/s}$$

3.3 Power transmitted by V-belt

Horsepower transmitted by the V-belt is calculated by the formula,

$$\text{Horsepower transmitted, } P = \frac{(T_1 - T_2)\,V}{75}$$

Where,

T_1 = tension on the tight side, Kg

T_2 = tension on the slack side, Kg

V = belt speed, m/s

When $V = 9.58$m/s,

$P = (T_1 - T_2) \times V / 75$

$(T_1 - T_2) = 6 \times 75 / 9.58$

$= 46.97$

$(T_1 - T_2) = 47$ Kg

When $V = 19.95$m/s

$P = (T_1 - T_2) \times V / 75$

$(T_1 - T_2) = 6 \times 75 / 19.95$

$(T_1 - T_2) = 22.56$ Kg

3.4 Ratio Tensions (for pulley A and B)

Ø for larger pulley = $180^0 + 2\sin^{-1}[(r_1 - r_2)/ C]$

r_1 = radius of driven pulley = 304.8 / 2 = 152mm

r_1 = radius of driver pulley = 101.6 / 2 = 50.8mm

$Ø = 180^0 + 2\sin^{-1}[(r_1 - r_2)/ C]$

$= 180^0 + 2\sin^{-1}[(152 - 50.8) / 492.89]$

$= 180^0 + 2 \times 12$

$= 204^0$

$= 204 \times \pi / 180$

$\emptyset = 3.56$ rad

$\emptyset$ for smaller pulley $= 180^0 - 2\sin^{-1}[(r_1 - r_2)/ C]$

$= 180^0 - 2\sin^{-1}[(152 - 50.8) / 492.89]$

$= 180^0 - 2 \times 12$

$= 156^0$

$= 156^0 \times \pi / 180$

$\emptyset = 2.72$ rad

For larger pulley,

$T_1 / T_2 = e^{\mu\emptyset/\sin(\alpha/2)}$

$= e^{0.25 \times 3.56 / \sin(40/2)}$

$T_1 / T_2 = 13.49$

For smaller pulley,

$T_1 / T_2 = e^{\mu\emptyset/\sin(\alpha/2)}$

$= e^{0.25 \times 2.72 / \sin(40/2)}$

$T_1 / T_2 = 7.30$

Smaller diameter pulley will govern the design

$T_1 / T_2 = 7.30$

$T_1 = 7.30\ T_2$

Therefore, from above equation,

$(T_1 - T_2) = 47$ Kg

$7.30\ T_2 - T_2 = 47$ Kg

$T_2 = 7.46$ Kg

$T_1 = 54.46$Kg

APPENDIX –IV

4. Design of Solid shaft

Design of solid shaft comprises

4.1 Diameter of solid shaft

Diameter of solid shaft is calculated by the following formula,

$$d = \sqrt[3]{\frac{16\,T}{\pi} \times T_s}$$

Where

d = diameter of solid shaft, mm

T = torque transmitted by the shaft, N-mm

f_s = allowable shear stress, kg/cm^2

4.2 Calculation of Torque

Torque is calculated by the formula,

T = F x r

Where,

T = torque, kg-m

F = force required to twist the rotor gang, kg

r = distance from the axis of flail knives, m

$$T = 39.15 \times 292.2$$

$$= 11439.63 \text{ Kg-mm}$$

$$\mathbf{T = 11.44 \text{ kg-m}}$$

Putting this value in above equation,

We have,

$$d = \sqrt[3]{\frac{16 \times 11.44}{3.142 \times 600}}$$

{For mild steel, f_s = 600 kg/cm^2}

$$= 2.13 \text{ cm} = 21.3 \text{ mm}$$

Hence adopt, **d = 25 mm**

APPENDIX –V

5. Design of Bearing

Let us design the bearing for the rotating shaft to support to the frame.

5.1 Diameter of Pedestal bearing

We are providing the shaft of 32mm dia. according to the stress on the shaft.

Dia. of Pedestal bearing d = 32mm

5.2 Bearing length (l)

From the Table No.9-5.1. (Pandya and Shah, Page No.463)*

Let us adopt (l/d) ratio of 2

$$l = 2 \times d$$

$$= 2 \times 32$$

$$\mathbf{l = 64mm}$$

5.3 Bearing pressure

While designing the shaft, we have calculated the resultant force 'R'

i.e. R = 258 Kg

For two bearings, force = R / 2 = 258 / 2

= 129 kg

Bearing pressure, P = Force / Area

= (R / 2) / (l / d)

= 129 / (64 / 32)

P = 64.5 kg/cm²

From Table No.9-5.1. (Pandya and Shah, Page No.463)*, the maximum value of Bearing Pressure is 7 to 14 kg/cm^2 . Therefore, it is within the limit.

The maximum permissible unit pressure is given by.

$$P = \frac{ZN}{475 \times 10^6} \times (d / c)^2 \times [1/ (d + 1)]$$

Where,

P = maximum permissible bearing pressure, kg/cm^2

Z = absolute viscosity of a lubrication in centipoises

N = speed of Pedestal, rpm

D = diameter of Pedestal, cm

c = clearance (difference between diameter of bushing and diameter of Pedestal)

l = length of bearing, cm

c / d = clearance ratio.

= 0.001 to 0.002 of dia for most bearings

Let us take c / d = 0.0015

Z = 25 centipoises for shaft

$$P = \frac{25 \times 425}{475 \times 10^6} \times (1 / 0.0015)^2 \times [6.4 / (3.2 + 6.4)]$$

P = 6.62 kg/cm^2

As the bearing pressure is less than maximum permissible pressure, the design is safe.

APPENDIX –VI

6. Cost Analysis

A) Fixed cost of Diesel engine

i) Capital cost of diesel engine (C) = Rs.30000

ii) Life of diesel engine (L) = 10 years

iii) Working hours per year (H) = 1000 hours

iv) Salvage Value (S) = 10% of capital cost

v) Rate of interest (i) = 18%

a) Depreciation (D) = (C - S)/(L x H)

= (30000 – 3000)/ (10 x 1000)

= Rs. 2.70/hr

b) Interest charges (I) = [(C + S)/2] x (i/100)

= [(30000 + 3000)/2] x (18/10000)

= Rs. 29.70/hr

c) Insurance, Taxes, Shelter cost = 30000 x (3/100)

(Each of 1% of initial cost) = Rs.9.00/hr

Total Fixed cost = Rs. 2.70 + 29.70 + 9.00 = **Rs.41.4/hr**

B) Variable cost

a) Fuel cost @ Rs.42/lit = 42 x 1.364 = Rs. 57.29/hr

b) Lubrication cost (30% of fuel cost) = Rs. 12.6/hr

c) Repair and maintenance cost @ 1% of initial cost

= 30000 x 0.01/1000 = Rs.0.3/hr

d) Operator cost @ Rs. 200/day = 200/8 = Rs. 25/hr

Total Variable cost = Rs. 57.29 + 12.6 + 0.3 + 25 = **Rs.95.19/hr**

C) Fixed cost of flail mower

i) Fabrication cost (C) = Rs. 13885

ii) Life of flail mower (L) = 8years

iii) Working hours per year (H) = 300hours

a) Depreciation (D) = (C - S)/ (L x H)

= (13885 – 1388.5) / (8 x 300)

= Rs. 5.20/hr

b) Interest charges (I) = [(C + S)/2] x (i/100)

= (13885 +1388.5)/2 x (18 x 100)

= Rs. 13.74/hr

c) Repair and maintenance cost @ 8% of Fabrication

cost = 13885 x 0.08/100 = Rs. 11.10/hr

Total cost of flail mower = Rs. 5.20 + 13.74 + 11.10

= **Rs.30.04/hr**

Total cost of operation = A + B + C

= Rs. 41.4 + 95.19 + 30.04

Total cost of operation = Rs. 166.63/hr

APPENDIX -VII

7. Cost of Flail mower unit

Description	Cost (Rs.)
CUTTING UNIT	
Flail Knives	1620
Flanges	1485
Self-locking nut and bolt	1080
Rotor shaft	385
Total cost of cutting unit	**4570**
SUPPORT FRAME	
Semi rectangular Square Frame	1200
Base frame	700
Pedestal Bearings	1300
Height adjustable wheels	560
Total cost of support frame	**3760**
POWER TRANSMISSION UNIT	
V-Belt	440
V-Pulley	760
Chain and sprocket drive box	1700
Total cost of power transmission unit	**2900**

HANDLE	
Handle	370
Engage-disengage lever	130
Accelerator	80
Cut-off lever	80
Total cost of handle	**660**
TRANSPORTING UNIT	
Ground wheel	1500
Hexagonal Axle	495
Total cost of transporting unit	**1995**
TOTAL COST OF FLAIL ASSEMBLY	**13885**
POWER UNIT	
Lombardini Engine	**30000**
Total cost of Flail mower unit = (Total cost of flail assembly + Cost of Power unit)	**(13885 + 30000) = 43885**