DESIGN OF HYDRAULIC MOTOR OPERATED BUSH-CUTTER

ABSTRACT

In the India, farmers encounter issues with trimming boundary bushes and unwanted vegetation that obstruct roadsides, railway tracks, and electricity poles. This overgrowth is particularly noticeable after rainfall. When it encroaches onto roadsides, it creates obstacles for machinery, bullocks, and pedestrians. Typically, manual labor is employed for bush trimming, involving hand-operated secateurs, various types of axes, bill hooks, pruning saws, and other manual tools. This manual approach is not only risky but also physically demanding, expensive, and time-consuming. The transmission of mechanical power over extended distances is inefficient and not only cumbersome but also has several disadvantages when compared to hydraulic power. Thus, the hydraulic motor operated bush-cutter was designed. If the developed machine cannot withstand the substantial forces encountered during bush cutting/pruning operations, it can become ineffective due to plastic deformation or component breakage. Therefore, it is imperative to meticulously design the developed machine to enhance its operational lifespan and reduce farming costs. A Solid Works software was used to create 3D models and simulation of the machine.

Key words: Hydrostatic, Circular blade, Pruning, Cutting angle, Cutting force

INTRODUCTION

The specification of hydraulic motor, type and the operation required are the most important to select the best motor with the available pump which use by machine to function properly. Awad et al. (2012) indicted that, using the hydraulic transmission system instead of the mechanical transmission system decreased the power requirements and the fuel consumed about 18.4 %, when converting the mechanical transmission of rotary plow to the hydraulic transmission. If the tractor-operated equipment for specific operations of bush-cutting/pruning were developed with hydraulic components, it would be a perfect solution for bush-cutting/pruning.Chavda, S. K. et al. (2022) It could be used for several aspects, such as: vegetation removal projects; cutting over rails on roadsides; navigating near waterways and lakes. To design and development an implement as an attachment to tractor that can prune the bush as per our requirement (Tatar et al., 2023). The study's goal was to complete the work in minimise time and at the lowest possible cost.

Aguilera and Martin (2001) Conducted a study on measurement of cutting forces and the power requirements during the machining of pieces of beech (Fagus Silvatica) and spruce (Picea excelsa). The related variables were cutting depth, feed rate and cutting speed. They observed cutting forces was 28 N and 91 N for 3 mm of cut depth; 83 N and 95 N for 5 mm of cut depth respectively. Dange et al. (2011) Investigated the cutting energy and force required for the pigeon pea crops. They concluded that, the cutting energy and cutting force were directly proportional to cross sectional area and moisture content at the time of harvesting of pigeon pea crop. Baneh et al. (2012) Designed and developed a cutting head for a portable brush cutter for harvesting four Iranian rice varieties. A circular saw blade with 24 cm diameter and 2 mm thickness and blade had 136 teeth with 0° rake angle, 30° clearance angle and 6 mm pitch. Made from aluminium sheet was designed and constructed. Results also showed that rice losses of the portable reaper were lower than manual harvesting and field capacity of machine was 4.20 times greater than manual harvesting. Pawar (2004) Design and Developed Hydro rotavator. They used hydrostatic power transmission system over the mechanical power transmission in the rotavator and it has been tested in the field to comparative study of performance. Also observed that, the operation of hydro-rotavator was smooth with less noise and vibrations as compared to mechanical rotavator. Initial cost of the hydro-rotavator has been reduced by ₹ 10,000 in comparison with mechanical rotavator. Mollapour et al., (2017) Design and developed of a motorized hydraulic hole-digger. They used Orbital hydro-motor maximum torque of 220 N m, External gear pump with displacement volume of 8cm^3 and flow rate of 12 litermin^{-1}. IC engine about 6.5 hp having a speed of 3600 rpm. Hydraulic oil tank with total volume of 24 liter was made from a sheet metal. The helical auger having a diameter of 200 mm and pitch of 180mm. Working condition at 30 cm depth, 20 cm diameter and 100-160 rpm rotational speed of auger and high soil moisture 25.95% in the silty-clay soil. They found that Maximum force 2100 N, Minimum specific fuel consumption was 0.0014 liter pit^{-1}.

Maximum device's power 2.548 kW occurred in deep soil 30 cm and low soil moisture in silty-clay texture. Generally, the research aims to determine the best-studied parameter cleverness levels for synchronize operation between hydraulic motor and circular cutting blade. The developed system can evaluated by determining the cutting force, efficiency of cutting height and consumed power.Extending mechanical power over long distances is inefficient. Transmitting mechanical power in this manner is also bulky and unwieldy. With a view to minimize both labour and time, a dissertation project on the designing and fabrication of a device operated by tractor that can perform operations like cutting and pruning of vegetative growth of roadside bushes was taken up. The idea behind the same was to minimize the cost of operation as against operating costly equipment like forestry mulchers and to use the idle hours of tractor usage and also to minimize the hazard through the cutting tool.

MATERIALS AND METHODS

The work has been carried out during year 2022 at the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, JAU, Junagadh. The machine consisted of main-frame, secondary frame, hydrostatic power transmission system, power transmission system and cutting unit. An engineering drawing of machine is shown in Fig. 1 and A Solid Works software was used to create 3D models and simulation of the machine.

Fig. 1: Detailed drawing of hydraulic motor operated bush-cutter

The detailed design of the functional components and different mechanisms were carried out. While designing and development of the hydraulic motor operated bush cutter machine, the basic emphasis was given on simplicity of fabrication, use of locally available material and minimum cost of fabrication. Ease of assembling and dismantling for repairs and inspection were duly considered.

Main frame and secondary frame:

Main frame and secondary frame was fabricated from mild steel square pipe and L-section for mounting hydraulic cylinder on frame isshown in Fig. 2 & 3. The main frame was provided with three-point hitch to mount the hydraulic motor operated bush cuter on tractor. A secondary frame mounted vertically on main frame is meant for mounting cutting mechanism.

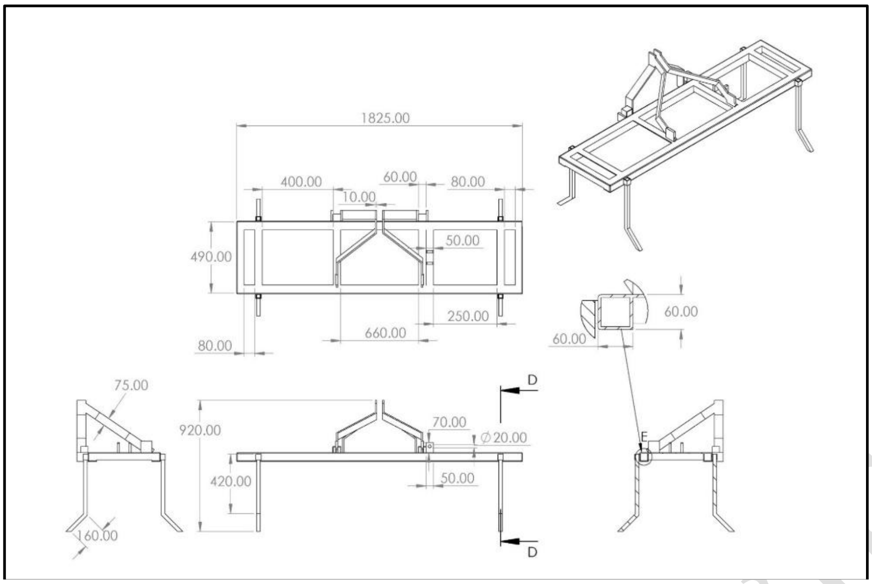

Fig. 2: Detail drawing of main frame

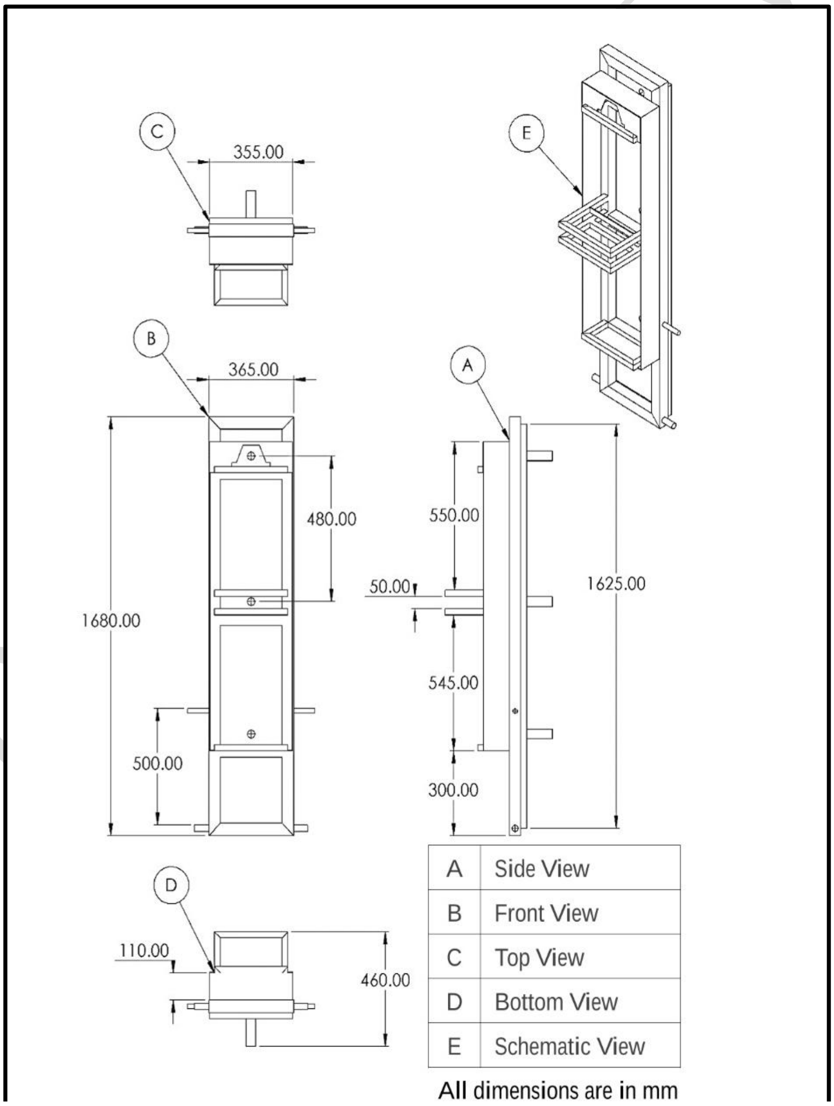

Fig. 3: Detail drawing of secondary frame

Hydraulic vane pump:

A pump is the heart of any fluid power system; it converts mechanical power into fluid power. The maximum discharge a vane pump can 90 l/min, whereas, it's maximum pressure is 250 bar. (Anon., 2022). The John Deere 5310 tractor model with 55 hp was chosen as the prime mover due to its capabilities to provide the power requirement for rotating the hydraulic motor. The rotating hydraulic motor on this tractor is sufficiently powered by the hydraulic vane pump, which has a 43.1 l/min capacity.

A. Pump performance and ratings

The discharge of pump 43 l/min and pressure 200 kg/cm^2, performance of pump is stated in terms of the volume of flow and the hydraulic horsepower calculated as (Krutz et al., 1984)

The equation for theoretical pump flow is,

$$Q_{theo} = D \times N \qquad \ldots\ldots\ldots (3.1)$$

Where,

Q_{theo} = Theoretical flow from the pump, l/min (Anon., 2022b)

N = Shaft speed, rpm.

D = Volume of displacement of the pump in one revolution, l/rev.

The actual pump flow is calculated as,

$$Q_{act} = D \times N \times V_{eff} \qquad \ldots\ldots\ldots (3.2)$$

Where,

V_{eff} = Volumetric efficiency of pump, %.

The volumetric efficiency is a function of both the internal leakage and the compressibility of the oil.

The torque required to drive the input shaft of pump is.

$$T_{theo} = \frac{100 \times P \times D}{2\pi} \qquad \ldots\ldots\ldots (3.3)$$

The actual torque required to drive input shaft is,

$$T_{act} = \frac{100 \times P \times D}{2\pi} \times \frac{1}{T_{eff}}$$

… … … (3.4)

Where,

T_{theo} = Theoretical input torque to create the given pressure rise through the pump, N.m.

P = Pressure difference across the pump, kg/cm^2.

D = Volume of displacement of the pump in one revolution, l/rev.

T_{eff} = The torque efficiency of the pump, %.

The torque efficiency is a function of sliding friction between parts, oil shear and churning losses with pump housing.

The horsepower required to drive a pump is,

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

… … … (3.5)

Where,

HP_{in} =Input horsepower, hp.

N = Shaft speed, rpm.

T =Input shaft torque, kg·m.

The hydraulic horsepower delivered by the pump is,

$$HP_{hyd} = \frac{P \times Q}{450}$$

… … … (3.6)

Where,

HP_{hyd} =Hydraulic horsepower delivered, hp.

P =Pressure difference across the pump, kg/cm^2.

Q =Actual volume of pump discharge, l/min.

The overall efficiency of the pump is,

$$AO_{eff} = \frac{HP_{hyd}}{HP_{in}} \times 100$$

… … … (3.7)

Hydraulic control valve

Valves are used in fluid power systems to control pressure, volume, and direction of flow. These valves are the primary devices used to sequence the motion of equipment. The number of positions and the number of ways (ports) generally specify the valve. But in this case, one spool 2/2 directional control valve for hydraulic motor, for hydraulic cylinder two spool 4/3 direction control valve was used.

Hydraulic vane motors

Speed of hydraulic motor is function of motor displacement and fluid flow to the motor. (Krutz et al., 1984)

The equation for motor speed is

$$N_{theo} = \frac{Q}{D} \quad \dots\dots\dots (3.10)$$

Where,

N_{theo} = Theoratical speed of motor, rpm

Q = Fluid flow to the motor, l/min

D = Volume of displacement of the motor for one revolution of the shaft, l/rev.

V_{eff} = Volumetric efficiency of motor, %.

The actual motor speed is,

$$N_{act} = \frac{Q}{D} \times V_{eff} \quad \dots\dots\dots (3.11)$$

The volumetric efficiency of motor increases as the motor displacement is increased and decreases as pressure increase.

The torque devolved at the motor shaft is a furcation of motor displacement and pressure drop across the motor.

$$T_{theo} = \frac{100 \times P \times D}{2\pi} \quad \dots\dots\dots (3.12)$$

The actual motor shaft torque is,

$$T_{act} = \frac{100 \times P \times D}{2\pi} \times T_{eff}$$

……… (3.13)

Where,

T_{theo} = Theoretical torque of motor shaft, N.m

T_{theo} = Actual torque of motor shaft, N.m

P = Motor inlet pressure minus motor outlet pressure, bar.

D = Volume of displacement of motor for one revolution of shaft, l/rev.

T_{eff} = Torque efficiency of the motor, %.

The horsepower provided by motor is,

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

……… (3.14)

Where,

N = Actual motor speed, rpm.

T =Actual torque of motor shaft, kg·m.

Hydraulic cylinders, hoses and fittings

Hydraulic cylinder was used for lateral movement of cutting unit outside to the main frame. Another two hydraulic cylinder were used to change angular position of secondary frame. Hydraulic hoses or steel tubings are used for fluid flow between components of hydraulic system.

RESULTS AND DISCUSSION

The hydraulic motor operated bush cutter was designed having main frame, secondary frame, hydrostatic power transmission system, mechanical power transmission system and cutting unit. Experiments were conducted to optimize machine parameters for maximum cutting efficiency. Hydraulic motor operated bush cutter was tested for evaluating performance in the field.

a) Design Calculation of Hydraulic Pump

The discharge of pump, torque and horse power required to driven shat, calculated as (Krutz et al., 1984)

i) Fluid flow rate

ii) Fluid pressure

iii) Pump displacement.

iv) Speed of pump shaft,

v) Torque required to drive input shaft of pump,

vi) Input Horse Power required.

vii) Horse power generated (Hydraulic hp)

Discharge and Pressure required by motor are

Q_m = 43 l/min

P = 200 kg/cm^2

Therefore, Pump output discharge and pressure should be, from equation (3.6)

Q_p = 43 l/min

P = 200 kg/cm^2

$$HP_{hyd} = \frac{P \times Q_p}{450}$$

$$HP_{hyd} = \frac{200 \times 43}{450}$$

$$HP_{hyd} = 19.11 \text{ hp} = (14.25 \text{ kW})$$

Pump displacement (D_p)

Discharge of pump Q_p = 43 l/min

Considering pump speed N_p = 3000 rpm

Volumetric efficiency V_{eff} = 95 %

From equation (3.2), pump displacement

$$D_p = \frac{43}{3000 \times 0.95} = 0.015 \text{ l/rev.}$$

D_p = Pump displacement $D_p = 0.015$ l/rev.

Torque required to drive pump shaft (T_p)

From equation (3.4), calculated Torque efficiency to drive pump shaft.

$$\text{Torque efficiency} T_p = \frac{10 \times P \times D_p}{2\pi} \times \frac{1}{T_{eff}}$$

… … … (3.8)

$$T_p = \frac{10 \times 200 \times 0.015}{2 \times \pi} \times \frac{1}{0.95}$$

$$T_p = 5.02 \text{ kg.m}$$

Horse Power required to drive the pump (HP_{in})

From equation (3.5), calculated horse power required to drive the pump.

$$HP_{in} = \frac{2 \times \pi \times N \times T_p}{4500}$$

… … … (3.9)

$$HP_{in} = \frac{2 \times \pi \times 3000 \times 5.02}{4500}$$

$$HP_{in} = 21.01 \text{ hp} = (15.66 \text{ kW})$$

(b) Design Calculation of Hydrostatic Power Transmission System(Hydraulic Motor)

Model selected for study – **VM3C – 027 – 1N00**

Power requirement for cutting blade = 15 hp (From $P = \frac{2 \times T \times V_c}{D}$) (Kovac and Mikles, 2010)

Circular blade speed (N) = 950 rpm

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

(Krutz et al., 1984) … … … (3.15)

$$T_m = \frac{P_{out} \times 4500}{2 \times \pi \times N}$$

$$T_m = \frac{15.6 \times 4500}{2 \times \pi \times 950}$$

$$T_m = 11.76 \text{ kg.m} \approx 12 \text{ kg.m}$$

Total required torque for circular blade shaft was 12 kg. m

Design Calculation of Hydraulic Motor

Design parameters of hydraulic motor

i) Speed of motor shaft.

ii) Fluid pressure at motor.

iii) Fluid flow rate.

iv) Motor displacement.

v) Output horse power of motor.

vi) Torque at motor shaft.

Motor displacement (D_m)

Torque efficiency of motor (T_{eff}) = 95%

Speed of motor shaft/rotor (N_m) = 950 rpm,

Torque required at motor shaft(T_m) = 12 kg. m

Pressure (P) = 200.78 $kg/cm^2 \approx 200\ kg/cm^2$

$$D_m = \frac{2 \times \pi \times T_m}{10 \times P \times T_{eff}} \quad \ldots\ldots\ldots (3.16)$$

$$D_m = \frac{2 \times \pi \times 12}{10 \times 200 \times 0.95}$$

$$D_m = 0.039 \approx 0.040\ l/rev$$

Fluid flow required for motor (Q_m)

Volumetric efficiency (V_{eff}) = 95%

$$Q_m = \frac{D_m \times N}{V_{eff}} \quad \ldots\ldots\ldots (3.17)$$

$$Q_m = \frac{0.040 \times 950}{0.95}$$

$$Q_m = 40\ l/min$$

Torque produced by motor shaft (T_p)

Pressure (P) = 200.78 $kg/cm^2 \approx 200\ kg/cm^2$

Motor displacement (D_m) = 0.040 l/rev.

Torque efficiency of motor (T_{eff}) = 95%

$$T_p = \frac{10 \times P \times D_m}{2 \times \pi} \times T_{eff}$$

$$\ldots \ldots \ldots (3.18)$$

$$T_p = \frac{10 \times 200 \times 0.040}{2 \times \pi} \times 0.95$$

$$\text{Torque developed at motor shaft } T_p = 12.10 \text{ kg. m}$$

The horsepower provided by motor is,

$$P_{out} = \frac{2 \times \pi \times 950 \times 11.76}{4500}$$

$$P_{out} = 15.59 \approx 16 \text{ hp} = 11.93 \text{ kW}$$

The design of the hydrostatic system necessitates the careful selection of components to meet the flow and pressure requirements of the hydraulic circuit.Due to the ease and excellence of the hydraulic transmission, this research is concerned to transmit power from tractor to a hydraulic motor operated bush-utter using a hydraulic cycle. The theoretical consideration and the previous results from different studies were used to determine a suitable of a hydraulic motor, which give a sufficient torque needed to cutting different stems. Based on the simulation results optimized design of machine was suggested.

CONCLUSIONS

Timeliness is the key to success in agriculture. The labour work is very time consuming and becoming costly day by day. The only alternative to labour is the use of machinery, farm implements, and equipment. As a result, farm mechanization is increasing day by day. Based on the operations to be performed, varieties of farm machines are designed. .It was specially designed for bush cutting and pruning of trees in orchards, fairly gnarly buzz saws in vegetation removal projects, cutting over rails on roadsides, navigating near waterways, lakes and horticultural gardens. When using a closed loop hydrostatic drive, fluid is circulated straight from the pump to the machine and then back to the reservoir.Looking to above facts, hydraulic power was selected as an alternative to mechanical power. In that case, hydraulic power systems have greater flexibility than mechanical and electrical systems. The rotating hydraulic motor on this tractor is sufficiently powered by the hydraulic vane pump, which has a 43.1 l/min capacity.Motor with following specifications is required to operate the selectedhydraulic motor operated bush cutter. Specifications of hydraulic motor fluid flow rate is 40 l/min, motor displacement is 0.040 l/rev., fluid pressure is 200 kg/cm^2, motor speed is 950 rpm, overall efficiency of motor, is 90% and Output horse power developed is 15 hp.

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