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Design; Construction and Evaluation of Engine Operated Rotary Tiller

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***Abstract*-Currently, as Ethiopia is importing most of the agricultural mechanization technologies, including power tillers, there are significant shortages for using powered farm machineries in the country. Thus, this activity was initiated to design and construct an engine operated rotary power tiller locally and test performances. Accordingly, the design of this machine was based on the total specific energy requirements which carried out for an L-shape rotary tiller blade through using mathematical model. This rotary tiller was operated by 10 hp motor engine out of this 2.25 hp of the power was used to dig the soil. The performance of the machine was evaluated in terms of theoretical field capacity, actual field capacity and field efficiency on clay soil. The results indicated that the theoretical field capacity, the actual field capacity and the field efficiency was 0.146 ha/hr., 0.134 ha/hr. and 91.78 % respectively at 1.11 g/cm3 soil bulk density and 30.3 % soil moisture content. The soil mean clod diameter after pass through by rotary was 0.127 mm. But, the designed rotary tiller requires some improvement on operation system as writing on recommendation parts before demonstration.**

***Keywords*- Design, tillage, rotary tiller, performance, power.**

I.INTRODUCTION

Tillage may be defined as the mechanical manipulation of soil for any purpose, but usually for nurturing crops. In the tillage operations, tillage tools direct energy into the soil to cause some desired effect such as cutting, breaking, inversion, or movement of soil. Soil is transferred from an initial condition to a different final condition by this process [Smith R J. etal. 1995].

Secondary tillage operations are intended to create refined soil conditions following primary tillage. The final tillage operation prior to planting a crop is usually secondary tillage, but farmers may use more than one secondary tillage operation. In some situations, a tillage operation may fit the definition of both secondary and primary tillage.

Rotary tillers are the tillage machine used for accomplishment both the primary and secondary tillage operations. Rotary tiller is a tillage machine used in arable field and fruit garden in agriculture. Rotary tiller has a mixing capacity seven times more than a plough. This tool decreases the soil traffic to a great extent by blending the soil. Using rotary tiller is increasing nowadays because of its various benefits [Topakci M. 2008]. Rotary tiller is advantageous over the conventional implement (i.e. moldboard plow and rake) due primarily to the main effect of the direct application of power to the soil-engaging tool rotating around a horizontal-transverse axis. Rotary tiller achieves both plowing and harrowing in a pass of machine on the field (Sirisak C., et al, 2008). The rotary tiller has the high capacity of mixing and pulverizing the tilled soil well; resulting in a good clod size distribution. The number of tillage passes required to achieve an acceptable tilth quality, using rotary tiller, is also significantly reduced in comparison to the series of operations that could result in the same tilth quality with the use of passive tools.

The major problem in Ethiopia is that using the same implement known locally as the" maresha," the ard (whose shape and structure have remained largely unchanged for thousands of years) still serves as a key farming implement.. In Ethiopia's traditional farming system, farmers rely on the ard which is pulled across the field by a pair of oxen for both primary and secondary tillage types.

So the objective of this activity was to design and develop an engine operated rotary tiller for tillage operation and evaluates its performance to solve the problems concerning secondary tillage.

II. MATERIALS AND METHODS

1. Description of the Machine:

The designed rotary tiller was operated by 10hp motor engine by guidance of one person. Totally there was 12 blade out of them 3 are jointly act on the soil. There was depth controlling mechanisms which act as a wheel.

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Fig 1. Description of designed and constructed rotary tiller.

2. Power Requirement:

The design characteristics of any rotary tiller blades are the biggest determinants of power consumption. The measurement of the total power required has been expressed in terms of total specific energy required per unit volume of soil tilled. Optimizing the total specific energy requirement is one of the performance efficiency and the selection of criteria for land preparation implements.

Dalin and Pavlov (1950) presented a general theoretical equation of rotary tiller to predict total power requirement as:

$$P_{total} = P_{push} + P_{cut} + P_{throw} + P_{loss} + P_{mf}$$

Where, P_{Total} = Total power requirement, kW, P_{Cut} = cutting power requirement, kW, P_{Throw} = throwing power the cut soil slice power requirement, kW, P_{Loss} = Power loss in the power train, kW, P_{mf} = overcoming soil-metal friction power requirement, kW, P_{Push} = pushing power requirement, kW.

The total specific energy requirement (power per unit volume of soil tilled) modification model is defined as a function of pushing (PPush), cutting and loosening the soil slice (Pcut), overcoming soil- metal-friction (Pmf) and throwing the cut soil slice (PThrow) power requirement and volume of soil tilled (Vst). The modified total specific energy requirement for the various rotary blades is exhibited as (Subrata Kr. et al., 2016).

$$E_{TSP} = \frac{P_{push} + P_{throw} + P_{mf} + P_{cut}}{V_{ST}}$$

3. Determination of power required to dig the soil:

The power requirement would be calculated using the following equations:

$$Pd = \frac{Cr * d * w * v}{76}(hp)$$

Where, Pd is power required to dig soil, Cr is soil resistance, w is width, d is depth of tillage

4. Calculation of the optimal diameter of rotor:

Torque is the most important factor that is affected by the dimensions. Bending moment and weight are neglected because of minuscule (very small) value of them [Bernacki et al. 1972]. Therefore, selecting the circular cross section for rotor axle and considering the torque, optimal diameter can be determined by the following relationship [Beer F, Johnston J. E. R, Dewolf J, et al, 2008]:

$$\boldsymbol{d = \sqrt[3]{\frac{16M_s}{\pi\tau}}}$$

Where, d is the optimal diameter of rotor in cm; Ms is the maximum torque at the rotor axle in N.cm; τ is the allowable shear stress at the rotor axle in N/cm2.

5. Rotary tiller blades design:

The design of the rotary tiller blades depends on the type and number of the blades and also the working condition of the rotary tiller. In this design, the L-type blades were considered for rotary tiller. In the rotary, one fourth of the blades action would be jointly on the soil. The number of rotary tiller flanges (fn) can be calculated by the following equation (Subrata Kr. et al. , 2015):

$$fn = \frac{A}{A_i}$$

Where, A is the working width and Ai is the distance between the flanges on the rotor.

6. Determination of the soil force acting on each blades:

The soil force acting on each of the blade was determined using the following formula (Subrata Kr. et al., 2010):

$$K_e = \frac{K_s C_p}{f_n Z_e n_e}$$

The dimensions of the blades are defined as the form of figure presented below. The values of w, B, S1 and S are considered as 10, 0.5, 15 and 3.5 cm respectively.

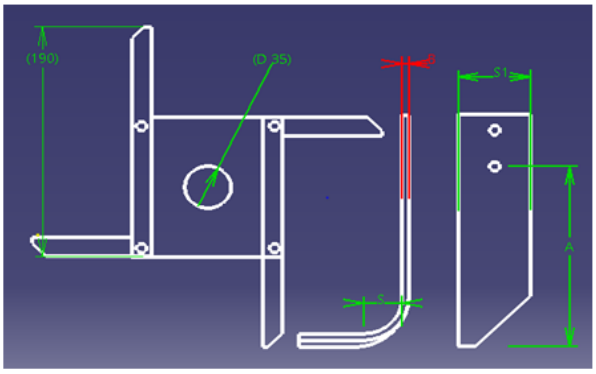

Fig 2. Dimensions of flange and blade

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7. Pulley and belt design:
According to Aaron (1975), the desired revolution per minute the diameter of driving and driven pulley will be determined as follow.

$$D_4 N_4 = D_3 N_2$$

$$N_4 = \frac{D_3 N_2}{D_4}$$

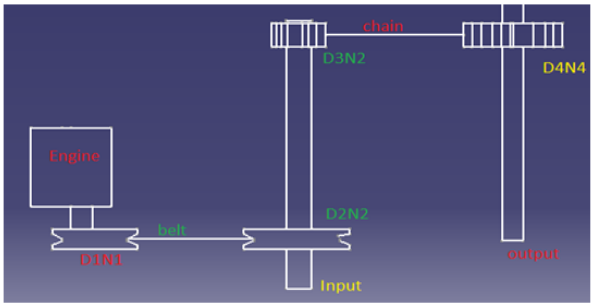

Fig 3. One pulley belt mechanism and one chain sprocket mechanism.

8. Performance evaluation of rotary tiller:
The performance indicator parameters of this machine would be measured both on station and in the field. These parameters are: Tilling capacity per hour, Depth of tilling, Width of tilling, Aggregate size distribution (clod mean diameter), Soil dry bulk density, Soil moisture content. The machine performance was evaluated using actual field capacity and design field capacity of the machine as shown in equation:

$$FCt = S * W(ha/hr)$$

$$FCe = \frac{land\,covered}{time\,taken}(ha/hr)$$

$$Field\ \ efficiency\ = \frac{FCe}{FCt} * 100$$

Where, FCt =theoretical field capacity, FCe = actual field capacity, S = forward speed (in m/s), W = width of the implement (in m)

III. RESULT AND DISCUSSION

1. Power Consumption Determination:
In general, by derivation and simplifying the equations described in the methodology, the total specific energy requirement was obtained 81.03 KJm3. This Specific energy/work is defined by Srivastava et al. (1993) as the ratio of the total energy expended during soil processing by a tillage tool to the volume of the soil disturbed.

Table 1. Measured and Standard Machine design parameter.

No.	Parameters	Notations	Values
Measured parameters			
1	Blade span (mm)	W	80
2	Width of soil cut (m)	W_c	0.06
3	Depth of soil cut(m)	D	0.083
4	Rotor radius (m)	R	0.205
5	Blade angle (degree)	θ	120
6	Clearance angle(degree)	β	18
7	Blade thickness (mm)	t	5
8	Engine power (hp)	p_e	10
9	Machine forward velocity (m/s)	v_f	0.75
10	Rotational speed (rpm)	N	428.29
11	Shaft diameter (mm)	D	4
Standard parameters			
12	Prime mover's efficiency	η_c	0.9
13	Coefficient	η_z	0.75
14	Specific soil resistance(kg/cm^3)	K_{sp}	7000

2. Determination of power required to dig the soil:
The power requirement to dig the soil was about 2.24 hp and the total power required to dig the soil using this rotary was obtained 2.25 hp. Using the draft and power requirements of tillage tools, the concept of specific energy or specific work was used extensively (Kepner et al., 1978; Srivastava et al., 1993) to determine the performance of different tillage tools; including the performance of rota vators (Beeny & Greig, 1965; Beeny & Khoo, 1970).

3. Determined blade bending, shearing and equivalent stress:
Considering the shape of the blade, the bending stress, the shearing stress and the equivalent stress was 121.5 kg/cm2, 292.72 kg/cm2 and 31.7 MPa respectively. This result indicated that the maximum bending stress, shearing stress and combined effect of the two are affect the blade shape when they are higher than these values.

4. Designed Pulley and belt:
The belt and pulleys are the power transmission elements. So while designing power transmitted by pulley and belt, and diameter of pulley w considered. The power transmission was both pulley and belt, and chain and reciprocate mechanism in order to reduce the speed of the rotary. The rpm of the rotary was reduced to 428.26 rpm.

5. Determined soil force acting on each blade:

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The soil force acting on each of the blade was determined using the above formula was 67.5 kg. This force was the combination of tangential force acting at the tip of the blade and soil force acts perpendicular to the edge of the blade.

6. Soil physical properties:

The performance evaluation of the machine was done on clay soil which had the following properties. These properties have significant influence on the energy requirements of tillage tools as studied by Ros, et al, (1995). This is because these properties affect the soil strength, which has to be overcome by a tillage tool during a soil tillage operation (Gill & Vanden Berg, 1967).

Table 2. Summary of soil physical properties.

Soil physical properties	Values
Soil moisture content (%)	30.3
Soil bulk density(g/cm^3)	1.11
Mean clod dia. (mm)	0.127

As shown in the table above, the mean clod diameter of the soil after plowing was about 0.127 mm. As Fang H., et al (2016) studied that the mean clod diameter was smaller at higher rotational speed, while the rate of soil breakage increased with increasing rotational speed.

7. Performance of the machine:

The machine performance was evaluated using actual field capacity and design field capacity of the machine. The width of operation, theoretical Field capacity, actual field capacity and the field efficiency of the machine was obtained 50cm, 0.146 ha/hr, 0.134 ha/hr and 91.78 % on clay soil respectively. Bayan A., et al (2018) study the performance of Sifang Power Tiller on secondary tillage and the result shows that, width of operation, theoretical field capacity, effective field capacity and efficiency on clay soil were, 60 cm, 0.15 ha/hr, 0.08 ha/hr and 53%, respectively.

IV. CONCLUSION AND RECOMMENDATION

1. Conclusion:

The Machine is necessary for the agriculture to increase the production and productivity as well as overcome the burden on the farmer The working capacity and efficiency of the machine was 0.134 ha/hr. and 91.78 % on clay soil at 30.3 % moisture content and 1.11 g/cm3 dry bulk density.

This machine was loosened the soil up to 0.127 mm mean clod diameter which is suitable for crop growth.

2. Recommendation:

- The machine is best for farmers having motor engine which used for thresher to use as dual purpose if some of the following problems are solved.
- The rotary tiller was selected soil condition to walk by its power and the wheel of the rotary will be modified because it was resist the forward motion of the rotary if the soil clod is big.
- The other problem of this machine is dust during operation which is very difficult to control. Therefore it required modification on controlling the dust.
- The rotary tiller need to incorporate clutch mechanism to manage the operation

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