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Design and Numerical Stress Analysis of Spur Gear (Power Tiller)

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Abstract: This paper deals with the design and stress analysis of spur gear of GT-1 Power Tiller (Global Tiller-1). It is widely used in Myanmar because they are more efficient and cheaper than any others types of tractors for agricultural works. The fundamental dimensions of engine are four strokes with compression ratio of 22.5. It produces maximum rated output power of 15 hp at 2400 rpm and maximum speed 24.2 km/hr at 2400 rpm. In gear design, gear material is chosen Carbon Steel (AISI 5160 OQT 400) and all gear are the same material. The gears are designed to transmit power and satisfy the dynamic check. In gear design, the number of teeth, face width, gear tooth features and pitch diameter are calculated. Three-dimensional model of Spur gear is drawn by using SolidWorks Software and analysed by Finite element method. The spur gears are designed according to the point of view of the strength. The result of spur gear design and stress depend upon the tooth profile and gear material properties. The spur gear is analysed with Carbon Steel (AISI 5160 OQT 400). Boundary constraints are defined and the deflection and strain for three-dimensional model are analysed.

Keywords: Spur Gear, Face Width, 3D model, Dynamic Check, SolidWorks

1. INTRODUCTION

Myanmar is an agricultural country and 85percent of Myanmar are farmers. Therefore, Government of Myanmar is always helping the farmers in various ways, it has distributed interest free agricultural loans to farmers, sold chemical fertilizer and farm implements to farmers cheaply, built dams and irrigation channels all over the country, taught modern methods of farming to farmers and helping them to have double cropping and mixed cropping.

Food is necessary for human being from many years ago to nowadays people do farming for this food, clothes and shelter all mankind is depended on this industry, and everyone is fundamentally concerned with its welfare. Agricultural engineering is the application of any and all branches of engineering to the extent that they may be used in farming, in rural living, rural processing of farm products.

Designer and technicians must design the machine and equipment to meet required standards. Every farm equipment and machine must be adaptable for required standard. There are many kinds of farm tractors such as LY-16 Power Tiller, Dongfeng Power Tiller, GT-1 Power Tiller, etc. Nowadays, Power Tillers are widely used in Myanmar because they are more efficient and cheaper than any others types of tractors for agricultural works. It can be used in various types of farm operations such as ploughing, harrowing, transporting and etc. In this thesis, one of the most important components of Power Tiller that is the gearbox.

To develop Myanmar's agriculture, Power Tillers are important from other country. But sometimes and in some where these Power Tiller and their components of Myanmar's agricultural and environmental conditions. Moreover, the gearboxes of power tiller are found. Therefore, some design of this gearbox is necessary. Therefore, in this paper 'Stress Analysis of Spur Gear" is presented. GT-1 Power Tiller is designed and constructed by Agricultural Mechanization Department for pulling and may be equipped with the diesel engine. It featured by compactness and simplicity in construction, easy operation and transferring, high durability, reliability and adaptability. The Power Tiller is equipped with riding installation for operations, so as to lighten the driver's degree of fatigue and raise its labor productivity, suit for paddy and dry field. It can be used not only as a transport vehicle with a trailer but also for primary and secondary tillage operations and harvesting of paddy and crops. Power Tiller is composed with many material parts and following Figure shows the main component of Power Tiller.

Figure 1. Components of Power Tiller

2. SPECIFICATION AND DESIGN CALCULATION

The design theory and calculation of transmission are mostly dependent upon the maximum torque of the input speed from the engine. In the gearbox, the components are housing, shafts, bearings, gears, shift fork mechanisms. In this paper, the design and stress analysis of spur gears are described. Gears are widely used for transmitting small or large amounts of power from one shaft to another. They operate by direct contact of one body upon the other and maintain a constant velocity ratio between the two shafts. Various types of gearing have been developed for this purpose which will operate quietly and with very low friction losses. Gears can be classified according to the natural position of shafts. Gears have the advantages of providing positive drive without slip and permit high torque to be transmitted. Gears can be used between shafts, which can be parallel or inclined to one another. Spur gears are toothed wheels whose tooth elements are straight and parallel to the shaft axis; they are used to transmit motion and power between parallel and shafts. Figure 2 shows the spur gear pair.

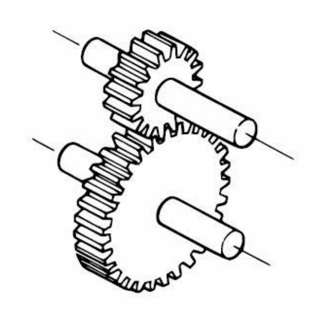

Figure 2. Spur Gear Pair

The design consideration and calculation of transmission are mostly dependent upon the maximum torque of the input speed from the engine. In gear design, Gear material is Carbon Steel (AISI 5160 OQT 400), all gear is the same material. To design the gearbox of power tiller, the required data are collected from the existing transmission.

Model	GT-1(Global Tiller-1)
Overall length	3055 mm
Overall width	1205 mm
Overall height	1225 mm
Overall weight	365 kg
Ground clearance	295 mm
Maximum speed	24.2 km / h
Compression ratio	22.5: 1
Max: power	15hp at 2400 rpm
Main clutch type	dry multi-disc clutch
Transmission	3 speed manual

Engine specification horizontal single cylinder - 4 stroke Diesel engine

Design Calculation of First Gears (Unknown Diameter Case)

Addendum = 0.8 m = 0.8 × 2.5 = 2 mm

Dedendum = 1 m = 1 × 2.5 = 2.5 mm

Whole depth = 1.8 m =1.8 × 2.5 = 4.5 mm

Minimum clearance = 0.2 m = 0.5 mm

When two gear mesh, the smaller gear is called the pinion and larger is gear. Profile angle selected 20 deg stub involute.

Number of teeth of pinion, np = 17 teeth

Number of teeth of gear, ng = 40 teeth

$$\text{Design Engine Power} = 15\,\text{hp} \times \frac{0.74596\,\text{kW}}{1\,\text{hp}}$$
$$= 11.185\,\text{kW}$$

Rated Engine Speed	= 2400 rpm
Diameter of engine pulley	= 90.5 mm
Diameter of main pulley	= 179 mm
Ultimate strength, Su	= 2220 Mpa
Endurance strength, S0	$= \frac{S_u}{3} = \frac{2220}{3} = 740\,\text{Mpa}$
Modulus of Elasticity, E	= 207 Gpa
Brinell Hardness, BHN	= 627

Power available is about 85% of the engine power because the frictional contact between the sides of the belt and the groves result in belt slip.

Therefore, Engine Power = 11.185 × 0.85 = 9.5 kW

Pinion and gear are same material; therefore, pinion is weaker. Therefore, base design on pinion.

When two gears mesh, the smaller gear is called the pinion and the larger is the gear. The symbol, Dp will be used for the pitch diameter of the pinion and the symbol, Dg will be used for the pitch diameter of the gear. Then np and ng are used for number of teeth of the pinion and gear respectively.

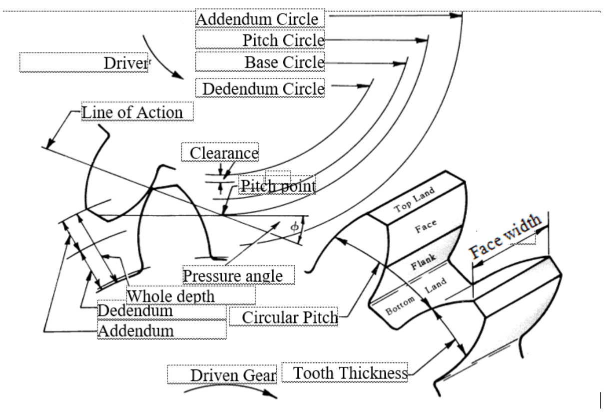

Figure 3. Parts of Gear Teeth

As the gears rotate, the common normal to the surface at the point of contact must always intersect the line of centers at the same point, called the pitch point as shown in Figure 3. The basic requirement of gear tooth geometry is the provision of angular velocity ratios (V.R) that are exactly constant. Manufacturing inaccuracies and tooth deflections will slight deviations in velocity ratio.

Pitch circle diameter D = z x m = 17 x 2.5 = 42.5 mm

Outside circle diameter = (z + 2) x m = (17 + 2) x 2.5 = 47.5 mm

Face width (b) = k max x π x m = 4 x π x 2.5 = 31.41 mm

Diametral pitch = number of teeth / pitch circle diameter

= 17 / 42.5 = 0.4 mm

To find dynamic load, Fd

$$F_t = \frac{M_t}{D_p/2} = \frac{2\times 74.77}{0.0425} = 3518.59\,N$$

$$v = \frac{\pi\, D_p\, N_p}{60} = \frac{\pi\times 0.0425\times 1213.4}{60} = 2.7\,m/s$$

$$m = 2.5, error = 0.01, C = 119kN/m\ (from\ Table\ A.2)$$

$$F_d = 4398.23 + \frac{21\times 2.16(24\times 119 + 4398.23)}{21\times 2.16 + \sqrt{(24\times 119) + 4398.23}}$$

$$= 6165.7N$$

To find endurance force, F0

$$F_0 = S_0 b\, y_p \pi\, m$$

$$= 740\times 10^6 \times 24\times 10^{-3} \times 0.117\times 2.5\times 10^{-3}$$

$$= 16319.94N$$

$$VR = \frac{D_g}{D_p} = \frac{D_g}{42.5} = \frac{n_g}{n_p} = \frac{N_p}{N_g}$$

$$D_g = 2.35\times 42.5$$

$$= 99.875\,mm$$

$$N_g = \frac{1213.4}{2.35}$$

$$= 516.34\,rpm$$

To find ratio factor, Q

$$Q = \frac{2\,D_g}{D_g + D_p} = \frac{2\times 99.87}{99.87 + 42.5} = 1.4029$$

To find wear load, Fw

$$F_w = D_p\, b\, K\, Q$$

$$= 42.5\times 10^{-3} \times 24\times 10^{-3} \times 6459.301\times 10^3 \times 1.4029$$

$$= 9242.98N$$

$$F_d < F_0,\ F_d < F_w$$

$$\therefore \text{Design is satisfied.}$$

The above calculation is first speed gear design calculation.

3. MODELLING OF SPUR GEAR

Involute spur gears are the most common form of gears which are used to transfer the motion between the parallel shafts. The main concerns while designing an involute spur gear include generation of involute. In earlier days to design an involute spur gear there are many theoretical procedures to draw an approximate involute but no procedure was present to draw a perfect involute for performing analysis. In the present day with the 3-D modeling software's it is easy to generate the involute spur gear with exact involute. The spur gear modeling was done by using SolidWorks software based on spur gear design calculation and modeling diagram shown in Figure 4. In this paper, Carbon Steel is chosen to make the FE model. It has high strength, hardness, good ductility, wear resistance and moderate ductility. In this study, 40 teeth gear is considered to analyze the Von'mises stress and deflection.

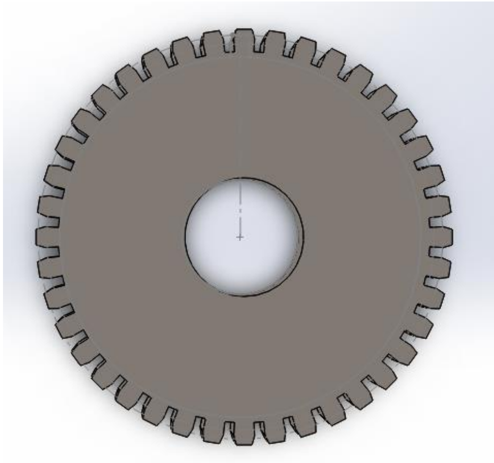

Figure 4. Spur Gear Modeling in SolidWorks

4. Analysis of Gear Tooth

Finite Element analysis for any three-dimensional model is performed in three main steps

1. Pre-processing
2. Solution
3. Post-processing

The pre-processing mainly involves the modeling of the three-dimensional part. The following are the main steps in pre-processing.

1. Engineering Data
2. Geometry
3. Meshing

In an analysis system, the main resource for material properties is engineering data, they can either be experimental or user defined. In this analysis, density and linear elastic properties like Young's Modulus 207 Gpa and Poisson's ratio 0.34 for cast iron are determined. The gear geometry generated from SolidWorks.

For practical considerations the stress on involute spur gear can be better approximated using Finite Element Method [3]. This method can be used in in approximating any kind of stress, strains and deformations in single parts and assemblies. Finite element method is a numerical method to obtain approximating solutions to partial differential equations and integral equations. This method originated for solving complex elastic and structural analysis problems.

The first people to develop this method were Alexander Hrennikoff and Richard Courant. In 1947 Olgierd Zienkiewicz coined the term Finite Element Analysis by gathering these methods. In 1952 Boeing made a great effort to analysis the aircraft structures using Finite Element Methods and in 1964 NASA developed a software in Fortran language called Nastran to analysis the aircraft structures. In mid-1970 due to advancement in computer technology many software's capable of performing Finite element analysis were available.

4.1 Meshing

Meshing is the method of converting continuous models to discrete parts. The goal is to select and locate finite element nodes and element types so that the associated analysis is sufficiently accurate. Element Aspect ratio must be near unity to obtain accurate results.

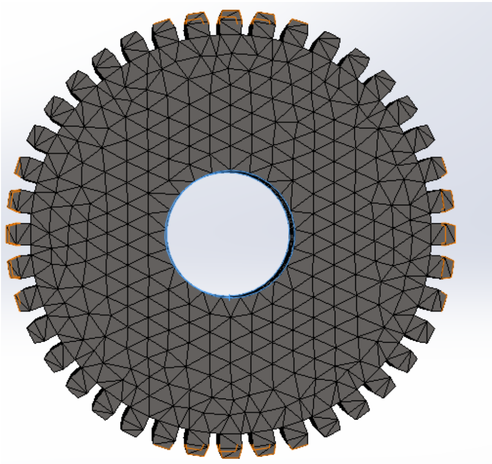

Figure 5. Mesh View of Spur Gear

Tetrahedral elements are used since stress is present all alone the thickness of the part. Patch independent algorithm is used since a finer mesh is required around edges and corner. For rest of the body a normal mesh is sufficient and in advanced meshing features the proximity and curvature feature needs to turned on since the curvature size function examines the curvature on the faces and edges and computes the element sizes so that the element size doesn't exceed the maximum size of curvature angle which are either defined by the user or taken automatically. The minimum size limit is defined as 0.1 in. The proximity size function allows defining the minimum number of element layers in the region that constitute gaps. The stress analysis of spur gear was done by using SolidWorks software, the SolidWorks diagram is shown in Figure 5.

5. RESULTS AND CONCLUSION

Analysis has been carried out by optimizing the material such as carbon steel.

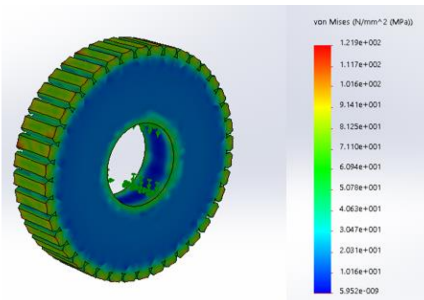

Figure 6. Von'mises Stress of Spur Gear

The results such as total deformation and Von's mises Stress are determined. Comparing the theoretical and numerical has the low values of total deformation, stress and strain. Therefore, it is concluded that carbon steel is suitable for the spur gear manufacturing. The gear is fixed at the center by the fixed support tool. Forces can be applied to the gear by selecting the edge from the graphics window and forces are defined in the component form. The post processing stage involves viewing of data files generated by the software during the solution phase. The Figure 6 displays the stress contour of the gear tooth. Gear tooth may not only break due to bending stress during its life time but develops pits on tooth surface due to high contact stresses fatiguing the surface by compression. Figure 7 and 8 show the deflection and equivalent strain of Spur Gear.

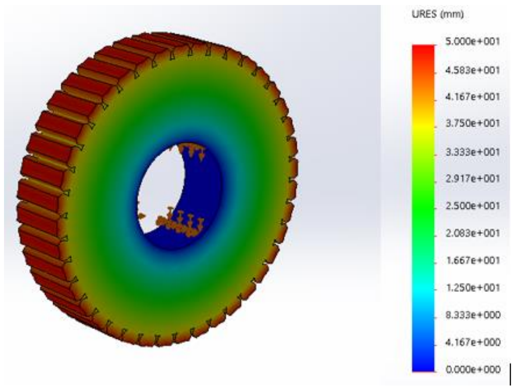

Figure 7. Deflection of Spur Gear

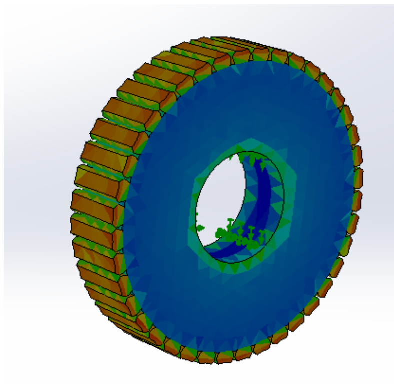

Figure 8. Equivalent Strain of Spur Gear

The maximum stress result obtained from finite element analysis was 122MPa while the maximum deflection obtained from the finite element analysis was 0.05 m under the same conditions. The ultimate stress of steel (C45) is 2220 MPa and the yield stress is 360MPa.

6. ACKNOWLEDGMENTS

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