Design and Fabrication of Lever Operated Solar Lawn Mower and Contact Stress Analysis of Spur Gears

D.Satwik[*1], Mr.N.Ramalingeswara Rao[*2], SreeramReddy[*3]

M.Tech Student, Department of Mechanical Engineering,VJIT College, R.R(D.t), Hyderabad, Telengana, India.

Associate Professor, Department of Mechanical Engineering,VJIT College, R.R(D.t), Hyderabad, Telengana, India.

ABSTRACT:

One of the main issue in a traditional lawn mower is the height of the grass cut cannot be adjusted spontaneously because the height adjustment of the rotor blade is done by lifting the whole deck with the help of wheel support and this mechanism takes time at least (4-5 minutes) to adjust the rotor.

The present proposed lawn mower has a spur gear displacement mechanism in which rotor blade height can be adjusted by using the lever attached to it and that can proportionally changes the height of the grass cut of the lawn and required grass cut can be achieved and this process of adjustment will be completed in less than 20 seconds. Arduino board is used to control the speed of the motor manually and sensor is also placed in front of the machine, Corresponding required program is to be written and dumped into board. Ultrasonic sensor provides the signal to the board before the time of collision (below 30cm from the obstacle). Buzzer receives a signal from the board and produces alarm that prevents the collision.

The fabrication of the proposed assembly of machine is to be done and the design of the machine is done by using design software CATIAV5.

Spur gears transmit the power between motor and the rotor. Contact stresses acting on the teeth of their respective spur gears are calculated theoretically using Hertz and AGMA equation. ANSYS is used to perform static structural analysis between the spur gears and contact stresses are obtained.

Keywords: Solar energy, Spur gear, Arduino board and FEA

I. INTRODUCTION

The name solar powered lawn mower provides the information that the usage of solar energy to power an electric motor which in turn actuates the rotor blade and that mows the lawn. By considering the different particular customer needs, many designs have been done and cost also place an important role in the manufacturing of particular designs where maintenance should also be considered before designing the machine. In this project the fabrication of solar lawn mower focus on the height adjustment of a rotor blade without affecting the electric motor or a body of a machine and some additional equipment is used to make a machine more useful. Main objective is to cut the grass in different heights according to our requirement and we have machines providing the same. The main drawback is the height adjustment can be made by lifting whole body with the help of wheels which takes lot of time to make that happen whenever you need to cut in different heights with this type of designs and probably usage will be more in parks and in some beautiful lawns. To overcome this drawback many designs have been considered and that too without any use of automation. One of the design has been selected and also very productive, convenient and easy to fabricate. By taking required measurements from the basic lawn mower and designed by using CATIA V5 (fig 1) .

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This following assumed machine design is used as a reference before fabrication.

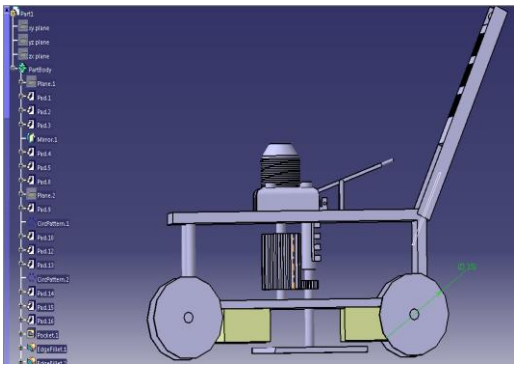

Fig 1: Idea of project as CAD model

II. MECHANISM DESCRIPTION

Electric brushless motor is taken to drive the rotor blade and solar panel is used to drive the motor, where the batteries perform charging and discharging action between the solar panel and the motor. The actual mechanism lies between the rotor and the motor using spur gears for the power transformation. Those two gears have different face width, teeth and pitch circle diameter. We have two shafts, the first shaft is connected to motor where we use big diameter gear having higher face width and the second shaft is connected to the rotor in which small gear is used for the power transmission from the motor to the rotor. And here another hallow shaft is taken and fixed on the other side of the rotor shaft using roller bearings. According to the figure 2 shown, outside diameter of bearing is equal to inside dia of hallow shaft and inside diameter of bearing is equal to the dia of the rotor shaft. This mechanism tends to stationary hallow shaft and rotating rotor shaft during the cutting process. we connect a lever on the other end of the hallow shaft. This lever is used to adjust the rotor height manually within no time, where the teeth of small gear slides over the face width of a large gear. The height adjustment depends on the face width of the large gear. Small holes are made on the hallow shaft with equal intervals where a small rod is used to insert inside the holes made, that stops the vertical motion of the rotor blade shaft fig 2 . Components used in this project are represented in the following table 1.

Fig 2: Mounted gears

2.1 Component list

S/N	ITEM	QTY	REMARK
1	DC motor	1	Rotating the blade
2	Battery	2	Power supply for motors
3	Solar panel	1	Power supply for batteries
4	Spur gears	2	Power transmission
5	Wheels	4	Mowing the mower
6	Ultrasonic sensor	1	Sensing the obstacle
7	Arduino board	1	Controlling the rotor speed
8	Rotor blade	1	Carbon steel

Table 1 : component list for solar lawn mower

2.2 Arduino board

Arduino is an open-source computer hardware and software by using which we can make small kits and arduino is a single-board microcontroller to make multidisciplinary projects more accessible by using electronics. Arduino board is used to control the speed of the rotor blade and for obstacle detection in this mower project. Some of the electronic components are used to make this arduino board to regulate the speed and detect the obstacle. First of all an open source

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arduino software is downloaded and the required program has to be written. The following components used to connect in arduino board are 1. Breadboard 2. Transistor 3. Diode 4. Resistor 5. LED's 6. Potentiometer 7. Capacitor 8. Ultrasonic sensor 9. Buzzer. These nine components are connected to the auduino board and the program is dumped into microcontroller using arduino software. The total apparatus is connected between the battery and the motor with which power supply goes through the arduino board and following circuit diagram fig 3 shows how to connect the components to the board.

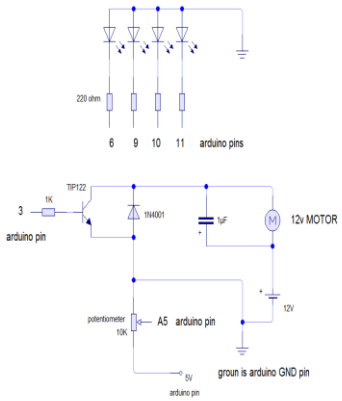

Fig 3: Circuit diagram

Ultrasonic sensor and buzzer is directly connected to the board according to the program written. Sensor is placed in front of a machine so that it detects the obstacle which comes under the distance of 40cms and buzzer produces alarm to avoid collision. Potentiometer contains a knob where it has 4 stages, with which we can vary the speed from stage to stage up to maximum 2000rpm. These rpm values should be defined in the program.

III. DESIGN ANALYSIS

The shearing force of most annual and perennial grasses found on most lawns is usually between 9.2N ~ 11.51N (Yong and Chow, 1991) Force required by cutting blade to shear the grass is given by;

3.1 **Selection of electric motor**

3.1.1 **DC Motor**

Speed = 2000 RPM

Voltage = 12 V

Power = 180 W

3.1.2 **Torque of a motor and force required by cutting blade**

We know that F= $\frac{T}{r}$, T= $\frac{P\times 60}{2\times\pi\times N}$ =0.862Nm (motor torque)

Considering second gear of teeth (18) $d_2 = 45mm$

Gear ratio R = $\frac{T_1}{T_2} = \frac{0.862}{T_2}$

$T_2 = \frac{0.862}{0.125}$ = 0.718 Nm

Mechanical advantage (MA) = $\frac{T_2}{T_1}$ = 0.832

Therefore net force acting on the blade F = $\frac{T_2 * m * g}{R}$ = 14.36 ≈ 14.5N

3.1.3 **Shaft calculation**

Shaft is made of mild steel and its allowable stress is F_s = 42Mpa

Torque = 3.14* F_s* $d^3/16$

Shaft diameter = $\sqrt[3]{\frac{T*16}{3.14*f_s}}$ = $\sqrt[3]{\frac{14.36*16}{3.14*42f_s}}$=11.87=10mm(taken)

3.1.4 **Battery calculation**

Required capacity = 12V; 15.04 Amp-hr
As the required amp is more than the capacity of batteries the run time of the motor deceases slightly let us say 45min.
Voltage = 12V, Current = 7 Amp
Max storage WATTS in single battery = 84 W

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10w solar panel is used and it takes 4 days considering 6 hours direct sunlight per day to charge complete two batteries.

IV. SPUR GEAR CALCULATIONS

S/N	Specification	Driving	Driven
1	Out diameter	6 cm	5 cm
2	Hole diameter	15 mm	10 mm
3	Face width	12 cm	2.4 cm
4	Teeth	22	18
5	Module	2.5	2.5

Table 2: Gear specification

Tangential load on spur teeth :

$F_t = \frac{2T}{D_p\,(pitch\ circle\ \ dia)}$

F_t= 7.297 lb = 32.46N

Bending stress :

$\sigma = \frac{F_t}{K_v' bYm} = 2.68\ {}^{N}/_{mm^2}$

4.1 CONTACT STRESSES

Hertz equation

$\sigma_c = -\ C_p \sqrt{\frac{K_v' W_t}{F \cos \varphi}} \times \sqrt{(\frac{1}{R_1} + \frac{1}{R_2})}$

σ_c = - 87.598 N/mm^2 (compressive force)

AGMA stress equation (*pitting resistance*)

$\sigma_c = Z_E \sqrt{W_t K_0 K_V K_S \frac{K_H}{d_{w1} b} \frac{Z_R}{Z_I}}$ SI units

$\sigma_c = 68.642\ {}^{N}/_{mm^2}$

V. SOLAR LAWN MOWER FABRICATION AND DESIGN

The fabrication has been done according to the reference design and the actual design is done through reverse engineering by taking the measurements of the actual fabricated model (fig4). CATIA V5 is used to design the model, in which different parts are designed separately and assembled together makes the actual design. Arduino board assembly is not included in the design such that the total machine and its mechanism could look understandable. The (fig 4) shows the complete assembled design of original model.

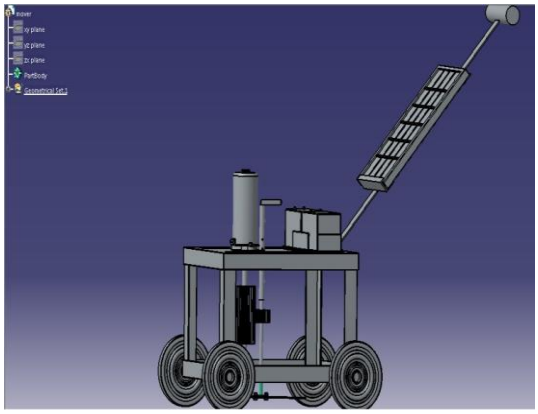

Fig 4: Final 3-D modeling of machine

Fig 5: Solar lawn mower

VI. FEM ANALYSIS TO ESTIMATE CONTACT STRESSES

The Finite Element Method is most widely used for stress analysis in a pair of gear. In addition, FEM software has been used for performing meshing simulation. Almost in all of the above cases Contact Stress calculation and Bending Stress calculation play more significant role in the design of gear. This study shows that Hertz theory is the basis of contact stress calculation and Lewis formula is use for calculating bending stress in a pair of gear.

3-DIMENSIONAL ANALYSIS OF SPUR GEAR: - For imported 3-dimensional geometry, firstly we select 3-D and static structural analysis from menu and

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connecting the geometry to the analysis tab. Then next we enter Young‟s modulus and Poisson‟s ratio of the material.

DEFINING THE CONTACT REGION: - Once the geometry is attached with static structural analysis tab, we have must define the contact between the two involute teeth, ANSYS has inbuilt option, which automatically reads the attached geometry for any predefined contacts or other boundary definitions. One of the most important things is to change the „Interface Treatment‟ to „Adjust to Touch‟. This is helping us to define the kind of contact between the selected bodies.

MESH GENERATION AND BOUNDARY CONDITION (supports and load):- A tetrahedron solid elements is used in mesh generations. Boundary condition refers to the external load on the border of the structure. We assumed gear 2 is with fixed support and gear 1 is subjected to a moment or torque along its axis with frictionless support.

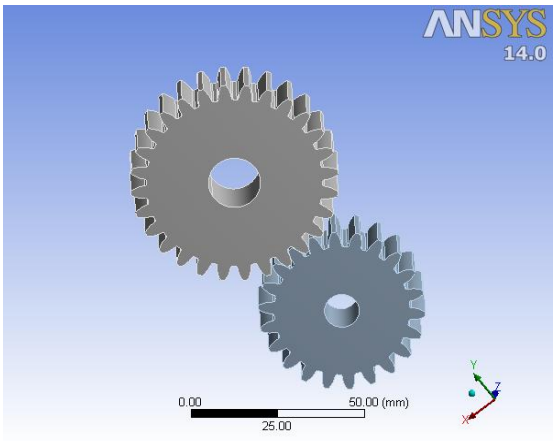

Fig 6: Assembly

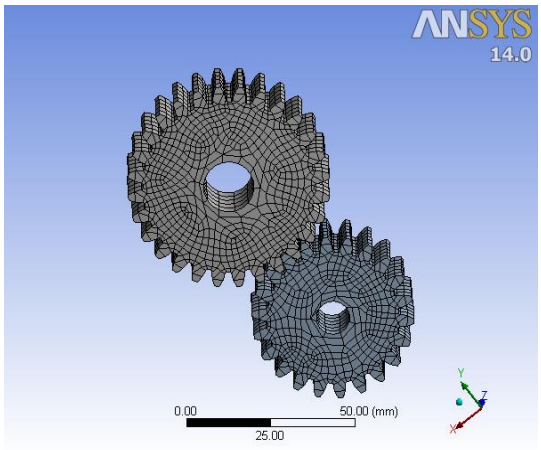

Fig 7: Meshing

VII. RESULT AND DISCUSSION

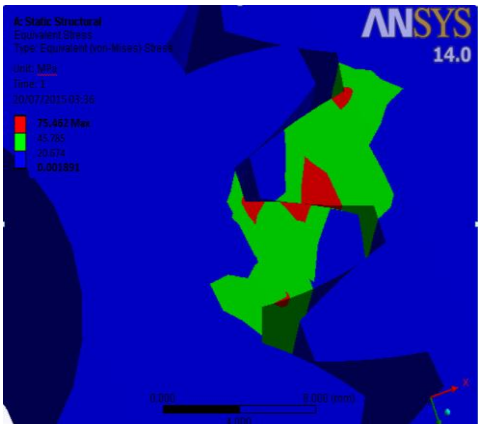

Fig 8: Stresses acting on the contact stress area

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CONTACT STRESS

Hertz equation	-87.598 Mpa
AGMA contact stress	68.642 Mpa
FEA	75.462Mpa

Table 3: Contact stresses

Theoretical result obtained by Lewis formula and Hertz equation and results found by AGMA/ANSI equations are comparable with Finite Element Analysis of spur gear. It is noticeable that the Lewis formula can be used for a quick calculation of the stress on the root of gear tooth. Contact stresses derived from analyzing by Finite element method (fig 8), the stress value is found to be close to the AGMA standards. The values found for SCS (Surface Contact Stress) is acceptable when compared with the AGMA standard and Hertz equation both. The displacement of the rotor is can be done from 0 to 5cm without considering the distance from ground to rotor. Displacement can also be increased with improved gear selections and bearing placements by using this paper as a reference. The speeds of rotor regulation can be changed according to our requirement and can put in use. The proposed speeds are 750,1200, 1600, and 2000 . The selection of speed should be done depending on the height of grass and required force. Solar panel with high watt configuration can be used, so that recharging of batteries are done in less possible time. The cost of the machine including material cost and fabrication cost is 7000 INR. When it is manufactured in more quantity, that may reduce the cost of the machine which could get in more affordable price. So the proposed machine has more advantages compared to the conventional machines.

VIII. CONCLUSIONS

The objective of this project is to design and fabricate the lever operated solar lawn mower. the total vertical displacement of the rotor blade that can be adjusted in less than 20 sec and is directly proportional to the face width of the driving gear. The grass cut can be varied from the 1cm to 6.5cm from the ground. The face width of the driving gear can be changed and corresponding bearing are attached if the customer's requirement of height of the grass cut is varied. The motor runs 45min continuously until the batteries are depleted. As we use the solar panel, the batteries requires 23 hours to recharge completely, so it requires 4 days considering 6hours/day direct sunlight. The program is written (see 4.11.5) according to the requirement and dumped into the board and the obstacle is sensed when it reaches near the machine (below 30cm) and RPM of motor is changed in four steps namely 700, 1200, 1600 and 2000. The design software CATIAV5 is used to design the parts of the machine and assembled in an assembly workbench according to the noted dimensions. Finding out the contact stresses acting between the spur gears for the given torque and rpm gives an idea for the redeveloping the gear design, which may reduce the chattering noise. The results which are obtained from the ANSYS software is compared in table 3. By this it is concluded that, the values which are calculated from the theoretical equations give a close call to the result obtained in the FEA. From these conclusions, it is observed that the proposed machine provides more productivity when compared to the traditional lawn mower. So the use of lever operated solar lawn mower saves the electricity, minimizes the time taken to adjust the height, prevents the collision occurrence and also motor speed controlling facility.

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D.Satwik: He is currently pursuing M.Tech, in the stream of Machine design. Department of Mechanical Engineering,VJIT College, R.R(D.t), Hyderabad, Telengana, India.

SreeramReddy: He was working Associate Professor, Head of the department of Mechanical Engineering, in VJIT College, R.R(D.t), Hyderabad, Telengana, India.

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