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Design and Analysis of Rotary Lawn Mower

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Abstract- **KAMCO Industries, Athani, India is a reputed industry undertaken by Kerala state government producing farm and agro-machinery used all over India. KAMCO has a product line up of several farm and agro machineries, but has not produced Lawn Mowers. We are trying to put forward a simple lawn mower design which can be added to the product lineup of KAMCO with minimal cost. Here we have focused on simplifying the design of existing lawn mowers. Simple mechanisms for height adjustments and grass collection has been employed for usability and cost reduction. The frame and height adjustment module has been analyzed with the help of ANSYS Workbench and conclusions have been made**

Keywords- Lawn Mower Design, Static Structural Analysis, Lawn Mower Frame, Height Adjustment Module

I. INTRODUCTION

Reel Mowers and Rotary Lawn Mowers are two types of mowers used for mowing grass. But researches has showed that the rotary lawn mowers are more effective than the reel mowers because of its clean mowing and provision for collecting grass. The most important part of the rotary mower is the cutting blade and cutter deck housing. The speed of cutting blade, angle and sail are some of the factors influencing the quality of cut.

According to Basil Okafor[1], For smooth grass cutting, a motor power of not less than 628.3W (0.84hp) having a rotational speed of 2,000-3,000 rev/min and producing a shear force of about 10.5 N is recommended. He also stated that a manually operated lawn mower handle should be angled at 45^0, he noticed that below 40^0 angle of handle bar the lawn mower becomes difficult to control.

According to Anonymous[2], The deck and blade designs vary depending on how the plant and other materials under the mower deck are to be discharged. Side or rear discharge decks are more common. The rear discharge decks are generally preferred for mowing areas where people might be around. Mower deck designs for zero discharge are becoming more common. This design chops the vegetation into finer bits and drops them into the canopy as the mower passes over. The advantages of mulching mowers are efficient recycling of clippings and improved safety because bystanders will not be hit by flying debris.

II. DESIGN OF DRIVE SYSTEMS

For our rotary mower, we are using Honda GX160 4 stroke petrol engine, because this engine is currently used in KAMCO Industries for their Garden Tiller and Power Weeded B30. This will reduce the cost of implementing a new engine for the Lawn Mower.

The specification of the engine were obtained and a model of the engine was made in SolidWorks 2011. The engine produces a power of 12.9kw (4hp) and a torque of 8lb-ft (10nm). The optimum speed is 3200rpm.

A. Design of Bevel Gear

In order to transmit the power from the drive shaft to the V-Belt drive system which are mutually perpendicular we require a Bevel Gear system. The calculations were done following the books Machine Design[3] and Design Data[4]. The specifications are given in Table 1. Since the gear ratio was assumed as 1, the specifications for driver and driven gears are the same. A key slot was provided to mate the gears with the shaft. The 3D model was created in Solid Works 2011 and rendered in Keyshot5.

Table 1: Specifications of Bevel Gear

Diametral pitch	5
No. of Teeth	28
Pitch Diameter	56mm
Addendum	2mm
Deddendum	2.396mm
Clearance	0.396mm
Pitch Angle	45^0
Pitch Cone Radius	39.598mm
Face Width	13.199mm
Outside Diameter	58.828mm
Back Cone Radius	39.959mm

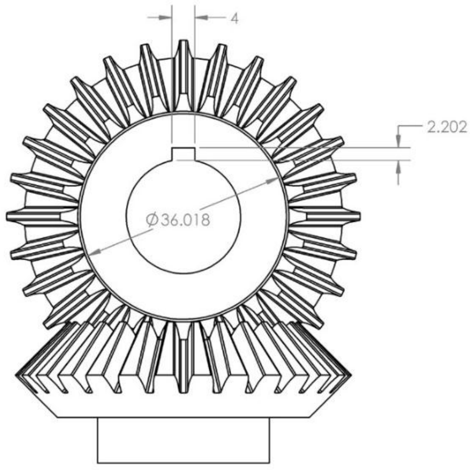

Fig 1: Bevel gear 2D sketch

Fig 2: Bevel gear 3D rendered image

B. Design of V-Belt Drive

In order to transmit power from bevel gear to the cutting blade shaft a v-belt system has to be designed. V-belt was chosen due to its reduced maintenance, noiseless operation and less friction. The calculations were done following the books Machine Design[5] and Design Data[6]. The specifications are given in Table 2. The 3D model was created in Solid Works 2011 and rendered in Keyshot5.

Table 2: Specifications of V-Belt Drive

Type of Belt	Type B 889 IS:249 V-Belt
Pitch dia of smaller pulley	56mm
Pitch dia of larger pulley	59.73mm
Centre distance	377mm
No. of belts	2 nos
Width of pulley	44mm
Centre to center distance of groove	19mm
Depth below pitch line	10.8mm
Edge of pulley to first groove	12.5mm
Distance down to pitch line	4.2mm

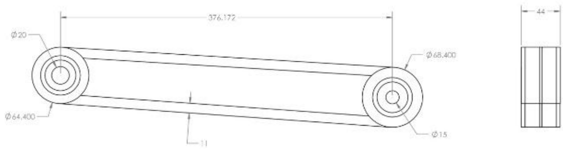

Fig 3: V-belt 2D sketch

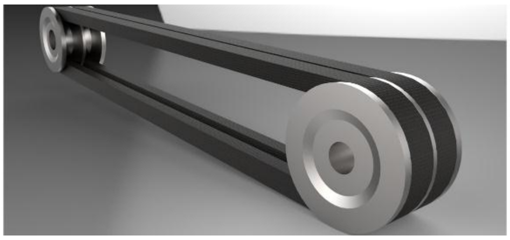

Fig 4: V-belt 3D rendered image

C. Design of Shaft Bearing

For the smooth rotation of the cutting blade shaft with respect to the mower body and to carry the load due to self weight, dynamic forces and belt tension we require a bearing. The calculations were done following the books Machine Design[7] and Design Data[8]. The specifications are given in the Table 3. The 3D model was created in Solid Works 2011 and rendered in Keyshot5.

Table 3: Specifications of Ball Bearing

Type of Bearing	SKF 15B C03 6302 (deep groove ball bearing)
Inside diameter	15mm
Outside diameter	42mm
Width of bearing	13mm
Abutment diameter on shaft	21mm
Abutment diameter on housing	36mm
Ball diameter	7.5mm
Corner radii	1.5mm
Max permissible speed	16000rpm

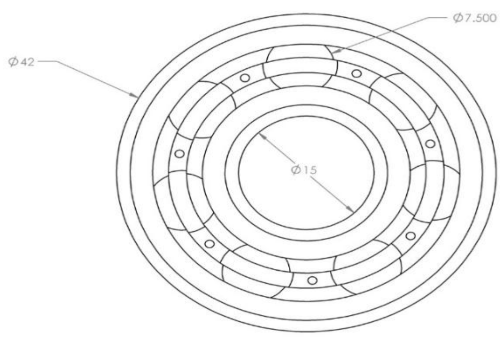

Fig 5: Ball bearing 2D sketch

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Fig 6: Ball bearing 3D rendered image

III. DESIGN OF LAWN MOWER FRAME

Shown below are two image of the lawn mower frame designs that we put up. The frame is a structural member which forms the back bone of our lawn mower. All the parts are connected to the frame in one way or another. For our frame we have used square pipes of 20mm length and 2mm thickness. Initially we came up with two designs for our frame. The major difference being the addition of a cross member, all the other dimensions are identical. In order to find what difference the cross member made we put both of these into analysis in ANSYS Workbench 14.

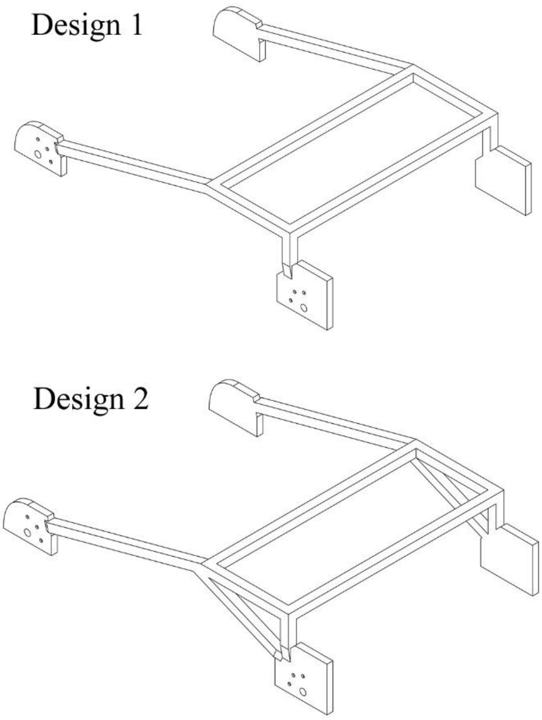

Fig 7: Frame comparison

Static structural analysis was carried out on both designs considering a vertical load of 300N, including a factor of safety 2. This load is acting on the two crossbars on the top of the frame. The results of the analysis are shown in Table 4.

Table 4: Comparison of Frame Designs

Design 1	Design 2
Material : Structural Steel	Material : Structural Steel
Max Deflection = 0.1010mm	Max Deflection = 0.0616mm (39% $decrease$)
Max Principal Stress = $9.608 * 10^6 Pa$	Max Principal Stress= $6.723 * 10^6 Pa$ (30% $decrease$)
Max Principal Strain = $4.750 * 10^{-5}$	Max Principal Strain = $3.191 * 10^{-5}$ (32% $decrease$)
Max Shear Stress = $8.806 * 10^6 Pa$	Max Shear Stress = $5.220 * 10^6 Pa$ (40% $decrease$)
Max Normal Stress = $9.1554 * 10^6 Pa$	Max Normal Stress = $6.145 * 10^6 Pa$ (32% $decrease$)
Max Strain Energy = $7.483 * 10^{-5} J$	Max Strain Energy = $4.195 * 10^{-5} J$ (43% decrease)

The percentage decrease in the stress and strain values are given in brackets. From these data obviously it is clear that the frame design 2 is better. So we decided to proceed with it. The analysis diagrams are shown below.

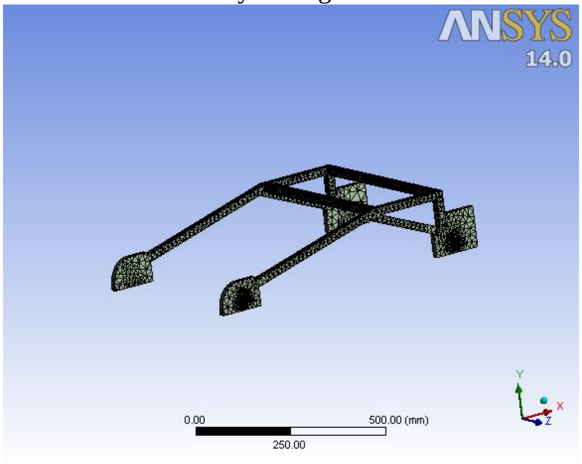

Fig 8: MESH

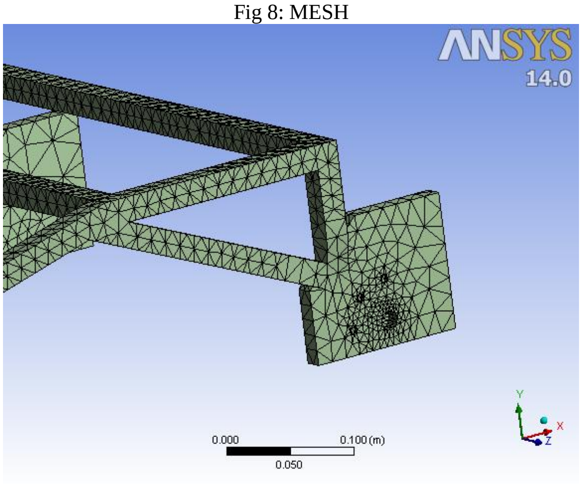

Fig 9: MESH(enlarged view)

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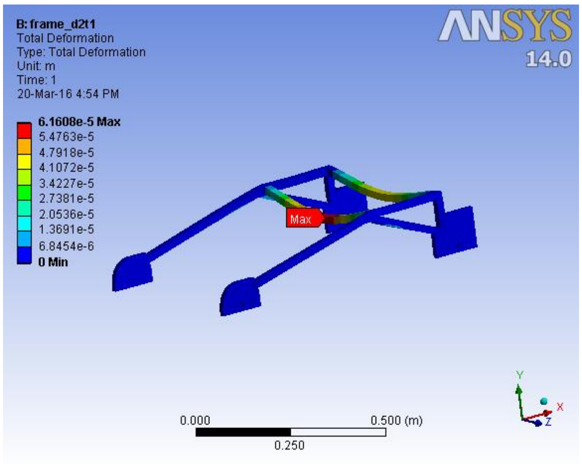

Fig 10: Deformation

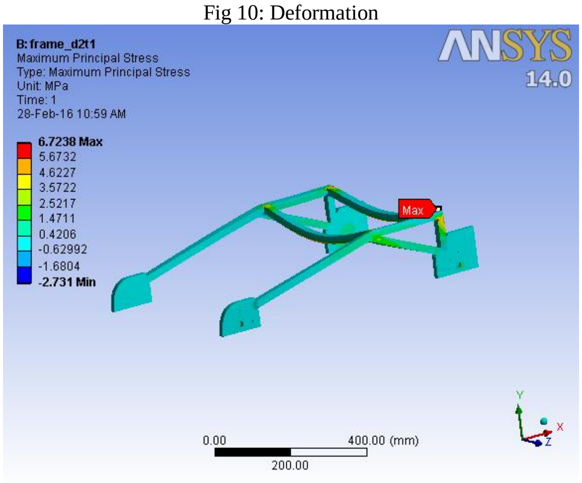

Fig 11:P-Stress

Fig.8 shows meshing of the frame design 2. The default mapped fine meshing was used on the entire frame with refinements given to the support ends. The total number of nodes and elements generated here is 42319 and 23201 respectively. Fig.9 shows the enlarged view of the mount holes towards the back side of the frame, the refinement given to the mounts can be seen here clearly. Fig.10 shows the deflection of the frame under loading. The maximum deflection occur on the support bars where the engine is mounted. The maximum value of deflection is 0.0606mm denoted by the red probe. Fig.11 shows the principal stress distribution which ranges from a minimum value of $-2.731 * 10^6 Pa$ to a maximum value of $6.723 * 10^6 Pa$. This value is less than the yield strength of Structural Steel which is $2.5 * 10^8 Pa$. So we can say the design is safe. The maximum values are represented by the red probe shown in each image.

IV. DESIGN OF WHEEL MOUNT/HEIGHT ADJUSTMENT MODULE

Wheel mount connects the wheel of the lawn mower to the frame. Suitable holes are provided on the frame for the installation of wheel mount. Each wheels of the lawn mower are provided with independent wheel mounts which will distribute the loads to all 4 wheels. It also serves another purpose, which is height adjustment. An adjustable lever with a cylindrical projection is provided for this purpose.

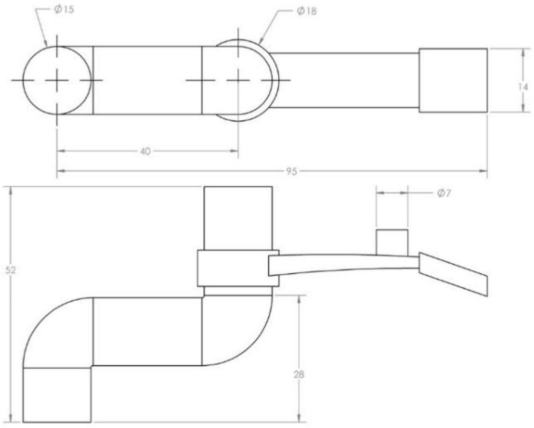

Fig 11: Wheel mount 2D sketch

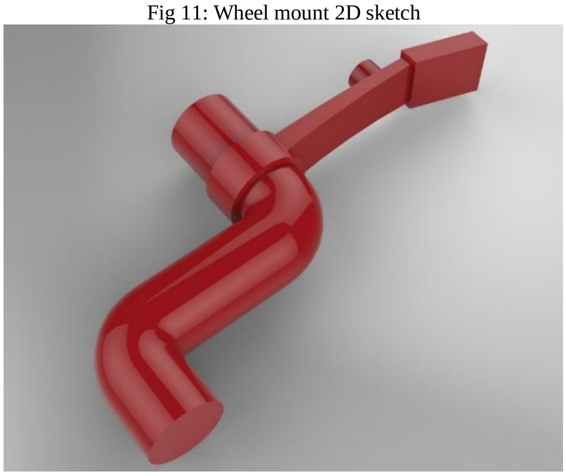

Fig 12: Wheel mount 3D rendered image

Three holes are provided on the frame named “L”,“M” and “H” which stands for Low, Medium and High respectively. The cylindrical projection provided on the lever can be swapped into these holes by pulling the lever backwards. Each of these positions changes the distance from the ground to the cutting blade, which results in a change in height of the grass which is being cut. Thus this system provides a simple and effective height adjustment for the mower.

Here another problem that arises is that, since the mount can be mounted in three different positions, the forces acting on the mount in these three cases will be different. So for the safe design of the mount these three cases has to be analyzed. The load acting on the mount will be the total weight of the lawn mower distributed among four wheels which gives us a value of 400N including a factor of safety 2. The comparison of data obtained from ANSYS Workbench 14 in three cases of mount are shown in Table 5.

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Table 5: Wheel Mount Position Analysis

Position	Low (L)	Medium (M)	High (H)
Height (ground to blade)	130mm	158mm	170mm
Total Deformation	0.0618mm	0.04884mm	0.0307mm
Max Principal Stress	$9.689 * 10^7 Pa$	$9.34 * 10^7 Pa$	$8.485 * 10^7 Pa$
Max Principal Strain	$4.231 * 10^{-4}$	$4.197 * 10^{-4}$	$3.588 * 10^{-4}$
Max Shear Stress	$4.616 * 10^7 Pa$	$4.027 * 10^7 Pa$	$3.472 * 10^7 Pa$
Max Strain Energy	$1.929 * 10^{-4} J$	$1.206 * 10^{-8} J$	$4.531 * 10^{-9} J$

From the above analysis data, maximum deformation is formed when the mount is in low position. But the maximum principal stress is generated when it is in medium position. Since the maximum stress formed in all three cases are less than the yield stress of structural steel $2.5 * 10^8 Pa$. We can say that the design is safe. The analysis diagrams of principal stress are shown below.

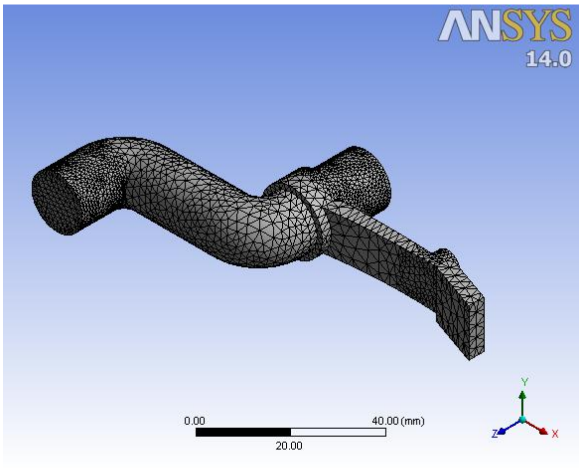

Fig 13: MESH

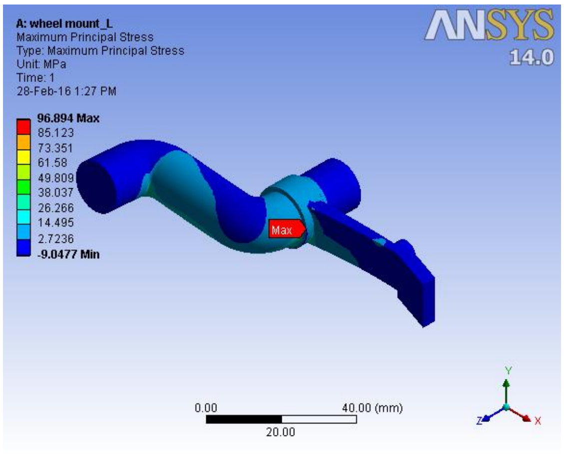

Fig 14: P-Stress (L)

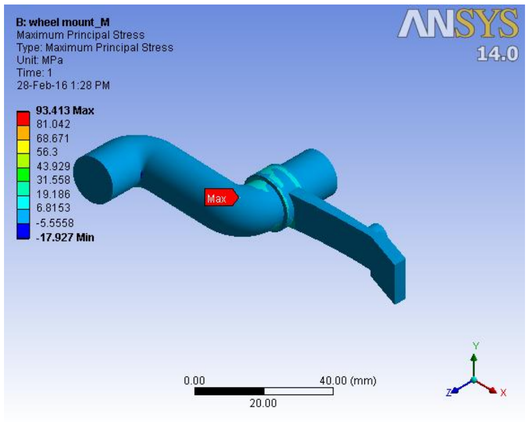

Fig 15: P-Stress (M)

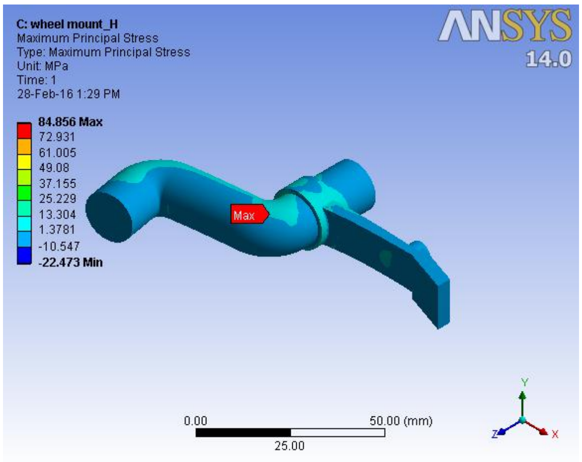

Fig 16: P-Stress (H)

Fig.13 shows meshing of the wheel mount. The default mapped fine meshing was used here with refinement given to the three cylindrical projections where the loads will be acting. The total number of nodes and elements generated here is 44429 and 27511 respectively. Fig.14 shows the distribution of principal stress when the mount is in low "L" position. Here principal stress ranges from a minimum value of $-0.904 * 10^7 Pa$ to a maximum value of $9.689 * 10^7 Pa$. Fig.15 shows the distribution of principal stress when the mount is in medium "M" position. Here principal stress ranges from a minimum value of $-1.792 * 10^7 Pa$ to a maximum value of $9.341 * 10^7 Pa$. Fig.16 shows the distribution of principal stress when the mount is in medium "H" position. Here principal stress ranges from a minimum value of $-2.247 * 10^7 Pa$ to a maximum value of $8.485 * 10^7 Pa$. Here the stress is evenly distributed over the entire component represented by a light blue color, hence the lowest maximum principal stress value is obtained in this position.

V. FINAL ASSEMBLY

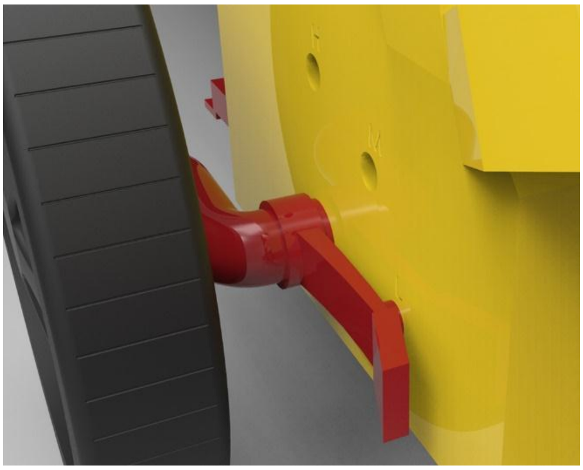

Fig 17: Wheel mount

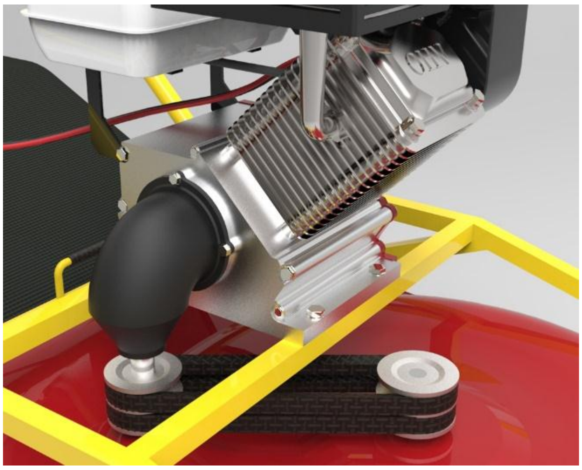

Fig 18: Bevel gear with casing and V-belt drive

Fig 19: Isometric view of mower

VI. CONCLUSION

A simple design for rotary lawn mower was achieved. The frame design ensures better strength and reliability which was proved using the analysis results, the frame was found to be safe under loading since the stress developed in it is below the yield stress of the material. The height adjustment module provides a simple yet effective means of cutting height adjustment, the stresses developed on it was also analyzed and was found to be safe under limits. The detailed design and analysis of the cutting blade will be published in a future journal.

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