Full Length Research Paper

Design & Development of Rotavator blade: Interrogation of CAD Method

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Received 3 August 2013; Accepted 26 September 2013

Abstract. Agricultural land preparation cost has increased to a new high label due to increase in fossil fuel prices. This directly increases the cost of food. Demand of food also increases due to high population rise and smaller land sizes (< 2–4 ha) due to fragmentation of land. So farmers are more interested to reduce the land preparation cost and increase the yield. Due to these facts, preparation of seedbeds for deep tillage in conventional tillage system, particularly in Indian farming, the situation is worsening day by day. This system of tillage escalates land preparation costs because it requires a series of operations using passive tillage tools to realize an acceptable till quality. It also ties down capital in the form of additional machinery and tillage tools; thus increasing significantly the cost of land preparation. Rotary tiller or rotavator is a tillage machine most suitable for seedbed preparation. In a Rotary tiller, Blades are the main critical parts which are engaged with soil to prepare the land. These blades interact with soil in a different way than normal plows which are subjected to impact and high friction that creates unbalancing and non uniform forces which result in blade wear. This actually decreases the service life of a blade. Therefore, it is necessary to design and develop a suitable blade so that self life is enhanced. This paper presents design and development of rotavator blade through the interrogation of computer aided design (CAD) method.

Key words: rotavator, CAD/CAM, 3D Model, FEA, blade wear

1. INTRODUCTION

Rotary tilling is a widely used tillage operation in Indian farming because of its superior ability to mix, flatten and pulverize soil. However, the use of rotary tiller is strongly restricted to “shallow” tillage because of its high energy requirements. Deep rotary tillage using less energy has recently become a subject of wide interest to combat soil fatigue caused by excessive use of chemicals among other reasons, and to convert paddy fields into dry fields such as kale fields. Rotary Tiller or rotavator is a highly effective mechanical tool for intensive tillage. It is one of the most efficient tillage systems when looking for solutions to specific soil tillage problems. No matter the soil type, soil conditions or the amount of residue, Rotavating will always produce the best result. The Rotavator can be easily adjusted for various working depths and soil finishes. The rotating blades chop and mix the residues evenly throughout the working depth, outperforming any other implement.

A rotary tiller is a specialized mechanical tool used to plough the land by a series of blades which are used to swirl up the earth. It can be adjusted according to the specific requirements of the soil (Hendrick and Gill, 1971c). Nowadays, utilization of rotary tillers has been increased in agricultural applications because of simple structure and high efficiency for this type of tillage implements. By taking advantage of rotary tillers, the primary and secondary tillage applications could be conjugated in one stage (Topakci et al., 2008). Despite of their high energy consumption, since rotary tillers have the ability of making several types of tillage applications in one stage, the total power needed for these equipments is low (Culpin, 1981). Because rotary tillers power is directly transmitted to the tillage blades, the power transmission efficiency in rotary tillers is high. Moreover, the negative traction existence in rotary tillers causes the required tractive force to be decreased and consequently, smaller tractors could be used with this type of tillage implements for land preparation. Power to operate the rotary tiller is restricted by available tractor power (Yatsuk et al., 1981). Rotavator perform well in suitable soil conditions but consume high amounts of energy. In the past, a number of studies were conducted to design suitable blades of rotavator in order to reduce the energy and power consumption (Shibusawa, 1993).

The continuous fluctuating impact of soil develops high stress on blade tip or blade critical edges. Due to these stresses blade wear takes place after certain period of usage which depends on soil type or variety. This time period ranges from 20-200 hours for local blades and 300-350 hours for imported blades in normal soil conditions (Saxena and Singh, 2010). Considering this, some work on material characterization has been done to improve the service
life of a rotavator blade but these works did not address to reduce the overall costs of blade. Another way to improve the service life of blade is the improvement in blade geometry. The geometry of tiller blades is considered to be the most important factor in their design since both the shape of the blade tip and the length of the tiller blade facilitate cutting (Jain-Song, 2007). Hence there is a need to improve the design through geometrical modifications so that will reduce the blade cost as well as land preparation cost. This paper describes the design improvement and development of blade through computational methods.

2. COMPUTER AIDED DESIGN (CAD) METHOD

2.1. CAD Technology

Computer aided design refers to the design process using sophisticated computer graphics techniques backed up with computer software packages to aid in analytical problems associated with design work. The 3D (Three dimensional) models created on a CAD system with the help of curves and surfaces. Those curves and surfaces are generally NURBS (Frain, 1988). Wire frame models are used as input geometry for simple analysis work such as kinematics studies; surface models are used for visualization and animations; solid models are used for engineering knowledge and visualization which are mathematically accurate for the description of the products and structures.

Computer Aided Design-CAD is defined as the use of information technology (IT) in design process. Its use does not change the nature of the design process but as the name implies, it helps the product designer. The designer is the main actor in the process; in all phases starting from problem identification to implementation. The advantages generally achieved from CAD include accurately generated and easily modifiable graphical representation, complex design analysis in short time, Finite Elements analysis, Motion analysis, Tolerance analysis & Design optimization (Bilalis, 2000). Therefore the product can be introduced earlier in the market, providing many advantages to a firm. CAD systems enable the application of concurrent engineering and can have significant influence on final product cost, functionality, and quality (Bilalis, 2000).

2.2. Finite Element Method (FEM)

The following are the three basic features of the finite element method (Reddy, 1984).

A) Discretization of the given domain into a collection of preselected finite elements; B) Derivation of element equations for all typical elements in the mesh; C) Assembly of element equations to obtain the equations of the whole problem; D) Imposition of the boundary conditions of the problems (D) Solution of the assembled equations (E) Post processing of the results

Finite Element (FE) is one of the methods used for evaluating a structure under static and dynamic loads before making the main model. This leads to improvements in the strength of the design. ANSYS is a general purpose software package based on the finite element analysis. This allows full three-dimensional simulation without compromising the geometrical details (Huges, 2000; Merdenci and Guven, 2007). Finite element method was used by many researchers in order to design the tillage tools or investigate the interaction between soil and tillage implement. Most investigation used a blade as the object studying the interaction between soil and tool, because its geometric simplicity made the corresponding FEM analysis relatively easier (Shen, 1998; Yong and Hanna, 1977; Mouazen and Nemenyi, 1999; Arya and Gao, 1995; Godwin and Spoor, 1977).

2.3. Computer Aided Engineering Tools (CAE)

Engineering analysis is concerned with analysis and evaluation of engineering product designs. For this purpose, a number of computer-based techniques are used to calculate the product's operational, functional, and manufacturing parameters. Finite element analysis (FEA) is one of the most frequently used engineering analysis techniques.

Besides FEA, tolerance analysis, design optimization, mechanism analysis, and mass property analysis are some of the computer aided techniques available to engineers for the purposes of analysis and evaluation of the engineering product designs.

3. BLADE DETAILS

Based on the market survey and available literature, it was found that generally three types of blades are used in a rotary tiller or rotavator. These are L’ shape, ‘C’ shape, & ‘J’ shape, to suit various operating conditions as shown in Fig.1. L-shaped blades are better than C or J type blades in trashy conditions as they are more effective in killing and they do not pulverize the soil as much (Adams, 1959). The detail of an L-shaped blade is shown in Fig.2. Again in India, L-shaped blades are mostly used in Indian rotavator which are normally mounted with three right handed and three left handed blades per flange as shown in Fig.3.
4. MATERIALS AND METHODS

Based on the available information from literature, it has been observed that ‘L’ type blade is most suitable for Indian farming conditions, as this blade does not pulverize the soil too much which is an advantage feature over other commercially available blades. Still blade wear takes place after certain hour of usage which must be overcome to increase the service life.

In this study to design and develop a ‘L’ type blade, advantages of CAD methods like 3D modeling and analysis was used. Accordingly at the initial stage 3D Modelling was done on the basis of geometrical parameters normally which are similar to a commercially available blades using 3D CAD software. This model was analyzed through ANSYS for Finite Element Analysis particularly to investigate the main causes of wear. Based on the analysis results,
it was noted that by altering some geometrical parameters improvement can be made and hence through the analysis a final blade has been designed. Table 1 and Fig. 4 show the specifications and important parameters of the blade, respectively. This blade was designed by considering: (1) cutting width which should be more than 40mm for cutting and breaking paddy residues into pieces and making a seedbed of sufficient width for direct seeding; (2) maximum radius of rotation should be more than 150mm to achieve a cutting depth of 60mm without the rotary shaft touching the surface. Fig. 5 shows the 3D Model and original photograph of the developed blade.

![Fig. 4: Important parameters of a rotary blade](image)

### Table 1: Various Parameters of the blade designed for the study

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Notations</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>w</td>
<td>Blade span, mm</td>
<td>40</td>
</tr>
<tr>
<td>( L_a )</td>
<td>Effective vertical length, mm</td>
<td>212</td>
</tr>
<tr>
<td>( L_b )</td>
<td>Blade cutting width, mm</td>
<td>88.7</td>
</tr>
<tr>
<td>( R )</td>
<td>Curvature between ( L_a ) and ( L_b ), mm</td>
<td>40</td>
</tr>
<tr>
<td>( \theta )</td>
<td>Blade angle, degree</td>
<td>108</td>
</tr>
<tr>
<td>( \beta )</td>
<td>Clearance angle, degree</td>
<td>20</td>
</tr>
<tr>
<td>( t )</td>
<td>Blade thickness, mm</td>
<td>8.0</td>
</tr>
<tr>
<td>( \varepsilon )</td>
<td>Bending angle, degree</td>
<td>22</td>
</tr>
</tbody>
</table>

![Fig. 5: Geometry (3D Model) the developed Blade](image)

### 4.1 CAD-MODELING AND ANALYSIS

The assembly or rotor shaft was done with 66 nos. of blade. There were six blades in a single flange as shown in Fig. 6. The three important steps in ANSYS programming used for CAD-modelling and analysis are Pre-processing, Solution & Post processing (Shinde and Shyam, 2011). The same steps are
followed here and analysis was done based on feedback available from the manufacturer and farmers for the developed blade in ANSYS 14.0 software. Analysis work was carried out using the input data, which are given in Table 2. These data are very much similar to the actual data generally observed while carry out a laboratory as well as field performance trials.

Table 2: Input parameters for the analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values /range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary tiller work depth</td>
<td>100 mm – 150 mm</td>
</tr>
<tr>
<td>Rotary tiller work width</td>
<td>1600 mm</td>
</tr>
<tr>
<td>Rotor rpm</td>
<td>200- 220</td>
</tr>
<tr>
<td>Blade peripheral velocity</td>
<td>5-6 m/s</td>
</tr>
<tr>
<td>Total number of blade</td>
<td>66</td>
</tr>
<tr>
<td>Number of blades on each side of the flanges</td>
<td>11</td>
</tr>
<tr>
<td>Prime mover forward speed</td>
<td>0.7- 1.7 m/s</td>
</tr>
<tr>
<td>$n_c$, number of blades which action jointly on the soil into the total number of blades</td>
<td>11/66</td>
</tr>
<tr>
<td>Prime mover Power ($N_c$)</td>
<td>30-40 hp</td>
</tr>
<tr>
<td>Traction efficiency ($\eta_c$)</td>
<td>0.8-0.9</td>
</tr>
<tr>
<td>Coefficient of reservation of tractor power ($\eta_s$)</td>
<td>0.7-0.8</td>
</tr>
</tbody>
</table>

The soil force acting on each of the blades (Ke) is calculated by the following equation:

$$K_s = \frac{KC_p}{iz\eta}$$  \hspace{1cm} \text{(Bernacki et al., 1972)} \hspace{1cm} \text{(1)}

Where, $K_s$ is the maximum tangential force (kg), $C_p$ is the coefficient of tangential force, $i$ is the number of flanges, $Z_c$ is the number of blades on each side of the flanges, and $\eta$ is obtained through division the number of blades which action jointly on the soil into the total number of blades. For designing blade, the maximum tangential force which can be endured by the rotor should be considered. The maximum tangential force occurs at the minimum of blades tangential speed is calculated by the following (Bernacki et al., 1972):

$$K_s = C_p \frac{75N_c\eta_s\eta}{u_{mn}}$$  \hspace{1cm} \text{(2)}

Where, $C_p$ is the reliability factor that is equal to 1.5 for non-rocky soils and 2 for rocky soils (Bernacki et al., 1972). On the above parameters including the design parameters as detailed in section 5.0 and using the equations 1&2 we get,

$K_s = 2083$ kg and $K_s = 378$ kg = 3800 N. These values were used in the analysis by ANSYS. The results are presented in the following section. Soil forces acting on each blade was calculated based on the above formulae and these values were used as input parameter along with other parameters as stated in Table 2.

4.2. Material properties

Material properties used in the analysis are presented in Table 3.
7. RESULTS AND DISCUSSIONS

The analysis results of left hand and right hand ‘L’ type blade in graphical mode have shown in Fig 6 and 7 respectively. The results have been computed and presented in Table 3. Similar analysis also done for standard used “C” type and “J” type rotavator blade. The results are compared and it was found that developed “L” type blade experienced least stress while deformation is almost similar. Ass in case of tillage tools, deformation is related to tool wear but stress plays a major role which results in wear of the tool. Here in this analysis, this stress variation is obtained because of variations in tool shape. The shape of the cutting edge can materially affect draft as well as vertical and lateral components of soil forces. These components of soil forces are important which results in stresses of the cutting edges. In the “L” shape blades these stresses are minimum as the shape is better than the other types. Fig 8 and 9 shows the comparison of results for deformations and stress respectively for other ‘J’ and ‘C’ type blades. From the figures it appears that the developed blade shows somewhat good characteristics of load sharing capacity over standard available blades.

![Fig. 6: Analysis results of ‘L’ type blade [Left hand] - a: 3D Model, b: Meshing, c: Deformation and d: Von mises stress respectively)](image1)

![Fig. 7: Analysis results of ‘L’ type blade [Right hand] - a: 3D Model, b: Meshing, c: Deformation and d: Von mises stress respectively)](image2)

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Blade variants</th>
<th>Soil force acting on the blade surface, N</th>
<th>Maximum Deformation, mm</th>
<th>Von mises stress, Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L type Blade (Left)</td>
<td>3800</td>
<td>0.5390</td>
<td>1.152x10^6</td>
</tr>
<tr>
<td>2</td>
<td>L type Blade (Right)</td>
<td>3800</td>
<td>0.5385</td>
<td>1.152x10^6</td>
</tr>
<tr>
<td>3</td>
<td>J type Blade (Left)</td>
<td>3800</td>
<td>0.6124</td>
<td>1.657x10^6</td>
</tr>
<tr>
<td>4</td>
<td>J type Blade (Right)</td>
<td>3800</td>
<td>0.5998</td>
<td>1.661x10^6</td>
</tr>
<tr>
<td>5</td>
<td>C type Blade (Left)</td>
<td>3800</td>
<td>0.5517</td>
<td>2.057x10^6</td>
</tr>
<tr>
<td>6</td>
<td>C type Blade (Left)</td>
<td>3800</td>
<td>0.5468</td>
<td>2.089x10^6</td>
</tr>
</tbody>
</table>

6. CONCLUSION

Computer Aided Design (CAD) is an effective tool for the development of any critical product. Here in this study CAD method has been explored to design and develop a critical ‘L-type’ blade, which happens to be the main parts of a tractor mounted rotavator. Finite Element Analysis was done for investigation of stresses experienced by the blade. A comparison was made between the developed blade and the other ‘C’ and ‘J’ type blade which are also commercially available blade. The results showed that deformations and stresses are minimum for the developed ‘L’ type blade. This ultimately enhances the shelf life of the...
blade. Thus, this research focuses on the design and development of a critical rotary tillers blade through CAD method. However further laboratory as well as field observation is required to verify the achieved results.

7. References

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