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Research Article

A Computational Approach for Design Improvement and Selection of suitable Curved Annular Rotating Disk Harrow for an Agriculture Use

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Abstract

India is an agrarian country and about 75 to 80 % people are farmers, their main occupation is farming. Also crop production is very important part of any economy. Without crop production nothing is possible. The crop production requires some kind of machining work to reduce the human effort. In this modern era many agricultural implements are available for crop production, which are highly efficient compared to conventional equipments. Various agricultural machining equipments are used for crop production such as rotavator, shovels, cultivator, plough, tillage tools, disk harrow etc. These equipments have direct interaction with the soil. Generally farmers used disk harrow agricultural implement for crop production tillage work. They faced a general problem of circumference erosion of disk harrow. This erosion occur main due to the size of soil particles. This erosion problem is a general problem faced by every farmer. It can be overcome by using some kind of engineering modifications like design and material modifications in disk harrow. In this research paper two disk harrow designs are proposed for life analysis and improvement. These designs are based on the existing model of disk harrow. The designs are modified on the basis of erosion parameters, so that erosion occurs less as possible. The currently used material is structural steel and equivalent materials are stainless steel and steel EN45. These materials are equivalent in mechanical properties and cost.

Keywords: *Agriculture, Farm, Machinery, Tools, FEA, FEM, ANSYS, Explicit, Deformation, Stress, Strain, failure, life and optimization.*

1. Introduction

Farm machinery is an important element for agriculture development and crop production in modern agriculture of many countries. The main objective of the machinery is to reduce number of labor, the difficulties of farm operations and maximize production.

Fig. 1: Disk harrow Assembly

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Agricultural mechanization has been receiving a considerable interest in recent years due to increasing demand for food due to the expansion of world population. In crop production technology soil tillage is one of the main energy-intensive operations. It is highly expensive, complicated, laborious, fuel consuming and time consuming as well.

Due to high prices of fuel energy the growers have been enforced to apply alternative economic tillage technology. It is obvious that energy saving tillage is preferred to reduce the cultivation costs. Disk Harrow is a primary as well as secondary tillage implement that cuts the soil to a shallow depth for smoothening and pulverizing the soil as well as to cut the weeds and to mix the materials with the soil. There are several types of harrow used in India such as spring harrow, roller harrow, chain harrow, disc harrow.

A Disc Harrow is such tough farming equipment which is peculiarly used for the refinement of that soil where crops are to be embedded and cultivated. Discs have evolved gradually from 10 to 12 inches (25.4 to 30.4 cm) in diameter and now vary widely in diameter from 16 to 22 inches (41 to 56 cm). These discs may be solid, concave or cutaway in design. Some disc types include serrated and scalloped. The type of disc also dictates functionality and the number of discs or blades is typically multiple with 12 to 14 blades per harrow. This number of blades is common on double or tandem disc harrows.

Fig. 2: Erosion of Disk Harrow

A number of factors determine the depth of penetration on a disc harrow. These include the angle of the disc, weight of the harrow, disc sharpness, disc size, and angle on the hitch. Today the disc harrow is commonly used after harvesting to cut up grain stubble left behind in the field. It is also employed as tillage implement aside from the plow.

2. Literature Review

Computational aided work and finite element based analysis have a variety of applications in the field of mechanical engineering. A disk harrow is considered in this project work for the life improvement on the basis of deformation, stress and strain for the selection of best material. Kshirsagar Prashant R, *et, al.*, (2016), has done the work on design and analysis one of such machine is Multifunctional Agricultural Vehicle (Kshirsagar Prashant R *et al,* 2016). Dehghan-Hesar H, *et, al.,* (2016), had presented a numerical investigation regarding the stress distribution on the new designed disc harrow using the ANSYS software (Dehghan-Hesar H *et al,* 2016). Kridsana Tianmanee *et al.*, (2016), had investigated the soil texture parameter in the upland of KhonKaen Province; Thailand (Kridsana Tianmanee *et al,* 2016). ManjeetPrem, *et, al.*, (2016), had done the investigation in cost, time and fuel consumption in agricultural tool (Manjeet Prem *et al*, 2016). John Morris Togo Kaji *et. al.,* (2015) had worked attempt to modify the conventional tillage implement for better use in agroforestry system [5].

Sachin V Pathak, *et. al.*, (2015) had done work on agricultural mechanization (Sachin V Pathak *et al*, 2015). Adewunmitaiwo, *et. al.,* (2015), had determine the wheel slippage of a 2-WD, tractor during primary tillage operations on the Atabadzi soil when the tractor was mounted with a two bottom and three bottom disc plough; determine wheel slippage of the tractor during harrowing operation on the soil when mounted with a tandem disk harrow; determine the level of significance of the soil surface condition effect on the tractor wheel slippage during any of the three tillage operations in the soil (Adewunmi TAİWO *et al*, 2015).

Naimatul lahleghari, *et,al.,*(2015) had worked on tillage practices affect physical properties of soil that are crucial for better crop production (Naimatullah Leghari *et al,* 2015). N. leghari,*et,al.*, (2015) work had conducted to evaluate the consumption of fuel at different tillage implements, tractor operating speed and its wheel slippage (N. Leghari *et al*, 2015). Anas DA bd Allah Mohammed A. Ali, *et, al.,* (2015), had done experimental work involved five implements which were tested at three speeds under two levels of soil moisture content (Anas Abd Allah *et al,* 2015).

3. Cad Modeling and Pre-Processing

Computer Aided Design software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

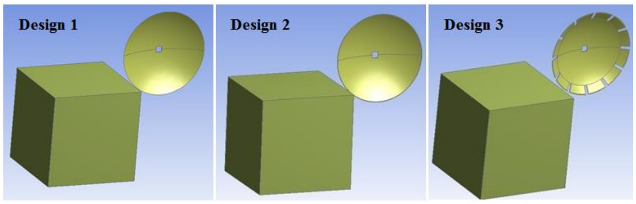

Fig. 3: CAD Models of Disk Harrow with Soil Body

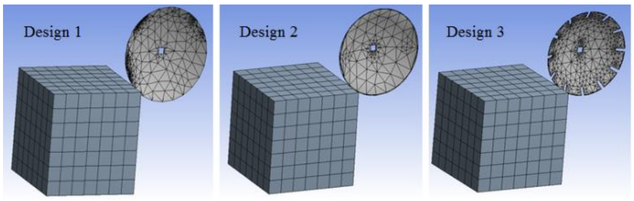

Fig. 4: Meshing view of all designs of disk harrow

CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. CAD modeling uses the computer to design objects or systems that model component attributes with real world behavior.

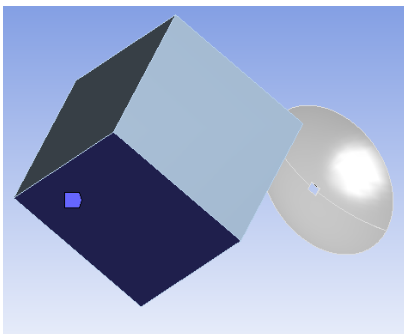

Fig. 5: Fixed support to the bottom side of the soil body

Parametric models use feature-based, solid and surface modeling design tools to manipulate the system attributes. One of the most important features of parametric modeling is that attributes that are interlinked automatically change their features. In other words, parametric modeling allows the designer to define entire classes of shapes, not just specific instances. Before the advent of parametric, editing the shape was not an easy task for designers.

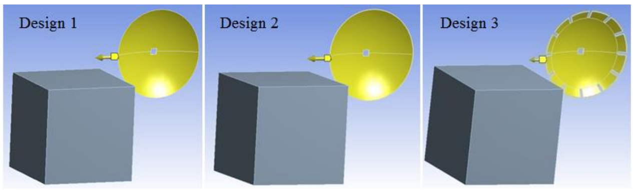

Fig. 6: Velocity of disk harrow (7 KM/Hrs.)

Autodyn simulates the response of materials to short duration severe loadings from impact, high pressure or explosions. It is best suited for simulating large material deformation or failure. Complex physical phenomena such as the interaction of liquids, solids and gases; the phase transitions of materials and the propagation of shock waves can all be modeled within Autodyn.

4. FEA Simulation and Post-Processing

Finite Element Analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

The following are the constant parameters, which remains fix during the whole finite element explicit dynamics analysis of the disk harrow using ANSYS Workbench. The constant parameters are,

- Fixed support to the bottom side of soil body,
- Velocity of the disk harrow 2 m/s (Tractor Speed),
- Type of Analysis,
- Type of soil: Sandy Loam
- Time steps.

The following are the variable parameters, which remains fix during the whole finite element explicit dynamics analysis of the disk harrow using ANSYS Workbench. The variable parameters are,

- Disk harrow designs,
- Disk harrow materials.

Case 1: Analysis of Disk Harrow Design 1 made by Structural Steel (Existing Design & Material of Disk Harrow and Soil is Sandy Loam)

The case study 1 describes the analysis of disk harrow design 1 with structural steel material on sandy loam. In this analysis the material of disk harrow is structural steel and material of soil body is sandy loam. All other environmental conditions remain same. The following are the output contour diagrams of disk harrow - sandy loam analysis.

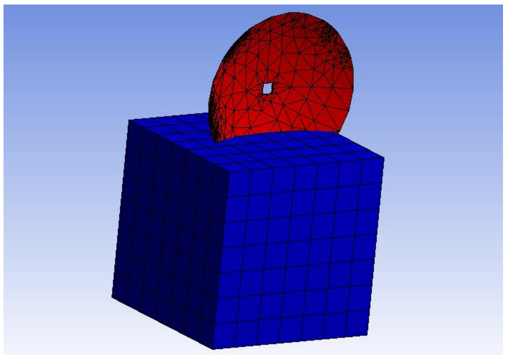

Fig. 7: Analysis of Design 1 with Structural Steel

- Total Deformation: 210.96 mm
- Equivalent Elastic Strain: 0.000489
- Equivalent Stress: 2.734 MPa

Case 2: Analysis of Disk Harrow Design 1 made by Stainless Steel (Existing Design & Proposed Material of Disk Harrow and Soil is Sandy Loam)

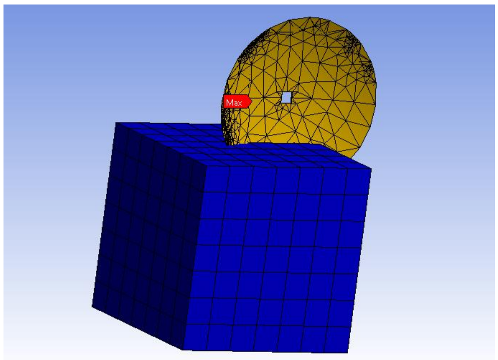

Fig. 8: Analysis of Design 1 with Stainless Steel

- Total Deformation: 204.84 mm
- Equivalent Elastic Strain: 0.000475
- Equivalent Stress: 2.655 MPa

Case 3: Analysis of Disk Harrow Design 1 made by Steel EN45 (Existing Design & Proposed Material of Disk Harrow and Soil is Sandy Loam)

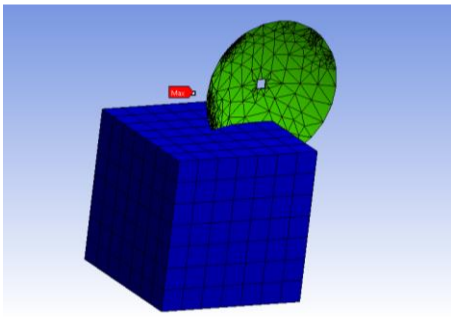

Fig. 9: Analysis of Design 1 with Steel EN45

- Total Deformation: 198.39 mm
- Equivalent Elastic Strain: 0.000460
- Equivalent Stress: 2.571 MPa

Case 4: Analysis of Disk Harrow Design 2 made by Structural Steel (Proposed Design & Existing Material of Disk Harrow and Soil is Sandy Loam)

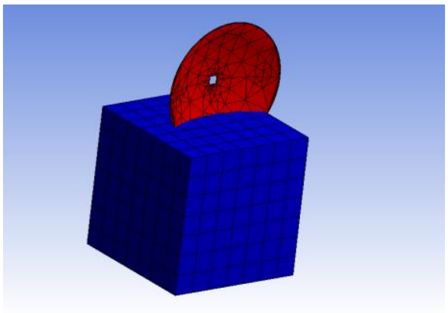

Fig. 10: Analysis of Design 2 with Structural Steel

- Total Deformation: 206.32 mm
- Equivalent Elastic Strain: 0.000478
- Equivalent Stress: 2.674 MPa

Case 5: Analysis of Disk Harrow Design 2 made by Stainless Steel (Proposed Design & Material of Disk Harrow and Soil is Sandy Loam)

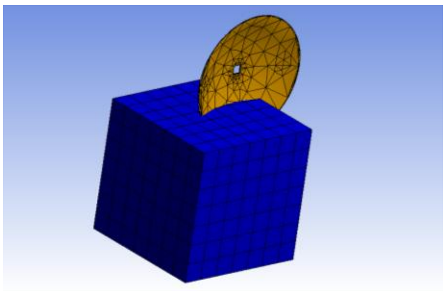

Fig. 11: Analysis of Design 2 with Stainless Steel

- Total Deformation: 200.13 mm
- Equivalent Elastic Strain: 0.000461
- Equivalent Stress: 2.578 MPa

Case 6: Analysis of Disk Harrow Design 2 made by Steel EN45 (Proposed Design & Material of Disk Harrow and Soil is Sandy Loam)

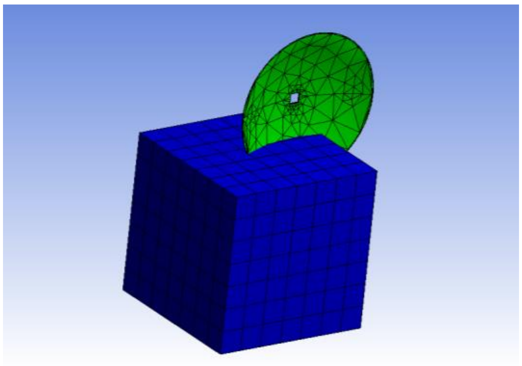

Fig. 12: Analysis of Design 2 with Steel EN45

- Total Deformation: 188.47 mm
- Equivalent Elastic Strain: 0.000437
- Equivalent Stress: 2.443 MPa

Case 7: Analysis of Disk Harrow Design 3 made by Structural Steel (Proposed Design & Existing Material of Disk Harrow and Soil is Sandy Loam)

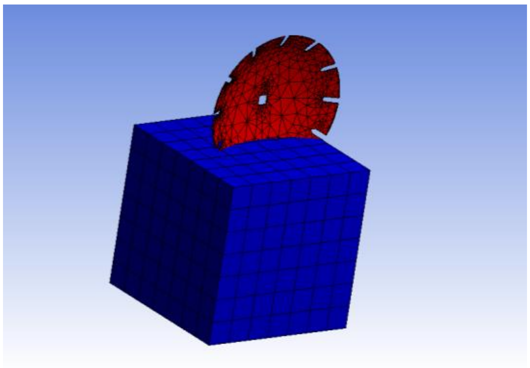

Fig. 13: Analysis of Design 3 with Structural Steel

- Total Deformation: 139.23 mm
- Equivalent Elastic Strain: 0.000323
- Equivalent Stress: 1.804 MPa

Case 8: Analysis of Disk Harrow Design 3 made by Stainless Steel (Proposed Design & Material of Disk Harrow and Soil is Sandy Loam)

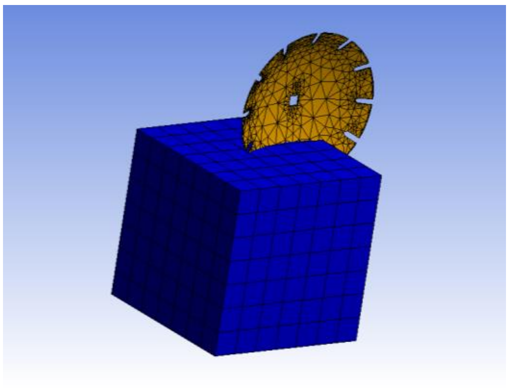

Fig. 14: Analysis of Design 3 with Stainless Steel

- Total Deformation: 127.08 mm
- Equivalent Elastic Strain: 0.000283
- Equivalent Stress: 1.554 MPa

Case 9: Analysis of Disk Harrow Design 3 made by Steel EN45 (Proposed Design & Material of Disk Harrow and Soil is Sandy Loam)

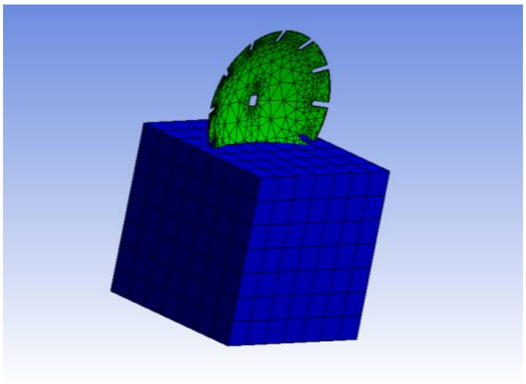

Fig. 15: Analysis of Design 3 with Steel EN45

- Total Deformation: 103.66 mm
- Equivalent Elastic Strain: 0.000232
- Equivalent Stress: 1.246 MPa

Thus, the finite element analysis of disk harrow with its all nine cases has been done by using ANSYS Workbench Explicit Dynamics Analysis. Each case has the analysis results in terms of numerical and graphical representation.

5. Selection of Suitable Model of Disk Harrow using MANOVA

Design optimization is the process of finding the best design parameters that satisfy project requirements. Engineers typically use design of experiments (DOE), statistics, and optimization techniques to evaluate trade-offs and determine the best design. Design optimization often involves working in multiple design environments in order to evaluate the effects that design parameters have across interrelated physical domains. It is a field of engineering that uses optimization methods to solve design problems incorporating a number of disciplines. It is also known as multidisciplinary optimization and multidisciplinary system design optimization.

Multivariate analysis of variance (MANOVA) is simply an ANOVA with several dependent variables. That is to say, ANOVA tests for the difference in means between two or more groups, while MANOVA tests for the difference in two or more vectors of means.

Table 1: Analysis of Disk Harrow on Sandy Loam

Case No.	Description of Case Studies		Total Deformation	Equivalent Elastic Strain	Equivalent Stress
	Designs	Materials	mm	mm/mm	MPa
1	Design 1	Structural Steel	210.96	0.000489	2.734
2		Stainless Steel	204.84	0.000475	2.655
3		Steel EN45	198.39	0.000460	2.571
4	Design 2	Structural Steel	206.32	0.000478	2.674
5		Stainless Steel	200.13	0.000461	2.578
6		Steel EN45	188.47	0.000437	2.443
7	Design 3	Structural Steel	139.23	0.000323	1.804
8		Stainless Steel	127.08	0.000283	1.554
9		Steel EN45	103.66	0.000232	1.246

Table 2: Mean analysis of dependent variables on the basis of design of disk harrow

S. No.	Dependent Variable	Design	Mean Value
1	Total Deformation (mm)	Design 1	204.73
		Design 2	198.31
		Design 3	123.33
2	Equivalent Elastic Strain (mm/mm)	Design 1	0.000475
		Design 2	0.000459
		Design 3	0.000279
3	Equivalent Stress (MPa)	Design 1	2.653
		Design 2	2.565
		Design 3	1.535

Table 3: Mean analysis of dependent variables on the basis of material of disk harrow

S. No.	Dependent Variable	Material	Mean Value
1	Total Deformation (mm)	Structural Steel	185.5
		Stainless Steel	177.35
		Steel EN45	163.51
2	Equivalent Elastic Strain (mm/mm)	Structural Steel	0.000430
		Stainless Steel	0.000406
		Steel EN45	0.000376
3	Equivalent Stress (MPa)	Structural Steel	2.404
		Stainless Steel	2.262
		Steel EN45	2.086

Thus, the mean analysis of dependent variables on the basis of design of disk harrow represents that minimum deformation occurs in Design 3, Minimum Equivalent Elastic Strain occurs in Design 3 and also the stress is minimum in disk harrow Design 3.

Also the mean analysis of dependent variables on the basis of material of disk harrow represents that the minimum deformation occurs in Steel EN45 material, the Equivalent Elastic Strain occurs minimum in Steel EN45 and the Equivalent Stress is also minimum in Steel EN45.

Thus, the disk harrow of Design 3 made by Steel EN45 material is the suitable combination of design and material, which gives the optimum value for efficient working in sandy loam soil.

6. Comparison of Proposed Model with Existing Model

The finite element analysis has been done by using ANSYS Workbench Explicit Dynamics Module and optimization done by using MANOVA statistical tool. On the basis of FEA & MANOVA the following are the comparisional outcomes of new model with existing model.

Table 4: Comparison of Existing Design with Proposed Design

S. No.	Dependent Variable	Design 1 + Structural Steel (Existing)	Design 3 + Steel EN42 (Proposed)	Improvement (in times)
1	Total Deformation (mm)	210.96	103.66	2.04
2	Equivalent Elastic Strain (mm/mm)	0.000489	0.000232	2.11
3	Equivalent Stress (MPa)	2.734	1.246	2.19

Table 5: Cost Analysis

S. No.	Disk Harrow Design + Material	Material Price (Rs./Kg)	Weight (Kg)	Price/ Piece (Rs.)	Manufacturing Cost (Rs.)	Total Cost/Piece (Rs.)	Set Price of 14 Pieces (Rs.)
1	Design 1 + Structural Steel	68	8.5	578	190	768	**10752**
2	Design 3 + Steel EN45	64	7.8	499.2	190	690	**9660**

Table 6: Comparison of Cost for Existing and Designed Model

Cost Analysis	Existing Model	Designed Model
Description	Design 1 + Structural Steel	Design 3 + Steel EN45
Set Cost (14 Pieces)	10752	9660
Cost Decreased by 10.16 %		

Thus on the basis of the above analysis the proposed model have 2.04 times less deformation, 2.11 times less strain and 2.19 times less stress compared to the existing model. The erosion in disk harrow is defined by the deformation, strain and stress occurs. Also erosion is directly proportional to the life of disk harrow. Here the outcomes i.e. total deformation, strain and stress have approx 2 times less value compared to existing value. If the erosion occurs 2 times less, then the life is increased by approx 2 times.

Thus the proposed model has 2 times greater life compared to the existing model of disk harrow.

7. Cost Analysis

The cost analysis of existing model and designed model is based on the material cost per kilograms and mass of the design. The analysis of cost is given above.

Thus the cost of designed model of disk harrow is 10.16% less than existing model.

Conclusion

The conclusion is completely based on finite element simulation results and MANOVA statistical results. The disk harrow had been analyzed with three different designs on three high strength based materials. The whole analysis had been done on sandy loam soil.

- The total deformation results shows the suitable design is design 3 with steel EN45 material.
- The equivalent strain results shows the suitable design is design 3 with steel EN45 material.
- Also the equivalent stress results shows the suitable design is design 3 with steel EN45 material.
- The life of existing disk harrow is approx 10 months, here the life of designed disk harrow is approx 2 times greater than existing model. Thus, the life of designed disk harrow is approx 20 months.
- The cost of existing model of disk harrow is Rs. 10752 and the cost of designed model of disk harrow is Rs. 9660. It shows that the cost of designed model is 10.16% less than the existing model of disk harrow.

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