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Design and Analysis of Disc Plough for Agricultural Industry

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Abstract

In recent years, technologies around the world are growing at exponential speeds in many fields like manufacturing, automobiles, computers, electronics, etc. The field of agriculture is not an exception. This paper mainly deals with analysis of problems involved in an agricultural instrument called Disc Plough. After thorough analysis of the machine and from various observations we came to know that the weight of the disc plough which is having two sets of 6 blades is such that it could not be pulled by 35 Horse Power tractors. We also came to know through various reports that in India most of the farmers are using 35 Horse Power tractors only. Hence the main objective of our paper is to change the design as well as the material of Disc Plough so that it is desirable for land tilling purpose for all types of soils present in India. The concept of reverse engineering is used for redesigning. The Disc Plough is redesigned using Pro/Engineer software. First a prototype of the main design with minimum number of blades was designed using Pro/Engineer software and analysis was done using Ansys software. Then the prototype is fabricated and checked for various stresses and loads. As it was successful, main design of Disc Plough for two sets of 6 blades is going to be fabricated. The model fabricated by us will have less weight compared to conventional Disc Plough. The fuel consumption by the tillers is reduced. The Disc Plough will produce a perfect seedbed in fewer passes.

Keywords: Agriculture, Disc Plough, Design, Analysis, Prototype.

1. Introduction

For the present growing population, the development in the agricultural engineering mainly focuses on modernisation in tillage, development in latest fertilisers and harvesting technologies. This study deals with changing the design of the existing tillage machine, which is used for small size gardens and farms. Tillage which is deeper is known as primary tillage and the shallower is known as secondary tillage. The primary tillage produces rough surface whereas the secondary produces smoother surface [2, 8].

Methods for the measurement and the mathematical representation of road and terrain profiles were described [7]. Observations on the interactions of the load, inflation pressure and dimensions of conventional pneumatic tyres running on different soil surfaces in the context of recent experimental and theoretical research on soil compaction were discussed [9]. A survey

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was conducted [5], to determine what information gaps existed in the human factors data base as far as agricultural engineers were concerned and attempts were made to stimulate research in those areas where gaps were found to exist. Stereotypes regarding the control of the motion of a cube with six degrees of freedom by a single control lever were assessed [6].

Statistical expression for the fatigue life at a welded connection which requires only constant amplitude stress/life data and the standard deviation and ruling frequency of the stress history was derived [4]. The expression has been used to predict fatigue lives from wide-band stress histories from an agricultural soil cultivator. Anthropometric data to calculate mean, range, standard deviation and 5th, 50th and 95th percentile values were collected and analysed [3]. Possibilities of use and benefit from utilising the Reverse Engineering methodologies and techniques in production process were explained [1], especially in the case where parts existed without 3D-CAD support. An advanced methodology for the repair of complex geometry and expensive components via RE, free-form surface modelling and machining was presented [10].

2. Case Study

This work mainly focuses on modification of disc plough attachment for tractors. Based on information gathered from customers of the machine, it was evident that the equipment was heavy and needed 60 Horsepower (HP) tractors; whereas an average farmer in India can afford only a 35 HP tractor. Hence, the motive of this study is to decrease the weight of the equipment through reverse engineering principle without affecting its functionality.

2.1. Analysis of the Machine

The following values were taken from the existing disc ploughing machine. The profile of the disc was scanned using digital scanner and the profile dimension was taken from it.

Diameter of circular blade	=	0.520 m
Thickness of the blade	=	0.00408 m
Angle of the blade	=	19^0
Cross section of sub links	=	square (0.068x0.068m)
Diameter of the shaft	=	0.024 m
Spring wire diameter	=	0.010 m
Pitch of the spring	=	0.013 m
Cross section of main links	=	L angle (0.1x0.1m)
Thickness of main link	=	0.010 m
Material	=	Hardened Cast Iron
Total weight of disc plough	=	935 kg

The following modifications are done on the existing design.

- The angle of blade is increased by 3 degrees.
- Profile of the blade is changed.
- Material of the whole machine is changed from cast iron to plain-carbon steel (mild steel).
- Unnecessary supporting frames were removed.

As the soil conditions are to be considered for ploughing, the testing of the agricultural soil is done. The blade must be designed such that it can withstand the load provided by the soil under various conditions, like in wet condition, dry condition etc. Also the various

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properties of soil like porosity, density etc. are tested which is explained in the sections to come. The modified disc plough is shown in Fig. 1.

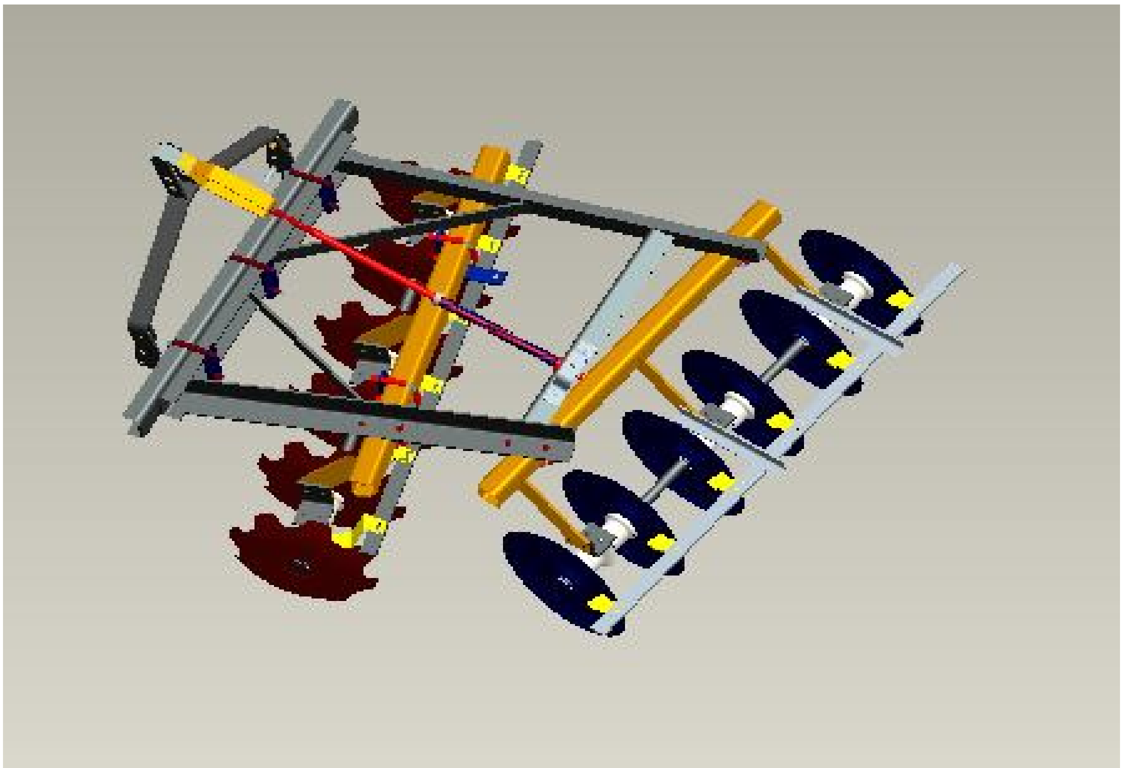

Fig. 1: Modified Disc Plough2.2. Advantages of modified Disc Plough.

- It has lesser weight compared to existing disc plough.
- It can be driven even by 35 HP tractors (which is used by many farmers in India).
- It consumes lesser fuel.

2.3. Prototype

Since the modified Disc Plough is much costlier to manufacture, first a prototype of it is manufactured with the available material. The prototype consists of 2 blades instead of 12 blades. In the prototype, a motor was attached for the driving of Disc Plough. The prototype can be driven manually or using electric supply.

3. Testing of Soil Characteristics

3.1. Soil Characteristics

There are various properties and characteristics of soil which are needed to be considered while designing the blade. Some of the properties which were tested and which were used for calculations are listed below:

- Porosity
- Density
- Specific gravity
- Water content

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3.1.1. Porosity of Soil

Porosity or void fraction is a measure of the void (i.e., "empty") spaces in a material, and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0 and 100%. *Porosity* or *pore space* in soil refers to the volume of soil voids that can be filled by water and/or air.

3.1.2. Density

Density is the weight per unit volume of an object. Particle density is the density of the mineral particles that make up a soil i.e. excluding pore space and organic material.

3.1.3. Specific Gravity

The specific gravity of soil is an important weight-volume property that is helpful in classifying soils and in finding other weight-volume properties like void ratio, porosity, and unit weight.

3.1.4. Water Content

Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics or wood. Water content is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the material's porosity at saturation.

3.2. Soil Testing

3.2.1. Determination of Specific Gravity of Fine-grained Soil

The experiment to determine the specific gravity is carried out as per the standard procedures and results are tabulated.

3.2.2. Specific gravity test

- The specific gravity G of the soil is given by $(W_2–W_1) / [(W_4-W_1)-(W_3-W_2)]$, where
  W_1 is average weight of the bottle
  W_2 is average weight of the bottle with soil
  W_3 is average weight of the bottle with soil and water
  W_4 is average weight of the bottle with water
- The specific gravity should be calculated at a temperature of 27^{o}C. If the room temperature is different from 27^{o}C, the following correction should be done. G' = k * G

Where

G'=Corrected specific gravity

k=[Relative density of water at room temperature]/ Relative density of water at 27^{o}C.

3.2.3. Determination of Density of Soil

Density of soil is determined by the sand replacement experiment. In this experiment particular volume of soil dug out from the field is used. The soil is weighed using a standard weighing machine. The density is calculated as follows.

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3.2.4. Determination of Water Content

A particular amount of soil is taken in a porcelain dish and it is weighed in standard weighing machine. Take it as W_1. The dish with the soil is kept in an oven and it is allowed to remain inside for 24 hours. After this the dish is removed from the oven and it is weighed separately using standard weighing machine. Take it as W_2. The Weight of the empty pan is taken as W.

Water content of soil=weight of wet soil–weight of dry soil

$=(W_1–W)–(W_2–W)$

Where, W_1=weight of wet soil with pan in kg

W_2=weight of dry soil with pan in kg

W=weight of empty pan in kg

Density=mass / volume (in kg/m^3)

k=[Relative density of water at room temperature]/ Relative density of water at 27^oC.

Water content of soil=weight of wet soil–weight of dry soil

$= (W_1–W)–(W_2–W)$

Where, W_1=weight of wet soil with pan in kg

W_2=weight of dry soil with pan in kg

W=weight of empty pan in kg

3.3. Numerical Evaluations

3.3.1. Numerical Evaluations for Specific Gravity in Soil

The table 1 shows the weight of bottle under various conditions after conducting three trials. The various conditions of the bottle under pycnometer test for carrying out the trials are weight of the empty bottle, weight of the bottle with soil, weight of the bottle with soil & water and weight of the bottle with water.

Table 1: Determination of Specific Gravity (Pycnometer Test)

Conditions	Trial 1	Trial 2	Trial 3
Weight of the bottle in kg (w_1)	0.679	0.657	0.618
Weight of the bottle with soil in kg (w_2)	0.707	0.780	0.729
Weight of the bottle with soil & water in kg (w_3)	1.671	1.655	1.596
Weight of the bottle with water in kg (w_4)	1.405	1.416	1.371

Weight of the bottle (w_1)=0.6513 kg

Weight of the bottle with soil (w_2)=0.7386 kg

Weight of the bottle with soil & water (w_3)=1.6406 kg

Weight of the bottle with water (w_4)=1.3793 kg

Specific gravity=$(W_2–W_1) / [(W_2–W_1)–(W_3–W_4)]$

=(0.7386–0.6513) / [(0.7386–0.6513)–(1.6406–1.3793)]

=0.5017

3.3.2. Numerical Evaluations for Water Content in Soil

Weight of the pan with wet soil (W1) = 1.899 kg

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Weight of the pan with dry soil (W2) = 1.779 kg
Weight of the pan (W) = 0.389 kg
Water content of the soil
$=(W_1–W)–(W_2–W) /(W2–W) \times 100\%$
$=\frac{(1.899–0.389)–(1.779–0.389)}{(1.779–0.389)} \times 100\%$
Water content of the soil is =8.633 %

3.3.3. Numerical Evaluations for Density of Soil

Length of the cube (l)=0.010 m
Breath of the cube (b)=0.010 m
Height of the cube (h)=0.005 m
Volume of the cube=l x b x h
$=5 \times 10^{-7}\ m^3$
Mass of the soil=2.662 kg (Direct observation)
Density of the soil=mass / volume
$=2.662 / 5 \times 10^{-7}$
$=5.324 \times 10^6\ kg/m^3$

4. Introduction- Reverse engineering

Reverse engineering (RE) is a new concept that denotes the process of generating engineering design data from existing components. This term is used to describe the process in which product development follows a reverse order. Rather than the conventional production drawing, the existing product is the starting point.

RE can be treated as the process of analysing a system to:

1. Identify the system's components and their interrelationships
2. Create representations of a system in a new modified form
3. Create the physical representation of the damaged parts.

RE is having applications in the following fields like software engineering, automotive, consumer products, microchips, chemicals, electronics, and mechanical designs. For example, when a new machine comes to market, competing manufacturers may buy one of the machine and disassemble it to learn how it was built and how it works. In some situations, designers give a shape to their ideas by using clay, plaster, wood or foam rubber, but a computer aided design (CAD) model is needed to manufacture the part. Another reason for need of RE is to compress product development time.

4.1. Principle of Reverse Engineering

The process of analysing a system has two goals:

1. To identify the system components and their interrelationship.
2. To create a representation of the system in another form or at a higher level of abstraction.

RE process can principally be seen as a process chain that is composed of three main operations as follows:

4.1.1. Digitisation of the objects

Here, the three dimensional shape of the product is acquired by any appropriate measurement method.

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4.1.2. Processing of the measured data

The three dimensional data acquired is processed in order to fulfil the requirements of the subsequent operation.

4.2. Creation of a CAD model

A complete CAD model of the product must be built in order to represent all relevant data of the product.

5. Prototype

This study initially proposed to fabricate the blade of disc plough for the actual design data. Since real time fabrication on disc plough is not economical, initially a prototype would be designed for testing purpose with reduced scale for the actual loading condition. A brief working of prototype is given below.

5.1. Working of prototype

The motor is coupled to the shaft with pulley by means of a belt drive. The motor is connected to the power supply through a regulator. When the power supply is switched ON, the motor shaft rotates.

The rotary motion of motor shaft is transmitted to the blade shaft, thus tilling the soil. Hence, the ploughing operation is done. It helps in better mixing of fertilizers, etc.

5.2. Design of prototype

The prototype contains wheel shaft, blade and blade shaft. The design of above components is dealt in detail in the following sections.

The design calculations for various parts are described as follows:

5.2.1. Design of roller shaft

Diameter of motor pulley	=0.080 m
Belt tensions T_1	=12.23 kg
T_2	=10.19 kg
Distance between rollers	=0.720 m
Shear stress τ	=42 MN/m^2
Torque acting on the shaft	=0.082 kgm

Equivalent twisting moment $T_e = \sqrt{(M^2+T^2)}$

T_e	=16.15 kgm
Diameter of shaft d	=0.026 m
Standard diameter of shaft	=0.030 m.

5.2.2. Design of Blade

Wheel diameter	=0.150 m
Outer diameter of blade	=wheel diameter +

ploughing depth

=0.150m+3inch

=0.150+0.0762 m

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=0.226 m

Standard outer diameter of blade=0.230 m

5.2.3. Design of blade shaft

Diameter of blade pulley	=0.05 m
Belt tensions T_1	=12.23 kg
T_2	=10.19 kg
Distance between motor pulley and blade shaft	=0.300 m
Shear stress τ	=42 MN/m^2
Torque acting on the shaft T	=0.082 kgm
Bending moment M	=6.73 kgm

Equivalent twisting moment $T_{e=}\sqrt{(M^2+T^2)}$

T_e	=6.73 kgm
Standard diameter of shaft	=0.021 m.

5.3. Fabrication of prototype

The components like blade, shaft, roller shaft, motor, and pulley are assembled on a frame to fabricate the prototype of the designed model. Fig. 2 shows the assembled view of the prototype.

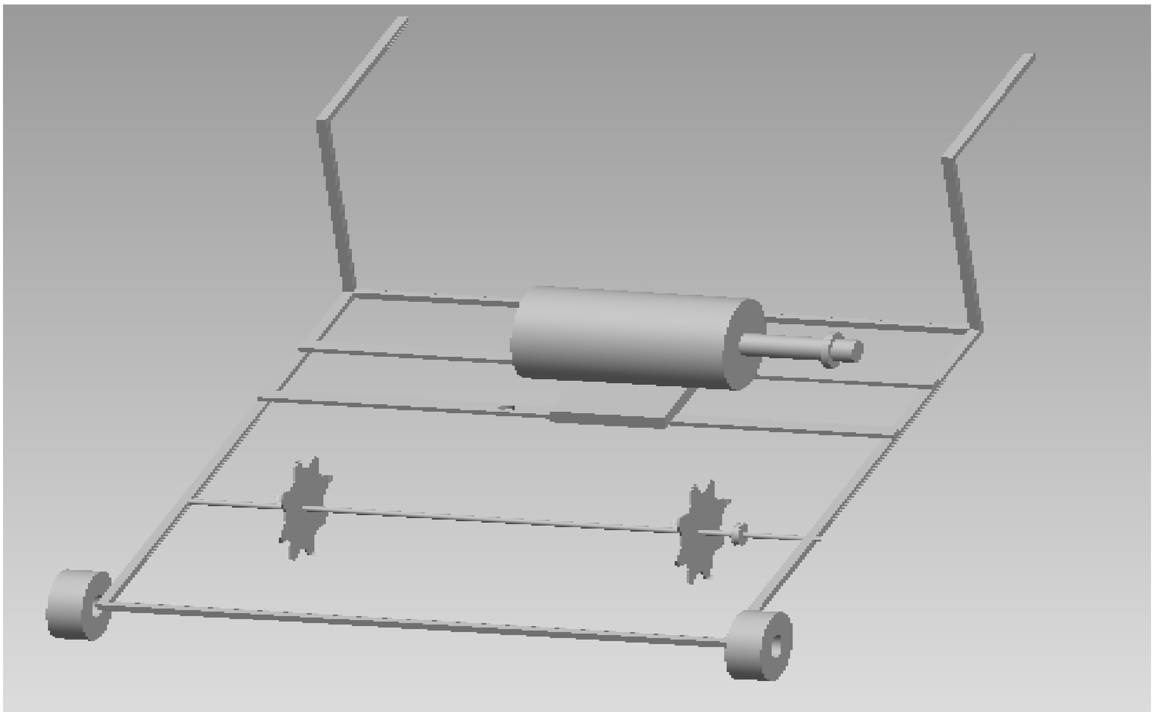

Fig. 2: Assembled View of the Prototype.

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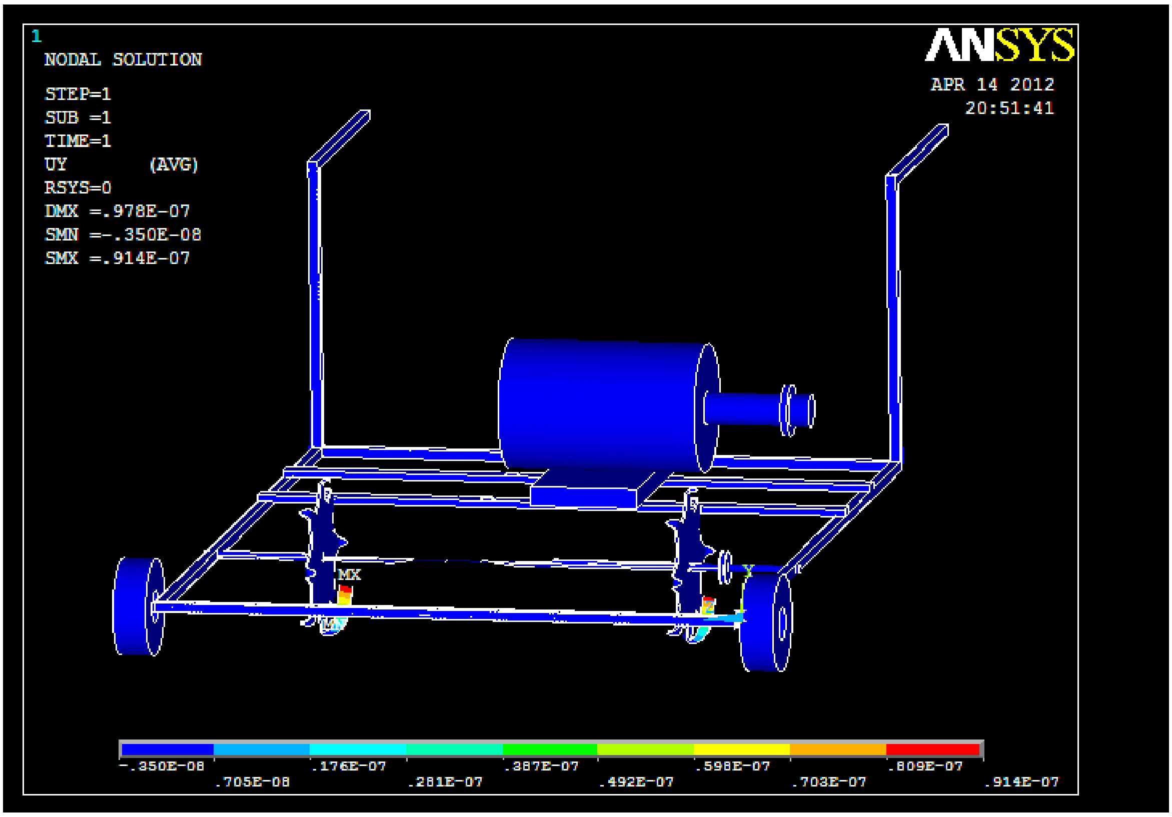

Fig. 3: Nodal Displacement in the component.

6. Analysis of the Prototype

6.1. Analysis of Nodal Displacement

In order to perform structural static analysis on the blades of prototype, a load test was conducted on wet sand, red soil and mountain soil. The result of the load test shows that the wet sand requires 200 N, red soil needs 230 N, while mountain soil requires a maximum of 285 N approximately. Fig. 3 shows the nodal displacement in the component.

A structural analysis using Ansys is carried out on the disc plough. Initially static load of 200 N is applied on the blades and checked for deformation. This load is taken as 200 N considering a normal soil with some amount of stones, other particles and sample operating speed of 750 rpm.

6.2. Analysis of Induced Stresses

The tiller was tested under various soil conditions like wet sand, red soil and mountain soil. In all the 3 cases, the design was found to be safe (as the working stress was less than the ultimate stress). The material used is plain-carbon steel. The ultimate stress of the material was found out to be 350 N/mm^2. Fig. 4 shows the induced stresses in the disc plough while tilling the red soil. The data was obtained when all the three soils (wet sand, red soil and mountain soil) were tested under a speed of 750 rpm is shown in table 2.

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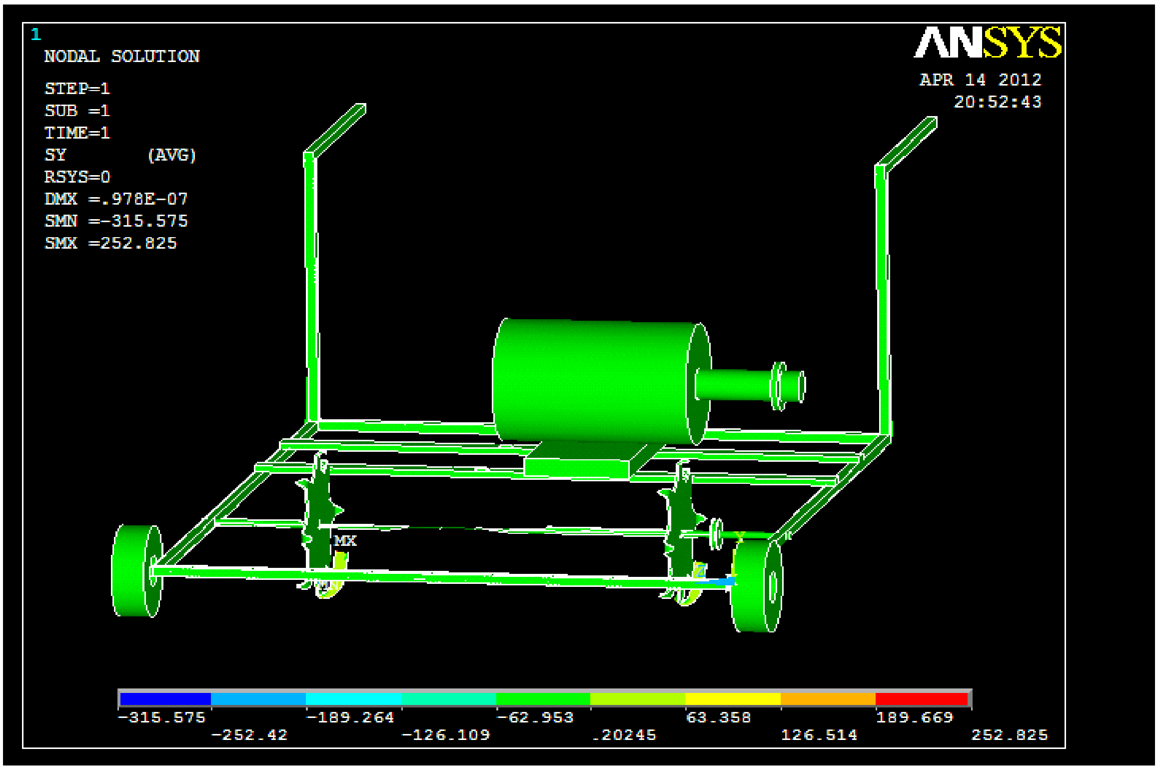

Fig. 4: Induced Stresses in the Component.

Table 2: Stress Induced In Different Soils.

S. No	Soil	Speed (rpm)	Induced stress N/m^2	Ultimate stress N/m^2	Result of Design
1	Wet sand	750	182.58×10^6	350×10^6	Safe
2	Red soil	750	202.45×10^6	350×10^6	Safe
3	Mountain soil	750	222.51×10^6	350×10^6	Safe

7. Advantages

- It can be driven manually by us using the handles.
- It can be driven by motor through electric power supply.
- It can be used for tilling of soil.
- It can be used for short as well as long areas.
- It can be used for mixing of manures.

8. Disadvantages

- It cannot be used for tilling greater depths in soil.
- It requires large amount of wire when tilling larger fields.

9. Applications

- It prepares land suitable for sowing seeds.
- It is used for eradicating weeds.
- It mixes manure or fertilizer into soil.
- It breaks up and renovates the soil.
- Rapid seedbed preparation is possible.

10. Conclusion

A Disc Plough loosens and aerates the top layer of soil which can facilitate the planting of the crop. It helps in the mixing of residue from the harvest, organic matter (humus) and nutrients evenly throughout the soil. It is used for destroying weeds. So it becomes an integral part of agriculture. As India is an agriculture based country, the modified disc plough will be of great use to farmers who cannot afford to buy 60 HP tractors and it helps them to save the fuel. The modified Disc Plough has lesser weight compared to the existing ones and thus it can be driven by even 35 HP tractors. The prototype is safe in all stress analysis tests and it is found that the design is safe.

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