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Dynamic and Fatigue Analysis on Tillage Equipment

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Abstract: *Tillage is an equipment attached to the tractor for ploughing the earth to remove the weeds so as to sow the seeds in a desired manner. The main tool in the tillage equipment is the blade flange assembly which has l-shaped blades and can run with the rated power of motor. This paper mainly focuses on the dynamic (modal, hormonic, transient) and fatigue analysis of the tillage equipment performed using ansys software. Firstly, dynamic analysis is performed and then optimization of the tillage is being done to get better efficiency and factor of safety. The paper covers modal analysis of tillage structure, harmonic analysis performed by providing the force step input and transient analysis performed by providing impulse or shock loads. In each case amplitude plots are extracted to know the dynamic behaviour of the tillage. In this paper, the estimation of life of tillage equipment is also covered. The work exhaustively utilised the nx-cad software for 3d modelling and the ansys apdl for performing dynamic and fatigue analysis of tillage equipment.*
Keywords: *Tillage, Modelling, Dynamic Analysis, Fatigue Analysis,Optimization.*

I. Introduction

Tillage is the agricultural preparation of soil by mechanical agitation of various types such as digging,stirring etc. Tillage equipment loosens the soil and mixes in fertilizer and/or plant material, resulting in soil with a rough texture. Now a days, new technologies are developing by human's knowledge and agricultural technology is one of them. Development of agricultural field is very costliest. Simple structures and good efficiency of components increase the utilization and life growth rate of components. These are all performed in design optimization. Tillage operations such as creation of seedbed movements of soil from high to low places, land levelling etc. have depend on design of tillage. To get good seedbed preparation, design optimization of tillage component is necessary.The main tool in the tillage equipment is the blade flange assembly which has L-shaped blades and can run with the rated power of motor.Current paper presented about 3D model of tillage component by using NX CAD software. Developed 3-D model of tillage component is imported into ANSYS using the Para solid format. The analysis shall be performed in a dynamic condition. Modal analysis, Harmonic analysis and Transient analysis are performed by providing inputs as force impulse or shock loads in FEA software and Fatigue Analysis is performed to check the life of the components.

The paper is organised in the following manner, section 2 gives the details of geometry of the Tillage equipment which is attached to the tractor for ploughing the earth. Section 3 includes the modelling of various parts of the Tillage. Modal and Harmonic analysis is carried out with calculations of tillage and is shown in the section 4. Section 5 discusses the optimization of the Tillage. Section 6 discusses about Modal,Harmonic,Transient and Fatigue Analysis of optimized Tillage.The results and conclusion are given in section 7 and References are given in Section 8.

1.1 Objectives Of The Project

- The main objective of the project is to create or model an efficient Tillage equipment for removing the weeds so as to sow the seeds in a desired manner.
- This can be done by analysing the Tillage equipment in ANSYS 11.0 under dynamic conditions with various types of analysis like Modal Analysis, Harmonic Analysis, Transient Analysis and Fatigue Analysis at the operated loads.
- The Tillage equipment parts are modelled and assembled in NX CAD software by providing suitable dimensions and after that the analysis was carried out.
- Firstly, Modal and Harmonic Analysis are done and depending upon the failures in the Tillage structure, Optimization was made. The optimized model undergoes all types of analysis for checking its behaviour at operated load.
- Modal, Harmonic and Transient Analysis are carried out to determine the behaviour of structure under operated loads whereas the fatigue analysis is carried out to determine the life of the component.

II. Geometry of the Tillage Equipment

The geometry of the Tillage equipment is shown in the fig.2.1.The structure consists of various parts which are assembled together to form a tillage equipment and are as follows. They are blade flange assembly which consists of L-shaped blades, two solid flanges which are added adjacent and opposite, Independent top mast, supports from either sides of the flanges to make the structure balanced and the flange support to which Topmast is constrained. One end of independent top mast is attached to the tractor and other end is attached to the flange support. The main tool in the Tillage equipment is the blade flange assembly which runs with the rated power of motor and is used to plough the earth in order to remove the weeds so as to sow the seeds in a desired manner.

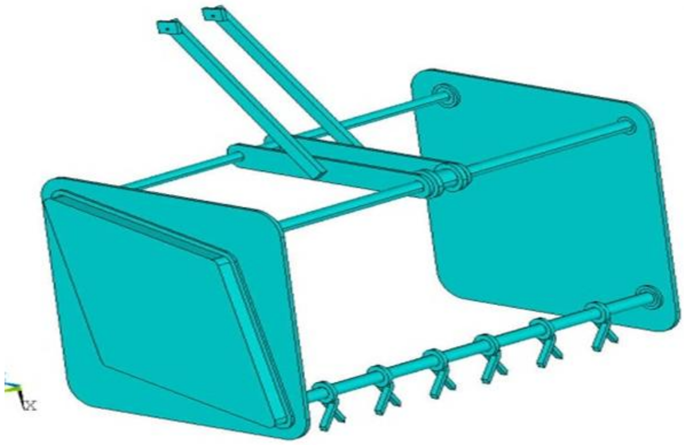


Fig 2.1: Geometry of Tillage Equipment

III. Modelling of Tillage Equipment

3D modelling of Tillage equipment consists of several parts. All the parts of tillage equipment are modelled in NX-CAD software.

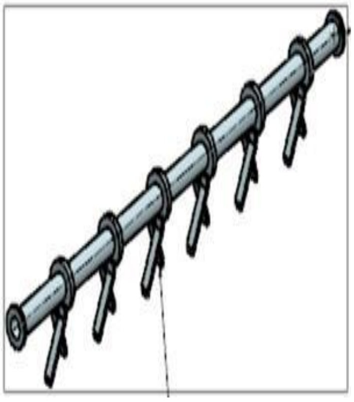


Fig3.1 Blade-Flange Assembly

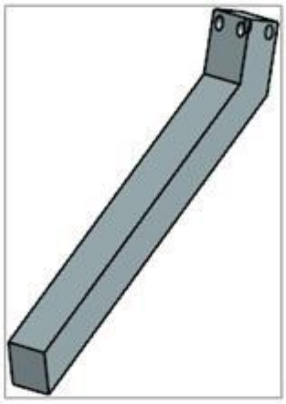


Fig 3.2 L shaped Blade

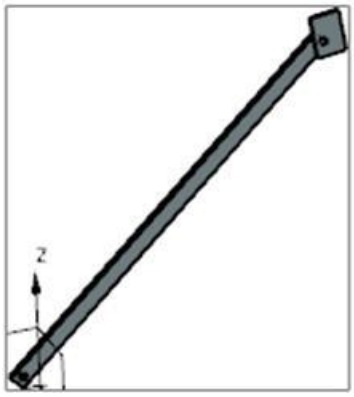


Fig 3.3 Independent Top mast

Fig3.4 Flange

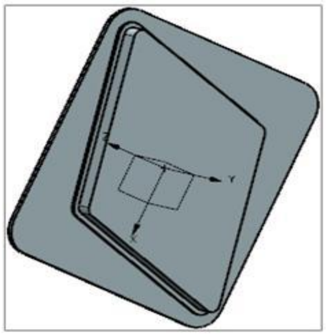


Fig 3.5 Support

Fig 3.6 Flange Support

IV. Dynamic Analysis on Tillage

The body is to be imported from Unigraphics to ANSYS 11.0 in the form of "Parasolid" format to do the further analysis. Here, Modal and Harmonic analysis was carried out with the calculations of tillage and Hadfield Manganese steel is used as a material for the Tillage equipment.

4.1 Modal Analysis:

Modal analysis was carried out on tillage equipment to determine the natural frequencies and mode shapes of a structure in the range of 0 to 3.5 Hz. After the analysis, it was found that only three frequencies exist in the range of 0 to 3.5 Hz and the mode shapes of those frequencies are as follows.

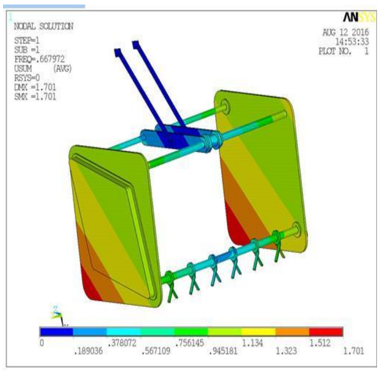


Fig shows mode shape of tillage equipment assembly@0.66Hz

Fig 4.1

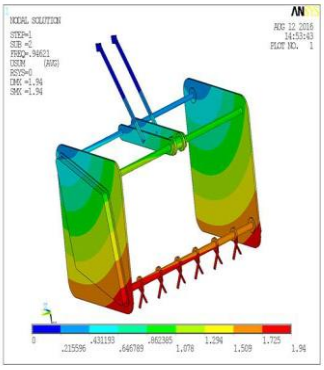


Fig shows mode shape of tillage equipment assembly@0.94Hz

Fig 4.2

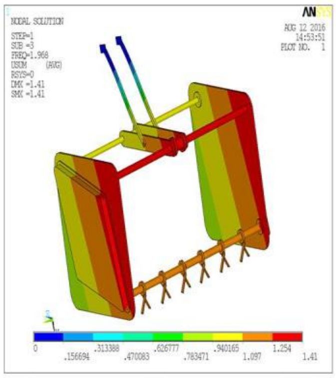


Fig shows mode shape of tillage equipment assembly@1.96Hz

Fig 4.3

Boundary Conditions:

- The positions where the tillage equipment attached to the vehicle is constrained in all DOF.
- The natural Frequencies and corresponding mass participations of tillage equipment in the range of 0 to 3.5 Hz are shown in the form of table.

Table 4.1

Mode	Frequency	Effective mass		
		X-Dir	**Y-Dir**	**Z-Dir**
1	0.66	4.48E-04	8.60E-02	7.58E-04
2	0.94	0.12029	6.28E-05	0.51882
3	1.96	1.23E-07	0.68576	1.68E-05
	Mass Participation	**15.3%**	**87.1%**	**65.3%**

Because of the huge mass participations at the above mentioned frequencies, the frequencies 0.94Hz and 1.96 Hz are critical frequencies. These frequencies may damage the tillage equipment component when a small excitation is given due to resonance. To check the magnitude values of deflections and stresses at the above mentioned frequencies due to the operating loads, harmonic analysis is carried out on the tillage equipment assembly.

Calculations required for Harmonic analysis are as follows.

4.2 Load Calculations

The blades are subjected to impact load when they interact with various types of soils and the impact load is dependent on the properties of soil. The soil pressure of various types of soil is given in Table 4.2(b).In that more amount of pressure is offered by heavy loam soil which produces 0.7kg/cm2 = 0.06867N/mm$^{2.}$

The force acting on the blade is calculated by using the following equations and parameters which are listed in Table 4.2(a) and Table 4.2(b)

Table 4.2(a): Input Parameters

S.No	Parameters	Values
1.	Rotor rpm	210
2.	Reliability Factor(Cs)	1.5(Non-Rocky soils)
3.	Prime mover tractor power(Nc)	45Hp
4.	Traction efficiency(ηc)	0.9
5.	Coeff.of reservation of tractor power(ηz)	0.8
6.	Prime mover forward speed(u mm/sec)	1700
7.	Coeff. of tangential force(Cp)	3

8.	No.of circular segments (i)	6
9.	No.of blades on each side of segment(Ze)	2
10.	No.of blades which action jointly on the soil(Ne)	1

Table 4.2(b): Properties of soil

S.no	Type of soil	Soil pressure(Kg/cm^2)
1	Sandy soil	0.2
2	Sandy loam	0.3
3	Slit loam	0.35-0.5
4	clay	0.4-0.56
5	Heavy loam	0.5-0.7

The tangential force acting along the blade is represented as

Ks =Cs(75*Nc*ηc*ηz/u)

Ks =2.144Kg

The soil force Ke=(Ks*Cp)/(i*Ze*Ne)

Ke=5.2538 N

Converting this force in terms of pressure i.e P=Ke/A

P=5.2538/2.54=2.0684 N/mm^2

As this P>P heavy laom, i.e 2.0684>0.06867 N/mm^2.Thereby this blade can easily dig the soil.
Therefore,the soil force 'Ke' is applied on the blades for further analysis.

4.3 Harmonic Analysis:

Harmonic analysis was carried out to determine the deflections and stress of a structure for all the frequencies in the range of 0-3.5Hz.

Boundary conditions:

The positions where the tillage equipment attached to the vehicle is constrained in all DOF. Flange assembly is rotated with an angular velocity of 21.98 mm/s. Force is applied on the each blade on the flange of the tillage equipment assembly.

Results: Displacements and stresses @0.66 Hz

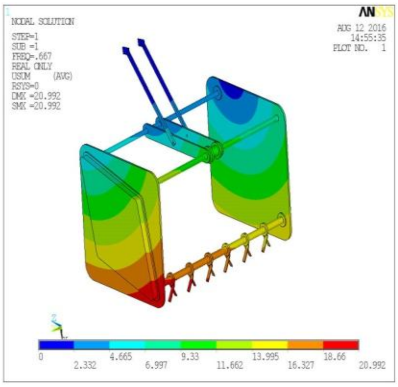


Fig 4.4 Max displacement on tillage

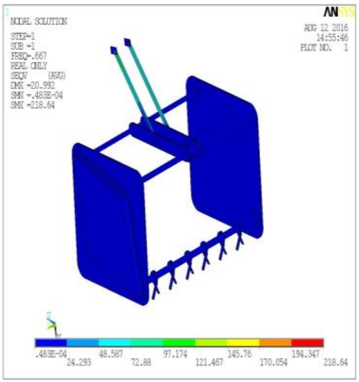


Fig 4.5 Von misses stress on tillage

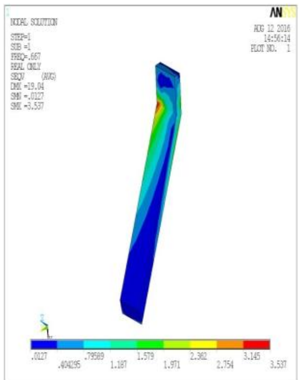


Fig 4.6 Von misses stress on blade

Displacements and stresses @0.94 Hz

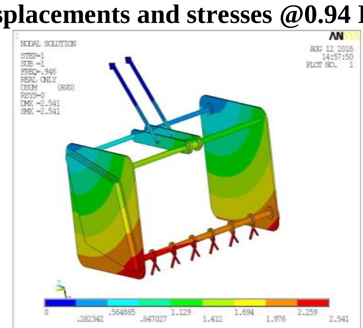


Fig 4.7 Max displacement on tillage

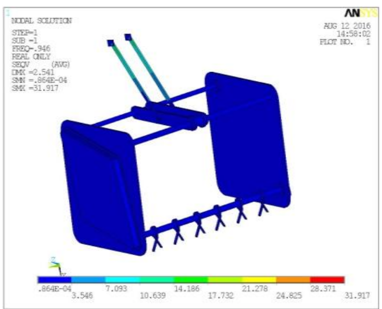


Fig 4.8 Vonmises stress on tillage

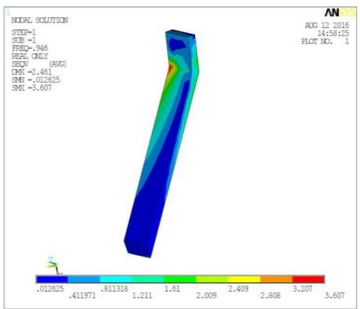
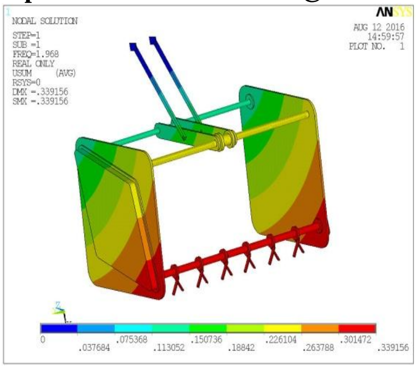
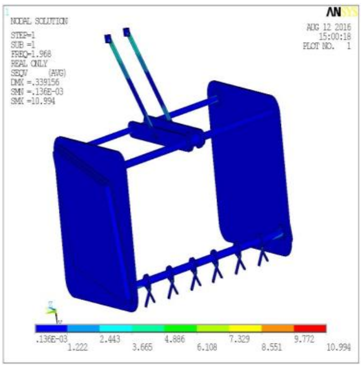


Fig 4.9 Vonmises stress on blade

Displacements and stresses @1.96 Hz





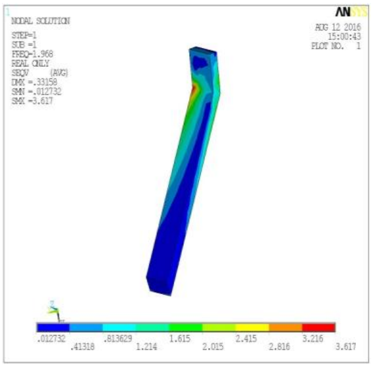
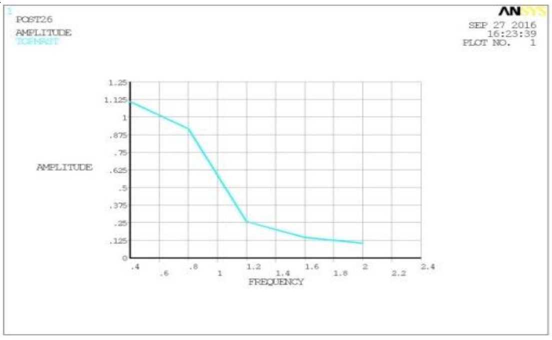
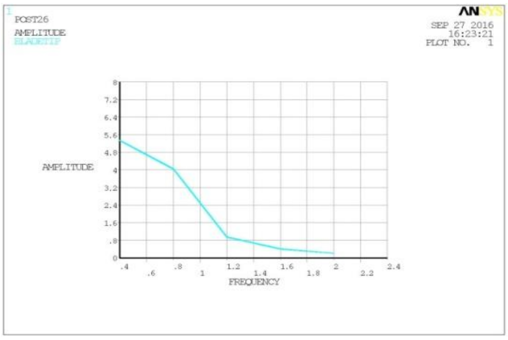


Fig 4.10 Max displacement on tillage **Fig 4.11** Vonmises stress on tillage **Fig 4.12** Vonmises stress on blade

Graphs:





Graph 4.1 Stepped frequencies of Topmast **Graph 4.2** Stepped frequencies of Blade Tip

From harmonic analysis results, the Von misses stress at all frequencies is less than yield strength of the material i.e. 380MPa. In case of 0.66 Hz frequency, the Vonmises stress is less than the yield strength, but considering factor of safety, it is very low. So, there is a chance of failure for sudden loads. Hence, modifications are to be done on the model of tillage equipment assembly to get the better factor of safety.

V. Modelling of Modified Tillage Equipment

Tillage equipment is modified by increasing the thickness of the independent top mast,diameter of hole on top mast and the thickness of the blade is increased for better factor of safety for forced vibrations.

S.No	Parameters	Existing Values(mm)	Optimized Values(mm)
1	Top mast	15	35
2	Hole of Top mast	8	15
3	Blade	6	10

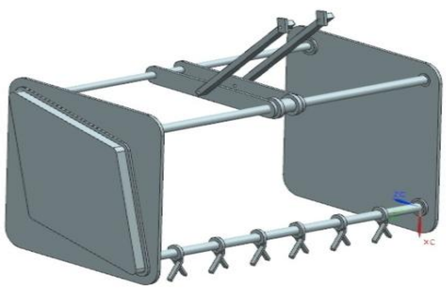


Fig 5.1 Modified Tillage Equipment

VI. Dynamic Analysis on Modified Tillage

The Modal analysis,Harmonic,Transient and Fatigue Analysis of the modified Tillage equipment is discussed here and the results are compared in the conclusions. The modal analysis of modified tillage equipment is as follows.

6.1 Modal Analysis

The positions where modified tillage equipment attached to the vehicle are constrained in all DOF. After modification, only two frequencies are in the range of 0-3.5 Hz which is shown below in the form of table and the mode shapes for those frequencies are as follows.

Table 6.1 Mode shape and Frequency

Mode	Frequency
1	1.31
2	1.45

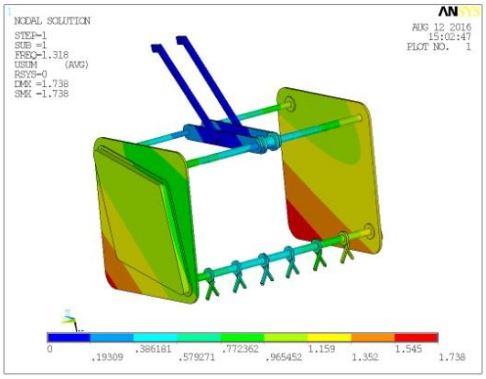


Fig 6.1 Mode shape @1.31 Hz

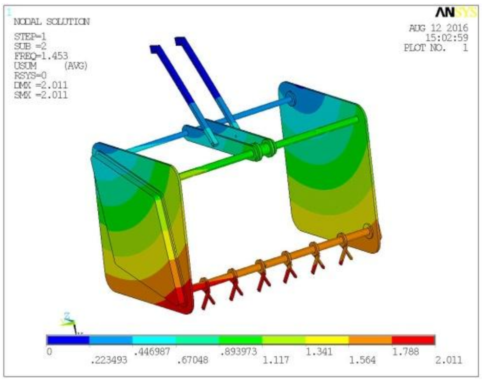


Fig 6.2 Mode shape @1.45 Hz

Table shows the natural Frequencies and corresponding mass participations of modified tillage equipment assembly in the range of 0 to 3.5 Hz.

Table 6.2 Natural Frequencies and Corresponding mass participations

Mode	Frequency	Effective mass		
		X-Dir	**Y-Dir**	**Z-Dir**
1	1.31	2.33E-03	8.60E-02	7.58E-04
2	1.45	0.1127	6.28E-05	0.5188
	Mass Participation(%)	**14.26 %**		**64.55%**

Because of the huge mass participations at the above mentioned frequencies, the frequencies 1.31 Hz and 1.45 Hz are critical frequencies.For that,Harmonic analysis is carried out on the tillage equipment assembly.

6.2 Harmonic Analysis

Harmonic Analysis at the frequencies of 1.31 Hz and 1.45 Hz at a stepped load input are as follows.The Max displacement and Vonmises stress of the tillage and blade at the particular load are shown below.

Displacements and Vonmises stress @ 1.31 Hz

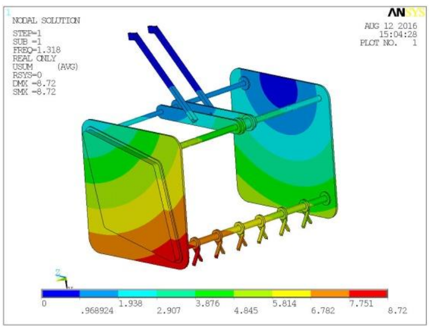


Fig 6.3Max displacement on tillage

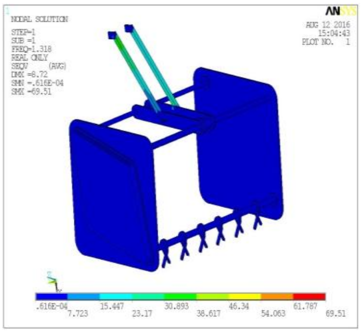


Fig 6.4 Max Vonmises stress

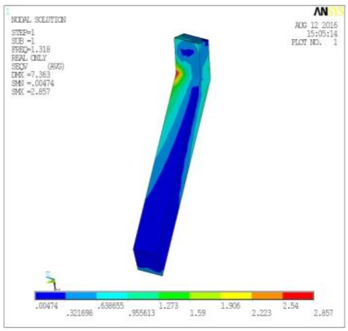


Fig 6.5Max Vonmises stress

Displacements and Vonmises stress @ 1.45 Hz

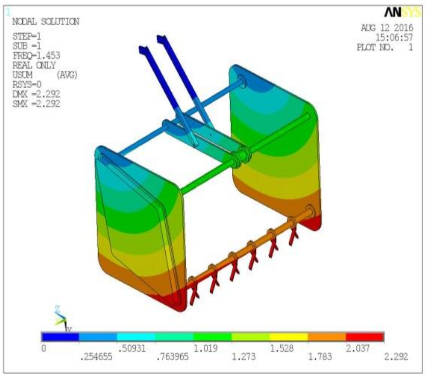


Fig6.6 Max displacement on tillage

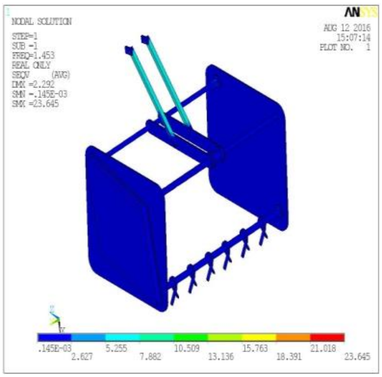


Fig 6.7 Max Vonmises stress

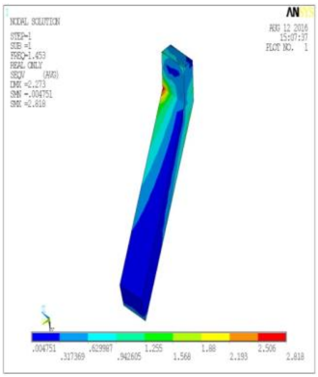


Fig 6.8 Max Vonmises stress

From harmonic analysis results, the Von misses stress at all frequencies are less than yield strength of the material i.e. 380MPa and factor of safety is also high. So, modified tillage equipment assembly further studied for transient loads.

6.3 Transient Analysis on Modified Tillage

Transient analysis is a technique to determine the response of a structure to arbitrary time-varying loads.

Boundary conditions:

The whole load is divided into 2 load steps (time period = 0.28sec) and each load step is divided into 10 sub steps for better convergence.Below figures shows the Vonmises stress of modified Tillage equipment in transient analysis.

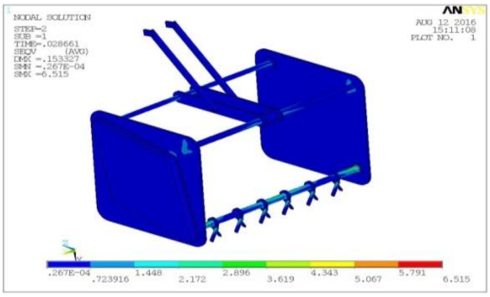


Fig.6.9 Vonmises stress at substep-1 of loadstep-2

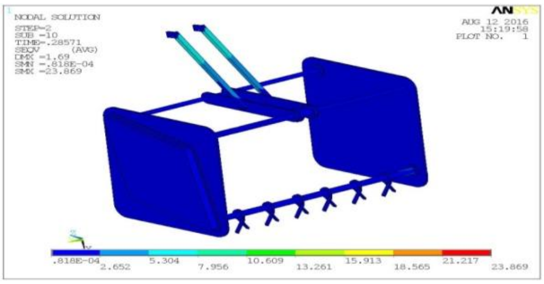


Fig.6.10 Vonmises stress at substep-10 of loadstep-2

From above results of modified tillage equipment,at every sub step of load step-2 has von misses stresses less than yield strength of material.The factor of safety of tillage equipment at every sub step of load step-2 is good. Hence, the modified tillage equipment is also safe for transient loads.

6.4 Fatigue Analysis

Fatigue analysis is done on the modified tillage assembly is to determine the life of the tillage assembly for operating loads. To determine the life of the tillage equipment assembly Goodman's diagram is plotted. To plot the Goodman's diagram, the minimum principal stress and maximum principal stress values are to be determined; along with parameters. Ultimate strength and endurance limit of the material are also to be determined.

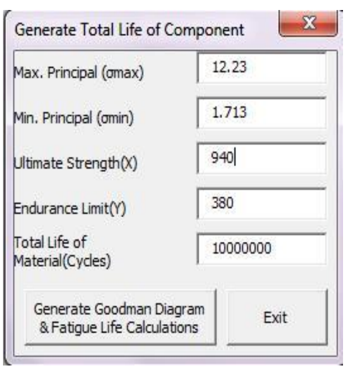


Fig.6.11 Total life of component

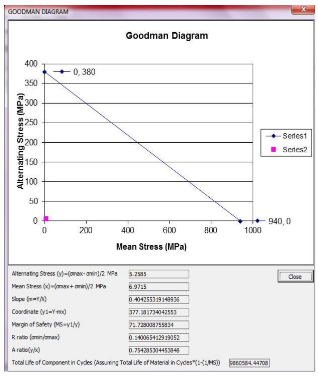


Fig.6.12 Goodman Diagram

From the diagram, the point lies below the line. So, it is concluded that the tillage equipment assembly has infinite life. From the above diagram, it is also mentioned that the total life of component (in cycles) is 9860584.44 cycles.

VII. Results And Conclusion

7.1 Results:

Tillage equipment assembly was modelled in NX-CAD software.Tillage equipment assembly was studied for different analysis. They are

1. Modal analysis
2. Harmonic analysis

Modal analysis of tillage Equipment:

The following observations are made from the modal analysis:

*The total weight of the tillage equipment assembly is 0.78 Tons.

*The mass participation of 0.12 tons is observed at frequency 0.94 Hz in X-direction which is 15.3% of the total mass of the tillage equipment.

*The mass participation of 0.68 tons is observed at frequency 1.96 Hz in Y-direction which is 87.1 % of the total mass of the tillage equipment.

*The mass participation of 0.51 tons is observed at frequency 0.94 Hz in Z-direction which is 65.3 % of the total mass of the tillage equipment.

To check the magnitude values of deflections and stresses at the above mentioned frequencies due to the operating loads, harmonic analysis is carried out on the tillage equipment assembly.

Harmonic analysis of tillage equipment assembly:

From harmonic analysis results, the Vonmises stress at all frequencies is less than yield strength of the material i.e. 380MPa. In case of 1.21Hz frequency, the Vonmises stress is less than the yield strength, but considering factor of safety, it is very low. So, there is a chance of failure for sudden loads. Hence, modifications are to be done on the model of tillage equipment assembly to get the better factor of safety.

3D Model of tillage equipment is modified and following analysis were done on the tillage equipment assembly. They are:

1. Modal analysis
2. Harmonic analysis
3. Transient analysis
4. Fatigue analysis

Modal analysis of modified tillage equipment assembly:

The following observations are made from the modal analysis:

*The total weight of the modified tillage equipment assembly is 0.79 Tons.

*The mass participation of 0.11 tons is observed at frequency 1.45 Hz in X-direction which is 13.9 % of the total mass of the modified tillage equipment.

*The mass participation of 0.086 tons is observed at frequency 1.31 Hz in Y-direction which is 10.8 % of the total mass of the modified tillage equipment.

*****The mass participation of 0.51 tons is observed at frequency 1.45 Hz in Z-direction which is 64.5 % of the total mass of the modified tillage equipment.

To check the magnitude values of deflections and stresses at the above mentioned frequencies due to the operating loads, Harmonic analysis is carried out on the modified tillage equipment assembly.

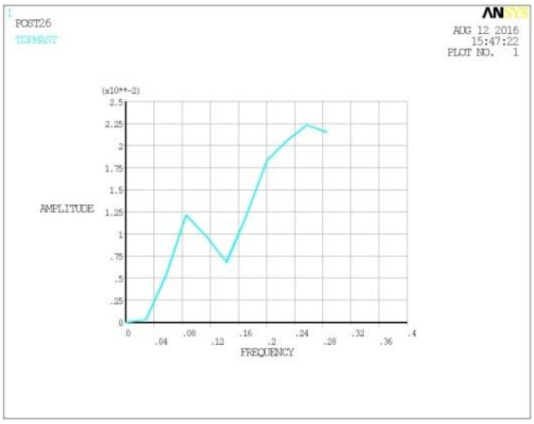
Harmonic analysis of modified tillage equipment:

From harmonic analysis results, the Von mises stress at all frequencies are less than yield strength of the material i.e. 380MPa and factor of safety is also high. So, modified tillage equipment assembly further studied for transient loads.

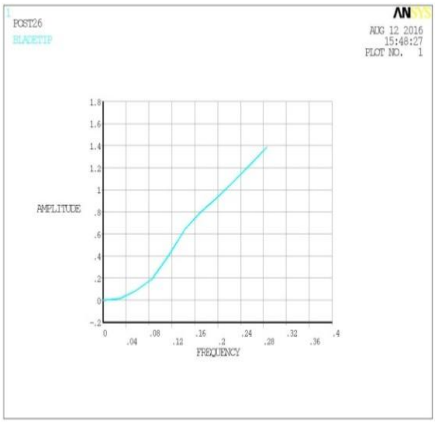
Table 7.1: Transient analysis of modified tillage equipment assembly:

Load sub step	Displacement	Vonmises stress	Factor of safety
STEP 1	0.15	6.5	58.4
STEP 2	0.21	6.05	63.3
STEP 3	0.35	14.04	26.3
STEP 4	0.55	10.92	34.5
STEP 5	0.81	6.94	54.7
STEP 6	0.99	13.03	29.2
STEP 7	1.17	19.81	19

STEP 8	1.38	22.20	17.2
STEP 9	1.54	24.72	15.2
STEP 10	1.69	23.86	15.8



Graph 7.1 Top mast



Graph 7.2 Blade Tip

From above results, modified tillage equipment assembly at every sub step of load step-2 has von misses stresses less than yield strength of material. The yield strength of the material (i.e. steel) is 380 MPa. The factor of safety of tillage equipment at every sub step of load step-2 is good. Hence, the modified tillage equipment is also safe for transient loads.

Fatigue analysis of modified tillage equipment:

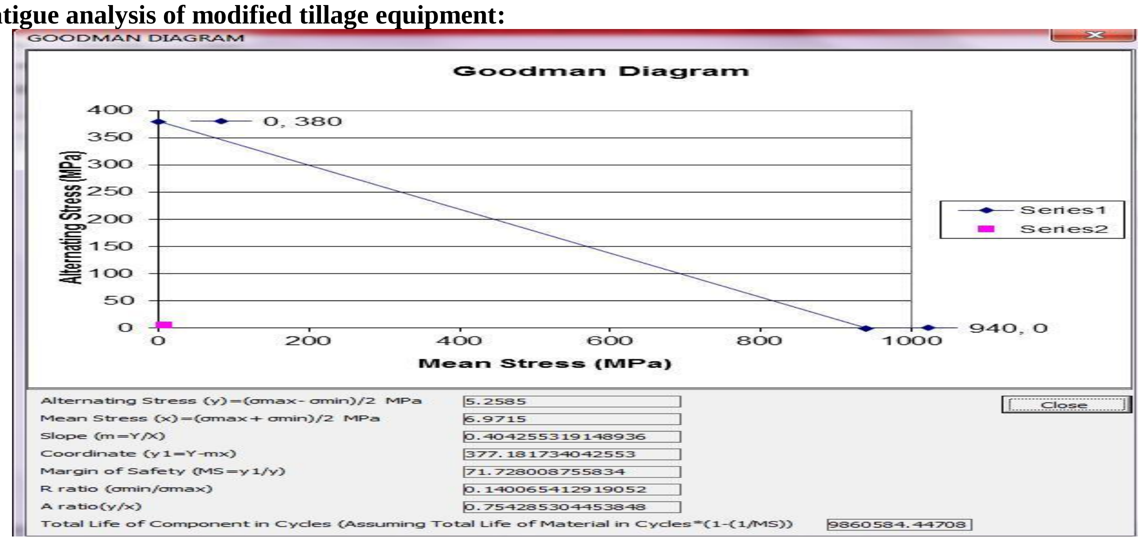


Fig 7.1 Fatigue analysis of modified tillage equipment

From the diagram, the point lies below the line. So, it is concluded that the tillage equipment assembly has infinite life. From the above diagram, it is also mentioned that the total life of component (in cycles) is 9860584.44 cycles.

7.2 Conclusion

The tillage equipment assembly was modelled in NX-CAD software and ANSYS software was used to perform the finite element analysis for Hadfield manganese steel. At first natural frequencies are plotted by performing modal analysis on tillage equipment assembly. Later on Harmonic analysis was carried on tillage equipment assembly. In harmonic analysis, the stress at all frequencies is less than the yield strength of the material but factor of safety is very low at 0.66Hz frequency. So, to get better factor of safety 3D model of tillage equipment assembly was modified. The modified tillage assembly was subjected to modal analysis, followed by harmonic analysis, Transient analysis and Fatigue analysis. All the analysis results are better than original tillage equipment assembly. Hence it was concluded that modified tillage equipment assembly was better than original tillage equipment assembly.

References

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