

Static and modal analysis of a deep soil loosening machine

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Abstract. The article will present a static analysis of the equipment in order to calculate the vector field distribution of the relative - resulting displacement in the structure, the Cauchy stress tensor and tensor fields distribution of the specific deformation in the same structure. This is done in order to improve the structure and highlight the most vulnerable points within an equipment depending on the way of working. After performing the static analysis, tensometric marks were mounted in the most vulnerable points to calculate the displacement of the material and to calculate the major forces that appeared in the structure during the field experiments. At the same time, the idea of the equipment prototype was to improve the equipment with vibrating elements on the working bodies of the body type in order to increase the degree of crushing and to reduce the advancing forces, respectively to reduce the fuel consumption. Therefore, a modal analysis was performed to calculate the vibrations that appeared in the structure in order not to resonate with the frequency of the motor mounted on the working member.

1 Introduction

The development of equipment for the preparation of the germination bed is a topical topic, and in this field there are several types of equipment for the preparation of the germination bed. [5] Most of the research was performed on equipment such as chisel / subsoiler, the research in the field was performed theoretically / laboratory / field. In all these works the same essential things are determined for a tillage machine the Cauchy stress tensor, and in other works the frequencies appearing in the structure are also investigated in order to determine the lifetime of the component elements within an equipment. [6-10] But testing a plow with a vibrating element mounted on each body has not been studied.

Due to the complexity of the designed equipment (fig.1) when it was subjected to analysis due to the lack of power of the computer, the analysis could not be performed, and it was simplified to perform the analysis only on the general framework.

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Fig.1. CAD model of agricultural reversible plow

2 Materials and methods

2.1. Boundary conditions (Structure support)

The structure is supported in three points by the system of connection to the tractor, figure 2. The connection to the tractor is done (exaggeratedly) by rigid fixing (annulment of all degrees of freedom on the contact surfaces between the tractor - plow connection elements).

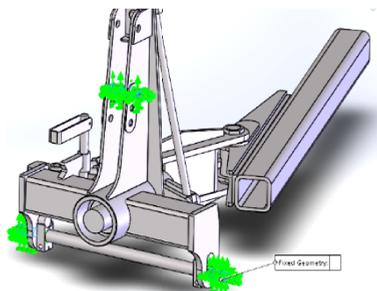


Fig.2. Way of supporting the structure

2.2. Structure loading

The loading of the structure will normally be done on the surface of the working organ in the opposite direction of advancing but taking into account that the framework is studied and not the working organs, because it is harder to replace than a working organ and much more expensive if it yields. . Therefore, a resistance force was applied resulting from the force applied on the three working organs and applied as a resistance force from the ground.

$$F_0 = ka_0b_0 + \epsilon a_0b_0v^2, \quad (1)$$

where index 0 sizes correspond to the working parts of the plow-body. In (1) F_0 is the resistance force of the soil to the action of the plow-body, a_0 , b_0 , are the working depth and width of the respective area of the working part, and k_0 , ϵ_0 , are the specific resistances to deformation of the soil and resistance coefficients to deformation of the soil due to the working speed.

The working speed was noted with v . In the considered example we used the values: $a_0b_0=0.39$ m, $k= 3500$ N·m⁻¹, $\epsilon= 2200$ kg/m³, $v= 5$ km/h. The forces were applied to the

structure according to the graphical representation in figure 3; a force on the working part of about 20 000 N will result.

Also, within the analysis the mass ($m=600$ kg) of the rest of the structure was added in the opposite direction of the force of about 5886 N.

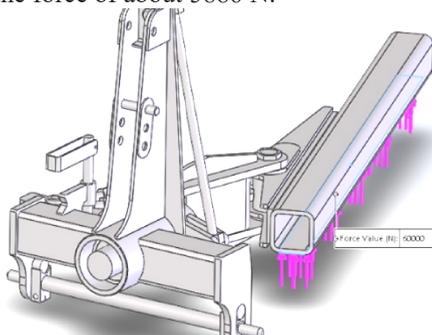


Fig.3. Way to apply loads (forces)

In addition to the force calculated using the formula, the traction force was determined also with the help of the strain gauges applied on the support for fixing the breast to the frame (Fig.4).

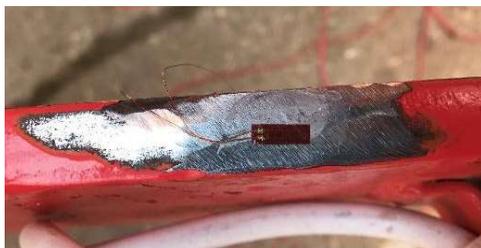


Fig.4. Attaching strain gauges to determine the traction force

This force was calculated under the field conditions and with the qualitative indices from table 1.

Table 1. Field conditions and qualitative indices

Soil compaction test-experimental plot		Soil moisture		Working width (cm)	Working depth (cm)
Depth (cm)	Penetration resistance, (kPa)	Depth, (cm)	Value (%)	100	28
0	386	0-10	15,5	105	31
2,5	537	10-20	25,7	97	33
5	596	20-30	28,4	101	32
7,5	737			93	30

10	772	98	31
12,5	877	100	30
15	1123	102	34
17,5	1193	96	33
20	1404	105	35
22,5	1650		
25	2071		
30	2120		

Figure 5 shows the diagram of the traction force resulted on the experimental plot by the aggregate AGRICULTURAL PLOW FOR 70 KW AGRICULTURAL TRACTORS + TAGRO 102 tractor.

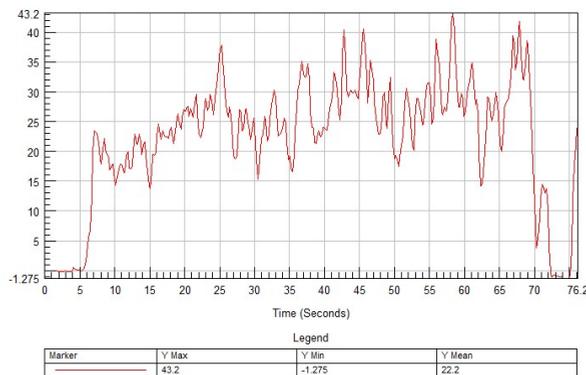


Fig. 5. Average traction force (kN)
 - Traction force of reversible plow with 3 plow-bodies IRUM Reghin

For performing the linear elastic static analysis, the global contact command was applied. This condition applied by the finite element analysis operator eliminates any kind of distances, creating stress conditions corresponding to a structure more rigid than the real one. Thus, the stresses will be higher than the real ones, and the relative displacements (deformations) are expected to have lower values than the real ones. The discretization of the structure can be seen in figure 6.

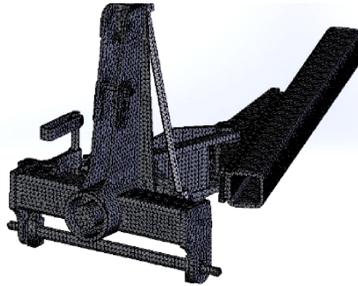


Fig.6. Structure discretization: projection of the finite elements on the boundary of the structure

The material that will be used in the structure analysis is the S275JR material, which has certain properties presented in figure 7.

Property	Value	Units
Elastic modulus	2.100000031e+011	N/m ²
Poisson's ratio	0.28	N/A
Shear modulus	7.9e+010	N/m ²
Mass density	7800	kg/m ³
Tensile strength	410000000	N/m ²
Compressive Strength in X		N/m ²
Yield strength	275000000	N/m ²
Thermal expansion coefficient	1.1e-005	/K
Thermal conductivity	14	W/(m·K)
Specific heat	440	J/(kg·K)
Material Dampning Ratio		N/A

Fig.7. Properties of material S275JR.

3 Results and discussion

The first result of the structural analysis are the reactions that appeared in the structure as a result of the applied force, and the other results are displacement in the structure, the Cauchy stress tensor and tensor fields distribution of the specific deformation, as well the safety factor.[1] Table 2 shows the values of the resulting forces' components, which are also found in the values of the reaction forces (in the three support zones).

Table 2. Values of the resulting forces components

Components	X	Y	Z	Resultant
Reaction force (N)	-3.01367	-54110.8	-2.17969	54110.8

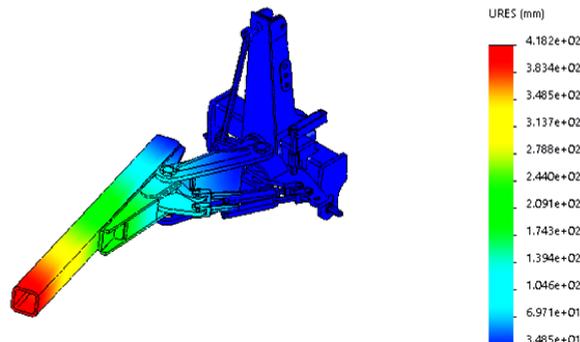


Fig.8. Distribution of the values of the relative resultant displacement field on the structure boundary

The distribution maps of the values of the relative resultant displacement field on the structure boundary are graphically shown in Figure 8. It is noted that the maximum value is located in the back of the structure. This maximum value can be exceeded if clearance of the structure and system connecting the plow and the tractor is taken into account. The increase of the displacement, under the conditions of the considered stress, with the admission of the clearances, contributes to the relaxation of the structure and implicitly the increase of the safety factor. However, exaggerated clearances generally lead to possible wear.

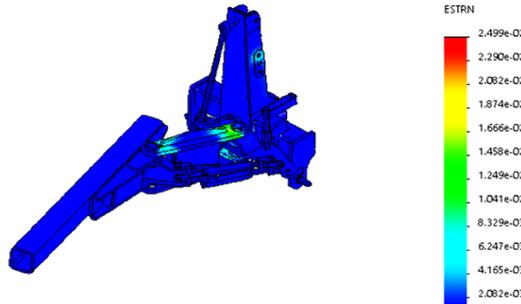


Fig.9. Distribution of total specific deformation field values on the structure boundary.

The distribution of the total specific deformation values is graphically represented by the colour map in Figure 9. Due to the fact that we work in the elastic-linear domain, the maximum tension will be located in the same area as the maximum specific deformation. The maximum equivalent stress is represented graphically in the same way, in figure 10, where it can be seen that very high stresses appear in the middle piece, being a very stressed piece, even if in the design and execution phase of the experimental model a reinforcement was added to eliminate these high stresses.

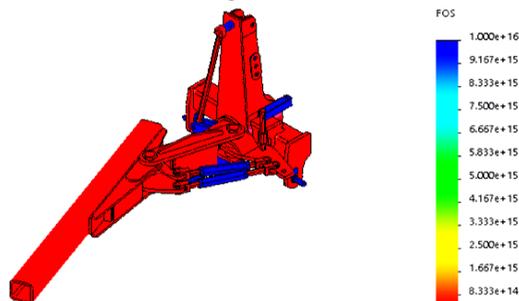


Fig.10. Distribution of the safety factor on the structure boundary

The safety factor is 8.33. For agricultural equipment that work with soil in order to prepare the germination bed, the value of the safety coefficient is between 1.8 and 2.2. The equipment can be oversized or has been designed and thinking to withstand certain accidents during work. Considering the maximum values of the equivalent stress, there is no danger for the structure material to cease.

Due to this very high coefficient, we'll perform an optimization regarding the material used; we'll run the simulation with a material that is weaker in terms of properties (fig. 11), but also cheaper, to reach a coefficient between 1.8 - 2.2.

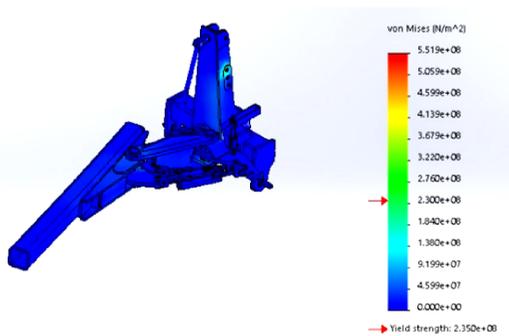


Fig.11. Representation of the equivalent stress distribution on the structure boundary for S235JR material

Because of this, you can no longer talk about observations on the safety factor since it is below 1 in that area. Due to the transformation of the experimental model into a prototype and the addition of the vibrating element to optimize the structure and avoid its resonance, a modal analysis of the basic structure of a plow was also performed. The analysed structure is a modern plow structure, with load bearing structure consisting of plates and pipes. Modal analysis or frequency analysis for this structure, aims to determine its own frequencies and to identify the components with maximum amplitude on each of the basic own frequencies.[4] The intense interaction with the tractor can induce the vibrations of the structure analysed into the resistance structure of the tractor, possibly retransmitted then through suspension to the tractor driver. The consequences can be estimated using the knowledge about vibrations effects on the human body. [2]

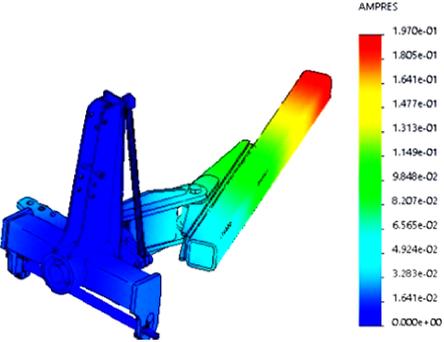
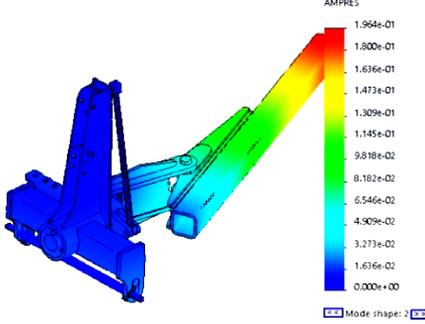
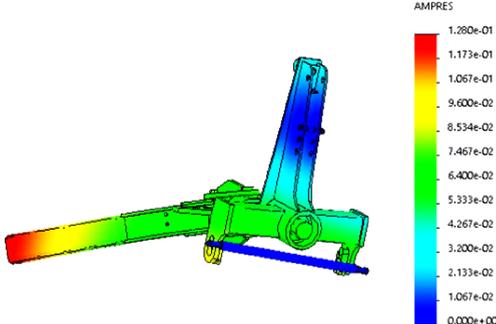
Starting from the findings of the modal analysis, improvements of the system can be made by small modifications of some components of the assembly or by modifying some adjustments allowed in operation or in the operating regime. Finally, we mention that frequency analysis is the first step in dynamic analysis, because the latter uses the first results to calculate the structure response to various time-varying loads. The relative displacements by directions and resultants in the structure, for each vibration mode, are given separately. Also, the colour maps of the relative displacements field are given, by component or resultant.[3] Table 3 shows, from the report of the SOLIDWORKS program, with the help of which (using the SIMULATION module) a frequency analysis was made, a list of the first five own frequencies, corresponding to five vibration modes, each with the normalized displacements on the three directions.

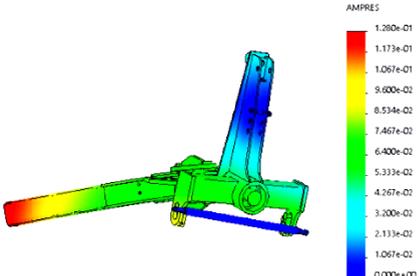
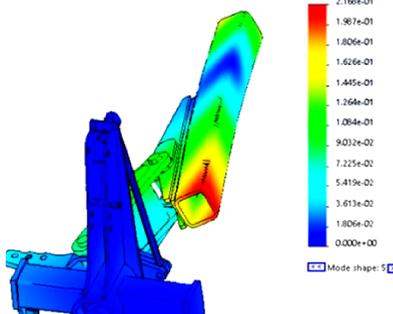
Table 3. First five own frequencies

Mode number	Frequency (Hertz)	Frequency (rad/s)	Direction X	Direction Y	Direction Z
1	16.128	101.33	3.6315e-005	0.00015334	4.8081e-005
2	18.625	117.03	0.021966	0.0088722	4.2245e-008
3	58.632	368.4	0.030122	0.049132	1.301e-006
4	67.257	422.59	0.00032949	0.00028952	0.00022521
5	100.68	632.59	0.00051331	0.00025398	3.3279e-005

Another way to give these results is shown in table 4, where the own frequencies and amplitude maps are given on the deformed form of the structure in the vibration modes corresponding to that frequency.

Table 4. Frequencies and amplitude maps

Mode	Frequency, Hz	Map of amplitude on the deformed form of the structure, mm
1	16.128	
2	18.625	
3	58.632	

4	67.257	
5	100.68	

4. Conclusions

1. Finally, own spectrum is also useful in identifying the source of parasitic own oscillations. Once this oscillation is identified, the source is usually looked for in the working regime: either accidental phenomena (different deficiencies of the aggregate) or, in the existence on the analysed structure of some working devices (pumps for spraying machines, mechanical cutting devices, etc.) that work on the structure's own frequencies or on very close frequencies. In these cases, changes of the working regime of the devices are made or the isolation of these devices from the rest of the structure is improved.
2. The usefulness of this analysis is proven especially in the test phase and even in the first stages of operation, when the working regime of a product of the type analysed must be improved.
3. The frequency of the engine added for introducing vibrations into the working part is not among the five own frequencies calculated. The engine having a speed of 3000 rpm, an engine frequency of 1.21 Hz will result, which is very far from the own frequencies of the equipment structure.

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