FINITE ELEMENT ANALYSIS OF MECHANICAL AGRICULTURAL PARTS

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ABSTRACT: This paper aims to provide valuable information about stresses in the tillage domain, one of the most known sectors in agriculture. A finite element analysis regarding the parts of this equipment is done using a dedicated software, Ansys Workbench, and analytical calculations have been estimated for corelating with the FEA results. Finally, critical sections are observed, and conclusions are drawn.

KEYWORDS: tillage, agriculture, spring, cultivator, finite element analysis.

1. Introducere

The purpose of this research is to do a Finite Element Analysis (FEA) on common tillage equipment used in agricultural applications. Tillage tools are subjected to a variety of loads in operation, therefore maintaining structural integrity is vital to extending their lifespan and improving their performance.

A FEA study helps us to predict how the tillage equipment will respond under different loading conditions and identify potential failure or deformation zones. The findings of the investigation might provide valuable ideas for improving the development and manufacture of tillage equipment, which would assist farmers and the agricultural industry by increasing output and decreasing costs. Finite element modelling (FEM) is used to examine complicated physical systems or structures. It involves dividing a bigger structure into smaller, finite parts, each with their own set of features and characteristics. These pieces are then joined at discrete places – nodes, to form a mesh that can be studied under different loading conditions providing a good visualization of the structure.

In our country, agriculture plays a significant role because people depend on it. Being the primary source of food, it is also an important economic contributor worldwide, this sector providing employment opportunities, which I also look forward to.

Throughout the mid-twentieth century, there was a considerable shift toward conservation tillage, which attempted to limit soil disturbance and conserve soil quality. This resulted in the invention of new tillage instruments, such as chisel plows and field cultivators, which were designed to work the soil at shallower depths and leave crop residue on the surface. Tillage tools are still evolving in response to technological and technical improvements. Many current tillage tools, for example, are built using computer-aided design (CAD) software and made with high-strength materials such as steel alloys. Furthermore, some tillage instruments now have modern features like as GPS navigation systems and hydraulic depth control.

Under the impact of the forces that give content and personality to the revolution in knowledge, society will undergo essential mutations, qualitatively superior, mutations that, as time progresses, will be on an increasingly upward slope. The increasing intensity of this process is guaranteed by the progressive power of the great scientific discoveries that emerged from the 2nd half of the last century [1].

Objectives of finite element analysis in this paper include the following: strength calculation, results interpretation, results comparison, and discussion.

2. Model understanding and analysis

The following model represents an agricultural cultivator. The CAD model (Fig. 1) is imported from Grabcad [2] and then adjusted and simplified in Design Modeller from Ansys to obtain a better model for the following finite element analysis.

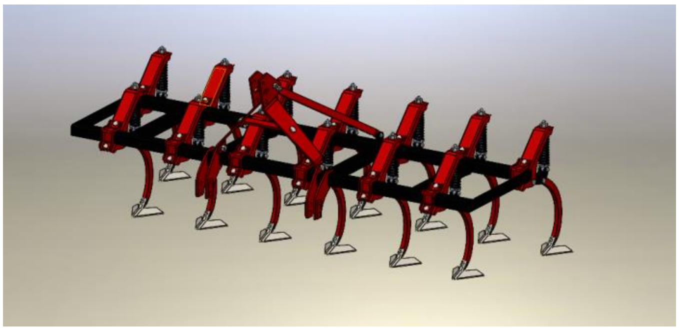


Fig. 1. Cultivator model imported into SolidWorks.

In order not to be distracted by the complexities of the entire machine, only a section (unit) of the cultivator was first analysed to gain deeper understanding of the mechanics and workings of that unit. This way, critical zones will be observed properly, and improvements may be suggested. The analysed unit is composed of several parts, each with its own function (see Fig. 2).

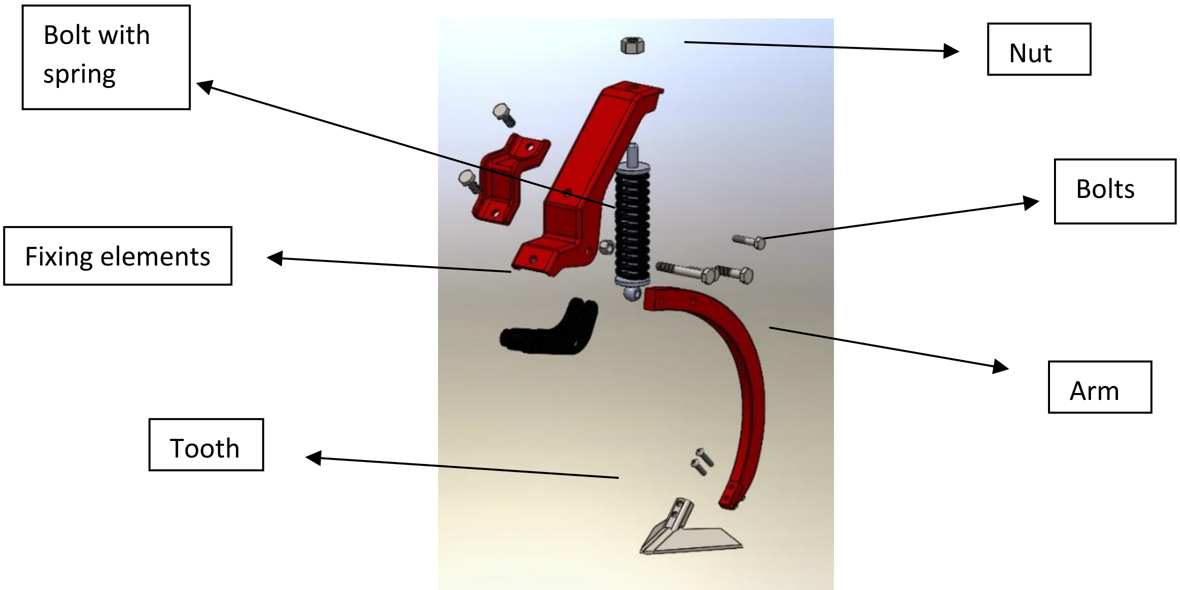


Fig. 2. The analysed unit in Ansys - exploded view.

The tooth is in V-shape to better penetrate and to minimize soil disturbance, improving the efficiency of the operation. The arm has a curvature radius of 280 mm reducing stress concentration and better distributing the load along its length. Fixing elements, including bolts and nuts, create a strong and reliable assembly which is then attached to the main frame.

The most important part is the bolt and spring part, which takes over a big part of the transmitted load. The design is made so that the arm moves backwords when the tooth section meets strange objects (rocks, tree roots etc.) and the length of spring will shrink. Because it represents a critical part in the model, the analysis shall first be focused on the spring. The figure 3 contains measures done on the bolt and spring assembly, measures that are needed for the analytic calculation.

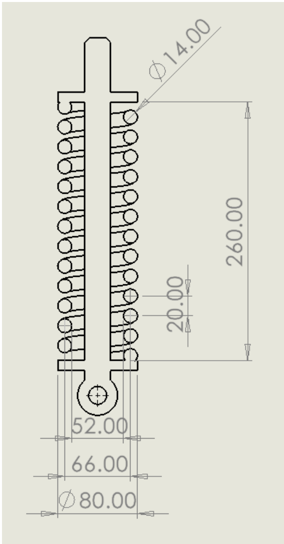


Fig. 3. Bolt and spring dimensions.

The spring model consists of a round-wire helical spring which is compressed by an axial force *F* while the downwards position, in the bolt that attaches the model with the rest of the components, is fixed. Using an engineering handbook [3] the maximum shear stress is calculated:

$$\tau = K_B \frac{8F \cdot D}{\pi d^3}. \tag{1}$$

The equation above is quite general and applies for both dynamic and static loads. K_B represents the Bergsträsser factor, which corrects both for curvature and direct shear, and is given by the measure of the coil curvature, the spring index *C*, defined as

$$C = \frac{D}{d}, \tag{2}$$

and then

$$K_B = \frac{4C+2}{4C-3}. \tag{3}$$

In our case, *C* has a value of 4.7, but for most common springs it is recommend to range between 6 and 12. Furthermore, the spring deflection *y* is computed using [3]

$$y = \frac{8F \cdot D \cdot N}{d^3 \cdot G}, \tag{4}$$

where *N* is the number of active coils and *G* is the shear modulus for steel. The total strain energy *U* is characterised by two components, shear and torsion:

$$U = \frac{T^2 \cdot l}{2GJ} + \frac{F^2 l}{2AG} \tag{5}$$

Knowing that [3]:

$$T = \frac{FD}{2}; \qquad l = \pi DN; \qquad J = \frac{\pi d^4}{32}; \qquad A = \frac{\pi d^2}{4}, \tag{6}$$

it results:

$$U = \frac{4F^2D^3N}{d^4G} + \frac{2F^2DN}{d^2G} \,. \tag{7}$$

Finally, the spring rate k is computed:

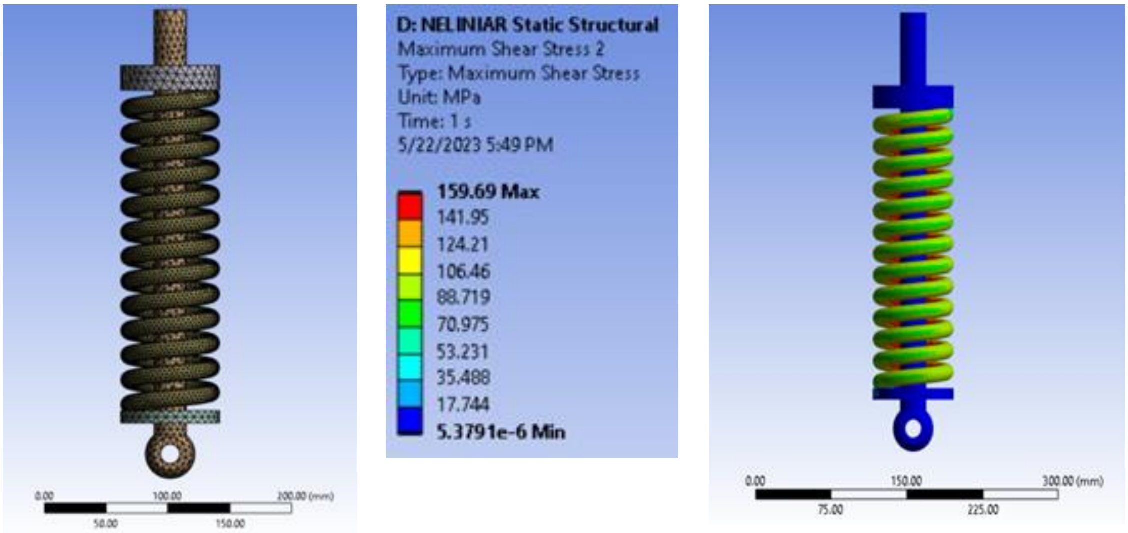
$$k = \frac{F}{y}; \qquad k = \frac{d^4G}{8D^3N} \,. \tag{8}$$

Results of the calculations may be affected by the spring index C and the different correction factors (K_B, K_W, K_S or K_C) used in literature [3]. A higher value is recommended for C, at least 8, and other correction factors directly influence the shear force results [3]. In Table 1, a comparison between the correction factors and maximum shear stress is presented for nominal force in the spring.

TABLE 1. Maximum shear stress in spring coil for different correction factors

Spring						Correction factor				SHEAR STRESS			
Force	Mean coil diameter	Wire diameter	Active coils	Shear modulus	Spring index	Bergsträsser	Wahl						
F[N]	D[m]	d[m]	N[-]	G[Gpa]	C[-]	Kb[-]	Kw[-]	Ks[-]	Kc[-]	τ [MPa]			
1890	0.066	0.014	13	79.3	4.7	1.315	1.332	1.106	1.189	152.262	154.237	128.039	137.662

The geometric complexity of the spring suggested a tetrahedron meshing type, with quadratic elements (10 nodes per element), this way the model is better discretizated without sacrificing the element quality.The FEM for bolt and spring (Fig. 4,a) includes a number of 99712 nodes and a total of 58905 nodes. Results may be affected by the total amount of finite elements (meshing density), so a finer discretization with a higher number of elements would provide better results. In this case a comfortable limit of 100,000 nodes is considered.



(a) Spring and bolt mesh (b) Maximum shear stress distribution

Fig. 4. Bolt and spring meshing and stress results.

Applying a force F_{tooth} on the tine (tooth) of the cultivator, a moment is created (see Fig. 5). Following the distances B (576.8 mm) and b (238.5 mm) with the respect to the point (O) a counterforce F_{spring} is computed (Fig. 5). This may be proven by the use of the following equation:

$$\sum M_O = 0 \qquad \Leftrightarrow \qquad F_{spring} \cdot b = F_{tooth} \cdot B \,. \tag{9}$$

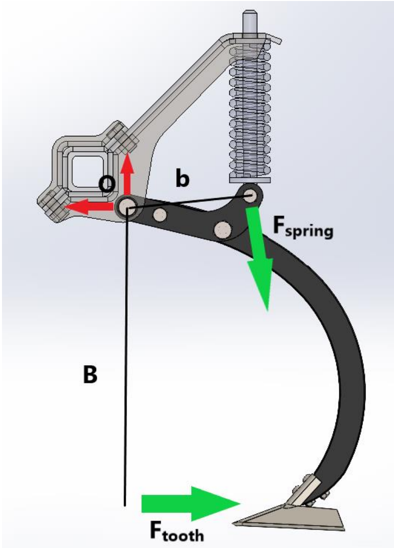
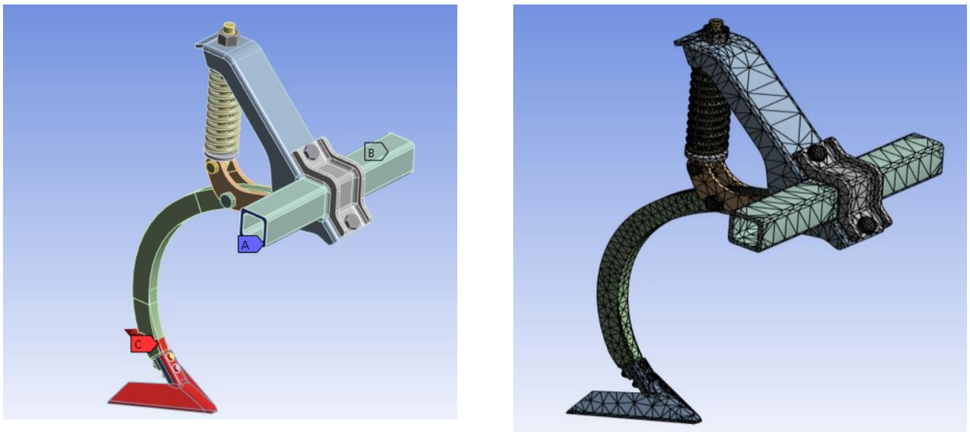


Fig. 5. Free body diagram for arm.

For the loading conditions, a force F_{tooth} of 1000 N is applied on the tine region (see point C in Fig. 6,a) and fixed supports are inserted at the frame cuts in A and B (Fig. 6,a). Tetrahedral elements were used to mesh the model, with smaller elements of same size applied in contact zones to ensure accurate modelling of contacts between parts.

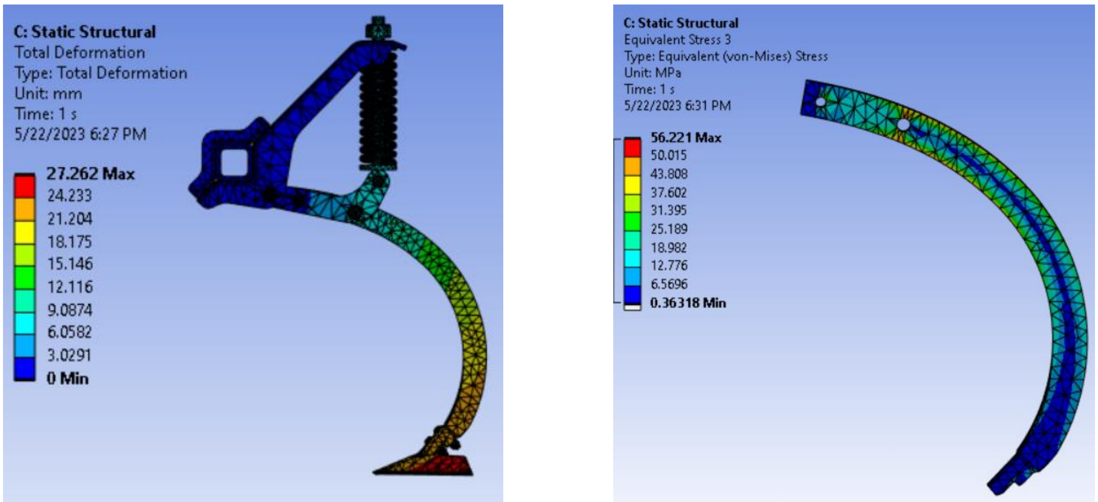


(a) Supports and applied force (b) Assembly meshing

Fig. 6. Boundary conditions and mesh setup in the unit finite element model.

Different type of contacts are used. For bolt and nut regions it is assumed that the parts are perfectly connected and can transfer loads without any relative motion between them, so the “Bonded” option is set, while in contact regions between fixing elements and bolt, “No separation” options is set because there is no separation between the parts. After the contact regions are set, the simulation is performed.

Some representative results, total elastic displacement of the repetitive analysed unit finite element model and the von Mises stress distribution in the arm are presented in Fig. 7.



(a) Total deformation of the unit FEM (b) von Mises stress distribution in the Arm

Fig.7. FEA results.

3. Conclusions

After examining the cultivator subassembly in Ansys Workbench and performing the finite element analysis, stress distribution zones are observed and assumptions about critical zones are drawn. As predicted, the arm take over a big part of the stress which is then distributed to the bolt and spring section. Being a safety mechanism, the spring compresses and further failures in the rest of the cultivator are minimized.

4. References

[1] Popescu G. (2017), Agriculture in the Equation of Progress, Editura Academiei Romane.

[2] https://grabcad.com/library/cultivator-kazayak-2.

[3] Budynas R. G., Nisbett J. K. (2015), Shigley's Mechanical Engineering Design, Tenth Edition, McGraw Hill Education.