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DESIGN AND OPTIMIZATION OF AN CHISEL-TYPE ACTIVE BODY INTENDED FOR SOIL WORK EQUIPMENT WITHOUT TURNING THE FURROW

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Abstract

Soil compaction is one of the major problems facing agriculture today because it increases soil strength and decreases fertility. Modifications to soil decompaction equipment, active bodies and management systems have been shown to provide opportunities to significantly reduce the incidence of compaction. The topic addressed in this paper represents a method of computer-aided design (CAD) combined with computer-aided engineering (CAE) used in the analysis of the choice of the optimal constructive variant to reduce the forward resistance forces of a chisel-type active body intended for soil work equipment without turning the furrow, in order to eliminate hardpan as well as deep compaction. Based on the resulting data, mass/drag coefficient ratios were determined for three analysed configurations. The comparison of these indicators led to the choice of the optimal constructive variant in the sense of the most performing, in order to reduce production costs with maximum efficiency.

Key words: *static simulation, dynamic simulation, design study.*

INTRODUCTION

Soil, in agriculture, is a means of production.
Mechanization technologies and increased agricultural production, but in recent years a negative impact of the use of heavy equipment has been observed, which, by changing the structure, has led to the deterioration of soil productivity and environmental quality (Shaheb et al., 2021).
Experimental research in an agricultural farm, related to soil works, showed that the occurrence of soil compaction is caused by the increase in the mass of agricultural tractors and aggregate machines (Ungureanu et al., 2015).
Farmers are currently moving towards adopting mechanical remedial strategies for soil compaction, such as subsoil, where tillage depth and tiller angle significantly affect fuel consumption while working, presenting an opportunity for optimization of fuel efficiency through proper design (Liu et al., 2023).
Soil loosening with technical equipment equipped with chisel-type active organs is influenced-negatively by the type of soil (clay), soil moisture (higher or lower than the optimum moisture) and the high degree of soil compaction, which lead to a force of high traction and implicitly high fuel consumption (Croitoru et al., 2016).
In the framework of a research project at INMA Bucharest, a soil processing machine was tested in real working conditions in the arable substrate (decompaction) in agergat with an Agrotron X720 tractor, which working in the experimental field, under soil compaction conditions , achieved average values of the variation index of the working depth (1.68%), the working width (1.44%) and the degree of loosening of the soil (18.1%) at the extremes allowed by agrotechnics (Marin et al., 2021).
Optimizing active working organs by applying layers of hard material increases their resistance to wear and hence their lifespan (Vladut et al., 2016).
In laboratory conditions, before carrying out the tests in real working conditions, for the optimization of a working part of a decompaction equipment, the CAD/CAM model is first created with the help of a 3D program, for example Solid Works, followed by more many series of analyzes and simulations using finite element structural models (Muraru et al., 2022).
If the active working organ meets the requirements for good operation after 3D geometric modeling and simulation, it can be

optimized. Otherwise, material dimensions, conditions, etc. used will be adjusted until the requirements are met. The transformation of the CAD model into a CAE model is carried out by checking, detecting and eliminating interference between the component parts of the sub-assembly or assembly of the product composition. To do this, select the subassembly or assembly to check, activate "Interference Detection" and the "Calculate" command. After accessing the "Calculate" command, the system obtains interference detection, and the interference areas are specified, and if they are not, it is specified: "No interference" (Makange et al., 2015).

The active organ model was tested by determining the static stress in the linear elastic domain. This is the normal way of testing the supporting structures of soil tillage machines. At the same time, simulations of other phenomena are possible on the same active organ model: vibrations (calculation of natural frequencies), dynamic analysis, stability analysis, vibrations in transport, etc. (Cardei et al., 2021).

One design-optimization method used in mechanical engineering is given by the SOLIDWORKS® Simulation application, which contains structural analysis tools that use finite element analysis (FEA) to predict the physical behavior of a product in the real world by virtually testing CAD models , leading to an accelerated design process, increased design quality and productivity, while reducing testing costs before proceeding with the manufacturing process (Manea et al., 2018).

SOLIDWORKS® Simulation is an easy-to-use portfolio of structural analysis tools that use (FEA)https://www.solidworks.com/product/solidworks-simulation.

Another method of optimizing a working part of an agricultural technical equipment using the computer-aided design (CAD) technique combined with computer-aided engineering (CAE) is the analysis of the ratio between the price of the material used per unit of safety factor. A high value of the safety coefficient, in relation to the usual allowed values, will show that there is an important potential for optimization. The comparison of the technical-economic indicators resulting from the calculations will lead to the choice of the optimal constructive variant in the most efficient way, thus contributing to the reduction of design validation time and to the reduction of manufacturing costs (Mateescu et al., 2016).

In this context, the paper presents a method of computer-aided design (CAD) combined with computer-aided engineering (CAE) used in the analysis of the choice of the optimal constructive variant, to reduce the forward resistance forces, of a chisel-type active body intended for equipment tillage without turning the furrow.

MATERIALS AND METHODS

The analysis of the choice of the optimal constructive variant, in order to reduce the forward resistance forces of a chisel-type active organ, was used in the design activity of an innovative technical equipment for the processing and inoculation of a biofertilizer in the arable substrate in order to restore the soil trophic chain (Figure 1).

The equipment was designed within a research contract no.: 760005/2022, specific project no. 3, with the title: "Fertile and healthy soil through conservation and biological practices".

SOLIDWORKS 3D CAD was used for the 3D geometric modeling of the technical equipment and for virtual testing through structural analysis, which uses the finite element analysis (FEA) method, SOLIDWORKS® Simulation, software developed by Dassault Systemes SolidWorks (https://www.solidworks.com/).

Figure 1. 3D geometric model made in SolidWorks of the innovative technical equipment for the processing and inoculation of a biofertilizer in the arable substrate

There are several possibilities for 3D geometric modeling of some metal elements in the composition of technical equipment in the field of agricultural mechanization with the SOLIDWORKS 3D CAD application, namely, the method of generating Solid Features with the Insert/Features command, or the method of generating Weldments or Sheet Metal solids. The method of generating solid Features was preferable, being special in this case

RESULTS AND DISCUSSIONS

The 3D geometric model of the working organ, which consists of a curved support on which the chisel-type active working organ is mounted at the bottom, was made in the variants: V1 in the welded version (Figure 2), which has carbon steel components of C45 quality, V2 in the forged version (Figure 3) from a high-strength low-alloy steel S355J2G3 and V3 in the cast version from a cast-iron material EN-GJMW-350-4.

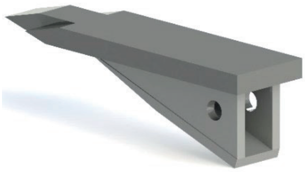


Figure 2. 3D geometric model of the chisel type active organ variant V1 - welded variant which has the carbon steel components of C45 quality

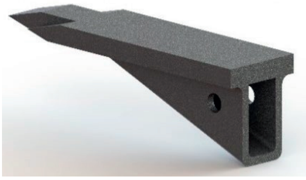


Figure 3. 3D geometric model of the chisel-type active organ variant V2 - forged in steel S355J2G3

Figure 4. 3D geometric model of the chisel-type active organ variant V3 - cast in cast iron EN-GJMW-350-4

After modeling each variant of the chisel-type active organ, they were assembled by means of an elastic pin with a support using the "Assemblies" module of the SOLIDWORKS 3D CAD application (Figure 5).

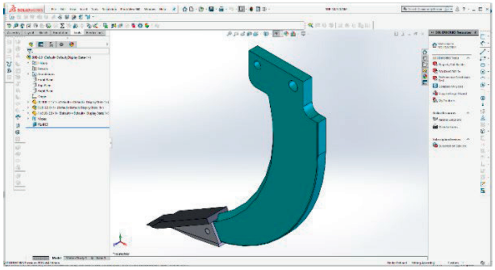
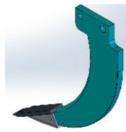
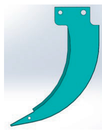
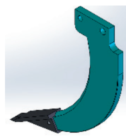
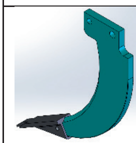


Figure 5. Working organ subassembly of the innovative technical equipment for processing and inoculating a biofertilizer in the arable substrate

Table 1 presents informative data of the constructive variants V1, V2 and V3 of the working organ subassembly of the innovative technical equipment for the processing and inoculation of a biofertilizer in the arable substrate.

Tabel 1 Informative data of the constructive variants V1, V2 and V3 of the working organ subassembly

V1	 Mass = 3.04 kilograms Volume = 3.9e+05 cubic millimeters Surface area = 8.95e+04 square millimeters		 Mass = 27.1 kilograms Volume = 3.47e+06 cubic millimeters Surface area = 3.61e+05 square millimeters
V2	 Density = 7.8e-06 kilograms per cubic millimeter Mass = 2.94 kilograms Volume = 3.77e+05 cubic millimeters Surface area = 7.66e+04 square millimeters	 Density = 7.8e-06 kilograms per cubic millimeter Mass = 23.9 kilograms Volume = 3.07e+06 cubic millimeters Surface area = 2.69e+05 square millimeters	 Mass = 27 kilograms Volume = 3.46e+06 cubic millimeters Surface area = 3.48e+05 square millimeters
V3	 Density = 7.25e-06 kilograms per cubic millimeter Mass = 2.98 kilograms Volume = 4.11e+05 cubic millimeters Surface area = 8.03e+04 square millimeters		 Mass = 27 kilograms Volume = 3.49e+06 cubic millimeters Surface area = 3.52e+05 square millimeters

In order to carry out the linear static structural analysis of the working body, where the stresses and deformations of a loaded sub-assembly could be evaluated, it was essential to define the main properties of the selected materials (Table 2).

Table 2. Properties of selected materials

Configuration / Material	Drip limmit (σc) (N/m^2)	Poisson coefficient	Modulus of elasticity (E) (N/m^2)
V1 / C45	750×10^6	0,28	2,1×10^{11}
V2 / S355J2G	490×10^6	0,28	2,1×10^{11}
V3 / EN-GJMW-350-4	350×10^6	0,26	1,7×10^{11}

The 3D geometric model of the working part of the loaded subassembly, which was entered directly into the linear static structural analysis, supported loads and supports, but upon discretization, the operation could only be performed after the elimination of some interferences.

After the stage of creating the constructive variants V1, V2 and V3 for the 3D geometric model of the working body, we moved on to the stage of analyzing their structural analysis with the help of the SOLIDWORKS® Simulation structural simulation application, which involved importing the geometry of the model made with the application of computer-aided engineering (SOLIDWORKS 3D CAD), defining the material of each component landmark, defining the restrictions appropriate to the discretizations, the analysis calculation to determine the stresses, the displacements under the effect of an applied load, the safety factor and the visualization of the results. The structural analysis involved the following operations:

- select the option static as the analysis type, solid for the discretization type and the FFEPlus solver;
- selecting the material from the SOLIDWORKS 3D CAD library and automatically assigning these properties to each component feature;
- applying the appropriate load. In accordance with the real mode of operation (from operation), the simulation scenario was adapted accordingly, the load being applied at the corresponding points;
- using the ("meshing procedure") to decompose the model into discrete elements. In general, a finite element model is defined by a mesh, which is completely made of a geometric arrangement of elements and nodes. Nodes represent points, where features such as displacements are calculated;
- running the analysis study to calculate the Von Mises stress, specific strain, relative displacement, and factor of safety, based on the geometry, material, load, constraint conditions, and discretization type.

Table 3 shows the minimum and maximum values of Von Mises stress, specific strain, relative displacement and safety factor for configuration V1.

Tabel 3. Minimum and maximum values of Von Mises stress, specific strain, relative displacement and factor of safety for configuration V1

Name	Type	Min.	Max.
Stress 1	VON: von Mises Stress	1.395e+05 N/m^2 Node: 30780	2.393e+08 N/m^2 Node: 72689
Displacement 1	URES: Resultant Displacement	0.000e+00 mm Node: 37	1.175e+01 mm Node: 78657
Strain 1	ESTRN: Equivalent Strain	8.097e-07 Element: 17909	7.228e-04 Element: 14451
Factor of Safety 1	Automatic	2.424e+00 Node: 72689	4.157e+03 Node: 30780

Figure 6 shows a sequence during the comparison of the results of the V1 configuration, which appear on the screen in the form of the Von Mises stress intensity distribution, the specific strain intensity distribution, the relative displacement field distribution and the power factor distribution

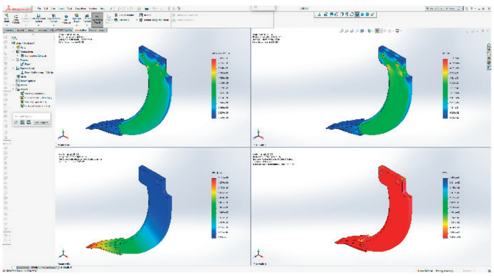


Figure 6. Sequence during the comparison of the results of configuration V1, which appear on the screen in the form of the Von Mises stress intensity distribution, the specific strain intensity distribution, the relative displacement field distribution and the factor of safety distribution

Table 4 shows the minimum and maximum values of Von Mises stress, specific strain, relative displacement and safety factor for configuration V2.

Table 4. Minimum and maximum values of Von Mises stress, specific strain, relative displacement and factor of safety for configuration V2

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.790e+04 N/m^2 Node: 59182	8.398e+07 N/m^2 Node: 84126
Displacement 1	URES: Resultant Displacement	0.000e+00 mm Node: 31	5.927e-01 mm Node: 77988
Strain 1	ESTRN: Equivalent Strain	2.110e-07 Element: 47054	2.326e-04 Element: 8042
Factor of Safety 1	Automatic	3.751e+00 Node: 84126	6.576e+03 Node: 59182

Figure 7 shows a sequence during the comparison of the results of the V2 configuration, which appear on the screen in the form of the Von Mises stress intensity distribution, the specific strain intensity distribution, the relative displacement field distribution and the power factor distribution

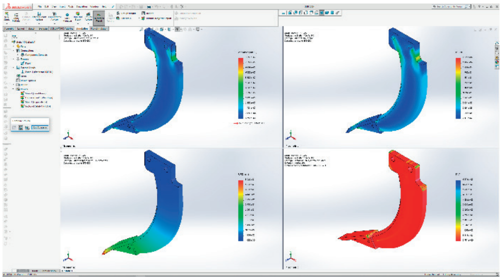


Figure 7. Sequence during the comparison of the results of configuration V2, which appear on the screen in the form of the Von Mises stress intensity distribution, the specific strain intensity distribution, the relative displacement field distribution and the factor of safety distribution

Table 5 shows the minimum and maximum values of Von Mises stress, specific strain, relative displacement and safety factor for configuration V3.

Table 5. Minimum and maximum values of Von Mises stress, specific strain, relative displacement and factor of safety for configuration V3

Name	Type	Min	Max
Stress 1	VON: von Mises Stress	2.870e+04 N/m^2 Node: 58811	6.799e+07 N/m^2 Node: 73201
Displacement 1	URES: Resultant Displacement	0.000e+00 mm Node: 112	6.211e-01 mm Node: 73744
Strain 1	ESTRN: Equivalent Strain	2.110e-07 Element: 47054	2.326e-04 Element: 8042
Factor of Safety 1	Automatic	4.032e+00 Node: 139	2.021e+04 Node: 58811

Figure 8 shows a sequence during the comparison of the results of the V3 configuration, which appear on the screen in the form of the Von Mises stress intensity distribution, the specific strain intensity distribution, the relative displacement field distribution and the power factor distribution.

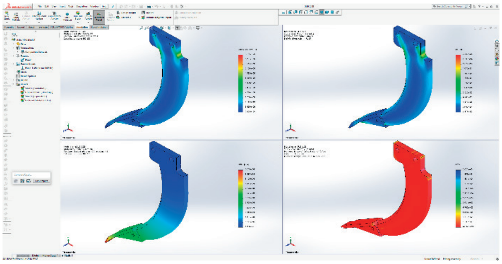


Figure 8. Sequence during the comparison of the results of configuration V3, which appear on the screen in the form of the Von Mises stress intensity distribution, the specific strain intensity distribution, the relative displacement field distribution and the factor of safety distribution

The results of the material consumption indicator unit per safety factor unit (Mass/ Safety Factor ratio) analysis proposed in choosing the optimal constructive solution for the work body are presented in Table 6.

Table 6. The results of the analysis on technical-economic criteria

Name	Unit of measurement	Constructive variants		
		V1	V2	V3
Factor of safety	-	2.424	3.751	4.032
Total mass	kg	27.1	27	27
Mass/Factor of safety	-	11.18	7.20	6.70

The comparison of these indicators led to the choice of the optimal variant (the V3 configuration was chosen), which has the lowest mass/safety factor ratio (6.7).

The indicator proposed for the analysis of the choice of the optimal variant, which is represented by the Mass/Safety Factor ratio, contributes to the reduction of design validation time and manufacturing costs.

CONCLUSIONS

- CAD-CAE applications are most often used in the design process by agricultural mechanical engineers for design, simulation, analysis, optimization and evaluation work;

- The analysis findings indicate that the maximum value of the von Mises stress is about 6.799e+07 N/m2, the largest strain is 0.6221 mm, and the factor of safety is 4.032. With the material EN-GJMW-350-4, the design of the working body in this study is safe to withstand up to 1000N.
- The comparison of these indicators led to the choice of the optimal constructive variant in the sense of the most performing, in order to reduce production costs with maximum efficiency.

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