Nonlinear analysis of dynamic loads of the model haulm removing working body

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Abstract. Significant rotation speeds are required for the qualitative removal of leaf-stem mass from the field when using a rotating working body. An urgent task is to obtain data to evaluate the nonlinear effect of forces on the working body when removing leaf-stem mass. In the article, the degree of influence of the weight of the stems of the leaf-stem mass and centrifugal forces acting on the top-working working body using non-linear dynamic analysis was studied. The implementation of computer simulation was achieved using the CAD-CAE SOLIDWORKS system. As a result of the nonlinear analysis in SOLIDWORKS Simulation, the results of the stresses, displacements, and deformations acting on the top-working working body model were obtained, which made it possible to identify weak points of the working body. The analysis of the obtained data revealed the influence of centrifugal force and weight of the cut leaf-stem mass on the knives of the working body of the haulm machine, which will allow taking these effects into account in the developed design.

1. Introduction

High-quality work of top-lifting machines is provided only with proper preparation of the field before harvesting. As studies have shown for the harvesting period, the weediness of the fields reaches 60 - 70%, the height of weeds in this case reaches 0.5 m. This is because the time between the last treatment of crops with herbicides and harvesting takes two to three weeks, which contributes to the growth of weeds [1].

When harvesting machines of the top-lifting type, if the field has not been previously prepared, the rotating elements of the top-lifting apparatus are clogged, which leads to a decrease in machine performance, breakdown, and an increase in the number of stops for cleaning [2]. For normal operation of harvesting machines for mechanized harvesting of potatoes, preliminary removal of tops is used.

The most productive are rotary working bodies. The simplicity of design and high quality of the cut determine the widespread use of such devices for various crops. Therefore, when creating a topping machine, a rotary cutting apparatus was used. At the same time, the cut tops are placed on the field or collected for subsequent use on livestock feed.

To obtain the optimal design and operational parameters of the working body and to optimize the air flow inside the casing, studies were carried out, which were reflected in the following works [1, 2].

Nevertheless, for unsupported cutting of tops, significant cutting speeds are required, therefore, a dynamic and static assessment of the design of rotary working bodies is an urgent task.
To assess the loads acting on the working body, a nonlinear dynamic analysis was used, since in real conditions this analysis shows more accurate results than linear. Non-linearity can be caused by the behavior of the material, large displacements and contact conditions.

2. Materials and methods

Finite element method (FEM) is currently one of the most common numerical methods used for simulations in mechanical engineering. Modern software systems usually allow using FEM, which enables solving mathematically difficult and time consuming operations in a meantime. The basic idea of the FEM is simple, as it requires to split the solution area to a finite number of sub areas - elements. It is necessary to create a network of finite elements on the model. The density of the network fundamentally affects the quality of the results and amount of used computer memory. FEM is used for solving problems of elasticity, dynamics, flow of liquids and gases. [3, 4].

A computer model of the topping working body was built on the basis of the finite element method. SolidWorks was used as a CAD-CAE system. SolidWorks Simulation is a finite element analysis (FEA) tool that allows users analyzing structural performance, such as displacement, stress, natural frequency, fatigue life, buckling load [5]. The analysis combines elements of kinetic studies and bonds in the motion calculation. The restrictions of the movement, material properties and the contact parts are also included in the calculation of the kinematic solutions [6, 7]. Thermal analysis calculates the temperature and heat flow based on the heat source, lead. SolidWorks Simulation allows viewing the results of finite element method analysis including graphs and animation [8].

3. Geometry and boundary conditions

Top-working body (Figure 1) with the following dimensions: knife width - 118 mm; knife length - 150 mm; knife thickness - 4 mm; rotor diameter 40 mm; the angle of the knives - 45 degrees.

![Figure 1. General view of the 3D model of the topping working body and its dimensions.](image)

When modeling, the following factors were taken into account: the forces acting on the part of the cut leafy mass; centrifugal forces acting on the working body due to rotation.

Steel 65G (GOST 535-88) with the parameters presented in table 1 was adopted as the material of the rotor and knives. Volumetric properties of the top-working working body: weight - 3.5227 kg,
volume - 0.000448751 m³, density - 7850 kg/m³.

| Parameter name               | Value                      |
|------------------------------|----------------------------|
| Name                         | Steel 65G (GOST 535-88)    |
| Model type                   | Linear Elastic Isotropic   |
| Default failure criterion    | Max von Mises Stress       |
| Yield strength               | 7.85e+008 N/m²             |
| Tensile strength             | 9.8e+008 N/m²              |
| Elastic modulus              | 2.15e+011 N/m²             |
| Poisson's ratio              | 0.28                       |
| Mass density                 | 7850 kg/m³                 |
| Shear modulus                | 8.4e+010 N/m²              |
| Thermal expansion coefficient | 1.18e-005 /Kelvin          |

Table 1. Material properties

The solver constructed with a finite element mesh with the parameters presented in table 2.

As fasteners for the upper and lower ends of the rotor, a slide roller was used, and for the cylindrical surface of the rotor, a fixed hinge.

Table 2. Mesh information

The following loads were assigned to the model:
- centrifugal acting on the rotor shaft. Angular velocity 190 rad/s. Angular acceleration 190 rad/s².
- normal force applied to the plane of the knives, characterizing the weight of the cut stems. On the front face of each knife, a force of 1H is applied.

4. The results of numerical research

As a result of the nonlinear analysis in SOLIDWORKS Simulation, the results of the stresses, displacements, and deformations acting on the model of the top-working working body model were obtained.

During the analysis of Figure 2, it can be seen that the minimum voltage acting on the top-working working body model (at a speed of 190 rad/s) is 1.315e+3 N/m², and the maximum voltage is 5.000e+5 N/m². Since the yield strength for given steel (7.85e+008 N/m²) is greater than its maximum
calculated value \((5.000e+5 \text{ N/m}^2)\), this means that the strength condition of the model is fulfilled. The maximum stresses are localized near the connection of the knives with the rotor shaft.

![Diagram of stresses](image1.png)

**Figure 2.** Model of a topping working body with applied initial conditions and a diagram of current stresses according to the Mises strength criterion.

At the nonlinear dynamic analysis, 1s was taken for the estimated time. Figure 3 shows a graph of the stresses acting on the top-working working body model versus time. The graph shows that the stress increased in a parabola.

![Graph of stresses](image2.png)

**Figure 3.** The graph of stresses acting on the model of the topping working body on time.
The dependence of the resulting movements of the knives under the action of the load on time is shown in Figure 4. The dependence is close to linear. Maximum displacements are concentrated on the periphery of the knives.

![Graph of the resulting movements of the knives under the action of the load on time](image)

**Figure 4.** Graph of the resulting movements of the knives under the action of the load on time

During the analysis, the minimum and maximum values of stresses and strains at a shaft rotation frequency of 190 rad/s were obtained. The results of nonlinear analysis are shown in table 3.

| Frequency of rotation, rad/s (rpm) | Min   | Max   |
|----------------------------------|-------|-------|
| VON: von Mises Stress, N/m²      | 190 (1815) | 1.315e+3 | 5.000e+5 |
| URES: Resultant Displacement, mm | 190 (1815) | 0.00028 | 6.47576 |
| ESTRN: Equivalent Strain        | 190 (1815) | 3.048e-8 | 0.00184 |

**5. Conclusion**

In the course of studying the degree of influence of the weight of the stems of the leaf-stem mass and centrifugal forces, a computer model was built, acting on the topping working body loads. Using nonlinear dynamic analysis, we obtained the results of stresses, displacements, and deformations acting on the model of the top-removing working body.

The analysis of the obtained data revealed the influence of centrifugal force and weight of the cut leaf-stem mass on the knives of the working organ of the topper, and maximum deformations and stresses occur mainly in the area of the knives attached to the rotor shaft. Used in the manufacture of knives and rotor shaft 65G steel (GOST 535-88) fully meets the requirements for this working body.

**References**

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