A study of the cultivator suspension's strength based on its solid model in Autodesk Inventor Professional

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Abstract. The article is devoted to the study of the stress-strain state cultivator suspension in the Autodesk Inventor Professional program. To solve this problem, a solid-state suspension model has been developed. Four schemes of the application of external forces and restrictions on the suspension parts movement are described, which describe the condition of the cultivator in critical situations – the suspension’s paw clings to an obstacle. The calculations were performed in the “stress analysis” environment. The obtained results made it possible to justify the possibility using two of the four considered schemes to formulate a plan for a comprehensive study of the cultivator's health when various changes are made to its design. The ultimate goal of design changes is to reduce metal consumption and the use of more affordable materials in the manufacture of the cultivator frame.

1. Research problem statement
The material presented in this article is completed part of a comprehensive study the cultivator design (figure 1), made in order to reduce the mass of its frame without loss performance [1, 2, 3]. The theoretical basis for the practical implementation of the calculations is made up of solid modeling methods [4, 5, 6] and the finite element method [7, 8, 9] in the Autodesk Inventor Professional environment [6, 10, 11].

![Figure 1. Solid state cultivator model (a): (b) – during transport, (c) – working condition.](image)

One of the devices through which external forces act on the cultivator frame is the suspension (figure 2). In figure 2 (b), securing attachment (bolts, nuts, and washers) are not shown.
When the cultivator is working, the force from the soil acts on the suspension. Usually it does not exceed 2 - 3 kN and is directed along the suspension axis. But in exceptional situations associated with unforeseen obstacles (stone in the ground, for example) the value and direction of this force changes. A possible result is the destruction of the suspension, but without damage to the cultivator.

The task of the study is calculation the value and determination the point of application and the direction of the force at which the suspension can be destroyed. In the future, when analyzing the strength of the frame and other elements of the cultivator, there is no need to use traditional methods for calculating the forces acting from the side of the suspension on the frame [12, 13, 14]. It is enough to include a simplified suspension model with the forces applied to it in the final model of the cultivator frame.

2. Cultivator suspension computational model

Figure 3 shows a cultivator suspension model containing an additional element for applying concentrated forces and restrictions on their movement. The direction of the force is determined either by the angle of its influence to the normal to the plane of application (the force is decomposed in vectors in the direction of the x, y, z axes), or by replacing one force with two (three) applied to the planes xz, yz (and xy). These planes are painted in the corresponding colors of the coordinate system of the model used in Inventor when performing calculations.

Figure 2. Cultivator suspension: (a) – complete and (b) – disassembled.

Figure 3. Computational model of the cultivator suspension.
At the initial research stage, by conducting a sequence of numerical experiments, the maximum value of the force applied to the paw of the suspension model in the y axis direction was established. Its value was 4.8 kN. To carry out further research, 5 kN was adopted.

When performing the calculations, it was assumed that the angle of force application relative to the direction of cultivator movement, in accordance with the requirements for its operation, does not exceed 30 degrees. When performing research, this angle is taken equal to 45 degrees.

Variants of the force application in the axis z direction were not considered, since during operation of the cultivator this value is negligible.

3. The stress-strain state analysis of the cultivator suspension

The article presents the results of the four most characteristic options for investigating the stress-strain state of the suspension that arise during operation of the cultivator in extreme situations associated with suspension destruction.

The main criterion for failure is the safety factor value. Additional data for analysis is the displacement of the suspension elements during its deformation. In addition, for a qualitative assessment of the operating conditions of the suspension, it seems important to have a general picture of the visual color display of these criteria values at the points of the object under study.

3.1. Scheme of study No. 1

Figure 4 presents the results of the stress-strain state study suspension in a typical operation mode, but with a maximum permissible load. The minimum value of the safety factor (0.25) at the point of stress concentration, which appeared due to a change in the suspension design for subsequent modeling. Extremely low safety factor (0.67) at the connection point between the bolt head and its body. The maximum displacement is 55.6 mm. The value is not critical for the material of which the suspension spring is made.

Figure 4. Scheme No. 1: (a) – strength and limitations, (b) – safety factor, (c) – deformation.

Restrictions: movement of the suspension's paw is fixed, movement of the cultivator's paw fragment, to which the force is applied, is possible only in the horizontal plane.

3.2. Scheme of study No. 2

Unlike option No. 1, a force located in a plane parallel to xy is directed at an angle of 45º relative to the y axis. Study results in Figure 5.
An additional element of the suspension's paw imposed a dependence of fixation (pinching), completely limiting its movement. In the research process, an option was considered in which instead of pinching, the hinge dependence was used. The value of the maximum displacement in this case increased slightly, the safety factor increased as expected, but also slightly.

3.3. Scheme of study No. 3
Dependencies of fixation (pinching) are imposed on a cultivator frame fragment; displacements only in a horizontal plane are placed on a paw. The results are presented in Figure 6. In comparison with option No. 1, the differences are insignificant.

**Figure 5.** Scheme No. 2: (a) – strength and limitations, (b) – safety factor, (c) – deformation.

**Figure 6.** Scheme No. 3: (a) – strength and limitations, (b) – safety factor, (c) – deformation.
3.4. Scheme of study No. 4

In contrast to option No. 3, here not only the direction of force is changed by 45º, but there is no restriction on the movement of the suspension's paw. As a result, deformations of the suspension elements increased, but the stress values in them did not change much.

![Figure 7](image)

Figure 7. Scheme No. 4: (a) – strength and limitations, (b) – safety factor, (c) – deformation.

Thus, it can be argued that the overall level of stresses in the suspension is little dependent on the scheme of external forces application. At the same time, when calculating the strength of this suspension type, preference should be given to scheme No. 4.

4. Conclusion

The possibility of using the Autodesk Inventor Professional program [4, 6] for performing strength calculations of products such as a cultivator suspension is confirmed not only by the results obtained on the basis of various modeling schemes, but also by experimental research data (not shown in this article). However, to assess the strength of the cultivator design as a whole (figure 1), the scheme of application of forces and limitations is of fundamental importance. And it can only be schemes No. 3 and No. 4.

For a comprehensive assessment of the stress-strain state cultivator design under various critical operating conditions, given the large number of application points (the number of suspensions is 15) and possible directions of external forces, many different research options will be required. Using the results presented in this article, their number can be reasonably reduced.

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