A study of the static lateral stability of a tillage machine-tractor unit on a virtual stand

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Abstract. The problems of studying the static lateral stability of machine-tractor units by the methods of multi-body dynamics (MBD) are considered. To create a simulation model, the virtual modeling method in CAD SolidWorks and CAE SolidWorks Motion was used. A 3d model of the MTZ-82.1 tractor was created, equipped with front and rear mounted three-point linkage. At the same time, all the basic structural elements and their geometric and mass-inertial parameters were preserved. The tractor was aggregated with front and rear mounted modular implements. To study the lateral stability, the tractor is mounted on a virtual stand consisting of a fixed base and a platform that changes the angle of inclination. Using a virtual stand, the lateral stability angles of three typical configurations of a machine-tractor unit and a tractor without attachments were obtained. For a tractor without attachments, the rollover angle was 34°, it was equipped with a single-beam rear mounted implement 36° (scheme 0 + 1), with a double-beam rear mounted implement 25° (scheme 0 + 2), with a front mounted implement and a double-beam rear mounted implement 36° (scheme 1 + 2). Verification of simulation data was carried out by comparing with experimental data obtained at a stationary stand. The difference in the values of the critical angles of lateral stability of the tractor, obtained by the results of virtual modeling and using the method of rollover the tractor on a stationary stand, is 3 ... 5°.

1. Introduction
Currently, there are two main methods for determining the angle of lateral static stability of a machine-tractor unit. The first is based on the use of stationary test bench having a platform that leans at various angles to the horizontal plane. The disadvantage of this method is the need for stationary expensive equipment manufactured in single copies [1-4].

The second method is based on the application of calculation methods [1]. Its use allows you to clarify the parameters included in the equation for calculating the moments. However, with its help it is impossible to take into account the dynamics of the process, the spatial scheme of the vehicle, the kinematics of the suspension, the non-linearity of the elastic characteristics of the suspension and travel limiters. Thus, to date, the assessment of the stability of vehicles can be reliably carried out only in a real experiment on a stand with a tipping platform.

Now widespread are the methods of virtual modeling. For this, programs for modeling multi-body dynamics (MSC.ADAMS, SolidWorks Motion, LMS Virtual.lab, SimPack, TruckSim) are used. They allow one to study static stability taking into account the dynamics of the object's behavior [5-15].
2. Material and methods
In the presented study, to create a tractor simulation model, the virtual modeling method was used in CAD SolidWorks and the SolidWorks Motion program. At the first stage, a simplified model of the MTZ-82.1 tractor was developed (figure 1). All stationary elements of the tractor were excluded from the model (shown in the figure in wireframe). To replace them, we used an equal mass ball of custom high density material. By adjusting the position of the ball, the center of mass of the simplified model is combined with the real operational center of mass of the tractor.

Further, for the layout of the simulation model of the tractor, simplified models of the front and rear three-point linkage have been created. They have a simple parameterized geometry and retain mass-inertial parameters. This allows you to use models with the least load on the computer and the minimum probability of errors.

For simulation studies, the three-point linkage model is supplemented by virtual elastic elements (figure 2, a). For this, a central bracket is additionally created synchronously moving in a longitudinally vertical plane with lower draft link. It is necessary for mounting virtual springs 1. The second mounting point is located on the lower draft link. Another pair of virtual springs 2 is installed at the central points of attachment of the hydraulic cylinders. By specifying the stiffness of the springs and damping coefficients, a wide range of operating conditions can be modeled. The lower draft links are moved due to linear virtual engines 3 applied in parallel to the axis of the cylinder.

To simulate the lateral displacement of the tractor resulting from tire deformation, the wheel model is also supplemented with elastic elements (figure 2, b).
A virtual spring connects the wheel disk and the tire having the possibility of axial displacement without relative rotation. By selecting the elastic coefficients and damping of the virtual spring, tire deformation can be simulated.

To study the lateral stability, the machine-tractor unit is installed on a virtual stand (figure 3). It consists of a fixed base and a platform that changes the angle of inclination.

The interaction between the contact pairs “platform – wheels” had the parameters of the standard SolidWorks Motion interaction “steel – rubber”.

During the simulation, the following parameters were monitored:
– the angle of inclination of the platform;
– the angle of the tractor;
– the contact force of the front and rear wheels distant from the axis of inclination of the platform (figure 4).

3. Results and discussion
To check the adequacy of the tractor simulation model, a virtual experiment was conducted to study the transverse static stability of the MTZ-82 tractor (figure 5, b). The simulation data were compared with those obtained experimentally at the stationary stand of the Kuban machine testing station (figure 5, a). In these studies, the angle of transverse static stability ranged from 29 to 31° [4].
Figure 5. The moment of rollover of the MTZ-82 tractor: (a) – at the stationary stand of Kuban machine testing station; (b) – on a virtual stand.

To accurately record the moment of the beginning of the rollover during the virtual experiment, the contact force of the front and rear wheels was monitored (figure 7, a and b). The graph shows that the contact force has the greatest fluctuations at the initial moment of modeling. This is due to the deformation of the wheel when installing the tractor on a stand. The oscillations fade out intensively within 2 seconds. Then, at the 10th second, the platform tilt motor turns on. The contact force of the front wheel begins to decrease immediately. The contact force of the rear wheel after a slight increase also decreases with an increase in the angle of inclination. The first was the separation of the rear wheel at an angle of inclination of 34° (the moment the contact force drops to 0). The separation of the front wheel occurred at an angle of 40°.

The difference in the values of the critical angles of lateral stability of the tractor, obtained according to the results of virtual modeling and using the method of rollover the tractor on a stationary stand, is 3... 5°. This can be explained by such factors as: different tire pressure, error in weighing, spatial distribution of unaccounted masses, track mismatch, difference in stiffness of real and virtual wheels, and settings for the interaction of the contact pair “platform – wheels”.

Using a simulation model of a tractor, it is possible to study the critical angles of lateral stability of various layout options of a machine-tractor unit with modular attachments [16]. We give an investigation of three typical configurations (figure 6).

An analysis of the simulation data of the rollover process of a tractor equipped with a single-beam rear mounted implement (0 + 1 scheme) shows that the contact force of the front wheel begins to decrease immediately. The contact force of the rear wheel after a slight increase also decreases with an increase in the angle of inclination. The first was the separation of the rear wheel at an angle of inclination of 36°. The separation of the front wheel occurred at an angle of 41°.

When rollover a tractor equipped with a double-beam rear mounted implement (scheme 0 + 2), the contact force of the front wheels begins to decrease immediately. The first was the separation of the front wheel with a tilt angle of 26°. Separation of the rear wheel occurred at an angle of 38°.

When rollover a tractor equipped with a front mounted implement and a double-beam rear mounted implement (1 + 2 scheme), the contact force of the front wheel begins to decrease immediately. The contact force of the rear wheel after a slight increase also decreases with an increase in the angle of inclination. The first was the separation of the rear wheel with a tilt angle of 36°. Complete separation of the front wheel occurred at an angle of 40°.
Figure 6. Rollover of various configurations of the machine-tractor unit.

The dynamics of changes in contact force for all schemes of machine-tractor units and a tractor without implements is shown in figure 7, a and b.

Figure 7. The contact force of the tractor wheels with the supporting surface.
Figure 8 shows the angles at which the contact force of the tractor wheels with the supporting surface is 0, that is, the rollover process has begun.

According to the results of a virtual experiment, the aggregates of schemes 0 + 1 (36°) and 1 + 2 (36°) have the best stability. A slightly smaller tipping angle on the tractor without implements (34°). Moreover, in all cases, the first occurs, the separation of the rear wheel. Associated with this is the better stability of the aggregates of schemes 0 + 1 and 1 + 2 with rear wheels loaded with implements. The unit scheme 0 + 2 has the least stability (25°). When rollover, the front wheel comes off first. This is due to the installation of a massive implement on the rear linkage in the absence of a counterweight.

![Rollover angles of various machine-tractor unit schemes.](image)

**Figure 8.** Rollover angles of various machine-tractor unit schemes.

4. **Conclusions**

The study of transverse static stability on a virtual stand allows you to quickly assess the stability of any configuration of the machine-tractor unit. In this case, in contrast to the static study of the center of mass of the 3d model, mass redistribution due to changes in the angle of inclination of the machine-tractor unit is taken into account here, i.e. taking into account the kinematics of the suspension, attachments, wheels and the nonlinearity of their elastic characteristics.

It is also possible to conduct longitudinal stability studies at the virtual stand. However, the obtained values of the angles differ slightly from static studies of the center of mass of the 3d model and, with this configuration of the machine-tractor unit, are uninformative. In the case of installing attachments having a mass center significantly shifted in the transverse direction, studies of longitudinal stability on a virtual stand will be noticeably more reliable than static ones. This is due to the longitudinal rollover of the unit with simultaneous lateral falling.

In the future, the machine-tractor unit simulation model can be used to study dynamic stability when moving along various supporting surfaces in various modes.

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