Study of the power parameters of the working bodies of tillage machines

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Abstract. The article presents data on the resistance of the working bodies of tillage machines, which are determined by dynamometry of the tool as a whole. The design of a dynamometric trolley of a small soil channel is proposed, which makes it possible to perform spatial dynamometry of the working bodies of tillage machines, i.e. finding the magnitude, direction and point of application of the resultant soil resistance forces. The method of studying the force loading of the attachment elements of the working bodies on the cultivator-plant feeder bead bar is considered. Force and linear parameters are taken as criteria that determine the stress state of fastening elements. Selected strain gauge structures that should be installed on the bar of the beams to receive and register vibrations and force loading of the attachment elements of the working bodies. A grapho-analytical method is proposed for calculating the parameters of a dynamic screw to determine the components of soil resistance forces and moments at individual points.

1. Introduction

The development of methodological and technical foundations for accelerated experimental research and testing of processes and working bodies of machines for the cultivation of agricultural crops on the basis of a small soil channel (SSC) equipped with a modern IMS using a personal computer allows improving the methods of experimental research and significantly reducing the time for their implementation. The assessment of a tool from the point of view of use in economic conditions is usually made on the basis of data on the resistance of the working bodies, depending on the depth, processing speed and width of the tillage working body. These resistances are determined by dynamometry of the tool as a whole [1].

To select a rational form of the working body, to compare two or more working bodies by their traction resistance, as well as to calculate and design agricultural machines, there is a need for a complete determination of the forces acting on the working bodies, in the absence of any intermediate travel devices between the working bodies and dynamometer [2].

2. Materials and methods

At the Department of Ground Transport Systems of Tashkent State Technical University, a traction trolley has been developed, which can be used for spatial dynamometry of the working bodies of tillage machines. Small soil channel is a laboratory complex consisting of a soil channel, traction trolley, trolley drive, adjustment mechanisms.
The traction trolley (Fig. 1) is equipped with a hitch mechanism, by means of which the investigated working bodies are installed on the trolley frame. The trolley powered by an electric motor and moves along the soil channel, thereby simulating an agricultural machine. This makes it possible to carry out the necessary experiments in the laboratory.

The study of the forces acting on the working body of the tillage machine makes it possible to develop a rational form of the working body and the method of its hanger to the machine frame, as well as to carry out the power calculation. Accurate knowledge of the spatial variation of the forces acting on the working body is necessary, for example, in order to determine the most favorable position of the control points of the attached implements and in order to correctly select the adjustment and setting mechanism for all possible load options. The spatial action of soil resistance on the working body can be determined using a dynamometric trolley [3].

![Diagram](image)

Figure 1. Dynamometric trolley diagram: 1; 2; 3; 4; 5; 6 - strain gauges, 7 - trolley; 8; 9; 10 - working bodies.

For example, let us consider the method of studying the force loading of the attachment elements of the working bodies on the cultivator-plant feeder bead bar [4,5,6]. The following power and linear parameters are taken as criteria that determine the stress state of the attachment elements of the working bodies:

1. Transverse - horizontal components of dynamic loads, causing a bending moment acting on the strut of the working body in the transverse-horizontal plane of the cultivator movement.
2. Longitudinal - horizontal components of dynamic loads, causing a bending moment acting on the strut of the working body in the longitudinal-horizontal plane of the cultivator movement.
3. Transverse - horizontal components of dynamic loads, causing a bending moment acting on the bead bar in the transverse - horizontal plane of the cultivator movement.
4. Vertical components of dynamic loads causing a bending moment acting on the bead bar in the vertical plane of the cultivator movement.
5. Forces arising at the point of contact of the bolt of the holder with the strut of the working body and contributing to the appearance of normal stresses.
6. Longitudinal components of dynamic loads, acting on the working bodies, causing stretching of the beads links in the longitudinal plane of the cultivator movement.
7. Parameters of linear displacements of working bodies $X_i$ and $Z_i$ in the transverse - horizontal and vertical planes of the cultivator movement relative to the tractor.
8. Parameters of linear displacements of working bodies $X_i'$ and $Z_i'$ in the transverse - horizontal and vertical planes of the cultivator movement relative to the tilled row spacings.
3. Results and discussion

The practice of carry out experimental studies of the stressed state of attachment elements of working bodies shows that the placement of strain gauges in randomly selected locations, even with a large number of them, does not allow restoring the full picture of the stress state. Therefore, the results of processing the experiment are closely related to the methods of placing the sensors on the elements of the cultivator’s beads. As a result of the analysis, it was revealed that under operating conditions, the weakening of the attachment of the working bodies, leads to a decrease in agrotechnical indicators, in particular, the stability of the course in the depth and width of the row spacing is not maintained [7,8].

A significant influence on the efficiency of attachment of working bodies is exerted by the spatial swings of the working bodies arising as a result of the swings of the tractor and the difference in soil resistance. Therefore, to obtain and register vibrations and force loading of the attachment elements of the working bodies, the following strain gauge structures should be installed on the experimental cultivator beads:

1. Strain gauge struts of working bodies (Fig. 1) with strain gauges 1; 2 which register transverse forces arising from the action of longitudinal and transverse components of dynamic loads on the working bodies.

2. Strain gauge bars with strain gauges 3; 4 which register transverse forces arising from the action of vertical and transverse components of dynamic loads on the working bodies.

3. Strain gauge locks with a strain gauge 5 which registers the forces arising from the tightening torque of the fastening bolt.

4. Strain gauge pins of hinged joints of the lower links of the beads with strain gauges 6, registering the longitudinal components of dynamic loads.

5. Strain gauge plates with strain gauges that register the movement of bodies relative to the tractor in the transverse horizontal $X_i$ and vertical $Z_i$ planes of motion.

6. Strain gauge plates fixed on the ski with strain gauges, registering the movement of the working bodies relative to the processed row spacing in the transverse horizontal $X_i$ and vertical $Z_i$ planes of motion.

To determine the components, knowing the support reactions, we can use the six equations of statics. It is known from the course of theoretical mechanics that an arbitrary system of forces can be reduced to the action of a dynamic screw. To solve this problem, we can use a grapho-analytical method for determining the magnitude and direction of the main vector, the position of the central axis in space and the point of its intersection with the surface of the working body, as well as the magnitude and direction of the main moment, its projection onto the direction of the main vector [9,10].

Let us write six equations of statics to determine the required quantities. The origin is taken at point $C$ (datum point) (Fig. 2.).

\[
\sum x = R_x - B_x - D_x = 0; \quad R_x = B_x + D_x
\]
\[
\sum y = R_y - U_y + E_y = 0; \quad R_y = U_y - E_y
\]
\[
\sum z = R_z + C_z - A_z = 0; \quad R_z = A_z - C_z
\]
\[
\sum M_x = M_x + E_y l_e + U_y l_e = 0; \quad M_x = E_y l_e - U_y l_e
\]
\[
\sum M_y = M_y - A_z l = 0; \quad M_y = A_z l
\]
\[
\sum M_z = M_z + B_x l_B + D_x l_B = 0; \quad M_z = B_x l_B - D_x l_B
\]
Figure 2. Layout diagram of strain gauges on the frame of a dynamometric trolley for spatial dynamometry of the working bodies of tillage machines.

The reactions of the supports at points A, B, C, D, E and U are perceived by the corresponding strain gauges and are recorded by the registering mechanism. In the above equations, the average reactions of the supports are substituted, found during the processing of dynamometer diagrams, the linear dimensions \( l \), \( l_0 \), \( l_b \) are determined by their direct measurement on the trolley.

The magnitude of the main vector is determined by the relation:

\[
R = \sqrt{x^2 + y^2 + z^2};
\]

The direction of the main vector is determined by the direction cosines:

\[
\cos(R, x) = \frac{x}{R}; \quad \cos(R, y) = \frac{y}{R};
\]

The magnitude of the main moment is determined from the formula:

\[
\cos(R, z) = \frac{z}{R};
\]

The direction of the main moment vector is determined by the direction cosines:

\[
M = \sqrt{M_x^2 + M_y^2 + M_z^2};
\]

The magnitude of the main moment and the direction cosines change when the datum point of the soil resistance forces changes (point C).

The magnitude and direction of the smallest moment does not depend on the choice of the datum point and is defined as:

\[
M_0 = \frac{XM_x + YM_y + ZM_z}{R};
\]

The direction of the smallest moment coincides with the direction of the main vector. The smallest moment is obtained when projecting the main moment onto the direction of the main vector. The quantities \( R \) and \( M_0 \) depend on choice of one or another coordinate system and are called static invariants of the given system of forces. The line of action of the main vector and the main moment projected on it has a well-defined position for a given system of forces.

The central axis is located at a distance \( r \) from the datum point \( C \), and the central axis is parallel to the principal vector \( R \).
\[ Z = \frac{\sqrt{M^2 - M_z^2}}{R}; \]

The distance is plotted perpendicular to the plane passing through the main vector and the main moment, in the direction in which the main vector \( R \) rotates counterclockwise relative to point \( C \). To construct the perpendicular in the coordinate axes, the direction cosines were found using the analytical geometry formulas.

After all the quantities have been determined analytically, the working body is built in the coordinate axes. The datum point \( C \) is taken as the origin, and the working body is drawn in the position that it occupied during the experiment relative to the point \( C \) of the dynamometer trolley. The components of the main vector \( R_x, R_y, R_z \) and the main vector itself; components of the main moment \( M_x, M_y, M_z \) and the main moment \( M \) are constructed. The smallest moment \( M_0 \) is plotted in the direction of the main vector \( R \). A perpendicular line is drawn. The value \( r \) is plotted on the perpendicular. Through the obtained point the central axis, a line parallel to the direction of the main vector \( R \) is drawn. The point of intersection of the central axis with the surface of the working body is found [11,12].

Carried out preliminary studies made it possible to determine some parameters of force loading and vibrations of working bodies on the frame of the dynamometric trolley: the moments on the counter of working body (strain gauges 1; 2) \( M_1 = 26 \text{ N·m}^2; M_2 = 43 \text{ N·m}^2; \) the moments on the bead bar (strain gauges 3; 4) \( M_3 = 275 \text{ N·m}^2; M_4 = 33 \text{ N·m}^2; \) the tightening force of the holder (strain gauge 5) \( P_5 = 20000 \text{ N}; \) pulling force (strain gauge 6) \( P_6 = 1820 \text{ N}. \)

4. Conclusion

Thus, the spatial effect of soil resistance on the working body can be determined using a dynamometric trolley. Since during operation the working body makes a uniform rectilinear movement, and an arbitrary system of active soil resistance forces acting on the working body with support reactions on the wheels is in equilibrium, then to determine the components, knowing the support reactions, we can use the six equations of statics. It is known that an arbitrary system of forces can be reduced to the action of a dynamic screw. Therefore, using a grapho-analytical method for calculating the parameters of a dynamic screw, one can build a working body and find the points of intersection of the central axis with its surface.

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