Technical means for determining the load of working enforcers of agricultural machines

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Abstract. The characteristics of a machine-tractor unit are determined by the indicators of the traction resistance of an agricultural machine, which require an experimental determination. The disadvantages of the known devices that provide measurements during volumetric dynamometry of the working enforcers of tillage machines are the complexity of the design and high measurement error. To improve the accuracy of experimental measurements of the dynamic loading of the working bodies of tillage machines, it is necessary to improve the technical means of measurement. Experimental determination of the loading of working bodies requires the use of a system of force sensors that affect the working bodies in different planes. Force sensors are manufactured mainly using strain gauges that are glued directly to the loaded parts. To determine the forces in the traction of the hydraulic suspension system of tractors, strain gauge fingers are used. It is shown that for the same distances of the sensors, the resulting signal does not depend on the distance of the force applied on the finger axis. Usually, force sensors are calibrated one at a time on special stands. The best calibration results will be achieved when all tenzometric fingers are installed in their proper places and all sensors are calibrated simultaneously. To do this, the intermediate plate is fixed using strain fingers on the levers of the tractor hydraulic suspension. Rymbolts are installed on the plate, to which a known force is applied three times and the readings of each of the strain fingers are taken. Solving the resulting system of equations, simultaneously find all the calibration coefficients. Additionally, a device is proposed, the kinematic scheme of which allows using a single measuring device, which simplifies the technology of measuring the force on the working body and increases its accuracy.

1. Introduction

During operation, the working bodies of agricultural tillage machines and tools interacting with the soil are subjected to dynamic loads, as well as abrasive and corrosive effects from the soil [1]. The efficiency of various machine-tractor units (MTU) for agricultural purposes [6, 10, 11] is largely determined by the characteristics of the traction resistance of an agricultural machine, which are...
probabilistic in nature.

When the MTA moves, the horizontal and vertical resistance to the movement of the working bodies from the soil increases with increasing loosening depth, which significantly limits their operational life, requiring strengthening of their working surfaces [9, 12, 13]. The disadvantage of the known devices that provide measurements for volumetric dynamometry of working organs of tillage machines and tools is the complexity of the design and a significant measurement error when moving the MTA (patents RU 2589217, SU 1522054, SU 1644730, US 4354390). One of the ways to reduce the error is to separate the measured forces in the vertical and horizontal plane (Patent 2684441 RU; Patent 2703423 RU. Patent 2703910 RU etc.). The review showed that improving the accuracy of measurements of the dynamic loading of the working bodies of tillage machines requires improving the measurement tools that reduce the error.

2. Materials and methods

The most common approach for experimental assessment of the MTU loading is the method of control dynamometry, which allows determining the dependence of traction resistance on the speed of MTU movement, in particular, during operations of basic tillage, intra-soil application of mineral or liquid complex fertilizers, and a number of others [11, 2].

Experimental determination of the efficiency of the MTA requires the use of force sensors that affect the working bodies in different planes. Force sensors are manufactured mainly using strain gauges [4, 13, 14, 15], which are often glued directly to parts that have a variety of cross-sections.

To determine the forces in the traction of the hydraulic suspension system of agricultural tractors, strain gauge fingers are used, which are cylinders with strain resistors attached to them (Fig. 1).

![Figure 1. Layout of strain gages for measuring vertical and horizontal loads.](image_url)
the load on the part.

![Bridge connection diagram for strain gages.](image)

**Figure 2.** Bridge connection diagram for strain gages.

To determine the horizontal force $P_h$, strain resistors 1, 2, 3 and 4 must be glued in a horizontal diametric plane (Fig. 1).

In this case, the strain resistors will not respond to the vertical load of the $P_v$ and the axial $P_a$, since under the action of $P_h$, the greatest normal stresses $\sigma_h$, and, consequently, the strain resistors at points 1, 2, 3, 4 will be the greatest. At points 1 and 4, the strain gages will be stretched, and at points 2 and 3, they will be compressed. Under the action of a vertical load $P_v$, the greatest stresses $\sigma_V$ will act at points B and H.

At points 1,2,3,4, the voltage $\sigma_r$ will be equal to 0 (Fig. 3) from the axial load, the resistance change of all strain gages will be the same.

![Stress plots from bending forces.](image)

**Figure 3.** Stress plots from bending forces.

In this case, there will be no change in the signal value in the measuring bridge. However, all this will be observed only if the strain resistors have the same resistance, are glued at the same distance from the point of application of the force, and are glued exactly in diameter at points 1,2,3,4.
3. Results and discussion
We show that for the same distances $l_1$ and $l_2$ (Fig. 4) and the connection diagram of the strain gages in Fig. 2 the resulting signal does not depend on the distance $l_0$ of the force applied on the finger axis.

![Figure 4. Scheme of action of forces on strain fingers.](image)

From the static equation (Fig. 4), it follows that:

$$ R_a \cdot c - P \cdot (c - l_0) = 0 $$

(1)

where follows:

$$ R_a = P - P \cdot \frac{l_0}{c} $$

(2)

$$ R_a = P - P \cdot \frac{l_0}{c} $$

(3)

The maximum bending stresses at the point K of the strain gauge finger are:

$$ \sigma_K = \frac{P \cdot l_1 - P \cdot l_0}{W_Z} $$

(4)

The maximum bending stresses at point M will be:

$$ \sigma_M = \frac{P \cdot l_2 \cdot l_0}{W_Z} $$

(5)

Given that $l_1 = l_2$, the sum of the stresses at points K and M will be:

$$ \sigma_\Sigma = \frac{P \cdot l_1}{W_Z} $$

(6)

As follows from the last dependence (6), the sum of stresses does not depend on the distance $l_0$ of the application of the force $RG$ along the length of the beam. Based on this, the installation locations of strain gages (Fig. 1) on the finger should lie in the same horizontal plane. At points 1, 2, 3 and 4, in which the maximum stresses from the horizontal force $P_h$ will act, and the stresses from the $P_v$ forces are zero, at the same distance from the supports on different sides of the point of application of the force.

Note that the stress formula gives accurate results if the distance from the point of application of force to the point at which the stresses are determined exceeds the diameter of the rod by at least 5 times (Patent 2682085 RU IPC G01L 5/16 (2006.01) Installation for spatial dynamometry of mounted agricultural machines and tools / Rogachev A. F., Karsakov A. A., etc. Published on 14.03.2019).
Usually, force sensors are calibrated on additional devices one at a time under conditions as close to real conditions as possible, which increases the accuracy of the experiment. The best calibration results will be when all the sensors (strain gauges) are installed in their regular places and all the sensors are calibrated at once.

This intermediate plate 1 (Fig. 6) is secured with strain gauges 2, 3 and 4 on the levers of the tractor 7. On the plate 1 is set to rimbaldi 5, 6, 7, to which is applied three times a known force $F$. Readings from each of the strain gauges are taken from the recording device.

Using the static equation:

$$P_L + P_R + P_U = P$$

a system of equations is compiled:

$$P_L + P_R + P_U = P$$ (7)
\[
\Pi_1^{L} K_1 + \Pi_1^{R} K_2 + \Pi_1^{U} K_3 = P,
\]
\[
\Pi_2^{L} K_1 + \Pi_2^{R} K_2 + \Pi_2^{U} K_3 = P,
\]
\[
\Pi_3^{L} K_1 + \Pi_3^{R} K_2 + \Pi_3^{U} K_3 = P.
\]

where \( \Pi_1^{L}, \Pi_1^{R}, \Pi_1^{U} \) - the readings of the devices of the left, right, and upper tensor fingers when the force \( P \) is applied at the first point; \( \Pi_2^{L}, \Pi_2^{R}, \Pi_2^{U} \) - readings of the devices of the left, right, and upper strain fingers when the force \( P \) is applied at the second point; \( \Pi_3^{L}, \Pi_3^{R}, \Pi_3^{U} \) - readings of the devices of the left, right, and upper tensor fingers when applying the force \( P \) at the third point; \( K_1, K_2, K_3 \) - sensor calibration coefficients.

Solving a system of equations, for example, by the Gauss method, or in the MathCad environment, all the calibration coefficients \( K_1, K_2, K_3 \) are found from the 3 equations of system (9).

However, all this will be observed only if the strain resistors have the same resistance glued at the same distance \( l_1 = l_2 \) and glued exactly in diameter at points 1 and 2, and the rod will remain straight during loading. In fact, under the action of the \( P_h \) force, the rod bends by an amount \( \delta \) and an additional bending moment appears from the axial force \( P_A \) (Fig. 7), equal to \( M_{l=1} = P_A \delta \), which will change the readings of the horizontal force sensor.

In addition, the \( P_h \) force is not actually applied at a single point \( S \), but acts on a certain site. Hence, the place of application of the resultant is unknown, and the values of the reactions in the supports and the voltage at the points where the strain gages are installed depend on the distance \( l_0 \).

![Figure 7. Diagram of forces in the longitudinal bending of the rod.](image)

In the case of forces acting on the strain gauge finger in different directions, it is difficult to avoid the impact of non-measured forces on the measured ones. The best option is if only one measured force is transmitted to the sensor.

4. Conclusion

The study of the evolution of design schemes of devices for direct measurement of forces on the working bodies of mounted tillage machines and tools in the MTU showed that the proposed structural and technological schemes provide increased accuracy by reducing the number of intermediate links. The developed technical solutions under patents of the Russian Federation 2682085, 2684441, 2703910 and 2703423 make it possible to directly determine the horizontal component of the traction force transmitted to the working body of the tillage tool during the MTU operation from the soil side. The proposed device provides the use of a single measuring device - a force sensor, to determine the total horizontal load on the working body of the MTU.

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