CALCULATION OF THE TRANSMITTED TORQUE UPGRADED FIXED CONNECTION

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Abstract. Renouncement and downtime of combine harvesters in operation lead to significant financial losses. One of the most important reasons for the downtime of this machinery is the failure of key connections, which account for up to 10.5 % of the total number of failures. The main disadvantage of this connection is that the keyway is a stress concentrator that reduces the fatigue strength of the parts, leading to an asymmetric deformation of the shaft and hub. The wear of individual parts of the fixed key connection is mainly due to the gradual surface destruction of the material of the parts, which is accompanied by the separation of particles, by changing the dimensions, geometric shape and properties of the surface layers of the material. The presence of gaps in the "bushing-shaft" connection also affects the reliability of the belt drives, since their constant pulsating loads, unloading and changing the inter-axis distance with variable frequency due to the turns of the key with the hub, take place. For real operating conditions of combine harvesters, the most effective installation is instead of existing key connections, where technical requirements permit, a removable hub for mounting a rotating element on the drive shaft, which can be made in the form of a repair kit with sufficient accuracy in the repair shops of farms. The use of the proposed modernized design of movable key connections first of all eliminates the main cause of the failure – the relative radial movement of the contacting mating parts, and also allows the hub and shaft to be pulled together without creating an eccentricity, which in turn will increase the service life of the connections. The article presents a method for calculating the transmission torque upgraded fixed connection, proposed for use in drives of combine harvesters instead of standard key connection. It presents the forces and tightening the conditions of the proposed strength of the connection.

Keywords: combine harvester, resource, conical sleeve, torque, fixed connection.

Introduction

It is based on previous studies [1] that the refusal key connection harvester is a loss of efficiency of the whole machine. Therefore, in order not to disrupt the process of harvesting of grain crops, necessary measures have to be taken to reduce the cost recovery time performance of critical parts and components of the combine and increase their resources, including the key connection.

Professor A.I. Yakushev [2; 3] proposed to use the factor of accuracy, which is the ratio of functional and design tolerances, to determine the accuracy of the geometrical parameters of the connection. Moreover, the accuracy stock should be created for each functional parameter affecting the performance of the product. According to the scientist, choosing the landing with the greatest accuracy factor of safety the durability of mobile connections increases, as the stock of materials for wear and the operational tolerance of landing increases.

I.V. Kragelsky developed a frictional fatigue wear model that depends on the stress-strain state of the material of the parts, the loading conditions, the properties of the lubricant and the environment. Fatigue wear occurs as a result of repeated deformation of the surface material, which leads to chipping of its particles and formation of microcracks. Methods for predicting the longevity of materials and the growth of fatigue cracks are presented in [4].

Studies of P.F. Dunayev, O.P. Lelikova, O.A. Leonova [5; 6] established that if in the compound "shaft-sleeve" there is a gap, the height of contact during rotation of the hub with key slot will deviate from the calculated depending on the angle of rotation. Therefore, the resource key connection will be determined by a gap in the connection and the angle of rotation of the hub and the shaft.

In most cases, declined to detail because the destruction of key connection is serviceable, it is difficult to produce a working surface: the streams of the pulley and the sprocket teeth of the involute, the cost of which is 80 % of the total cost of the items [7].

The wear of the contacting surfaces of the key, shaft and sleeve is the most common and precedes other types of damage.

Materials and methods

For real environments the most effective constructive solution of harvesters is to replace the existing key connection, where it allows the specifications of a removable hub for mounting a rotating member on the drive shaft [8] (Fig. 1), which can be manufactured in the form of a repair kit with sufficient accuracy in repair shops of farms.

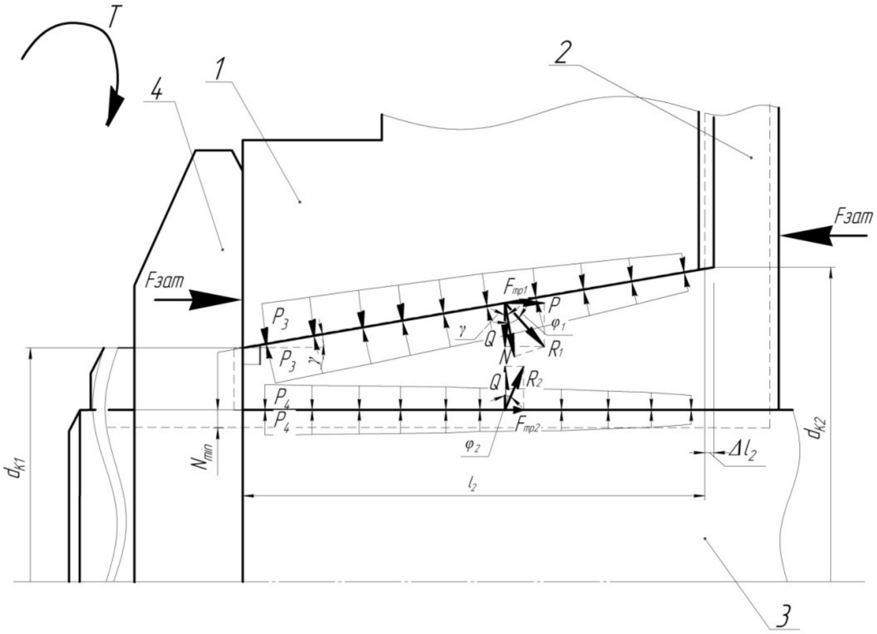

Fig. 1. **Scheme of the proposed upgraded connection:** 1 – hub of the pulley; 2 – conical split sleeve; 3 – drive shaft; 4 – lug nuts

Based on the structural features of the conical sleeve the stress σ_{max}, created on the strength of tightening will be greatest at the minimum surface of the cone. Then from the bond strength minimum allowable wall thickness of the cone b_{K1} is determined from the expression:

$$b_{K1} = \frac{2F_{tight}}{\pi\left(d_{K1} - d_{в}\right)\cdot[\sigma]} \tag{1}$$

where d_{K1} - minimum diameter of the conical sleeve, m;
F_{tight} – strength of the tightening, N;
$d_{в}$ – diameter of the cylindrical hole of the conical sleeve, m;
$[\sigma_{см}]$ – allowable bearing stress key material, MPa.

As for the variable wall thickness inherent in different properties of elasticity of the conical sleeve, characterized by longitudinal and transverse strain, then to account for this effect we have introduced a new parameter - the ratio of the wall thickness of the sleeve to its minimum diameter Δ:

$$\Delta = \frac{b_{K1} + d_{K1}}{d_{K1}}, \tag{2}$$

where b_{K1} – wall thickness of the conical sleeve, m;

For the ransmitted torque T, designed for removable mounting the hub of the rotating member on the drive shaft, it is possible to introduce the functional dependence:

$$T = f(F_{tight}\, d_{в}, d_{K1}, d_{K2}, b_{K1}, K, l, \Delta, HB, Ra, n), \tag{3}$$

where d_{K2} – maximum diameter of the conical sleeve;
K – taper;
l – link length, m;
HB – hardness;
Ra – roughness, micron;
n – rotation frequency, s^{-1}.

Analyzing the components according to (3) it is possible to determine the most significant, controllable and independent from each other, and to use them as the main factors in the experimental determination of the transmitted torque.

Of these factors less manageable is the roughness compound Ra in view of difficulties in obtaining a high accuracy of homogeneous values for several experimental samples, as well as the entire area of the contacting parts of the compound and, as already stated, change its value after every disassembly-assembly of the compound, so conventionally the factor can be attributed to the unmanageable.

The strength of the tightening F_{tight} is manageable, the most important and decisive factor in ensuring the efficiency of the proposed connection. With its zero value of the design it will not be operational.

The diameter of the shaft $d_{в}$, the length of connections l and rotation frequency n give constructive-technological features of each of the actuators of combine harvesters, so they change and variations in operating conditions are not appropriate.

The minimum diameter of the conical sleeve d_{K1} is an independent, managed and sufficiently relevant parameter since it accounts for most of the normal stresses that occur when tightening the connections. The same factor is the thickness of the wall of the conical sleeve b_{K1} defining the performance of the proposed design. At low wall thickness of the conical sleeve its destruction will occur or formation of cracks on the sidewalls. We suppose to unite these two meaningful factors in one – factor Δ, which represents the attitude of thickness of a wall of the plug to its minimal diameter and considers interrelation of these parameters at a variation of the geometrical sizes of the connection.

Hardness HB of the material of the conic sleeve should conform with hardness of the material of the drive shaft (HB 170). Thus, the material of the conic sleeve should possess elastic and plastic properties, therefore the size of thickness of the wall of the conic sleeve b_{K1} will depend on a variation of the given factor.

The maximal diameter of the conic sleeve d_{K1} will depend directly on the size of the value of the taper K, therefore the last parameter is chosen as it is more constructive, meaningful and independent of other factors, being thus manageable more expediently.

Thus, the most meaningful factors of a removable hub for installation of the rotating element, passed to affect the operating torque, will be the force of tightening the connection $X_1 = F_{tight}$ (N), taper sleeves $X_2 = K$, and the ratio of the sleeve wall thickness to its minimum diameter $X_3 = \Delta$.

As the magnitude of the response function performed the transmitted torque $Y = T_{r,}$ at which it started cranking the removable inner surface of the hub relative to the shaft. For the mathematical model of the relationship of these parameters and determination the extent of their impact on the effort to start turning in the compound, "the inner ring – shaft" experiment was implemented according to Box-Behnken plan three factors.

Results and discussion

As a result, data and dropout insignificant factor regression equations were obtained:

$$T_r = -141208.587+270.992F_{tight}+6781.88K+161185.65\Delta+15.82F_{tight}\cdot K -$$
$$-17.795F_{tight}\cdot\Delta - 0{,}322F_{tight}{}^2-61499.2K^2-69390\Delta^2. \quad (4)$$

Figure 2 graphically displays the response surface function of the transmitted torque T_r starting turning depending on the strength tightening $F_{tight,}$ taper sleeve K and the ratio of the wall thickness of the sleeve to its minimum diameter Δ, consistently taken mutually by fixing the third argument.

Studies have shown that an increase in the amount of the strength tightening F_{tight} from 380 N to 390 N, if $K = 0.125$, the transmitted torque is increased by 54 Nm and then it goes to the recession 1887 Nm, but if $K = 0.075$, there is a similar relationship with the values T_r = 1818 Nm, 1854 Nm, 1843 Nm, respectively. A similar dependence of the force Tr tightening was observed by varying the ratio of the wall thickness of the sleeve to its minimum diameter Δ, which is determined by the tensile strength of the material used in the manufacture of the proposed soybeans.

a)

b)

c)

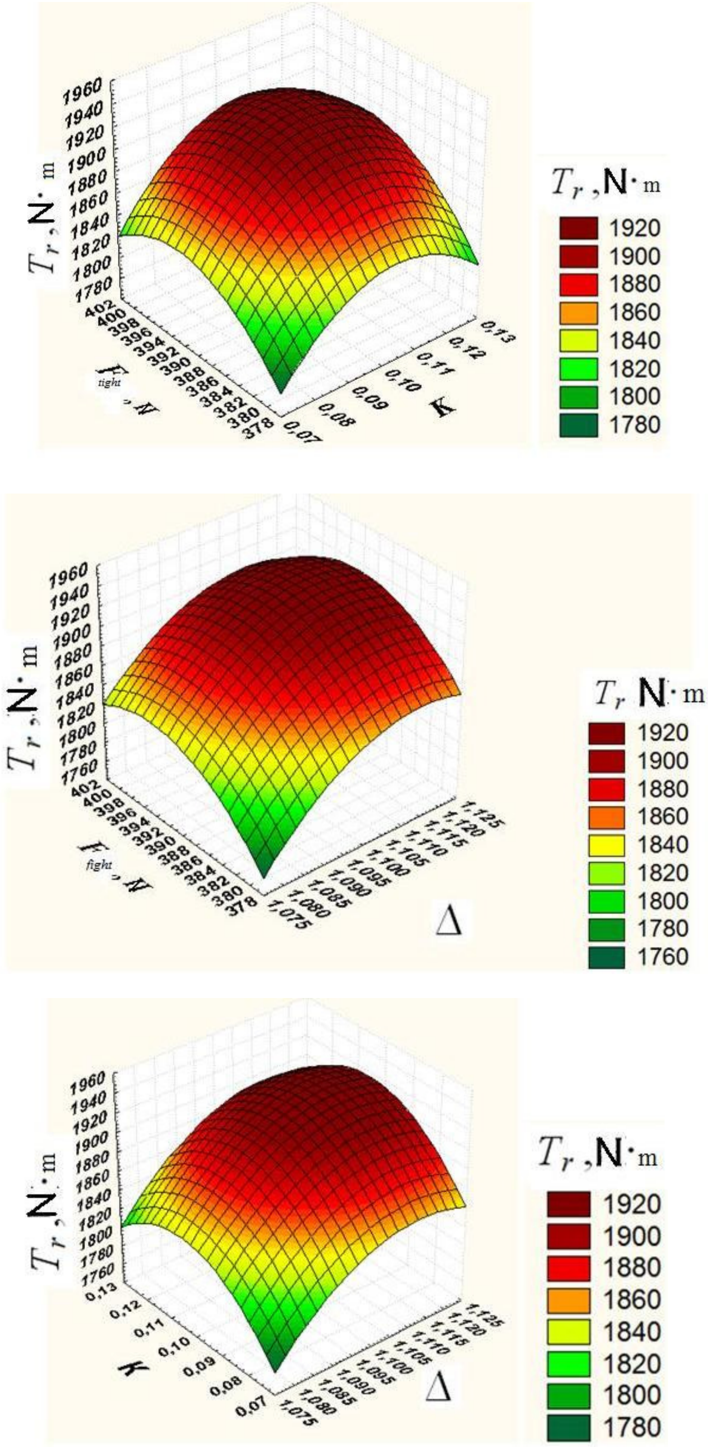

Fig. 2. **Surfaces load function starts rotation depending on:** a – tightening force and tightening taper sleeve *K*; b – strength tightening F_{tight} and correlation coefficient of the wall thickness to its minimum sleeve diameter Δ; c – taper sleeve *K* and the coefficient ratio of the wall thickness of the sleeve to its minimum diameter Δ

With the combination of the factors $K = 0.075$ and $\Delta = 1.08$ the transmitted torque will be minimal $Tr = 1808$ nm.

Further, with the increasing taper of the sleeve to 0,1 and the ratio of the wall thickness of the sleeve to its minimum diameter to 1.1 the transmitted torque *Tr* increases by 6 %. But with further increase of these parameters $K = 0.125$ and $\Delta = 1.12$ the tendency of decrease of the transmitted torque to a value equal of 1894 Nm was observed, which indicates the effect of non-uniformity of pressure distribution by increasing the ratio of the wall thickness of the hub to its diameter.

Therefore, by analyzing the response surface for various combinations of factors, we can draw the following conclusions. The maximum value of the transmitted torque is equal to 1933 Nm determined by the joint effect of the existence of three factors that can be achieved with the force of tightening the connection 392 N, taper sleeves 0.1 and the ratio of the wall thickness of the sleeve to its minimum diameter 1.115.

Conclusions

As shown, the implementation of the proposed upgraded connection allows to increase the efficiency of the use of combine harvesters at the expense of operational management of their reliability, by reducing the number of failure and the time of recovery in case of its occurrence. The elimination of the gap in this compound eliminates oscillatory motion around the shaft of the pulley hub and provides the ability to perform multiple parsing and assembly operations.

Thus, by the analysis and combination of the basic provisions of the theory of elasticity and resistance of materials the mathematical dependence of the calculation of the transmitted torque upgraded fixed connection was obtained.

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