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Dynamic properties of screw-bolts connections of sowing machine

Key words: vibration, dynamic properties, screw-bolts connections, sowing machine, local stresses, mathematical model, bolt loosening

Introduction

Threaded connections (TC) are extensively used in the transport industry. They are easy to implement, cost effective. Accidents caused by weakening of threaded joints are typical. For example, the collapse of the car body can be caused by the weakening of the bolts. A vehicle is a complicated system under the influence of vibration caused by an inequality of the road surface, variable speed, unbalance of the rotating elements. These vibrations are distributed through the vehicle and also affect the connection. Under their action, these compounds gradually begin to weaken. This can lead to serious accidents. The main factors influencing the relaxation of TC are the amplitude, frequency and gradient of vibration. For their determination it is necessary to clarify the picture of the propagation of vibration in the vehicle, especially the process of its transmission from the wheels to the sensitive element – the connection.

Review of previous research

Threaded connections, especially those related to machines, are exposed to significant levels of vibration during their operation. Although the frequencies of these oscillations are distributed over a wide range, the general effects of dynamic loading on bolted connections are similar. Main effects: (1) loosening the nut/bolt and (2) failure due to fatigue failure.

Agricultural machines operate under the influence of continuously changing external conditions. The analysis of the technological process of agricultural machinery shows that the main external factors influencing their work are the profile of the surface of the field, the hardness and moisture of the soil, the speed of the unit, the instability of the engine, the traction of the wheels of the tractor and others. Vibration of sowing machines mainly arises due to the irregularities of the surface of the field. In conditions of constant vibration and blows inevitable loss of stiffness, the occurrence of backlash, displacement of elements.

The calculation of TC is considered in monographs (Junker, 1969; Mocherniuk, 1970; Yakushev, Mustaev & Mavlyutov, 1979; Birger & Iosilevich, 1990).

Considerable attention of researchers is concentrated on the development of numerical methods for solving such problems. These are methods of finite elements, methods of boundary elements, some combined methods. However, raises the question of rational selection of the level of complexity of the model. In papers (Ibrahim & Pettit, 2005; Wang, Song, Liu, Li & Xiao, 2013) an overview of problems of durability and durability of TC is presented. Although a lot of work on the application of FE to calculate TC is known, analytical methods are used constantly, for example (Kovtun, 2011; Kurushin, Kurushin & Barmanov, 2011; Sakai, 2011), where the relaxation mechanism of TC is considered.

At the same time, in most publications, insufficient attention is paid to reliability issues during the operation of agricultural machinery. Reliability of TC is, first of all, a guarantee of long-term preservation of the efforts of preliminary tightening during operation. Quality of TC cannot remain stable for a long time due to many factors that adversely affect the process of production and operation of agricultural machines and seeders, in particular.

Formulation of the problem

Reliability of a vehicle is determined by the reliability of its sensitive elements. Figure 1 illustrates a general concept of a vehicle (wheeled car in terms of its reliability).

Here the sensitive element can be as elements of the design of the machine, and the driver and cargo. In our case, this is TC. The integrity of TC is influenced by a number of factors: the diameter and length of the bolts, the configuration of the connection, the condition of the surface of the bolts and their connected parts of the construction, the accuracy of the manufacturing, the use of fixing devices (counter nuts, Grover’s washers etc.). The main factor is the amplitude and gradient of vibration. Consider it in this section. Let’s introduce the following criterion of loss of integrity of TC

$$J_C = J_C(S(f), G(f)). \quad (1)$$

Here $S(f)$ is the spectral density of vibration in the vicinity of the TC, $G(f)$ – the configuration of the connection (f – frequency). It includes all the geometric parameters of TC, and the constructive solution of the elements that are interconnected. Such a criterion is chosen on the basis of the following considerations: firstly, the amplitude and the number of oscillation cycles influence the relaxation

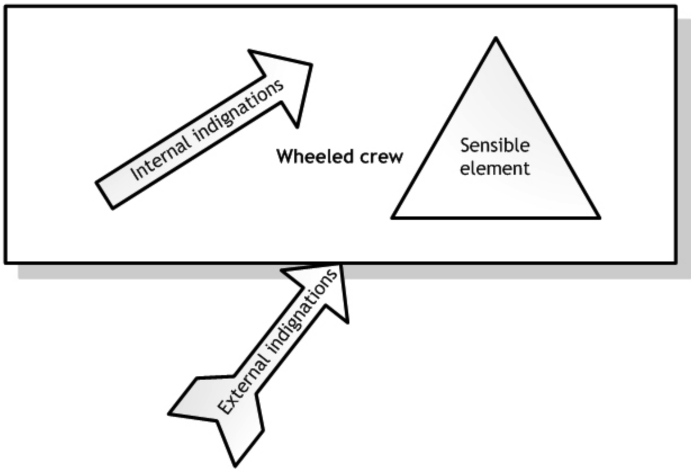

FIGURE 1. General scheme of the vehicle (internal sensible element)

of the TC. But not only, the frequency and geometric parameters influence. It is known that the elements of structures can resonate with external vibration, which causes a multiple increase in the amplitude of their oscillations (Timoshenko, 1967).

We first investigate the first value in (1). To do this, consider the drill as a wheeled car – a trailer. In Figure 2 the general (volume) scheme of a trailer with places of bolted connections (1–11) is resulted.

For modelling of dynamics of wheeled cars the most common single-mass model (Timoshenko, 1967; Bolotin, 1978). Such models are still widely used and known in foreign publications

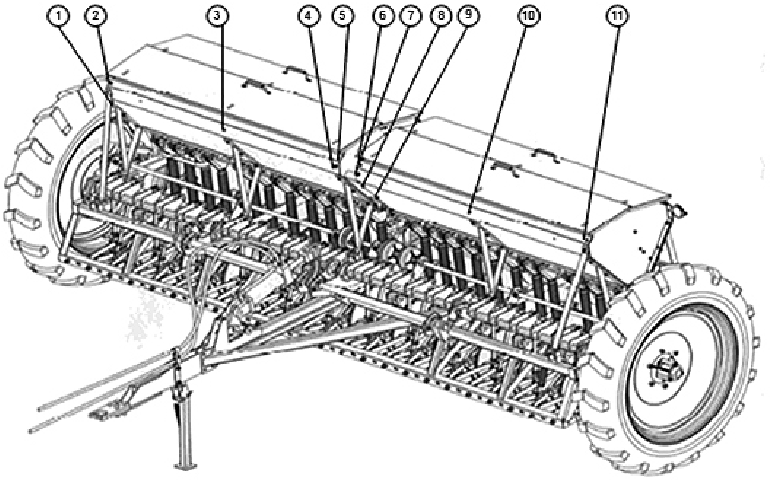

FIGURE 2. General (volume) scheme of a trailer with places of bolted connections (1–11)

as "quarter-car model" (Lee & Singh, 2008). Widely used are flat models, known as "one-half-car model" (Gopala Rao & Narayanan, 2008). The calculation scheme of the trailer is based on the decomposition of the general scheme on a number of partial lower orders (Mikishev & Rabinovich, 1968; Stotsko, Diveyev, Sokil & Topilnytskyy, 2006; Inoue, Yokomichi & Hiraki, 2013).

Modelling of vibration damages in seeders

The dynamics of the sawing machine is complicated by the grain's influence in the hopper. A series of calculation schemes has been developed to study the dynamics of granular materials in capacities. Basically, in addition to the calculation of bunkers in agricultural machinery, this is due to the following areas: (1) calculation of tanks with liquid for aerospace engineering, tank for transport (Mikishev & Rabinovich, 1968); (2) vibration processing of details; (3) the use of granular materials for damping the fluctuations of machine structures (Diveyev, 2015; Diveyev, Vikovych, Martyn & Dorosh, 2015).

To simulate the dynamics of grain in the hopper, apply a SDOF model. In Inoue et al. (2013), such a model is called the equivalent of single granules (ESG). Comparing measurements, the simulation provides close matching of measurements throughout the frequency range. Model ESG is a simple way to calculate damping, in comparison with the discrete elements method (DEM) – a discrete element method that requires a lot more parameters. However, it should be noted that the response of the system depends solely on the filling of the container with granules, in particular, the size of the container, the density of the granules, its diameter. Let's consider the scheme of the sawing machine (Fig. 3).

The equilibrium equation can be written as follows

$$m_1 \frac{d^2 u_1}{dt^2} + k_1 \left(u_1 - u_0 \right) + + F_1 \left(u_1 - u_2 \right) = F(t), \quad (2)$$

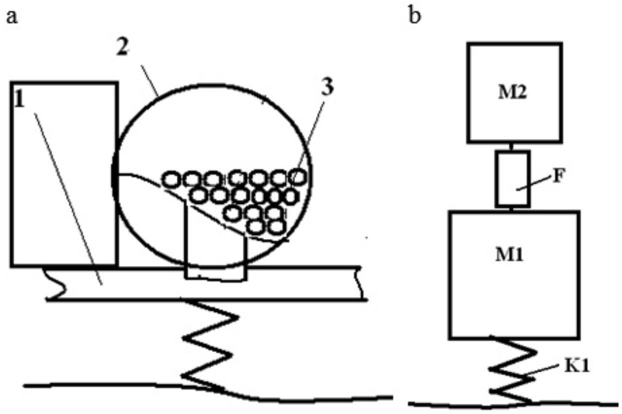

FIGURE 3. Diagram of the seeder: a – body (1), hopper (2), grain (3); b – RS seeders

$$m_2 \frac{d^2 u_2}{dt^2} - F_1(u_1 - u_2) = 0.$$

Here, m_1 is the weight of the trailer, m_2 – the weight of DVA, k_1 – the rigidity of the frame with the wheels (no suspension), $F(t)$ – external perturbation from the surface of the field, $F(u_1 - u_2)$ – non-linear force of interaction between the grain in the hopper and the case of the drill, u_i – appropriate displacement. For this non-linear function, you can write the following value

$$F_1 = -K_v(x_R - A_i)\ |x_R| > A,$$
$$F_1 = 0\ |x_R| > A_i. \quad (3)$$

Here A is the clearance, K_v – reduced stiffness of tank walls, $x_R = (u_1 - u_2)$ – the difference in the displacements of the reduced weight of the grain and the tank. If we consider the equation of fluid fluctuations in a tank (Mikishev & Rabinovich, 1968) and a simplified scheme of dynamics of granular material in a container (Stotsko et al., 2006; Diveyev, 2015; Diveyev et al., 2015), then it may be noted that these equations are similar.

If we assume that the oscillations are small (that is, the grain in the tank does not beat its upper cover), then system (2) can be linearized and write in the classical form two linear equations with linear viscoelastic friction

$$m_1 \frac{d^2 u_1}{dt^2} + c_1\left(\frac{du_1}{dt} - \frac{du_0}{dt}\right) +$$
$$+ k_1(u_1 - u_0) + c_2\left(\frac{du_1}{dt} - \frac{du_2}{dt}\right) + \quad (4)$$
$$+ k_2(u_1 - u_2) = F(t),$$

$$m_2 \frac{d^2 u_2}{dt^2} - c_1\left(\frac{du_1}{dt} - \frac{du_0}{dt}\right) +$$
$$+ k_1(u_1 - u_0) + c_2\left(\frac{du_1}{dt} - \frac{du_2}{dt}\right) +$$
$$+ k_2(u_1 - u_2) = 0.$$

Experimental field studies

For the experimental researches a mobile complex of vibrometry has been developed. Wheeled machines in the process of work create vibration loads on the frame and the elements attached to them. The source of these loads is the following main factors: rectilinear relief, imbalance of rotors, non-stationary (transitional) hydro or gas-dynamic processes. Cyclical loads can lead to cracks in the construction material and, as a result, result in loss of performance. Significant vibrations also arise in transport processes, in particular when transporting goods, passengers, when performing agricultural work. Vibration and noise also negatively affects sensitive elements: the person, the device, the coupling equipment, and so on.

The study was conducted in two modes of movement of the drill: with tightened bolts and weakened bolts. In Figure 4 is a graph of the spectral density of the vibration signal of the drill: theoretical values and experiment with the clamping bolts.

From Figure 4a it is evident that the spectral density of the signal strength is concentrated in the region of low frequencies up to 100 Hz. In the spectrum there is a frequency of 10 and 20 Hz. The main power falls on low frequencies a

b

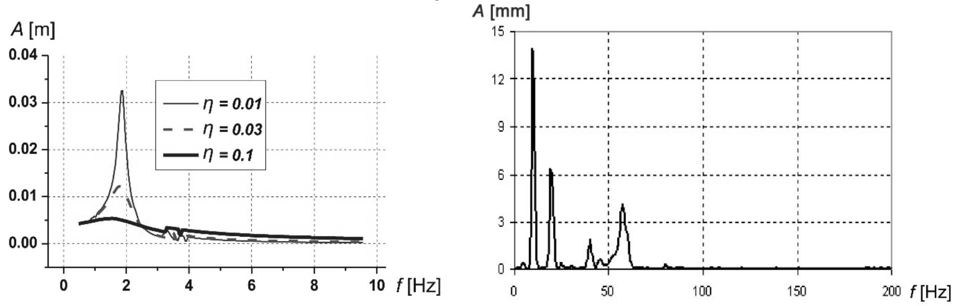

FIGURE 4. Spectral density of seeder vibration: a – theoretical values; b – experiment with the clamping bolts

of 10 and 20 Hz. From Figure 4b it is seen that the spectral density of the signal strength with the weakened bolts is concentrated in the frequency range up to 5 Hz, as in theoretical case. The main power of the signal is 5 Hz.

Theoretical model of threaded connection

Often simple discrete models are used for simulation of TC (Kovtun, 2011; Kurushin et al., 2011; Sakai, 2011). Such models allow us to estimate the state of TC on the basis of both theoretical and experimental research. To study the integrity of TC, which is tested on the stand, consider the design scheme of non-linear oscillations of the design in the presence of gaps in the TC. Let's illustrate schematically TC (Fig. 5).

Figure 6 shows the calculation scheme of TC. Here, M_p is a small intermediate mass, M – a sum of end mass and effective mass of the plate, rigidity K_1 and damping C_1 connections (linear), K_n – non-linear connection.

In order to avoid a complicated calculation of the serial connection of a linear and non-linear elastic element, we introduce some small rigid mass, breaking the plate onto a small initial hard part, and elongating the elastic longitudinally (Fig. 6b). The equations for this calculation scheme of TC with the gap and the additional mass will be

$$m_1 \frac{d^2 u_1}{dt^2} + k_1 \left(u_1 - u_0 \right) + \\ + F_1 \left(u_1 - u_2 \right) = F(t), \qquad (5)$$

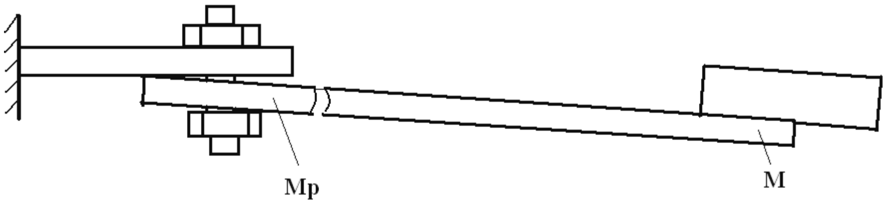

FIGURE 5. Loosening TC scheme

$$m_2 \frac{d^2 u_2}{dt^2} - k_1 (u_1 - u_0) -$$
$$- F_1 (u_1 - u_2) = 0.$$

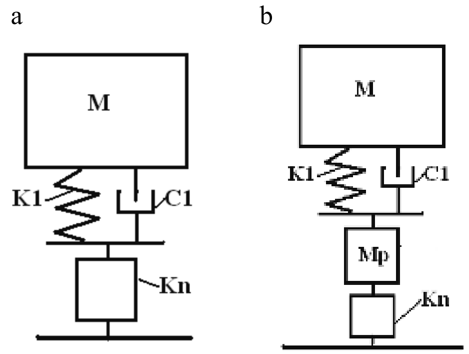

FIGURE 6. Scheme RS: a – single-weight; b – two-mass

They are similar to equations (2) and (3) with a non-linear function. In this case, in addition to viscous friction, dry friction between the bolt surface and the hole surface is also considered

$$F_1(X_R) = -K_G(x_R - A_i) - K_G \eta_G \frac{dx_R}{dt},$$
$$|x_R| > A; \quad -K_v(x_R) - K_v \eta_G \frac{dx_R}{dt} -$$
$$-C_t \, sign\left(\frac{dx_R}{dt}\right), \quad |x_R| < A_i. \qquad (6)$$

Here, A is the clearness, K_G – the linear rigidity of the bolt resistance sites, $K_G \eta_G$ – the viscous damping in the site, K_v – the rigidity of the bolt's resistance when moving between the supports, $K_v \eta$ – the corresponding viscous damping, C_t – corresponding dry friction.

For this model, a Fortran program was also compiled. Figure 7 shows both experimental and theoretical vibrograms of acceleration of oscillations.

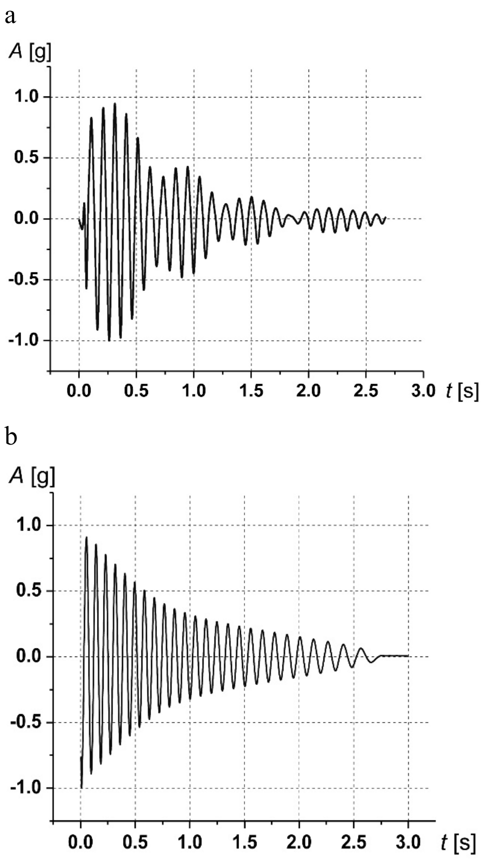

FIGURE 7. Vibrograms of accelerations: a – experimental; b – theoretical with different initial deviations

Conclusions

The research was conducted to determine the technical condition of the drill and the impact of operation on the state of the threaded joints. A block diagram of the 16-channel system for collecting and processing signals of vibration diagnostics for remote measurement from the mechanical structures of mobile platforms (watering systems, drills, cars and others) was developed and the devices of the system were made. To do this, a study was made of the spectral characteristics of the vibrations of the mechanical constructions of the drill in different modes of its movement using a mock-up of the multichannel vibrating system. In order to detect the state of the threaded joints of the bearing structures of the drill, a synchronous recording in the digital form of the vibration signals was made. For the survey, the method of spectral analysis of multidimensional periodically non-stationary random signals was used. In the process of testing, the dynamic loading of bolted joints installed on the respective knots and components of the drill was evaluated.

From the conducted research it follows that the maximum vibrations acting on the TC of the drill may be in the vicinity of high-frequency resonances of TC. Studies were conducted both in field and laboratory conditions (on a specially made stand), where typical samples of TC and a reduced model of the drum tank were used. In parallel, non-linear mathematical models of the oscillations of the seeder and the weakened TC were developed. The theoretical results qualitatively correspond to the experimental data. Note that in order to identify the model parameters it is necessary to conduct a number of additional studies, such as a simulator simulating a seeder with a tank filled with grain, and a TC study under different conditions. The maximum vibrations acting on the coupling of the seed drill may be in the vicinity of high-frequency resonances of the connection. This increases the weakening of the connection, as not only the amplitude of oscillation increases, but also the number of load cycles increases significantly. One of the measures that can reduce these negative effects may be the vibration of the TC. The high-frequency components of the vibration in this case will be filtered using a suspension. Note that sprinkling is a general global trend in heavy agricultural machinery. The use of a system of vibration absorbing devices can serve as an alternative.

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Summary

Dynamic properties of screw-bolts connections of sowing machine. A vehicle is a complicated system under the influence of vibration caused by an inequality of the road surface, variable speed, unbalance of the rotating elements. The main factors influencing the relaxation of threaded connections (TC) are the amplitude, frequency and gradient of vibration. Although the frequencies of these oscillations are distributed over a wide range, the general effects of dynamic loading on bolted connections are similar. Main effects: (1) loosening the nut/bolt and (2) failure due to fatigue failure. The analysis of the technological process of agricultural machinery shows that the main external factors influencing their work are the profile of the surface of the field, the hardness and moisture of the soil, the speed of the unit, the instability of the engine, the traction of the wheels of the tractor and others.

To study the integrity of TC, which is tested on the stand, consider the design scheme of nonlinear oscillations of the design in the presence of gaps in the TC. The study was conducted in two modes of movement of the drill: with tightened bolts and weakened bolts. For the survey, the method of spectral analysis of multidimensional periodically non-stationary random signals was used. In the process of testing, the dynamic loading of bolted joints installed on the respective knots and components of the drill was evaluated.

From the conducted research it follows that the maximum vibrations acting on the TC of the drill may be in the vicinity of high-frequency resonances of TC. In parallel, nonlinear mathematical models of the oscillations of the seeder and the weakened TC were developed. The theoretical results qualitatively correspond to the experimental data.

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