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Analysis of the physical features of the operation of stands with a closed power flow for testing v-belt gears

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Abstract. Currently, there are practically no sufficiently satisfactory analytical methods for predicting the reliability of newly designed machines. Basically, the task is solved on the basis of information obtained largely during resource bench tests of parts, assemblies and aggregates. The stands used for carrying out resource tests of machine transmissions can be divided according to the type of loading into open loading stands and closed loading stands. Open loading stands are driven by an AC or DC electric motor and are decelerated by a special braking system. Closed loading stands load the transmission without the use of braking systems. This article discusses the physical features of the operation of stands with a closed power flow used for testing V-belt gears, which can significantly reduce energy costs. The analysis of the application of an analytical method for predicting the reliability of newly designed machines is carried out on the basis of information obtained largely during resource bench tests of parts, assemblies and aggregates.

1 Introduction

Currently, there are practically no sufficiently satisfactory analytical methods for predicting the reliability of newly designed machines.

Basically, the task is solved on the basis of information obtained largely during resource bench tests of parts, assemblies and aggregates. The stands used for carrying out resource tests of machine transmissions can be divided according to the type of loading into open loading stands and closed loading stands [1].

2 Research methods

Open loading stands are driven by an AC or DC electric motor and are decelerated by a special braking system. Of the braking systems, the most reliable are DC generators with ballast resistances. In some cases, for example, if there is a DC power supply network in the laboratory, partial energy recovery is performed into the network. Closed loading stands load the transmission without the use of braking systems [2]. Stands of this type are

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characterized by the fact that the loading of the elements of the tested gears is carried out by using the internal elastic forces of the system.

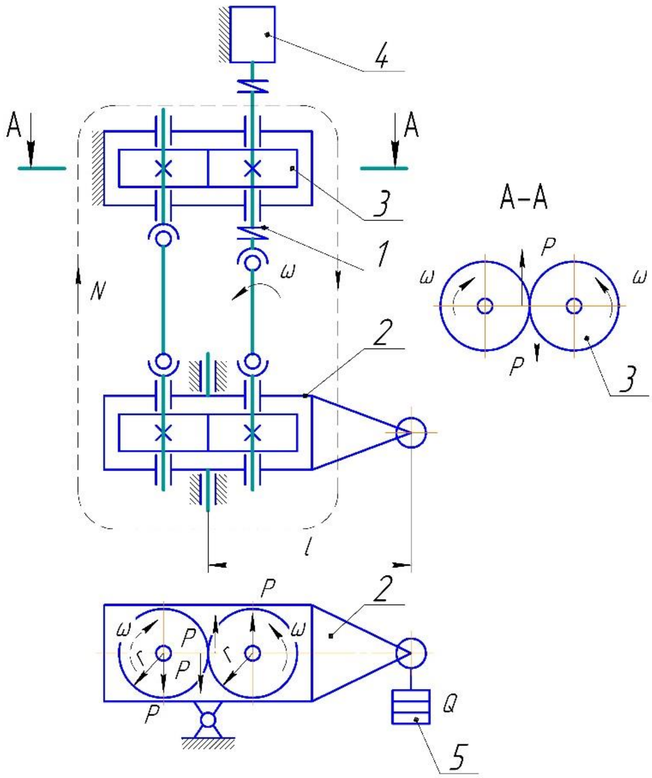

Fig. 1. Diagram of a closed-loop test bench for gearing gears: 1 – coupling; 2 – planetary loader; 3 – gearbox under test; 4 – electric motor; 5 – additional loads.

Due to the closed loop, the initially created internal forces are preserved during the rotation of the transmission. These forces cannot carry out the work, therefore, the excited load in a closed-loop stand is called the apparent "circulating" power.

According to the method of loading the tested transmission, closed-loop stands can be divided into stands for testing gearing gears and stands for testing friction gears.

Closed-loop stands for gearing gears load the tested transmission by pre-twisting the shafts and other elastic elements of the gears using a special coupling 1 (Figure 1) in the stationary state of the transmission [3]. This loading is maintained and controlled by a special planetary loader 2 (Figure 1) with additional loads 5 (Figure 1).

The torque reproduced in the test gear 3

$$M = P_{\mathrm{i}} = \frac{Q*l}{2},$$

where: P_i - circumferential force on the gear wheel of the planetary gearbox;

r - gear radius;

l – shoulder;

Q - the total force applied to the shoulder l (the weight of the gearbox and the load).

From the physical meaning of the occurrence of a load in a closed loop, it follows that the power consumed by the stand from the motor 4 (Figure 1) is spent on overcoming the friction resistance in preloaded kinematic pairs, therefore much less than the apparent power circulating in a closed loop [4]. The total power circulating along the contour consists of the apparent N_1 and the power N_2 expended by the engine to overcome the friction forces:

$$N = N_1 + N_2 \quad (1)$$

In closed-loop stands, it is important to know the direction of the circulating power flow. The direction of the power flow is counted from the link connected to the engine, from the corresponding leading links to the driven ones. To recognize the master and slave link, it is necessary to keep in mind the following obvious rule: at the leading link, the direction of its angular velocity ω does not coincide with the direction of the moment M of the forces acting on it; at the driven link, the direction ω coincides with the direction M.

Figure 1 shows the designations of the master and slave links, as well as the corresponding direction of the power flow N. The direction of the power flow allows you to evaluate the most loaded sections of the circuit. On the stand (Figure 1), the gear wheels of the gearbox 2 are loaded more than those of the gearbox 3.

In closed-loop stands for friction gears, it is impossible to load the tested transmission by pre-twisting the shafts and other elastic transmission elements, since these loads are balanced by the forces of friction bonds, which change when the stand is started, losing their original values. In these stands, loading is carried out due to a constant small kinematic misalignment of the gears entering the closed loop [5-7].

Figure 2 shows a diagram of a closed-loop test bench for V-belt gears. We have selected the diameters of the pulleys as follows:

$$D_{12} > D_{22} = D_{21} = D_{11} \quad (2)$$

Due to this selection of pulley diameters, the pulley D_{22} tends to rotate the shaft at a higher speed than the pulley D_{21}. This kinematic misalignment causes the appearance of elastic forces that create a constant torque in the closed circuit of the stand [8-10].

Using the above rule for determining the direction of the power flow for the stand circuit in Figure 2, we get: pulleys D_{12} and D_{21} are driving, and pulleys D_{22} and D_{11} are driven. The direction of the power flow is indicated by the arrow N and goes from the pulley D_{12} to the pulley D_{11}.

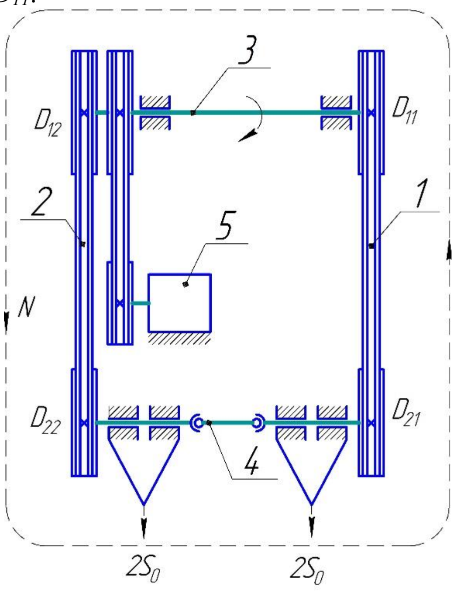

Fig. 2. Diagram of a closed–loop test bench for belt drives: 1,2 - belts; 3 – shaft with fixed supports; 4 – shaft with movable supports; 5 – motor.

We determine the amount of torque that acts in a closed loop, with a given mismatch of diameters, noted in expression 2).

According to the direction of the power flow, the first drive pulley is D_{12}, and the last driven pulley is D_{11}. For this closed loop consisting of almost identical V-belt gears, the following expression can be written, which determines the relative slip of the V-belts due to kinematic mismatch of the pulley diameters:

$$2\xi_1 = \frac{n_{11}-n_{12}}{n_{12}} = \frac{n_{11}}{n_{12}} - 1,$$

where: ξ_1 – relative sliding of each of the two V-belt contours;

n_{11}; n_{12} – the corresponding rotational speeds of the pulleys. From here

$$\frac{n_{11}}{n_{12}} = \frac{D_{11}D_{21}}{D_{11}D_{22}};\ \xi^1 = \frac{1}{2}\left(\frac{D_{12}D_{21}}{D_{11}D_{22}} - 1\right). \quad (3)$$

The torque M_1, excited in a closed circuit due to mismatch of the pulley diameters, can be determined according to the sliding curve of each of the V-belt gears included in the circuit (Figure 3). If the reproducible load is within the permissible norms for V-belt transmission, then according to Figure 3

$$M_1 = tg\alpha\ \xi_1;$$

or

$$M_1 = \frac{tg\alpha}{2}\left(\frac{D_{12}D_{21}}{D_{11}D_{22}} - 1\right). \quad (4)$$

Hence the apparent circulating power

$$N = \frac{M_1 n_1}{716{,}2}. \quad (5)$$

The power expended to overcome the friction forces can obviously be expressed in terms of N_1 as follows:

$$N_2 = (1-\eta_0)\ N_1,$$

where η_0 - the total efficiency of all elements of the transmission stand.

The total power of the leading link of the closed circuit of the stand

$$N = N_1 + N_2 = N_1(2-\eta_0) \quad (6)$$

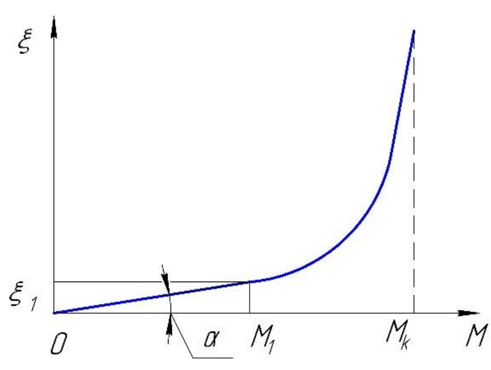

Fig. 3. Belt drive slip cur.

From the consideration of the scheme of a closed-loop stand for testing belt drives (Figure 2), it follows:

1. When changing the direction of the angular velocity ω and preserving the condition of expression (2), the direction of the power flow and the value of expression (5) do not change.
2. When replacing the condition of expression (2) with a new one:

$$D_{12} < D_{22} = D_{21} = D_{11} \quad (7)$$

the speed of the pulley D_{22} will be less than the speed of the pulley D_{12}. Shaft 4 will be affected by a torque directed in the other direction [12-14]. In this regard, the direction of the power flow will reverse, then the pulleys D_{11} and d_{22} are driving, and the pulleys d_{12} and d_{21} are driven.

3. It is also obvious that the condition

$$D_{21} > D_{11} = D_{12} = D_{22} \quad (8)$$

will give the same results as expression (2), and the condition

$$D_{21} < D_{22} = D_{12} = D_{11} \quad (9)$$

will give the same results as expression (7).

From the considered conditions of expressions (2), (7), (8) and (9) the general rules follow:

- if $D_{12} \cdot D_{21} > D_{11} \cdot D_{22}$, the direction of power flow will go from D_{12} to D_{11}. If $D_{12} \cdot D_{21} < D_{11} \cdot D_{22}$, the direction of power flow is from D_{11} to D_{12};
- at the same time, the direction of the angular speed of rotation of the shafts does not change the direction of the power flow [15].

3 Conclusions

From all that has been considered, the following conclusions can be drawn:

1. Closed-loop stands have a number of advantages compared to stands with open loading using braking devices.
2. Closed-loop stands can significantly reduce energy costs and do not require special braking systems.
3. They are simpler in design, as well as in some cases simplify the adjustment and control of loading modes.

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