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Experimental investigation on interaction of wave disk generator with flexible gear

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Annotation. Power processes that proceed upon interaction between the flexible gear and the wave disk generator were investigated. Experimental values of the normal load q distribution in an area of the flexible gear contact with the wave generator disks were determined. This load was applied to the flexible gear on the side of the wave generator disks (from the principal axis ϕ of the wave gearing) and selected for various torque M_2 values being transmitted. Moreover, a dependence of the resultant force R , impressed by the flexible gear to the wave generator disks, on the torque M_2 values was determined. An experimental investigation under conditions of the heavy engineering has been scheduled. A wave gearing built in the Type VZ-1120 Gearbox of the MP-600AS torpedo car swivel mechanism was used as the prototype. It was investigated on a universal test stand with an opened power loop. Investigation results obtained in such a way are used in heavy engineering as the guiding data for performance of the development and design engineering works and optimization of the heavy wave gearbox performance.

1. Review

Weight of the mechanical drive is estimated as 15-20% of heavy machines weight. And more than 50% of failures happen because of transmission or gearings glitch. These units' weight reaches tens and hundreds of tons because of the limited reason for productivity increase, design and logistic simplification. The use of multiple-stream kinematic diagrams including those with flexible links is the efficient way of perfecting the driving equipment by increasing load-carrying capacities of the gearings. Elastic deformations permit to simplify techniques of the power flow differentiation. Distribution of the power flow in a largely extended field of contact allows one to reduce loads applied to the teeth, eliminate limitation concerning bearing capacities of the gearings in terms of their jamming, bending or contact stresses and ensure transmission of the high torques with far less overall dimensions and specific amount of metal. A multiple reduction of loads applied to the teeth permits to eliminate limitations concerning criteria of thermal power, bending and contact stresses, drastically increase load-bearing capacities of such gearings, lessen their sizes and weights and raise efficiency of mechanical drives. Geometry, kinematics and power analyses along with the analyses for contact and bending strength have been carried out mostly for comparatively small wave gearings with the cam-type wave generators [1 - 3]. Interference and overshoot of the teeth were not sufficiently investigated and load-carrying



capacities and power losses were not impartially assessed for heavy disk generator wave gearings. The perspective of implementation of heavy wave gearings is complicated by these facts.

Experimental investigation on interaction of the wave disk generator with the flexible gear results is set out. Analysis of these data allows clarifying force factors influence on the quantitative and qualitative values of heavy wave gearing properties (with the aim of optimization and perfection of its design shapes and parameters).

2. Methods of Investigation.

Power processes that proceed upon interaction between the flexible gear and the wave disk generator were investigated. A wave gearing built in the Type VZ-1120 Gearbox of the MP-600AS torpedo car swivel mechanism was used as the prototype. It was investigated on a universal test stand with an opened power loop.

To evaluate load distribution acting on the wave generator and flexible gear, the amount and character of the power factors in an area of interaction between the wave generator disks and the flexible gear were determined. Power factors in an area of interaction between the wave generator disks and the flexible gear may be ascertained by the method of strain measurements. Strain resistors are secured on the faces of each wave generator disk on both sides. Strain resistors are calibrated by way of analyzing applied radial forces, which may be measured by the load gage coupled in a manner of kinematics and forces with the area of disk, and the relevant strain measurement data.

In the course of processing oscillograms of the localized disk element movements, root-mean-square values of the readings taken from strain resistors installed on localized elements of the three wave generator disks have been used. Strain resistor readings have been taken simultaneously at equal values of angle φ_k for each disk. Loads and torques M_2 for the wave gearing under investigation have been taken step by step.

3. Load Distribution in an Area of the Flexible Gear Contact with the Wave Generator Disks

Small-sized wave gearings have been mainly implemented in heavy engineering with their kinematic and power analyses carried out without allowance for peculiarities of the flexible gear deformation by the wave disk generator. Interference and overshoot of the teeth were not sufficiently investigated and load-carrying capacities and power losses were not impartially assessed for heavy wave gearings. Due to the scale factor, it seems to be difficult to transfer obtained findings onto heavy wave gearings. Since the above problems have not yet been solved, this impedes elaboration of the wave gearings for heavy engineering [4 - 6]. Elaboration of the highly loaded mechanical gears with flexible links is an urgent scientific and technological problem of gearbox-making. Solution of this problem will permit to increase power and capacity of the machine drives, lessen their overall sizes and weights, improve performance of the heavy engineering products [7 - 9].

Experimental research was carried out on the universal stand with an open power loop. A wave gearing of the Type VZ-1120 Gearbox integrated with the MP-600AS torpedo car swivel mechanism was tested as the prototype.

Experimental values of distributed loads applied to the flexible gear on the side of the wave generator disks (from the position of a principal axis) at various torque rates on a low-speed shaft of the wave gearing have been obtained. A character of the resultant force that acts on the wave generator disks on the side of the flexible gearing versus the torque rates of the wave gearbox low-speed shaft has been determined.

Flexible gear 1 is subject to deformation under the effect of the wave generator and conforms to the definite shape. Due to this, intermittent wave-shaped transmission of the rotary motion of the wave gear may be provided (Fig. 1). Due to action of the wave generator and torque M_2 on the low-speed shaft side, a complex stresses state of the flexible gear may originate.

To evaluate loads acting on the wave generator and establish a stressed and deformed state of the flexible gear, the amount and character of the power factors in an area of interaction between the wave generator disks and the flexible gear shall be determined [8-10]. A wave generator of the wave gearing

under investigation consists of three disks 2 having the same radius and being installed with eccentricity e on the high-speed shaft. Power factors in an area of interaction between the wave generator disks and the flexible gear may be ascertained by the method of strain measurements. With this aim in view, strain resistor 3 is secured with glue on the faces of each wave generator disk on both sides in a symmetrical manner and in radial direction.

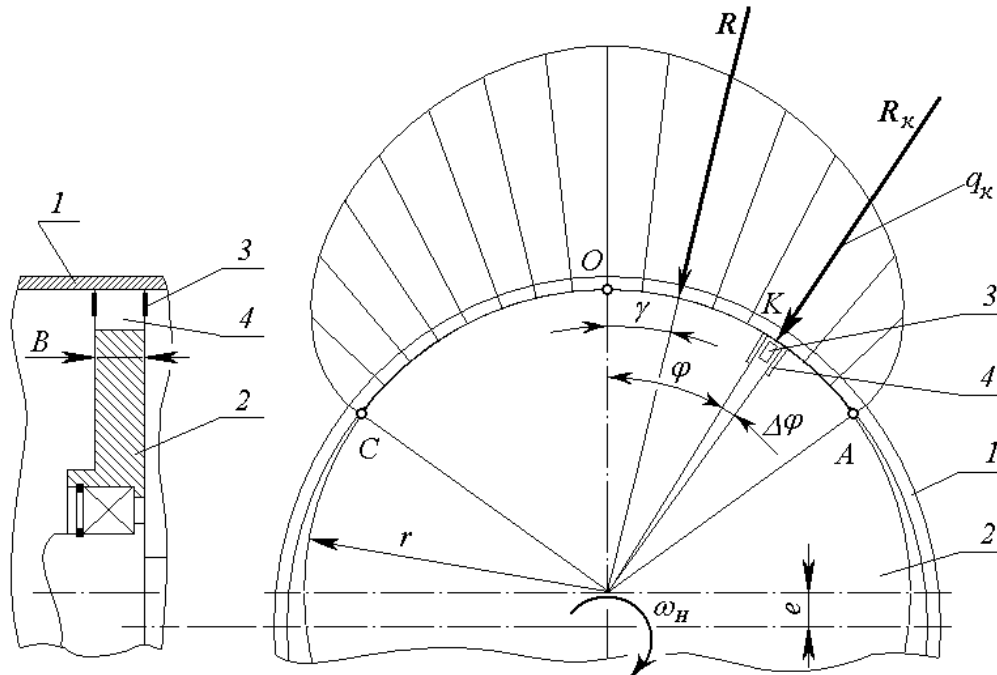


Figure 1. Simulation of interaction between the wave generator and the flexible gear 1: 2 – wave generator disk. 3 – 2FKPA strain resistor. 4 – through slot

The places of gluing strain resistors are separated by through rectilinear slots 4. Both strain resistors are connected in series to one working arm of the strain amplifier half-bridge [2]. The signal from strain resistors is recorded upon rotation of the wave generator with rotational frequency $n_1 = 5$ rpm. Strain resistors are calibrated by way of analyzing applied radial forces R_1, R_2, \dots, R_k , which may be measured by the load gage coupled in a manner of kinematics and forces with the area of disk 2 localized by slots 4, and the relevant strain measurement data. Strain resistors 3 are glued to the wave generator disks and isolated from the oil both with special synthetically-based oil-resistant coating. Specific pressure q_k , N/deg. applied to the disk on the side of the flexible gear may be calculated as follows:

$$q_k = \frac{R_k}{\Delta\varphi}. \quad (1)$$

To determine the mechanism of a load q_k distribution in relation to position of the wave generator longer axis, a mark of the moment of matching this axis with the radial straight line passing through the middle of the localized disk portion – the place of strain resistor locations – shall be put on the plot (Fig. 2). Strain resistors provide measurements of the disk deformations in a radial direction.

Synchronization of matching the larger axis of the wave generator with the radial straight line, which passes through the middle of the localized disk element and the maximum radius of the wave generator. Contacts are installed on the eccentric shaft. The moment of closing the contacts is registered by the pulse on an oscillogram that corresponds to the generator rotation angle $\phi = 0$. Deviations of the contact positions from the preset ones shall not exceed $\pm 3^\circ$.

Based on the results of normal specific pressure q_k ratings obtained in conformity with formula (1), a vertical scale, on which the angular coordinate φ_k is counted off, is along the horizontal line

$$\varphi_k = \pi \frac{OK}{l}. \tag{2}$$

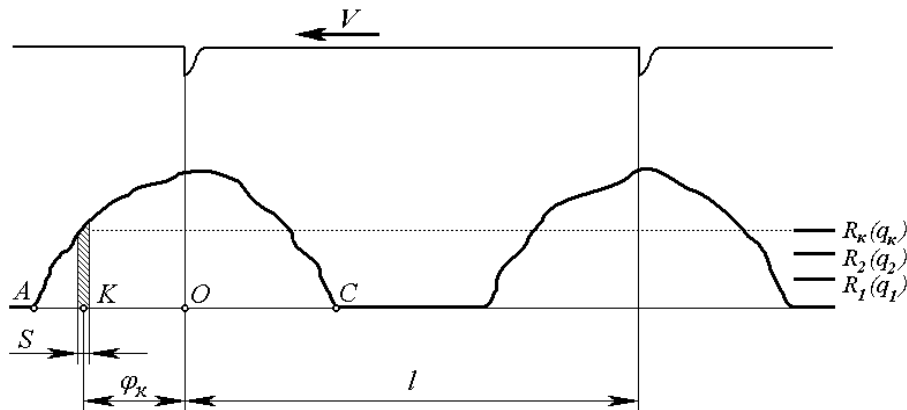


Figure 2. A plot of the flexible gear pressures applied to the wave generator disk

A positive value of φ_k is taken from the maximum wave generator axis towards its rotation ω_H . Direction of the oscillograph tape advance is denoted by V. Based on the results of computations (1) and (2), there are curves of pressure q distribution on an arc of the wave generator disk contact with the flexible gear at various torque ratings of the type VZ – 1120 wave gearbox (Fig. 3).

Based on the plots, a radial load R acting on the flexible gear on the wave generator disk and an angle γ between the resultant vector and larger axis of the wave generator may be computed.

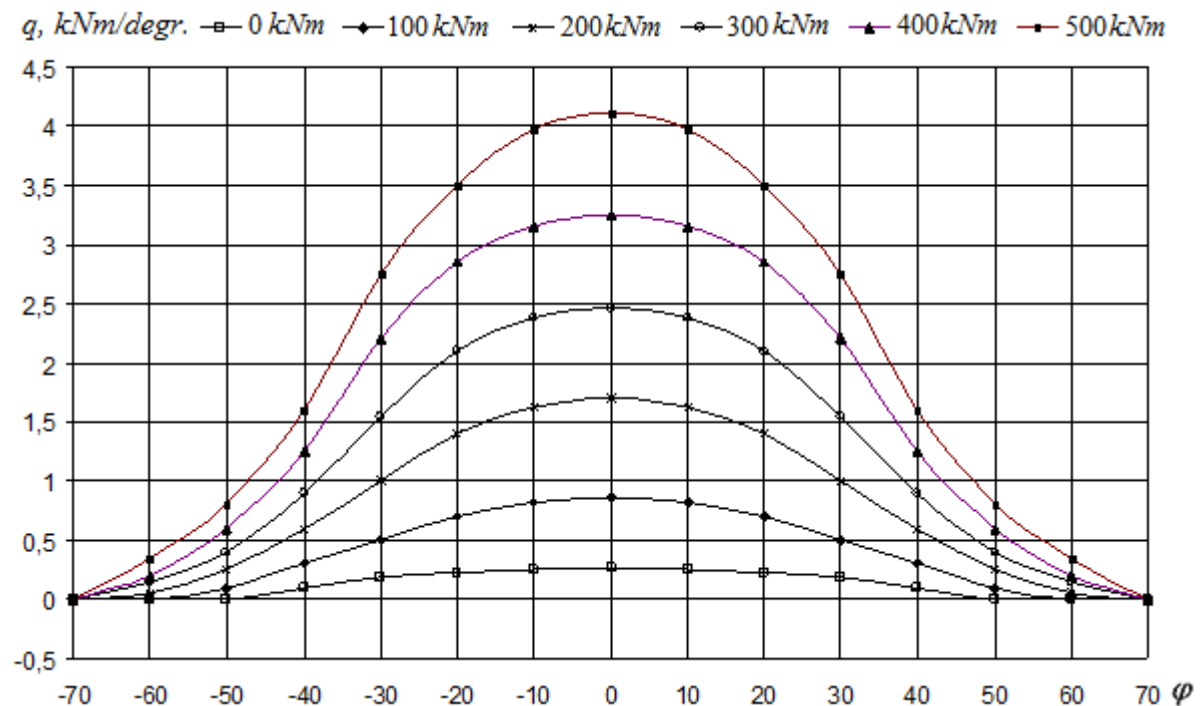


Figure 3. Load q applied to the flexible gear on the disk side versus positions of the wave generator longer axis and loading torque M_2 ratings (0, 100, 200..., 500) kNm

Resultant force R equals the sum of elementary force projections on an axis which coincides with the direction of the \bar{R} vector. To do this, the horizontal axis is divided in sections S each corresponding to the value of angle φ_k . Then, an average value of load q_k on divided section S may be found. Finally, by using the value of q_k obtained, resultant force R acting on the wave generator disk on the flexible gear side may be computed as follows:

$$R = \sum_{k=1}^n q_k S \cdot \cos(\varphi_k - \gamma) = S \sum_{k=1}^n q_k \cdot \cos(\varphi_k - \gamma). \quad (3)$$

Each value of q_k is determined as a root-mean-square value of several data obtained from the set of oscillograms for one and the same moment of the angle φ_k measurement. Let us set angular coordinate γ which determines the position of the resultant force R point of application to the wave generator disk:

$$\gamma = \frac{\sum_{k=1}^n q_k \sin \varphi_k}{\sum_{k=1}^n q_k \cos \varphi_k} = \frac{\sum_{k=1}^n q_k \varphi_k}{\sum_{k=1}^n q_k}. \quad (4)$$

Based on the results of resultant force R (3) and angular coordinate γ (4), a plot which illustrates variation of radial force R versus transmitted torque M_2 rating may be constructed (Fig. 4). The values of resultant force R and angular coordinate γ may be calculated by means of the plot given in Fig. 2. To do this, section AC shall be divided in a row (25-30) of equal portions with points K .

Vertical line Y_k shall be passed through each point K of section AC . Values obtained from equations (1) and (2) are substituted into equation (3) and the desired values are found:

$$R = m \sum_{k=1}^n Y_k \cdot \cos\left(\pi \frac{OK}{l} - \gamma\right), \quad \gamma = \frac{\pi}{l} \cdot \frac{\sum_{k=1}^n Y_k \cdot OK}{\sum_{k=1}^n Y_k}, \quad (5)$$

where m = scale factor determined during calibration.

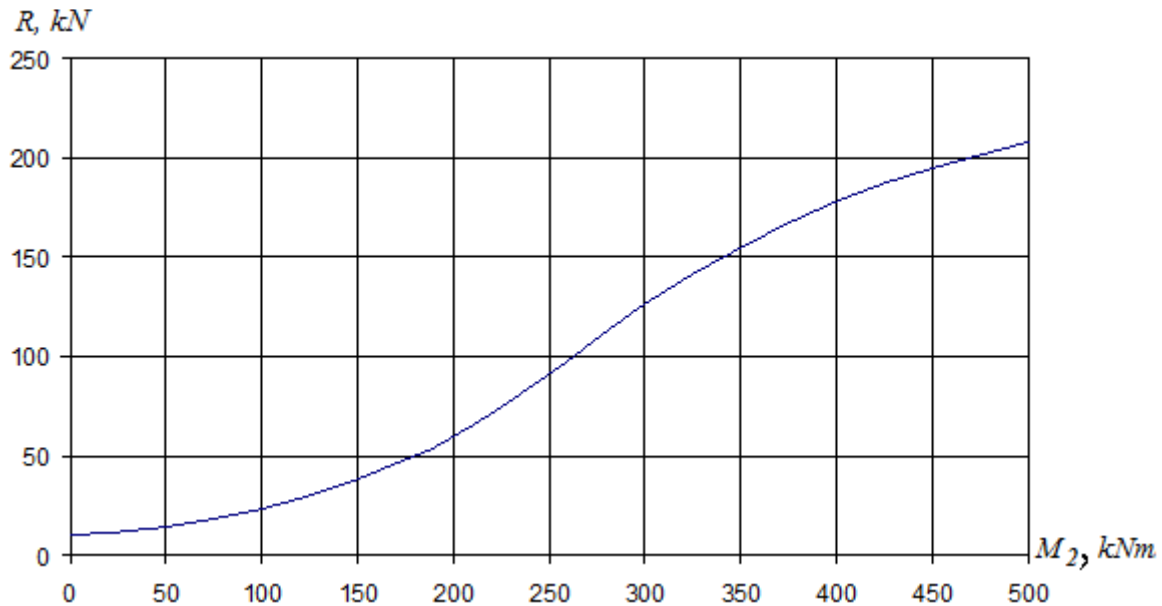


Figure 4. Radial force R acting on the wave generator disk versus torque M_2 value of the low-speed shaft

Based on experiments, values of the distributed loads acting in an area of the flexible gear contact with the wave generator disks depending on positions of the wave gearing longer axis at various values of transmitted torque M_2 have been obtained.

4. Summary

The findings obtained during the study of the power factors in an area of interaction between the wave generator disks and the flexible gear allowed one to determine the character of normal load distribution over the flexible gear on the part of the wave generator, as well as to ascertain dependence of radial force R acting on the wave generator disk on torque M_2 .

Experimental data analysis shows that an area of interaction between the wave generator disks and the flexible gear expands with an increasing of torque M_2 : in bonds φ_{\min} $[-50^\circ \dots +50^\circ]$ without load, $M_2 = 0$, and up to φ_{\max} $[-70^\circ \dots +70^\circ]$ at load maximum, $M_{2 \max} = 500$ kNm. In the latter case, radial force R (acting on the wave generator disk) is 210 kN at load maximum $M_{2 \max}$.

Investigation results obtained in such a way are used in heavy engineering as the guiding data for performance of the development and design engineering works and optimization of the heavy wave gearbox performance.

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