Experimental research of the resilient keyed joints statics

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Abstract. This article deals with the problem of shaft-hub connections rigidity and one way of solving it by using the new constructions of resilient keyed joints. Methods of experimental research of the resilient parallel keyed joints statics are described by showing dependences between their deformations, torque and sizes, and conclusions in comparison with theoretical research are made.

Key words: shaft-hub connection, resilient parallel key, torque transfer.

INTRODUCTION

The need to improve the efficiency and reliability of the drives of machines and mechanisms requires the improvement of their parts connections designs. The most common connections of machine elements in mechanical engineering are the connections of a shaft-hub type, which include keyed connection as well. Traditionally, rigid keys are being used in machinery. These keys have a high rigidity and transmit the torque from the shaft to the hub, or vice versa, instantaneously, that often causes shock loading, which negatively affects the durability of parts and whole drive in general. When transmitting torque there is a possibility that shaft will twist at a certain angle. Then in the case of rigid connection, for example, the position of gears is effected and tooth contact line may decrease. The shaft-hub connections with resilient parallel keys transmit torque more softly due to forces of the key deformation. We have obtained theoretical dependences between deformations, torque and sizes of these keys in previous research [7-10]. Therefore, there is a need for experimental verification of static loading mode in such connections, and that will be the theme of the following work.

RECENT RESEARCH AND PUBLICATIONS ANALYSIS

The connections with rigid keys are widely known [1]. In addition, a number of resilient keys for connections of shafts with hubs were developed at the level of patents [2-6]. Use of these keys allows to change the stiffness of the connection and to transmit torque from the shaft to the hub, or vice versa, softer, i.e. without shock, which positively affects the durability of the drive.

Works [7-10] are dedicated to theoretical issues of resilient parallel keyed connections statics. However, these theoretical studies require further experimental research and confirmation of the results.

The aim of this work is to conduct experimental research of statics of resilient parallel keyed joints used to connect various rotation parts during the torque transfer.

MAIN PRESENTATION

Among all new constructions of resilient keys we have chosen the one presented on the Fig. 1 due to relative simplicity of its manufacturing and because it reflects the principle of work of the whole class of resilient keys, perhaps, in the best and most simple way. It's called resilient parallel key with the cavity equidistant to its external surface.

Fig. 1. Resilient parallel key with the equidistant cavity

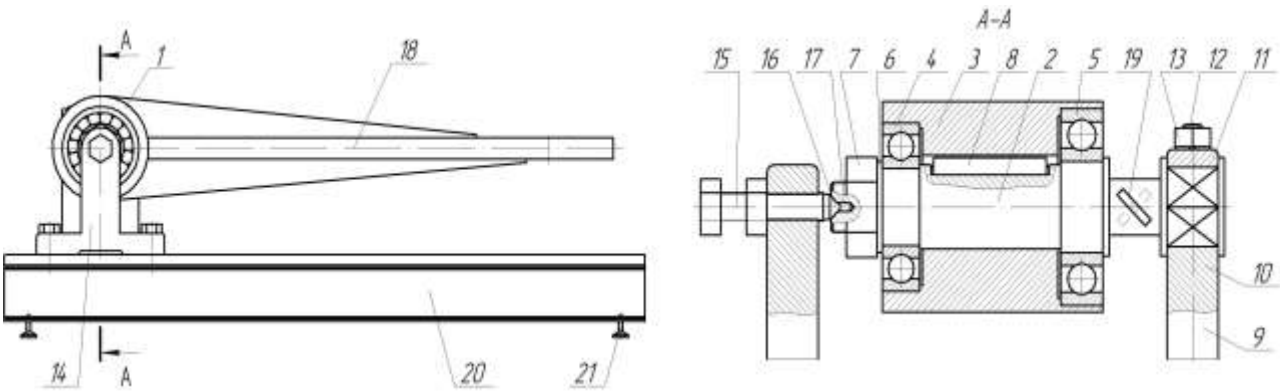

Fig. 2. Scheme of the basis of stand for the experimental research of the parallel keyed connections

The method of theoretical calculations for this resilient key is presented in [7]. Here we are going to verify its results by experiment.

Experimental research of the static properties of such connections in comparison with the rigid ones were conducted on a specifically designed and manufactured stands [11-15].

Scheme of the basis of patented stands for the experimental research of the static and dynamic properties of resilient parallel keyed connections is shown on Fig. 2, and it contains the keyed connection 1 itself, which consists of a fixed shaft 2, loading bushing 3, bearings 4 and 5, washer 6, nut 7 and key 8. Fixed shaft is rigidly mounted through a square tail section by studs 12 and nuts 13 in the resistance 9, which consists of a body 10 and cover 11. To avoid bending deformations of the fixed shaft the removable support 14 was installed and the screw 15 was set in the threaded holes of it, which through a conical end 16 interacts with a pivot hole 17 of the fixed shaft. Loading bushing of the keyed connection is rigidly connected to one end of the lever 18 by welding, and on the second end of it - special equipment for different types of loading can be placed. Measurement of strain and vibration phenomena in keyed connections for different types of loads is taken by measure sensor 19. Keyed connection with resistors mounted on the frame 20. To install the frame in the horizontal position there are legs 21 for regulation.

One should mention, that this stand allows you to research keyed connections not only under static loading but also subjected to various types of stress, caused, for instance, by periodical or dynamic loadings of other nature. It uses additional removable equipment for that case.

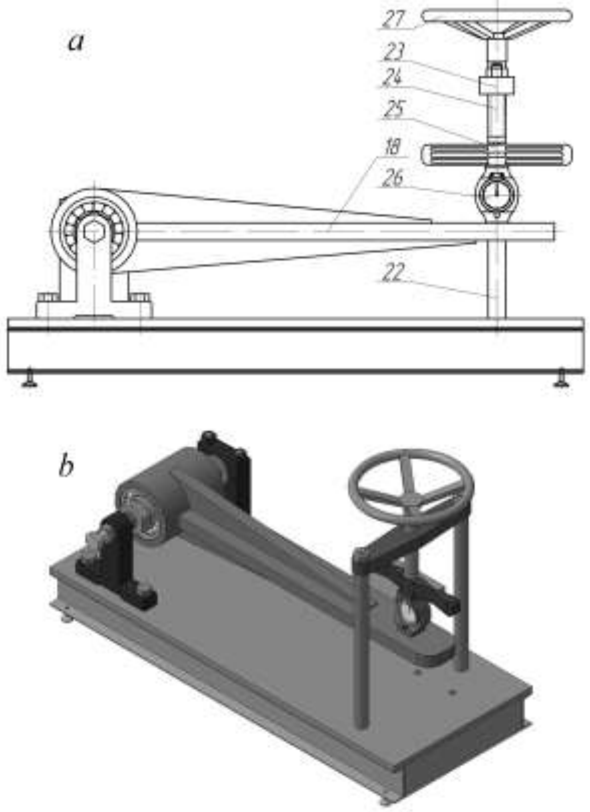

Fig. 3. Stand with equipment for the research of statics and calibration of the measure sensor:

a – scheme of pressure sensor calibration; *b* – general view or the stand.

During research of resilient keyed connections loaded with static torque we use equipment shown on Fig. 3, where vertical uprights 22 with the crossbar 23 are installed on the frame, above the free end of the lever, and screw 24 is set in the threaded hole of bar, which is due to dynamometer 25 interacts with the lever 18. Screw is driven by flywheel 27.

Diameter of shaft-hub connections d = 60 *mm*, and parallel resilien key (Fig. 4, *a*) has the following dimensions of width, height, length and width of cavity: $b \times h \times l$ = 18 × 12 × 90 *mm*, b_1 = 4, 6, 8, 10 *mm*, -i.e. the ratio b_1 / b equals from 0.3 to 0.6, respectively.

By way of comparison compounds with standard rigid parallel key of compared sizes b × h × l = 18 × 12 × 90 mm (Fig. 4, *b*) were also tested.

All aforementioned dimensions are shown on Fig. 4.

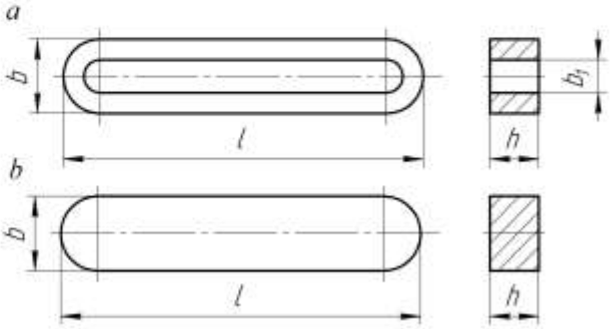

Fig. 4. Parallel keys: a – resilient; b – rigid

Experimental research of statics was performed as shown on Fig. 5. Static torque was created by loading of rigid or resilient keyed connection with weights mounted on the free end of lever. Each cargo weight is F_g = 100 N. To create a static torque on the lever loads F_g = 100, 200, 300, 400, 500 N were installed. The lever arm of the force from the cargo weight l_{Fg} = 700 mm, and the weight of lever itself F_{gl} = 358,3 N with lever arm of the force from lever weight applied in the center of mass l_{Fgl} = 240 mm. Then the static torque created by these loads is respectively: 156, 226, 296, 366 and 436 N·m. A measure sensor attached to the fixed shaft and gage station TS-8 was used to record findings.

Measurement of deformations was carried out using the hardware and software gage station TS-8 (Fig. 6). It is designed to measure, decode and transmit signals of strain gauges for storage to determine the deformation and moments by means of tenzometric measurements.

The structure of TS-8 gage station is shown on Fig. 6. It includes:

- Control unit,
- Block with strain gauges - 8 pcs,
- Battery 12 V,
- Power unit 12V 0,6 A,
- Connecting cables.

Given gage station provides:

- continuous measurement and recording of signals of strain gauges for eight hours,
- display of measured signals on the PC screen in real-time,
- remote adjustment of balance and signal amplification,
- setting frequency separately for each channel within specified limits.

In our case, we used a single channel of the TS-8 complex to measure the deformation of the shaft due to installed on the shaft measure sensors, depending on the torque and size of investigated keys.

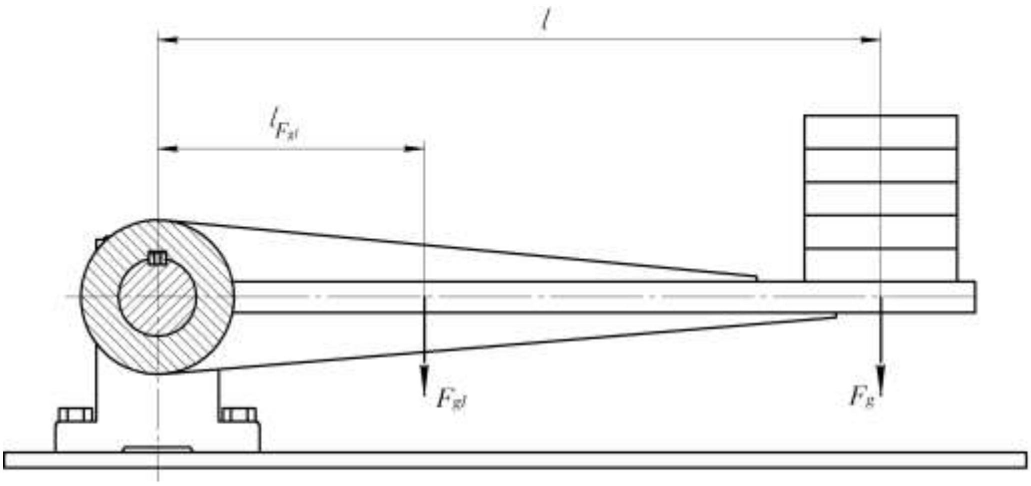

Fig. 5. Stand with equipment for the research of static loadings due to weight

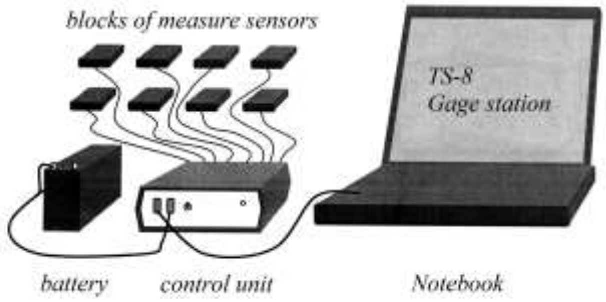

Fig.6. Gage Station TS-8

Decryption of obtained oscillograms was performed according to the results of the sensor calibration carried out on the equipment, where at the free end of the lever on the frame vertical uprights with crossbar were mounted. Crossbar had a threaded hole with set screw that through dynamometer DOS 200 interacted with the lever (Fig. 3, *b*). The screw is driven by handle. Through the measure sensor and measure station TS-8 data were recorded for constructing the calibration graph.

Fig. 7 shows a scheme of the resilient deformation of parallel key in shaft-hub connection. If you turn the hub relative to the shaft at the angle φ, key deformation will be δ.

Table 1. Results of the theoretical and experimental research of the resilient parallel key deformation dependence from the torque

T, N·m	$b_1 = 4mm$		$b_1 = 6mm$		$b_1 = 8mm$		$b_1 = 10mm$	
	δ_t	δ_e	δ_t	δ_e	δ_t	δ_t	δ_t	δ_e
156	0,098	0,12	0,187	0,20	0,380	0,36	0,863	0,90
226	0,143	0,15	0,271	0,28	0,550	0,52	1,251	1,33
296	0,186	0,16	0,354	0,34	0,721	0,69	1,638	1,61
366	0,231	0,26	0,438	0,45	0,891	0,87	2,026	2,00
436	0,275	0,29	0,522	0,49	1,062	1,03	2,413	2,22

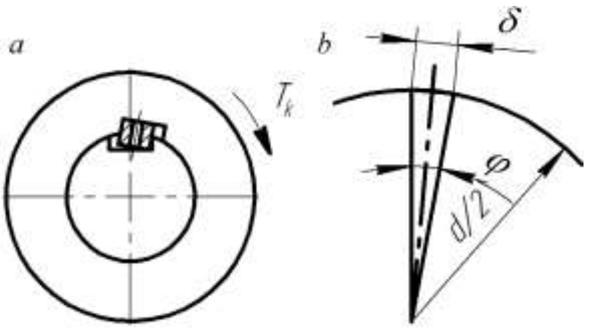

Fig.7. Scheme of the resilient parallel key deformation:

a – hub positioning according to shaft; *b* – *δ*-*d* relation through angle *φ*.

To determine the resilient deformation of parallel key in conjunction with the shaft hub we used scheme shown on Fig. 6, which graphically shows the dependences between the angular displacement of the lever 2, and at the same time of the hub 1. Measuring of the angular displacement of lever 2 is performed by indicator 3, shown on Fig. 8 and 9.

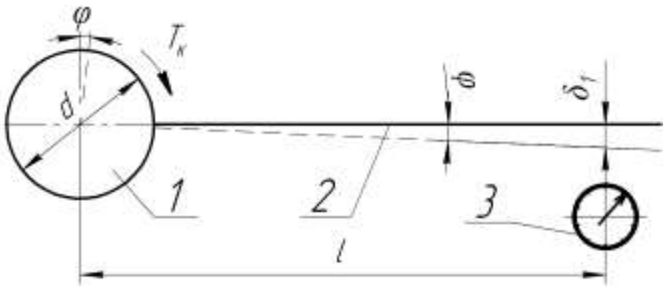

Fig. 8. Scheme for definition of the resilient key deformation that is the result of lever angular displacement

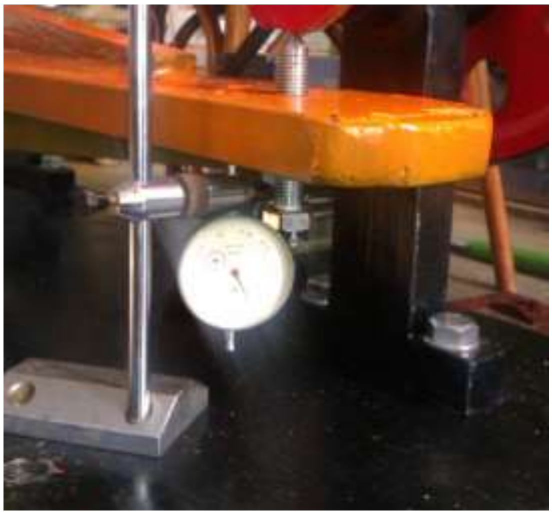

Fig. 9. Measuring of the lever angular displacement by the dial indicator

Experimental deformation δ of resilient parallel key was found depending on δ_1 based on the following proportion:

$$\frac{\delta_1}{l} = \frac{2\delta}{d}. \qquad (1)$$

Hence:

$$\delta = \delta_1 \frac{d}{2l}, \quad \text{or} \quad \delta = 0{,}042857\ \delta_1. \qquad (2)$$

At every stage of the experimental research of resilient keys we conducted experiments ten series each and processed them according to recommendations [17].

The results of theoretical calculations [7] and experimental research results of the dependences between the deformation of the resilient parallel keys and torque are summarized in Table 1. According to Table 1 theoretical and experimental graphical dependences between torque and deformation, obtained for a set of connection with resilient parallel keys of the same external dimensions but different width of equidistant internal cavity, were built, as shown on Fig. 10.

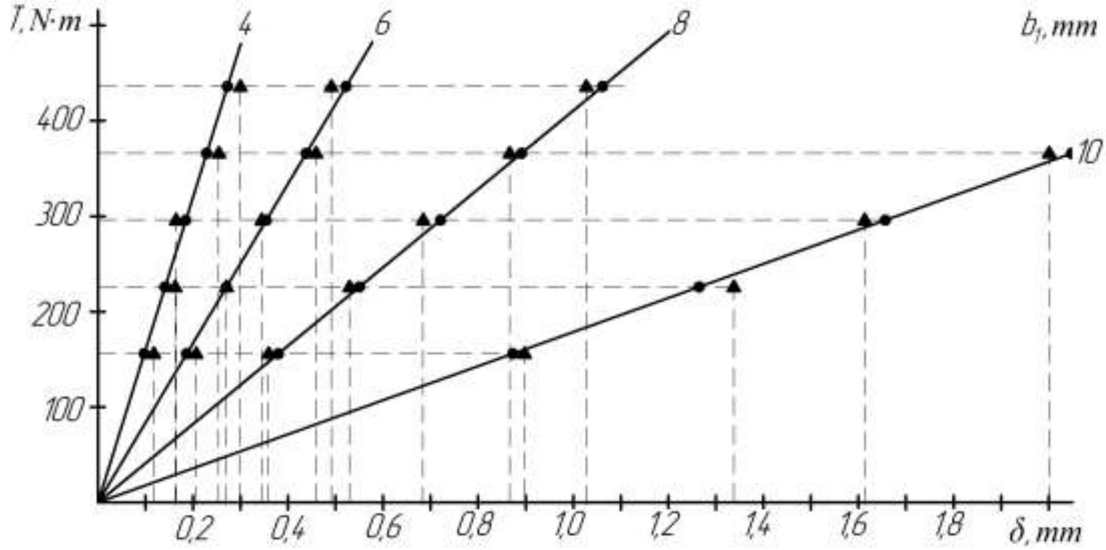

Fig. 10. Graphical dependences between torque and key deformation: ● – theoretical; ▲ – experimental

CONCLUSIONS

Experimental results have confirmed the theoretical principles derived for resilient parallel keys while transferring the static torque.

As we can see it from the graph (Fig. 10) deviation is not big and quantitatively does not exceed 5-7 % most.

So the developed stand with the equipment for experimental research of resilient keyed joints in static loading mode can be used and in fact does verify the results of analytical calculations. That gives an opportunity for further experimental research of the subject, not only in static loading mode, but also dynamic, by using specified removable equipment for periodical and instant shock loadings.

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