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THE ANALYSIS OF THE KINEMATIC ACCURACY OF THE ACTUAL HARMONIC DRIVE ON A TEST BENCH

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S u m m a r y

The article presents the results of experimental harmonic drive gear. An analysis of the accuracy of the rotary motion of the transmission was made. The analysis included determining the kinematic deviations in various measuring ranges. The study was conducted on a specially prepared test bench, on a physical model of a harmonic drive. The transmission has been designed, made and tested for the geometric correctness in accordance with applicable standards. The measurements of the angles of the rotation of the passive shaft were carried out with high accuracy using the optical dividing head and compared with the theoretical values. On that basis, according to the Polish PN-ISO 1328-1: 2000, they were determined kinematic displacement values, which were compared with the limit values.

Keywords: harmonic drive gear, angle of deviation, kinematic accuracy, bench testing

Analiza dokładności kinematycznej przekładni falowej na stanowisku badawczym

S t r e s z c z e n i e

W artykule przedstawiono wyniki badań eksperymentalnych zębatej przekładni falowej. Prowadzono analizę dokładności ruchu obrotowego przekładni, poprzez określanie wartości odchyłki kinematycznej dla różnych zakresów wartości pomiarowych. Badania wykonano na specjalnie przygotowanym stanowisku pomiarowym, dla fizycznego modelu zębatej przekładni falowej. Przekładnię zaprojektowano, wykonano oraz sprawdzono pod względem poprawności geometrycznej, zgodnie z obowiązującymi normami. Pomiar wartości kąta obrotu wałka biernego prowadzono przy zastosowaniu podzielnicy optycznej. Wykonano analizę porównawczą z uwzględnieniem ustalonych wartości teoretycznych kąta obrotu. Była podstawą określenia zgodnie z PN-ISO 1328-1:2000 wartości odchyłek kinematycznych, które porównywano z wartościami dopuszczalnymi.

Słowa kluczowe: przekładnia falowa, odchyłka kątowa, dokładność kinematyczna, badania stanowiskowe

1. Introduction

In recent years there has been a significant increase in the requirements for harmonic drives with a focus on the accuracy and the smoothness of the motion, as well as their durability due to the new range of the applications in the aerospace and aerospace industries. With the new construction and technological solutions and also by the use of new materials, has broadened significantly the scope of the

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transmissions wave, which permanently have been applied in automation, robotics, optics, and precision machine tool industry [1].

One of the major advantages of toothed harmonic drive is its high kinematic accuracy. In addition, these transmissions are characterized by the ability to obtain a large gear ratio in one stage, low speeds of the gears slippage or possibility to deliver the power to the hermetic space [2]. The disadvantages of these transmissions include the difficulties in implementing a flexible wheel with small module of the toothed ring (m = 0.1÷2 mm) and a high level of the lower threshold gear ratio [3].

The standard harmonic drive gear, shown in Figure 1, consists of a flexible wheel, a rigid wheel and a generator. The principle of the operation of the transmission is that the relative movement of the cooperating wheels is the result of the elastic deformation of one of them. The wheel deformed by the wave generator is called the flexible gear and the internally toothed wheel is called the rigid gear. A rotating generator causes the deformation along a flexible wheel, transmitting the movement to the cooperating flexible or rigid wheel. The gear rims of the flexible and rigid wheels, of the harmonic drive, intermesh in the areas of their cooperating. The rest of the teeth of the wheels pass up. Each of the three basic elements of the transmission can be driven or driving, and the transmission can be operated as a reducer, a multiplier or a differential transmission.

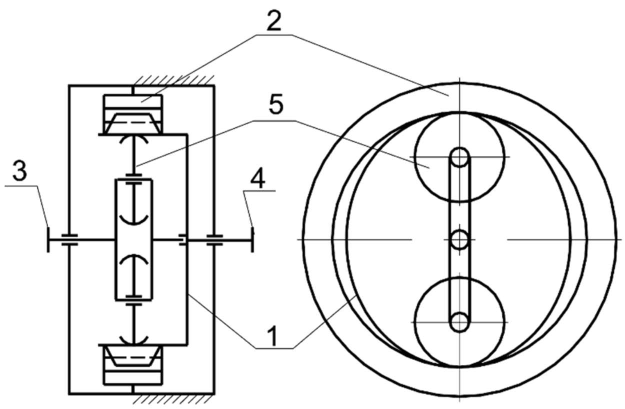

Fig. 1. The scheme of the wave reducer with the roll generator; 1 – the flexible gear, 2 – the rigid gear, 3 – the input shaft, 4 – the output shaft 5 – the wave generator

However the Polish norm, PN-79 / M-88514, defines a harmonic drive as a cylindrical transmission, wherein the generator (1) deforms the elastic gear (2) in the radial direction, causing the cooperation with the rigid gear (3) in moving areas of engagement with the generated wave deformations [4]. In the area of the meshing, at the same time, is 20 to 50% of the number of teeth of the flexible gear which allows transfer of the significant loads with relatively small dimensions of the transmission.

A classic harmonic drive reducer with flexible steel wheels are usually manufactured with the ratios of u = 65-320. The single-stage transmissions with gear ratios to u = 400 are also produced [5, 6]. They ensure a high efficiency of up to 95%, which is a very good result at such high ratios. The two-stage reducers with ratios in the range u = 3600-90000 are also created. These transmissions have a much lower efficiency, and their lives reaches the 40000 hours [7, 8] and depends mostly on the stability of the flexible gear.

2. Preparation of the test bench

A contemporary design process of a gear transmission mostly based on computer calculations. Such calculations include various simplifications and are based on approximate models. Frequently numerical methods are sufficient, but for a more responsible construction can not be avoided experimental research. The most accurate results of an analysis can be achieved only on the basis of physical models of gear on their actual working conditions.

Therefore has been designed and manufactured a prototype of a harmonic drive to test the selected characteristic parameters of that transmission. All components of the gear transmission have satisfactorily undergone the control of the correctness of their execution in the Laboratory of Metrology and Quality Control, the Department of Manufacturing Engineering and Automation of the Rzeszów University of Technology. Then the harmonic drive was assembled and conducted validation tests of its function that allowed to use it for further testing bench.

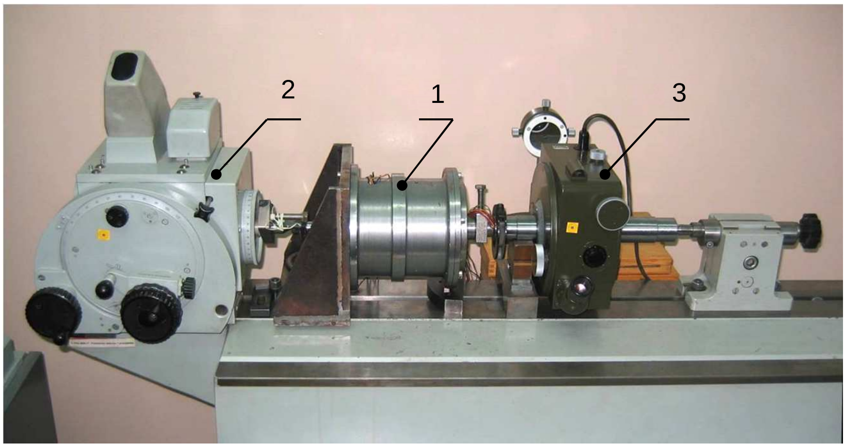

Fig. 2. The measuring position to designate a kinematic deviations of the harmonic drive gear: 1 – tested transmission, 2 – the active optical dividing, 3 – passive optical dividing

The research focuses in verifying the kinematic accuracy of the harmonic drive that allows to use it in the drivers of industrial robots and machine tool drives. For this purpose, a test stand for testing kinematic deviations was prepared where the harmonic drive was mounted (Fig. 2).

The measuring position consists of a harmonic drive, two optical dividing used to determine the angle of division with the accuracy of 1 second [9]. The active optical dividing is for precise rotation of the input shaft by a predetermined angle. At the same time, the output shaft is rotated by an angle whose value is read on the passive optical dividing.

3. Performing measurements

An experimental determination of the kinematic precision of the harmonic drive includes, inter alia, the determination of the total kinematic deviation and the kinematic deviations on the scale. PN-ISO 1328-1: 2000 [10] defines the kinematic deviation of the gear $F_i^{'}$ as the maximum of the difference between measured on the pitch circle, the observed and theoretical peripheral displacement during the full rotation of the test gear. The kinematic deviation of gear on the scale $f_i^{'}$ is the value of the kinematic deviation in the section corresponding to one pitch. Both deviations should be checked assuming that the gear wheels are in contact with each other on the homonymous sides of the teeth. In the case of gear wheels with a large number of teeth instead of specifying deviations in individual pitches and the data obtained to calculate the total error, can be determined the kinematic deviations in segments which are the result of the division of a circumference of the wheel to *k* equal parts including, for example several divisions [10]. The kinematic deviations are determined for the gear in the appropriate class of the manufacturing accuracy. As the output is assumed class 5, and the other are determined after applying the relevant conversion factors. The research should be carried out in transmission with loose of the side at a low load which ensuring the one-side mesh.

Checking the kinematic displacement of the harmonic drive consisted of three steps in which the measured angles of rotation of the output shaft connected to a rigid wheel with predetermined angles of rotation of the input shaft on which is mounted a generator.

In the first step, by the active dividing, the generator was given rotations at 10° until its one full rotation. At each pitch the results of the passive dividing were reading. The measured values were then subtracted from the theoretical angle corresponding to the rotation of the input shaft by a given angle. According to the norm [11] kinematic displacement values are defined as the length of the arc expressed in microns, which is why the unit of the measured angular values should be aligned with the norm, and then verify with the ranges permitted for each class of wheels accuracy.

Figure 3 is a graph of the kinematic deviations measured for the value of the measurement section corresponding to an angle of 10° in the test harmonic drive. In the graph is given the value of the total kinematic deviation of the harmonic drive $F_i^{'}$ = 76,64 μm.

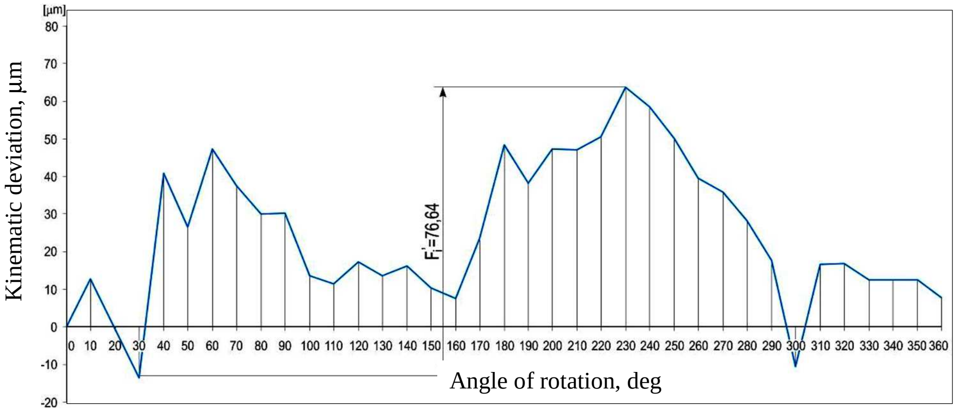

Fig. 3. The values of the kinematics displacement measured for a full rotation of the generator with pitch of at 10º

In the next step, measurements of the rotation angle of a rigid wheel were made, at one full rotation of the generator with a pitch corresponding to the angle of 5°. In this case, the value of the total kinematics' deviation, of the study wave transmission, amounted $F_i^{'}$ = 47,03 μm. The values of the kinematic deviations measured for subsequent sections are shown in Fig. 4.

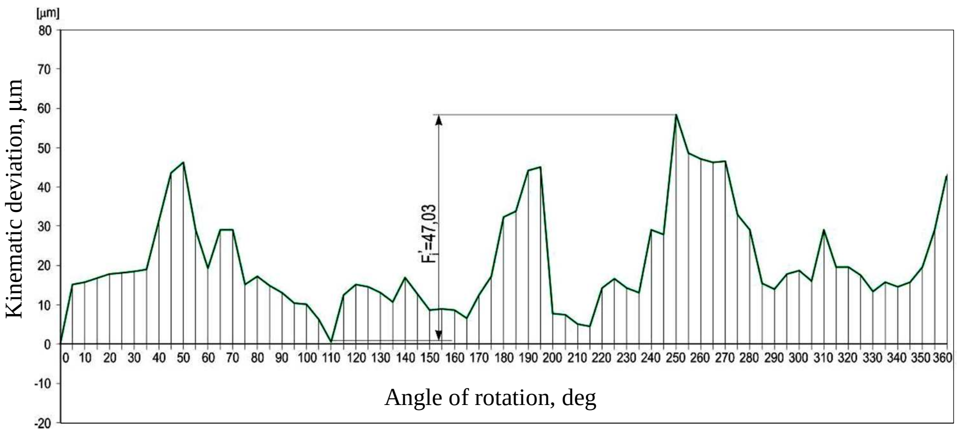

Fig. 4. The values of the kinematics deviations measured for a full rotation of the generator at pitch ratio of 5°

In both presented results of the measurements, at different steps of measuring, the measured combined kinematic deviations $F_i^{'}$ are smaller than the limit value defined by the standard in annex A and amounting to the 7th grade accuracy of wheels $F_i^{'}$ = 80,39 μm.

In addition, also carried out a verification of the kinematic deviations for the angle of rotation of the generator equal 1º. Before the measurements established that it will be implemented in twelve sections, each with a range of 5º, spread evenly around the circumference. Measurements were made, taking as a reference angle the value measured at the first point of each section of the measurement.

Figures 5 and 6 shows the values of the kinematic deviations, in the chosen parts of the flexible wheel, measured at the output shaft for the measuring distance corresponding to the rotation of of 1º the input shaft.

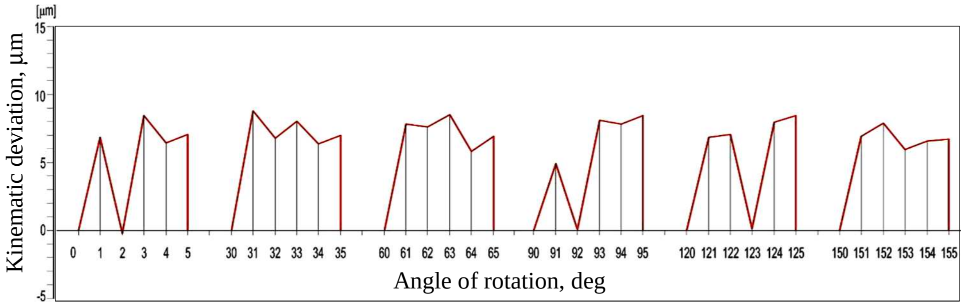

Fig. 5. The values of kinematics deviations measured in pitch of at 1º for measuring section 1-6

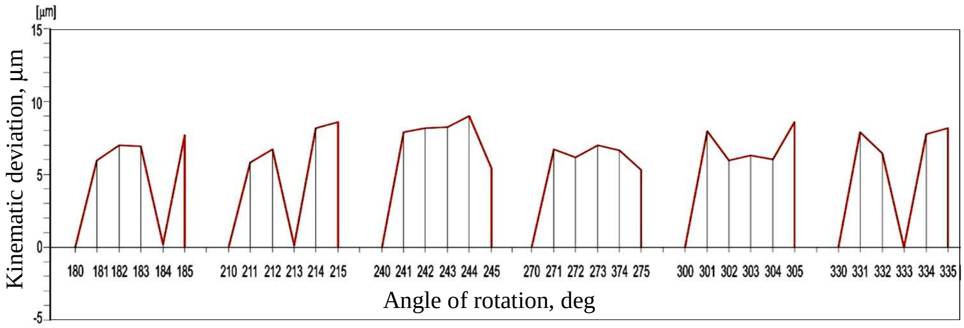

Fig. 6. The values of kinematics deviations measured in pitch of at 1º for measuring section 7-12

The measured kinematic deviations does not exceed 10 μm of the arc length, at the measuring section, which is less value than the allowable deviation and much smaller value than the size of the circumferential backlash of inter j_n.

Despite the fact that the measurement of kinematic deviations are not obligatory according to the standards [11], it should however be used to control the wave transmission, especially used in precision mechanisms.

4. Conclusions

The wave transmissions represent a unique variation of the drive gears, not only because of its characteristic structure, but a unique load transfer scheme. These difficult working conditions, particularly of the deformable flexible wheel, causes the need for more in-depth analysis at the design stage. Toothed wave gears must satisfy the demands of the quality and the durability due to the specific scope of their application.

To use their in precise control mechanisms, aviation and robotics enforces very high kinematics` accuracy in this type of construction. Therefore, any new solution introduced into production must undergo extensive testing performed on physical models.

The article presents the presentation of just such a position used for testing toothed wave. The article provides information of the preparation of the transmission and research station and also describes how to carry them out.

They were also presented the results of the kinematic deviations of the designed and made gear wave. The whole process of testing was conducted in accordance with the guidelines contained in the standard applicable to the precision performance.

The results of this study indicate the high kinematic accuracy of the gear wave, which confirms the possibility of its use in precision mechanisms and control systems for machine tools.

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