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Krzysztof OLEJARCZYK*, **Marek KALBARCZYK****

A GEOMETRICAL SURFACE TEXTURE STUDY OF CYCLOID DRIVE DISCS AFTER BENCH TESTS

BADANIA STRUKTURY GEOMETRYCZNEJ POWIERZCHNI KÓŁ PRZEKŁADNI CYKLOIDALNEJ PO TESTACH LABORATORYJNYCH

Key words: cycloid gears, wear resistance, surface roughness.

Abstract: The article presents the results of a geometrical surface texture study of cycloid drive discs after bench tests. For this purpose, the working surfaces, such as peak and valley areas of the epicycloid and the holes inner surfaces of both discs, were investigated using contact profilometry. From each surface, a transverse profiles were extracted, before and after 50 cycles of bench test. The discs and the profiles were examined for signs of wear and roughness changes. For each profile, the Ra and Rz roughness parameters were determined. On the base of the obtained profiles and the values of roughness parameters, it can be stated that the assumed test parameters provide stable working conditions, with an uninterrupted lubrication film, which results in practically negligible and unmeasurable wear. Taking into account the operating specification of a helicopter winch as an example of potential application of the presented cycloidal drive, the developed solution fulfils the requirements concerning wear resistance.

Słowa kluczowe: przekładnie cykloidalne, odporność na zużycie, chropowatość powierzchni.

Streszczenie: W artykule zaprezentowano wyniki badań laboratoryjnych trwałości kół przekładni cykloidalnej. W tym celu z powierzchni współpracy kół wyodrębniono obszary szczytu i doliny powierzchni epicykloidalnej, a także wewnętrzne powierzchnie otworów, które poddano badaniom przy użyciu profilometrii stykowej. Dla każdej z powierzchni wyznaczono profile chropowatości przed i po 50 cyklach testu stanowiskowego. Koła, jak również profile zostały poddane analizie pod kątem obecności śladów zużycia i zmian chropowatości. Dla każdego z uzyskanych profili wyznaczono parametry chropowatości Ra i Rz. W oparciu o uzyskane profile i wartości parametrów chropowatości można stwierdzić, że przyjęte parametry testowe zapewniają stabilne warunki pracy z nieprzerwanym filmem smarowym, czego efektem jest niemalże pomijalne, niemierzalne zużycie. Jednym z przykładowych zastosowań opracowanej przekładni cykloidalnej jest wyciągarka śmigłowcowa, a biorąc pod uwagę specyfikę jej pracy, uzyskane rozwiązanie konstrukcyjne spełnia wymagania dotyczące zapewnienia wystarczającej odporności na zużycie.

INTRODUCTION

Due to the use of cycloidal drives as machine parts working under high loads, the resistance to wear of their individual components is crucial for the overall gear durability. A schematic view of the tested cycloidal drive is shown in **Fig. 1.**

Publications **[L. 1, 2]** present the methodology of designing a cycloidal gear and describe the influence of selected geometrical parameters on its durability. Kinematic error analysis and tolerance allocation of cycloidal drive are shown in **[L. 3]**. In **[L. 4]**, tooth modification and dynamic performance are given. In **[L. 5]**, the

* ORCID: 0000-0002-9055-161X. Kazimierz Pulaski University of Technology and Humanities in Radom, Stasieckiego 54 Street, 26-600 Radom, Poland.
** ORCID: 0000-0003-0286-5705. Kazimierz Pulaski University of Technology and Humanities in Radom, Stasieckiego 54 Street, 26-600 Radom, Poland; Łukasiewicz Research Network – Institute for Sustainable Technologies, Pułaskiego 6/10 Street, 26-600 Radom, Poland.

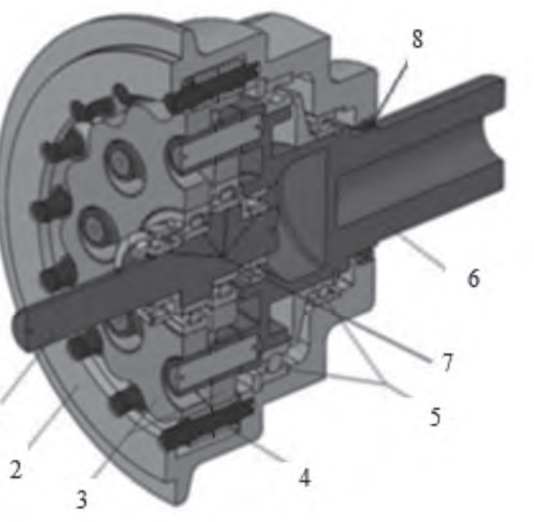

Fig. 1. Cycloidal drive: 1 – input shaft, 2 – housing, 3 – cycloidal discs, 4 – outer pins with sliding sleeves, 5 – bearings of the output shaft, 6 – output shaft with inner pins and sliding sleeves, 7 – eccentric bearings of the input shaft, 8 – sealing of the output shaft

Rys. 1. Przekładnia cykloidalna: 1 – wałek wejściowy, 2 – obudowa, 3 – koła cykloidalne, 4 – piny zewnętrzne z tulejami ślizgowymi, 5 – łożyskowanie wałka wyjściowego, 6 – wałek wyjściowy z pinami wewnętrznymi i tulejami ślizgowymi, 7 – ułożyskowanie mimośrodowe wałka wejściowego, 8 – uszczelnienie wałka wyjściowego

influence of the lubricant type on the obtained efficiency was examined. Publication **[L. 6]** presents a model of loads acting on a cycloidal disc, the method of calculating the values of these forces, and the results of cycloidal drive tests in terms of the application of slide and needle roller bearings. Basic issues of the durability of cycloidal discs in experimental studies are shown in **[L. 7]**. The results of the tests of sliding sleeves mounted on internal pins, made of bronze and used in the cycloidal drive, are presented in **[L. 8]**. Their very poor durability was the main reason for further research aiming on the increase in wear resistance of cycloid drive elements.

As it has been noticed on the base of literature review, the wear resistance of cycloidal discs has not been sufficiently investigated, thus the following article presents the results of a surface texture study of cycloid drive discs after bench tests.

METHODOLOGY

The elements of the tested cycloidal gear, such as discs, pins and sliding sleeves, were made from 32CDV13 steel with a hardness of 58 ± 1 HRC. The bench tests were carried out using the test rig described in detail in **[L. 9]**.

Taking into account the helicopter winch as an example of a potential application of the developed cycloid drive, for the bench tests, the following test parameters closely corresponding to the operating specifications of a helicopter winch cycloid drive were assumed: 25°C of working environment temperature, 3500 rpm of input rotational speed, 32 Nm of load, 50 measuring cycles, and 1 h duration of a single cycle.

For the cycloidal discs working area investigation, a Taylor Hobson Form Talysurf PGI 830 contact profilograph was used. Two discs were tested: A – from the side of the input shaft, and B – from the side of the output shaft. The measuring position was chosen in accordance with the discs assembly order in the test rig, with the bearing notation on the opposite side from the profilograph measuring head. The discs description method is shown in **Figure 2**, and it is based on a reference axis (dotted line) crossing the centre of the first tooth in line with the first (h1) and the fifth hole (h5).

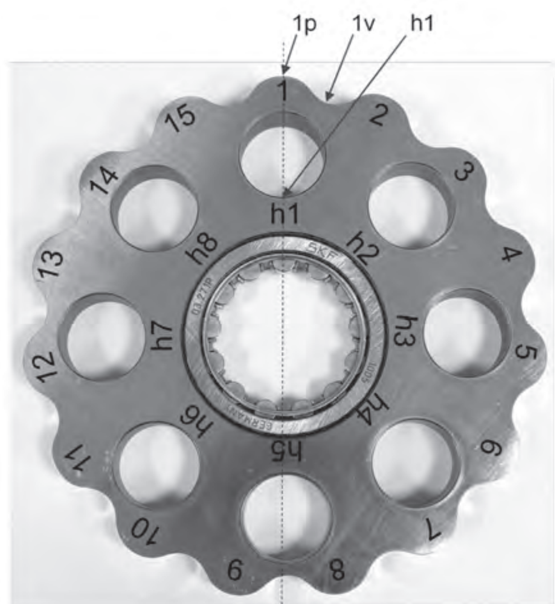

Fig. 2. The applied markings for the cycloidal discs measurements

Rys. 2. Koło cykloidalne wraz z przyjętymi oznaczeniami

To make it possible to compare the profiles obtained before and after the 50 cycle test, three areas of interest were distinguished: the peak of a particular tooth, the bottom of the valley between the teeth, and the bottom of the hole. From each area, a profile was extracted, denoted, respectively, as follows: 1p (profile from the first tooth peak area), 1v (profile from the valley between the first and the second tooth), and h1 (profile from the bottom of the first hole). For each of the profiles, the roughness parameters were determined in accordance with ISO 4287. As an initial organoleptic assessment has shown, there were only very minor signs of wear noticeable on the discs working surfaces, so in addition to the Ra average roughness, the Rz parameter was also selected, since it is calculated in respect of the deepest valleys of the particular profile. Rz, being the maximum height of the profile, is sensitive to the differences between valleys and peaks, so it can be very useful in the case in which the wear is limited to the cutting of the tips of surface irregularities.

EXPERIMENTAL RESEARCH RESULTS

The profiles were limited by cutting the chamfered edges to approx. 11 mm of length, which corresponds to the working area width. The examples of profiles taken from the upper epicycloid surface, before and after 50 test cycles, are presented in **Figure 3**.

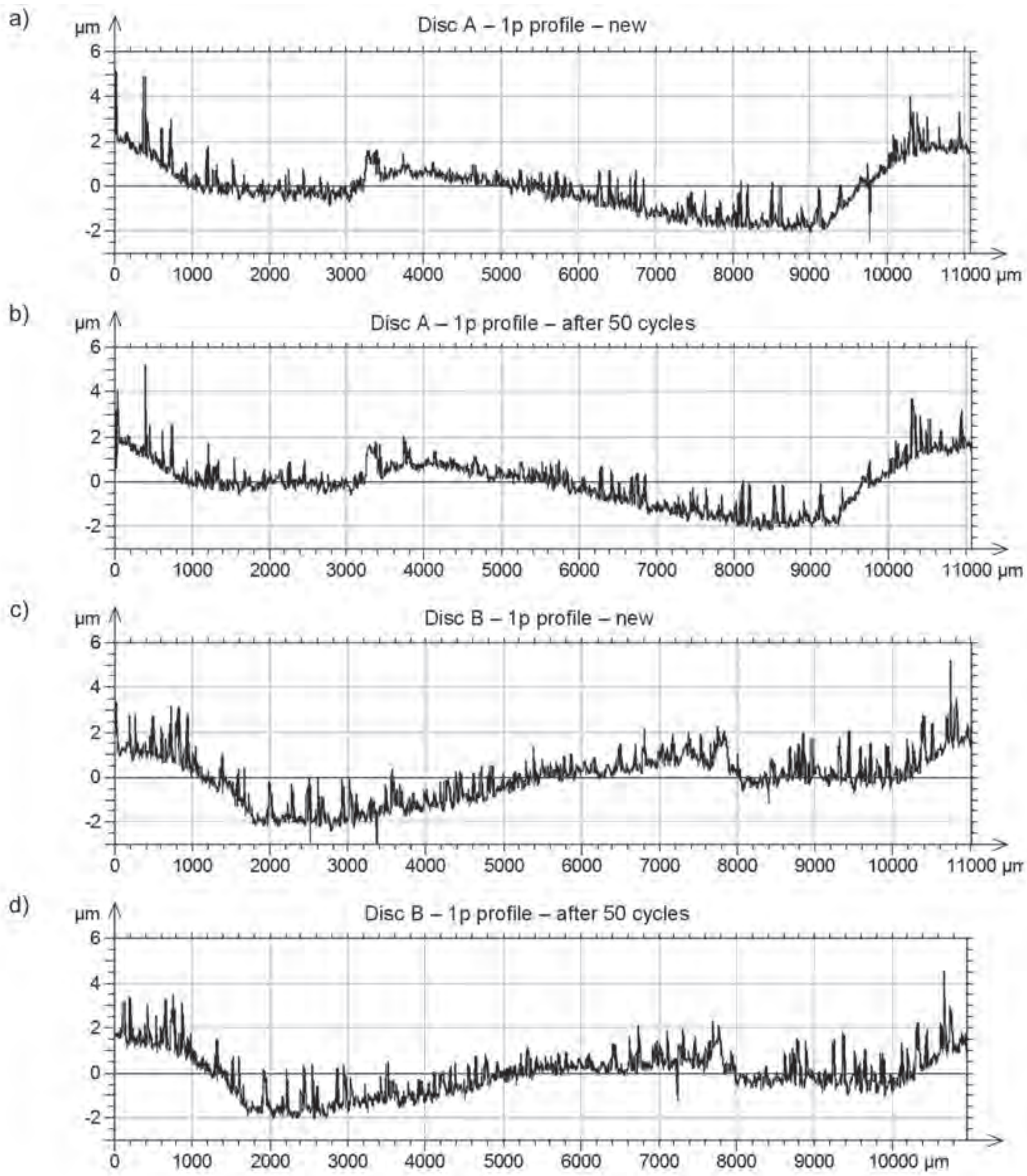

Fig. 3. Representative profiles of the upper epicycloid surface of: a) new Disc A, b) Disc A after 50 test cycles, c) new Disc B, d) Disc B after 50 test cycles

Rys. 3. Reprezentatywne profile górnej powierzchni epicykloidalnej: a) nowego koła A, b) koła A po 50 cyklach pomiarowych, c) nowego koła B, d) koła B po 50 cyklach pomiarowych

The representative profiles taken from the valley of epicycloid surface, before and after 50 test cycles, are presented in **Figure 4**.

Taking into account that the measurement position was chosen in accordance with the discs assembly order in the test rig, the profiles obtained for Disc B are almost a mirror reflection of the ones extracted from Disc A. The profiles demonstrate a shape with relatively high irregularities, which are a result of the production process. The presence of such form deviations results, among others, in the reduction of contacting areas, which leads to increase in contact pressure and can be a cause of excessive wear. However, as can be seen in the above figures, there are nearly no difference between the initial profiles and the ones extracted after 50 cycles of test, in other words, there are no visible signs of wear.

The representative profiles taken from the bottom of the first hole inner surfaces, before and after 50 working cycles, are presented in **Figure 5**.

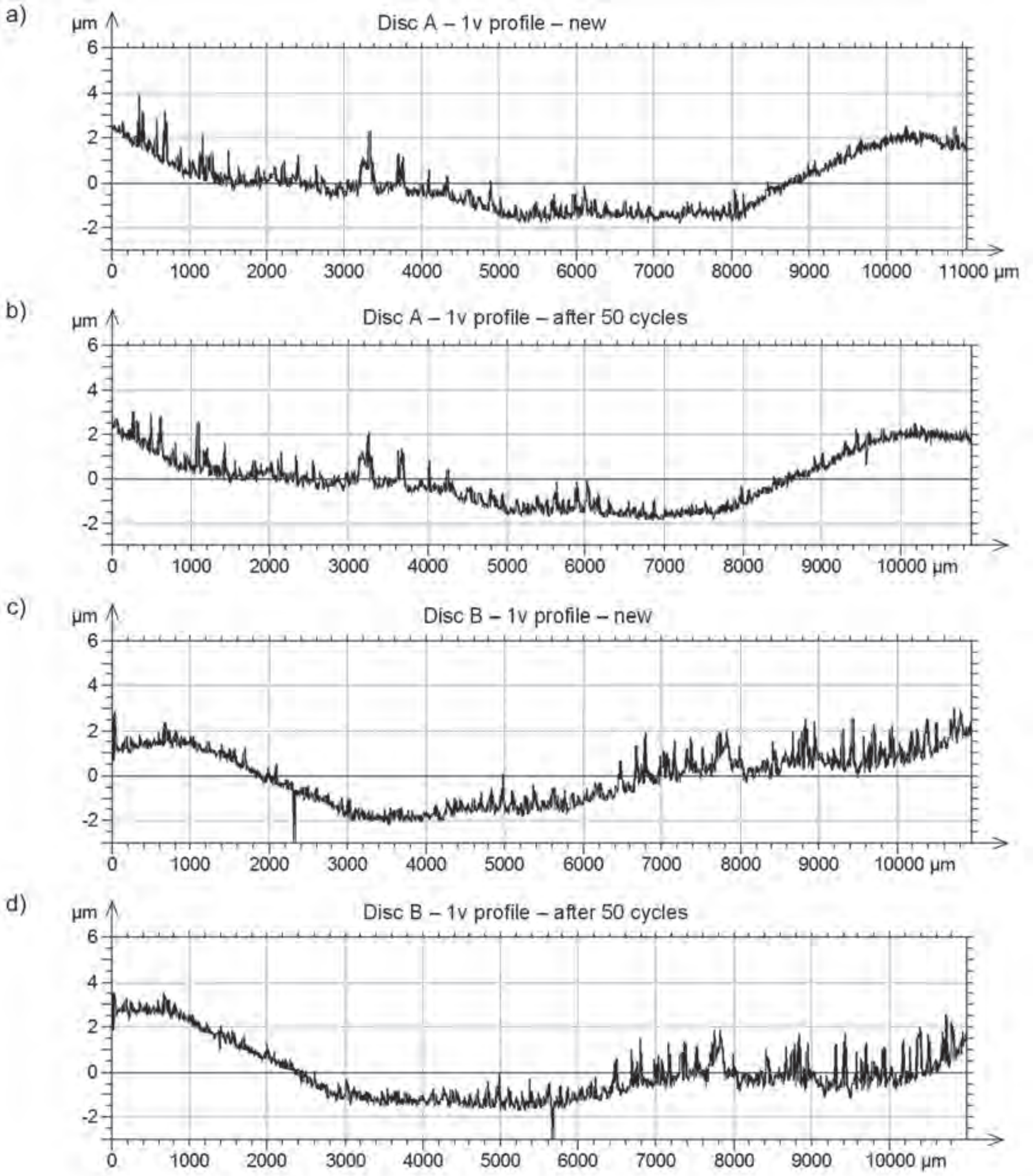

Fig. 4. Representative profiles of the valleys of epicycloid surfaces of a) new Disc A, b) Disc A after 50 test cycles, c) new Disc B, d) Disc B after 50 test cycles

Rys. 4. Reprezentatywne profile dolnej powierzchni epicykloidalnej: a) nowego koła A, b) koła A po 50 cyklach pomiarowych, c) nowego koła B, d) koła B po 50 cyklach pomiarowych

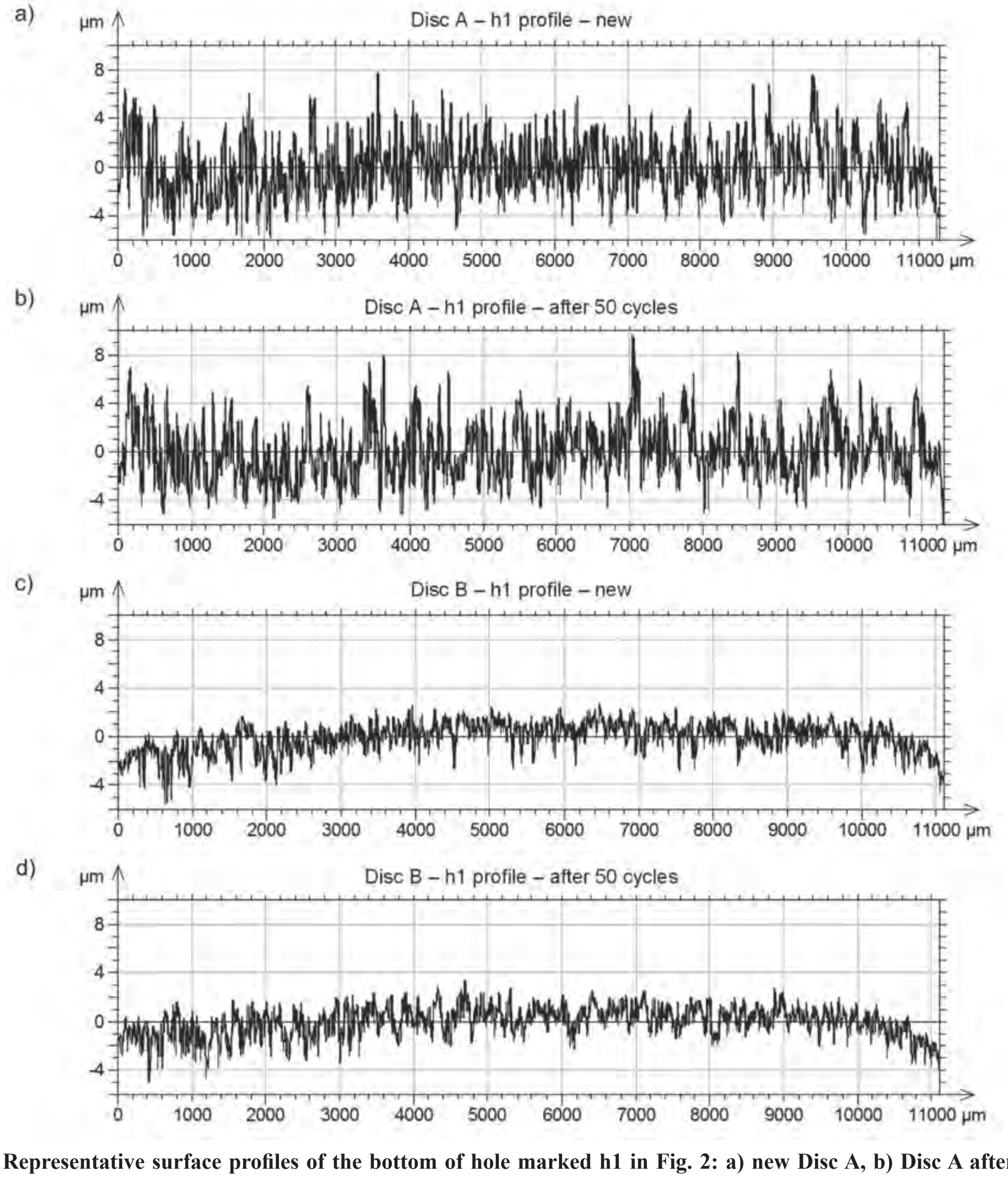

Fig. 5. Representative surface profiles of the bottom of hole marked h1 in Fig. 2: a) new Disc A, b) Disc A after 50 test cycles, c) new Disc B, d) Disc B after 50 test cycles

Rys. 5. Reprezentatywne profile powierzchni otworu oznaczonego h1 na rys. 2: a) nowego koła A, b) koła A po 50 cyklach pomiarowych, c) nowego koła B, d) koła B po 50 cyklach pomiarowych

Comparing the holes inner surface profiles from Disc A and B, the difference in the surface finish is very pronounced in the aspects of roughness and form. In the case of Disc A the amplitude of surface irregularities is very high; however, the form of straight mean line is maintained. In the case of Disc B, the production process resulted in a visibly convex form, but with a much smoother surface. In usual cases, it could be expected that such divergence in the surface character would result in the differences in wear mechanism and intensity; however, in case of both discs, the profiles extracted before and after 50 cycle test are nearly indistinguishable.

The Ra values determined for the profiles obtained before and after the test are presented in **Figure 6.**

As shown in the above chart, the Ra values before and after the test are nearly equal. Only in the case of the h1 profile, taken from the first hole of Disc B, there can be seen a slight increase in average roughness after the test.

The Rz values, calculated for the profiles before and after 50 cycle test are presented in **Figure 7.**

In the case of Rz values, the differences between the profiles, taken before and after the 50 cycle test, are even less pronounced than in the case of Ra. The profiles and the obtained roughness parameters indicate that the assumed test parameters provide the working conditions resulting in practically negligible wear.

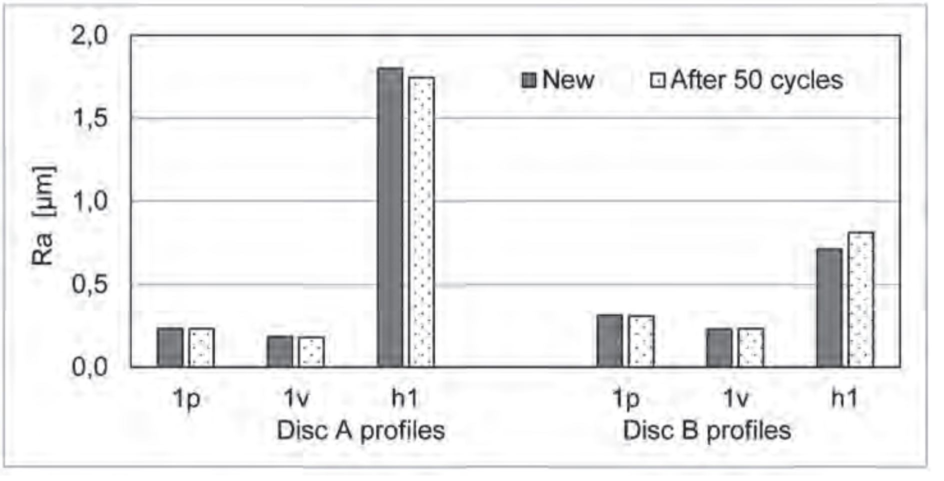

Fig. 6. The Ra average roughness parameters of the profiles recorded for investigated areas of Discs A and B before and after the 50 cycle test

Rys. 6. Wartości parametru Ra dla profili uzyskanych z badanych powierzchni kół A i B przed i po 50 cyklach pracy

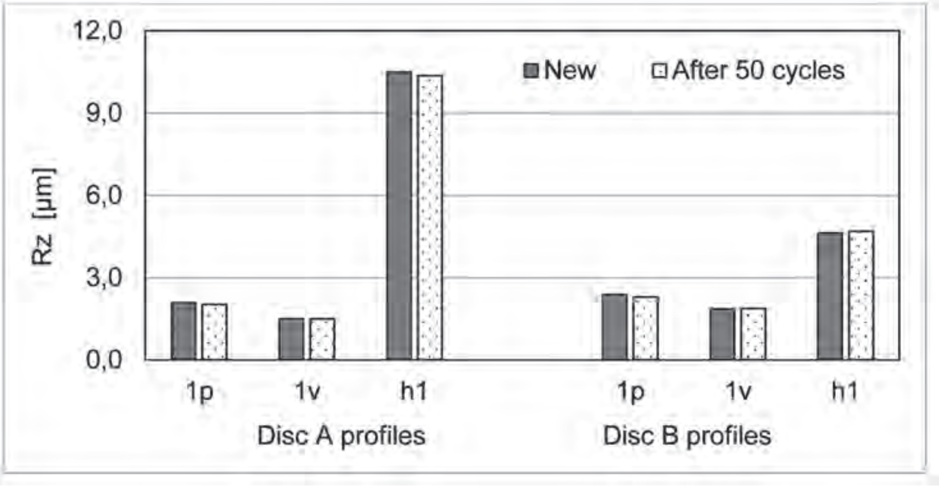

Fig. 7. The Rz parameter values of the profiles recorded for investigated areas of Disc A and B before and after the 50 cycle test

Rys. 7. Wartości parametru Rz dla profili uzyskanych z badanych powierzchni kół A i B przed i po 50 cyklach pracy

CONCLUSIONS

The surfaces of investigated discs are highly influenced by the production process, with a residual form visible in the profiles taken from the peaks and valleys of epicycloid surface. Discs A and B differ from each other also in terms of roughness of particular working areas. As an example, the first hole inner surface of Disc A characterizes with more than two times higher roughness than the corresponding area of Disc B.

Despite the identified form differences and surface irregularities, there can be seen no significant signs of wear on the investigated discs, which confirms that, in the case of the developed cycloid drive, the selected test parameters provide stable working conditions with an uninterrupted lubricating film preventing the wear of the working surfaces of the discs. Taking into account the operating specification of a helicopter winch as the one of potential applications of the presented cycloid drive, the developed solution fulfils the requirements concerning wear resistance. On the other hand, to be able to evaluate the long term durability of the particular elements of cycloid drive, it would be require the modification of the test parameters to much more severe levels and increase the duration of testing.

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