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# IMPACT OF THE GEOMETRY ACCURACY OF THE CYCLOIDAL GEAR OUTPUT SHAFT WITH PINS OF THE EFFICIENCY AND VIBRATIONS

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***Abstract***

*Cycloidal gear is characterized by [2]:*

- *Large ratio (up to 171:1) from one stage of reduction, which minimizes the weight and dimensions of the reducer.*
- *Minimizing the centrifugal forces as the only high-speed element is the input shaft with an eccentric bearing.*
- *Minimizing internal clearance due to simultaneous meshing of a large number of teeth. In contrast to gears with involute teeth, 10-50% of teeth are found in cycloidal gears with simultaneous meshing. It depends on the size of the gear and the load. The minimum number of teeth engages when running in bulk.*
- *Low noise and low vibration for large torques and variable speeds.*
- *High efficiency in a wide range of loads, because rolling elements are used in every place responsible for the transfer of torque.*
- *Permissible load up to 500% of the rated torque.*

*All above mention point lead into long-term and trouble-free operation, however the above features require high accuracy. The article described comparison of efficiency, vibration and noise obtained for 3 cycloidal gear modules:*

1. *Two-disc gear with single rollers for both discs (Chmurawa prototype [1]).*
2. *Three-disc gearbox with separate rollers for each disc (new idea) with gear components: output shaft with pins, housing with rollers (wheel with internal tooting), and input shaft, made with the manual lathe.*
3. *The same three-disc gearbox with output shaft with pins made with the CNC.*

*Different levels of accuracy and thus corresponding vibration patterns were obtained.*

***Keywords:*** *cycloidal gear, efficiency, vibrations*

## 1. Introduction

The cycloidal drive has shown relevant operating properties: long and reliable working life, large range of gear ratio in comparison with the traditional gearboxes, minimal vibrations and low noise, overload capacity, reverse applications as a multiplicator, satisfactory efficiency, and compact design. Et al. [3] investigated the influence of geometrical parameters on the cycloid drive efficiency. They summarized that the optimum choice of design parameters has a significant impact on its efficiency. M. Blagojevic et al. [4] developed a model of cycloid drive, which takes into account only the friction in contact of the cycloid disc and housing rollers, while occurrence of friction in other locations was neglected. They notice that the appearance of friction has a significant impact on the core strength parameter of the cycloidal speed reducer. In the other paper M. Blagojevic et al. [5] introduce a dynamic model of the cycloid drive which take into consideration the elastic connection with stiffness and dumping between: input shaft with eccentric cam – cycloid gear, cycloid gear – housing roller and cycloid gear – output shaft pin. The simulation shows that the biggest influence on dynamic operating of the cycloid drive comes from the coefficient of the damping during the contact between the cycloid gear tooth and the central gear roller as well as from its stiffness.

## 2. Research object

The most common design solution are gears with two discs, in which the reaction forces on bearings from the working discs create a bending moment on the high-speed input shaft. The introduction of a third disc, shifted by 180º from the centre dial, allows this moment to be reduced to zero, Fig. 1. To compensate for centrifugal force, the outside discs are twice the width of the centre disc. Each disc works with its own, separate set of bronze rollers, separated by Teflon washers, which reduce the friction forces.

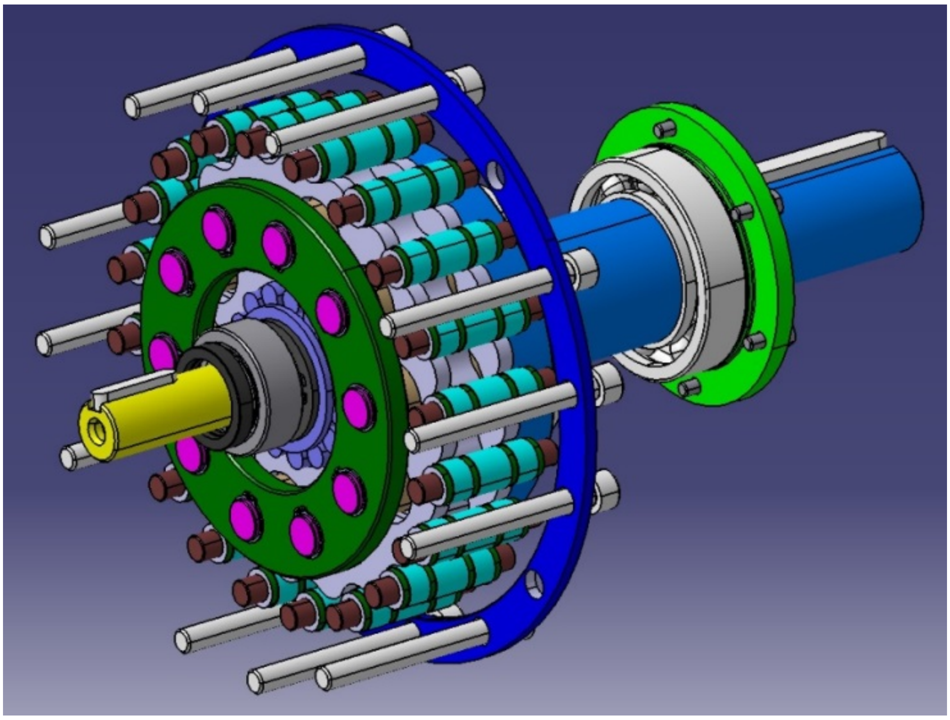


*Fig. 1. Three cycloidal disc gearbox preparation – 3D model*

In the three-disc solution, the discs, housing and bearings of the double disc gear were used. Only the input and output shafts as well as the internal gear wheel were changed due to the different length of these elements resulting from the width of the three discs. Contact pairs were introduced: bronze-steel, teflon-steel and steel-steel between the rollers, discs and pins of the equilibrium mechanism.

The research was carried out on the test bench presented on Fig. 2, which principle of operation was presented in [2].

The following results will be compared in this study:

– Two-disc gear with single rollers for both discs (Chmurawa prototype [1]). This prototype was modernized by introducing changes as in Fig. 1, i.e. elements made of bronze and Teflon.
– Three-disc gearbox with rollers separate for each disc (own proposition) and gradually replaced: output shaft with pins (New LSS), body with rollers (circle with internal toothing – New Housing)) and input shaft. The components of the three-disc transmission were made in two technologies: workshop using a manual lathe and a NCN machine. Different levels of accuracy and thus corresponding vibration patterns were obtained.

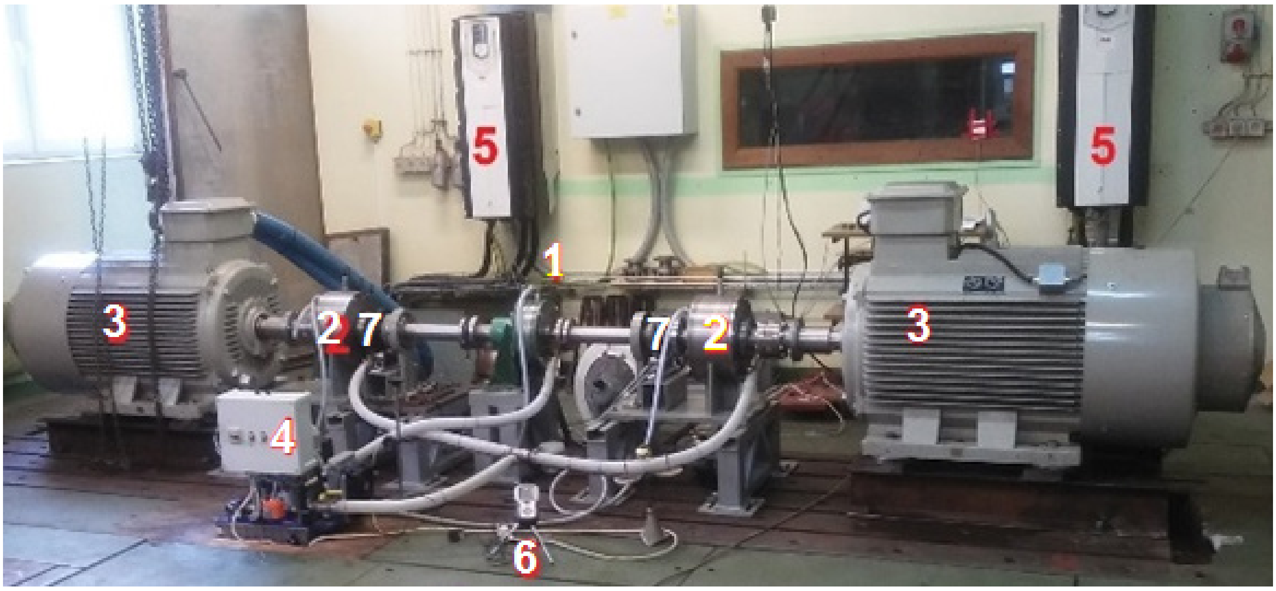



*Fig. 2. Test bench of cycloidal gearbox: 1 – cycloidal gearbox with three discs, 2 – planetary gear set, 3 – electric motor end generator, 4- oil supply system, 5 – converter, 6 – sound meter, 7 – torque end speed sensor*

## 2. Test results and conclusions

The efficiency (Fig. 3) and vibration of the gear housing in three directions was compared.

The results shown in Fig. 3 indicate high repeatability and independence from the rotational speed of the input shaft. The 3-disc gearbox has a higher efficiency by several percent at a torque of approx. 150 Nm. In the other ranges their efficiency are similar, which is the result of using the same Teflon spacers and bronze rings.

The three disc cycloid drive, in which the split of the pins on the pins is made on the CNC with angular accuracy ±0.0015 rad and radial ±0.01 mm (Tab. 1), has twice lower vibration amplitudes compared to manual lathe with angular accuracy ±0.015 rad and radial ±0.2 mm (Tab. 2), thus achieving the level corresponding to the Chmurawa prototype (Tab. 3).

As indicated earlier, the next steps were to machine a gear housing with a higher accuracy of the rollers and the input shaft.

*Tab. 1. Workshop execution (with a dividing head)*

| A(1-6) | A(2-7) | A(3-8) | A(4-9) | A(5-10) | ΔA |
|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | mm |
| 140.86 | 141.03 | 141.15 | 140.93 | 141.16 | 0.30 |

| B(1-2) | B(2-3) | B(3-4) | B(4-5) | B(5-6) | B(6-7) | B(7-8) | B(8-9) | B(9-10) | B(10-1) | ΔB |
|---|---|---|---|---|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| 54.75 | 54.95 | 54.86 | 54.56 | 54.65 | 55.05 | 54.48 | 54.78 | 54.90 | 54.94 | 0.49 |

*Tab. 2. Execution on a CNC machine*

| A(1-6) | A(2-7) | A(3-8) | A(4-9) | A(5-10) | ΔA |
|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | mm |
| 141.04 | 141.06 | 141.05 | 141.06 | 141.08 | 0.04 |

| B(1-2) | B(2-3) | B(3-4) | B(4-5) | B(5-6) | B(6-7) | B(7-8) | B(8-9) | B(9-10) | B(10-1) | ΔB |
|---|---|---|---|---|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| 55.32 | 55.32 | 55.30 | 55.30 | 55.33 | 55.30 | 55.28 | 55.31 | 55.31 | 55.29 | 0.05 |

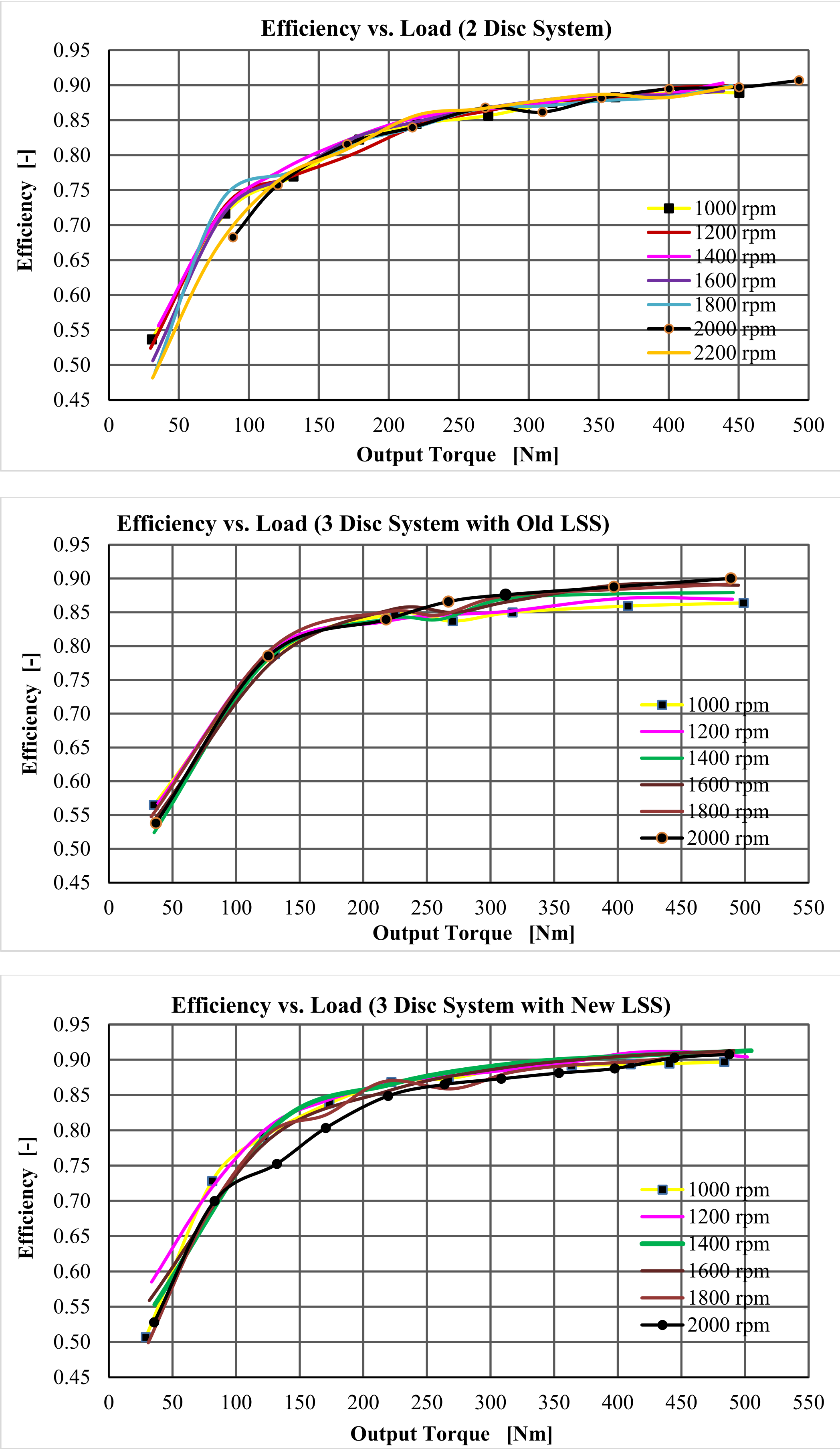



*Fig. 3. The efficiency comparison*

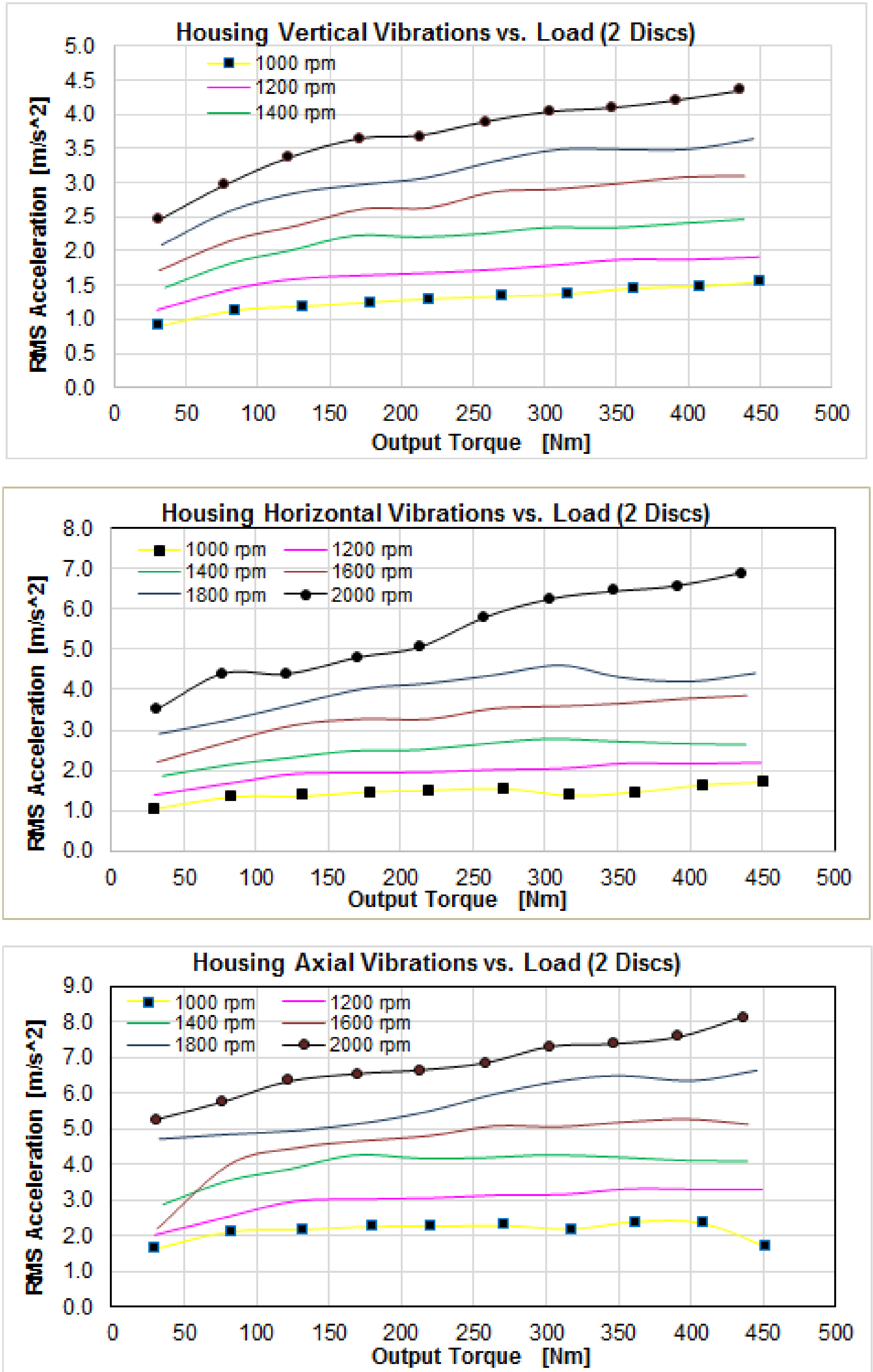
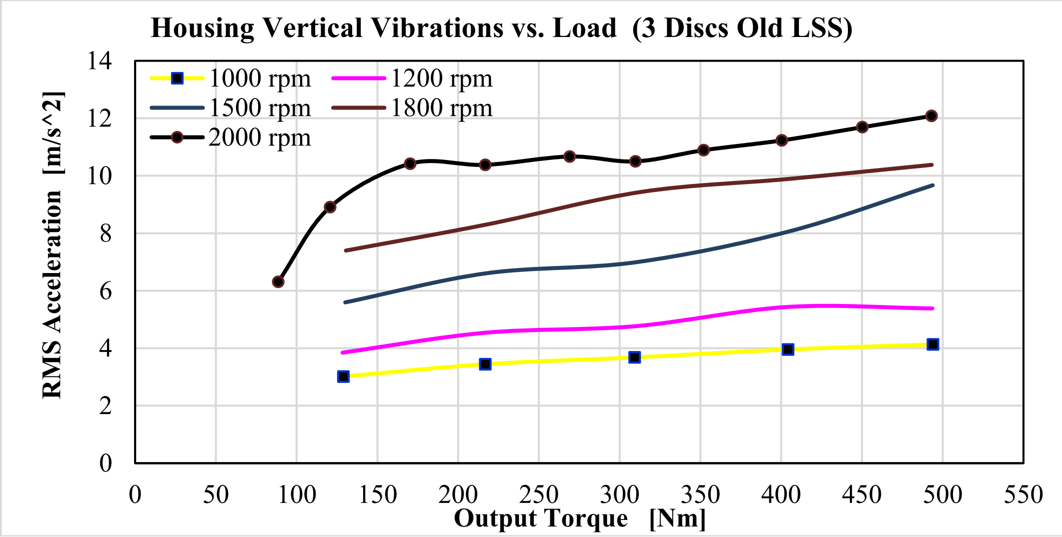
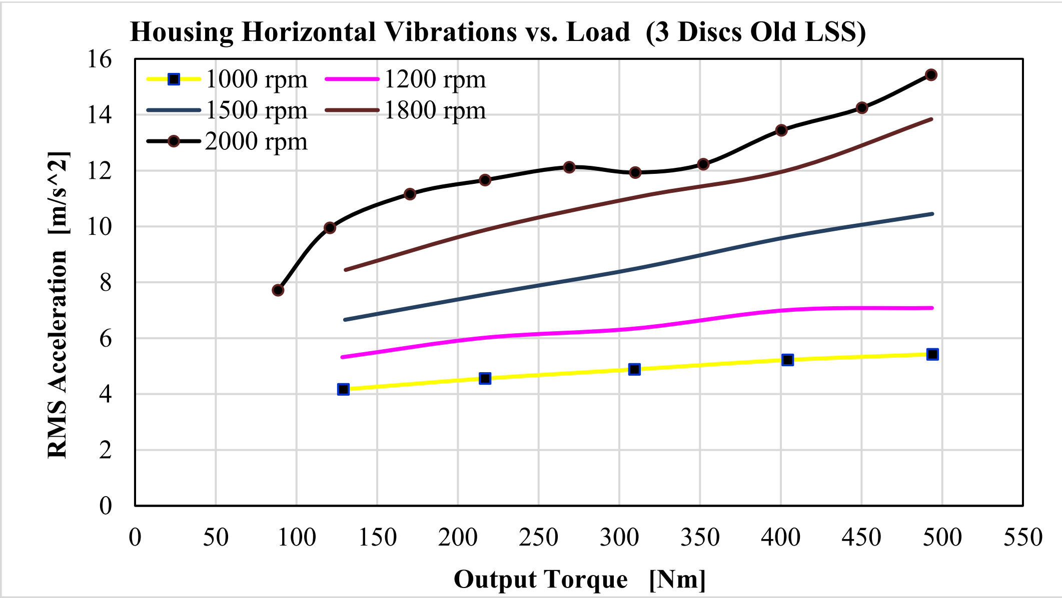



*Fig. 4. Vibration of two-disc cycloid drive*



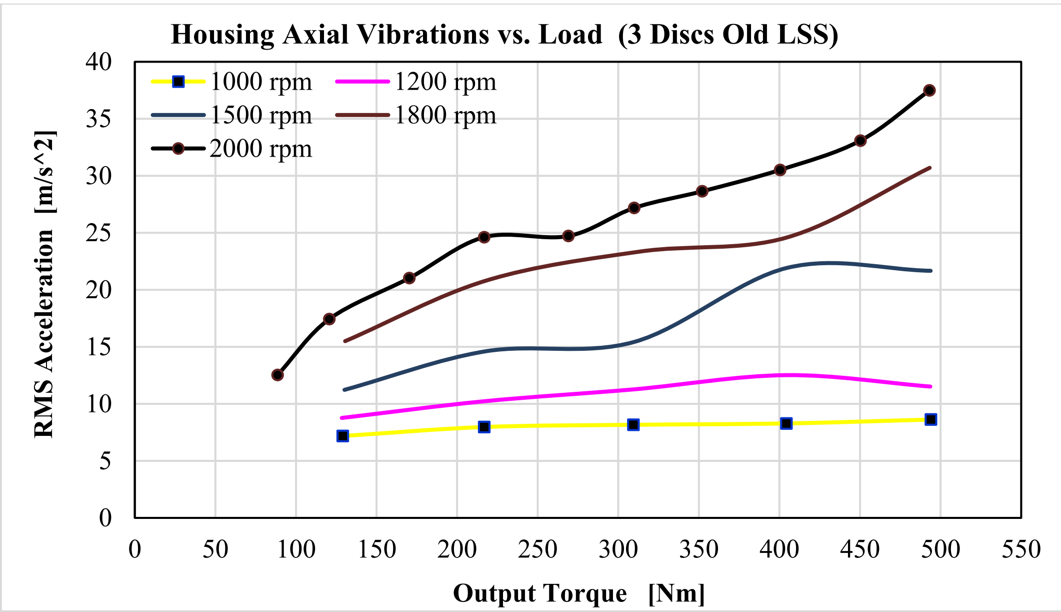




*Fig. 5. Vibration of cycloid drive made with manual lathe*

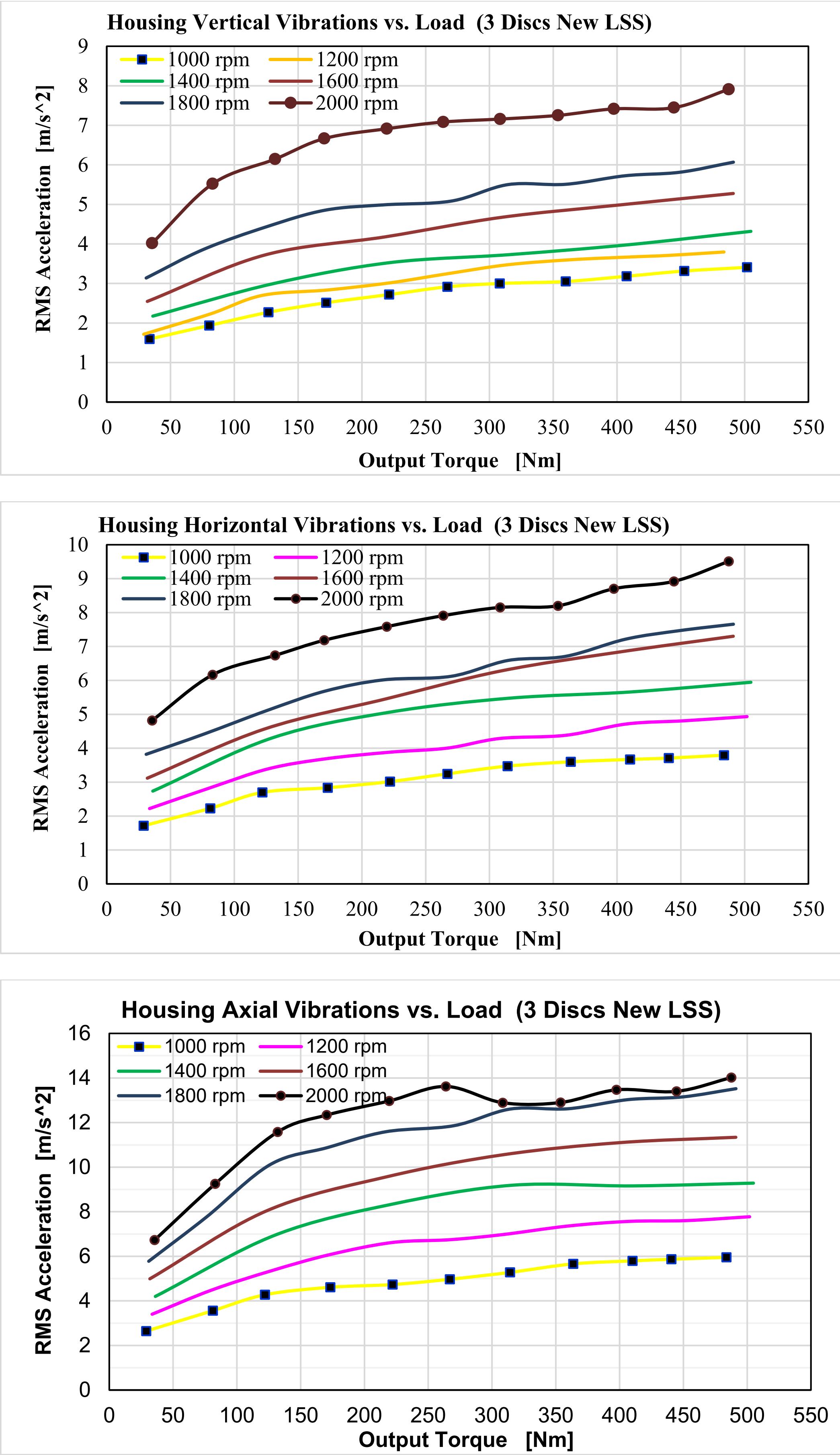



*Fig. 6. Vibration of cycloid drive made with CNC*

*Tab. 3. Execution of double-disk transmission according to Chmurawa*

| A(1-6) | A(2-7) | A(3-8) | A(4-9) | A(5-10) | ΔA |
|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | mm |
| 140.95 | 140.99 | 140.97 | 140.99 | 140.95 | 0.05 |

| B(1-2) | B(2-3) | B(3-4) | B(4-5) | B(5-6) | B(6-7) | B(7-8) | B(8-9) | B(9-10) | B(10-1) | ΔB |
|---|---|---|---|---|---|---|---|---|---|---|
| mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| 55.30 | 55.30 | 55.27 | 55.31 | 55.30 | 55.25 | 55.30 | 55.30 | 55.30 | 55.30 | 0.05 |

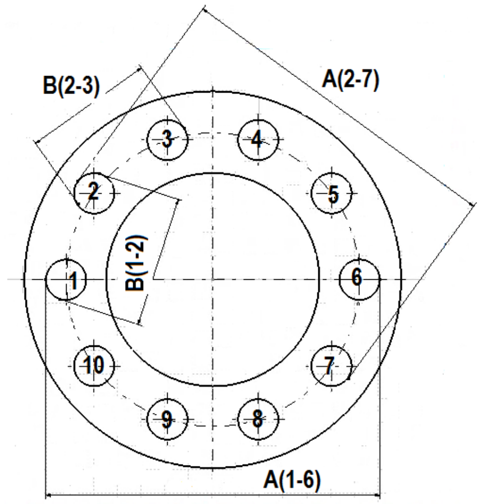



*Fig. 7. The method of measuring the size determining the accuracy of the location of the pins in the low-speed shaft*

Noise measurement was made using DT-8852 sonometer (Fig. 2). The measurement conditions did not meet the standards hence; the results give only a general view of its level.

Figure 8 shows the total noise level generated by all unites during tests. The sound generated during standstill by the fans: motor, generator and inverters reached 73-74 dBA and only through the oil system is 65-66 dBA.

It can be assumed that the noise produced by the cycloidal gear is much lower than the determined limit from Fig. 8.

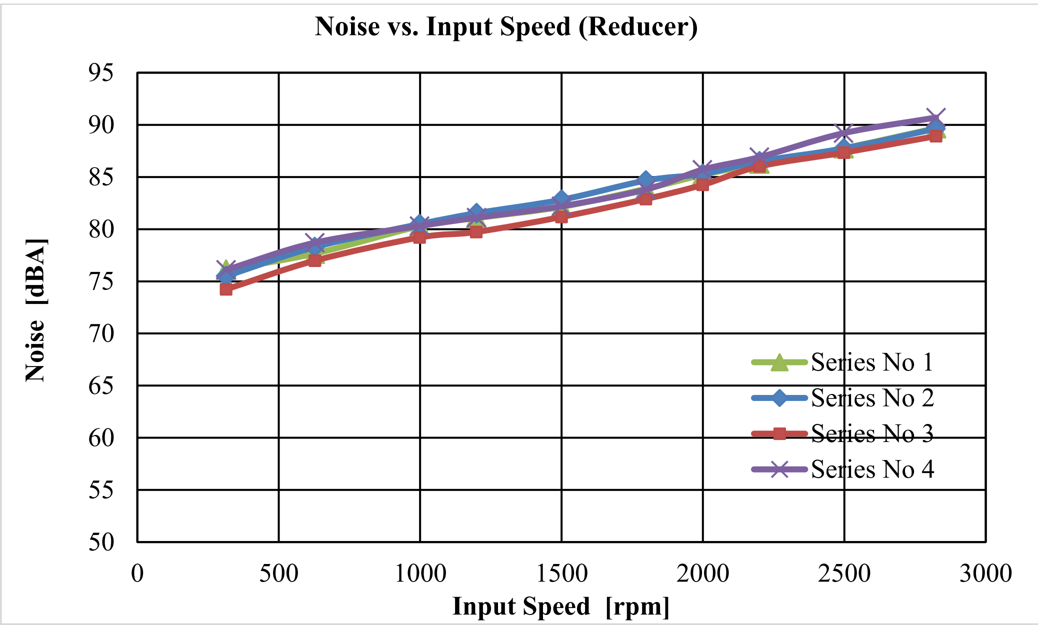



*Fig. 8. The noise level of the station during the cycloid gearbox tests*

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