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DEVELOPMENT AND MANUFACTURING OF AN EXPERIMENTAL FLAT WHEEL STRAIN WAVE GEAR UNIT AT K.K.K. 99 LTD

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Abstract: The functions of the main components of a flat-wheel harmonic drive are similar to the functions of a traditional harmonic drive, but the features of the flexible and the solid wheels are different. This paper reports the development and investigation of the experimental flat wheel harmonic drives. The development project was sponsored by Ministry for National Economy.

Keywords: *development and investigation, harmonic drive, Ministry for National Economy*

1. INTRODUCTION

The K.K.K. 99 Kft. has received a grant in the GINOP 2.1.7-15 tender for research and development of flat wheel strain wave gear drives. The design of the teeth, the ideal shape of deformation and the other functional parts highly influence the behavior of the device and also the manufacturing cost. This article deals with the development of all the different combination of potential drive units as well as their tests and their evaluation. Our goal was to develop a flat wheel strain wave gear unit, which can be a competitor for the currently available cylindrical alternative.

2. THE WORK PRINCIPAL OF FLAT WHEEL STRAIN WAVE GEAR DRIVE

The mentioned flat wheel strain wave gear is a special variant of the generally known harmonic drive. It consists of a rotational wave generating input element with a cam surface on its axial extent (4), a flexible axial bearing (3), which indirectly also deforms a flexible wave gear element (2), thus connecting it to the rigid gear (1) and in return, turning it. These are the main parts of the gear unit, which is illustrated in *Figure 1.*

A double wave gear unit connects on two opposite edges which means that one turn of the input element only turns the flexible gear for two teeth divisions. This all implies that this design can achieve a very high gear ratio (i = 80 – 320). [2]

For the desired movement it is required to guarantee the ideal teeth parameters (deformation, teeth shape, teeth gap, etc.) for the connection of the two main gear elements without teeth head overlap or teeth head interference. The teeth surface geometry is determined by a deformation and teeth connection model reported in a previous study [2], while the flexible wave gear deformed shape was calculated by using finite element method.

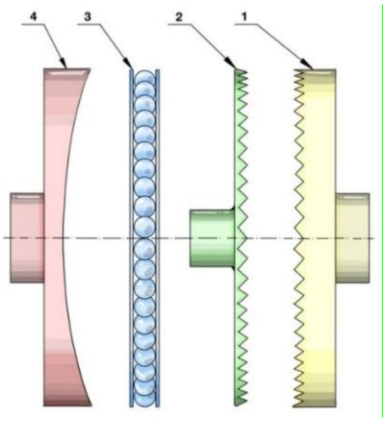

Figure 1
The main elements of a flat wheel strain wave gear unit: rigid gear (1), wave gear (2), flexible bearing (3), wave generator input cam (4)

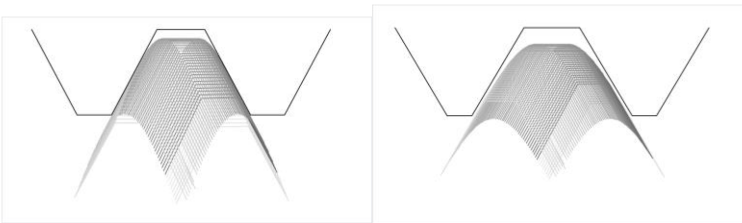

Figure 2
The plot of one teeth of the flexible gear in the rigid counterpart in unloaded condition on the outside (left) and on the inside (right) edge

3. DESCRIPTION OF THE DEVELOPMENT PHASES

For the validation of the analytic and finite element calculations, real word tests must be carried out hence the goal of the project was to produce prototypes. Prior to the examination the design phase took place where the manufacturing, assembly and other cost driving aspects were considered resulting in the best combination of geometry. Next, all the considered parts were manufactured with different movement influencing versions so that we were able to assemble seven distinct drive units for comparative tests. Based on the results we were able to determine the effect certain parts have on the behavior of the drive unit and to understand the advantages or disadvantages of the developed devices. These results will greatly influence the position of the product on the market and its place in the industry.

Figure 3
Exploded view of the designed flat wheel strain wave gear unit

4. Conceptional design, the chosen drive combinations

During the research other types of precision drives were evaluated. Based on these results we had many different mechanical options and combinations which can cost-effectively fulfil the requirements. We also had the possibility to choose from many kinds of materials, lubricants and fasteners.

The first step was to achieve the proper bearing arrangement of the four main elements illustrated in *Figure 1*. Next, the special torque motor's stator and rotor were installed. Since it is very compact its installation must meet certain requirements from the manufacturer. The connection of all these is the drive housing which has adjustments for assembly and connecting surfaces for electrical components. It is important to mention the special four wire bearing maintaining the vital output stiffens.

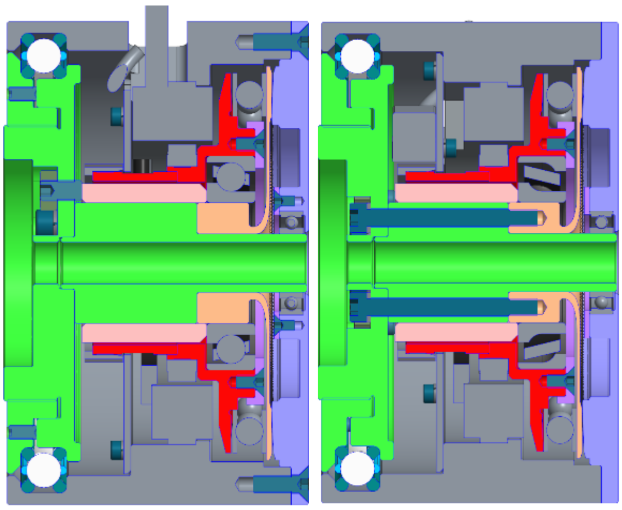

Figure 4
Section of the final strain wave gear unit design

The main elements were manufactured in different variants so that we can have a ratio of 120 or 160, different cam surfaces and various flexible bearing sizes. We also had multiple sensor options and drive houses with or without heat sink grooves.

5. Test arrangements and used measuring instruments

For standardizing the tests we have created a robust stand, shown in *Figure 5*, which can hold all the different gear unit combinations. The unit installed on this mount can be loaded with a steel brake rotor and copper brake pads or for low displacement with a steel bar and weights.

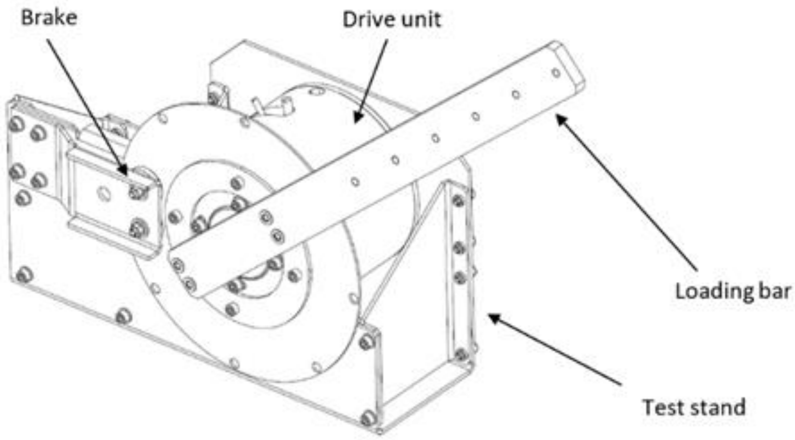

Figure 5
Test stand for prototype gear unit tests

On the outer edge of the loading bar we can measure the displacement with an indicator dial gauge. For torsional stiffness measurements we first had to determine the displacement of the test environment. For this we replaced the drive unit with an equally sized but prominently stiffer component, which was loaded the same way as the gears would be. Since we worked out the displacement of the other elements (table, loading bar, adapters, test stand) we can deduct the real torsional stiffens of only the gear unit itself. During the tests we recorded the required electrical current and also the deflection, which gives us the overall angular stiffness.

With the same arrangement we can also measure position repeatability, which is crucial for precision drives. For this we had a constant torque load moving from horizontal position to a –30[°] and then back again to see how much error accrue.

The application of these drives in some of the areas requires long lifetime. To simulate these conditions, we measured the drawn current, the temperature of the housing and the motor and the noise level while increasing the load and the speed. The temperature gain was measured with the resistance probe of a multimeter while the distribution was inspected with a thermal imaging camera. We used a sound level meter to determine the noise level. While these measurements were adequate to compare different constructions the data was heavily influenced by the surrounding environment's amplifying effect.

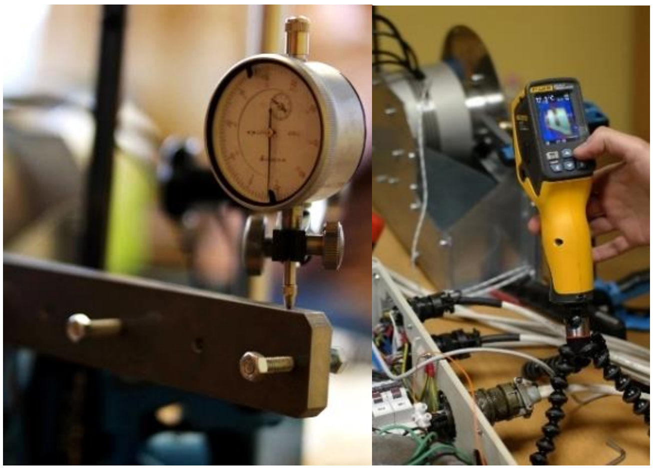

Figure 6

Displacement and position repeatability test with an indicator dial gauge, heat distribution inspection with a thermal imaging camera

6. Test results

During the tests we examined seven different drive combinations. The different combinations were created by choosing the appropriate options from the configuration table shown below.

Table 1

Drive unit configuration table

<table>
<tr><td>Generator input unit</td><td>2° ball bearing</td><td colspan="2">2.3° ball bearing</td><td>2 roller bearing</td></tr>
<tr><td>Bearing size</td><td colspan="2">1.25 - 0.4 mm</td><td colspan="2">1.4 - 0.5 mm</td></tr>
<tr><td>Encoder</td><td>Inc. D20</td><td colspan="2">Inc. D80</td><td>Analog</td></tr>
<tr><td>Gear ratio</td><td colspan="2">120</td><td colspan="2">160</td></tr>
<tr><td>Housing</td><td colspan="2">Smooth</td><td colspan="2">Grooved</td></tr>
</table>

To record the test results, we created a standardized report sheet. This document contains all the used parts and the results of all the test, including the position repeatability, torsional stiffens and the lifetime simulation. During the measurements we had the possibility to observe the different electrical parameters in real time for the motor controller. These were the drawn current, voltage, speed, position target and difference. For example, we were able to detect that at higher speeds stronger controller manipulation was needed due to the slight runout of the angular contact bearing.

With these tests we have gained a great amount of experience. The analog encoder sensor had shown that while it was able to work with the drive system it lost signal at higher speeds and temperatures. This meant we could only achieve significant results with a digital transmitter. While the gear set with a ratio of 160 required more current it was also a bit less noisy at higher speeds. On the thermal images it was clearly shown that the housing with grooves provided a lot better cooling for the motor.

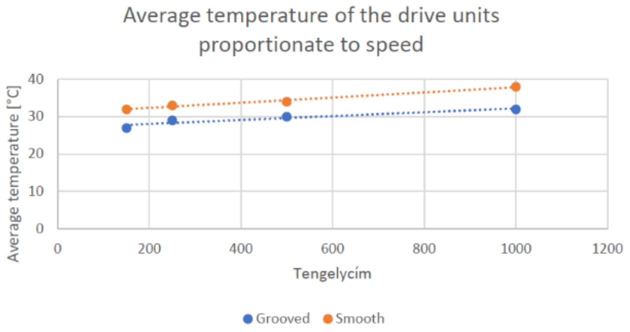

Figure 7
Temperature gain difference between grooved and smooth housing

The position repeatability test showed that the higher resolution D80 encoder does not have much advantage against the D20 variant since with the same gear set the rotational error was repeatedly lower than an arcminute. The installation of the axial-angular contact roller bearing resulted in a lower noise level opposed to the ball bearing variant, but it also meant a higher runout and a higher current consumption.

7. Its place on the market

It can be admitted that for a commercially available drive the ratio of 120 or 160 is quite high, in this field mostly planetary gears are on the market. We can further narrow down the competitor products since ours is a compact system joined with a servo drive so it can work independently while its size is also moderate at Ø 133 × 100 [mm]. The average position repeatability is 0.7 [arcminute] which is also an impressive value. Mean torsional stiffness being just above 6.2 [Nm/arcminute] is comparable to that of the Bonfiglioli precision planetary drives' with similar power capabilities.

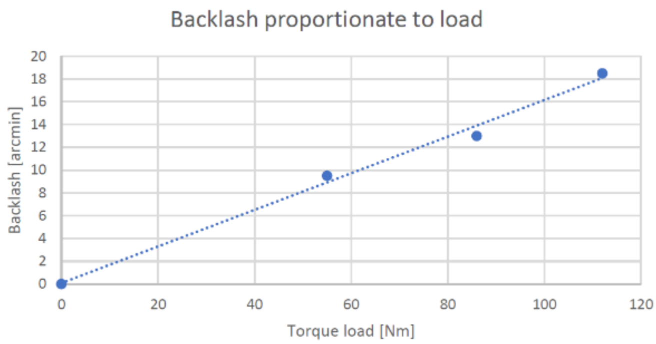

Figure 8
Backlash in regards to torque load

One of the main advantages of the developed drives is that we are able to set up the teeth connection with stepless dial. Its effect is shown in *Figure 8* where we can see that the backlash stays below 2 [arcminute] until 10 [Nm] torque load, which is above the capabilities of the Bonfiglioli drives that have 4-6 [arcminute] of backlash.

8. FURTHER DEVELOPMENT POSSIBILITIES

The research of the strain wave drives resulted in a lot of new experience, which can influence a more advanced generation of prototypes. Our next goal is to implement such modifications that can further optimize the device parameters. The flexible axial bearing could be used with smaller ball bearings to improve running properties. Or using oil lubrication on the teeth could lower resistance. In this case we need to provide the sealing for the whole unit but this would mean lower frictional losses, lower noise level and would also benefit the heat dissipation. All the examined drive units are the same size but they can be configured in a way to suit the different use cases.

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