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DEVELOPMENT OF A PRECISION DRIVE UNIT AT K.K.K. 99 LTD TO BE UNIVERSALLY USED AS ROBOT JOINTS WITH HIGH POWERDENSITY AND MODULAR CONSTRUCTION

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Abstract: A highly innovative gear unit set has been developed and manufactured to be widely used in medical industry, manufacturing robots or high precision manipulators. The main elements of the drive unit are the gear ratio reducing strain wave gear, the torque-motor and the force-torque measuring sensor, which can be combined arbitrarily. In one unit the motor series size is given but its power output (longer motor) and the gear reduction ratio can be varied. Assembling these parts, the result of this RnD project is a high precision drive with minimal dimensions, which, on itself, is able to position rotating movement precisely and while at halt it can also keep that position with high torsional stiffness. What makes the modular precision drive unit whole, is the controlling system. The above-mentioned machine elements can be assembled into different configurations so it can become part of a SCARA, humanoid or Delta robot. As a result of this project the created precision drive prototypes could provide tests and results that may influence the mechatronic and mechanical engineering profession.

Keywords: *research and development, high precision, strain wave gear*

1. Introduction

The K.K.K. 99 Kft. has received a grant in the 2018-1.1.1-MKI-2018-00152 tender to develop and manufacture a high precision drive system that can be widely used as rotational joints in medical and industrial robots or high accuracy manipulators. The present paper deals with the construction of these drives, their properties, the tests they undergone and their results. After describing the different types of precision drives we evaluate the outcome.

2. The work principal of the strain wave drives

Strain wave drives are high ratio, backlashless, high power density precision drives. *Figure 1* illustrates their main elements. It consists of a rotational wave generating input element with a cam surface on its axial extent (3), 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. The latter two elements both have a trapezoid tooth shape, the difference is that on the flexible wave gear there are fewer teeth by the amount of cam tips the generator has. These parts are all coaxially positioned so the unwanted imbalance effect of cycloidal drives is not present here to restrict the top speed of the input.

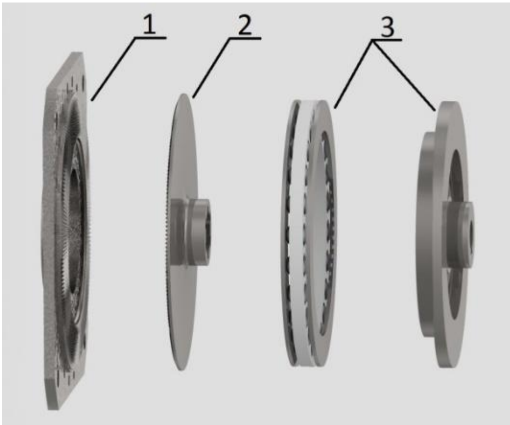

Figure 1

The main elements of the flat wheel strain wave gear unit: rigid gear (1), wave gear (2), flexible bearing and wave generator input cam (3) [3]

There are different designs of strain wave gears. The industry uses mostly the cylindrical type, which teeth are on the cylinder mantle of the elements. However, there is also a flat wheel type that has the teeth on the front of a round disc and the deformation is in the axial direction rather than the radial.

Figure 2

Experimental cylindrical and flat wheel strain wave drives

During this tender project the four strain wave gear unit shown in *Figure 2* were manufactured. Two flat wheel and two cylindrical strain wheel version was built, which can both be with and without an integrated brake. Some parts in these drive units are interchangeable so it was possible to try out different combinations. As a result of this the input generator's cam profile and the rolling elements of the flexible bearing can be varied during the tests.

3. Introduction of the Test Environment and the Instruments

In order to examine our drive units, we had to construct a specific test environment and choose the adequate measurement instruments. These will help us collect the data we need to compare the properties of each configuration to one another and also to the competitors on the market. We can categorize the tests into two groups. First, the test stand shown in *Figure 3* was constructed to measure the base parameters of each drive. This structure is made from steel plates and bars to have a solid foundation, here we can load the gear units with a steel brake rotor. It is also equipped with a force measuring device that makes it possible to monitor the given load in real time. This force sensor is connected to a signal amplifier then the data is filtered by the software. This data is forwarded to a PC by a National Instruments USB-6212 multifunctional data acquisition device. Further measurements were made with a FLUKE Ti110 thermal imaging camera and an Agilent U1732 LCR meter. An LCR meter is a type of electronic test equipment used to measure the main physical parameters (inductance, capacitance, and resistance) of an electronic component.

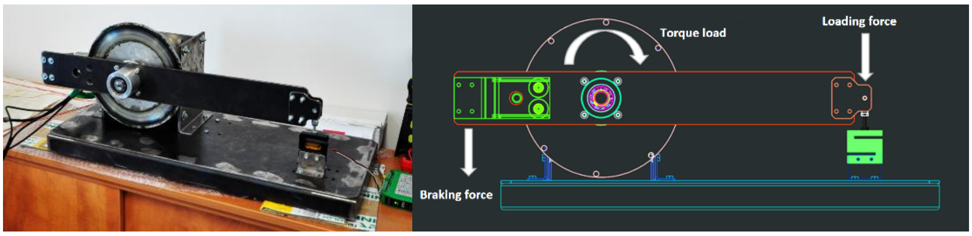

Figure 3
Test stand for the drive units

Several important results came from these tests. We got to measure the drawn current for several load sets, the temperature gain in each state on the housing and on the brake, the frictional losses and the position repeatability for the gear sets. Next, we constructed a manipulator that had flat wheel strain wave drive as its first joint and cylindrical wheel drive as the second and third.

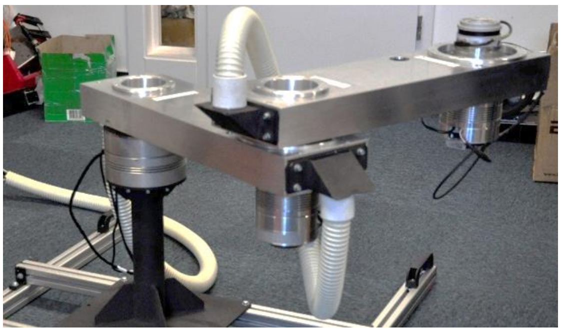

Figure 4
Manipulator with strain wave drives

This assembly mostly resembles a SCARA robot and specialized for testing the developed precision drives as they would be used and equipped in robots, which would be their most common field of use. With this manipulator we were able to conduct further tests. The vertical deflection, the rigidity of the system all together and the position repeatability was measured with this structure.

4. Results from the flat wheel (SV2) strain wave drive

We began with the measurement of drawn current at different load and speed levels for the flat wheel drive. The results ranged from 2.5–7.5 [A] depending on the load. It is clearly shown in *Figure 5* that the current for the motor is increasing with the load and the speed but with decreasing increments.

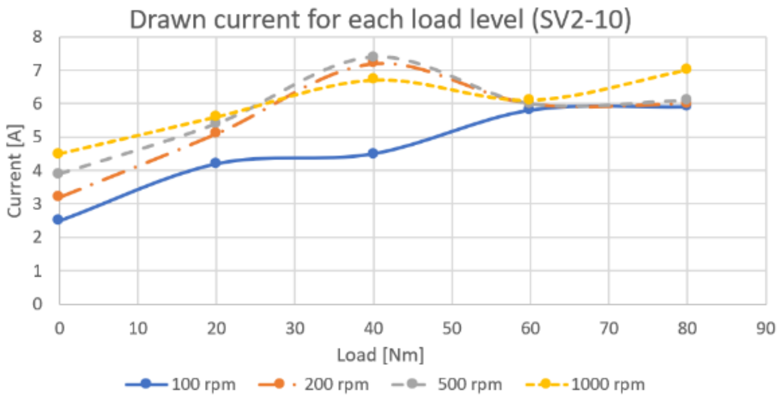

Figure 5

SV2-10 drive unit current drawn

At the peak of the control unit's power, which is 10 [A] at 500 [RPM], the drive unit equipped with a brake was able to produce 183 [Nm] torque while the brakeless version 175 [Nm]. These results are quite impressive for a drive with these dimensions. Only the flat wheel units have an integrated temperature sensor so that measurement was only possible with these. As expected, both the internal sensor and the thermal camera showed temperature gain proportional to the time.

Last, we measured the torsional stiffness and position repeatability. For the position repeatability test we mounted a laser pointer to the end of the arm then moved back and forth the drive (60°–90°) and observed the error that accrued at the distance of 10.5 [m]. According to the visual observation the start and end point difference resulted in 0.0055° for the position repeatability. To ensure good measurement we also evaluated the data from an encoder on the output shaft, which gave 0.0035° error for the drive unit with brake and 0.0036° for the brakeless version. For torsional stiffness we calculated 0.07 [arcminute/Nm] at 35 [Nm] torque load for the SV2-10 drive. This is a decent advantage compared to the currently available precision drives.

5. TEST RESULT WITH THE CYLINDRICAL STRAIN WAVE DRIVE (HHH)

The main advantage of the cylindrical type drive is that the flexible elements are far easier to deform thus presenting less force on all of the moving parts. This also means less current drawn for the motor during operation 0.3–4.5 [A] and better mechanical efficiency.

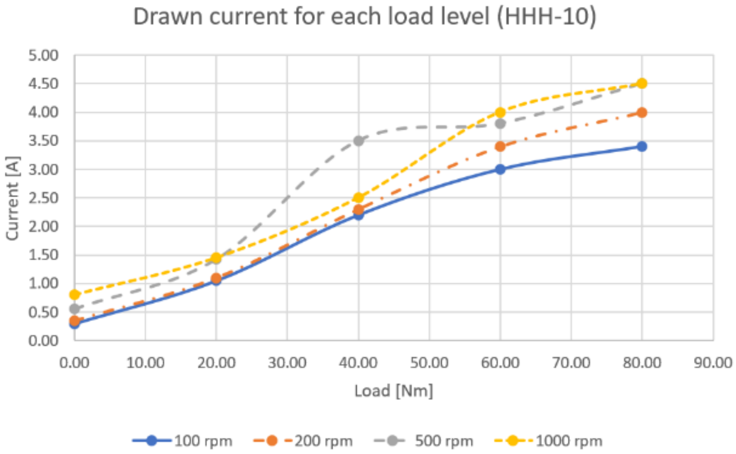

Figure 6
Current drawn by the HHH-10 drive system

Less frictional loss results in less temperature gain, so the temperature stayed below 27 [C°] after the initial fluctuation. The manual position recovery test shows similar results with the flat wheel drives but using the digital encoder we recorded 0.0044° error, which means these are a couple thousandths less accurate than the competition.

6. TESTS WITH THE ROBOT CONFIGURATION

We carried out three important tests with the experimental manipulator. For real time force and torque measurements we mounted an OnRobot HEX-H sensor on the end of the last arm, which allowed us to measure the effect different loads have on the whole assembly in real time.

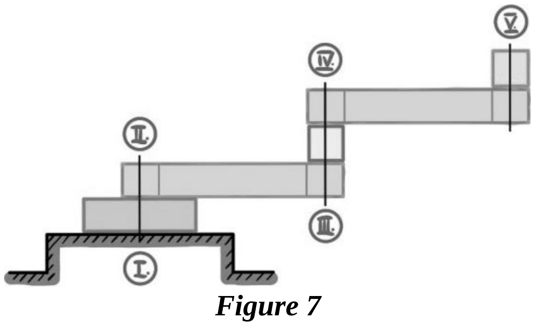

Figure 7
Experimental robot configuration with designations for each highlighted point

We measured the vertical deflection at the highlighted points shown in *Figure 7*. The results revealed that on the first joint, which is constructed with a flat wheel drive, significantly less deformation occurred than on the other two with their cylindrical drives. We also calculated the torsional stiffness of each joint and the whole system while maintaining a uniform sideways load on the structure. The six-axis sensor was used to accurately measure the given load, then these values were combined to obtain the overall stiffness from the displacement.

Finally, we measured the position recovery error after a complicated series of movements back and forth, then back to the starting position. For this we defined a course for the robot to follow a couple of cycles and then observed the same laser pointer start and end position like we did at the torsional stiffness and vertical deflection tests.

7. Comparison and Summary of Results

After all the tests, the results were summarized and compared. It is important to mention that for all four torque motors the parameters measured with the LCR meter were slightly different from the catalog values so we applied the recorded amount. The flat wheel strain wave drives are less sensitive since they needed relatively less power as we increased the load, although they needed more at just idle states, which means they are less efficient to run at low conditions. They also have a better torsion stiffness and their position recovery error is just 0.0035°, which makes them more robust than the cylindrical types.

The cylindrical strain wave drives needed less torque to idle but their power consumption increased rapidly with the given load. This concludes that it is better to use it at lower loads. Their torsional stiffness is a bit modest compared to the flat wheel types, it is most likely due to the geometry of the flexible elements, which allow for more displacement at less torque. Since their position repeatability is 0.0044° they are less accurate than the competition.

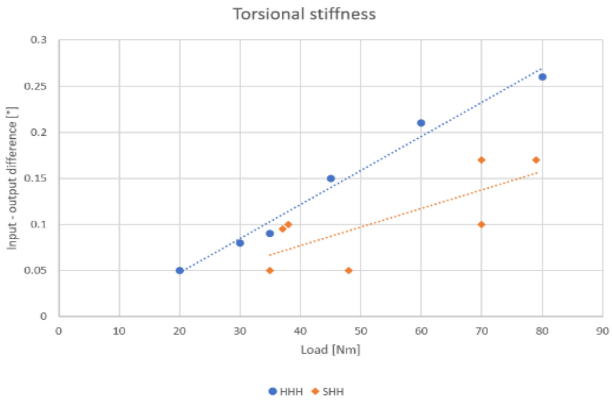

Figure 8

Rotational deflection increase with the gained load for both the flat and cylindrical strain wave gear set

In *Figure 8* you can see how the rotational deflection increased as the load gained for both drive types. It is necessary to mention that these results for both units are far better then what the currently available industrial precision drives can offer.

The tests carried out with the manipulator proved that the robot arms deflected less than the drives, since their complicated construction allowed more elasticity but the overall displacement is still very low. Torsional stiffness measurements showed similar results. The most significant result is the position recovery error of the whole system since it is only 0.05° after two cycles.

8. SUMMARY

After concluding the tests and measurements, it is clear that the precision drive system developed by the K.K.K. 99 Kft. has achieved the expected results, which makes them suitable for the required tasks. Our future plan is to utilize the accumulated experiences and knowledge to further dial in the existing drive units and also to develop a line of products from them.

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REFERENCES

[1] www.harmonic-drive.com.

[2] Krisch R. (2010). *Síkkerekes hullámhajtó-művek fejlesztése*. PhD study, BME.

[3] Kardos Sz., Krisch R. (2015). Síkkerekes hullámhajtómű alapelemeinek optimálása. *GÉP*, 6. sz., pp. 65–68.