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A GEOMETRICAL AND FORCE MODEL OF A MINI CYCLOIDAL GEARBOX FOR A 4-LEGGED ROBOTIC PLATFORM

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Abstract. *Modern light work platforms with four legs can be used in many areas: from toys to specialized mini transporter systems. In such representatives of robotics, a necessary factor for their efficiency is a high torque at a low frequency of rotation on the drives of their four legs. At the same time, a very important condition is the light weight of the drives, which actually consist of electric motors and gearboxes, specifically designed to create a high torque at a low frequency. In order to significantly reduce the weight of the reducer, it is proposed to make most of the cycloidal gearbox parts from plastic, except for the bearings and the shaft with the key. The most important part of the cycloidal gearbox is the cycloidal disk. The article proposes a 3-dimensional model of a cycloidal reducer designed by the authors for a four-legged walking robot toy. The outer diameter of the gearbox is 38 mm, while the weight will not exceed 350 grams if the device is made of steel parts, and not more than 120 grams if its biggest parts are made of plastic.*

Key words: *Robotic actuator, Cycloidal disk, Pet-robot, Gearbox,*

1.INTRODUCTION

Robotic pets are very popular today. Most of natural pets are small: dogs and cats, but they are brisk so the pet simulated robots must be prompt too. A similar problem of mini specialized robotic platforms also exists in the engineering discipline of mechatronics. Therefore, robotics engineers who deal with such types of mini 4-leg robots have to solve

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the problem of the strength of materials and use compact and lightweight activators. The major problem here lies in designing a lightweight and very efficient compact cycloidal gearbox.

2. LITERATURE REVIEW

Cycloidal planetary gears are widely used for mechanical efficiency, especially in automatic wheels and quadruped platforms [1]. Paper [2] describes a humanoid robotic platform, and describes the design criteria, hardware, software, and experimental testing of the platform. But it does not offer a gear design. Paper [3] presents general trends in humanoid robot motors, which of course include the use of lighter drive structures. In [4], the authors developed a highly efficient compact cycloidal gearbox for leg robots, which uses needle bearings in all parts where contact occurs during the energy transfer process inside the gearbox, significantly improving the efficiency compared to a cycloid gearbox with a free roller. The publication proposes a lifting structure that distributes the load and allows the cycloidal speed reducer to reliably respond to shocks that may occur during the locomotion of the legged robot. However, it weighs 766 g, so it can be used for leg work, but not for small pet robots. The CBD studied in [5] is a single-stage reducer with a compact design and a wide range of sizes, which only contains CBR bearings. Therefore, it is relevant for the problem of designing an ultra-light and compact cycloidal transmission.

3. THE 3-DIMENSIONAL MODEL OF A SINGLE-STAGE CYCLOIDAL GEARBOX WITH COMMON BALL BEARINGS

Cycloidal gearboxes have a high reduction ratio, high efficiency, high stiffness and are of compact size, compared to conventional gearbox mechanisms, so that they are attractive candidates for limited space and precision applications such as a little toy – a pet simulated 4-legged robot. The design of the actuator as a mutual device, as shown in Fig.1, consists of a modern mini brushless direct current electrical motor (1) and a mini dimension single-stage gearbox (2) available to operate together with the output motor shaft.

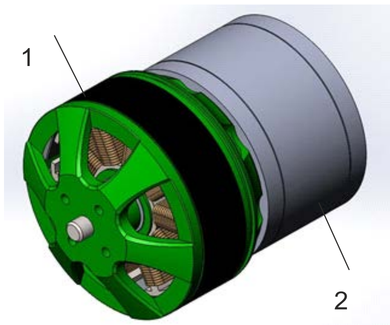

Fig. 1 Assembly of the BLDC electrical motor and the Cycloidal Gearbox

So, four such drives are needed for a four-legged mini-robot: each one consists of a motor and a gearbox on the output shaft. In fact, in terms of the saturation of parts, gearboxes and motors are leaders in the design of such robots. However, the motor does not have a significant potential for weight reduction, for example: the Multistar Elite 3508-268KVMultirotor motor can be used to achieve such reduction. Its weight is 78.6 grams, diameter 41.8 mm, and shaft diameter 4 mm. Another matter is the gearbox itself, which can be made of light alloys or plastic, except, of course, its shaft. It, as well as the key and rollers, should obviously be made of hardened steel.

Fig. 2 shows the parts of the cycloidal gearbox developed in study [6]. Detailed development of such gearboxes enables assembling of the small sizes and compact design of a gearbox model [7].

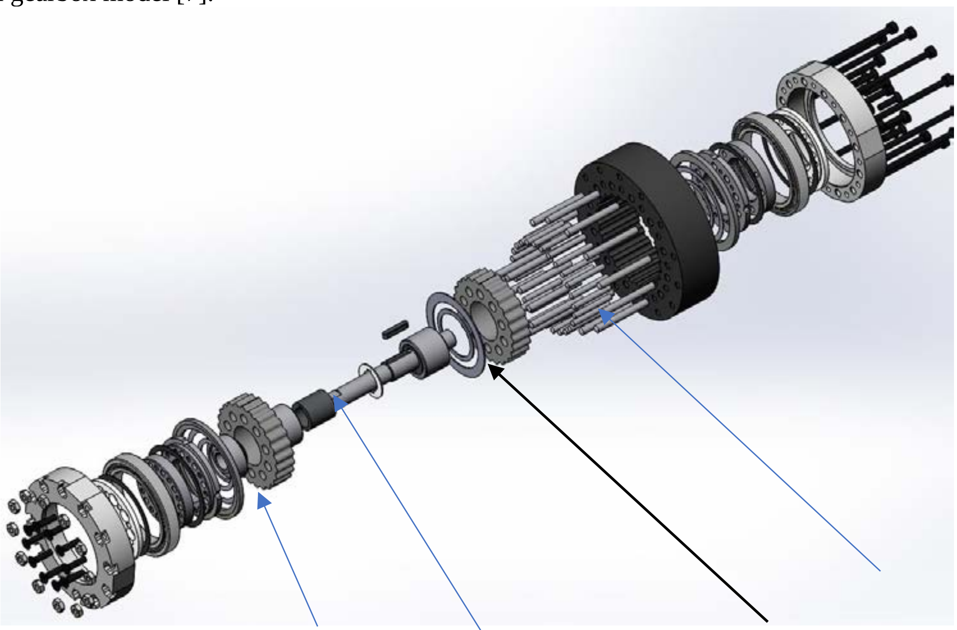

Fig. 2 Exploded View of the Cycloidal Gearbox. Parts:1 - shaft, 2 - cycloidal discs, 3 - rollers.

In order to determine the maximum permissible forces that can be perceived by the gearbox, it is necessary to determine the forces acting on the most loaded parts and structural elements of the gearbox: satellites, drive shaft, fingers and threaded holes of the carrier (fig. 3).

The calculation of the forces acting on the cycloid disk, spindles, fingers and bearings of the satellites is carried out according to the method given in [7].

4. METHODOLOGY FOR CALCULATION OF THE FORCES ACTING ON THE CYCLOID DISK

The SMath program is used to speed up the calculation process and avoid errors (Fig. 3, 4).

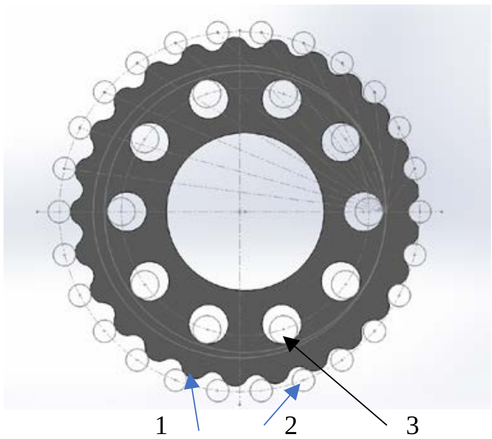

Fig. 3 Profile of a three-dimensional model of a cycloid disk (satellite) 1, rolls 2 and fingers 3.

Based on the dimensions of the selected radial thrust bearings and the desired moment and angular velocity at the output of the gearbox:
R_b =16 mm (the radius of the circle of the center of the threads and the uncorrected centroid b);
z_b = 26 (the number of threads);
z_a = 25 (the number of satellite waves (cycloid disk)).

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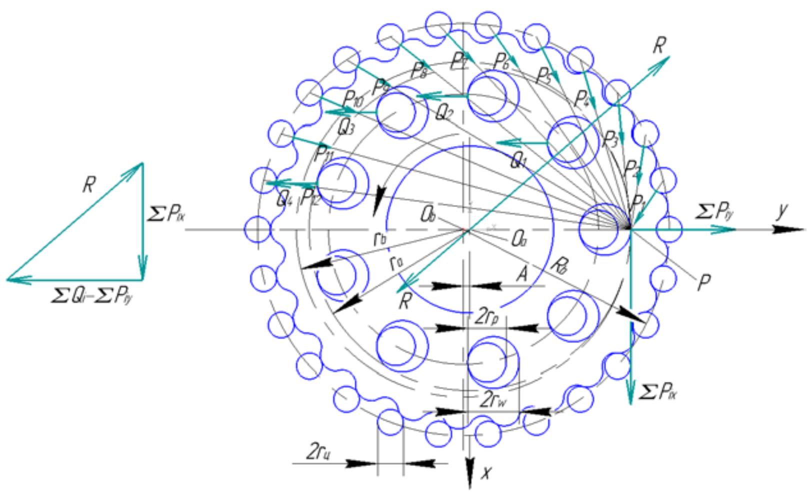

Fig. 4. Distribution of works in the satellite

The radius of the uncorrected centroid a is determined as follows:

$$R_a = \frac{\left(\frac{2\pi R_b}{z_b} \cdot z_a\right)}{2\pi} = 15{,}385[mm] \quad (1)$$

Eccentricity of the uncorrected transmission:

$$A_0 = R_b - R_a = 0{,}615[mm] \quad (2)$$

Selected eccentricity is A= 0.5 mm.
Transmission correction factor:

$$\xi = 1 - \frac{A}{A_0} = 0{,}1875 \quad (3)$$

Radius of the centroid b:

$$r_b = R_b(1 - \xi) = 13[мм] \quad (4)$$

Radius of the centroid a:

$$r_a = R_b - A = 12.5\ [mm] \quad (5)$$

Since cycloidal gearboxes usually use two cycloidal disks, the eccentricity of which is directed opposite to each other to reduce vibrations, it is necessary to calculate the moment acting on one satellite. It is worth taking into account the possible uneven distribution of the moment between the satellites, caused by manufacturing inaccuracy:

$$M_C = 0{,}55 M_V = 15{,}4\ [Nm] \quad (6)$$

The maximum load acting on the finger in contact with the satellite:

$$Q = \frac{4M_C}{R_w n_w} \cdot 1{,}35 \quad [N] \quad (7)$$

The sum of forces between the fingers and one satellite:

$$\sum Q_i = \frac{4}{\pi} \cdot \frac{M_C}{R_W} = 1867{,}42\ [N] \quad (8)$$

5. RESULTS OF CALCULATION OF THE FORCES ACTING ON THE CYCLOIDAL DISK

According to formulas (1-5), Table 1 contains the calculated geometry data of the satellite project:

Table 1 Determination of the satellite geometry

Dimension	Calculated result
Radius of the uncorrected centroid a (mm)	15.385
Eccentricity of the uncorrected transmission (mm)	0.69
Transmission correction factor	0.185
Radius of the centroid b (mm)	13
Radius of the centroid a (mm)	12.5

where are
R_w =10.5 mm - radius of the circle on which the axes of the fingers lie,
n_w = 26 - number of fingers,
M_V = 28 Nm - torque acting on the transmission according the electromotor.

According to formulas (6-8), Table 2 contains the calculated forces data of the satellite project:

Table 2 Calculated forces of the satellite model

Dimension	Calculated result
Moment between the satellites, caused by manufacturing inaccuracy (Nm)	15,4
Maximum load acting on the finger in contact with the satellite (N)	792
Sum of forces between the fingers and one satellite (N)	1867,42

6. CONCLUSIONS

1. The diameter and length of the developed cycloidal reducer are small enough and can be used with modern mini BLDC electrical motors.
2. The predicted weight of the developed cycloidal reducer is 120 grams only.
3. The model of the ultra-lightweight and compact cycloidal reducer is developed, and it can be suggested to as a drive for small pet simulated 4-legged robots.
4. The obtained values of geometric data and forces acting on the cycloid disk are the basis for further research into the created model and its ability.

REFERENCES

1. Bednarczyk S., 2014, Cycloidal planetary transmission, Visnyk NTUU «KPI». Mashynobuduvannia: zbirnyk naukovykh prats, 1(70), pp. 84–87.
2. Taejin Jung, Jeongsoo Lim, Hyoin Bae, Kang Kyu Lee, Hyun-Min Joe, Jun-Ho Oh, 2018, Development of the Humanoid Disaster Response Platform DRC-HUBO+, IEEE Transactions on Robotics, 34, 1, pp.1-17. doi 10.1109/TRO.2017.2776287
3. Sensinger J. W., Lipsey J. H., 2012, Cycloid vs. harmonic drives for use in high ratio, single stage robotic transmissions, The International Conference on Robotics and Automation, Vol. 606, Issue 11, pp. 4130-4135.
4. KangKyu Lee, Seungwoo Hong, Jun-Ho Oh, 2020, Development of a Lightweight and High-efficiency Compact Cycloidal Reducer for Legged Robot, International Journal of Precision Engineering and Manufacturing, Vol. 21, pp. 415–425.
5. XiaoXiao Sun, Liang Han.,2019, A New Numerical Force Analysis Method of CBR Reducer with Tooth Modification. Journal of Physics: Conf. Series 1187, 032053. doi:10.1088/1742-6596/1187/3/032053
6. Onysko O., Karabegovic I., Dasic P., Penderetskyi M., Melnyk O., 2021, The Stress State of Compact Mechatronic Satellites of a Cycloidal Reducer. Journal of Engineering Sciences, Volume 8(2), pp. D12-D17. doi: 10.21272/jes.2021.8(2).d3
7. Penderetskyi M, 2021, Development of a 3D model of a cycloidal gearbox for the actuators of a four-legged stepper robot, Master's Thesis, Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine, 413 p. 30.