Improving operational characteristics of wave gears

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Abstract. The advantage of wave gears is a possibility to obtain greater transmission ratios in one stage. The main drawback is a short life of a flexible gear due to large deformations with cyclically changing stresses. The proposed technical solution provides using a roller chain instead of the flexible gear. The gear arrangement is similar to a two-wave gear in which there is a wheel used instead of the flexible gear, with each tooth of it consisting of three rollers located in axial alignment. Middle row rollers are located along the edge of the master jaw. The outermost row rollers of the located along the lesser diameter of the jaw come into external engagement with two immobile gear wheels which have the number of the teeth equal to the number of the chain rollers. As a result, the chain does not rotate. The outermost row rollers that are located along the greater diameter of the jaw come into internal engagement with the follower wheel. At the cost of the differences of the follower wheel teeth and the chain rollers, the motion transmission occurs. The supposed transmission arrangement allows providing a transmission ratio in one stage up to 6 and higher that reduces the dimensions of the actuator.

1. Introduction
At present, transmissions with an involute tooth profile have become most widespread. However, they have a significant drawback: the teeth contact occurs along the line and, at the point of contact, high contact voltages appear in power transmissions, since the overlap ratio is not more than 1.1-1.5. That is, only one pair of teeth works 90-50 % of time. Together with rolling, sliding also takes place during the teeth operation, and the more the transmission ratio of the gear set, the greater the sliding is. This leads to power losses and intensive wear of the work surfaces.

For a single-stage cylindrical gear, a transmission ratio of \( i \leq 6 \) is recommended, as \( i > 6 \) leads to the greater dimensions of the transmission, and thus it is necessary to use multistage variants, which results in increase of the specific amount of metal in actuators.

Involute gear transmissions have been used for 250 years and have not had any fundamental changes. The problem of increase of the bearing capacity of transmissions while reducing their dimensions is becoming more critical in engineering. This problem cannot be solved by further improvements of the involute gear transmissions, as well as the transmissions of other known designs. One needs new technical ideas, such as using alternative kinds of engagement; providing multipaired engagement; reducing contact voltages by means of using circular tooth profiles; replacing sliding friction with rolling friction; optimizing the arrangement and structural designs of mechanical transmissions [1].

We have offered the constructions of mechanical transmissions that are based on new types of engagement [1–6], improving the construction of the known transmissions [1, 7-13], improving the arrangement of mechanical transmissions [6, 14, 15]. The offered technical solutions make it possible to reduce the effect of the problems mentioned above on the operating capability of technical systems.
One of the ways to improve technical characteristics of mechanical actuators is to develop the construction of wave gears which allow obtaining greater transmission ratios in one stage. The most widespread gears are two-wave gears implementing \( i = 80–320 \). Other advantage is high loading capacity, which is ensured by a greater overlap ratio (a multipaired engagement). Efficiency of such transmissions is comparatively larger.

The main drawback of wave gear transmissions is a short life of a flexible gear due to large deformations with cyclically changing stresses. This allows applying them for shorter-acting actuators with a minimal transmission ratio of \( i = 80 \).

As an alternative to wave gear transmissions with involute profile, transmissions with circular teeth profile began to appear, which significantly increases the load capacity of these transmissions as compared to those having an involute teeth profile. In these transmissions, the flexible gear is a chain with rotating rollers, which makes it possible to implement rolling friction at the place of contact [1, 16-19] and exclude the main drawback of wave gears – the lesser life span of the flexible gear.

2. Coaxial transmission with an intermediary roller chain

Figure 1 represents a diagram of the transmission which consists of a roller chain located between two coaxial wave gears that are in engagement with the chain [1, 20-24].

The roller chain 3 with a number of rollers \( n_3 \) is connected by an external engagement with the master gear wheel 2 that has \( n_2 = n_3 - 1 \) number of teeth.

At the same time, the chain 3 is connected by the internal engagement with an immobile wheel 4 that has \( n_4 = n_3 + 1 \) number of teeth.

Gear wheels 2 and 4 have circular valleys with a radius equal to a half of the diameter of the roller. The teeth pitches of the wheels and rollers are equal.

With a definite ratio of the pitch and diameter of the rollers, a condition of the assembly is fulfilled, that is, part of the chain rollers will be engaged with the master wheel 2, and part of them will be engaged with the immobile wheel 4. Due to the difference in numbers of the wheels and rollers of the chain during the rotation of the master wheel 2, the chain rollers 3 after the disengagement with this wheel enter into the internal engagement with the immobile wheel 4 that starts rotating the chain 3 in the same direction with the master wheel.

The transmission ratio of the mechanism in Figure 1:

\[
i = \frac{n_3}{n_4 - n_3} = n_3,
\]

That is, the transmission ratio from the master wheel 2 to the driven chain 3 is equal to the number of the chain rollers.

Therefore, except the obvious advantages of circular tooth profile in the form of rotating rollers of one of the (chain) wheels, this transmission has a substantial advantage over cylindrical gears – the implementation of a transmission motion from 6 and higher in one stage. However, the transmission considered has one considerable drawback – motion from the moving chain is transmitted to the driven shaft 8 (Figure 1) through the link 7 via extra roller 6 which is located on the elongated axis 5 of the roller chain and enters into the link groove. Therefore, torque to the driven shaft through the link 7 is transmitted by one roller located at the side of the chain. Such chain loading diagram substantially prevents using the transmission as power transmission, as during the constant contact of one roller with the surface of the groove of the link 7, there is one-pair implementation of the link and roller engagement. If to draw an analogy with cylindrical gearing, a transmission overlap ratio represented in Figure 1 is equal to 1.
Figure 1. The construction diagram of the transmission from two coaxial gear wheels with an intermediary roller chain: 1 – drive shaft, 2 – master gear wheel, 3 – roller chain, 4 – immobile wheel, 5 – elongated axis of the chain, 6 – extra roller to transmit the motion from the chain to the link, 7 – link, 8 – driven shaft.

3. Wave gear with a triple strand roller chain
Transmission described in [16] at the expense of the wave generator (Figure 2) has an arrangement close to the classic two-wave transmission and more balanced loading diagram due to the application of a triple strand roller chain.

Figure 2. The construction diagram of the wave gear with a triple strand roller chain: 1, 2 – wave generator disks, 3 – wave generator bearings, 4, 5 – wave generator rings, 6 – chain, 7 – input shaft, 8 – immobile gear wheel (body); 9 – output shaft, 10 – driven gear wheel.

The wave generator consists of disks 1 and 2 with an off-center positioning, on which rolling bearings 3 are located. On the bearings, rings 4 and 5 are placed. A standard triple strand roller chain 6 is placed on these rings with a slight tightness of fit. The rollers are teeth of the flexible gear. On the diagram, the links connecting the roller axes are indicated by lines. The wave generator is fixed on the input shaft 7. The teeth of the immovable body 8 are engaged with the rollers of the first two strands. On the outlet
shaft 9 there is a wheel 10, the teeth of which are engaged with rollers of the third strand of the chain. The number of teeth of the wheel 10 is equal to the number of the chain rollers. The input and output shafts are coaxial. When rotating the wave generator, the chain rollers, being displaced from the center, get into the engagement with the teeth of the immovable wheel 8 and, due to the difference of numbers of the teeth and rollers, the chain will rotate together with the driven wheel 10. Bearings 3 ensure free rotation of the rollers.

All the kinematic dependencies, which are true for regular two-wave gears, are applicable to this transmission.

Due to the assembly condition, the number of teeth of the immobile wheel is:

\[ z_8 = z_6 + 2 \]  

where \( z_6 \) is the number of the chain rollers.

Then the transmission ratio from the driving unit (the wave generator) to the driven chain is going to be defined as:

\[ i = \frac{z_8}{z_8 - z_6} = \frac{z_6 + 2}{2}. \]  

The driven wheel 10 is going to be rotated with the same speed, as the triple strand engagement of the chain with this wheel is a wave gear coupling.

Following the results of research on the transmission, it has been found [6, 16, 25-27] that its life span depends on the increase of the chain pitch as far as the wear of the pin joints occurs. In particular, the chain rotation speed has a significant effect on the wear of the pin joints.

A drawback restricting the capacity of the transmission represented in Fig. 2 is an asymmetrical loading distribution for the rollers located in different strands of the chain.

4. Pin-joint and roller gear transmission

We have offered a construction of a wave gear [7] that eliminates drawbacks of the above-mentioned mechanisms and ensures symmetry of the chain loading.

In Figure 3 there is a diagram of the construction of the offered pin-joint and roller gear transmission.

![Figure 3](image)

**Figure 3.** The construction diagram of the pin-joint and roller gear transmission: 1 – jam; 2 – chain; 3 – driven gear wheel; 4, 5 – immobile gear wheels; a, c – rollers of the external strands of the chain; b – roller of the internal strand of the chain.

The roller chain 2 has three independent rollers a, b, c that rotate with different speeds. With the middle rollers, chain 2 covers the master jaw 1 (performed as an ellipse) along the contour. In the
diagram, the units that connect the axes of the rollers are designated with lines. The rollers of the outermost strands (a, c), with an arrangement of the chain at the sections of the jaw with a larger diameter, come into engagement with teeth of the wheel 3. The rim gear of the wheel 3 has a cutout that prevents its contact with rollers b. The stop of the chain 2 is carried out with an engagement of its outermost strands with two immobile gear wheels 4 and 5 that have a number of valleys that are equal to a number of the chain (Figure 2, view A–A, the units that connect the roller axes are not designated). Multipaired engagement of the offered transmission will allow substantially increasing the loading capacity comparing to involute gear transmissions; and the coaxiality of the gear wheels, chain and jaw will reduce its dimensions with the transmission ratios from 6 and higher.

Kinematically, pin-joint and roller gear transmission is similar to a two-wave gear transmission, and, from the assembly condition it follows that:

$$z_3 - z_2 = 2$$

(4)

where $z_3$ and $z_2$ are the numbers of teeth and rollers of the driven wheel and chain, respectively.

Then the transmission ratio is:

$$i = \frac{z_3}{z_3 - z_2}.$$

(5)

For the transmission represented in Figure 3:

$$i = \frac{14}{14 - 12} = 7.$$

(6)

Directions of motion of the driving and driven units coincide. The increasing number of teeth will lead to the transmission ratio increase.

Testing of a sample of the pin-joint and roller gear transmission confirmed a possibility of engagement and motion transmission of the offered construction of the mechanical transmission, and also the equality of the transmission ratio to the one analytically defined [8].

5. Conclusion

The offered technical solutions are directed to the elimination of the main drawback of the wave gears – short life of the flexible gear, its replacement with a wheel with teeth in the form of rollers that are located on the axes fixed by pinning (by analogy with the chain).

The main criterion of the operating capability of the wave transmissions in which roller chains are used in the capacity of the flexible gear is a wear of the pin joints of the flexible gear (it is analogous to the wear of the pin joints of the chain transmission). The life length of such transmissions depends on the increase of the chain pitch as far as the wear of the pin joints occurs. As the wear of the pin joints is heavily affected by the speed of the chain rotation, the offered pin-joint and roller gear transmission has an increased longevity at the expense of the non-rotating chain. Pin-joint and roller gear transmission is able to transmit substantial capacities at the expense of the multipaired engagement and implementation the rolling friction in the engagement. Transmission with non-rotating roller chain has a limited loading capacity due to non-symmetrical distribution of the loading for rollers, but allows significantly simplifying its construction and reducing its weight. With this, the other advantages of the pin-joint and roller gear transmission remain unchanged, and this will allow using the offered technical solution with actuators with moderate capacity.

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