Reduction Gearbox Motion Transmission Using a Crankshaft and Bellows

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***Abstract* – The article deals with a technical design of the reduction gearbox with motion transmission using the inlet crankshaft and bellows. It describes the original technical design and presents the proposed elimination of the drawbacks of the original design which has also been practically executed by producing a prototype device which was observed to exhibit absolute functionality.**

***Keywords* – gearbox, crankshaft, bellows, reducer, torque**

1. Introduction and the Original Technical Design

In general, a gearbox is a technical device with the motion transmission system in form of an individual subsystem of machines. Gearboxes are used when there is a need for adjusting the characteristics of the motion of an actuating device, for example an engine, to the required characteristics of the motion of a particular machine, for example the revolutions of a milling cutter during the working process, or to the operating conditions, such as a car driving up a hill.

DOI: 10.18421/TEM93-27
https://doi.org/10.18421/TEM93-27

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Received: 29 June 2020.
Revised: 05 August 2020.
Accepted: 10 August 2020.
Published: 28 August 2020.

A reduction gearbox is a gearbox in which the reduction is linked to the main gearbox, which is shifted either manually or automatically, with one or two positions - one for driving on roads (High; in fact equal to the disengaged reduction) and the second for off-road driving (Low). Speed gear reduction (Low) is used in order to increase the tractive force which is essential for off-road driving. A gearbox reduction lever may also be used to add a drive of an axle, most frequently the fore axle, or to lock the inter-axle differential (Mitsubishi Pajero).

A gearbox represents a mechanical unit which is widely used in the mechanical engineering segment. This group of products includes a frequently used subgroup of gearboxes used to reduce revolutions and increase the output torque. They are reducers which are needed due to the fact that majority of driving motors exhibit high revolutions and low torque, whereas most applications require low revolutions and high torque. Such transformation of mechanical parameters is provided by reducers which are currently subjected to strict requirements. Conventional reducers with front toothing wheels only fulfil such function when their relatively high weight, wheel clearance and not very high efficiency are tolerable. However, with regard to the requirements of the automation technology, mechatronics, robotics, aviation technology etc., for which such properties are inconvenient, the assortment of conventional gearboxes has been supplemented with newly developed special gearboxes (harmonic, planetary, cyclo-gearboxes, bearing reducers, rollers etc.), including a widely used type of harmonic strain wave gears (see: J. Jovankovič, M. Žalman: Mechatronické systémy (Mechatronics Systems), section 9, AT&P journal 10/20006; Balara, M. et al.: The Three Mass Model of Harmonic Transmission. International Journal Automation Austria, Heft 1, 2, Jg. 6, 1998, Wien, Austria, ISSN 1562-2703, pp. 27–36; http://harmonicdrive.de/en/technology/harmonic-driver-strain-wave-gears/). A harmonic strain wave gear (Harmonic Drive, harmonic gear - HG) is a modern type of gear with a high gear ratio and high efficiency. It consists of the following parts: [5]

- A wave generator which forms the input part of the gearbox; it has an elliptic roller with a ball bearing of a relatively large diameter;
- A flexspline with teeth arranged around its outer circumference (a deformable cylinder) with the number of teeth t_1;
- A rigid internal gear sleeve with the number of teeth t_2; it forms the output part of the gearbox; the number of teeth t_2 is usually larger than t_1.

When the input shaft of the wave generator revolves, its elliptic shape is transmitted, at an equal circular frequency, to the elastic wheel with external toothing. As a result of precession, the wheel makes a relatively low movement in the opposite direction. During the movement, approximately 15 % of all teeth are engaged at the same time. This explains the transmission potential for high torques and a small clearance.

Advantages of harmonic gears include the coaxial input and output, high gear ratio i = 70 to 350, and the fact that it facilitates hermetic separation of the input shaft from the output shaft [10],[11]. Disadvantages of harmonic gears include the fact that the reducer does not endure excessively strong dynamic impacts, extraordinary requirements for material quality, and the flexible connection at the output generates angular speed. Another disadvantage of such reducers consists in strict requirements for advanced production technology and production accuracy. This results in high prices of such reducers which are proportional to the complexity of their production.

For the purpose of defining the key terms, Figure 1. shows the stainless steel bellows.

Figure 1. Stainless steel bellows

2. Basis of the Original Design

The advantages listed above have been partially, and sometimes even completely, eliminated in the technical design presented herein. The proposed gearbox consists of a rigid stator coil with internal toothing which comprises a rolling wheel with external toothing. The end of the (input) crankshaft is inserted in this rolling wheel and secured with a retainer ring. The crankshaft is placed in the input bearing in the rotary position. One end of the bellows is firmly attached to the rolling wheel in a coaxial arrangement while the other end of the bellows is firmly attached to the output wheel in a coaxial arrangement; the output shaft is firmly inserted into the output wheel, in the rotary position inside the output bearing. [12]

When the (input) crankshaft rotates, the outer circumference of the rolling wheel rolls away from the inner circumference of the rigid stator coil. The points of the rolling wheel circumference move along the hypocycloid trajectories; other points of the wheel move along the shortened hypocycloids. As the axes of the crankshaft stubs are shifted, relative to each other, the centre of the rolling wheel rotates around the gearbox axis (axis of the crankshaft and the output shaft). Concurrently, the circumference of the rolling wheel rotates slowly in the direction opposite to the direction of the (input) crankshaft rotation. This motion is transmitted from the rolling wheel to the output wheel through the attached bellows; the axis of the bellows rotation is identical to the axes of the rotation of wheels to which it is attached at respective ends. The output wheel transmits the reduced revolutions to the output shaft. As a result, reduction of the input revolutions and multiplication of the output torque occur in the gearbox. [12]

List of drawings:

The innovated technical design is explained in more details in the drawing presented in Fig. 2. – the overall arrangement of the functional parts of the device. Fig. 3. shows (the frontal view) the arrangement of the functional parts at the device input [12], [13].

3. Examples of the Innovated Technical Design

Figures 2. and 3. represent the examples of the technical design of the gearbox according to the proposal presented herein. The gearbox consists of a rigid stator coil 1 with internal toothing which comprises a rolling wheel 2 with external toothing. The end of the crankshaft 3 is inserted in the rolling wheel 2 and secured with a retainer ring 4. The crankshaft 3 is placed in the input bearing 5 in the rotary position. One end of the bellows 6 is firmly attached to the rolling wheel 2 with external toothing, in a coaxial arrangement. The other end of the bellows 6 is firmly attached to the output wheel 7 in a coaxial arrangement. The output shaft 8 is firmly inserted into the output wheel 7, in the rotary position inside the output bearing 9 [12].

When the (input) crankshaft 3 rotates, the outer circumference of the rolling wheel 2 rolls away from the inner circumference of the rigid stator coil 1. The points of the rolling wheel 2 circumference move along the hypocycloid trajectories; other points of the wheel move along the shortened hypocycloids. As the axes of the crankshaft 3 stubs are shifted, relative to each other, the centre of the rolling wheel 2 rotates around the gearbox axis (axis of the crankshaft 3 and the output shaft 8). Concurrently, the circumference of the rolling wheel 2 rotates slowly in the direction opposite to the direction of the (input) crankshaft 3 rotation. This motion is transmitted from the rolling wheel 2 to the output wheel 7 through the attached bellows 6; the axis of the bellows rotation is identical to the axes of the rotation of wheels to which it is attached at respective ends 2 and 7. The output wheel 7 transmits the reduced revolutions to the output shaft 8 [12].

The gear ratio N of gearbox revolutions n is determined by the difference between the internal circumference S_{si} (number of teeth T_{si}) of the stator coil 1 and the external circumference S_{oo} (number of teeth T_{oo}) of the rolling wheel 2 in the ratio to the internal circumference S_{si} (number of teeth T_{si}) of the stator coil 1.

The following applies to the above listed parameters:

$$N= (S_{si} - S_{oo})/ S_{si} = (T_{si} - T_{oo})/ Z_{si} = n_{out} / n_{in} \qquad (1)$$

where:

N is the gear ratio;
n_{in} are the input revolutions of the gearbox; and
n_{out} are the output revolutions of the gearbox. [1],[3],[4]

The torque, as well as power and maximum revolutions per minute, are the key parameters of combustion engines (however, they relate to all rotary actuation systems, i.e. all rotary motors and potential designs) [9].

The calculation of torque and motor revolutions for a particular motor power:

$$P = \omega.M \qquad (2)$$

where:

- *P* is the power in Watts - *W;*
- *ω* is the angular velocity in radian per second, *rad/s;* and
- *M* is the torque in *Nm* [6],[7]

A convenient formula to be applied in real operations is as follows:

$$P = \frac{2\pi Mf}{60} \qquad (3)$$

where:

- *P* is the power in *W*;
- *M* is the torque in *Nm;* and
- *f* is the frequency in revolutions per minute *rpm* [2],[8],[9]

The gearbox with the proposed design is intended for the reduction of the input revolutions and for increasing the torque at the output of the device.

Annotation and summary:

The gearbox consists of a rigid stator coil (1) with internal toothing in which there is a rolling wheel (2) with external toothing. The end of the crankshaft (3) is inserted into the rolling wheel (2) and secured with the retainer ring (4) while the crankshaft (3) is placed in the rotary position in the input bearing (5). One end of the bellows (6) is firmly attached to the rolling wheel (2) with external toothing, in a coaxial arrangement, while the other end of the bellows (6) is firmly attached to the output wheel (7) in a coaxial arrangement. The output shaft (8) is firmly inserted into the output wheel, in the rotary position inside the output bearing (9) [12],[14].

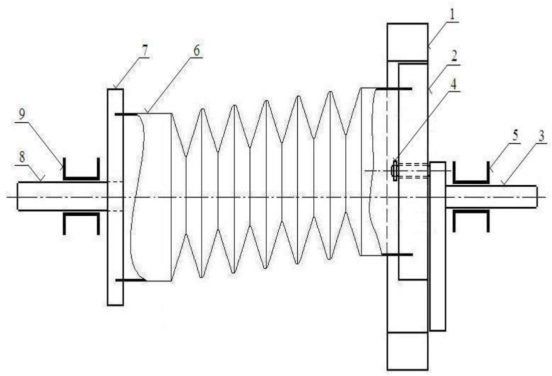

Figure 2. Overall functional scheme of the proposed technical design

Legend:

1. Rigid stator coil
2. Rolling wheel
3. Crankshaft
4. Retainer ring
5. Input bearing
6. 6 Bellows
7. Output wheel
8. Output shaft
9. Output bearing

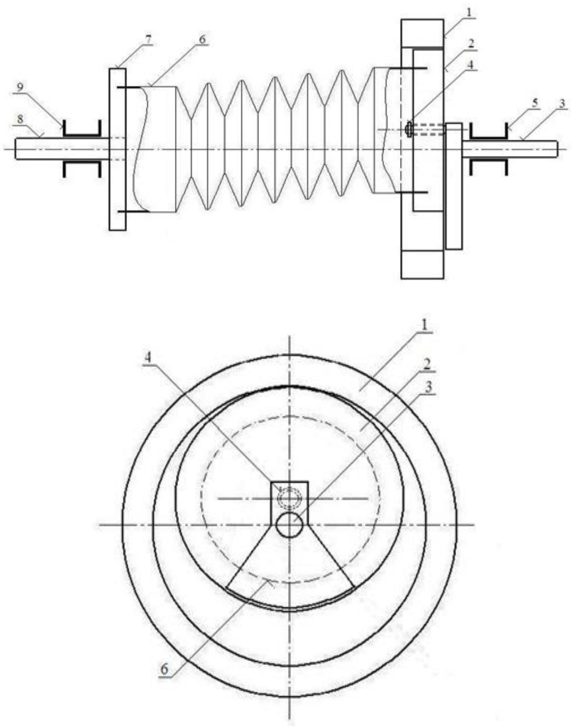

Figure 3. Overall functional scheme of the proposed technical design; a vertical projection and a section plan

4. Conclusion and Industrial Applicability of the Proposed Technical Device

The applicability of the products manufactured within the current mechanical engineering on global markets depends on their constant innovations and modernisation, and especially on managing the production technology. The trends of increasing the level of mechanical engineering products head towards more advanced technologies, production organising and shortening the technological preparation cycle in accordance with the requirement to automate technological as well as production processes.[15]

The proposed device with the technical design described herein may be applied in all cases when the use of gears – reducers is required, i.e. in order to reduce revolutions and increase the torque at the output of the device. This mainly applies to mechanical engineering, automation technology, mechatronics, robotics, aviation technology, medical technology etc.

Acknowledgment

This work was supported by the projects VEGA 1/0393/18 and KEGA 55TUKE-4/2020 granted by the Ministry of Education, Science, Research and Sport of the Slovak Republic and by the Project of the Structural Funds of the EU, ITMS code: 26220220103. The patent application published by the Industrial Property Office under the registration number 50025-2017.

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