Analysis of the influence of direction of helical teeth in the universal helical gear reducer on service life of the bearings that support the reducer shaft

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Abstract. The paper analyses the problems of the influence of direction of helical teeth in the universal helical gear reducer on service life of the bearings that support the reducer shaft, i.e. on the overall load carrying capacity of universal gear reducer. Directions of helical teeth for all gear units is adopted in that way that the overall axial force at the reducer shaft is lowest as possible, i.e. axial forces of a shaft are in counterbalance. It is a practice the same output gear pair is used within a helical gear reducer made in universal casing for two- and three-stage gear reducer. However, these gears are produced with different directions of helical teeth in order to obtain the lowest axial force on the fifth geared shaft. However, some gear reducer manufacturers, trying to simplify the production and reduce the number of manufactured components, produce the gears with the same helical teeth direction for both two- and three-stage gear reducers. In that way, they do not reduce the value of axial force on the fifth geared shaft in three-stage gear unit, but they make addition of axial forces that certainly affects the service life of the bearings and thus the overall load carrying capacity of the gearbox. Analysing the concrete case, this paper researches the justification of implementation this procedure.

1. Introduction

Universal helical gear reducers are usually produced as single-, two-, three- and multi-stage gear reducers. Although, there are many manufacturers who do not produce conventional single-stage gear drives [1, 2, 3]. Some manufacturers produce two-stage gear reducers in special housings only for two-stage drives. However, their three-stage gear drives are built by connecting two-stage and single-stage gearbox, or four-stage gear drives are made by connecting two pieces of two-stage gearboxes. Most of the manufacturers produce two-stage gear drives in universal housings for two- and three-stage gear drives. Therefore, their two-stage gear reducers are a little bit more expensive than two-stage gearboxes mounted in special housings for two-stage gear drive. Nevertheless, their three-stage gear reducers assembled in the same universal housings are much cheaper than three-stage gearboxes built by connecting two-stage and single-stage gearbox [2, 4]. Which concept of manufacturing will be adopted depends on the market orientation of the producer, i.e. which segment of the market they want to pay special attention. Namely, the most required gear ratios are in the area covered by high gear ratios of two-stage gear reducer and low gear ratios of three-stage gear reducer. Major manufacturers...
have generally chosen this second variant, i.e. the gear drives assembled in universal housings for two- and three-stage gear reducers. While, smaller manufacturers usually use the first variant, i.e. the gear drives built in special housings in order to ensure the better placement on the market [4].

As already mentioned, in the case of multi-stage helical gear reducers, but not only helical, it is practiced that axial forces (occurred on gears and transmitted from shaft to bearings) have to act against each other in order to reduce the overall axial value. In this case, axial loading of the bearing will be less, so their service life will be longer [5]. The directions of gear helical angles for single-stage gear reducers are usually adopted randomly. For example, pinion has right direction of helical angle and driven gear has left, but it can be reverse. However, for two-stage gear units, the direction of helical angle of the third gear (or fifth gear for the three-stage gear unit) is selected so that the axial force of the third (fifth) gear is reversed with the axial force of the second gear. Since it is used the same output gear pair for three-stage gear reducer, the third output gear pair should be made with opposite direction of helical angle in order to ensure the reduction of overall axial force on the fifth geared shaft. The production of two sets of output gear pairs (the largest and most expensive) is a major problem for most of smaller manufacturers of gear reducers. Therefore, they abandon this concept and produce only one set of output gear pair, so they produce only one direction of helical angles of the third gear pair. In this way, the axial forces of the fifth geared shaft are not reversed, so it is interested to consider the real impact of producing only one direction of output gear pair to the service life of the bearings on the fifth geared shaft of three-stage gear reducer [5, 6].

2. Problem Discussion
If single-stage gear reducer is observed, the output gear shaft rotates in the right rotation direction, looking toward the reducer (Fig.1). In that case, the axial force on the pinion acts from the motor and the force is held by the bearing from the electric motor since the gearbox is connected directly with special reducer motor [5]. Reducer electric motors are characterized by smaller flanges (in order to achieve smaller dimensions of motor gear units), they have smaller thickness of free end of shaft or have a hole at the front surface of the shaft (in order to mount small pinions), they have stronger bearings (in order to accept large force from the pinion) and they have better sealing with the motor shaft (in order to prevent oil leakage from the gearbox housing to the electric motor housing) [6].

In the case of two-stage gear units, all the first gear pairs are kept the same as in single-stage gear unit because there are a large number of them (in order to connect different pinions with different second gear, so to provide gear ratio according the standard progression R20). The direction of helical angles of the second stage gear pair (or the third gear pair, since the same gears are used in three-stage gear unit, just with opposite helical angle direction) is adopted in that way so the axial forces on the third (or fifth) geared shaft are in a reduction as much as possible (Fig.2).
In the case of three-stage gear units, the first gear pair is also kept the same as in single-stage gear unit, but the second and third gear pairs are adopted with such direction of gear helical angle that the axial forces on the third and fifth geared shaft are in reduction at the shaft as much as possible (Fig.3).

Figure 3. Graphic presentation of the axial forces action on the gears of a three-stage gear reducer where the output gears are with different directions of helical angles for adopted rotation direction.

In order to simplify the production and to reduce the number of necessary components, smaller manufacturers practice to use the third gear pair with only one direction of helical angle (Fig.4). In that case they could not provide the reduction of axial forces on the fifth geared shaft. Hence, the axial forces do not reverse each other on the fifth geared shaft of three-stage gear reducer. However, these forces are not large due to the small helical angle, but they are also not negligible due to the large torques on the fifth geared shaft. At the end, it is assumed that the sum of these axial forces will not be so large. The approval for such procedure is also reflected in the fact that the fifth geared shaft rotates significantly slower than the third geared shaft, which it certainly has more favourable impact on service life of the bearings [4, 5].

Figure 4. Graphic presentation of the axial forces action on the gears of a three-stage gear reducer where the output gears are with only one direction of helical angles (the axial forces are summarized) for adopted rotation direction.

Nowadays, the first gear pair usually provides gear ratios per standard progression R20, where the highest gear ratio value of some manufacturers reaches up to 15 [7]. Therefore, it is necessary to have two gears pairs, as the second gear pair in two-stage variant, which are the third gear pair for three-
stage gear unit. In that case it is possible to have another second (third) gear pair with lower gear ratio for two-stage gear units, where the overall gear ratio of two-stage gear reducers is in the range of 3-4 till usually above 50. The problem of this approach can obtain for small gear ratio of the second gear pair when the large torque “enters” to the gear reducer which requires stronger components. Therefore, it is often case to see only one output gear pair, but some first gear pairs are produced as multipliers, which allows having small gear ratios for two-stage gear unit. For three-stage version, it is necessary to have only one pair of gears as the second gear pair of reducer, where the highest gear ratio usually exceeds 300 [7, 8].

3. Solving the Identified Problem

If three-stage gear reducer is observed with the third output gear pair with both directions of helical angles or with only one (Fig.3 and Fig.4), it is evident that in the first case axial forces acts against each other and reduce the overall axial force on the shaft, while in the second case the axial forces are summarized and additionally support the bearings, depending on the rotation direction of the output shaft. Of course, the axial forces could be also summarized on the third geared shaft, but here they are larger due to the larger helical angle. The rotation of the bearings is considerably faster, so for these reasons summarizing of axial forces is done at the fifth geared shaft [8, 9]. The fourth and the fifth gear are mounted on this shaft. These gears have much smaller helical angle, but the torque is larger, so the forces on the gears have also large values. In the case of three-stage gear reducer with axis height of 115 mm, with output nominal torque $T_2N = 450$ Nm and gear ratios per each stage $i_{1/2max} = 6.36$, $i_{3/4} = 7.09$, $i_{5/6} = 5.6$ and efficiency of each gear pair $\eta = 0.98$, it follows that the torque of the fifth geared shaft for the most favourable loading case is calculated:

$$T_4 = T_5 = \frac{T_{2N}}{i_{5/6} \eta_{5/6}} = \frac{450}{5.6 \cdot 0.98} = 81.997 \text{ Nm}$$

(1)

![Figure 5](image_url)

Figure 5. Analysis of forces on the gears of the fifth geared shaft for adopted rotation direction and right direction of helical angle of the fifth gear, where the axial forces have partially reduction.
All necessary data about the gears are known: \( z_4 = 78, \ m_{n3/4} = 1.25 \text{ mm}, \ \beta_{3/4} = 20^\circ, \ d_4 = 103.757 \text{ mm}, \ F_{t4} = 1580.5 \text{ N}, \ F_{r4} = 612.2 \text{ N}, \ F_{a4} = 575.3 \text{ N}, \ z_5 = 10, \ m_{n5/6} = 2 \text{ mm}, \ \beta_{5/6} = 15^\circ, \ d_5 = 20.705 \text{ mm}, \ F_{t5} = 2984.5 \text{ N}, \ F_{r5} = 2122.2 \text{ N} \ [10, 11]. \)

If analysis of forces in vertical and horizontal plane is observed for the case that axial forces partially reverse each other and that left bearing (A) accepts the overall axial force (Fig.5), it follows that the reaction of the supports are \( F_A = 3694 \text{ N}, \ Z_A = 1547 \text{ N}, \ F_B = 5326.3 \text{ N}, \) so the calculated service life of the bearing A designated by 6303Z is \( L_{hA} = 20200 \text{ h} \) and the bearing B designated by NUP 2203 is \( L_{hB} = 20200 \text{ h} \) for the lowest speed [12]:

\[
n_4 = n_5 = \frac{n_{em}}{i_{1/2\max}} = \frac{1450}{6.36 \cdot 7.09} = 32.2 \text{ rpm}
\]

Considering the forces on the fifth geared shaft in the case the axial forces are summarized (Fig.6), it follows that the reaction of the supports are \( F_A = 3553.6 \text{ N}, \ Z_A = 2697.5 \text{ N}, \ F_B = 5805.8 \text{ N}, \) so the calculated service life of the bearing A is less due to larger axial force \( L_{hA} = 10850 \text{ h} \) and the bearing B is \( L_{hB} = 16500 \text{ h} \) for the same rotation direction and the same lowest speed as in previous case [10, 11].

![Figure 6](image)

**Figure 6.** Analysis of forces on the gears of the fifth geared shaft for adopted rotation direction and left direction of helical angle of the fifth gear, where the axial forces are summarized.

If it is observed the case with opposite direction of rotation, the analysis of forces for the case that axial forces partially reverse each other is shown in Fig.7. The reaction of the supports are \( F_A = 4113.5 \text{ N}, \ Z_A = 2697.5 \text{ N}, \ F_B = 2755 \text{ N}, \) so the calculated service life of the bearing A is \( L_{hA} = 17000 \text{ h} \) for the lowest (the most favourable) speed. Since the support force in the bearing B is much lower for this rotation direction, its service life is not problematic and it is higher than \( 10^3 \text{ h} \) [10, 11, 12].

Observing the analysis of forces on the fifth geared shaft for the opposite direction of rotation and the case the axial forces are summarized (Fig.8), it follows that the reaction of the supports are \( F_A = 4426.2 \text{ N}, \ Z_A = 2697.5 \text{ N}, \ F_B = 2729.3 \text{ N}, \) so the calculated service life of the left bearing is less than required \( L_{hA} = 8130 \text{ h} \). Service life of the right roller bearing is also higher than required, so it is satisfied for this way of shaft loading.
Figure 7. Analysis of forces on the gears of the fifth geared shaft for opposite direction of rotation and right direction of helical angle of the fifth gear, where the axial forces have partially reduction.

Figure 8. Analysis of forces on the gears of the fifth geared shaft for opposite direction of rotation and left direction of helical angle of the fifth gear, where the axial forces are summarized.
According to this analysis, it can be noticed that the service life of the bearings is not affected too much with the direction of axial forces. Service life of the left bearing is lower when the axial forces are summarized, but it is not great difference when the axial forces reduce each other. Decreasing of helical angle value of output gear pair could be interesting for reducing the axial forces on the fifth geared shaft. Since the helical angle of the output gears is less, the axial force on the fifth gear will be lower: \( z_4 = 78 \), \( m_{n3/4} = 1.25 \text{ mm} \), \( \beta_{3/4} = 20^\circ \), \( d_4 = 103.757 \text{ mm} \), \( F_{t4} = 1580.5 \text{ N} \), \( F_{r4} = 612.2 \text{ N} \), \( F_{a4} = 575.3 \text{ N} \), \( z_5 = 10 \), \( m_{n5/6} = 2 \text{ mm} \), \( \beta_{5/6} = 10^\circ \), \( d_5 = 20.308 \text{ mm} \), \( F_{t5} = 8075.1 \text{ N} \), \( F_{r5} = 2984.5 \text{ N} \), \( F_{a5} = 1423.9 \text{ N} \). If this analysis is calculated for both rotation directions and both helical teeth directions of the fifth gear, the service life of the ball bearing will be satisfied in all loading ways of the shaft [10, 11, 12].

4. Results of the Calculation

On the basis of implemented analysis and calculations, it can be concluded that service life of the bearings is pretty similar for different loading ways. Service life of the right roller bearing is not threatened by any rotation direction or direction of helical teeth, so it is always higher than required. The left roller bearing of the fifth geared shaft is problematic since it is mounted in the housing wall where much larger bearing of the output shaft is situated, so there is no place for adopting stronger bearing.

For the present situation of output gear pair and helical angle \( \beta_{5/6} = 15^\circ \), there is a case when due to helical angle direction and rotation direction, left roller bearing can not reach required service life. However, if helical angle value is reduced \( \beta_{5/6} = 10^\circ \), axial loading of the bearing will be lower and its service life will be satisfied for any loading way of the fifth geared shaft (Table 1).

Table 1. Support forces and service life of the left bearing of the fifth geared shaft for both rotation directions and both helical teeth direction of the fifth gear.

| The way of loading | Forces in the left support and service life of ball bearing if helical angle is \( \beta_{5/6} = 15^\circ \) | Forces in the left support and service life of ball bearing if helical angle is \( \beta_{5/6} = 10^\circ \) |
|--------------------|-------------------------------------------------|-------------------------------------------------|
| Right direction of rotation of output gear, where the axial forces have partially reduction | \( F_{rA} = 3694 \text{ N} \); \( L_{hA} = 20200 \text{ h} \) | \( F_{rA} = 3733 \text{ N} \); \( L_{hA} = 23700 \text{ h} \) |
| Right direction of rotation of output gear, where the axial forces are summarized | \( F_{rA} = 3553.6 \text{ N} \); \( L_{hA} = 2697.5 \text{ N} \); \( L_{hA} = 10840 \text{ h} \) | \( F_{rA} = 3642.3 \text{ N} \); \( F_{rA} = 1999.1 \text{ N} \); \( L_{hA} = 15200 \text{ h} \) |
| Left direction of rotation of output gear, where the axial forces have partially reduction | \( F_{rA} = 4113.5 \text{ N} \); \( L_{hA} = 17000 \text{ h} \) | \( F_{rA} = 4228.5 \text{ N} \); \( L_{hA} = 16500 \text{ h} \) |
| Left direction of rotation of output gear, where the axial forces are summarized | \( F_{rA} = 4426.2 \text{ N} \); \( L_{hA} = 2697.5 \text{ N} \); \( L_{hA} = 8130 \text{ h} \) | \( F_{rA} = 4431.4 \text{ N} \); \( F_{rA} = 1999.1 \text{ N} \); \( L_{hA} = 11400 \text{ h} \) |

5. Conclusion

Based on the carried out analysis, it follows that the adopted directions of helical teeth on the fifth geared shaft do not affect much the service life of bearings. Therefore, it is completely justified to manufacture only one output gear pair with only one helical teeth direction. First of all this procedure is justified for small manufacturers of gear reducers, but also some large manufacturers use this way of producing.

By producing the output gears with smaller value of helical angle, it is possible to reduce axial forces and to reduce the axial loading of the fifth geared shaft and the bearings, which means longer
service life of the bearings. It is very important since the possible space in housing wall is very limited and it is not possible to mount stronger bearing.

Using a simple calculation, that all manufacturers of gear reducer have, it can be easily determined the maximal torque at the output shaft of reducer, and that all components can transmit this load, where the most loaded bearings can reach the projected service life of 10000 h (industrial bearings).

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