The Influence of the Bearing Lifetime on the Performance of Universal Gear Drives with High Gear Ratio Values

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Abstract. The problem of defining the load (nominal torque on the output shaft - T_{2N}) of universal gear drives depending on the size of the gear ratio is analysed in this paper. It is logical that the load capacity of gear drive depends on the weakest gear component. Since the gears are the most expensive components of gear unit, it tends to maximize their performance. However, for low gear ratio, i.e. for high speeds, the bearings often limit their load capacity since the same bearings are used in all transmission ratios because it is not practiced to oversize the bearings at low speeds. Nowadays, when high values of gear ratio are used, it is interesting to consider the dependence of the nominal torque at the output regarding to gear ratio and operating life of the unit.

1 Introduction

Nominal torque, i.e. load carrying capacity, not only for universal gear drives, is limited by the load carrying capacity of the weakest component in the gear unit. Since the gears are the most expensive components, it is trying to maximize their use, so the gears are usually the elements that limit load carrying capacity of gear drive. That means the other components can transfer somewhat higher load [1-3].

However, the load carrying capacity of the bearings, in some cases, can also affect the load capacity i.e. nominal torque of gear reducer [4, 5]. Within the same axis height of universal gear reducer, the same bearings are used for all values of gear ratios. Changing of gear ratio causes the changing of speed of shaft and bearings. In such a way, it consequently changes the operating life of the bearings [6, 7]. Since optimal operating life of the bearing is usually adopted as 10,000 hours (five years of operating, with fifty working weeks in a year and forty working hours per a week), the bearing should be calculated in that way to provide expected lifetime for all, or at most, gear ratio values [1-3]. Nevertheless, since nowadays the gear ratios are changed in wide range, usually 1:10, it appears the bearings will be highly oversized if for the highest speed the bearing lifetime should be satisfied, so at least 10,000 operating hours. Therefore, the rotation is usually calculated with some mean speed value, so that the bearings are slightly oversized for low speeds, while the load carrying capacity, i.e. nominal torque is reduced in order the lifetime of the bearing must achieve projected lifetime of 10,000 hours. This approach can be noticed at all gear reducer manufacturers [8, 9]. This paper analyses the possibility of solving this problem particularly for the gear drives with higher values of gear ratio that are nowadays applied at almost all modern solutions of gear drives.

2 Problem description

During the design of universal gear reducer, calculation is started from projected load capacity whose numerical value is, as a rule, adopted from a standard progression R20. Regarding to the size of gear reducer, it increases with the grow progression factor $q_T = 2$ [8, 10, 11]. This means these values are integer numbers. When individual components of gear reducer are designed, the maximum load values that can be transferred are defined for each component. The smallest value of these partial loads represents the actual load carrying capacity of the gear drive for each value of gear ratio and within the each size of gear reducer, so that the progression factor is $q_T \approx 2$. These actual values of load capacity can be slightly higher in order to use the available resources of gear reducer. Also, the values can be less in order to avoid premature failure and thus not to shorten the lifetime of the gear reducer.

As already mentioned, the limiting parameter of gear drives with small values of gear ratio, i.e. high speeds, are usually bearings whose the lifetime is calculated according to following expression [2, 4, 6]:

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$$L_h = \frac{10^6}{60\,n}\left(\frac{C}{F}\right)^{\alpha} \quad (1)$$

If the bearing operating life should be 10,000 hours, the permitted force on the bearing can be calculated as:

$$F = C\sqrt[\alpha]{\frac{100}{60\,n}} \quad (2)$$

This relatively short operating life is adopted justifiably since the most bearings operate longer than projected operating life; some of them three time longer. Also, stronger gear reducer is usually adopted, i.e. actual service factor of the selected gear unit has to be the same or higher than the required value of the service factor, which also causes the longer bearing operating.

Since the load of the bearing depends on the torque, and for output shafts it also depends on the permitted overhung and axial forces, it follows that permitted loads of the bearing directly affects the load carrying capacity of gear unit, i.e.:

$$T_{2N} \approx \frac{K}{\sqrt[\alpha]{n}} \quad (3)$$

where:
K – constant,
α – exponent which value is equal 3 for ball bearings, and 3.33 for roller bearings.

If it is supposed that the ratio of the highest and lowest number of revolution is 10 [11, 12], it indicates that the load capacities will vary by almost 2 times, which is very high. However, in real operating, this difference is not so great, since the reduction of the gear ratio, for almost the same value of nominal torque, affects that the other components in the gear reducer can be higher loaded. Also, the bearings can be higher loaded, which certainly have an effect in reducing of their service life, so that the difference in capacity is significantly lower (slightly higher than 1).

3 Solving of the identified problem

If load carrying capacities of single stage gear reducers are observed (Table 1), increasing the speed of output gear, i.e. reducing the value of the gear ratio evidently affects the increasing the load carrying capacity of the gear transmission at the beginning, but then its value stagnates [13, 14].

Table 1. An overview of the load carrying capacities values of the gear pairs within a single stage gear reducer [13].

***h* =100 mm, *a* = 100 mm**										
u	9.88	8.89	7.90	7.09	6.33	5.62	4.93	4.50	3.94	3.50
***T* $_{N2}$, Nm**	254	275	323	374	459	555	536	622	623	599
u	**3.14**	2.78	2.52	2.26	2.03	1.81	1.59	1.42	1.26	1.12
***T* $_{N2}$, Nm**	**536**	703	696	697	681	656	618	569	521	502

However, if the load capacity of single-stage gear units is considered, it is evident that the load capacities (Tables 2, 3 and 4) are in decreasing with increasing the speeds, although the gears could be able to transmit a higher torque in these cases. This reducing the capacity is due to the bearings are not able to carry so much loads [15-20]. It can be also noticed that load capacity is reduced for low speeds (high transmission values), but it is a consequence of using smaller module to enable production of small pinions which enable high transmission values [11, 13].

Table 2. Nominal output torque values of single-stage gear units of manufacturer SEW for particular values of the gear ratio for different axis heights and center distances [15, 16].

SEW, RX87, *h* =100 mm, *a* = 93,5 mm								
u	8.65	7.63	7.20	6.45	5.56	5.07	4.50	3.78
***T* $_{N2}$, Nm**	139	149	140	192	225	250	290	305
u	**3.48**	**3.09**	**2.76**	**2.48**	2.15	1.93	1.60	1.39
***T* $_{N2}$, Nm**	**405**	**405**	**405**	**405**	385	355	315	290

Table 3. Nominal output torque values of single-stage gear units of manufacturer NORD for particular values of the gear ratio for different axis heights and center distances [17,18].

NORD, SK51E, *h* = 112 mm, *a* = 106 mm							
u	13.27	9.09	6.82	5.50	4.04	**3.31**	2.86
T_{N2}, **Nm**	290	320	400	220	410	**492**	456
u	2.5	2.06	1.82	1.64	1.52	1.44	1.24
T_{N2}, **Nm**	426	382	341	325	310	305	275

Table 4. Nominal output torque values of single-stage gear units of manufacturer SIEMENS for particular values of the gear ratio for different axis heights and center distances [19, 20].

SIEMENS, E88, *h* =100 mm, *a* = 99 mm									
u	10.33	9.46	8.42	7.69	7.07	6.53	6.06	5.65	5.11
T_{N2}, **Nm**	230	210	245	245	290	300	280	320	370
u	4.70	4.23	3.90	**3.30**	2.88	2.45	2.09	1.71	
T_{N2}, **Nm**	385	400	385	**450**	435	420	420	365	

If the analyzed gear transmissions are considered, it is evident that the maximum values of the load capacity are obtained for the gear ratio about 3.3. When using the dependence defined by the equation (3), it follows that the values of the nominal torque of the first (Table 2) and the last manufacturer (Table 4) correspond to this equations. It is interesting to note that all three manufacturers have similar values of gear ratios of the transmissions with the highest load carrying capacity.

According to analysis of the implemented solutions, it is evident that for low gear ratios, when the load carrying capacity is smaller, the gear pairs with lower capacity, with smaller modules could be used. However, it is not practiced, since it requires a larger number of tools for their production (milling and grinding), as well as more frequent adjustment of machines when changing tools. This certainly affects the cost of production.

When analysed first gear pair is built in two- or three-stage gear unit, its impact on load carrying capacity of the gearbox is considerably reduced. The first gear pair is much less loaded than their actual load capacity since output gear pair is used with high gear ratio in two- and three-stage gear units (Fig. 1). The first gear pair from the first larger size of single-stage reducer is used in two-stage gear unit. The same output gear pair is used in two- and three-stage gear units, so their load capacities are the same and do not depend on load capacity of the bearing.

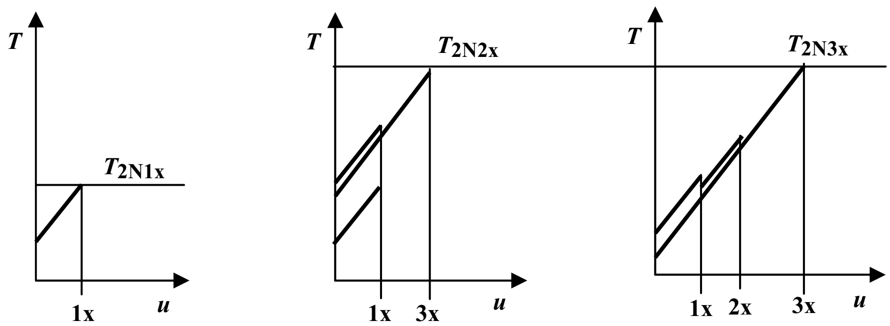

Fig. 1. Graphic description of the load of particular gear pair within single-stage (a), two-stage (b) and three-stage (c) gear unit.

4 Conclusions

Analysing helical gear drives of different manufacturers and comparing their technical characteristics, firstly nominal output load and gear ratio, certain conclusion can be defined regarding the bearings lifetime. Based on this analysis, it is evident that load capacity of gear reducer is limited by the permissible loading of the bearing, i.e. its lifetime. That means load capacity of gear unit will be limited at high speeds, i.e. for small values of gear ratio. This is quite justified, since if the projected lifetime of the gear unit should be the same at low and high speeds, it means the bearings would be greatly oversized, and in some cases, due to the size of the bearing, they could not be fitted into the universal gear unit.

This problem is particularly identified for gear units with high gear ratios, which today has become quite common case for almost all gear manufacturers. Namely, the ratio in the output gear pair (input and output speeds) could be very high, sometimes often over 10 times between input and output speed. This requires either stronger bearings or to reduce the load capacity of the gearbox for a small values of gear ratio (for high speeds). In such transmissions the lifetime could be almost two times higher with a lower speed. Reduced load capacity of the gearbox for small gear ratios does not make problem since small gear ratios are less demanded within the single-stage gear units. This transmission can be also realized by using the belt drives. If it should be realized by gear pairs, it could be used two-stage gearbox with low gear ratio instead of single-stage gear unit. If two-stage gearbox does not satisfy, three-stage gearbox can be used, or if it is a case with low transmission in three-stage gearbox, then four-stage gear unit can be used, etc.

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