Innovative design solutions of universal motor gearbox with helical gears

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Abstract. *Due to very force competition, all producer, not only manufacturers of gearboxes, have been forced to constantly improve their products. This has led to the harmonization of the technical characteristics of their gear units, even though they are not yet defined by the standard. Modern solutions of universal helical gearboxes are characterized, first of all, by large torque capacity and high values of gear ratio in the frame of relatively small overall dimensions of the gear unit. This paper provides an overview of common activities undertaken by manufacturers of universal helical gearbox to improve technical characteristics of their products.*

1 Introduction

Due to very strong competition, all manufacturers of universal gearboxes seek the way how to create some competitive advantage of their products to improve their product placement. Many manufacturers try to obtain customers by short-time delivery (mostly within 72 hours), while other manufacturers try to attract customers by the high quality of their products. [1, 2] However, some manufacturers who attract customers by low product price (achieved by either cheaper labour, or a more suitable conceptual solution, either slightly lower quality of their reducers). Of course, some manufacturers try to attract customers by an attractive appearance with the same or even higher quality of their gear units.

Each of these actions has certain effects, and as a result the producer is able to survive on the market.

2 Problem description

The main problem that occurs during improving characteristics of universal gearboxes is how to achieve larger load torque capacity and higher value of the highest gear ratio in the same time within the same axis height. Also, the problem is how to reduce the number of components, how to facilitate the way of installation, how to increase universal using of gearboxes, how to make them cheaper and more attractive [3, 4]. The installation of signal and diagnostic components is also one of the challenges.

3 The ways of solving the problem

Within the same axis height and the same axial distance, increasing of torque capacity can be achieved by gear module increasing (size of the gears) which directly causes the teeth number reduction of both gears. Therefore, this action is possible only for small or medium gear ratio values, but with the strengthening of the other gearbox components. However, for large values of gear ratio, since minimum teeth number is 7 or 8, increasing the module is not possible, so these gear ratios are defined by slightly lower load capacity. Another way is to increase the axial distance (for all gear ratios) which certainly results in higher production costs because larger gear wheels are used.

Transferring older gear manufacturing technology to modern production lines provides production of small pinions with only 7 or 8 teeth which give significant positive effect in this improving (Fig. 1-1,2). Increasing of only axial distance can give similar results (Fig. 1-3), but this requires additional expansion of gear unit housing as well as widening of the openings in the housing (to mount large gear wheel). In the case of applying small pinions and larger axial distance, it is possible to significantly increase the largest gear ratio values (Fig. 1-4), which is most commonly done today [3, 4].

For assembling the large gears into the gearbox housing, it is necessary to open the housing from the top to insert the gear (Fig. 2). In this way, the stiffness of the housing is somewhat reduced, so it is necessary to search a way for the structural solution to increase its stiffness. Increasing the housing stiffness can be done by using a robust cover, by using special shape of housing (Fig. 2-1), or by opening only slow-motion housing chamber (Fig. 2-2).

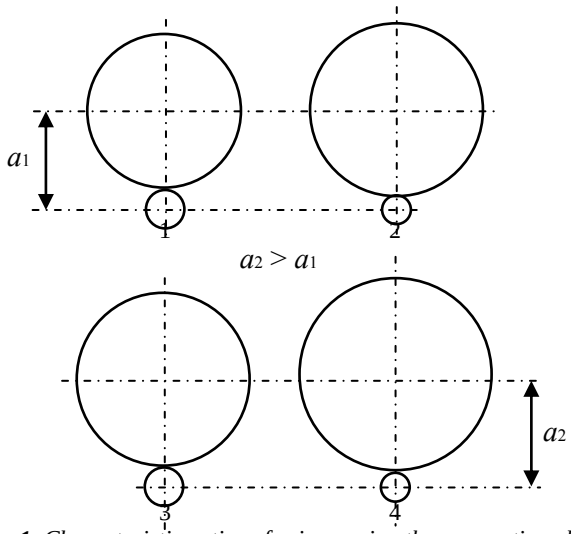
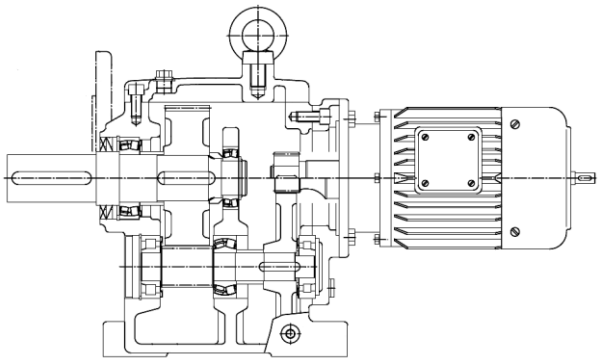


Fig. 1. *Characteristic actions for increasing the gear ratio value: reduction of pinion diameter (1-2), increasing of axial distance (3), reduction of pinion diameter and increasing of axial distance (4).*



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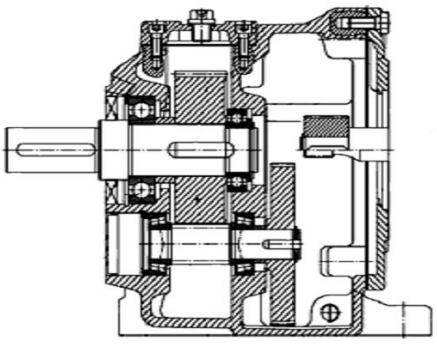

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Fig. 2. *Structural solution of two-stage motor gearbox with top openings on both chamber (1) and with top opening on slow-motion chamber (2), solution of company Nord [5, 6].*

Since within the same axis height and same mounting dimensions, gear units have installed gear wheels with larger axial distance, so they could provide high value of gear ratios. Therefore, the shape of the housing should be modified with additional side extension (Fig. 3) which provides more place for larger gear wheel diameter and increased stiffness of gearbox housing.

In order to reduce the diameter of pinion gear on the shaft of the electric motor, it is necessary to press the pinion into the hollow shaft of the electric motor (Fig. 4). It should not be pressed on the shaft of the electric motor, as it has been the case so far.

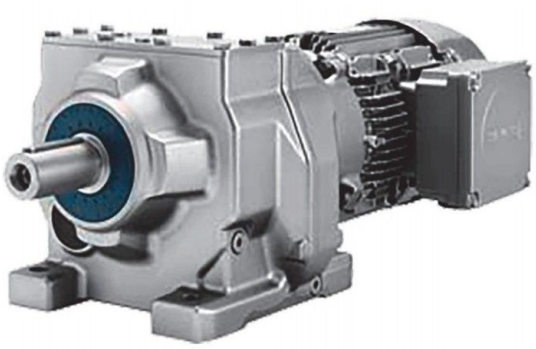


Fig. 3. *Structural solution of three-stage motor gearbox with additional side extension, solution of company Siemens [7].*

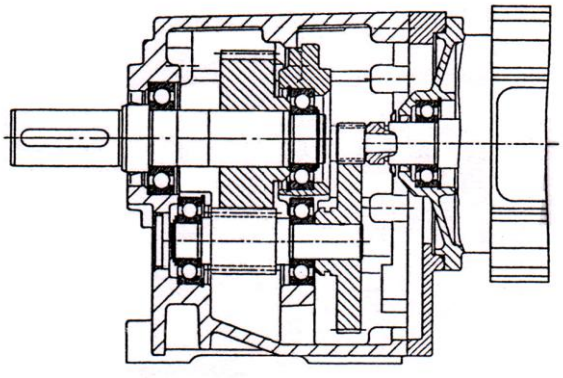


Fig. 4. *Structural solution of two-stage motor gearbox with pressed pinion inside the hollow shaft of the electric motor, solution of company Lenze [8, 9].*

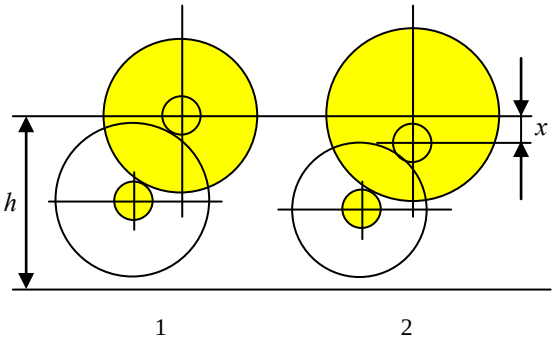


Fig. 5. *Schematic display of the influence of gear distance increasing of output gear pair on the reduction of the driven gear diameter of the first pair and obtained axial distance between input and output shaft (x): (1) existing classic solution and (2) the innovative solution.*

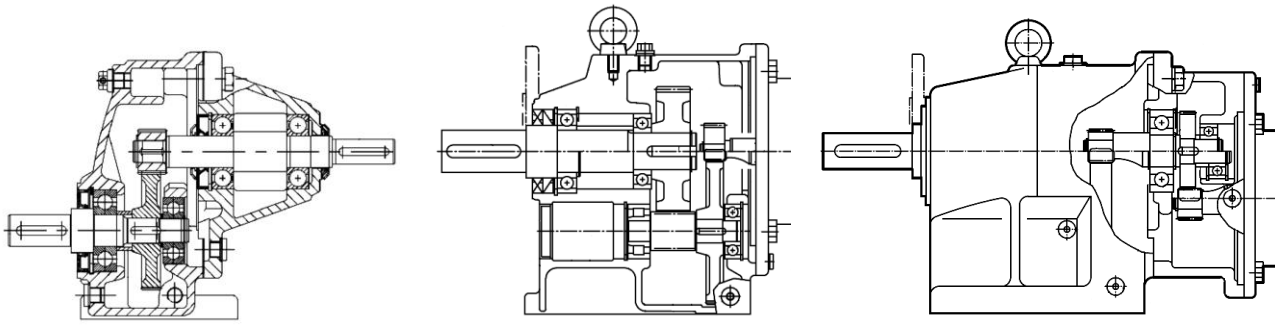
Increasing the gear distance is required, not only to increase gear ratio but also that torque appeared inside the unit is less as possible. The gear ratio value of output pair must be high to reduce the torque inside the unit which depends on output nominal torque. In that way, significant strenghtness of inside components is not required. Increased gear distance of output gear pair for two-stage and three-stage gearboxes, due to the limited space of axis height, requires a reduction of the driven gear diameter of the first gear pair (Fig. 5-2). If the concept of coaxial input and output shaft has to be maintained, the gear ratio of the first pair will be reduced. However, modern gear units left the concept of the coaxial unit, so the gear distance of the first pair is reduced (Fig. 5-2) and thereby the gear ratio of that pair and the whole unit is increased. [3, 4]

Increasing of the load capacity (T_N) of gear unit certainly requires the reinforcement of all gearbox components, but first of all the output shaft and supported bearings. Further increasing of the load capacity of the gear unit requires finding better materials for gears. While further increasing of the gear ratio per gear pair is limited by the fact that gear units with high gear ratio always use large (expensive) gears. However, in certain segments of gear ratio, it is not justified, since competition can offer a cheaper solution with smaller gear distances. The present values of gear ratio can currently be considered as a limit beyond which it should not go. Technical characteristics of the present solutions of universal gearboxes of leading manufacturers presented in Table 1 confirms this statement.

Table 1. *Overview of maximum values of gear ratio and output load capacities (i_{max} / T_N) of gearboxes of leading manufacturers. (Torque value is not related with a given gear ratio)*

Axis height-*h*, mm	Nord [5, 6]		Siemens [7]		SEW [10, 11]	
	Two-stage	Three-stage	Two-stage	Three-stage	Two-stage	Three-stage
90	72.38 / 200	343,92 / 200	41.40 / 140 55.95 / 200	217.89 / 140 235.29 / 200	28.37 / 130 - / 200	135.09 / 130 134.82 / 200
115	54.41 / 430	402.80 / 450	52.14 / 320 59.99 / 450	280.89 / 320 307.02 / 450	33.79 / 300 - / 450	176.88 / 300 186.89 / 450
130	56.65 / 610	362.43 / 640	60.97 / 600	328.97 / 600	- / 600	199.81 / 600
140	26.86 / 820	395.46 / 870	54.47 / 840	330.23 / 840	- / 820	195.24 / 820
180	42.67 / 1600	439.77 / 1700	57.36 / 1680	311.60 / 1680	34.40 / 1550	246.54 / 1550
225	42.76 / 2900	456.77 / 3300	51.17 / 3100	348.88 / 3100	32.05 / 2560	289.74 / 3000

Innovation done by most of the manufacturers of gearboxes is reducing the number of the components or at least reducing the number of expensive components. This is important, especially for smaller manufacturers, since the overall production costs are reduced. This innovation provides such a concept of the gear unit, as well as the whole row of gearboxes, that will ensure lower costs of manufacturing. Small manufacturers usually produce single-stage or two-stage gearboxes and with their combination get three-stage or four-stage gear units (Fig. 6).



1 2 3

Fig. 6. *Innovative solution of single-stage (1), two-stage (2) and three-stage gearbox – built by connecting single-stage and two-stage gear unit (3), solution of company Nord [5, 6].*

Large leading manufacturers produce single-stage gearboxes and two-stage and three-stage units assembled in universal housing (Fig. 7). By their combination, they obtain four-stage, five-stage or six-stage gear units. Of course, these manufacturers produce more complex and expensive solutions, although there are manufacturers who produce two sets of the same height of reducer and in such way, they successfully compete with both manufacturers, although this production is most complex and expensive.

Since reducing the production costs can certainly be achieved by reducing the number of expensive components, some smaller gearbox manufacturers produce only one type of universal housing, but with the flange. In that way, using the screw connection and flange, they can connect another housing when they require lager stage variant (Fig. 8).

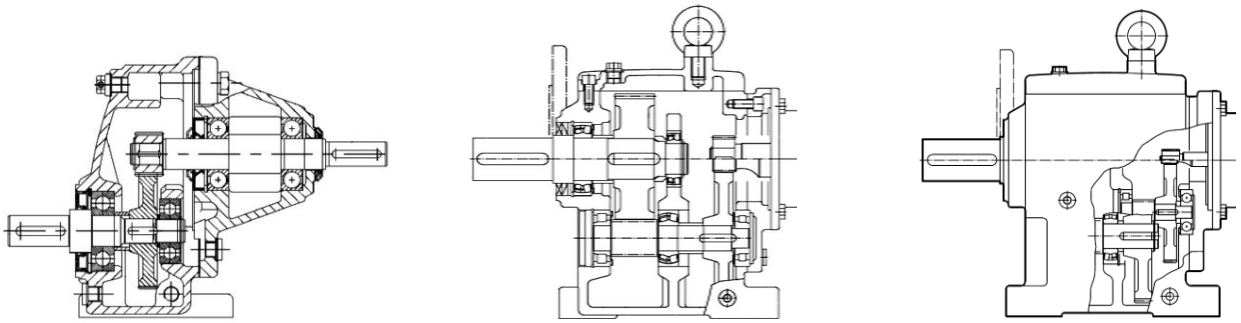


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Fig. 7. *Innovative solution of single-stage (1), two-stage (2) and three-stage gearbox – built in universal housing for two-stage and three-stage gear unit (3), solution of company Nord [5, 6].*

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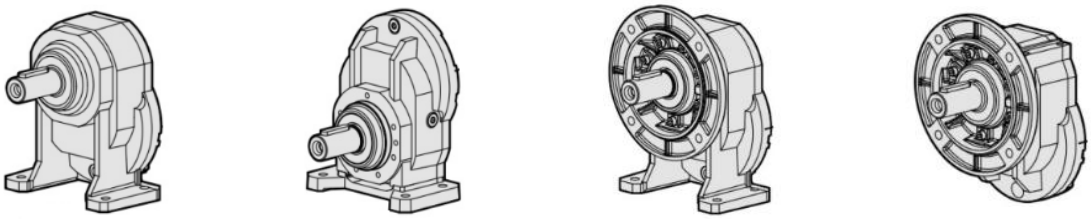
Fig. 8. *Innovative solution of gearbox built in universal housing with flange, (1) solution of company Robus [12], (2) solution of company MSF [13].*



1 2 3 4

Fig. 9. *Innovative solution of single-stage gearbox: (1) foot-mounted and upper output shaft position, (2) foot-mounted and lower output shaft position, (3) foot-mounted with flange and (4) flange gearbox, solution of company Motovario [14].*

The greater adaptability of gear units and its components can be achieved first of all by using different mounting shapes and positions (Fig. 9).

Special attention is paid to the possibility of delivering motor gear unit with standard IEC electric motor (Fig. 10-1) which provides greater adaptability of components, i.e. providing motor is much easier, or in case the customer wishes to purchase and install electric motor separately (Fig. 10-2).

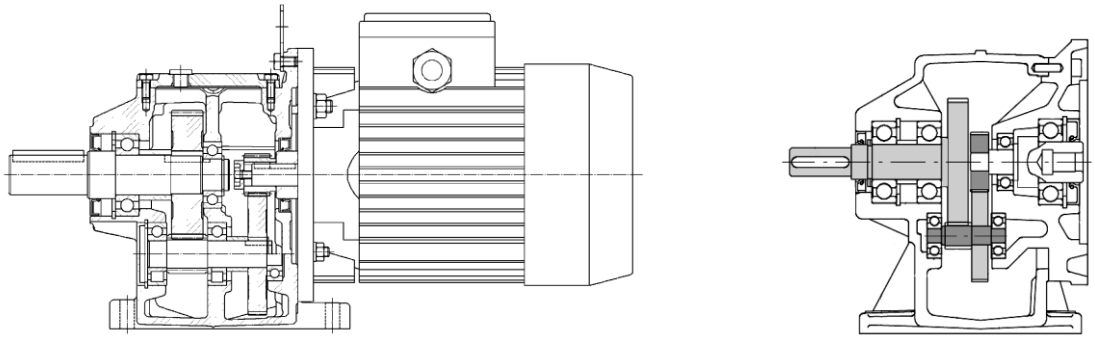


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Fig. 10. *Innovative solution of motor gearbox: (1) solution of company Rossi [15], (2) solution of company Pujol [16].*

Many manufacturers of universal gearboxes want to additionally expand their production program by introducing so-called shaft-mounted gear units (Fig. 11). The installation of these gearboxes is much easier. They do not need large flanges and axial aligning of an output shaft of reducer with the input shaft of the operating machine. Shaft-mounted gear units offer more compact design, although in some cases they can support input shaft of connected machine.

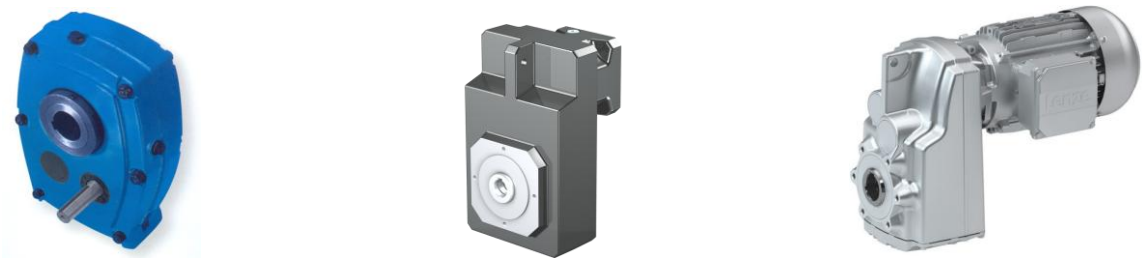

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Fig. 11. *Innovative solution of shaft-mounted gearbox with axial mounting: (1) solution of company Renold [17], (2) solution of company Stöber [18], (3) solution of company Lenze [8, 9].*

Prettier design and more attractive form are always important to improve their placement on the market because the customers like to see the attractive product (Fig. 12 and 13), than the product which is not.

Many manufacturers paint their gearboxes in industrial colours, but also in other colours if there is a special customer's request. These special requirements are additionally paid to customers.

Especially, it should be noted that the largest number of universal gearboxes are today supplied with the so-called regulated drive which adjusts the rotational speed to the specific technological requirements. Usually, these drives have integrated so-called soft starts, which avoids the use of expensive (hydrodynamic) couplings and instead of them they use ordinary couplings.

1 2 3

Fig. 12. *Innovative solution of two-stage universal gearbox: (1) solution of company Sesame [19], (2) solution of company Bege [20], (3) solution of company Aokman [21].*

1 2 3

Fig. 13. *Innovative solution of three-stage universal gearbox: (1) solution of company PGR [22], (2) solution of company ASC [23], (3) solution of company AutomationDirect [24].*

Conclusions

Based on the given analysis, it can be concluded that modern solutions of universal gearboxes have fairly uniform technical characteristics. That means these gear units have axis heights produced in a standard row of R20/2, nominal output torques are given in a row R40/6, while the largest gear ratios are given up to 15 for single-stage gearbox, about 50 and more for two-stage gearbox, and about 400 and more for the three-stage gearbox. Additionally, some large manufacturers of universal gear units produce two gear pair sets for the same axis height (large load capacity with lower gear ratio, and smaller load capacity with high gear ratio) in order to successfully compete with small manufacturers of gearboxes. Also, all their gear units are characterized by high quality and attractive form. Such arrangement solutions ensure that almost all customers requirements are fulfilled. However, due to the gearbox market saturation, all the above measures will not produce satisfactory results if it is not required according to the regulations of Industry 4.0. It is necessary to create, so-called, smart product, i.e. gearboxes that will incorporate different sensors, for example, the sensor of temperature, the regulator of oil level, vibration sensor, etc. These additional regulators and sensors will notify the operator or the operating system in the event of reaching limit value. In the case of reaching critical value, they will shut off the driving system and notify the operator accordingly.

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