INFLUENCE OF SHAFT HEIGHT ON TECHNICAL CHARACTERISTICS OF UNIVERSAL HELICAL GEAR UNITS

Milan RACKOV, Ruzica TRBOJEVIC, Sinisa KUZMANOVIC
Faculty of Technical Sciences, Novi Sad, Serbia & Montenegro, kuzman@uns.ns.ac.yu

Shaft height (distance between axis of the output shaft and mounting surface), through overall dimensions of gear units, has a great influence on technical characteristics of universal speed reducers. It is defined by standard that values for shaft height are being selected from series R20. Since those values are too dense, most of the gear units manufacturers usually use series R20/2 or R10. However, standard doesn't specify values of technical characteristics for particular shaft height, and because of that there are different values of gear ratio and nominal torque on the gear units market.

1. Introduction

Basic mechanical characteristics of universal speed reducers (nominal torque - load capacity and speed ratio) significantly depend on shaft height of gear unit. Therefore, it is defined by standard that shaft height takes values from the standard series R20. However, since this series is relatively dense which increases production costs, manufacturers of speed reducers usually adopt shaft height values from the series R20/2. These numbers were from the standard series R10 before, but nowadays, in order to improve mechanical characteristics of speed reducer, first bigger series R20/2 is adopted. Of course, some intervalues are inserted in particular segments of shaft heights, in order to satisfy customers demands and to efficiently eliminate concurrents. This partly disorganizes series order, but it is undoubtedly rational move. This paper deals with analysing of influence of gear units shaft height on gears diametars and other characteristics of one-stage speed reducer.

2. Shaft height influence on diametar of driven gear

One-stage speed reducers with helical gears are usually manufactured that driven gear is positioned under the pinion. So, it follows that the shaft height (distance from ground surface to axis of driven gear) is important data when defining technical characteristics of gear unit. Therefore, driven gear dimension depends on thickness of housing wall, manufacturing precision and module of gear pair. Considering that manufacturing precision is pretty high, the biggest possible outside diameter of driven gear d_{a2} will be adopted for concrete value of shaft height h = 90 mm. Distance between ground surface and outside surface of driven gear is ought to be as smallest as possible. Because of this a groove below driven gear should be made from the inside of housing. The wall thickness on that place has to be at least 5 mm and 2 mm is for free space between housing and driven gear. This means that the biggest possible radius of driven gear is 7 mm smaller than shaft height. Values of speed ratio are bigger if diameter of driven gear is bigger, so it is adopted that dimension of driven gear is: r_{a2} = 90 – 7 = 63 mm, i.e. d_{a2} = 126 mm (fig. 1).

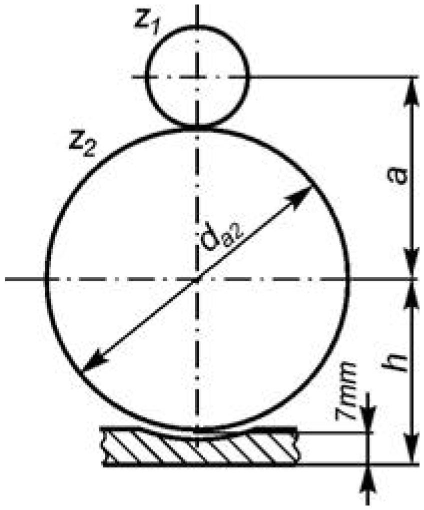


Fig. 1 Influence of shaft height and thickness of housing wall on diametar of driven gear for one-stage gear unit

Since module also influences on gear dimension, necessary teeth numbers z_2 will be determined and influence of helical angle ß = 20, 25 ? 30° will be analysed for several standard values of module m_n = 1, 1.25, 1.5 ? 2 mm. Outside diameter of driven gear is calculated by equation:

$$d_{a2} = d_2 + 2 \cdot m_n \cdot (1 + x_2) = \frac{m_n \cdot z_2}{\cos ß} + 2 \cdot m_n \cdot (1 + x_2) \qquad (1)$$

wherefrom it follows that teeth number z_2, for the case of the biggest possible diameter of driven gear and without addendum modification $?_2 = 0$, is given by expression:

$$z_2 = \cos ß \cdot \left(\frac{d_{a2}}{m_n} - 2 \right) = \cos ß \cdot \left(\frac{126}{m_n} - 2 \right) \qquad (2)$$

The biggest possible teeth number of driven gear is obtaining for the smallest module values and the smallest helical angles (fig. 2), which also ensures the biggest speed ratios.

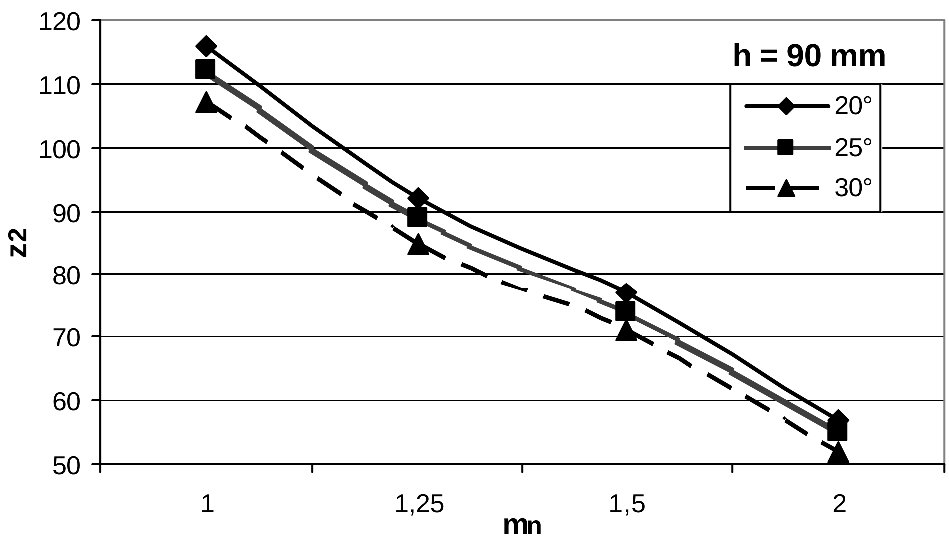


Fig. 2 Influence of shaft height, module and helix angle on teeth number of driven gear in universal one-stage gear unit

3. Influence of gear unit concept design

Speed ratio pretty much depends on applied type of connection between pinion and electric motor or, between pinion and shaft of electric motor for motor gear units. The pinion can be mounted on shaft of standard IEC electric motor (fig. 3?), or on shaft of special gear units motor (fig3b). Advantage of standard gear units is that they have smaller price, but their shaft diameter is too big, and also pinion dimension. Shafts of special gear units motors are thiner, so smaller pinions can be placed on it obtaining bigger speed ratios. Even smaller dimensions of pinion are possible by solution with pressed pinion in hollow shaft of motor (fig. 3c) and solution with impressed bush on the shaft of standard motor (fig. 3d). The last mounting solution is often used, because it enables application of cheaper electric motors and bigger speed ratio values. Also, there is a solution with geared motor shaft, but this increases production costs.

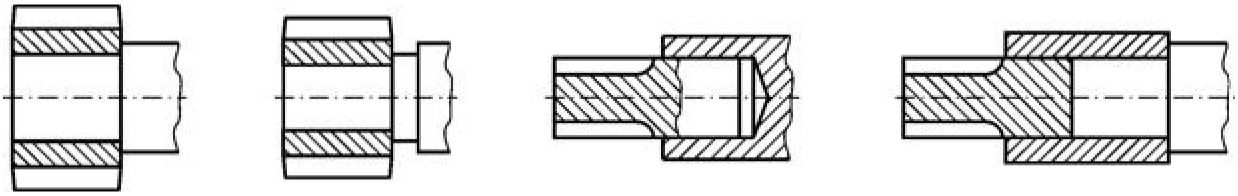


Fig. 3 Typical concept design solutions of mounting pinion on shaft

Using this latest concept of mounting pinion on shaft, diameter of pinion can be very small and thus speed ratios are increased, especially when using gears with extra small teeths number (z_1 = 7 - 10).

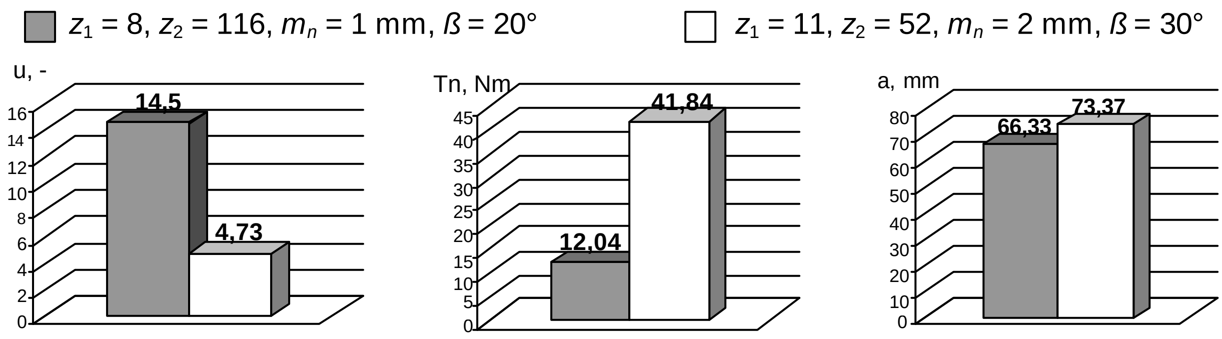
Introducing gear module and considering its influence on load capavity of gear unit, a range of results is being obtained. These results help designers to easily select particular range of load capacities and speed ratios, with which they want to have good competitivness with their reducers.

4. Calculation of output characteristics of speed reducer for different geometry of gears

In further calculation speed ratios and torques of gear pair are analysed for extra small teeth number of pinion z_1 = 8, 9, 10 ? 11 and for biggest possible diameters of driven gear, as previously calculated. For these teeth numbers, module values m_n = 1, 1.25, 1.5 ? 2 mm and helix angle *ß* = 20, 25 ? 30° will be combined. It's adopted 1450 min^{-1} revolution number, and gear width is always the same 12 mm. Comparing obtained values, the most optimal combination will be recommended.

When manufacturing gears with small teeth numbers, profile shift values have to be within specific boundaries. Lower boundary value is boundary of undercutting, and upper boundary value depends on minimal alowable gear width on outside diameter, watching out not to occur sharp teeth on the top. Since the pinion is with extra small teeth number, the gear with 8 teeth and helix angle 20° ? 25° must have some small undercutting. This undercutting is minimal and it is permissive, because it doesn't have big influence on load capacity of gear. The pinion with 8 teeth and helix angle 30°, as gears with more teeth can be manufactured without undercutting.

Combining specified parameters, extreme possible values of speed ratio and load capacity are obtained for analysed shaft height 90 mm. For relative small difference of axis distance values, i.e. overall dimensions of gear unit, great difference are obtained between minimal and maximal speed ratio and load capacity (fig. 4).



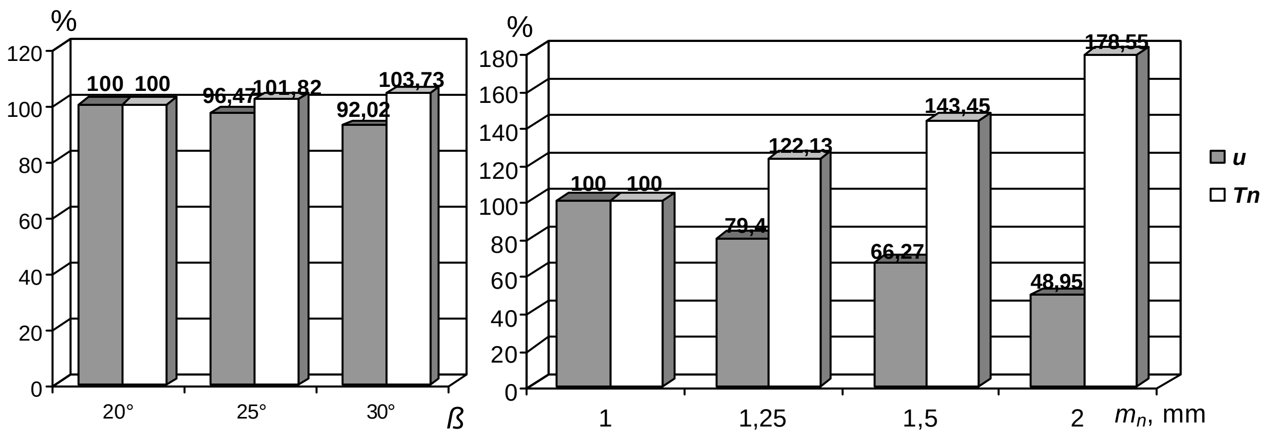
?) b) c)

Fig. 4 Minimal and maximal values of speed ratios (?), output torques (b) and axis distances (?)

Speed ratios and torques are in indirect proportion, so for the analysed one-stage gear reducer with shaft height 90 mm, it can be realised big speed ratio 14.5, and in the same time small output torque 12.04 Nm. Speed reducer with the same shaft height can have even 3.5 times bigger output torque, but also speed ratio just 4.73. All these output characteristics can be realised for axis distance difference of just 6 mm.

Speed reducers manufacturers tend to make reducers with the biggest possible values of both speed ratio and output torque. Since these characteristics are in diametrical relation, some compromise have to be achieved and the most optimal values of technical characteristics of reducer have to be found out.

The calculation is based on well-known gears kinematics and strenght equations for the previously specified parameters. Obtained results show that gear module has much more influence on speed ratio and output torque than gear helix angle.



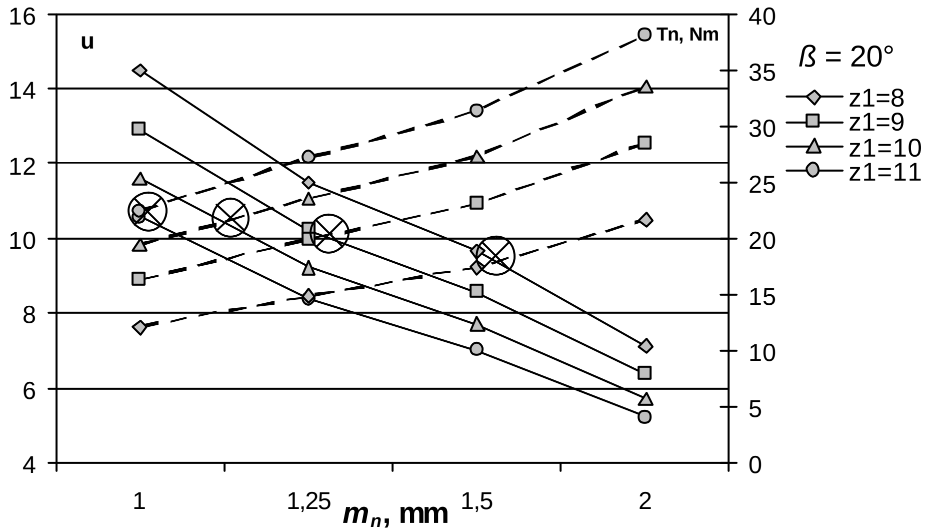
a) b)

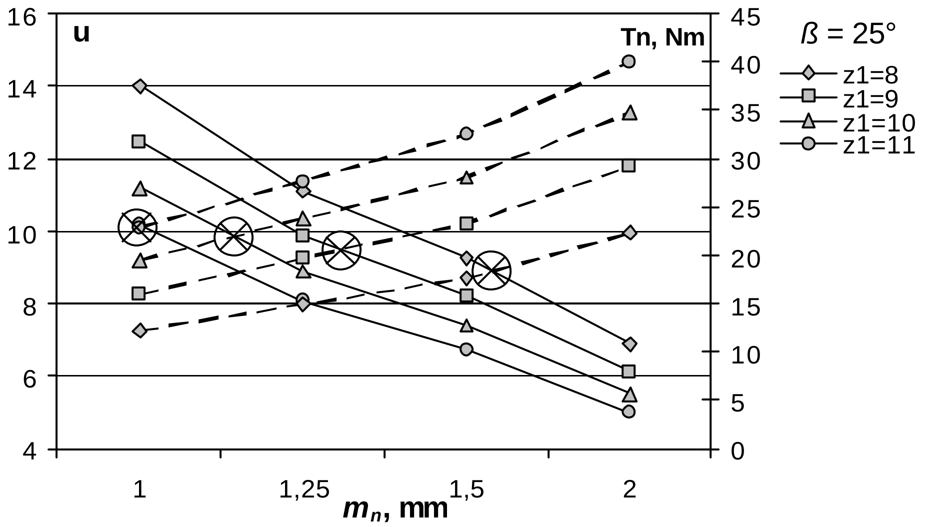
Fig. 5 Influence of gear helix angle (a) and gear module (b) on speed ratio and output torque of one-stage gear units with shaft height h = 90 mm

Speed ratio values are decreasing a little, with increasing gear helix angle. Thus, with increasing helix angle per 5°, speed ratio decreases approximately 3.5 - 4 %, and output torque negligibly increases per about 1.8 %, no consideration on gear module and teeth number (fig. 5?). On the contrary, increasing gear module just for 1 mm, load capacity of gear unit can be increased for 78 %, and speed ratio can be smaller for a 50 % (fig. 5b).

Pinions with extra small teeth numbers can not transfer big torques. Big speed ratios can be realised with them, but these pinions have small load capacity. Since gear helix angle negligibly influences on load capacity increasing and speed ratio decreasing, gear module value is very significant for output characteristics of speed reducer, so their influence will be analysed further.

It is very hard to find out and to adopt parameters that gives both characteristics the biggest possible, because when load capacity is greatly increased, speed ratio is significantly decreased. On fig. 6 in diagrams, speed ratios are presented with continous lines and torques with dashed lines. These diagrams show that some high values of speed ratio and torque can be achieved with teeth numbers 11, 10 and 9 and with smaller gear module. Although load capacity increases with helix angle increasing, analysis show that optimal values of output characteristics are obtained for smaller gear helix angles.





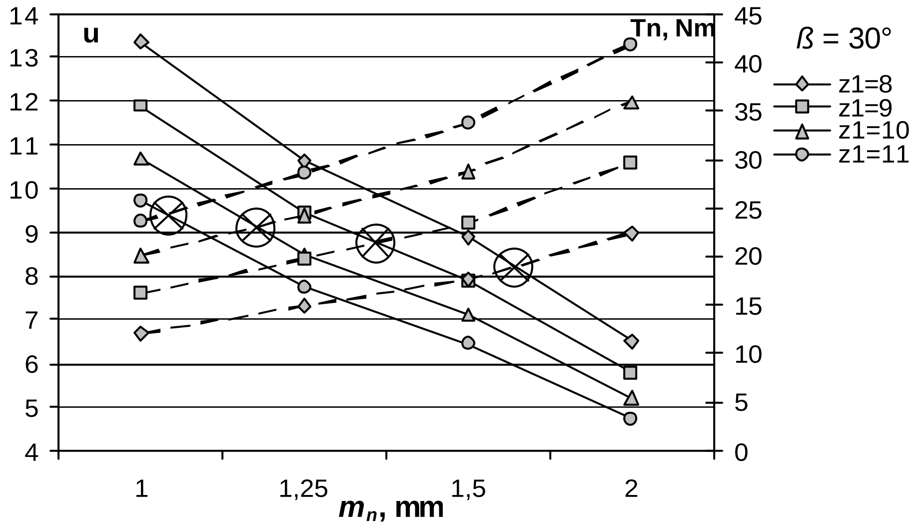


Fig. 6 Influence of gear module and teeth number on output characteristics of gear unit with shaft height h = 90 mm

Based on carried out analysis of calculation results, a few optimal solutions, that provide approximately same high both speed ratio and output torque, are suggested for implementation (fig. 7).

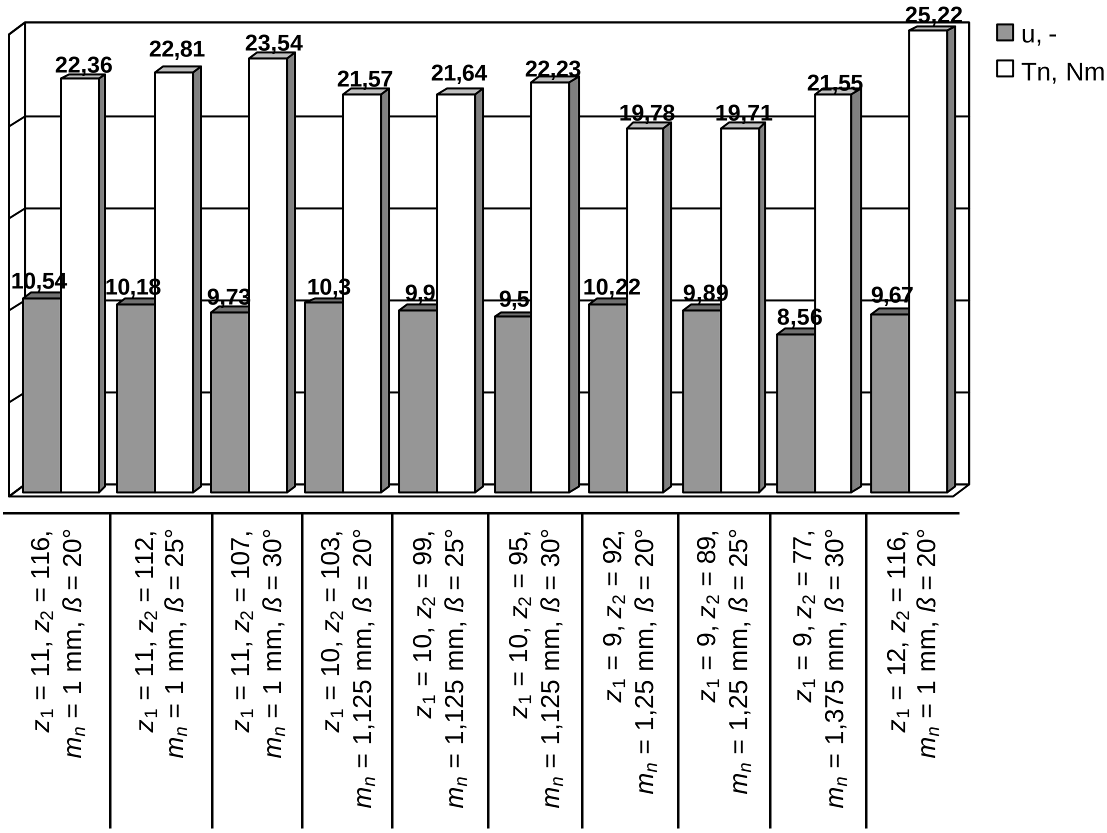


Fig. 7 Suggested optimal solutions of output characteristics of speed reducers with shaft height h = 90 mm

For the practical implementation of one-stage gear reducer with shaft height 90 mm, some optimal approximately same values of *u* and T_n could be achieved by pinion with 11 teeth, gear module 1 mm and helical angle 20°, 25° ? 30°, or by other pinion with z_1 = 10,

m_n = 1 - 1,25 mm and ß = 20°, 25°, 30°. These optimal values can also be obtained by pinion with 9 teeth, but with module 1,25 mm, and even bigger for helix angle ß = 30°.

Comparing values of output characteristics of suggested solutions, it can be concluded that bigger output values are obtained for bigger teeth number of pinion z_1 = 11 and smaller module. It's also proved that pinion with 12 teeth and module1 mm could realise optimal values of output parameters (T_n = 25.22 Nm and u = 9.67). Values of output torque continually increase for teeth numbers 13, 14 and more, but speed ratio values are rapidly decreasing, so they can't achieve optimal output values.

Range covered by these optimal values is range of average speed ratios and torques values, and the customers are usually the most interested in these reducers. Speed reducers with extreme values of output characteristics, e.i. big speed ratios and small output torque, or big torques and medium speed ratios, are rarely requested by the customers. When designing these reducers, just one criteria is substantial: the biggest possible speed ratio or the biggest possible load capacity.

5. Influence of range covered by universal gear units

Gear units can be devided into three groups, in dependence of output characteristics values: gear reducers with optimal values of output characteristics (range ?, fig. 8), gear units with extreme values of load capacity (range ?, fig. 8) and gear units with extreme values of speed ratios (range ?, fig. 8).

When calculating and designing gear units with extreme output values, designers tend to achieve the biggest possible load capacities and speed ratios. Thus, bigger load capacity of reducer can be achieved by applying quality materials and machining, but also with increasing gear module and helix angle. Extreme values of speed ratios can be obtained by decreasing gear module and teeth number of pinion. Extra small teeth number can be achieved, as already explained, by impressed pinion in hollow motor shaft or in a bush which is mounted on the shaft of standard motor. Of course, it influences on increasing of overhang lenght, and that also negatively affects on load capacity of gear pair.

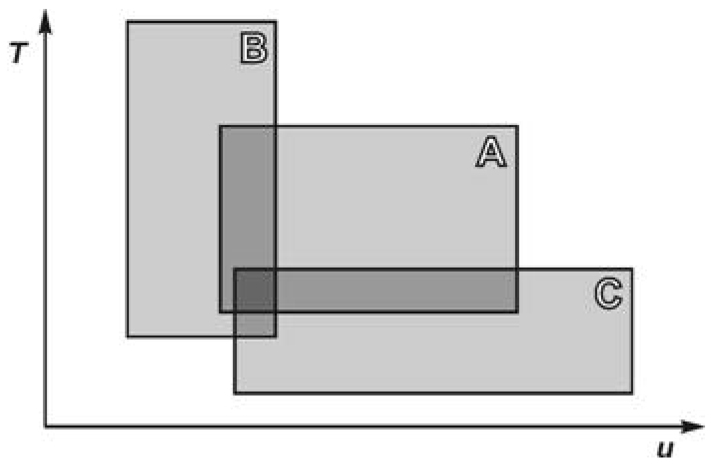


Fig. 8 Typical ranges of speed ratios and load capacities of universal speed reducers

Great manufacturers of helical gear units provide average values of speed ratios and load capacities, so if smaller manufacturers want to be concurrents, they have to produce gear units with extreme values of technical characteristics, i.e. big speed ratios and small output torque, or big torques and medium speed ratios. However, in recent years, struggle for the costumers is growing. Great manufacturers of gear units want to cover additional ranges with extreme values. Therefore they offer two gear sets for the same gear unit housing, so, with lower prices, they don't leave any uncovered range of technical characteristics for their concurrents.

6. Conclusion

Output parameters of universal gear units depend, above all, on their shaft height, so reducers are arranged by this criteria in catalogs and brochures. Shaft height is limiting factor for diameter of gears, and such also for the output characteristics of gear reducers. Analysing and optimizing parameters of gears and their influence on load capacity and speed ratio, for the same shaft height, it is concluded that it shouldn't use pinions with extra small teeth number to achieve optimal output characteristics. Also, manufacturing of these small pinions is very expensive. For the analysed shaft height 90 mm, it is confirmed that the most optimal adapted load capacity and speed ratio is obtained for 11 teeth of pinion and gear module 1 mm. Bigger modules influence on speed ratio decreasing, for the shaft height is constant, and teeth numbers influence on load capacity decreasing.

Literature

1. KUZMANOVIC Sinisa: *Universal Helical Gear Units*, Faculty of Technical Sciences, Novi Sad, 1998
2. MILTENOVIC Vojislav: *Machine Elements*, Machine Faculty, Nis, 2004
3. OGNJANOVIC Milosav: *Machine Elements*, Naucna knjiga, Belgrade, 1999