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POSSIBLE WAYS OF REDUCING THE NUMBER OF GEARS IN UNIVERSAL GEAR UNITS

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Summary

This paper analyzes possibilities of reducing the number of necessary gears in the family of universal motor gear reducers with helical gears, since both the production and storage of a large number of different gears cost a lot and impose a great burden for any gear manufacturer, as it can be seen from literature [1,2] that focuses on this problem. The paper particularly emphasizes the necessity of narrowing down the assortment of gear reducers and the possibility of changing the design solution between the pinion and the electric motor as they represent the basic possibilities for reducing the number of necessary gears. The paper also points out the need for a special selection of preferred gear ratios and corresponding gears as one of the possibilities for reducing the total number of gears. This can certainly result in faster delivery of a gearbox with the preferred gear ratio.

Key words: *pinion, gear wheel, universal motor gear reducer*

1. Introduction

Today, professional literature does not consider the problem of determining the necessary number of gear pairs or gear wheels in the family of universal motor gear reducers. This is not considered to be a serious problem which should receive closer attention because as many gears as we think are needed are accepted in a given case. However, determining the number of gear pairs is a very important and interesting issue, which must receive close attention. It is not only because the number of gears seriously affects the costs of production [3] and the cost of storage of gears, semi parts and spare parts in particular, but also because the number of gears strongly affects the delivery time of new or rebuilt reducers. Today, when delivery times of universal gear reducers are very short (sometimes only 72 hours) and when their price is very low (due to fierce competition), great attention must be given to this problem, because gears often take up to 50% of the total reducer production costs.

2. The aim of the study

The objective of this paper is to present basic possibilities and ways of reducing the number of necessary gears in the family of universal motor gear reducers [4, 5]. This is essential because the production costs of a number of different gears, as well as their storage costs [1, 6], are extremely high and represent a great financial burden for each manufacturer of gear reducers.

3. Description of the problem

A very large number of different factors affect the total number of necessary gear pairs or gears. Primarily, it is the company policy of the manufacturer [7] which defines the segment of the market on which the company wants to put its gear reducer (Fig. 1). If the company wants to cover a larger segment of the market, it is necessary to produce more sizes of the reducer [8], which certainly requires a larger number of different gear pairs, and that increases the costs of production. Depending on the product range of gear reducers, manufacturers are usually divided into three different categories: large manufacturers, that meet almost total demand of the market, medium manufacturers, covering the highest demand area as well as a very small lower demand area, and small manufacturers, that are specialized in, for example, very small reducers, or very big reducers, or gear reducers in the highest demand, where they quite successfully compete with large manufacturers, thanks to some of the benefits of their products.

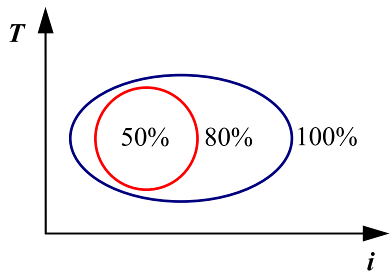

Fig. 1 Demand for gear reducers on the basis of gear torque and ratio

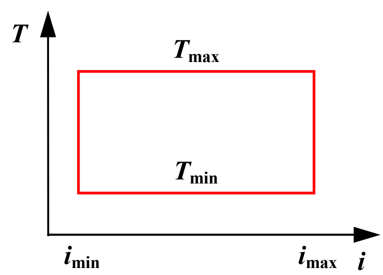

Fig. 2 The area of torques and gear ratios that will be covered with the projected family of gears

The offered supply should be constantly analyzed within the defined segment of the market, especially for reducers of extreme sizes, and the justification of their presence in the production programme should be observed. The reduction of a large number of gears can be achieved by eliminating unprofitable gears of extreme sizes. Of course, sometimes the result of this step is that customers cannot buy all the sizes they need from the same suppliers they usually want to. However, this is not a common case, so this solution is mostly justified for small and medium gear reducer manufacturers.

The number of gear pairs (gears) is to a large extent defined (limited) by the range in width (gear ratio) and in height (output torque values), Fig. 2 [4,5,9].

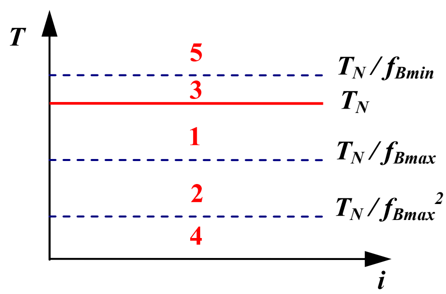

Fig. 3 Application fields of the universal gear reducer according to torque values: 1 - the main area, 2 – the additional area, 3 – the critical area (used only for short drives), 4 - the area where the reducer is oversized, and 5 – the critical area where the breakdown of the reducer happens immediately

The next factor that strongly affects the number of gears is the value of the highest gear ratio and nominal torque. Unfortunately, there are no standards which give information about these data, so the manufacturers of universal gear units define their own nominal torque (Fig. 3) and the highest values of the gear ratio within the standard recommended shaft height, taking care to meet $q_T = q_L^3 = f_{B\max} = 2$, where q_T – is the factor of increase in torque, q_L – the factor of increase in linear dimensions (shaft height in this case) and $f_{B\max}$ – the highest value of the service factor.

The solutions of leading manufacturers (for example SEW [10]) are usually adopted as a “standard” and almost all manufacturers comply with it in order to provide mutual interchangeability of their gear reducers. This standard has a relatively high load capacity and medium gear ratio (Fig. 4) [4, 11]. Smaller manufacturers of gear reducers have immediately noticed the “weakness” of such an order and developed a gear reducer with a lower nominal torque and a high gear ratio, so that in certain market segments they can successfully compete with large manufacturers of gear reducers. Of course, shortly after that, the majority of large manufacturers responded by providing two sets of gears within the same housing, one set with high load capacity - low gear ratio and the other with small capacity - high gear ratio. Although this dramatically increased the number of gears for those manufacturers, it prevented the competition from offering something that the leading manufacturers did not have.

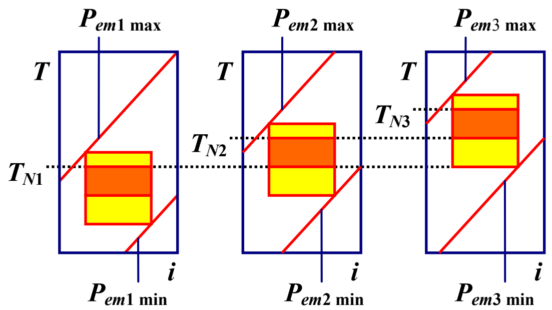

Fig. 4 Torque and gear ratio areas covered by particular manufacturers of gear reducers

Introduction of a middle size of gear reducers (T_{NM}), which is between two standard sizes of gear reducers, is a special reason that influenced the increase in the number of gears (Fig. 5) [5, 9].

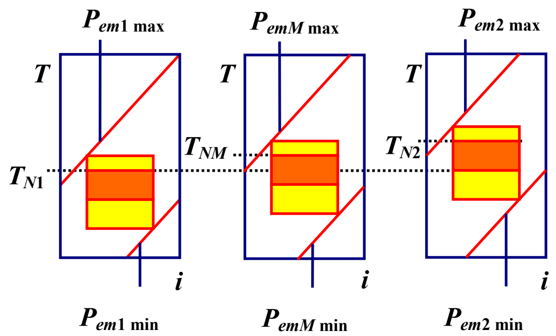

Fig. 5 Torque and gear ratio areas covered by certain sizes of gear reducers by introducing an additional size

There is a recommendation that the shaft height of the universal gear reducer should be adopted from the numbers of the standard R20 series. Since it is a very dense series, in the beginning, the numbers from the R10 series, which was not as dense as the R20 series, were adopted as the shaft height. However, the R10 series was soon abandoned and a bit larger shaft heights were adopted. These were from the standard R20/2 series, which had the same growth factor as the R10 series. With this new solution, the housing became a little higher and a slightly higher gear ratio could be achieved. In addition, stronger electric motors (with a larger flange diameter) could be mounted in this housing. With this new design, large manufacturers of gear reducers tried to get rid of the competition that was not able to invest in new tools. Today, in the area with the highest demand some manufacturers are introducing additional sizes (from the R20 series) in order to be able to offer a cheaper solution in certain market segments. Unfortunately, this new solution increases the number of necessary gears even more.

The adopted conceptual solution of the universal gear unit has a certain impact on the necessary number of gear pairs. Namely, universal gear reducers can be produced in various ways: as single-stage, two-stage, three-stage and multi-stage gear reducers. Single-stage reducers are usually made in a single gear housing. Two-stage reducers can be produced in a special housing for two-stage gear pairs, or in the universal housing for two-stage and three-stage gear pairs. Three-stage reducers can be produced in a special housing for three-stage gear pairs, or in the universal housing for two-stage and three-stage gear pairs, or by combining two-stage and single-stage housings, etc. Some manufacturers do not produce single-stage gear reducers, since there is a relatively small demand for them on the market. However, there are some manufacturers that produce single-stage reducers with a high gear ratio the value of which overlaps with the area of two-stage reducers, and thus they can successfully compete with two-stage reducers in a certain segment of gear ratio. Of course, there are some manufacturers that do not produce four-stage and multi-stage gear reducers. Regardless of the design, every multi-stage reducer has the first gear pair, the second gear pair, etc., so the number of gears does not depend on the concept much, but it depends a lot on the highest gear ratio, i.e. the nominal torque of the gear pair. If the gear ratio is high (and the capacity low), there is a larger variety of different gear ratios on offer, which is good and justified, but unfortunately it also results in a higher number of necessary gears.

The design solution of the gear reducer has great influence on the number of necessary gears. The number of gear pairs for the same shaft height of the housing greatly depends on the space available for the gears. Therefore, wider housings are used now, as they enable larger shaft distances for the same mounting dimensions of the housing. Additionally, the way of mounting the pinion onto the electric motor shaft also has a great influence on the number of necessary gears. Today, pinions are often either impressed into the shaft of the electric motor in order to obtain a high gear ratio, or they are placed on a special bushing mounted onto the electric motor shaft. The number of necessary gears also depends on the available technology. A higher gear ratio can be achieved with modern technology so that the pinions can have less than 10 teeth. Also, the concept of the parallel gear unit has been abandoned, and high and slow running gear chambers have been opened so that big gears can be placed inside, etc.

4. How the problems can be solved

The most important task, regardless of whether a manufacturer produces only single-stage gear reducers, is to define the magnitude of gear ratios and the number of gears (Fig. 6) of the first gear pair. The values of gear ratios are typically adopted from the standard R10 series. If the R20 series were to be applied, there would be too many first gear pairs, especially the pinions, which are made with various openings (so that they could be mounted on different sizes of electric motors) [12]. The highest value of the gear ratio is adopted depending on the available technology (the pinion with the smallest number of teeth) and the adopted way of mounting the pinion on the electric motor shaft. The pinion is usually mounted on the shaft of the electric motor. Such an approach limits the size of gears and thus the value of the gear ratio as well. If we want to use smaller pinions (at a high value of the gear ratio), the pinions must either be impressed in a special bushing mounted on the electric motor shaft, or in the shaft of the electric motor, or the electric motor shaft must be made as a gear shaft (which is the most complex and the most expensive solution). Until recently, the highest values of the gear ratio of the first gear pair were between 6.3 and 7.1 and nowadays they have increased to 8 and even up to 12.5. The choice of the highest gear ratio to be adopted depends on the adopted gearing concept (high gear ratios and a smaller load capacity or vice versa). However, as it has already been said, it is quite common that two sets of gears are offered for the same shaft height of the housing.

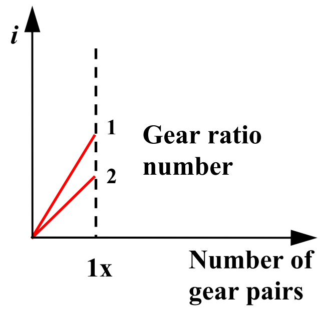

Fig. 6 Gear ratio distribution for one-stage reducer

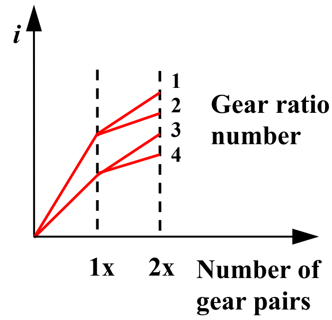

Fig. 7 Gear ratio distribution for two-stage reducer

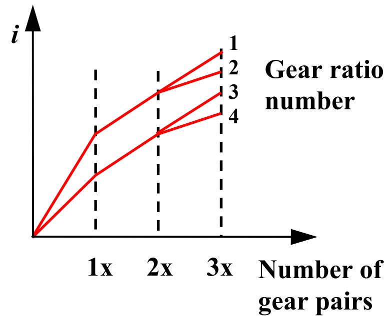

Fig. 8 Gear ratio distribution for three-stage reducer

For two-stage and multistage reducers, the gear ratio is offered according to the R20 series. Gear ratios for two-stage gear reducers are usually obtained in the combination with two second gear pairs (Fig. 7). Gear ratios for three-stage reducers are obtained in the combination of one second and two third gear pairs (Fig. 8), but it can also be done differently.

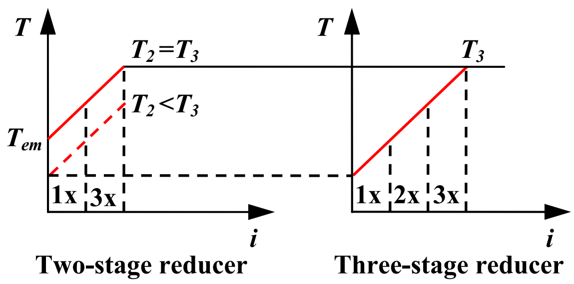

Fig. 9 Necessary load capacity of gear reducers for particular gear ratios of reducers

Based on the diagram of torque (Fig. 9), certain gear pairs of three-stage reducers are differently loaded. If we use the concept that two-stage reducers are manufactured in the special housing for two-stage reducers, and three-stage reducers are manufactured by combining a two-stage and a single-stage reducer, it follows that the first smaller size of the single-stage reducer will have to be used for the first gear pair of the three-stage unit, which is not usually a problem. However, the situation changes when the same housing is used for manufacturing two-stage and three-stage gear reducers (which happens more often), i.e. when the same output shaft and gear wheel are used for two-stage and three-stage units in order to rationalize their structure. These output shafts and gears will not be used rationally in the two-stage gear unit (if the first couples from the three-stage reducer are kept), or stronger first pairs must be used in the two-stage unit (which is the most common case), so that in the three-stage reducer the first pairs must be used from the first smaller two-stage unit.

Some manufacturers define the same load capacity for two-stage and three-stage gear units, while the others offer smaller load capacity not only because the output pairs in a two-stage unit rotate faster and thus bearings and gears do not allow such heavy load, but also because the same size of the electric motor and the same pinion i.e. the opening diameters in the pinions, should be used with all the stages (Fig. 10). This is certainly a justified solution and it should be applied [1,4]. Determining the number of necessary (different) pinions with various openings (only for those pinions that are mounted on the electric motor shaft), for the same gear ratio, is done according to the diagram of power shown in Fig. 11. This procedure depends on the size of the nominal torque and especially on the electric motor used (a standard IEC[1] motor or a special reducer motor), as well as on the size of the reducer flange. Based on this diagram (Fig. 11), it is defined for every gear ratio which electric motors it would be justifiable to connect with such a reducer, and also, openings in pinions and required flange diameters of electric motor are specified (if it is the case of special reducer motors), Fig. 12 [5].

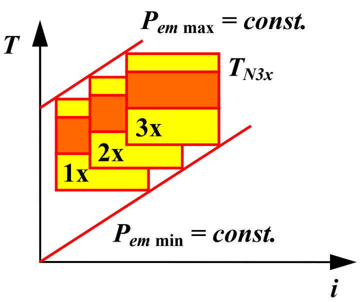

Fig. 10 Nominal torque and gear ratio areas of gear reducer covered by one-, two- and three-stage units for the same size of universal gear reducer

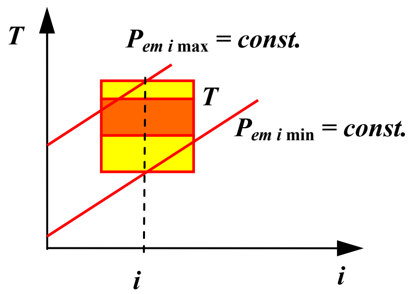

Fig. 11 Nominal torque changes depending on the size of reducer gear ratio (in logarithmic coordinates)

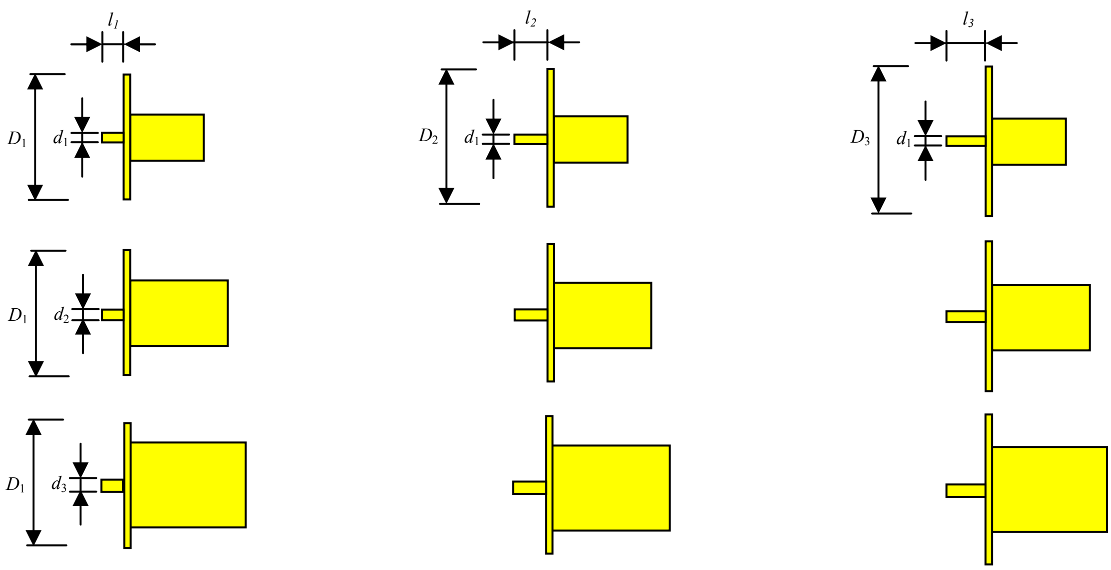

Fig. 12 Review of necessary installing dimensions of electric motors for certain sizes of gear reducers

[1] IEC motors – standard electric motors covered with IEC 60034 (International Electrotechnical Commission standard)

Since there is no standard in this field and if it is possible regarding strength, it is allowed to shift torque values up and down from the projected values. In the final determination of the torque value, the characteristics of competitive solutions must be taken into account, in order to provide mutual interchangeability of gear reducers [13].

The value of the output torque for each size of the gear ratio is defined separately, depending on the load capacity of gears, keys, shafts, bearings and housings. Some manufacturers produce the output pair with a different helical angle for two-stage and three-stage reducers, in order to decrease the axial force on the gear shaft of the output pair, which strongly affects the total number of gears. Other manufacturers use stronger bearings (even cylindrical roller bearings), that can take much larger axial force, and in that way avoid a large number of gears.

The way to obtain different gear ratios (the numbers from the standard R10 series) depends on the adopted concept of the motor mounting on the reducer housing. The tendency is to have fewer output gears which are large and expensive and more input gears which are small and inexpensive (although this is not the rule). If the pinion is not mounted directly on the shaft of the electric motor, it is not necessary to provide the pinion (for each gear ratio) with various openings, which reduces the number of gears directly. This is usually achieved by positioning one pinion with different bushings, which allows for the use of more first gear couples and less of the other gear pairs; it is usually only one or two pairs in each next gear stage. This approach can result in a reduction in production costs, even though the costs are increased due to the application of bushings or adapters for IEC motors.

Table 1 Typical values (R10) of gear ratios of the first gear couple for the same size of gear unit and possible mounting connections (hole diameters in the pinion) with characteristic sizes of electric motors

i	Sizes of electric motors			
	71	80	90	100
1.25	x	x	x	**x**
1.60	x	x	x	**x**
2.00	x	x	x	**x**
2.50	x	x	**x**	
3.15	x	x	**x**	
4.00	x	**x**		
5.00	x	**x**		
6.30	**x**			
8.00	**x**			

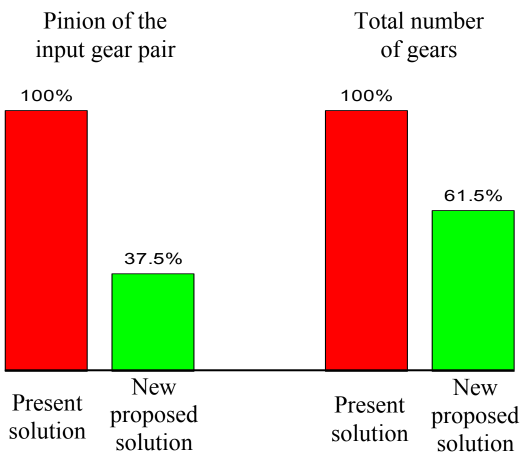

Fig. 13 The number of pinions of the input gear pair and the total number of gears in the present solution and in the new proposed solutions for three-stage gear reducers

If we take into consideration only one size of the three-stage gear reducer designed for installing only four sizes of electric motors (Table 1), it is evident that the pinion has to be made with different openings for particular gear ratios in order to be installed with certain electric motors. In the analyzed case, this means there should be 24 different pinions. If the pinions were made only with the largest hole for each gear ratio, it would mean that only 9 pinions would be enough. That is to say, the number of the pinions would be reduced by approximately 62%, or the total number of gears would be reduced by 33%, which is a significant reduction (Fig. 13). Of course, this approach requires having four shafts and four adapter flanges for IEC motors. However, the number of special reducer electric motors with different flanges would be reduced, i.e. only four standard IEC motors would have to be kept in stock, which justifies this new approach. An obvious example of the justification of this approach is the company PUJOL which applies it [10].

As it has been mentioned before, motor gear reducers can be produced with special reducer motors (which are characterized by special flanges, special diameters of the shaft end and stronger shaft bearings), but they can be also produced with standard IEC motors, which are mounted to the housing directly or through an adapter for IEC motors. Large manufacturers usually use special motors since they have many advantages (simpler, cheaper and more compact design, the possibility of achieving higher gear ratio, the possibility of heavier loading of the motor shaft and better tightness). Since large manufacturers buy large quantities of special motors, they get them quickly and at the cost of standard motors, so their way of manufacturing completely pays off. Also, large manufacturers usually have their own electric motor factory, so they usually do not have a problem with buying special motors.

Smaller manufacturers are forced to use standard IEC motors, mainly due to the price and the delivery time, and they try to compensate for all the advantages of the special motor by attaching the motor with a reducer in a suitable way. Since it is very difficult to compensate for all of the advantages of the special motor, we can see very different design solutions in practice.

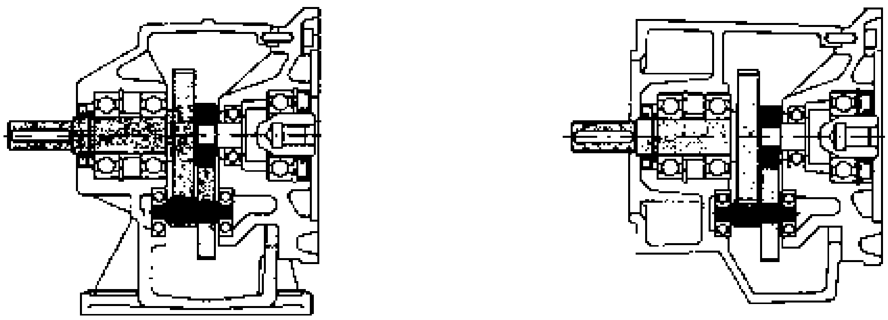

Fig. 14 A characteristic solution for the two-stage gear reducer with an adapter for IEC motors, manufacturer PUJOL

A successful example is the manufacturer PUJOL [10] whose production program has only gear reducers with an adapter for IEC motors and the classical output shaft (Fig. 14), but they also deliver motor gear units, i.e. they install standard IEC motors on their reducers with an adapter for the IEC motor.

This solution provides fast delivery of cheaper standard IEC motors and the number of pinions is largely reduced (only one hole size is used in the gear), while special flanges, special bushings and a pair of bearings are always delivered with the standard IEC motors. Of course, all this complicates the production, but for smaller manufacturers it is a secure way to reduce the number of gears and thus simplify the production.

Only four-poles (three-phase asynchronous) motors are considered in defining the required motor power, because they have the best starting characteristics and are the easiest to purchase. Different motors can be also delivered as the motor gear drive, but usually at a higher price.

In order to reduce the number of gears that need to be kept in stock, some manufacturers emphasize the preferred ratio, which they can offer immediately (these values are usually printed in bold in catalogues), while for other ratios they offer longer delivery times. This practice could be a solution for other manufacturers of gear reducers as well.

5. Conclusion

In the family of universal gear reducers, selecting the smallest possible number of gear pairs and gears is of utmost importance. Reducing the number of gears can be achieved in the following ways: by narrowing down the range of reducers, by modifying the method of mounting the pinion on the shaft of the electric motor, by modifying the way of combining gears, by emphasizing preferred gear ratios and corresponding gears which are used within certain gear ratios, by making a more rational choice of the electric motor size (power), etc. A particularly interesting option for reducing the necessary number of gears is using adapters for IEC motors. This solution enables a large reduction in the number of different gears and electric motors that need to be kept in stock. This is favourable for faster delivery and easier and faster service (or repair) of gear reducers.

In fact, instead of three types of gear reducers, only two types are made, and instead of five or six types of electric motors (sizes of flange on the motor), only one type of electric motor is used (the standard IEC motor with its flange). It is certainly a great advantage that should not be ignored by smaller and medium manufacturers of gear reducers.

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