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PERFORMANCE OF HEAVY-DUTY PLANETARY GEARS

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ABSTRACT

Wind energy is widely spread in the world owing to the shortages of fossil energy and its environmentally friendly character. The economy of wind turbines can be increased using large equipment producing electric power up to 5 MW. Large wind turbines need heavy-duty drive systems with great power/weight ratio, high efficiency and high gear ratio. There were performed theoretical investigations on heavy-duty planetary gears being able to transfer the high power from the wind turbine to the generator.

KEYWORDS
Planetary gear, differential gear, wind turbine

1. INTRODUCTION

Use of wind energy is not only an environmentally friendly technology, but the huge wind farms having many wind-turbines produce electric energy economically. The development of wind energy industry in Europe is one of the quickest among industry branches. More and more off-shore wind turbines are planted along the sea shores exploiting the beneficial wind flow producing twice more electric energy than the wind turbines an the land According to the expectations the off-shore wind farms will produce at least 20 000 MW electric power. Such a large scale plans can be coming true only planting more and more huge wind turbines reaching the power as high as 5 MW

The main structure elements of wind turbines are rotors, generators and drive systems transmitting power from the wind wheels to the generators. The drive system increases the slow rotation speed of the rotor up to the rotation speed being necessary to the proper operation of the generator. The main parts of the drive systems are tooth gear boxes, which are often planetary gears being able to meet the following strict requirements stated against the drive systems:

- High load carrying capacity (high power/mass ratio)
- High gear up ratio in the range from 60 to 220 (low gear ratio)
- High efficiency.

Solutions meeting these requirements are two- and three-stage planetary gears consist of simple planetary gears KB. Varying the inner gear ratio (ratio of tooth number of ring gear and sun gear) of the simple planetary gear stage KB the performance of planetary gear can be changed and tailored to the requirements.

Recently some new types of planetary gears (differential planetary gears) have been appeared in drive systems of large wind mills, which can divide the applied power between the planetary stages, so increasing the load carrying capacity of the planetary drives [1, 2]. The performance of such a planetary gear depends on its kinematics, its inner gear ratios and the connections between the planetary stages. Only detailed calculations can reveal the behavior of such planetary gears and show the best construction for a given application.

In a recently published paper [1] the performance of three planetary gears: a two-stage planetary gear KB+KB, a three-stage planetary gear KB+KB+KB and a differential planetary gear GPV were compared, sketches of structure of which are presented in Fig 1, 2 and 5. In this paper two further differential planetary gears are discussed. Their structure can be seen in Fig. 3 and 4.

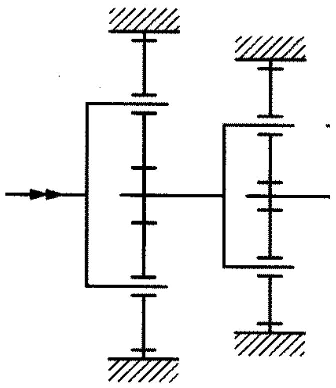

Fig. 1 Planetary gear KB+KB

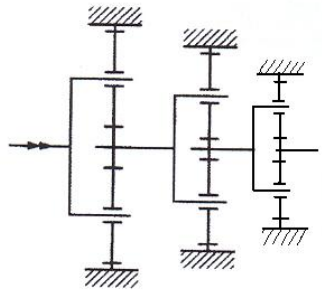

Fig. 2 Planetary gear KB+KB+KB

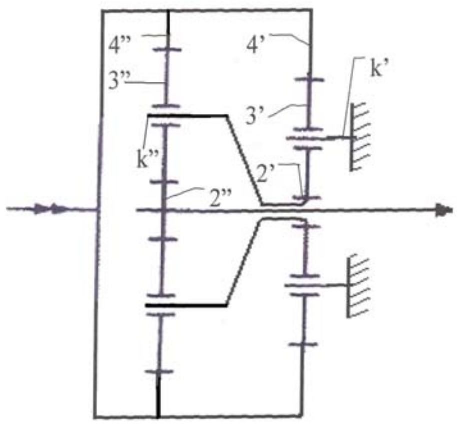

Fig. 3 Differential planetary gear PKG

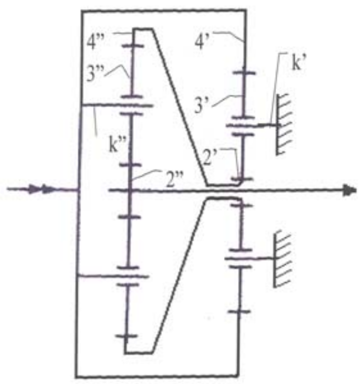

Fig. 4 Differential planetary gear PV

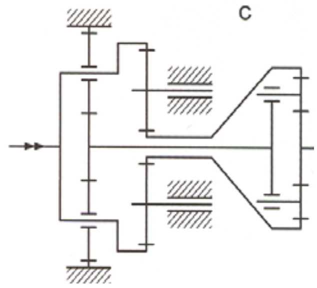

Fig. 5 Differential planetary gear GPV

2. COMPARING THE PROPERTIES OF PLANETARY GEARS

In the following the gear ratio and the gear efficiency of different planetary gears (Fig.1-5) and also the power distribution between the gear stages are compared, which were calculated using the equations developed by us. In this calculation the limits of geometry were not taken into consideration (the values i_b were increased with rising the number of teeth of ring gear while the axis distances were also increased).

The results of our analysis are presented in the Fig. 6-17. In the figures the following notations are used:

$i_{b''}$- is the ratio of the number of teeth of sun gear and ring gear at the first stage,

$i_{b'}$ - is the ratio of the number of teeth of sun gear and ring gear at the second stage

i_b - is the ratio of the number of teeth of sun gear and ring gear at the third stage.
η - is the gear efficiency
i - is the gear ratio. (Speeding gear ratio is 1/i)
Fig. 6 and 7 shows that the planetary gear KB+KB can reach a high speeding gear ratio (low gear ratio), and a good efficiency, which vary with changing the values of i_b'.
The three-stage planetary gear KB+KB+KB results higher speeding gear ratio but at lower gear efficiency. This fact can be seen when the curves of the Fig. 6 and 7 are compared with the curves of Fig. 8 and 9. Even at the same gear ratio, the efficiency of three stage-planetary gear KB+KB+KB is lower than the two-stage planetary gear KB+KB.

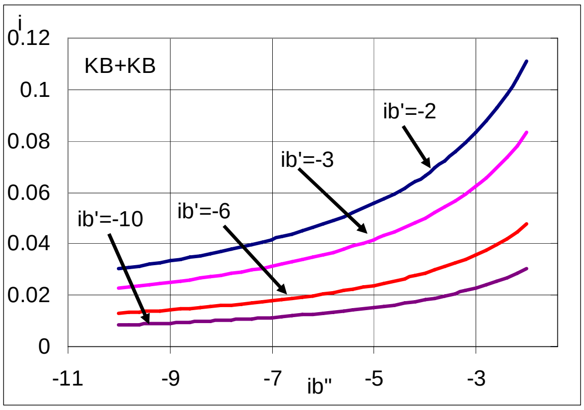

Fig. 6 Planetary gear KB+KB

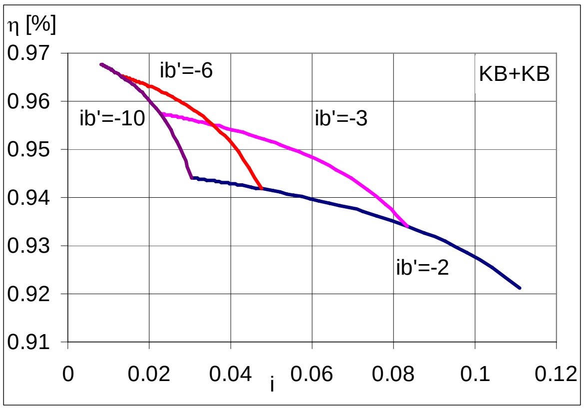

Fig. 7 Planetary gear KB+KB

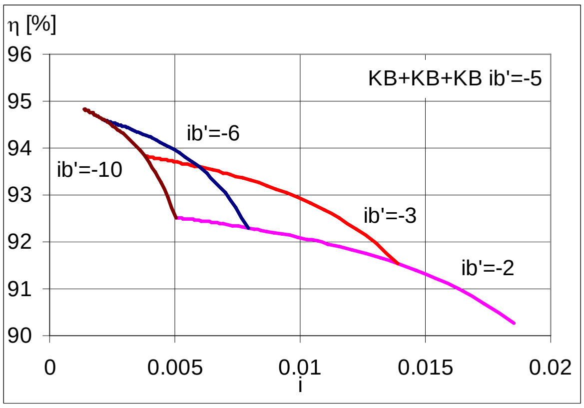

Fig. 8 Planetary gear KB+KB+KB

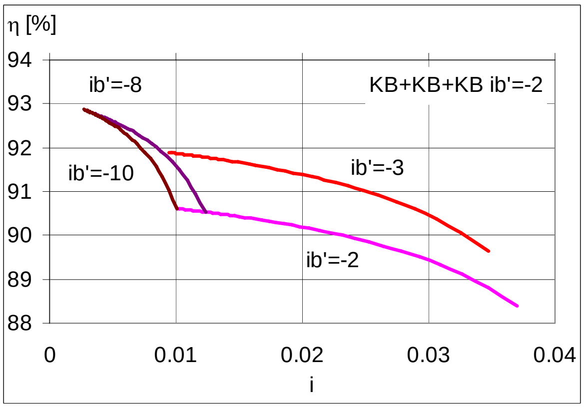

Fig. 9 Planetary gear KB+KB+KB

At the two- and the three-stage planetary gears all powers transmit through each stages of planetary gears. At differential planetary gears there are possibilities to distribute the power between two planetary stages resulting higher load carrying capacity at the same sizes or decrease the sizes and mass of planetary gears at the same applied power. PKG is a differential planetary gear input shaft of which drives the ring gears of both planetary stages. Calculated characteristics of planetary gear PKG are presented in Fi. 10 – 12. Diagrams in these figures show that the efficiency of planetary gears PKG is higher than the planetary gears KB+KB and especially KB+KB+KB due to the power distribution.
The power ratios of the two stages P4''/P4' are lower at higher value of i_b', but increasing with rising the gear ratios of planetary gears PKG (Fig. 12).
The calculated characteristics of planetary gears PV (Fig 4) are presented in Fig. 13 – 15.

The power ratio of differential planetary gears PV (Fig. 13) changes in the opposite direction with increasing the planetary gear ratio than at the planetary gears PKG (Fig. 12), but it also decreasing with increasing the gear ratio. Its values are a little higher at the same gear ratio than the power ratios of planetary gear PKG.
The planetary gear PV also is suitable to transmit power at high gear up ratio with high efficiency. There is not too much differences between their efficiency, thanks to the power distribution.

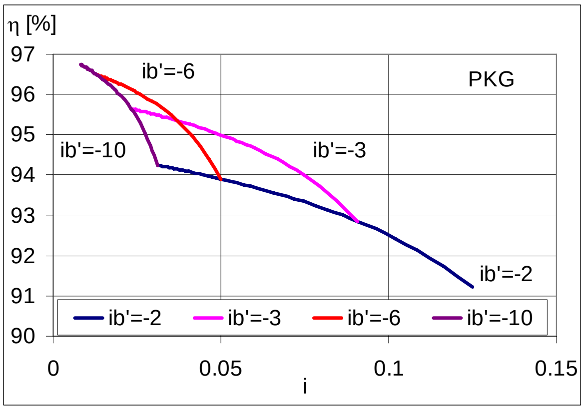

Fig. 10 Planetary gear PKG

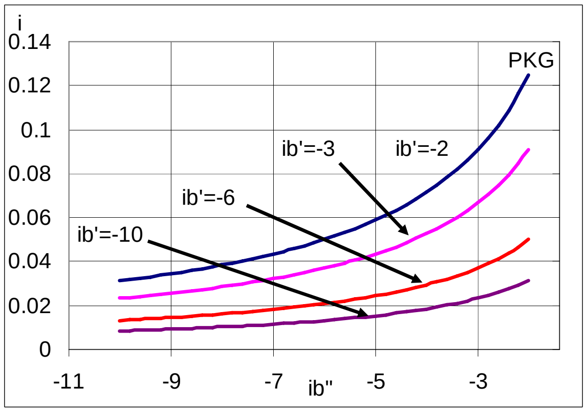

Fig. 11 Planetary gear PKG

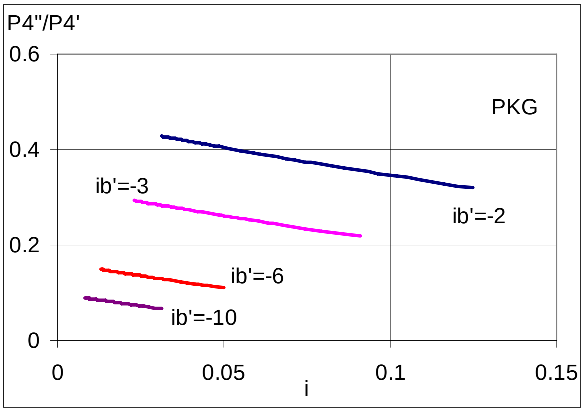

Fig. 12 Planetary gear PKG

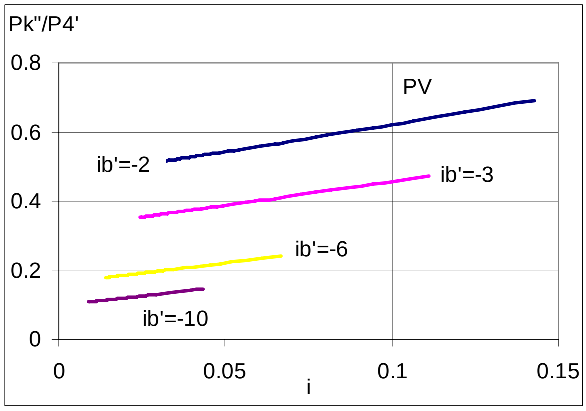

Fig. 13 Planetary gear PV

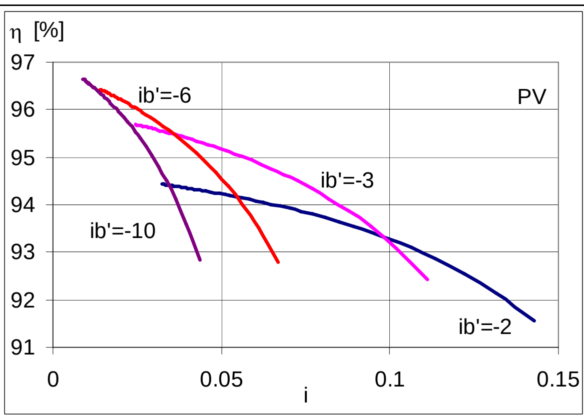

Fig. 14 Planetary gear PV

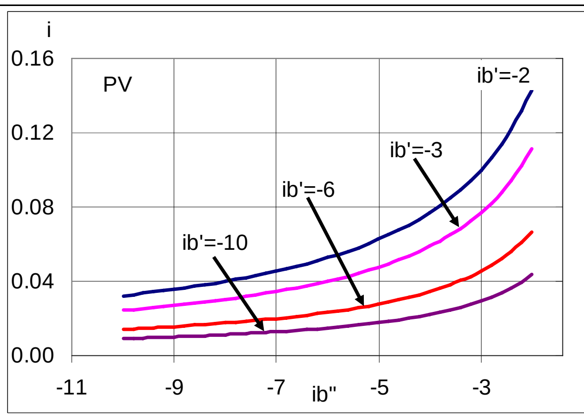

Fig. 15 Planetary gear PV

A third variant of the differential planetary gear is the type of GPV (Fig 5), which has three planetary stages. Its input shaft drives both the carrier of the first planetary stage and the ring gear of the second planetary stage, while the third planetary stage has two driver elements: the ring gear is driven by the sun gear of the second stage and the carrier is driven by the sun gear of the first stage. The behavior of this planetary gear was presented in an earlier publication [1]. As it was proved differential planetary gear GPV is suitable to transmit power at high gear up ratio at high efficiency (Fig. 16). Its efficiency is much higher than the efficiency of three-stage planetary gear KB+KB+KB (Fig. 17).

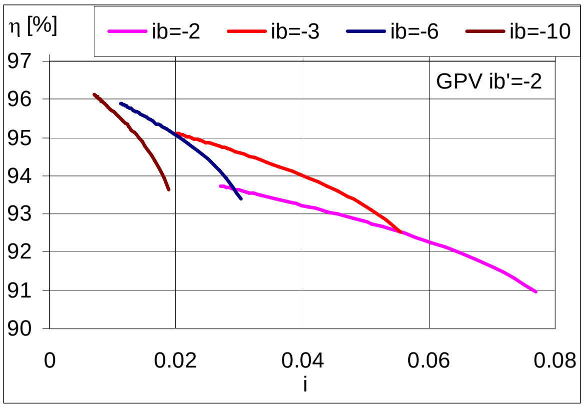

Fig. 16 Efficiency of planetary gears GPV as a function of gear ratio at different inner gear ratios of third stage

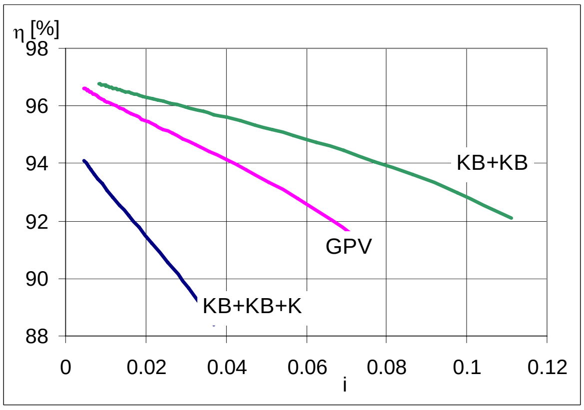

Fig. 17 Efficiency of planetary gears as a function of gear ratio, when all inner gear ratios being equal

3. CONCLUSIONS

The results of the theoretical investigations presented above allow drawing the following conclusions:

- The differential planetary gears distributing the applied power between two planetary stages have higher efficiency than the three-stage planetary gears.
- The power ratio of the two planetary stages depends on the gear up ratio of the differential planetary gears: higher the gear up ratio leads to lower power ratio.
- There are not too many differences between the efficiency of differential planetary gears presented above.
- Further investigations have to be executed to determine, which variant of the differential planetary gears are most beneficial to transmit high power at high gear up ratio and high efficiency.

The investigations will be continued to determine the optimum structure of differential planetary gears taking into consideration also the results of investigations on materials of gears and on lubricants [7, 8].

4. REFERENCES

1. Csobán, A., Kozma, M.: Comparing the performance of heavy-duty planetary gears. Gépészet 2006, Ötödik Országos Gépészeti Konferencia. Budapest, 23-24 May 2006. Excepted for publication.
2. Gold, P.W.: Windenergieanlagen mit Getriebe. Antriebstechnik 6/2005. 42-49
3. Berger, G.: Windenergieanlagen effizienter gemacht. Antriebstechnik 6/2005. 55-57

4. Terplán, Z.: Fogaskerék-bolygóművek. Műszaki Könyvkiadó, Budapest, 1979.
5. Müller, H.W.: Die Umlaufgetriebe. Springer-Verlag. Berlin, 1971.
6. Kozma, M.: Hajtásrendszerek. Műegyetemi Kiadó. 2001.
7. Kalácska G.- Eberst O.- Keresztes R.: Investigation of friction of polymer gears. 8th International Conference on Tribology. Veszprém. June 2004. p. 51 – 57.
8. Kalácska G.- Kocsis Z.- Keresztes R.: Developed test method for laboratory evaluation of engine oils. 8th International Conference on Tribology. Veszprém. June 2004. p. 213 – 221.