11th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

SPEED MULTIPLIERS VARIANTS USED IN WIND TURBINES AND HYDRO-POWER STATIONS

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ABSTRACT
The paper main objective is to extend the library of planetary multipliers that can be used in wind turbines' and hydro units' applications, by tacking into account the conditions of obtaining higher efficiencies and smaller transmission ratios for a reduced overall dimension. The analysis is based on examples of 1 DOF planetary multiplier with one and two sun gears.
Keywords: efficiency, planetary gearbox, speed multiplication ratio.

1. INTRODUCTION
Mechanical power transmission by multiplying the angular speed under a constant transmission ratio represents the function of a large group of products known as *speed multipliers*. Most wind turbine drive trains and hydro-power stations actuation include a gearbox to increase the speed of the input shaft to the generator. An increase in speed is needed because the wind turbines rotors and the hydro turbines shafts turn at a much lower speed than is required by most electrical generators. The range in which the input angular speed must be increased is 5 … 30 [2,3]. There are two basic types of gearboxes used in wind turbines and hydro-plants applications: parallel-shaft gearboxes and planetary gearboxes. In the first case, in order to obtain higher values of the transmission ratio, multiple stages are placed in series. This arrangement increases the transmission ratio but, in the same time, increases the gearbox overall dimension. The planetary gearboxes have a number of significant differences from parallel-shafts multipliers: the input and output shafts are coaxial, that reduces the overall dimension; there are multiple pairs of gear teeth meshing at any time, so the loads on each gear are reduced; the gearboxes are relatively light and compact.
The paper main objective is to extend the library of planetary multipliers that can be used in wind turbines' and hydro units' applications. Generally, the increase of the multiplication ratio i is accompanied by the corroboration, in different combinations, of the following disadvantages:
a) the reduction of efficiency,
b) the increase of the radial / axial overall size,
c) the increase of the complexity degree,
d) the increase of the technological costs etc.
The development of new schemes of speed multipliers means the minimization of some of the disadvantages, in the condition of an increased multiplication ratio. The analysis is based on examples of 1 DOF planetary multipliers.

2. EXAMPLES OF PLANETARY SPEED MULTIPLIERS

A source that can be used in developing new schemes of multipliers for wind turbines and hydro stations is represented by the planetary reducers [1]. Some representative solutions of 1 DOF simple planetary multipliers developed from reducers with a large technical use, by inverting the energy flow are illustrated in Fig. 1. The multipliers are equipped with 2 sun gears (Fig.1,a,a_1) and one sun gear (Fig.1, b,b_1,…,e_1). The solutions are comparatively analyzed with the aim to identify the possibilities of using them as amplifiers, accomplishing the conditions of high multiplication ratios (in the range 5…30), high efficiencies and reduced overall sizes [2,3].

The multiplier from Fig.1,a, a_1 uses the classical spur planetary unit with one satellite gear, having a large technical utilization. According to Fig.1,a, a_1, and under the prerequisite that the associated fixed axes unit (obtained by reversing the motion relative to the carrier H) has the quantities:

$$\eta_0 = \eta_{1,3}^{H} = \eta_{1,2}^{H}\eta_{2,3}^{H} = 0{,}97^2 = 0{,}94; \quad i_0 = i_{1,3}^{H} = \frac{\omega_{1,H}}{\omega_{3,H}} = -\frac{z_3}{z_1} = -\frac{80}{20} = -4$$

and

$$w = \operatorname{sgn}(\omega_{1,H}T_1) = \operatorname{sgn}\left[\frac{\omega_{1,H}T_1}{\omega_{1,3}T_1}\right] = -1 \tag{1}$$

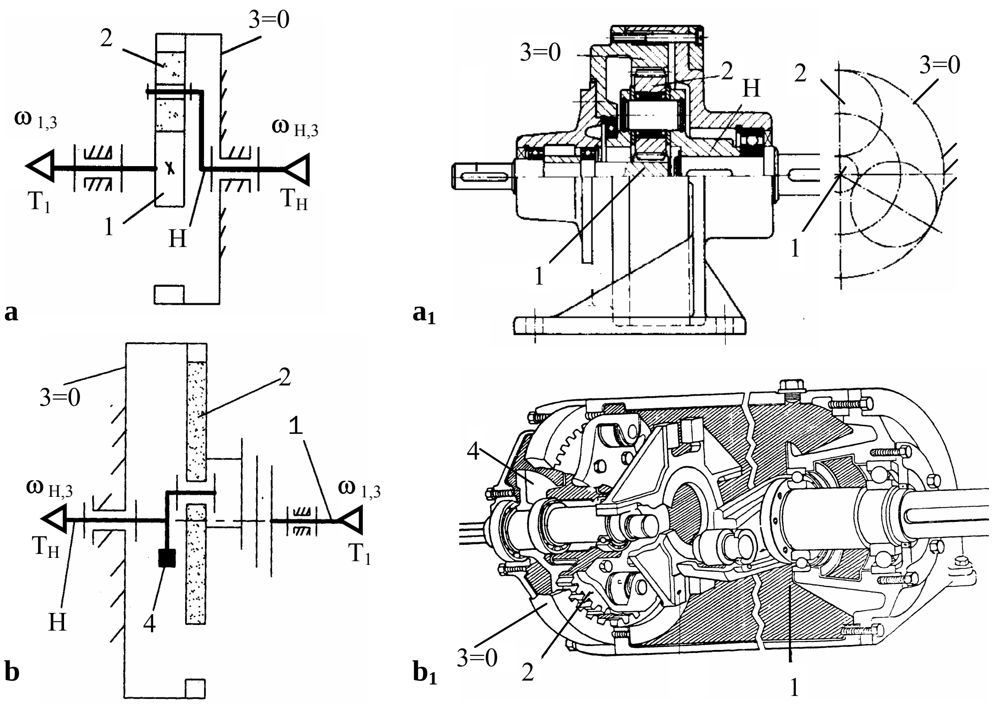
for the analyzed speed multiplier there are obtained:

$$i = i_{1,H}^{3} = \frac{\omega_{1,3}}{\omega_{H,3}} = \frac{\omega_{1,H} - \omega_{3,H}}{\omega_{H,H} - \omega_{3,H}} = 1 - i_0 = 1 - (-4) = +5 \quad \Rightarrow \quad \omega_{1,3} = i \cdot \omega_{H,3} = 5 \cdot \omega_{H,3}; \tag{2}$$

$$\eta_{H,1}^{3} = \frac{-\omega_{1,3}T_1}{\omega_{H,3}T_H} = -\frac{T_1}{T_H} i = \frac{1 - i_0}{1 - i_0\eta_0^{w}} = \frac{5}{1 + 4(0{,}94)^{-1}} = 0{,}951 \quad \Rightarrow$$

$$T_1 = \frac{T_H}{i}\eta_{H,1}^{3} = -\frac{T_H}{5}0{,}951 = -0{,}19 \cdot T_H = -\frac{T_H}{5{,}263} \tag{3}$$

This means that the considered planetary multiplier (Fig.1,a,a_1) amplifies the input angular speed *five times* and, implicitly, reduces the input moment *5,263 times*. Therefore, a reducer of this type can be used as amplifier with an excellent efficiency ($\eta^{3}_{H,1}$=0,951 >η_0=0,94) and a relatively simple structure, but it can not obtain higher multiplication ratios i, due to the excessive increase of the internal ratio i_0 and implicitly of the radial overall size.



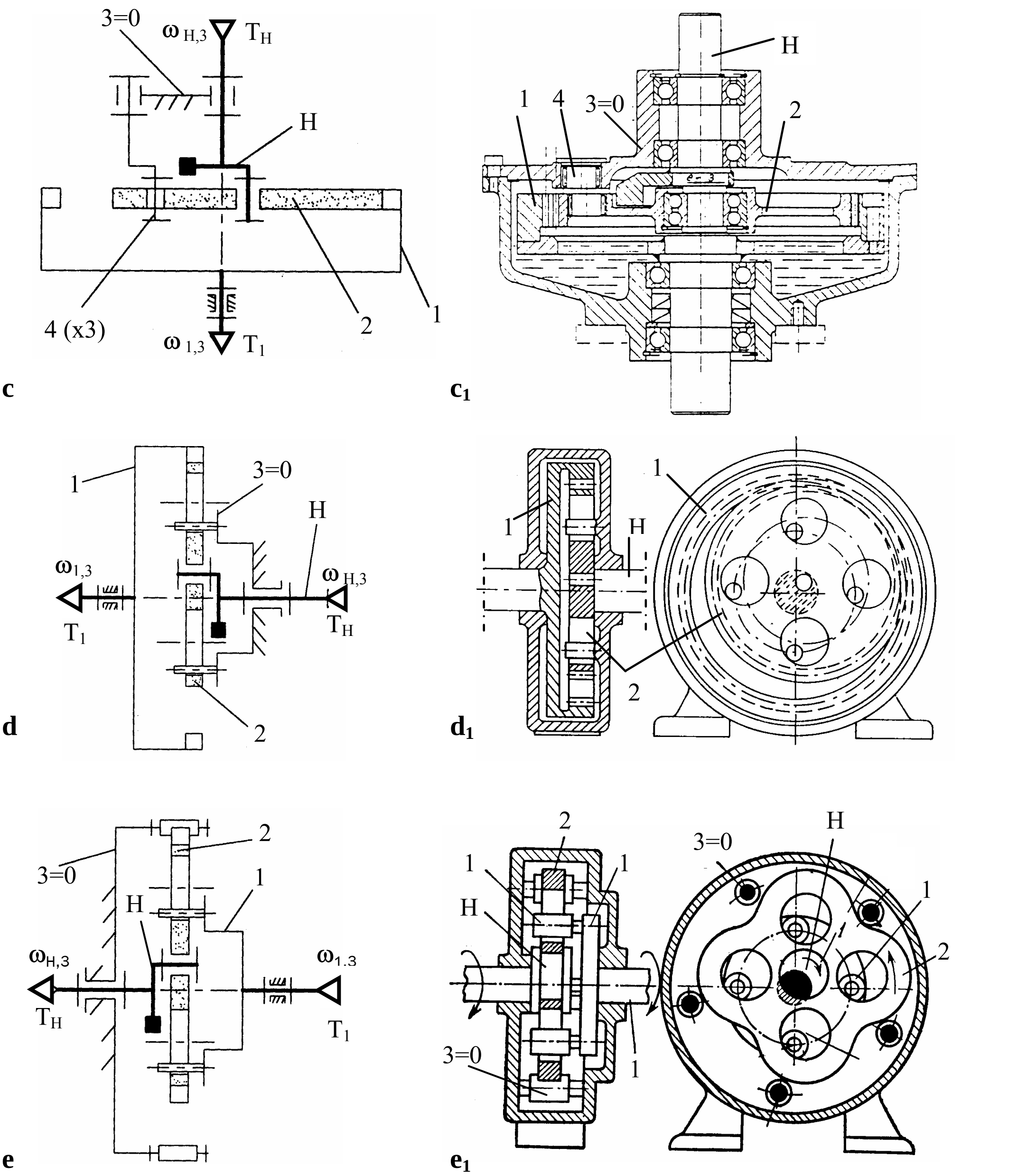


Figure 1. Examples of simple planetary multipliers (a … e).

3. COMMENTS AND CONCLUSIONS

1) The reducers with one sun gear are relatively new developments of the planetary reducers with two sun gears. The solution consists in replacing one of the two gear pairs with a homokinetic coupling with a superior efficiency. Some representative examples of speed multipliers derived from 1 DOF planetary reducers by reversing the power flow, are illustrated in Fig. 1, b...e_1.

2) The multiplication ratios and the efficiencies of the multipliers from Fig. 1, b,…e, are systematized in Tab. 1, in the premise of knowing the gears' teeth numbers (i_0) and the interior efficiency η_0; the values are obtained using the same calculus procedure as for the speed multiplier with two sun gears from Fig. 1,a (rel. 1,2,3). The following conclusions are highlighted from the comparative analysis of the data included in Tab. 1:

A. The speed multipliers with cycloidal gears can obtain multiplication ratios that are comparable to the reduction ratios of the reducers from which they were derived; this type of multipliers can obtain high multiplication ratios because the cycloidal gears can simply accomplish the condition $\Delta z \geq 1$.

Table 1. Comparative analysis

The multiplier type	The transmission ratio and the efficiency of the **fixed axes unit**	The reduction ratio and the efficiency for the **reducer** from which the multiplier is derived	The multiplication ratio and the efficiency for the speed **multiplier**; the multiplier transmission functions
Fig.1, b,b_1 - multiplier derived from the a *Strateline* reducer; it has an internal spur gear pair (2-3), with *involute* teeth and a *homokinetic* radial coupling of *Green* (*Oldham* with rollers) type	$\eta_0 = \eta_{1,3}^{H} = 0{,}99$ $i_0 = i_{1,3}^{H} = +1{,}0357$ $w = \mathrm{sgn}(\omega_{1,H} T_1) = +1$	$i = i_{1,H}^{3} = -\frac{1}{28{,}01}$ $\eta_{1,H}^{3} = 0{,}773$	$i = i_{H,1}^{3} = -28{,}01$; $\eta_{1,H}^{3} = 0{,}71$ $\omega_{H,3} = 28{,}01 \cdot \omega_{1,3}$ $T_H = \frac{T_1}{40}$
Fig.1,c,c_1 - it is used a radial semi-coupling of *Schmidt* type, homokinetic, with three cranks (4) that are in a parallel and equiangular disposal (at 120°);	$\eta_0 = \eta_{1,3}^{H} = 0{,}99$ $i_0 = i_{1,3}^{H} = +o{,}9655$ $w = \mathrm{sgn}(\omega_{1,H} T_1) = -1$	$i = i_{1,H}^{3} = +\frac{1}{29}$ $\eta_{1,H}^{3} = 0{,}781$	$i = i_{H,1}^{3} = +29$ $\eta_{1,H}^{3} = 0{,}717$ $\omega_{H,3} = 29 \cdot \omega_{1,3}$ $T_H = -\frac{T_1}{40}$
Fig.1,d,d_1 - it uses a semi-coupling Schmidt with bolts.	$\eta_0 = \eta_{1,3}^{H} = 0{,}99$ $i_0 = i_{1,3}^{H} = +o{,}9655$ $w = \mathrm{sgn}(\omega_{1,H} T_1) = -1$	$i = i_{1,H}^{3} = +\frac{1}{29}$ $\eta_{1,H}^{3} = 0{,}781$	$i = i_{H,1}^{3} = +29$ $\eta_{1,H}^{3} = 0{,}717$ $\omega_{H,3} = 29 \cdot \omega_{1,3}$ $T_H = -\frac{T_1}{40}$
Fig.1,e,e_1 - it has a internal spur gear pair (2-3), with cycloidal teeth and a coupling Schmidt semi-coupling with bolts.	$\eta_0 = \eta_{1,3}^{H} = 0{,}996$ $i_0 = i_{1,3}^{H} = +1{,}0087$	$i = i_{1,H}^{3} = -\frac{1}{115}$ $\eta_{1,H}^{3} = 0{,}682$	$i = i_{H,1}^{3} = -115$ $\eta_{1,H}^{3} = 0{,}54$ $\omega_{H,3} = -115 \cdot \omega_{1,3}$ $T_H = \frac{T_1}{20}$

B. The previous conclusion remains valid, in principle, also for the involute gears, with the following specification: the multiplication ratios are smaller due to the fact that the internal involute gears can usually accomplish only $\Delta z \geq 4$.
C. The efficiencies obtained by the transmissions as speed multipliers are comparable to the efficiencies of the reducers from which they derive, being a little bit smaller (Tab. 1).
D. The results analysis highlight the fact that the planetary cycloidal reducers with one sun gear can be efficiently used as speed multipliers by reversing the role of the input and output shafts; thus, a considerable enlargement of the library of speed multipliers can be obtained (Fig. 1, e, e_1).
3) Taking *into account that the micro wind turbines and hydro units usually need multiplication ratios between 5 and 30, it outcomes that the previously presented schemes are directly usable.*

4. REFERENCES

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