Speed Multipliers
for Renewable Energy Systems – Hydro and Wind

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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 taking into account the conditions of obtaining higher efficiencies and higher multipication ratios for a reduced overall dimension. The presented solutions are derived from some representative speed reducer by the flow power inversion. By means of these solutions, a comparative analysis of the structural, kinematical and dynamic specific features of different types of planetary speed multipliers is presented in the paper.

Key words

Speed multiplier, efficiency, multiplying ratio, kinematical analysis, planetary gearbox.

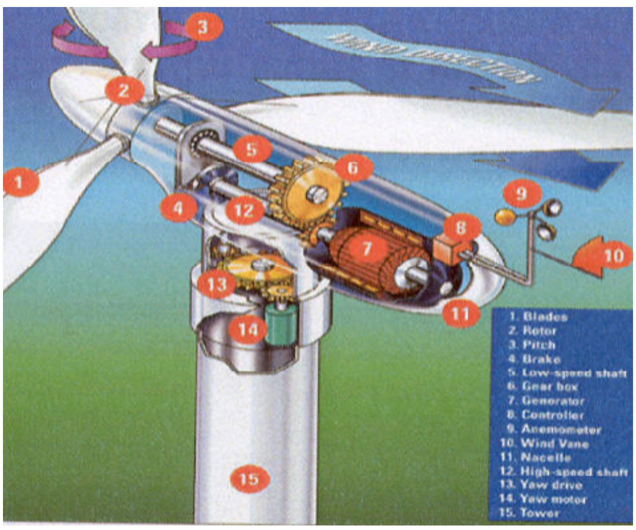
1. Introduction

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 turbines and hydro systems drive trains (Fig. 1, a, b) include a gearbox to increase the speed of the turbine shaft to the generator. An increase in speed is needed because the turbines rotors 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 [1,2].

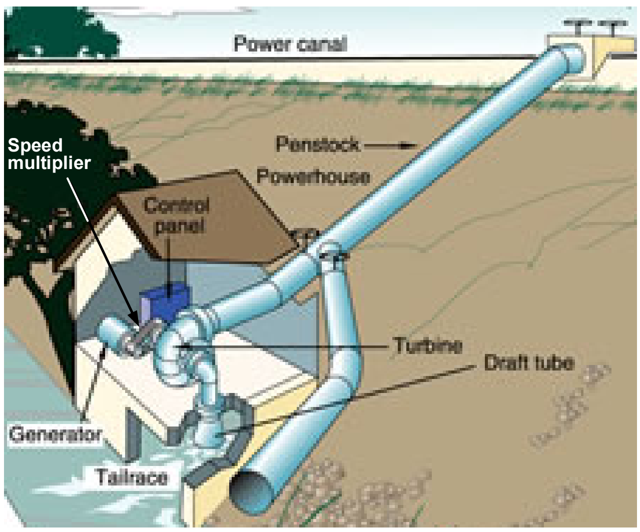
There are two basic types of gearboxes used in **wind turbines** applications: parallel-shaft gearboxes and *planetary gearboxes* [1]. In the first case, in order to obtain higher values of the transmission ratio, multiple stages are placed in series. This arrangement increases the multiplication ratio but, in the same time, increases the overall dimension. Unlike the parallel-shaft gearboxes, the *planetary gearboxes* have some significant differences: the input and output shafts are coaxial, that reduces the radial and axial dimensions; there are sometimes multiple power branches, so the loads on each gear are reduced; the gearboxes are relatively light and compact.

There are several options for coupling the generator to the turbine in **hydro systems** [2] that allow an increase in speed: belts, chains and gears. They are used with standardized turbines in the small-hydropower range where gearing is required but where other drives lack the capacity to handle the power and their cost becomes an insignificant component of total plant cost. Each type has its advantages and disadvantages:

1) spur gears, used mainly in low power applications; there are characterized by relatively small transmission ratio, imposed by the overall dimensions;
2) orthogonal bevel gears, used in low power applications; they can be used only with small



a



b

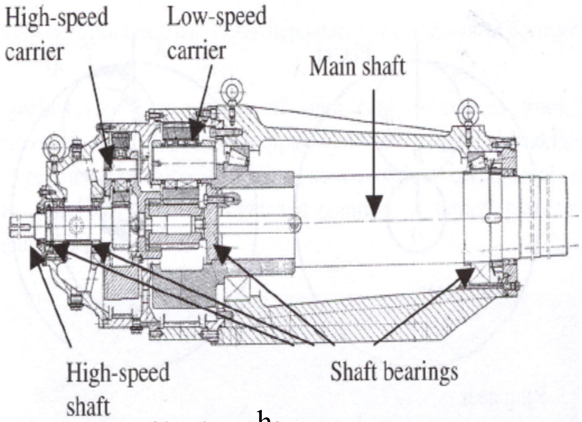
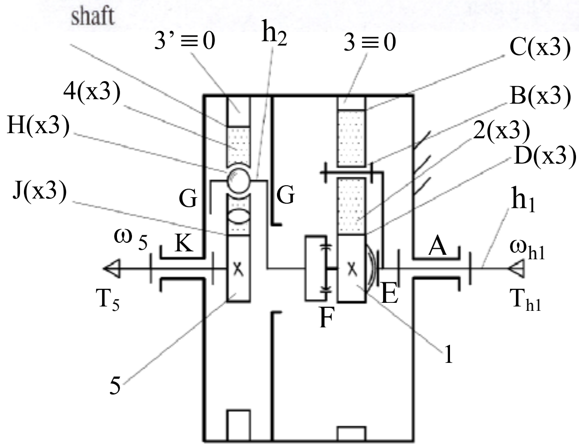
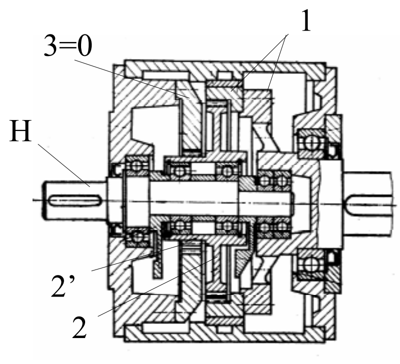
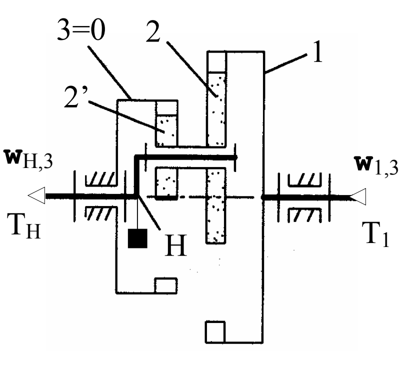
Fig.1. Wind turbine (a) and hydro system (b) drive trains

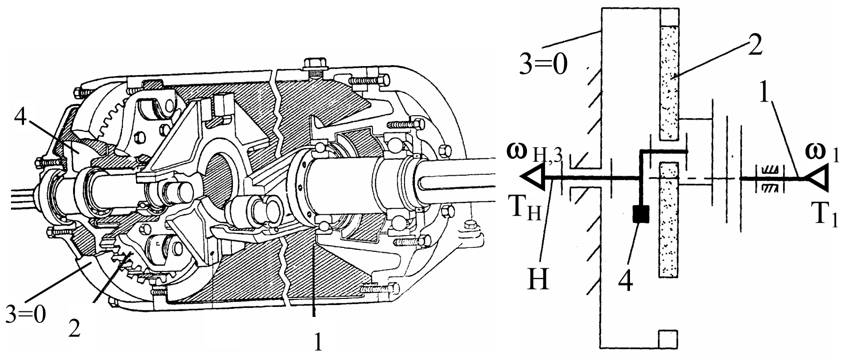
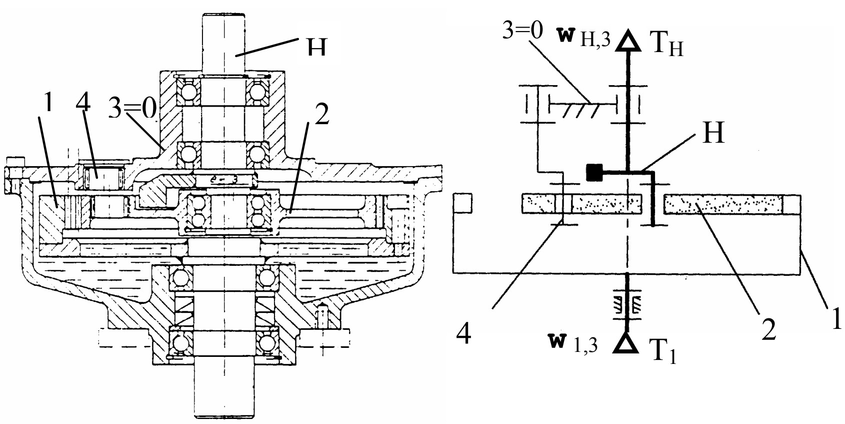
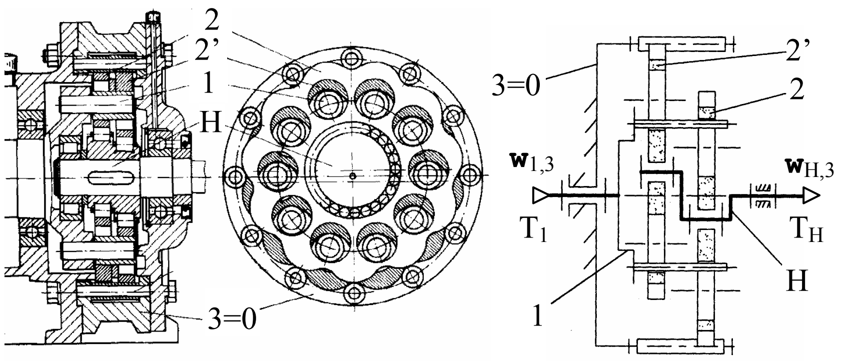
transmission ratios; while the ratio increases the systems overall size increases, too;

3) belt transmission, used in applications of low power; have a simple maintenance; the trapezoidal belt transmission is the most used in hydropower units, but its efficiency is relatively small. The transmissions with gear belts are efficient mainly for very small units, with capacities under 3 kW, at which the efficiency haves critical values;
4) planetary transmission: the planetary transmission applied in precessional variant is compact and with a medium efficiency; it is used in the small hydro developed on Prut river.

New schemes of speed multipliers (Tab.1, b,…e) are compared to a speed multiplier used in wind turbines (Tab. 1,a); the new solutions are derived from some representative speed reducer by the flow power inversion [3]. The analysis of the structural, kinematical and dynamic specific features of the different types of planetary speed multipliers is presented in the paper.

TABLE 1. A comparative analysis of some representative speed multiplier solutions

The multiplier type	The multiplier structural scheme	The multiplication ratio and the efficiency for the fixed axes mechanism (η_0, i_0) and the speed multiplier, respectively; the multiplier transmission functions
a. Two-stage planetary multiplier used in wind turbines	 	$i = \omega_{output} / \omega_{input} =$ $= \omega_5 / \omega_{h1} = +22{,}5$ $\eta = 0{,}9529$ $\omega_5 = \omega_{5,3'} = 22{,}5 \cdot \omega_{h1}$ $T_5 = -\frac{T_{h1}}{23{,}61133}$
b. Multiplier derived from a involute planetary reducer [3] with two sun gears (1;3) and a double satellite (2=2')	 	$\eta_0 = \eta^H_{1,3} = 0{,}94$ $i_0 = i^H_{1,3} = +0{,}98437$ $i = \omega_H / \omega_1 = +64$ $\omega_{H,3} = 64 \cdot \omega_{1,3}$ $\eta^3_{1,H} = -3{,}021$ => Transmission is blocked! It is running if: $1 - i_0/\eta_0 > 0$

c. Multiplier derived from the a *Strateline* reducer [3]: involute planetary multiplier with one sun gear (3=0), a simple satellite (2) and a *Green* coupling (1-2).		$\eta_0 = \eta^H_{1,3} = 0{,}99$ $i_0 = i^H_{1,3} = +1{,}0357$ $w = sgn(\omega_{1,H} T_1) = +1$ $i = \omega_H / \omega_1 = -28{,}01$ $\eta^3_{1,H} = 0{,}71$ $\omega_{H,3} = 28{,}01 \cdot \omega_{1,3}$ $T_H = \frac{T_1}{40}$
d. Multiplier derived from a involute planetary reducer with one sun gear (1), a simple satellite (2) and 3 mechanisms of parallelogram type (4-2-H-3, at 120°) [3].		$\eta_0 = \eta^H_{1,3} = 0{,}99$ $i_0 = i^H_{1,3} = +0{,}9655$ $w = sgn(\omega_{1,H} T_1) = -1$ $i = \omega_H / \omega_1 = +29$ $\eta^3_{1,H} = 0{,}717$ $\omega_{H,3} = 29 \cdot \omega_{1,3}$ $T_H = -\frac{T_1}{40}$
e. Multiplier derived from a cycloidal reducer with one sun gear (3), 2 equiangular simple satellites (2, 2') and 10 equiangular bolt mechanisms of parallelogram type [3].		$\eta_0 = \eta^H_{1,3} = 0{,}99$ $i_0 = i^H_{1,3} = 12/11 =$ $= +1{,}0909$ $i = \omega_H / \omega_1 = -11$ $\eta^3_{1,H} = 0{,}88$ $\omega_{H,3} = -11 \cdot \omega_{1,3}$ $T_H = \frac{T_1}{12{,}5}$

2. Requirements

In order to extend the library of planetary multipliers that can be used in wind turbines' and hydro units' applications, the first step is to establish a list of requirements. The following main requirements must be accomplished by a speed multiplier for wind and hydro units:

1) the increase of the multiplication ratio:
$i = \omega_{output} / \omega_{input}$;
2) the increase of efficiency η,
3) the reduction of the radial / axial overall size,
4) the reduction of the complexity degree,
5) the reduction of the technological costs etc.

3. Planetary Speed Multipliers

The two-stage planetary multiplier represented in Table 1,a, is used in wind turbines [1]. The low-speed shaft h1 (the main shaft), supported by bearings, is rigidly connected to a planet carrier, which holds three identical small gears (satellites) mounted on short shafts and bearings. These gears mesh to a large ring gear and a small sun gear, forming a planetary unit that works as a speed multiplier. In order to increase the kinematical multiplying ratio, a second planetary unit of the same type, is serially connected to the first one: the sun gear 1 drives the high speed carrier h2, to which it is by a teeth coupling connected. The high speed shaft 5 is supported by bearings mounted in the case (Tab. 1, a and b). The turbine rotor is attached to the low-speed shaft h1 while the generator is coupled to the high-speed shaft and is also bolted to the case.

Some representative solutions of 1 DOF simple planetary multipliers developed from reducers with a large technical use [3], by inverting the energy flow are presented in Tab. 1, b…e. The new schemes of multipliers are equipped with 2 sun gears (Tab. 1, b) and one sun gear (Tab.1, c, d, e). The last solutions consist in replacing one of the two gear pairs with a homokinetic coupling with a superior efficiency.

The new solutions and the wind multiplier from Tab. 1,a are comparatively analyzed with the aim of accomplishing the needed requirements: obtaining high multiplication ratios (in the range 5…30), high efficiencies and reducing the overall sizes.

4. Comments and Conclusions

The different schemes of speed multipliers (Tab. 1) that are considered in this paper take into account the minimization of some of the disadvantages, in the conditions of an increased multiplication ratio.

The multiplication ratios of the speed multipliers, the efficiencies and their transmission ratios for speeds and torques are also 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.

The following conclusions are highlighted from the comparative analysis of the data included in Tab. 1:

1) taking into account the values of the multiplication ratio obtained by the multipliers from Tab. 1, it outcomes that the schemes are directly usable in small wind turbines and hydro units, excepting the scheme from Tab.1, b;
2) 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 $\Delta z \geq 1$;
3) the multiplication ratios of the involute gears are smaller due to the fact that the internal involute gears can usually accomplish only $\Delta z \geq 4$;
4) the efficiencies of the planetary gearboxes from Tab. 1 decrease as their multiplication ratios increase; the best efficiency is obtained by the multiplier from Tab. 1,a; but, in this case, the degree of complexity and overall size are maximum;
5) the complexity degree and overall dimensions are smaller at the planetary multipliers derived from reducers, due to the use of homokinetic couplings; the multipliers from Tab.1, c, d and e have the simplest structure;
6) the technological costs of the multiplier with cycloidal teeth (Tab. 1, e) are smaller than of the multipliers with involute teeth due to superior accuracy needed in last case (see Tab.1, b).

The results analysis highlight the fact that the selection of one particular planetary multiplier to be applied in a practical case depends on the design requirements established in the pre-feasibility study.

References

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