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INNOVATIVE PLANETARY TRANSMISSION USABLE IN RES

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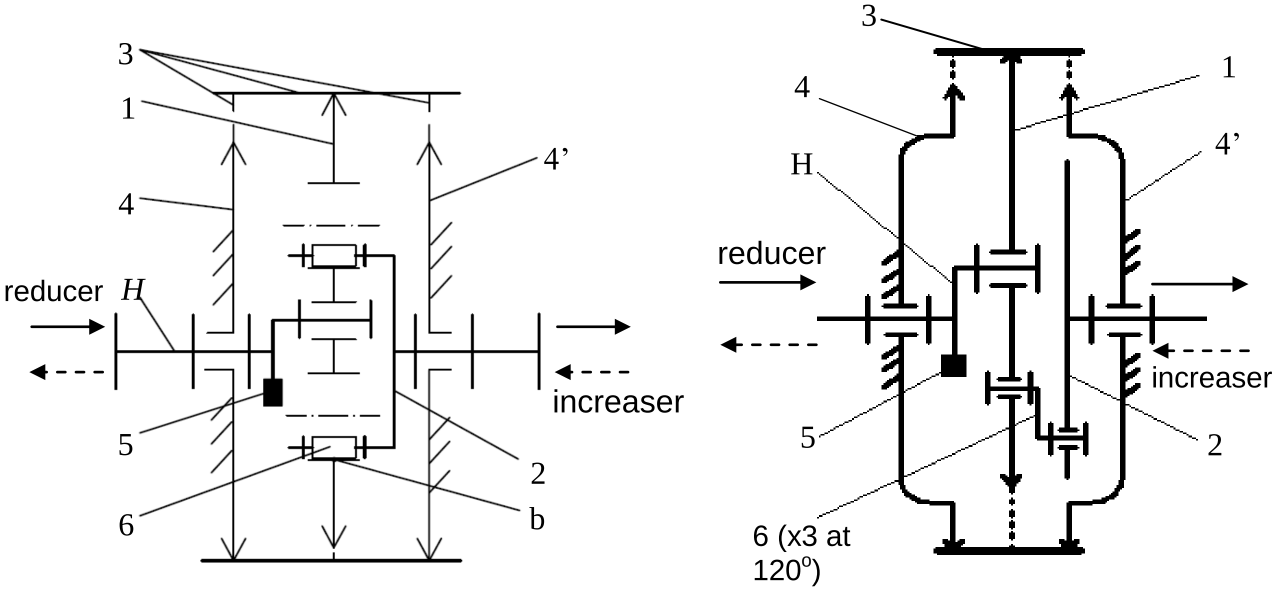
Abstract: in most of the renewable energy systems (RES) it is required to use different mechanical transmissions that increase/decrease the angular speed of a driving element (turbine or electric motor) to the optimal speed required by the given application. Firstly, the structural configuration of an innovative planetary transmission with deformable element is presented in the paper; then the analysis and synthesis are performed. Finally, a possible implementation of the transmission as speed increaser for a small wind turbine is presented.

INTRODUCTION

The paper presents an innovative planetary transmission with deformable element (chain), developed/proposed by the authors [2] that can be used in RES to adapt the input speed of a driver element to the output needs. The characteristics of the transmissions, usable in this domain, are defined by the following specific requirements: high transmission (reducing or increasing) ratio; a high as possible efficiency; reduced complexity, weight and overall dimensions [1, 8].

The proposed solution/structure promises a high efficiency, due to the replacement of the sliding friction with rolling friction; and high transmission ratios because of the possibility of reducing the difference between the sprockets teeth numbers to one. This planetary solution uses a chain with three strands as deformable element, two central gears with a single satellite gear and a Schmidt coupling. The chain with 3 strands, used as deformable element and the sprockets can be replaced with wide cog belt and special pulleys [2].



a. **b.**

Fig. 1. Two structural solutions for the planetary transmission with deformable element (chain) a. with Schmidt coupling and b. with connecting rods

During operation, the center of the: cylindrical joints (H-4 and 2-4'), rollers (6) and the conjugated holes, forms a parallelogram profile, which ensures, the synchronous rotation of the elements 1 and 2.
The planetary transmission has two running cases:
- as 1 DOF speed reducer: when the shaft H and the disc 2 are the input, respectively the output element, while the central gears (4 and 4') are fixed (see Fig. 1).
- as 1 DOF speed increaser: when the disc 2 and shaft a are the input, respectively the output elements, while the central gears/sprockets (4 and 4') are blocked (see Fig. 1).

NUMERICAL SIMULATIONS AND SYNTHESIS

In the numerical simulations, for example, it is considered the case in which the teeth number of the satellite gear 1 (z_1) is maintained constant, while the teeth numbers of the central gears (z_4=z_4') are variable. For this case, the variation of the transmission ratio (i) as function of the difference between the teeth numbers (z_4-z_1) is represented in Fig. 3,a and b. Two situations are distinguished for both running cases:

- when z4<z1, illustrated in Fig. 3, a,
- when z4>z1, illustrated in Fig. 3, b, respectively.

Using the technical literature, the values of the internal efficiencies for the chain transmission with fixed axes (98%) and for the Schmidt coupling (99.5%) were adopted.
The calculus algorithm used for the achievement of the diagrams from Fig. 3 and 4 is further presented (see also Fig. 2).

- the known main parameters of the fixed axes mechanism, obtained by motion inversion are [3,4,6]:
  - the internal transmission ratio (i_0), as function of the teeth numbers z_1 and z_4:

$$i_0 = i_{24}^a = \frac{\omega_{2a}}{\omega_{4a}} = i_{21}^a \cdot i_{14}^a = (+1)\left(+\frac{z_4}{z_1}\right) \tag{1}$$

- the internal efficiency, as function of the efficiency of the components: η_{chain} si $\eta_{coupling}$:

$$\eta_0 = \eta_{24}^a = \eta_{21}^a \cdot \eta_{14}^2 = \eta_{chain} \cdot \eta_{coupling} \tag{2}$$

- the transmission ratio (i) is given by relation 3:

$$i = i_{a2}^4 = \frac{\omega_{a4}}{\omega_{24}} = \frac{-\omega_{4a}}{\omega_{2a} - \omega_{4a}} = \frac{1}{1 - \dfrac{\omega_{2a}}{\omega_{4a}}} = \frac{1}{1 - i_0} \tag{3}$$

- the overall efficiency of the speed reducer (η_r) can be calculated as follows [3,4,6]:

$$\eta_r = \eta_{a2}^4 = \frac{-\omega_{24} T_2}{\omega_{a4} T_a} = \frac{-T_2/T_a}{\omega_{a4}/\omega_{24}} = \frac{-T_2/T_a}{i_{a2}^4} = \frac{1-i_0}{1-i_0\eta_0^w}, \tag{4}$$

where w is given by:

$$w = \mathbf{sgn}(\omega_{2a} T_2) = \mathbf{sgn}\left(\frac{\omega_{2a} T_2}{-\omega_{24} T_2}\right) = \mathbf{sgn}\left(\frac{\omega_{2a}}{\omega_{2a} - \omega_{4a}}\right) = \mathbf{sgn}\left(\frac{i_0}{1-i_0}\right) \tag{5}$$

- the overall efficiency of the speed increaser (η_i) is obtained similarly:

$$\eta_i = \eta_{2a}^4 = \frac{-\omega_{a4} T_a}{\omega_{24} T_2} = \frac{-T_a/T_2}{\omega_{24}/\omega_{a4}} = \frac{-T_a/T_2}{i_{2a}^4} = \frac{1-i_0\eta_0^x}{1-i_0} \tag{6}$$

$$x = -w$$

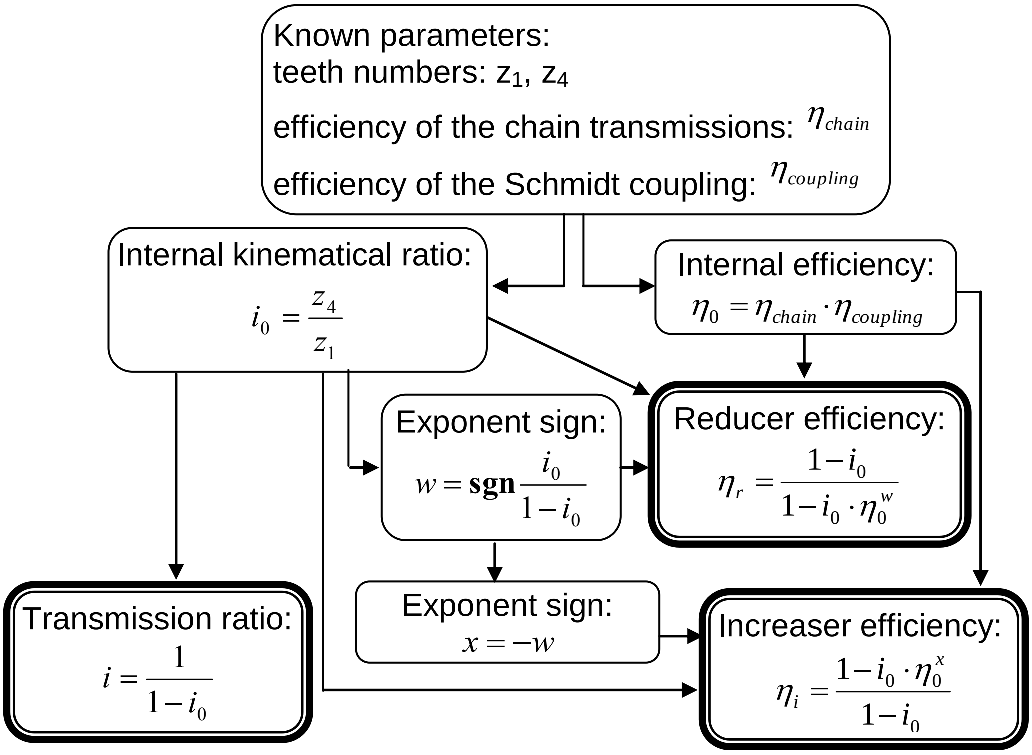
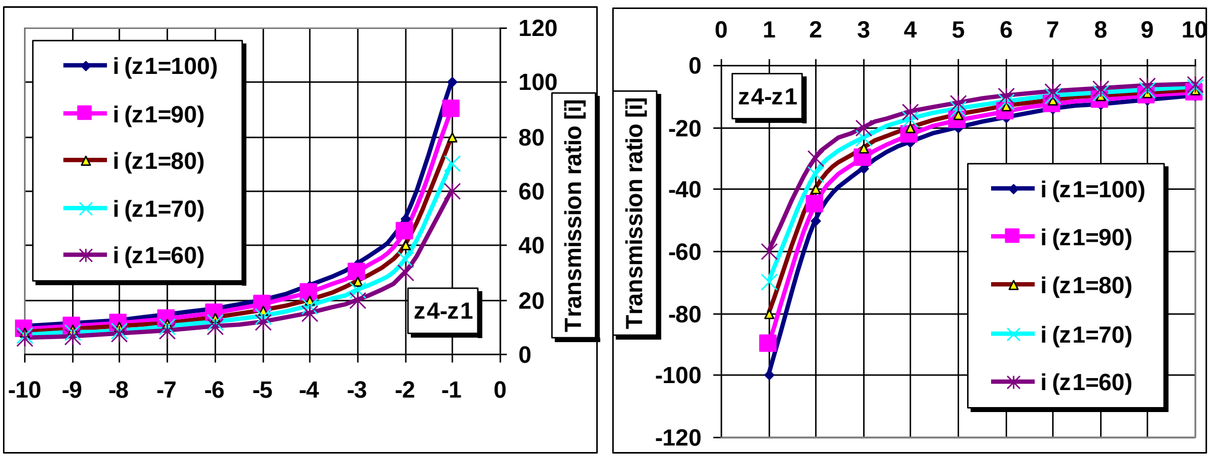


Fig. 2. The logical diagram used for the transmission analysis

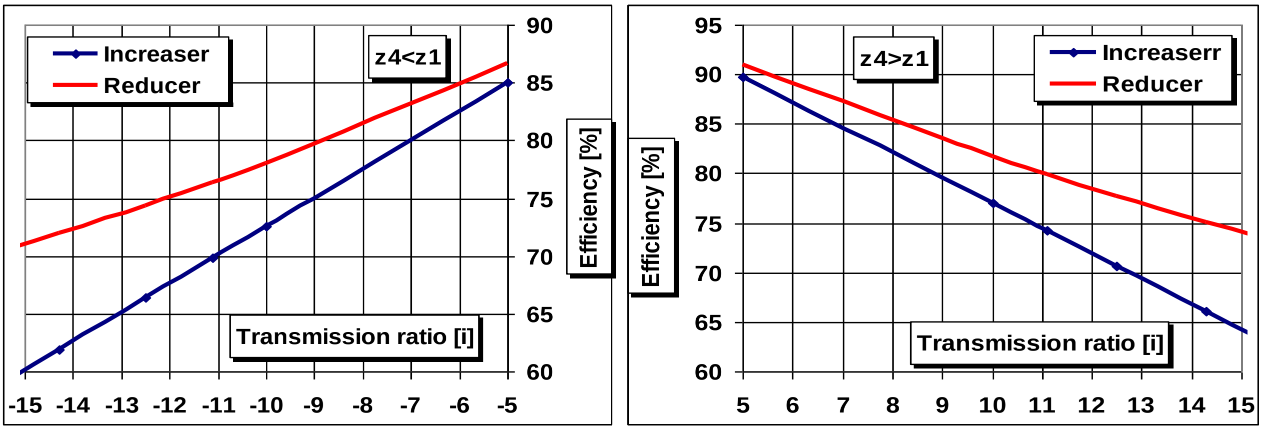
The numerical simulations were made by using the premises presented above, relations (1)-(6) and the logical diagram from Fig. 2. The results are presented in Fig. 3 and Fig. 4 as follows:

- Fig. 3 presents, comparatively, the variation of the transmission ratio as function of the difference between the teeth numbers ($i = i(z_4 - z_1)$), for both structural cases: $z_4<z_1$ (Fig. 3, a) and $z_1<z_4$ (Fig. 3, b), respectively;
- Fig. 4 describes the variation of the efficiency as function of the transmission ratio ($(\eta = \eta(i))$) for both structural ($z_4 < z_1$: Fig. 4, a) and $z_4 > z_1$: Fig. 4, b) and running cases: speed reducer and increaser.



a. **b.**

Fig. 3. The variation of the transmission ratio (i), when:
a. z_4-z_1>1 and b. z_4-z_1<1



a. b.

Fig. 4. The variation of the efficiency for both running cases, when:
a. z_4-z_1>1 and b. z_4-z_1<1

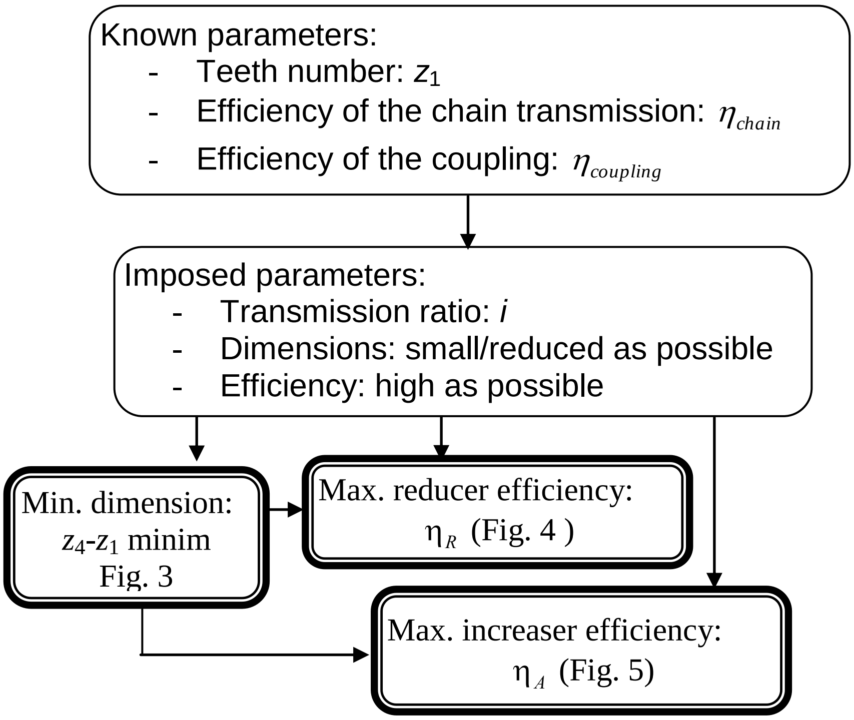


Fig. 5. The logical diagram used for the transmission synthesis

The logical diagram presented in Fig. 5 allows the selection of the optimal solution in terms of efficiency and overall dimensions for a given reducing or increasing ratio.

CASE STUDY

By using the results of the numerical simulations and synthesis algorithm presented above, the authors propose an example of application for this transmission, namely as speed increaser in a small wind turbine.

In order to increase the efficiency of the assembly, the turbine has to work at lower speeds (150-200 rpm), while the generator has to work at much higher speeds (1200-2000 rpm) [5, 7, 8]. Therefore, a speed increaser with a multiplication ratio of 10 must be placed between the rotor and the generator.

By applying the algorithm presented above, the following values for the gears teeth numbers and efficiency are obtained for an increasing ratio of i=10: z_1=60, z_4=66 and η=77% (see Fig. 6).

The diagrams presented in Fig. 6 were derived from the simulations presented in Fig. 3 and 4, taking into account only the case in which z_1=60 teeth in order to ease the determination of the optimal structural configuration with minimal overall dimensions and maximum efficiency. From constructive and dynamic considerations, only the case in which $z_4>z_1$ was taken into account, in order to minimize the size, weight and inertial effects, implicitly, generated by the moving satellite gear (the central gears 4 are blocked). In the same time, this configuration presents a better efficiency than the second structural variant, when $z_4<z_1$ (see Fig. 7, c. and d).

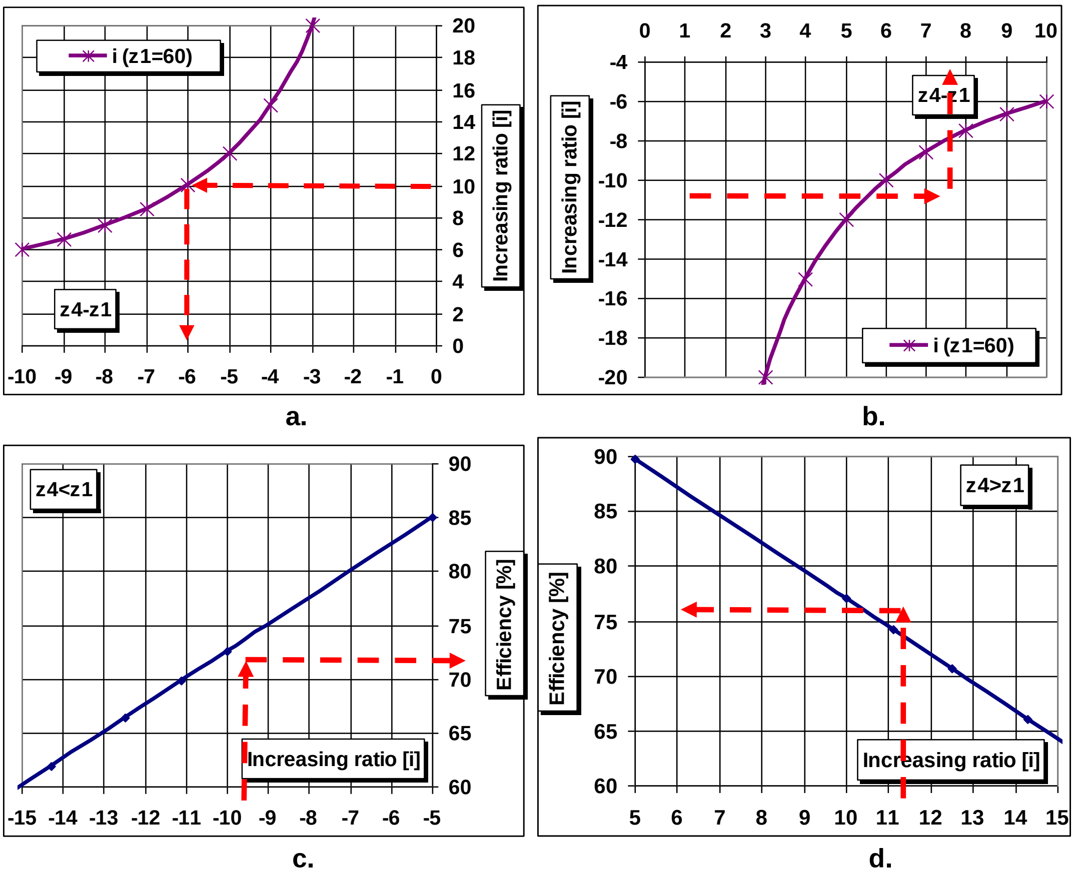


Fig. 6. The variation of the efficiency and transmission ratio as function of the structural configuration (difference between the teeth numbers)

Under these premises the implementation of the constructive variant, made with the aid of the modern CAD/CAE software (AutoDesk Inventor and Dassault Systemes CATIA) is presented in Fig. 8.

CONCLUSIONS AND REMARKS

The following conclusions can be stated:

- the use of the presented innovative planetary transmission with deformable element as speed increaser between the turbine/rotor and generator ensures a good functioning of the whole (wind or micro-hydro) system with high efficiencies, by improving the quality of the whole assembly;

- the transmission works with higher efficiencies as speed reducer, but in micro-hydro plants and small wind turbines it is recommended to be used as speed increaser, because it can run at low increasing ratios (|i|<15) with relatively high efficiencies, in comparison with other solutions;

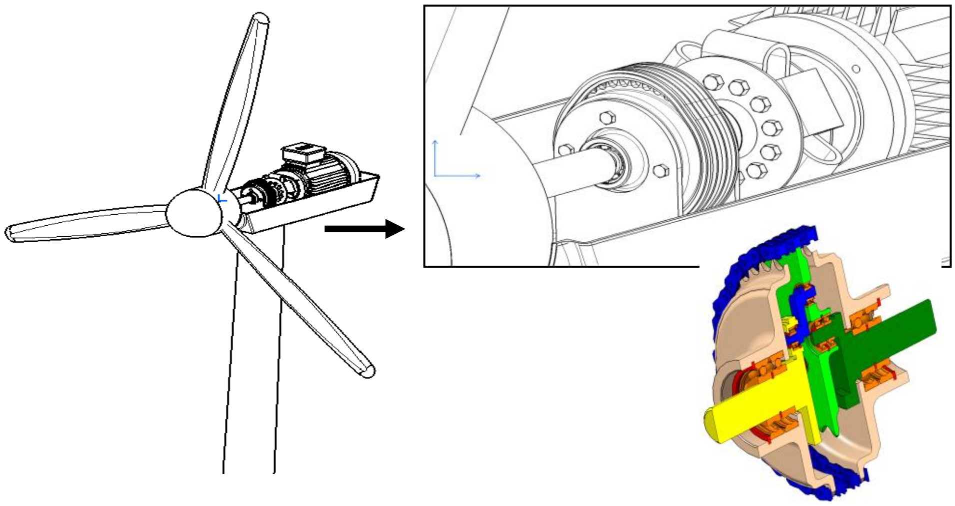


Fig. 7. The virtual prototype of the wind turbine

- in the same working conditions, the transmission presents better efficiencies when the central gears are larger ($z_4>z_1$), than in the second case, when the satellite gear is larger ($z_1>z_4$);
- the use of the structural solution with the larger central gears fixed ($z_4>z_1$) is recommended due to the constructive and dynamic reasons;
- in both running cases (as speed increaser and as speed reducer) the efficiency of the transmission decreases with the increase of the of the transmission ratio;
- the coverage of the gears ensures an increased loading capacity/power density;
- the presented transmission structure ensures the interchangeability of the components, and, in the same time, allows the fine setting of the transmission ratios with high efficiencies and reduced overall dimensions, in comparison with other existing solutions.

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