GEAR RATIOS OF DOUBLE STEP MULTIPLIERS FOR WIND TURBINES FROM MINIMUM VOLUME CONDITION

Cristina Bozan, Radu Velicu, Gheorghe Moldovean

Abstract: *The speed multiplier is one of the most important parts of the wind turbines transmission. In comparison with other kind of gear transmissions the speed multiplier of the wind turbines has some main characteristics: the input torque is bigger than the output torque, the input rotation is smaller than the output rotation, the weight and the overall dimensions must be as reduced as possible. This paper presents possible solutions of speed multipliers for wind turbines and how the transmission ratio must be divided on the two gear steps, considering the criterion of minimum volume of gears, for each of the possible solution*
Key words: *gear ratio, minimum volume.*

1. INTRODUCTION

The sustainable energy sources offer an inexhaustible energy potential and are available immediately. The utilization of sustainable resources will lead to a higher acceptance of renewable and to the spread of their use worldwide. This development is an important contribution to protecting the global eco-system and for improving the quality of life.

As long as there is sunlight, there will be wind. The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas. Wind energy is transformed in electricity by means of the wind turbines. One of the main elements of the power transmission of the wind turbine is the speed multiplier.

Since the rotor blade rotation is low the gearbox (multiplier) is used with the aim to rich higher values of the rotational speed needed by the electric generator in order to produce the electrical power.

In order to define the basic notions that are to be used in this paper, a two steps external cylindrical gear is presented in figure 1.

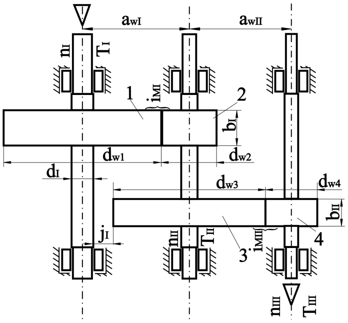


Fig.1. Two steps external cylindrical gear common speed multiplier

The symbols used can be defined as follows:

- a_{wI} – centre distance for step I;
- j_I – clearance between the wheel from step II and the low-speed shaft from step I;
- i_{MI} – multiplier ratio in step I;
- i_{MII} – multiplier ratio in step II;
- a_{wII} – centre distance for step II;

For gear calculation, gear ratios are:

$$u_I = i_{MI}; u_{II} = i_{MII} = \frac{i_M}{i_{MI}}; i_M = u_I u_{II} \quad (1)$$

The process of optimization of a transmission with several gears is mainly based on choosing the right gear ratio for each of the consisting steps of the transmission. Many studies [1, 3, 4, 8, 9] have been developed in order to optimize the choose of the gear ratios of the consisting gears of a transmission, starting with different criteria, like: minimal summed centre distances, minimal volume of gears, minimal length, minimal width, minimal weight, minimal area of the frontal section of the transmission.

2. SOFTWARE

In this paper we try to optimize a transmission with several gears used in the multiplier of a small or medium wind turbine. The process of optimization is mainly based

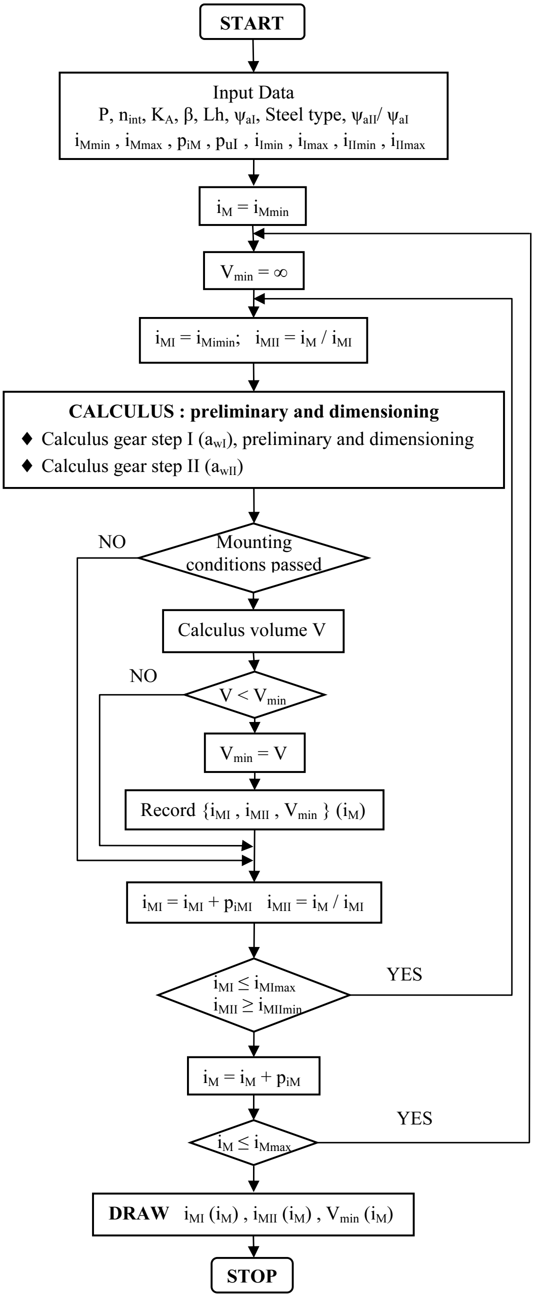


Fig.2. Logical flow

on choosing the right gear ratio for each of the consisting steps of the transmission. Based on the logical flow from fig. 2, software was developed for determining optimal gear ratio considering the criterion of minimal volume of gears. The structural models analyzed are: two steps external cylindrical gear common speed multiplier (fig.1), two steps coaxial external cylindrical gear (fig.3), two steps internal external common cylindrical gear (fig.4), two steps internal external cylindrical gear with coaxial input and output shafts (fig.5).

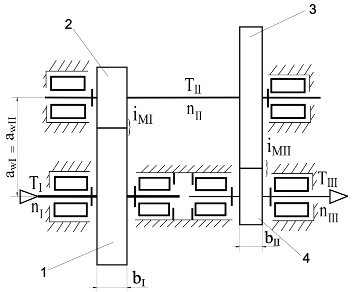


Fig.3. Two steps coaxial external cylindrical gear

This paper is dealing with choosing the optimized gear ratios of the consisting gears of double steps speed multiplier, in different constructive solutions. In this case the problem is a little different, even if calculation of a speed multiplier can be developed on the speed reducer obtained by movement inversion output torque for speed multiplier being input torque for speed reducer. In the case of speed reducers one of the inputs for determining optimized gear ratios is a constant input torque T_{inp}. In the case of speed multipliers a constant input torque T_{inp} means, for different transmission ratios, different output torques, so different input torque for the reversed speed reducers.

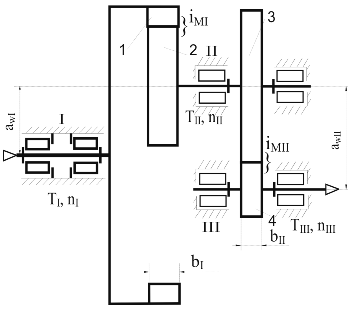


Fig.4. Two steps internal external cylindrical gear

The main imposed restrictions for the consisting cylindrical gearings are [7]:

- Avoiding the teeth profile interference;
- Achieving a minimum transverse contact ratio of $\varepsilon_{\alpha min}$=1.3;
- Avoiding the sharpening of the gearing wheels teeth $s_{a1} \geq s_{amin}$ and $s_{a2} \geq s_{amin}$;
- Choosing the minimal normal module according to the applied treatment. (m_{nmin} =1.5 mm, for case hardening, respectively m_{nmin} = 2.0 mm, for cementation or nitrating);
- The actual stresses for the two main stress types should not be bigger then the corresponding permissible stresses, $\sigma_H \leq \sigma_{HP}$; $\sigma_{F1} \leq \sigma_{FP1}$, $\sigma_{F2} \leq \sigma_{FP2}$;
- Tolerance of actual transmission ratio relative to imposed transmission ratio is ±3%;
- The gear ratio must be in the range of (1.5…8) for external gears and in the range of (2.5…10) for external gears.

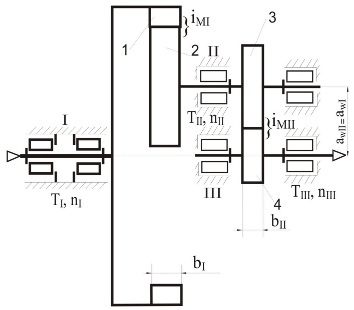


Fig.5. Two steps coaxial internal external cylindrical gear

The imposed clearance, in the case of the common double step speed multiplier with external gears, presented in fig. 1 [5], the mounting condition is

$$j_I = a_{wI} - d_I/2 - d_{w3}/2 \geq j_{I\min} = 15...20\,mm. \qquad (2)$$

In the calculus is taken into consideration the fact that the internal wheel is ring shape.

3. CONCLUSIONS

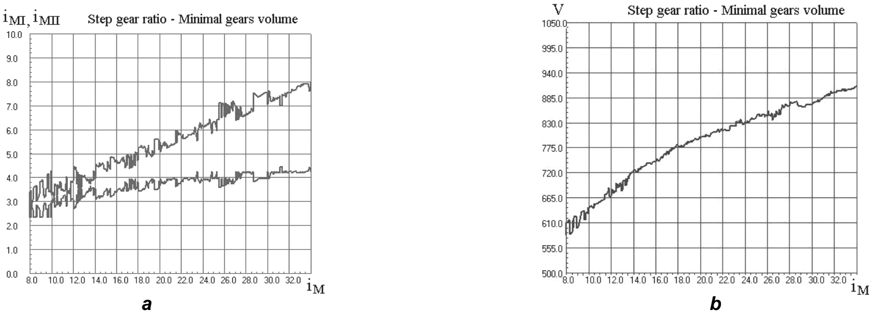
Calculations have been developed for a speed multiplier with the following inputs: input power $P = 30\ kW$, input rotational speed $n_{inp} = 100\ rot/\min$, application factor $K_A = 1.1$, helix angle for both gears $\beta = 0^0$, total imposed running time $L_h = 10000\ h$, width coefficient $\psi_{aI} = 0.3$, width coefficient ratio $\psi_{aII}/\psi_{aI} = 0.8$, $u_{min} = 1.5$ for external gears and $u_{min} = 2.5$ for internal gears, permissible torsion stress for shaft pre-dimensioning $\tau_{atI} = 40\ MPa$, clearance $j_I = 15$, gears are made of cementation steel with $\sigma_{H\lim} = 1500\ MPa$, $S_{H\min} = 1.25$, $\sigma_{F\lim} = 500\ MPa$, $S_{F\min} = 1.56$.

The graphic from figure 6.a. is the representation of optimized gear ratios of the consisting gear steps, depending on the global transmission ratio, in the case of the two steps common external cylindrical gear speed multiplier (see fig. 1).

The diagram from fig. 6.b is the variation of volume *V*, in the case of the same speed multiplier.

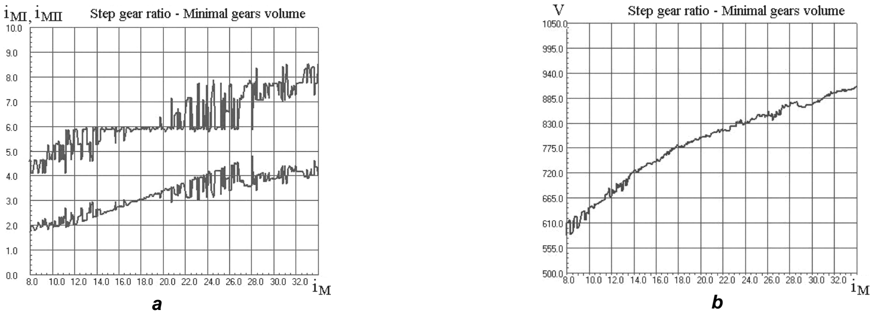
For the case of the two steps internal-external cylindrical common gear speed multiplier (see fig. 4), figures 7.a and 7.b are obtained where are represented the diagrams for optimized gear ratios respectively volume, depending on the global transmission ratio.

The following general conclusions can be drawn from the presented results:



a ***b***

Fig. 6. Two steps common external cylindrical gear speed multiplier



a ***b***

Fig. 7. Two steps common internal- external cylindrical gear speed multiplier

- The optimized gear ratios of the consisting steps are constantly increasing with the imposed global transmission ratio;

- The gear ratio of the second step is usually bigger than the one in the first step regardless of the construction type;
- The volume values variation increases with the imposed global transmission ratio;
- The volume values variation of internal-external gears speed multipliers is smaller than for external-external gears speed multipliers.

The non-uniformity of graphics for the gear ratios value comes from variables with prescribed values (round number of teeth, standardized modules), restrictions and mounting conditions.

REFERENCES

[1] Abuid, B.A., Ameen Y.M. Procedure of optimum design of a two-stage spur gear system, JSME Intl. J. Series C, Vol. 46 No 4 (2003), 1582-1590.

[2] Bozan C. A., Moldovean G., Velicu, R. Structural synthesis on speed multiplier with fixed axis gearing used in wind turbine, Transilvania University Bulletin, Brasov (2008), 75-80.

[3] Bozan C. A., Velicu, R., Moldovean G. Transmission ratio of double steps speed multipliers for wind turbines, Proc. of Power Transmission, Kallithea, Greace (2009), 149-154.

[4] Božidar R. Multicriterion optimization of multistage gear train transmission, Facta Universitatis, University of Belgrade, Mech. Eng. Vol.1, No 8, 2001, 1107 – 1115.

[5] Miloiu, G., Dobre, G., Visa, F., Vintila, H. Optimal design of two step gear units, regarding the main parameters, VDI Berichte No 1230, 1996, 227-244.

[6] Moldovean G., Bozan, C. A., Velicu, R. On the overall dimension of speed multiplicators with cylindrical gears used for small power wind turbines. Proc. of CSE Conference, Brasov, Romania (2008), 463-468.

[7] Moldovean G. et al. Angrenaje cilindrice si conice. Metodici de proiectare, Editura Lux Libris, 2002.

[8] Ngoc Pi V. A study on optimal determination of partial transmissions ratios of helical gearbox with second-step double gear-sets, Proc. of World Academy of Science, Vol. 27 (2008), 113-116.

[9] Ngoc Pi V. Optimal calculation of partial transmission ratios of four-step helical gearbox for getting minimal gearbox length, Proc. of World Academy of Science, Vol. 27 (2008), 109-112.

[10] *** Kisssoft AG – Development plants. www.kisssoft.ch.

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The paper is reviewed