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EFFICIENCY CALCULATION OF PARTS IN CLOSED CIRCUIT WITH SPUR-BEVEL GEARBOXES

VÝPOČET ÚČINNOSTÍ ČLENŮ UZAVŘENÉHO OKRUHU S KUŽELOČELNÍMI PŘEVODOVKAMI

Abstrakt

Uzavřený zkušební okruh. Tok výkonu v uzavřeném okruhu. Výpočet účinnosti agregátů v nehnané větvi okruhu. Výpočet účinnosti agregátů ve hnané větvi okruhu. Účinnost v závislosti na měřených veličinách.

Annotation

Closed testing circuit. Power flow in a closed circuit. Efficiency calculation of aggregates in non-driven branch of a circuit. Efficiency calculation in a driven branch of circuit. Efficiency according to measured values.

Efficiency calculation is the very important point for analysis of the power flow in a closed testing circuit. Calculation is going from measured values of torque moments and revolutions on the relevant connecting shafts H_1 and H_4.

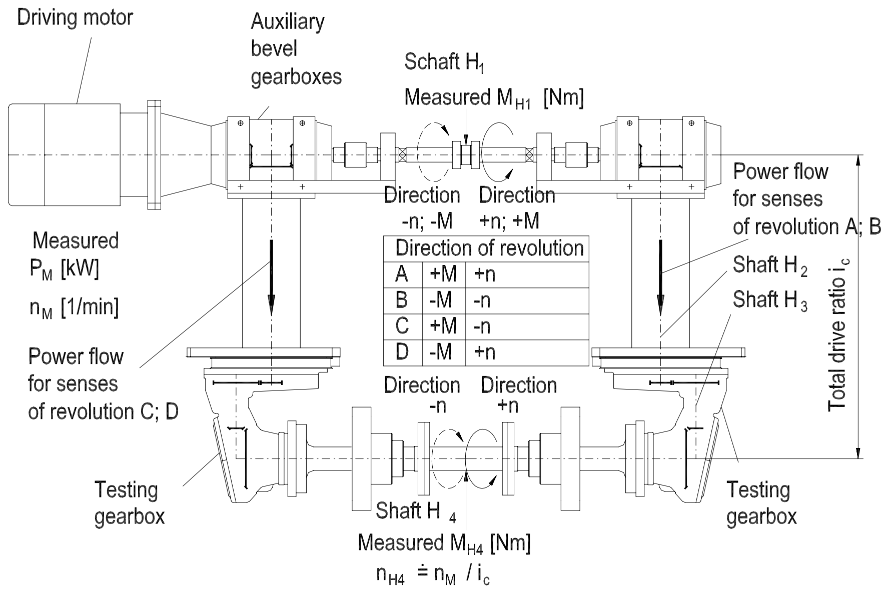

Fig. 1

Closed testing circuit with spur-bevel and bevel gearboxes is shown in fig.1. There are marked meassured places and power flow directions according to the sense of torque moment and the sense of revolutions. Sense of power flow was analyzed in [1]. Auxiliary gearboxes have bevel gears with

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straight teeth. Spur-bevel gearboxes A_1 and A_2 have bevel gears with curved teeth with middle angle of the helix $\beta_m \approx 30^\circ$ (Gleason gear) so effficiency is also dependet on sense of revolutions, because pinions of bevel pairs of constituent gearboxes are alternately pulled and pushed from a mesh.

Direction of the power flow in the non-driven branch of the circuit for sense of loading *A,B* is shown in fig. 2 and direction of the power flow in the driven branch of the circuit for sense of loading *C, D* is shown in fig. 3.

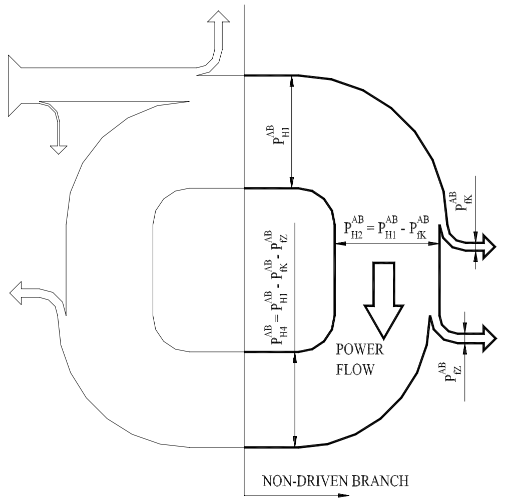

Fig. 2

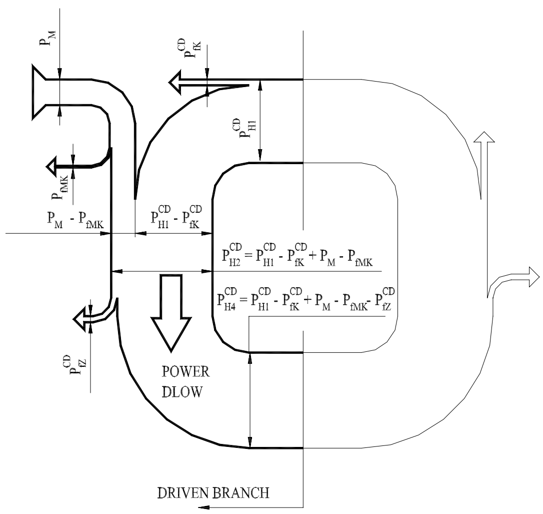

Fig.3

There are signs in the fig. 2 and fig.3:

P_{H1}^{AB}, P_{H1}^{CD} ...... power on the shaft H_1 got from measured torque M_{H1} and revolutions n_{H1}

P_{H4}^{AB}, P_{H4}^{CD} ...... power on the shaft H_4 got from measured torque M_{H4} and revolutions n_{H4}

P_{fK}^{AB}, P_{fK}^{CD} ...... power loss in auxiliary gearboxes

P_{fZ}^{AB}, P_{fZ}^{CD} ...... power loss in testing gearboxes

P_M .... electric power

P_{fMK} .... power loss given by transfering power to the closed circuit (mechanical loss of the motor and one gear of the auxiliary gearbox).

Note: Superscripts *A;B* and *C;D* define sense of the loading according to fig. 2 and 3.

Equilibrium of the power flow for sense of the loading *AB*:

$$P_{H1}^{AB} = P_{H4}^{AB} + P_{fK}^{AB} + P_{fZ}^{AB} \quad . \tag{1}$$

Equilibrium of the power flow for sense of the loading *CD*:

$$P_{H1}^{CD} + P_M - P_{fMK} = P_{H4}^{CD} + P_{fK}^{CD} + P_{fZ}^{CD} \quad . \tag{2}$$

Powers P_{H1}^{AB}, P_{H4}^{AB}, P_{H1}^{CD} and P_{H4}^{CD} are calculated from meassured torques and relevant revolutions from the general relationship:

$$P = M_k \cdot 2 \cdot \pi \cdot n \,. \quad (3)$$

Efficiency in non-driven branch of the closed circuit will be according to (1):

$$\eta_C^{AB} = \frac{P_{H4}^{AB}}{P_{H1}^{AB}} = \frac{P_{H1}^{AB} - P_{fK}^{AB} - P_{fZ}^{AB}}{P_{H1}^{AB}} = 1 - \frac{P_{fK}^{AB} + P_{fZ}^{AB}}{P_{H1}^{AB}} = \eta_K^{AB} \cdot \eta_Z^{AB} \,, \quad (4)$$

where

$$\eta_K^{AB} = \frac{P_{H1}^{AB} - P_{fK}^{AB}}{P_{H1}^{AB}} = 1 - \frac{P_{fK}^{AB}}{P_{H1}^{AB}} \,, \quad (5)$$

$$\eta_Z^{AB} = \frac{P_{H1}^{AB} - P_{fK}^{AB} - P_{fZ}^{AB}}{P_{H1}^{AB} - P_{fK}^{AB}} = 1 - \frac{P_{fZ}^{AB}}{P_{H1}^{AB} - P_{fK}^{AB}} \,. \quad (6)$$

Efficiency in the driven branch of the closed circuit will be according to (3):

$$\eta_C^{CD} = \frac{P_{H4}^{CD}}{P_{H1}^{CD} + P_M - P_{fMK}} = \frac{P_{H1}^{CD} + P_M - P_{fMK} - P_{fK}^{CD} - P_{fZ}^{CD}}{P_{H1}^{CD} + P_M - P_{fMK}} = 1 - \frac{P_{fK}^{CD} + P_{fZ}^{CD}}{P_{H1}^{CD} + P_M - P_{fMK}} = \,, \quad (7)$$
$$= \eta_K^{CD} \cdot \eta_Z^{CD}$$

where

$$\eta_K^{CD} = 1 - \frac{P_{fK}^{CD}}{P_{H1}^{CD} + P_M - P_{fMK}} \,, \quad (8)$$

$$\eta_Z^{CD} = 1 - \frac{P_{fZ}^{CD}}{P_{H1}^{CD} + P_M - P_{fMK} - P_{fK}^{CD}} \,, \quad (9)$$

$$\eta_{MK} = 1 - \frac{P_{fMK}}{P_M} \,. \quad (10)$$

According to (10) will be:

$$P_{fMK} = (1 - \eta_{MK}) \cdot P_M \,. \quad (11)$$

Efficiency in the non-driven branch of the closed testing circuit can be described by torque moments:

$$\eta_C^{AB} = \eta_K^{AB} \cdot \eta_Z^{AB} = \frac{M_{H4}^{AB}}{i_K \cdot i_Z \cdot M_{H1}^{AB}} \,. \quad (12)$$

For the driven branch:

$$\eta_C^{CD} = \eta_K^{CD} \cdot \eta_Z^{CD} = \frac{M_{H4}^{CD}}{i_K \cdot i_Z \cdot \left(M_{H1}^{CD} + \eta_{MK} \cdot M_M\right)} \,. \quad (13)$$

For measuring results of torque moments in the concrete range M_{H4} is made out linear regression and it is possible to calculate, according to equations (12) and (13), middle values of a total efficiency in constituent branches of the circuit. Next possible step is to describe relationship between the total efficiency and the torque moment by linear regression:

$$\eta_C = a + b \cdot M_{H4} \,, \quad (14)$$

Measuring for different senses of loading may run on different levels of torque moments, but the efficiency is needed to define on one level of the torque moment. It is possible by using the equation (14).

Sum of all power losses is covered by power of motor in closed circuit. We suppose that power losses of constituent aggregates is not depended on the sense of the power flow:

$$P_M \cong P_{fMK} + P_{fK}^{AB} + P_{fZ}^{AB} + P_{fK}^{CD} + P_{fZ}^{CD} \ . \quad (15)$$

Sum of power losses in shown case according to fig. 1 $P_{fK} + P_{fZ}$ also depends on the sense of pinion loading in the constituent branches of the bevel gear of the tested gearbox, because there are gears with curved teeth. At directions of loading *A* and *C* the pinion is pulled to a mesh, came up to get worse mesh conditions. Efficiency in this sense of loading is worse then in the sense C and D, when the pinion is pushed from mesh due to curved teeth.

It is necessary to make conditions, that values of power losses $P_{fK} + P_{fZ}$ are comparable at a specific combination of a flow in both branches. Power losses can be separated in constituent aggregates:

$$P_{fK}^{A} + P_{fZ}^{A} \cong P_{fK}^{C} + P_{fZ}^{C} \ , \quad (16)$$

$$P_{fK}^{B} + P_{fZ}^{B} \cong P_{fK}^{D} + P_{fZ}^{D} \ . \quad (17)$$

For auxilineary gearboxes, where bevel gears with straight teeth are used:

$$P_{fK}^{A} \cong P_{fK}^{B} \cong P_{fK}^{C} \cong P_{fK}^{D} = P_{fK} \ . \quad (18)$$

Total losses and supposed power of the motor for constituent senses of loading can be calculated:

$$P_M \cong P_{fMK} + P_{fK} + P_{fZ}^{A} + P_{fK} + P_{fZ}^{C} \ , \quad (20)$$

$$P_M \cong P_{fMK} + P_{fK} + P_{fZ}^{B} + P_{fK} + P_{fZ}^{D} \ . \quad (21)$$

For these suppositions and approximations of efficiency of auxiliary bevel aggregates it can be determined efficiency of the tested aggregate and the technological aggregate.

We can determine loading of constituent aggregates according to determining their efficiencies. Supposed durability of constituent aggregates during testing can be calculated when we know loading spectrum, gear materials and Wohler's curves.

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