SUMMARY

Analysis of non-uniform loading in a marine propulsion gearbox

The aim of the dissertation was to work out the analytical-numerical design methodology of a marine propulsion gearbox. The presented methodology, in combination with modern CAE tools, allows for the determination of sources of non-uniform gear tooth load characteristics. For the needs of the following dissertation, a large number of analyses and simulations were carried out in order to identify the most relevant factors influencing non-uniform tooth load character. Based on the calculated results, recommendations for marine gearbox designers were formulated. The additional loads on the toothing produced by external and internal sources are represented in the strength calculation by load factors. Load factors determination methods with different levels of calculation complexity were discussed, and the achieved results were compared.

The first part of the work contains load factors description in addition to recommended values and determination methods presented in accordance with international standard and certification rules. The application factor K_A accounts for dynamic overloads from sources external to the gearing was taken from the torsional vibration analysis (TVA) of the complete drive train. The theoretical basis of the method and dynamic characteristics of marine propulsion line components were presented. Values for the internally generated dynamic loads, represented in the strength calculation by the dynamic factor K_v, was calculated from dynamic analysis of the gearbox. Gearbox modeling and calculations were performed in Multibody Simulation (MBS) software designed for dynamic analysis of any mechanical system. Key assumptions made during physical model structure creation were defined. The modeling techniques and parameters of the dynamic model elements in MBS software were presented. Non-uniform load distribution across the gear face width, introduced in the strength calculation by face load factor K_β, was estimated by the procedure described in ISO 6336-1 (2006), annex E. Thanks to the implementation of this method in the CAE commercial software, it was possible to investigate and identify the most relevant factors for load distribution in a very effective way. Moreover, this dissertation contains a flank line modification design procedure and its verification under manufacturing deviation. The transverse load factor

K_α, accounts for the effects of the non-uniform distribution of transverse load between pairs of teeth that are simultaneously engaged. This load factor was calculated from an isolated dynamic gear model with two degrees of freedom. The calculation was performed in the MBS software environment.

Values of factors determined by means of comprehensive analysis were compared to the results obtained from the simplified calculation and the values recommended by classification societies. In the last part of the dissertation, a comparative analysis of gearbox component strength and system reliability was presented. The calculations were performed for load factors achieved from methods with different levels of accuracy and calculation complexity.

Keywords:

Marine gearbox, Marine propulsion system, Multibody simulation (MBS), Torsional vibration analysis (TVA), Load factors