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Multibody Based Tool for Simulation of the Turbocharger Rotor Dynamics

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Abstract: The turbocharger is a unique example of the rotating machinery. Not only for its very high speed, but also because of its compact design and difficult operating conditions (i.e. high temperature, harsh vibrations, etc.). Moreover, measuring of most parameters characterizing the rotor dynamics is a very difficult task. Thus, it is advantageous to replace the real turbocharger with a computational model and determine the turbocharger rotor dynamics using such a simulation tool.

The first part of the paper describes the theoretical background of the simulation tool. The second part presents the example of the simulation results and the last part discusses the possibility of experimental verification of the simulation tool.

The theoretical background can be divided in to two parts – theory of the hydrodynamic model of the floating ring journal bearing; and the theory of the rotor modeling and modal reduction. The whole model is designed as the uncoupled hydrodynamic model, and the structural solution is used (i.e. the hydrodynamic solution is solved separately and its results are imported to the solution of the rotordynamics itself).

The hydrodynamic model of the floating ring bearing is treated as two separate oil films (i.e. inner and outer oil film). The inner oil film separates the shaft from the floating ring and the outer oil film separates the floating ring from the housing bore. Moreover, the knowledge and experience of our research team were used at the first stage of the development of the turbocharger simulation tool.

The hydrodynamic pressure distribution in the oil film is solved separately for the inner and outer oil film. The solution is based on the nonlinear Reynolds differential equation, which is based on the modified Navier-Stokes equation and continuity equation transformed for cylindrical shape of the bearing oil gap. The basic form of the Reynolds equation is well-known, but more important is the form of the equation after simplifications (Eq. 1) which enables to use the uncoupled solution.

$$\frac{\partial}{\partial x}\left(\frac{h^3}{\eta}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{\eta}\frac{\partial p}{\partial z}\right)=6U\frac{dh}{dx}+12\frac{dh}{dt} \tag{1}$$

The equation is solved by iterative numerical solution, using Gauss-Seidel method. The solution also considers cavitation and pin tilting effect. On the other hand, for the purpose of the hydrodynamic solution, the deformation of the shell and pin is neglected. The pressure distribution depends mainly on the dimensionless oil film thickness, which is described in Eq. 2.

$$H=1+\big(\varepsilon-Z\cdot\gamma\cdot(1-\varepsilon)\big)\cdot\cos\varphi+\delta\cdot Z\cdot\sin\varphi\cdot\sqrt{1-(\varepsilon+(1-\varepsilon)\cdot|\gamma|^2)} \tag{2}$$

The second main part of the theoretical background deals with the modeling of the turbocharger rotor. The rotor is created in three stages; firstly the shaft is discretized by the FE method, then the modal reduction of the FE model is performed, and in the last step the rotor is assembled in the MBS environment.

Several types of results are determined using the simulation model – e.g. bearing eccentricity, floating ring speed, power loss, wheel nose displacement, etc. For example, the Fig. 1 shows the Waterfall diagram of the displacement on the compressor wheel nose. Speeds of the floating rings, rotor and its combination, and their multiples are plotted in the diagram. This type of plot helps to track down the vibration modes and to determine their cause.

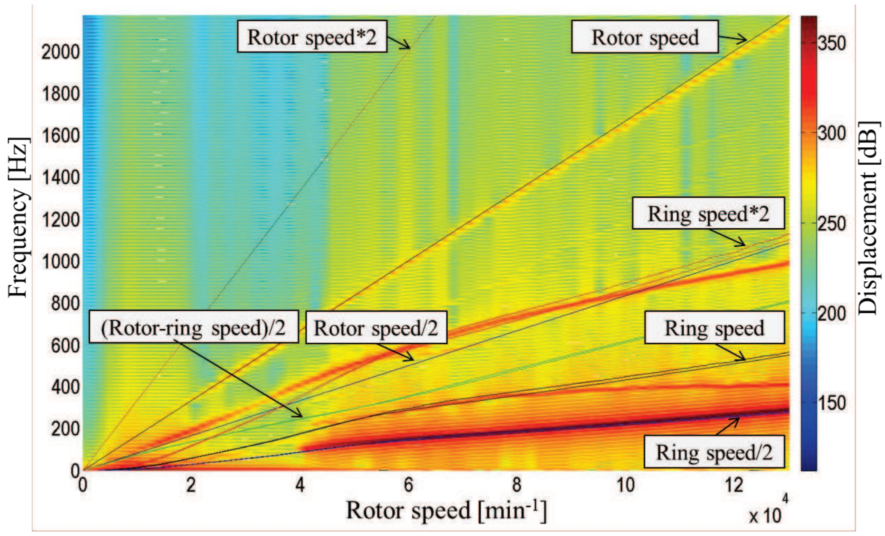

Fig. 1: The Waterfall diagram of the displacement on the compressor wheel nose

Summary

This short paper presents the basics of the turbocharger model developed by our research team. This model aims to help designers to develop new turbochargers quicker, cheaper and more effective combining both simulation and experimental measuring. The current turbocharger model can be considered a foundation for further development and improvement of each part of the model.

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