Quasi-Newton method applied to elastohydrodynamic lubricated cylindrical joints

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Abstract

In this contribution, a Quasi-Newton method is embedded in the time integration process of multibody systems with elastohydrodynamic lubricated cylindrical joints, in order to solve the nonlinear relation between pressure and deformation. For the classical Newmark scheme, it is shown, how this new methodology allows an efficient integration with time step sizes of order $5e-5s$. Furthermore, the used elastohydrodynamic lubrication model is presented. It is based on a finite element discretization of the Reynolds equation. For non-conforming fluid and structure meshes, a consistent and a energy conserving coupling method like in [1], both based on the Mortar method, are compared. The numeric methods are tested with a simulation model of a rigid rotor with unbalance, where one side is elastically supported and the other side by a flexible journal bearing, see Figure 2.

The first part presents the elastohydrodynamic lubricaton model. To solve for the pressure distribution $p(y,z)$ inside the flexible bearing, the Reynolds equation [3] is adapted to the cylindrical joint in the unwrapped bearing shell, see Figure 1. Neglecting terms of second and higher order in the fluid film height $h(y,z)$, following form can be derived:

$$\frac{\partial}{\partial y}\left(h^3\frac{\rho}{\eta}\frac{\partial p}{\partial y}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\rho}{\eta}\frac{\partial p}{\partial z}\right)= \\ 6\rho\left(\omega_2 R_2+\omega_1 R_1\right)\frac{\partial h}{\partial y}+12\rho\left(-\cos(\varphi)\dot{e}_x(z)-\sin(\varphi)\dot{e}_y(z)+\Delta u_2\right)-12\rho\,\omega_2 R_2\frac{\partial \Delta h}{\partial y} \tag{1}$$

The terms $\Delta h(y,z)$ and $\Delta u_2(y,z)$ belong to the elastic deformation of the bearing shell. A numerical solution is obtained by a finite element discretization. For the consideration of cavitation, the Reynolds boundary condition for the pressure is implemented. Therefore, a linear complementary problem is solved. The coupling of fluid pressure and structure displacement is realized by the Mortar method. It is shown, that only a consistent coupling method ensures a small coupling error, when non-conforming meshes for the fluid and structure domain are used [4].

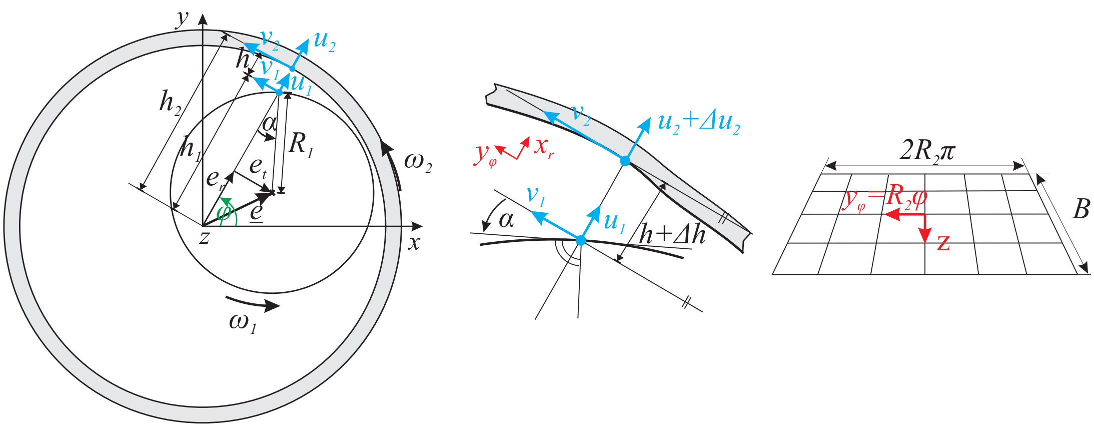

Figure 1: Positions and velocities in the fluid film of a cylindrical joint

The elastohydrodynamic lubrication model gives a nonlinear force $\mathbf{F}(\mathbf{q},\dot{\mathbf{q}})$ depending on the elastic as well as rigid degrees of freedom, which can be included in multibody systems. This is done in the second part of the contribution, where a rigid rotor with unbalance and gyroscopic effects is analysed, see Figure 2. The equations of motion, which have to be solved, have the following form:

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{D}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{Q}(\mathbf{q}, \dot{\mathbf{q}}, t) + \mathbf{F}(\mathbf{q}, \dot{\mathbf{q}}) \tag{2}$$

External forces beside the bearing force are summarized in $\mathbf{Q}(\mathbf{q}, \dot{\mathbf{q}}, t)$. For the time integration of this system, the well-known implicit Newmark scheme using the trapezoidal rule is applied [5]. The implicitness of the integration scheme guarantees robustness, since the force of the flexible journal bearing is highly nonlinear. As a consequence, a nonlinear residual equation has to be solved, which is done by a Quasi-Newton method as suggested in [2] for fluid structure interaction. It is to mention, that a classical Newton-Raphson method is hardly applicable, since the Jacobian would have to be calculated by finite differences, which would be very time consuming, since the system has many elastic degrees of freedom (more than 1000) and the evaluation of the bearing force itself is already very expensive.
A side effect of this contribution is to see, how the elasticity of the bearing shell changes the pressure distribution and hence influences the dynamic behaviour of the rigid rotor.

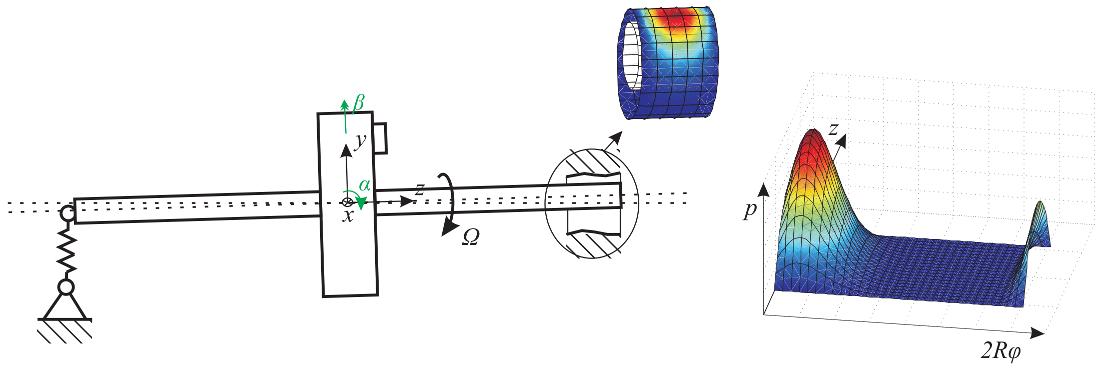

Figure 2: Rigid rotor with flexible journal bearing on the right end with typical pressure distribution

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