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DAMPER BEARING ROTORDYNAMICS

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INTRODUCTION

High side loads reduce the life of the Space Shuttle Main Engine (SSME) High Pressure Oxygen Turbopump (HPOTP) bearings. High stiffness damper seals have been recommended to reduce the loads on the pump and turbine end bearings in the HPOTP (Tecza, et al., 1989). The seals designed for use on the pump end are expected to adequately reduce the bearing loads; the predicted performance of the planned turbine end seal is marginal. An alternative to the suggested turbine end seal design is a "damper bearing" with radial holes from the pressurized center of the turbopump rotor, feeding a smooth land region between two rough-stator/smooth-rotor annular seals. An analysis has been prepared to predict the leakage and rotordynamic coefficients (stiffness, damping, and added mass) of the damper bearing. The following paragraphs describe:

1) governing equations of the seal analysis which has been modified to model the damper bearing,
2) differences between the upstream conditions of the damper bearing and a typical annular seal,
3) predictions of the damper bearing analysis, and
4) assumptions of the analysis which require further investigation.

GOVERNING EQUATIONS

The governing equations for the bulk-flow model of an annular seal with incompressible flow have been published by other authors (e.g., Childs, 1984, and Nelson and Nguyen, 1987): the continuity equation, and axial and circumferential momentum equations. The equations define the relationship between the clearance, pressure, axial velocity, and circumferential velocity (H, p, U_z, and U_θ) as functions of the spatial variables θ and z, and time t. Assuming small motion of the seal rotor about a centered position within the stator, a perturbation analysis is used to develop zeroth-and first-order perturbation equations. The zeroth-order solution provides the zero-eccentricity flow conditions (including the seal mass-leakage flow rate), with rotor rotation but without precession. Pressure perturbation values, part of the first-order solution, are integrated to provide the reaction forces on the rotor due to the assumed "small" circular orbit. The seal stiffness, damping, and added mass coefficients are related to the reaction forces on the rotor by the following equations:

$$F_r = - K - c\omega + M\omega^2 \, ,$$
$$F_\theta = k - C\omega$$

In the above equations, F_r and F_θ are the radial and tangential (i.e., tangential to the rotor "orbit") forces on the rotor, K and k are the direct and cross-coupled stiffness coefficients of the seal, C and c are the direct and cross-coupled damping coefficients, M is the "added mass", and ω is the orbit frequency in rad/sec. The cross-coupled coefficients account for the fact that motion in one direction causes a force component perpendicular to the motion. If the tangential force is positive, it acts to support forward whirl (whirl in the direction of rotation), a destabilizing effect. The cross-coupled stiffness increases with an increasing fluid circumferential velocity component.

UPSTREAM CONDITIONS

The upstream conditions of the proposed damper bearing differ from those of the typical damper seal. For a damper seal, the upstream pressure is assumed constant; i.e., the assumed whirl motion does not cause a perturbation in the upstream pressure. The upstream fluid "reservoir" is assumed to have a nonzero circumferential component ("swirl") due to the rotation of the rotor, but no axial velocity. For the damper bearing, there are actually two seals, with the same inlet conditions. The exit pressures at the ends of the damper bearing are assumed equal. The total pressure upstream of each seal is the sum of the rotor internal pressure and the pump head due to the rotating feed holes, less the losses through the feed holes and the losses due to turning of the flow from the radial direction to the axial direction. The losses are functions of the flow velocity through the feed holes, as is the pump head if the angle of the feed holes from the radial direction is nonzero. If the feed holes are drilled at an angle opposite to the direction of rotor rotation, the swirl upstream of the seals is lower than for zero angle holes, which reduces the destabilizing cross-coupled stiffness of the seal. For a whirling rotor, the flow through the "tight" side of the seal is lower than the flow through the "wide" side. If the feed holes are drilled to reduce upstream swirl, the perturbation in the pump head and losses upstream of the damper bearing would result in a larger local pressure drop through the tight side of the seal than on the wide side. This perturbation in the upstream pressure has been included in the damper bearing analysis, and is the main difference between the damper seal and damper bearing analyses.

PREDICTIONS

The analysis has been programmed in FORTRAN, and runs in less than a minute on a personal computer. Using data from Tecza et al., and an inlet feed angle of 30 degrees from the radial direction for eight feed holes, the predicted stiffness is more than twice that predicted for the turbine end damper seal proposed by Tecza et al., (1,500,000 lb/in compared to about 700,000 lb/in), an improvement in load carrying capacity. The predicted cross-coupled stiffness (160,000 lb/in) is about 10% of the direct stiffness, as required by Tecza et al., and the direct damping is higher than required (210 lbs/in compared to a requirement of 125 lbs/in).

RECOMMENDATIONS

Based on the predictions of the present analysis, the damper bearing is preferable to the damper seal proposed by Tecza, et al. However, two aspects of the model which should be investigated further are:

1) the inlet loss model, and
2) the wall shear stress model.

Previous experimental and analytical work on annular seals in compressible flow have shown that the choices of an inlet loss model and wall shear stress model have significant effects on seal rotordynamic predictions. For example, two models with different inlet loss and wall shear stress (or friction factor) models may predict seal leakage within a few percent of experimental data, but stiffness coefficients that differ by an order of magnitude.

REFERENCES

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