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DISK FLEXIBILITY EFFECTS ON THE ROTORDYNAMICS OF THE SSME HIGH PRESSURE TURBOPUMPS

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Introduction

Rotordynamical analyses are typically performed using rigid disk models. Studies of rotor models in which the effects of disk flexibility have been included indicate that it may be an important effect for many systems. This work addresses this issue with respect to the Space Shuttle Main Engine high pressure turbopumps. Finite element analyses have been performed for a simplified free–free flexible disk rotor model and the modes and frequencies compared to those of a rigid disk model. Equations have been developed to account for disk flexibility in rotordynamical analysis. Simulation studies have been conducted to assess the influence of disk flexibility on the HPOTP. Some recommendations are given as to the importance of disk flexibillity and for how this project should proceed.

Research Accomplishments

This research effort has accomplished the following tasks.

1.) A simplified finite element model of the HPOTP rotor has been developed. This model accounts for the flexibility of the first and second turbine stage disks. All the other rotor disks are modelled as rigid structures.

2.) Equations have been derived that include the effects of disk flexibility on rotordynamical behavior. The equations are quite similar in form to those typically used for rigid disk models, but two additional matrix terms are included. The resulting equations are of the form:

$$\{\ddot{q}_y\} + \Omega[\Gamma + A]\{\dot{q}_z\} + [\omega_n^2 + \Omega^2 B]\{q_y\} + \text{(damp. and intercon. terms)} = \{0\}$$

$$\{\ddot{q}_z\} - \Omega[\Gamma + A]\{\dot{q}_y\} + [\omega_n^2 + \Omega^2 B]\{q_z\} + \text{(damp. and intercon. terms)} = \{0\}$$

The two additional terms in these equations, A and B, are modal integrals over each rotor disk and reduce to the corresponding rigid term when the rigid disk modes are used. Axial coupling effects are neglected in this development.

3.) Modifications to include disk flexibility in the current rotordynamical analysis package have been implemented. **Stab** and **Tran** have been modified and appropriate data files have been generated to incorporate disk flexibility effects.

4.) A number of simulation and parameter variation studies have have been performed. The revised rotordynamical analysis programs have been tested with modal data from a simplified rotor finite element model. (HPOTP phase 1 rotor with flexible turbine stage disks) Eigenanalyses indicate that flexible disk effects are exhibited at frequencies significantly above the operating speed range of the HPOTP. Only minor effects are observed for synchronous vibration. Transient studies in which rub and bearing deadband are incorporated into the turbine interstage seal were also conducted (using TRAN). These studies indicate that the excitation of high frequency modes can lead to predictions of signficantly different dynamical behavior by rigid and flexible disk rotor models.

Recommendations

1.) Include disk flexibility effects in rotordynamical analyses in which supersynchronous frequencies are of interest.

2.) Develop a technique to modify contractor supplied free–free rotor frequencies and mode shapes to account for disk flexibility effects. This would serve to simplify the finite element work required to implement the analysis procedure and to insure compatibility between NASA analyses and contractor analyses.

3.) Extend the analysis procedure to include axial coupling effects.

4.) In order to develop further physical insight into the effect of rotor disk flexibility, construct appropriately scaled rotor models and study their responses using a rotor test kit.

5.) Examine dynamic data from SSME engine tests to determine if any 'anomalous' behavior can be related to disk flexibility effects.