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13. ABSTRACT (Maximum 200 words)

Annual reports from the two current research investigators, Professors Dara Childs and Alan Palazzolo, are presented. The reports describe progress by two AFRAPT-supported Ph.D. students, George Kleynhans and Timothy Barrett. The two research topics are "Gas Honeycomb Annular Pressure Seal Analysis," and "Reanalysis and Probabilistic Design for Frequency Dependent Square Lambda Matrices."

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AFRAPT RF6802

Gas Honeycomb Annular Pressure Seal Analysis

1995 - 1996 Annual Report - AFRAPT

Objectives

This research effort was designed to provide a better analysis tool (computer code) to predict the leakage and rotordynamic characteristics for gas honeycomb annular pressure seals. The objective was met by: (a) incorporating a new turbulent viscous shear stress model for the honeycomb surface and comparing it with previous models and experimental measurements and (b) mechanizing a 2-control-volume for flow in honeycomb seals. The new turbulent viscous shear stress model was anchored to experimental data obtained from a new test apparatus designed to measure the drag torque on annular seals.

Status of Effort

The program has been completed. The test apparatus was used to measure friction-factor data for shear-driven flow. Data from the test program were incorporated into a 2-control-volume model for transient flow within honeycomb seals. The new model predicts a strong frequency dependency for the reaction-force components. Comparison between measurements and predictions with the new theory show generally good agreement; however, available data are valid over a small frequency range (40 ~ 70 Hz) versus a desired range out to 500 Hz. Mr. Kleynhans received his Ph.D. in May of 1996 and is now employed at Lufkin industries in Lufkin, Texas.

Accomplishments/New Findings

The new analysis predicts that the honeycomb cell depths serve to decrease the effective sonic speed within the seal so that resonances can be created within the frequency range of interest for rotordynamics. Because of this phenomenon, the traditional linear differential equation of motion (Stiffness, Damping, and Mass) used to model the force/motion relationship can no longer be applied, and a new transfer function model was derived.

Personnel Supported

George Kleynhans (Ph.D., May 1996)

Publications

Kleynhans, G., and Childs, D., "The Acoustic Influence of Cell Depth on the Rotordynamic Characteristics of Smooth-Rotor/Honeycomb-Stator Annular Gas Seals," ASME Paper No. 96-GT-122, accepted for publication in the *Journal of Engineering for Gas Turbines and Power*.

Interactions/Transitions

a) Presentation: The results of this research were presented at the 1996 ASME Gas Turbine Conference, Birmingham England.

B) Transitions: Based on the results of this research, a proposal (see attached Proposal Cover Page) was submitted to private manufacturers and users of centrifugal compressors. A new 2-year project will be launched in March 1997 with twelve industrial sponsors to verify the predicted strong frequency dependency of the rotordynamic coefficients. If verified, the results may allow the addition of more stages to back-to-back centrifugal compressors.

New Discoveries, Inventions, or Patent Disclosures

None

Honors/Awards

None

AN R&D PROGRAM TO DEVELOP VALIDATED COMPUTER PREDICTION CODES FOR HONEYCOMB STATOR AND HOLE-PATTERN STATOR ANNULAR GAS SEALS

Abstract

A two-year test program is proposed for validation testing of honeycomb and hole-pattern stator seals. An existing apparatus will be modified for testing, with supply pressures of 250 psi (17 bars) and speeds out to 20,000 rpm with excitation frequencies from 50 to 500 Hz. Seals having a maximum diameter of 4.75 inches (121 mm) and a maximum length of 4 inches (102 mm) will be tested. Four honeycomb seals will be tested for a range of hole-depth to clearance ratios. Two hole-pattern-stator seals will be tested. Test data will consist of direct and cross-coupled, frequency-dependent, complex transfer functions.

Final deliverables from the program will include the test data and a FORTRAN source-code copy of a (presently-available) computer code for predictions of the dynamic characteristics of honeycomb-stator and hole-pattern-stator annular gas seals.

Introduction

Figure 1 illustrates a honeycomb-stator, annular gas seal. The cell size in this illustration is greatly exaggerated for clarity. Honeycomb seals have been used for a long time in turbomachinery to reduce leakage. At the same radial clearance, they leak substantially less than a see-through labyrinth seal. However, there was no clear sense that honeycomb-stator seals could markedly improve rotordynamic characteristics prior to Rocketdyne's use of these seals to eliminate subsynchronous and synchronous vibration problems with the High Pressure Oxygen Turbopump (HPOTP) of the Space Shuttle Main Engine (SSME).

Based on NASA's initial favorable experience, the Turbomachinery Laboratory (TL) at Texas A&M University (TAMU) initiated a NASA-funded research and development program to investigate the dynamic characteristics of honeycomb seals. For small motion about a centered position, the conventional rotordynamic-coefficient model for annular gas seals is

Barrett, T.S., Palazzolo, A.B., Kascak, A.F., "Probabilistic Critical Speed Determination by Receptance Based Reanalysis," Proc. of the 6th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, pp. 272-288, Honolulu, 3/96.

Barrett, T.S., Palazzolo, A.B., "Reanalysis For Probabilistic Rotor Critical Speeds with Gyroscopics and Speed Varying Support Stiffness," paper submitted to Journal of Sound and Vibration.

D. PROFESSIONAL PERSONNEL

Timothy S. Barrett - M.S. Mechanical Engineering, Texas A&M University, Ph.D. completed, dissertation title: "Reanalysis and Probabilistic Design For Frequency Dependent Square Lambda Matrices," Dr. Alan B. Palazzolo*, Associate Professor, Texas A&M University.

Albert F. Kascak*, U.S. Army at NASA Lewis Research Center.

Dr. Y.T. Wu*, Harry Millwater*, Southwest Research Institute.

E. INTERACTIONS AND TRANSITIONS

1. Telephone conversations with NASA Lewis, NASA Marshall, SWRI,
2. New application of probabilistic design to magnetic bearing supported rotors.
3. Timothy Barrett received Ph.D. degree.

of systems with gyroscopic moments and speed dependent parameters.

4. Probabilistic solution of rotor systems supported by magnetic bearings with uncertain transfer functions.
5. Comparison of effects of statistical probability distributions on resultant critical speed prediction.
6. Application of eigensystem reanalysis techniques to advanced sampling methods of Wu, et. al.

B. STATUS

Timothy Barrett graduated with his Ph.D., M.E. in August, 1996 and is currently employed with Boeing, Seattle, Washington. Probabilistic techniques have been studied and implemented to the critical speed problem with great success using bearing stiffness as a random variable. The critical speed extraction algorithm for non-line type structures has been developed and probabilistic results with speed dependent bearing stiffnesses has shown excellent agreement with known solutions. Reanalysis has been shown to reduce computer computational time (CPU time) by a factor of 7, which for a large number of samples is quite significant.

In addition, probabilistic techniques have been applied to magnetic bearing simulations, assuming uncertain transfer function coefficients. This shows a similar level of computation time savings as the probabilistic critical speed problem.

C. PUBLICATIONS

Barrett, T.S., Palazzolo, A.B., Kascak, A.F., "Active Vibration Control of Rotating Machinery Using Piezoelectric Actuators Incorporating Flexible Casing Effects, Journal of Engineering for Gas Turbines and Power, January, 1995, Vol. 117, pp. 176-187.

Reanalysis and Probabilistic Design for Frequency Dependent Square Lambda Matrices

Timothy S. Barrett
Texas A&M University

A. RESEARCH SUMMARY

This research presents a new design methodology for rotordynamic critical speed simulations by accounting for the uncertainty of model parameters. Eigenvalue reanalysis is coupled with probabilistic sampling techniques, i.e. Monte Carlo simulation, and is used to predict probabilities of critical speed occurrence in a specific speed range with the bearing support stiffness and rotor geometry, including bearings preload, treated as random variables described by mean, standard deviation, and distribution type. Speed dependent system properties may also be accommodated with this new procedure. A new receptance based reanalysis approach, including gyroscopic moments, is employed to greatly increase computational efficiency of the approach. The reanalysis procedure is shown to be more efficient than even a transfer matrix based probabilistic approach when applied to line type structures. Results from this new approach far outperform a QR method of eigenvalue extraction applied to the same line type structure, showing that the reanalysis approach is most beneficial for non-line type structure problems which must be solved by QR-Jacobi type methods. Novel contributions of the research include:

1. A new critical speed extraction algorithm for non-line type structures with gyroscopic moments and speed dependent bearing stiffnesses.
2. Development of a reanalysis procedure for undamped pure gyroscopic systems.
3. Development of an efficient reanalysis scheme for critical speeds