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SIMULATION OF CRYOGENIC TURBOPUMP ANNULAR SEALS

Prepared By: Alan B. Palazzolo, Ph.D.

Academic Rank: Associate Professor

Institution and
Department: Texas A&M University
Mechanical Engineering Department

NASA/MSFC:

Office: Structures and Dynamics
Division: Control Systems Division
Branch: Mechanical Systems Control

MSFC Colleague(s): Donald P. Vallely
Steve Ryan
J. Mark Darden

The works of Black(1), von Pragenau(5), Childs(2), and later San Andres(4), have clearly demonstrated the potential that annular seals have for affecting the rotordynamic behavior of pumps. The goal of the current work is to develop software that can accurately predict the dynamic coefficients, forces, leakage and horsepower loss for this type of seal. The fruit of last year's research was the computer code SEALPAL which included capabilities for linear tapered geometry, Moody friction factor and inlet pre-swirl. This code produced results which in most cases compared very well with check cases presented in the literature.

Satya Padavala joined this effort in March 1992 and quickly wrote the code TAMUSEAL I. That code improved SEALPAL by correcting a bug and by adding more accurate integration algorithms and additional capabilities: Moody's and Hir's friction model, and Arbitrary Axial Profile. The reliability of these new features was confirmed by "Hir's", "Wavy Seal" and "Partially Tapered" check cases from the literature, and was reported in;

"Dynamic Coefficients for Incompressible Liquid Annular Seals Including Either Moody's or Hir's Friction Models and Arbitrary Axial Profile," by Palazzolo, A.B. and Padavala, S., June 1992, MSFC Report.

The TAMUSEAL 1 code was then used to predict dynamic coefficients and leakage for the NASA/Pratt and Whitney Alternate Turbopump Development (ATD) LOX Pump's damper seal. The units studied (3-1, 4-1D, 6-1D and 3-1A) had damper seals with converging/diverging axial taper and were modeled with both Hir's and Moody's friction factors. The results showed that the Moody model produced lower stiffnesses than the Hir's, but the difference was small except for extremely divergent seals (4-1D). The results of this study were presented in;

"Simulation Results for Hirs and Moody Models of ATD Units 3-1, 4-1D, 6-1D and 3-1A," by Palazzolo, A., Padavala, S. and Rachamadugu, S., July 13, 1992, MSFC Report.

The theory for eccentric seals was developed during this period following Nguyen and Nelson's(3) work. These authors had employed a Fourier series interpolation in order to implicitly separate out the angular variable from the axial variable, converting the governing steady state partial differential equations (P.D.E.) to ordinary differential equations (O.D.E.). The Fourier interpolation was replaced with a spline based interpolation and the latter approach was significantly more efficient and yielded higher convergence reliability, especially for very eccentric seals. The equations were programmed into

the enhanced code TAMUSEAL II, following an intense derivation verification.

The eccentric capabilities of the TAMUSEAL II code was applied to analyzing the ATD Build 3-1 at 65%, 100% and 115% RPL. The code was run in the prescribed preload mode so that its results yielded the eccentric location of the shaft in the seal due to increasing load along the anticipated side load direction of 290 degrees. The results showed significant changes in most of the dynamic coefficients for side loads greater than 400 lbs. (eccentricity greater than 0.3). A complete summary of results for this study may be found in;

"Results From Study of Eccentric Seal Analysis of ATD Unit 3-1 at 65%, 100% and 115% Power Levels," by Palazzolo, A.B. and Padavala, S., MSFC Report, July 15, 1992.

The capabilities of TAMUSEAL II were next expanded to include variable circumferential profile. This option resulted from the need presented by predicted distortions of the ATD seal obtained from MSFC/Sverdrup finite element results of the entire casing. The following report includes results from a variable circumferential profile simulation of ATD LOX pump unit 3-1 at 115% RPL;

"Simulation of Annular Seals for Cryogenic Turbopumps Including Effects of Arbitrary Profile in the Circumferential and Axial Directions, Eccentricity, Preload an Moody and Hirs Friction Factors," by Palazzolo, A., and Padavala, S., MSFC Report, August 11, 1992.

This report also contains an extensive theoretical manual for TAMUSEAL II, several verification cases for eccentric seals and a complete user's manual for TAMUSEAL II.

Specific conclusions drawn from this work include the following:

TAMUSEAL II results are in good agreement with simulation and test results presented in the literature (see Figure 1)

Eccentricities above approximately 0.4 may have a very significant affect on all dynamic coefficients (see Figure 2)

Variable profile and choice of friction factor models may significantly influence dynamic coefficients, especially at high divergence or eccentricity.

Future work in this area includes variable fluid properties, thermal-elasto-hydrodynamic modeling, transient force determination and friction factor testing.

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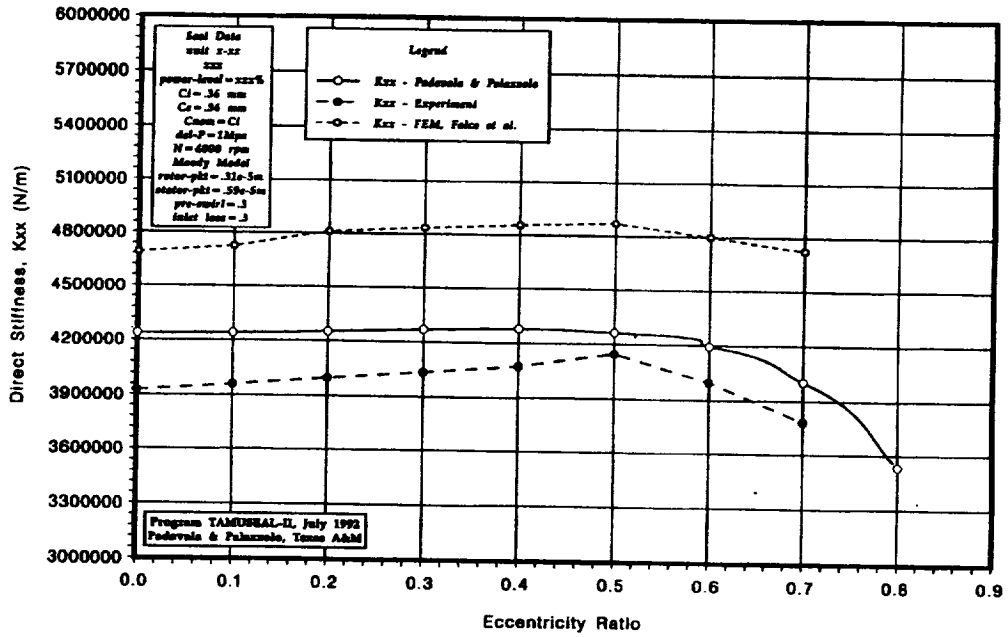


Figure 1 Direct Stiffness vs. Eccentricity Ratio-Comparison Between Methods

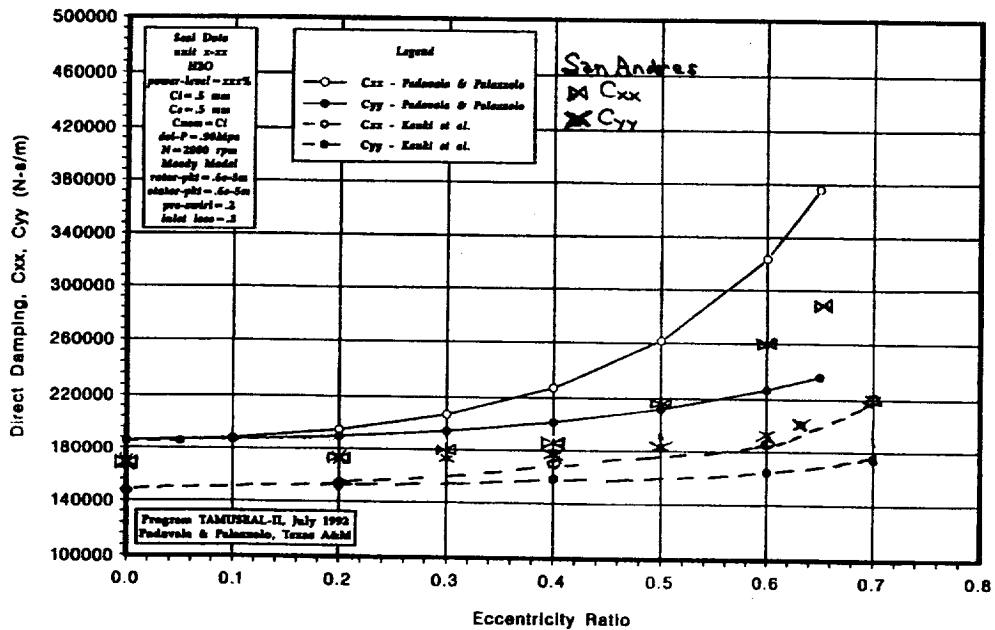


Figure 2 Effects of Eccentricity Ratio on Direct Damping