DISCUSSION

M. L. Adams[2]

The authors deserve congratulations for making a significant contribution to the state-of-the-art in the rotordynamical facet of sealing technology.

The approach of modifying seal geometry to improve rotordynamic factors is also a practical approach for the other fundamental sealing types aside from the smooth-bore geometry as modified by the authors, e.g., modified "high damping" labyrinth seals. The authors' work and some other recently published works strongly suggest that close attention to seals as rotor vibration attenuators (not just leakage controllers) has considerable potential for improving equipment designs.

There are numerous seal geometries (or modifications thereof) which one might wish to study and attempt to optimize. The authors' results are just one such example. In order to screen the numerous potentially beneficial geometries, it would seen that marked improvements to computational approaches are needed. That is, to experimentally test (and if warranted, optimize) every attractive new idea seems impractical, given cost considerations. In addition to the authors' quantitative comparisons between test results and computed results, have the authors gained any new insights which warrant recommendations on how improved analyses should be approached?

E. B. Jackson[3]

The authors are to be congratulated for another excellent paper relative to improving the state of knowledge of dynamic seals. The systematic test procedure and broad coverage of potential design parameters has led to results that the industrial community can readily use for guidance in designing seals more specifically tailored to meet the rotordynamic and performance objectives of the machine. Of particular interest was the effect damping of the seals as, to the discussor's knowledge, no previous experimental results had been published showing this effect of the holes. (Previous results[4] had shown the significant decrease in stiffness if the hole area is as large as 67 percent, but almost no decrease in stiffness if the hole area is 42 percent.)

There are several questions that I would appreciate having the authors address:

1. Is the parameter h/Cr the best nondimensional parameter for characterizing the effectiveness of the hole depth? For example, another possible parameter would be h/d where d is the diameter of the hole. It is known that with flow over a cavity, the effective loss is larger if the depth of the hole is less than the width due to the unsteady nature of the generated vortex in the cavity.
2. Were the edges of the holes "sharp"? If yes, it would be of interest to test with only the upstream edge (relative to the absolute flow vector) radiused as this tends to promote flow into the hole which can increase the effective resistance. Thus, with the same hole size, a potentially lower leakage and higher damping could be achieved.
3. The authors evidently backed out an effective roughness of their rotor and stator for making the theoretical predictions. Were these roughness values based on the leakage flow only, or chosen to give the best overall match of both leakage and dynamic coefficients? Also, could these roughness values be provided for the different hole patterns?
4. Why was the loss coefficient data not plotted for the higher pressure drops on hole patterns 2–6 (reference Fig. 7)?
5. The last two of equations (4) are used as defining equations for K_{ef}, C_{ef}, and M_{ef}. These equations assume a certain speed dependency (e.g., F_θ/A is linear with speed with a zero intercept). Did the test data indeed support the form of the two equations?
6. Were the authors satisfied with the accuracy and repeatability of their data? For example, standard deviations were determined from the curve fits; were these low compared to the average values? Also, in Tables 1 and 2, the lowest Reynolds no. data typically are less consistent. Is this due to accuracy with the lower pressure drop or is it a Reynolds no. effect?

G. L. Von Pragenau[5]

The paper reports on data from a test series with damping seals, conducted for the NASA Marshall Space Flight Center in support of the space shuttle main engine (SSME). Damping seals are annular seals with smooth journals and stators having pockets to hinder circumferential flow. Whirl forces are thus inhibited while leakage is minimized. Damping seals replaced labyrinth seals in the high pressure oxygen turbopump (HPOTP) of the SSME and helped to suppress a 90 percent subsynchronous whirl. The tests verify the feasibility of damping seals which was analytically predicted in 1981.

The main objective of the reported tests is the optimization of stator pocket patterns to maximize damping effects. The tests show for round-hole stator pockets an optimum hole area ratio of 34 percent relative to the total surface area and 2.89 as optimum hole-depth ratio relative to the radial seal clearance. Leakage is rather low, i.e., 54 percent of an annular seal with a smooth stator. The comparison of the dynamic parameters indicate acceptable predictions of the damping effect, but fluid film mass and stiffness values are underpredicted. The discrepant values have not blocked the new seal's application and better agreement is expected when theory and tests are further improved.

The reported data are from a seal tester with two smooth seal journals. The seal journals are mounted 0.005 in. eccentrically on the shaft and generate a synchronous whirl of 0.005 in. radius. The eccentricity is the simplest whirl generator, but couples the whirl speed directly to the shaft speed. Thus independency is lost, as the authors point out, and pure damping can not be separated from the whirl force. Instead the difference of both forces is determined and denoted as net tangential force. Similarly defined is a net radial force which consists of the stiffness and mass forces minus the whirl rate force. The comparison with theory is based on the net forces.

The test results have contributed much to a better understanding of damping seals. Future tests which permit the separation of force components should be helpful in clarifying the reported data discrepancies. The authors are congratulated for their effort in pursuing new seal technology.

[2]Department of Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland, Ohio 44106.

[3]Rocketdyne.

[4]Mackay, R. H., "An Investigation Into the Bearing And Leakage Characteristics of Simulated Honeycomb and Serrated High Pressure Annular Seals," Honors Report for Degree of B. Sc. In Mech. Engr., Heriot-Watt University, Edinburgh, Apr. 1972.

[5]NASA Lewis Research Center, Cleveland, Ohio 44135.

Authors' Closure

The interest expressed by the discussers in this work is appreciated. Taking the questions in order, our response is as follows:

1) We are not encouraged by the prospects of more sophisticated analysis procedures for the problem at hand, e.g., two or three-dimensional finite-difference or finite-element analyses. We feel that additional basic test data would be helpful; specifically, friction-factor data from flat-plate testing would be very helpful in evaluating different proposed roughness patterns.

2) Plots of the test results using h/d instead of h/C_r ratios were not productive. No systematic variation in damping or stiffness could be shown with respect to h/d.

3) The hole edges were "sharp."

4) Effective surface roughness values were obtained from leakage data and measured axial pressure-gradients. The loss data from Fig. 7 were not plotted at higher pressure values because of unreliable flow meter data at higher Reynolds numbers. The vortex flow meters used to obtain the current data have been replaced with turbine flowmeters. Data are currently being taken with the turbine flowmeters, which will be presented in a subsequent publication.

5) The test data supported the assumed form of the solution of equations (4) fairly well, particularly for the circumferential force component.

6) We have found the data to be quite repeatable. Tests which have been repeated over the course of months yield quite similar results. The accuracy and repeatability of the results definitely improve with increasing pressure differential, the magnitude of the forced pressure oscillations increases and thereby improves the signal-to-noise ratio.