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DISCUSSION

B. S. Nau and R. T. Rowles

The author is to be congratulated on taking the first steps towards the analysis of face seal behaviour in an operational mode which has not previously received attention. This mode is one in which the sealing faces, nominally flat but in reality wavy, begin to make physical contact over extended regions. The basic assumption is that the Reynolds equation applies with the Christensen modification to take account of short wave-length surface roughness (as opposed to long wave-length waviness). The modification involves the use of mean effective values of film thickness h (or h') which are derived from an assumed Gaussian frequency distribution. Additionally, part of the load on the interface is assumed to be carried by the contacting surface asperities.

Further complexities have been introduced into the analysis by taking account of seal face deflections due to the interface pressure distribution, and by incorporating a simple wear model.

To reduce the problem as posed to manageable proportions the author has taken a one-dimensional view, i.e. radial flow between the seal faces is neglected. Clearly this is a very severe restriction and one hopes that it will be possible to take a more realistic two-dimensional view before too long.

An aspect of the model which requires careful thought is the character of the roughness. In fig. 2 the author shows this in the form of circumferential parallel grooves. Examination of almost any seal face after use shows that this is not unreasonable, however, in the present model these grooves vary in depth after a period of wear. It is as if an initially wavy face is scored and then lapped to partially remove the high areas, leaving grooves of circumferentially variable depth. Observation suggests this is unrealistic, such a model would generate pressures in the grooves much greater than for a more realistic constant depth groove.

Turning to the author's conclusions from the numerical solution of a number of different cases, one's intuitive reaction is that all is not well. For instance, it appears that the model predicts that for initial wave amplitude below 3.65 microns there would be no hydrodynamic film, only asperity contact. Experience of measured film thicknesses at BHRA is that waves much thinner than this will support fully hydrodynamic films. Indeed, a waviness of 3.65 microns is excessive for a mechanical seal and one would imagine that any roughness sufficient to swamp hydrodynamic pressures with such a wave height would itself be excessive.

In the time-dependent wear situation the model predicts about 12 microns carbon wear per 100 h, a high wear rate in practical terms. By contrast with this prediction actual seals have been observed to operate efficiently for periods of years, necessarily with very low wear-rates.

The author's comments on the points raised would be very much appreciated.

Authors' Reply

The authors appreciate the discussion submitted by Dr. Nau and Mr. Rowles. To overcome the limitation of one dimensional flow pointed out by the discussion, the complete two dimensional problem including cavitation has now been solved. The first results of this two dimensional work have been presented6 and further work is in progress.

The second point raised by the discussers is concerned with the assumption of a tangentially variable roughness height. The authors are also troubled by this assumption but have followed the mixed lubrication model outlined by Christensen. It should be pointed out that a roughness height variation of only 10 percent is predicted by the model (see Fig. 4) as being necessary to develop the hydrodynamic and asperity load support required for equilibrium. Thus the tangential increase in roughness required is quite low. However, this point does raise a fundamental question. What is of great importance to both the asperity and the hydrodynamic load support is the exact nature of the roughness distribution under conditions of partial contact. In the model used for the paper the distribution is simply truncated at the contact level. What is needed is more information on how the surface roughness and its distribution evolves as a function of the mean separation h. Obtaining this information will be difficult and will require an accurate model of the wear process itself. So the approach used appears to be a reasonable assumption given the present lack of understanding of such processes. However, recognizing the importance of this question, the authors are presently studying various wear mechanisms in an attempt to develop a better load support model.

As for the third point raised by the discussers, the results for the base case are based on an initial waviness of 4 μm. Fig. 4 shows that this wave flattens such that the net waviness is only 0.25 μm. The particular seal ring used in the example has a very low stiffness be-

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cause it is a solid carbon ring. Thus large amounts of initial waviness can be tolerated before leakage will become excessive because the large waviness is essentially flattened.

If the ring had a greater stiffness, for example, a steel ring with a carbon insert, then the initial waviness and net waviness could be nearly the same. In this case the authors agree that 3.65 μm could be quite excessive.

As for the discussers’ final point, there are many factors which might effect wear rates in actual seals. For the seal under study, hydrodynamic effects do decrease with time and the wear behavior predicted is actually similar to what has been observed for this type of water seal. However, it is recognized that if better seal materials are used, wear will be much less than 12 μm per 100 h for the conditions of the base case. This number was used as an example.