DISCUSSION

W. J. Derner

We feel that the writer should be encouraged to continue this important work. His concept of unit cells offers a potential of more practical assessment of bearing capacity and prediction of life.

The development of a life equation which includes application, processing factors and their interrelationship is a welcome step forward which should be pursued quantitatively. At Rollway Bearing Company, a practical approach similar to that described in this paper is in use and is being extended in current application studies.

However, it is difficult to approach the prediction of bearing life using too material factors when in the original Swedish work, this appears only in the dynamic capacity equation. How does the author justify the inclusion of a material factor in the life equation without a re-examination of the material factor in the capacity equation? To this end, could we not expand the part of the life equation inside the brackets (viz. the C/P ratio term) to include a material factor which is dependent on the stress level in the particular application?

C. A. Moyer

Mr. McCool has provided an interesting review regarding the state of flux now existing in recognizing a modern, up-to-date "standard" for rating bearings within the bearing industry. His selection of figures attached to his paper illustrate the point that differences in material and manufacturing processes are profound enough to make the rating differences given in the various manufacturers' catalogs real and believable. The same point has been made by several bearing manufacturers for the past ten years.

Because of this the Timken Company has maintained that each bearing producer must conduct enough fatigue testing of bearings to establish their own material constants that apply to their bearings along with establishment of each bearing manufacturer's own rating methods if their accumulated data dictate this should be done. Customers are now needing and demanding better ratings and methods to estimate expected bearing lives within their applications so that the older concepts of rating standardization by approximation and committee consensus no longer holds and the kind of data Mr. McCool references is clear proof of the danger of doing this.

Mr. McCool suggests some modifications to the load rating system. As Mr. McCool knows the modifications in the form of three "A" factors he suggests were part of a proposal for changing load ratings submitted to the AntiFriction Bearing Manufacturers Association (AFBMA) Engineers' Committee at their meeting of December 14, 1967. There was considerable work by a Task Force from members of the Load Rating Subcommittee to generate the proposal but the final decision of AFBMA to reject the proposal. In the light of this we wonder what Mr. McCool's intention is in discussing the remnants of a proposal already turned down by the majority of the bearing industry. Does the author's company consider developing the concepts for their own use?

We also wonder if Mr. McCool has any evidence that the "A" factors stated are mutative as indicated? One of the objections to such an approach is that bearing users may think they can compensate for poor lubricant conditions by using a superior grade bearing steel. In actuality a shift of fatigue mode from material associated to surface associated may be a likely prospect for the poorer environmental conditions of thin film and low viscosity Mr. McCool refers to in his paper so that the various factors will not be multiplicative.

A. J. Ruffini and W. V. Smith

The recognition, of fatigue influencing factors outside the bearing manufacturers control, evidenced in Mr. McCool's paper is most welcome. The suggested use of interim life factors could serve to accelerate the more exact definition of the physical meaning of the terms and the identification of the components included in each term. From the user's viewpoint, the expansion of the bearing fatigue life expression, to provide the capability of predicting the probable bearing life as terminated by any cause, would be the goal. The need for an expanded expression is more evident when the service failure analysis showing less than ten percent fatigue failures is considered. The military services must include failures in stored bearings and in redundant machines.

The reliability factor A1 can be considered as representing a distribution. The Weibull distribution does not identify the presence of more than one population in a sample. Some evidence exists that, in bearings with exceptional ball and race roundness and small deviations between ball diameters, a sizable reduction in early failures occurs. Would this type of behavior seriously affect the values cited for A1 in the high reliability region?

The environmental factor A2 must be composed of a great number of components. The identification of a major portion of such components, and their interactions must be accomplished if the formula is to be useful. If the ratio of h/x proves to correlate well with failure, then all those parameters affecting elastohydrodynamic film thickness could be introduced in a simple fashion. The paired tests suggest that the h/x ratio interacts strongly with one or more unidentified variables. Identification of the variables and obtaining confirmed analytic expressions for their interactions with the h/x ratio will greatly increase the usefulness of the expression.

In addition to the usual physical and chemical factors contained in the environmental factor, some means must be found to express the effects of poor workmanship by a mechanic or of poor design by the machine designer that makes poor workmanship inevitable.

Author's Closure

Mr. Derner has accurately observed that material factors could be included in the formula for the dynamic capacity C.

The reason that this approach is not recommended is that it might trigger a proliferation of different formulas for C among the members of the bearing industry. Maintaining a common formula for C, but having each manufacturer establish an easily understood factor by which the standard life calculation can be modified in line with his specific experience, may avoid plunging the industry into the chaos of incomparability.

In this sense the writer is in agreement with Mr. Moyar that the responsibility devolves upon the individual manufacturer to establish and then live up to his own claims regarding his products' useful service life. It would however be a grave disservice to the bearing user if each manufacturer departed unnecessarily from accepted standards.

In further response to Mr. Moyar it should be clarified that this paper does not reflect a corporate "intention" or action program. It was solicited by the session organizers and contributed by us in the sensible belief that the best way of illuminating the current state of the life rating art is to have a public airing of all sides to

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the question. In this same interest, Mr. Derner would be of assistance by publishing his thoughts on life prediction.

The paper's recommendations are not in exact accord with the final proposal rejected by the AFBMA. In particular, the concept of using a common load-life exponent for ball and roller bearings is not recommended.

With respect to Mr. Moyar's last comment it should be pointed out that an early version of the proposal submitted to the AFBMA load-rating committee contained tabulated values of the factor $A$, corresponding to various survival probabilities. These values were based upon the work reported in reference [7]. An astute committee member observed that the proposed values were tantamount to using a Weibull shape parameter of 1.5 in the high reliability region.

The Appendix to the paper shows mathematically that this is approximately true.

Mr. Moyar is certainly correct that the correction factors for lubricant and material can be multiplicative only over a moderate range of values. A more exact treatment using the point of view of competing failure modes is advocated in [C1] which describes a continuation of the work reported in reference [4] of the paper.

Messrs. Ruffini and Smith are quite right in pointing out that fatigue failure is but one and not always the major failure mode for rolling bearings (cf. reference [11]). The paper was, however, limited in scope to fatigue failure, since that is the area dealt with in the AFBMA standard.

Ideas we have developed since the present paper was submitted shed new light on the role of $h/\sigma$ in determining surface initiated fatigue.

Finally, since the main purpose of the present paper was to stimulate discussion of an important topic, the writer is especially grateful to Messrs. Derner, Moyar, Ruffini, and Smith for having acceded.