puter programs for evaluating them, together with results of tests.

While the computer programs associated with levels (*b*) and (*c*) are generally proprietary, the preceding discussion has clearly demonstrated that the models themselves and the assumptions built into them have been fully presented and are available in the open technical literature.

In closing, while continuing the search for simplified life prediction models, we feel there still remains much to be extracted from models based on a combination of experimental data and sound physical assumptions before it becomes necessary to resort to curve fitting, with its many inherent dangers.

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A. P. Noronha[2] and H. Schlicht[2]

We read Dr. Tallian's contributions to contact fatigue life prediction models with a great deal of interest.

In Part I of his two-part paper, the author describes and compares most of the engineering and research life prediction models that are known and used today.

To the author's description of the FAG bearing life prediction model, we would like to make the following comments:

The author states that the FAG model is based on the assumption that "failures originate primarily, if not exclusively, at the surface." This statement is not right. Depending on the cleanliness and thickness of the lubricant film, the initiation of failure can be at the surface or below the surface. The FAG model takes care of this aspect through the a_{23}-factor.

In case the contacting surfaces are fully separated by a very clean lubricant, fatigue occurs due to initiation of cracks at weak points within the material. These weak points could for example be nonmetallic inclusions. The FAG model considers this failure mode through the f-factor, which leads to a_{23} values in the region I of the a_{23}-κ-diagram (Fig. 1a).

In the presence of a contaminated or unsuitable lubricant, failures originate at the surface of the material. Region III of the a_{23}-κ-diagram covers this mode of bearing failure.

Finally, the region II of the a_{23}-κ-diagram considers not only failures that originate at the surface but also fatigue due to the initiation of cracks under the surface. This region covers most of the practical applications in which bearings run in the presence of clean lubricants with additives.

The different modes of failure that are considered in the FAG model, have been explained in detail in numerous publications, for example in the references in this discussion.

The author describes the FAG life prediction model in which the fatigue limit of rolling element bearings has been integrated. Simultaneously he refers to some of our latest publications. Our initial publications regarding the existence and importance of the fatigue limit of rolling element bearings were presented in the 60's, as our references demonstrate.

In the second part of his paper the author presents a new fatigue life prediction model. This is a very remarkable model, since with a suitable choice of the different parameters, this new model covers the fatigue life predicting capability of all known engineering models. The new model needs to be matched to experimental data. Our references (1968–1985) contain a good selection of fatigue life experimental data for rolling element bearings. We hope that other bearing manufactures, as well as users, supply the author with more experimental and field data.

In deriving the new fatigue life model, the author had to make a few assumptions. This certainly has to be done in the first stage of development. The fatigue life prediction capability of the new model could be increased extensively if the author could do away with the following restrictions in the future:

—limitation of the model to line contacts
—constant traction coefficient within the contact area
—neglect of residual stresses

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I Transition range to the endurance strength. Preconditions: utmost cleanliness in the lubricating gap, loads not too high.
II High degree of cleanliness in the lubricating gap, suitable additives in the lubricant
III Unfavourable operating conditions, contaminants in the lubricant, unsuitable lubricants

Attainable fatigue life L_{na}

$$\boxed{L_{na} = a_1 \cdot a_{23} \cdot f_t \cdot L}$$

a_1 = life adjustment factor for failure probability
$a_1 = 1$ for failure probility of 10%
a_{23} = life adjustment factor for the material and operating conditions
f_t = temperature factor
L = rating life
ν = operating viscosity of the lubricant
ν_1 = rated viscosity

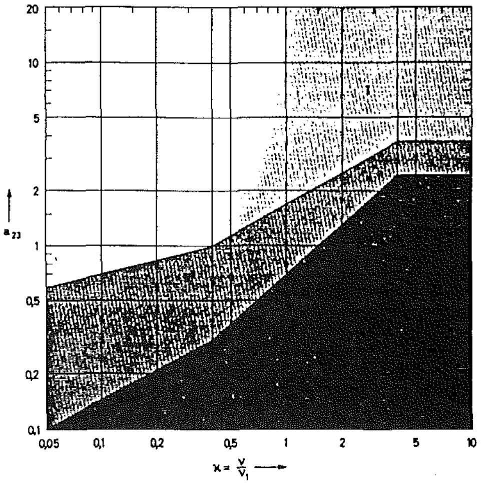

Fig. 5 a_{23}-κ diagram

Our investigations have shown that these limitations greatly influence the fatigue life of rolling element bearings.

We congratulate the author for his valuable contribution to the prediction of rolling element bearing fatigue life. We wish him success in the further development of his model.

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Author's Closure

Drs. Noronha and Schlicht correctly point out that, in my attempt to be concise, I have failed to do justice to the consideration that the Schlicht-FAG model gives to *both* subsurface and surface defects as failure initiators. As I went to some pains to explain in Part II of my paper: the decision to confine the model to *surface* defects only, is based *not* on any physical claim that these are the only significant defects, but on the intent to show that *even with a stark simplification* such as the neglect of subsurface defects, a model well fitted to published results can be obtained.

It should be a warning to the builders of advanced models, that their labor may bring no more practical verisimilitude than does a suitable simplified approach. Needless to say, this kind of success is possible only within limited parameter ranges, whereas physically more sophisticated models may have a broader application field.

The discussors list three important generalizations desirable in my life model: three-dimensional contacts, non-constant traction coefficients across the contact area and inclusion of residual stress effects. Of these, the first two require extensive computational work without necessarily promising significant new general facts about model behavior. The question of residual stresses, on the other hand, is fundamental. To address it, the choice of a critical stress measure must be reexamined, as it makes a great difference to the results, whether the shear stress range, or the von Mises stress is taken as this variable.

Ioannides et al. explain in detail why they prefer in-depth physical models over simplified models. Given unlimited resources, time and skill, their approach is surely preferable. It does, however, tend to lead to a "large-laboratory monopoly" if not a manufacturers' monopoly in life modeling. The broader tribological community can be excused for wishing for an alternative, which I would call "textbook" modeling. That is what I have attempted.

Two of the specific comments in the discussion reflect a misreading of my papers.

1. I do not claim that life depends only on products of independent factors.
2. The variable δ in Fig. 4 of Part II is *not* a defect depth. It is defect depth *ratio*, applied to a constant contact. In the paper, defect depth is not treated in isolation.

The references cited in this discussion, of which only Ioannides and Harris (1985) is published in this country, are gratefully noted and will serve to broaden this author's knowledge of progress made by the Ioannides group.

Lastly, as a former long-time employee of a bearing manufacturer, this author is well aware of the constraints to open publication that the business interests of such an industry impose on its employees. The fact remains however, that this places those "inside" the manufacturer's operation at an advantage in knowledge over outside users, which a tribologist working independently may justifiably wish to mitigate.