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# DISCUSSION

**T. Merriman**[1]

The discusser compliments the authors on their significant contribution to the understanding of bearing cage dynamics. The research is particularly useful because it has included some experimental investigations. Any number of analytical models can be constructed to model cage dynamics, however, conclusions drawn from these models may lack conviction without supporting evidence from the real world. We find several of the significant conclusions drawn by the authors to be in agreement with our own modelling efforts and perception of the problem. The inclusion of the Tevaarwerk-Johnson traction model is certainly a good addition to bearing modelling. Also, the conclusion with regard to the importance of ball-cage friction is correct and the experiments conducted to support this conclusion appeared sound: simple and conclusive.

I have several comments and questions on the paper. The authors draw many conclusions about the natural frequency of the cage motion based upon accelerometer data obtained at the bearing outer housing. The dynamic response of the bearing outer housing, although somewhat an indicator of internal bearing forces, is not the dynamic response of the bearing cage. This effect may be responsible for the observed invariance of instability frequency with so many variables. The bearing housing will tend to respond at its own natural frequency, distinct from the cage frequency.

The authors state, "The temperature increases will potentially degrade the lubricant, increase the occurrence of instability, and thus result in a self generating cycle of instability." From the readers point of view there is not much text in the paper with regard to this general conclusion. Could the authors comment?

In reference to Fig. 12, the author concludes that "It is clear from this study that viscous lubricant drag has an adverse effect on both the magnitude of the instability and the frequency of occurrence." Figure 12 dealt with the effect cold lubricant versus warm lubricant, which will substantially alter the viscosity of lubricant supplied to the ball-race interface. I would think that the change in cage stability therefore cannot be solely, or even substantially, attributed to viscous drag effects without carefully considering other effects temperature will have on the bearing.

Finally, a comment with regard to retainer motion study. The authors must consider that the addition of an aluminum band to the cage for use with capacitance probes adds significant mass, which will greatly alter the cage dynamic response. It is an ingenious technique, however, it does greatly alter the system being measured, probably tending to stabilize cage oscillations.

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## Authors' Closure

The authors would like to thank Dr. Merriman for his thoughtful comments and questions. With regard to housing or rig dynamic contaminations of retainer frequency data, the authors were also concerned about this effect. This is the reason for determining the rig frequency characteristics indicated in Fig. 6 at approximately 1230 to 1280 Hz. The appearance of a clear spike of 832 Hz in Fig. 7, coincident with audible noise, is clear, unambiguous evidence of the retainer instability. Note that the rig natural frequency does not appear, being only excited when vibrated at its own frequency. One therefore must conclude that rig dynamics had little effect on retainer frequency measurements. This was also confirmed by additional tests performed, but not reported, where the natural frequency of the rig was changed with added weights but had no effect on the observed retainer frequency.

The authors comments that increased localized temperature from instability heating could aggravate instability further is based on the deteriorated state of the lubricant observed after CMG bearing life tests. The periods and severity of instability increased markedly during the life tests. Post-test inspection showed dried, blackened lubricant in the retainer pockets and blackened retainer material. This is consistent with increased instability activity and with increased ball pocket friction leading to increased temperature and power loss (see the approximate 30 percent motor current increase shown in Fig. 9). Since this significant increase in heating is confined to relatively small ball/retainer contact patches, it is not surprising that the high local contact temperature could be responsible for further lubricant breakdown.

In reference to Fig. 12, it is true that 33°C grease provided stable retainer performance whereas 26°C grease did not. This temperature difference is believed small in relation to bearing dimensional changes due to temperature. The dominant effect, however, is on oil viscosity which decreased by about 50 percent. Furthermore, the additional viscous drag of grease versus oil at the same temperature (see Fig. 12) induced increased retainer instability. The observation that oil viscosity can trigger instability is not original with the authors, but has been reported many times (e.g., see Kannel et al., 1971 and Stevens, 1980).

Dr. Merriman is correct that the 0.2-mm thin aluminum band, despite weighing 0.5 g or 15 percent of the retainer weight, enhanced retainer stability as noted in the Retainer Motion Study section of the text. In recognition of this, most of the data presented in the paper (retainer instability threshold data, power increase, and lubrication effects) were determined without the aluminum band present. Only retainer motion characteristics were found with the necessary artifact. Since the critical retainer instability frequency did not change with the presence of the band, the authors are comfortable with the motion test data appearing in Figs. 13 through 16.