## DISCUSSION


### J. L. Farey[2]


I am very pleased to see analytical work being conducted in the area of high frequency vibration of ball bearings. Many investigators are successfully using this region of the bearing vibration spectrum to diagnose the condition of a ball bearing. A better understanding of the generation of high frequency vibration in ball bearings will aid all of us in the field.

I would however like to see new experimental work done in verifying the presence of the predicted vibration components. I do not have access to reference [3] of the paper, but have examined reference [1] which contains the data used for Fig. 6 of the paper. The experimental frequency spectrum is shown in Fig. F-1 of reference [1]. From this figure and the calculation of the paper, it would seem that the analytical/experimental agreement is excellent. If, however, one examines Fig. F-2 of reference [1], which is a vibration spectrum of the same bearing at 5 percent of the load, one would expect to see the signals at 55 KHz and 8 KHz to be reduced in frequency by the amount predicted in Fig. 4 of the paper. Fig. F-2 of reference [1], however, shows that the two signals have not shifted in frequency at all and remain at approximately 8 KHz and 55 KHz. It would seem therefore that these two signals are fixed resonances and not the Elastic Contact Frequency and the Bearing Kinematic Frequency signals as suggested in the paper.

Great care must be exercised in the high frequency region to eliminate transducer resonances. The signal at 55 KHz is particularly suspect in this regard. Its amplitude is almost directly proportional to bearing load which might be expected for an accelerometer resonance.


[2] Shaker Research Corp., Ballston Lake, N.Y.


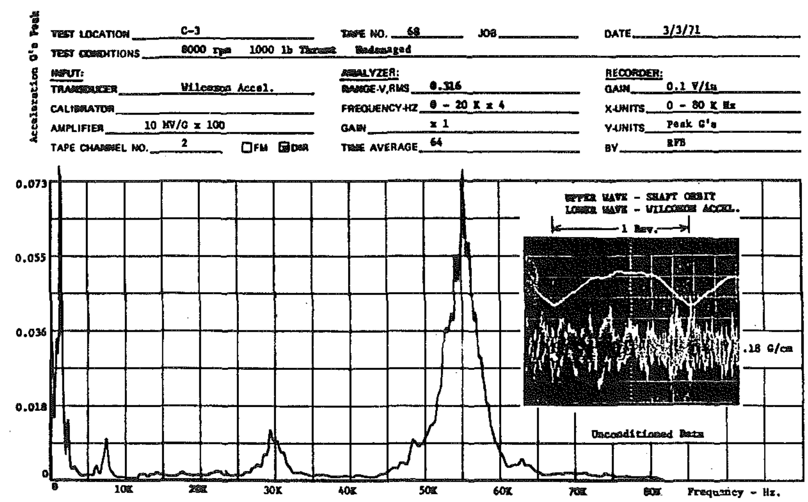


Fig. F-1 Radial acceleration spectrum, 1000 lb thrust, 8000 rpm undamaged

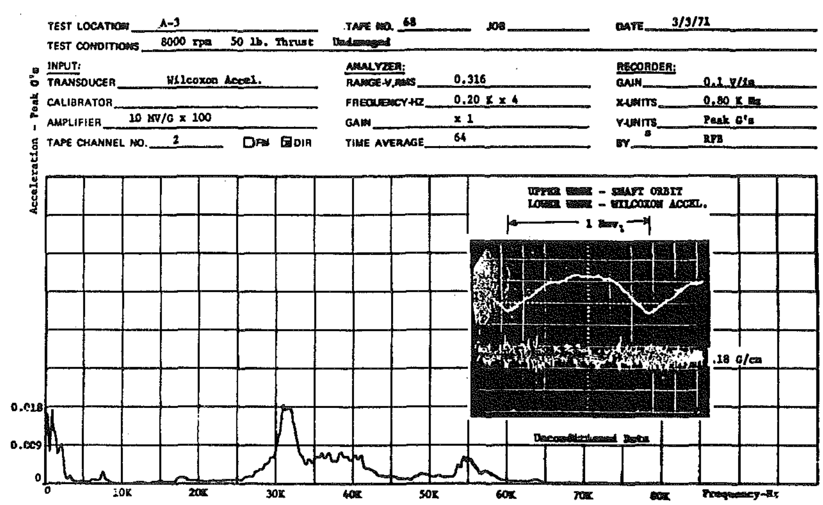


Fig. F-2 Radial Acceleration spectrum, 50 lb thrust, 8000 rpm, undamaged

## O. G. Gustafsson[3]

The authors present very interesting results from their simulation technique to determine two heretofore unknown natural frequencies of ball bearings.

In their analysis, the authors study the vibration of the ball complement only and neglect the influence of the outer ring mass, while in the experiments the outer ring vibration was measured. This is understandable since including the effect of the outer ring mass and flexibility would make the analysis even more complex. The discussant feels that, at least in their first approach, the authors are justified in neglecting the effects of the outer ring and in using a frictionless model, since the two natural frequencies have been clearly identified under steady-state conditions in experimental vibration spectra.

In the discussant's laboratory, a series of outer ring resonances, different from those mentioned by the authors, were studied, considering the effects of outer ring mass and flexibility in its own plane.[4] The effect of ball mass was, however, neglected. The ball contacts were assumed to act as linear springs. The natural frequencies of the free outer ring (not mounted in a housing) are given by the equation

$$f_n = \frac{1}{2\pi}\left[\frac{(n^2-1)^2\dfrac{\pi EI}{R^3} + \dfrac{k_N Z}{2}}{\pi\rho_0 AR(1+1/n^2)}\right]^{1/2}$$

$$Z \geqq 2n+1$$

where

$f_n$ = natural frequency in Hz
$E$ = Young's modulus of elasticity
$I$ = second moment of area of the ring cross-section
$R$ = mean radius of the ring
$k_N$ = linearized Hertzian coefficient
$\rho_0$ = mass density of ring
$A$ = cross-section area of ring
$Z$ = number of balls
$n$ = any integer > 0

The six lowest natural frequencies were computed for the authors' bearing A under the assumption that the ring and ball dimensions are the same as those of a 6210 bearing. These frequencies are 370, 472, 520, 607, 744, and 947 Hz. The lowest frequency, 370 Hz, represents rigid body motion of the outer ring, while the higher frequencies include the effects of outer ring bending. It is seen that in this case, all the computed resonant frequencies are too low to be observed in the authors' spectrum. Higher flexural natural frequencies also occur throughout the spectrum, but the amplitudes at these frequencies are generally too small to be detected. The outer ring resonances are highly influenced by the bearing dimensions. For a 6312 bearing, the computed three lowest natural frequencies are 2.49, 3.51, and 5.37 kHz. Fig. 7 shows an experimental spectrum of a 6312 bearing, which indicates fairly good agreement with the three computed frequencies.

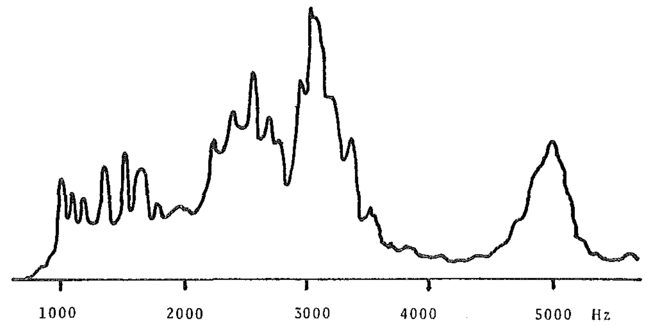


**Fig. 7 Vibration spectrum of 6312 bearing from 1000 to 5000 Hz**

# Authors' Closure

The authors agree with Mr. Farey in the fact that more experimental data is needed in order to understand the dynamic characteristics of rolling bearings. It is true that a number of frequencies, other than the two defined by the authors, are present in any experimental spectrum. The precise load dependence of the various frequencies is also not known and the authors agree that some of the frequencies could indeed be independent of load or other operating conditions. In view of all these uncertainties the objective of this paper is only to show that the computed characteristic frequencies do indeed exist in experimental frequency spectra discussed in this paper.

At a light load of 50 lb, in the case of Bearing B, the computed elastic contact and kinematic frequencies will respectively reduce to about 32.2 kHz and 1.80 kHz. The existence of these frequencies in the spectrum shown in Fig. F-2, by Mr. Frarey, cannot be completely denied. The fact that relatively small peaks continue to exist at about 8 kHz and 55 kHz, once again suggests a more extensive analytical and experimental investigation aimed at a systematic characterization of all dominant frequencies. The authors agree that it is important to eliminate transducer and other resonances associated with the experimental apparatus.

Bending of the outer race will certainly contribute to several characteristic peaks in the very low frequency region as pointed out by Mr. Gustafsson. The authors look forward to a more complete dynamic simulation which to some extent will allow for the flexibility of the races.

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[3] SKF Industries, Inc., King of Prussia, Pa.

[4] Gustafsson, O. G., Tallian, T. E., et al., "Final Report on the Study of the Vibration Characteristics of Bearings," U. S. Department of the Navy, Bureau of Ships, Contract NOb-78552, SKF Report AL63L023, DDC AD 432 979, 1963.