

in the slope of the instability threshold curve and the manner in which the operating line crosses it. Operation curves representing variable average temperature operation cycles intersect the threshold curve in two points whereas those representing constant average temperature cycles intersect the threshold at only one point.

## References

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## DISCUSSION

### E. R. Maki<sup>6</sup>

During the presentation of their paper the authors used an animated movie to display the orbiting of a rotor in both stable and unstable modes of conical whirl. This method of presenta-

<sup>6</sup>Mechanical Development Dept., GM Research Laboratories, Warren, Mich.

tion has considerable potential to aid the visualization of complex motions associated with rotor systems and is, I believe, the first time the problem has been approached in this manner. However, the paper itself does not provide any description of the method or equipment used to make the movie. Would the authors give us the benefit of their experiences and provide additional information on this technique?

## Authors' Closure

During the investigation, the results of two representative dynamic unbalance calculations were recorded on punched cards as well as in standard line printer output form. The results of one of these calculations appear in Fig. 4. The second calculation was made with all parameters identical to those shown in Fig. 4 except for the angular velocity ratio  $\omega_j/\omega_g$  which was equal to 2.5. Thus, it represented an unstable configuration, which may be seen by plotting in Fig. 5 a point corresponding to  $\epsilon_0 = 0.5$  and  $\omega_j/\omega_g = 2.5$ .

Subsequently, the punched card data representing these two cases of calculated behavior of the rigid rotor as a function of time were converted into an animated movie in order to present the results in a way which could be easily visualized. A relatively simple computer program accepted the rotor behavior data as input and projected it, together with a conceptual rotor shape, on a cathode ray tube. (CDC-6600 computer system.) Time-step by time-step the data was projected and recorded on 35 mm film. The film was then converted to 16 mm size by standard reduction techniques and edited by the authors. The resulting film was shown during the presentation of the paper. Figs. 12 and 13 show representative frames from this film for the stable (Fig. 4) and unstable calculations, respectively.

Mr. Maki is correct in his observation that little use has been made of this technique, at least in the area of rotating system dynamics. The authors are aware, however, of numerous cases (references [10–14]), in which this procedure has been utilized to good advantage. Of particular interest is reference [13] which discusses not only the work of the author but also that of Mr. K. Knowlton of the Bell Telephone Laboratories. (It should be mentioned that films illustrating applications of the animation technique are available in 16 mm form from the Technical Information Library, Bell Telephone Laboratories, Murray Hill, N. J.) Undoubtedly other equally interesting applications exist.

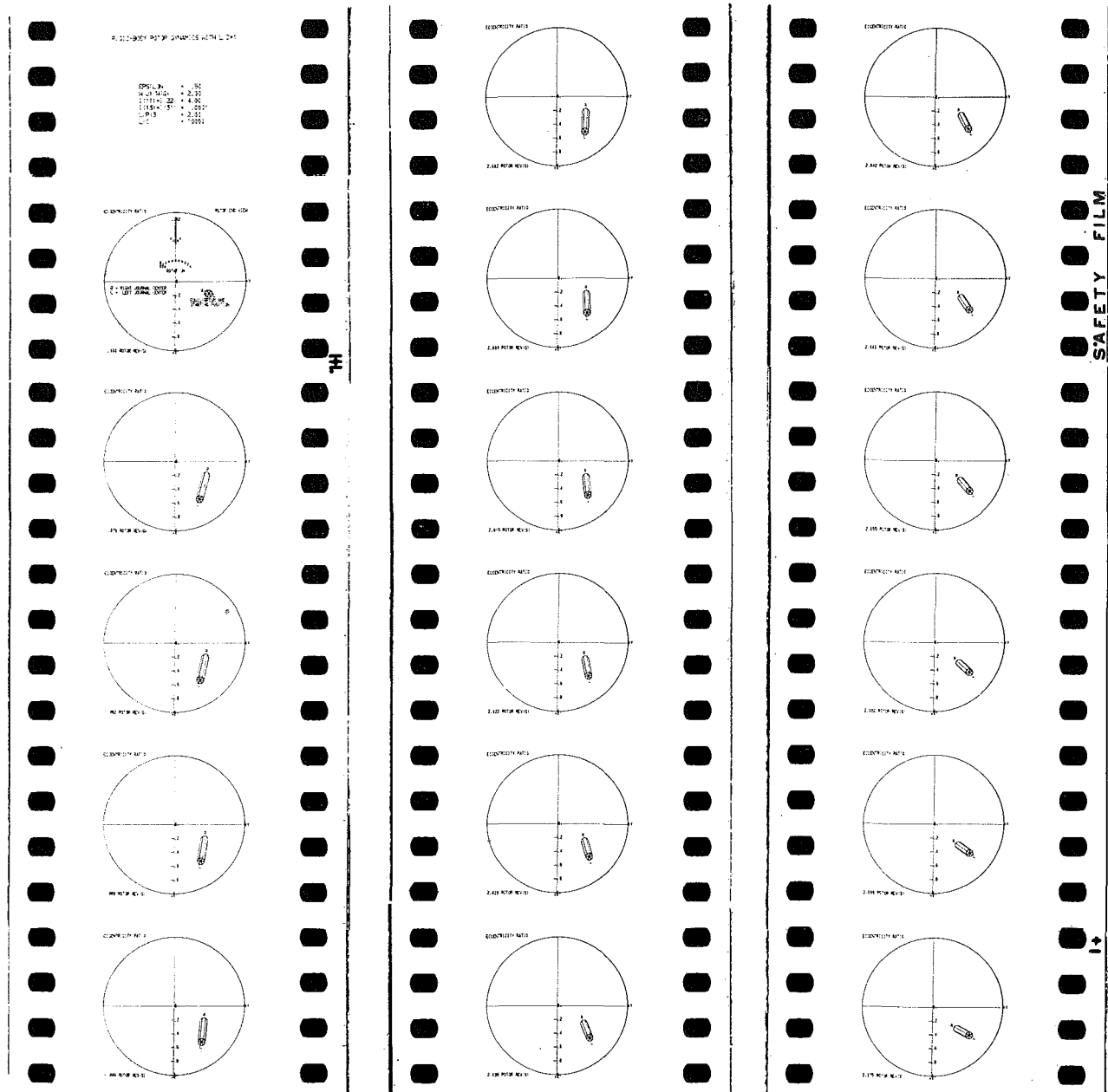


Fig. 12 Animated display of stable, dynamically unbalanced, rigid rotor motions

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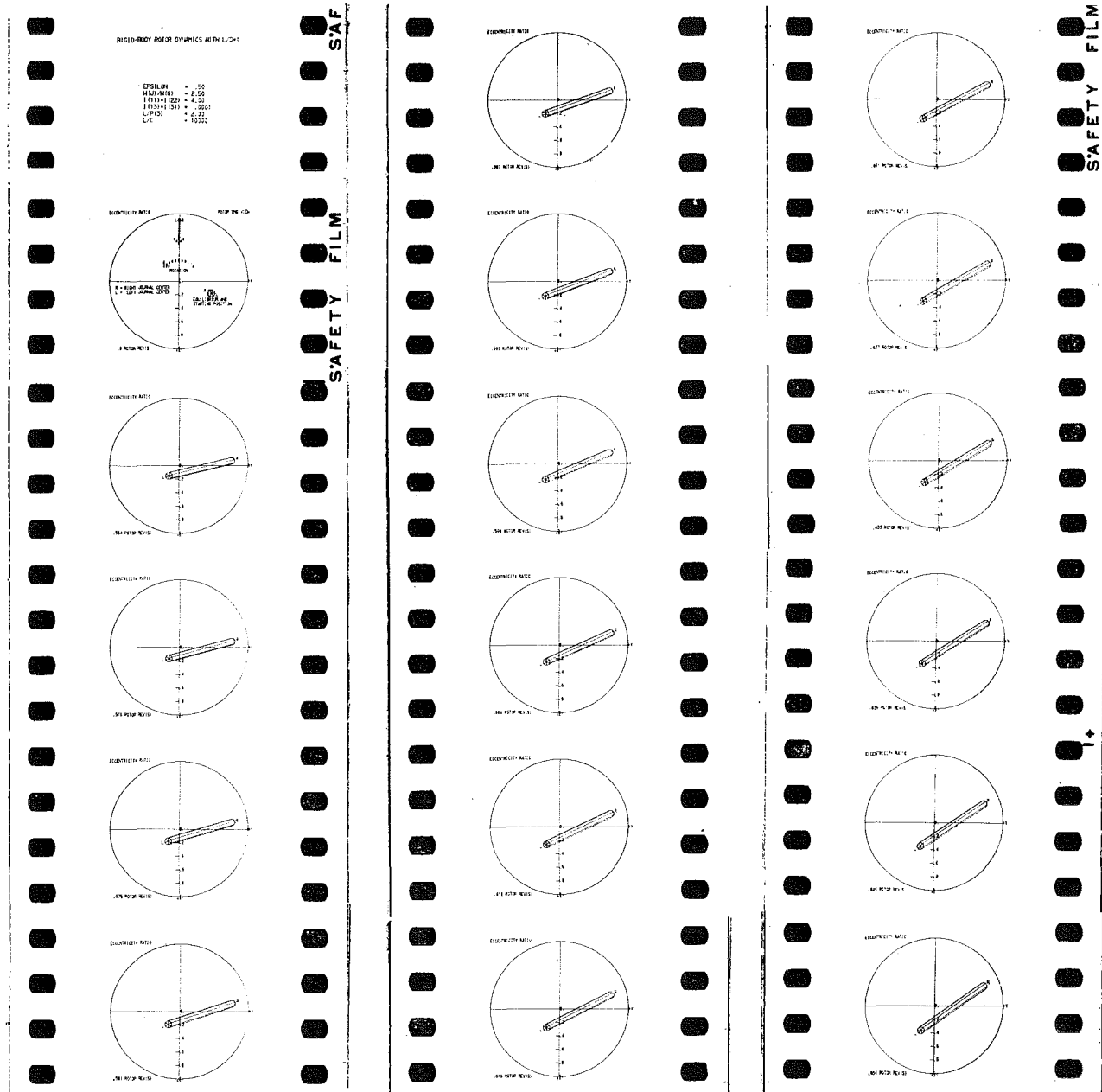


Fig. 13 Animated display of unstable, dynamically unbalanced, rigid rotor motions

The authors wish, finally, to observe that while the animated film technique for presentation of vibration results may still be in its infancy, it will undoubtedly receive increased attention in the future. A parallel may be drawn between it and the computer driven plotter, which has become a mainstay in the senior author's organization in recent years. The presentation in easily visualized form, of information which could otherwise only have been gleaned by examination of literally reams of paper, certainly leads to design and analysis efficiency. The economic implications are obvious.

#### Additional References

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