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The use of Vibration Interferograms in Vibrating Cylinder Sensor Design

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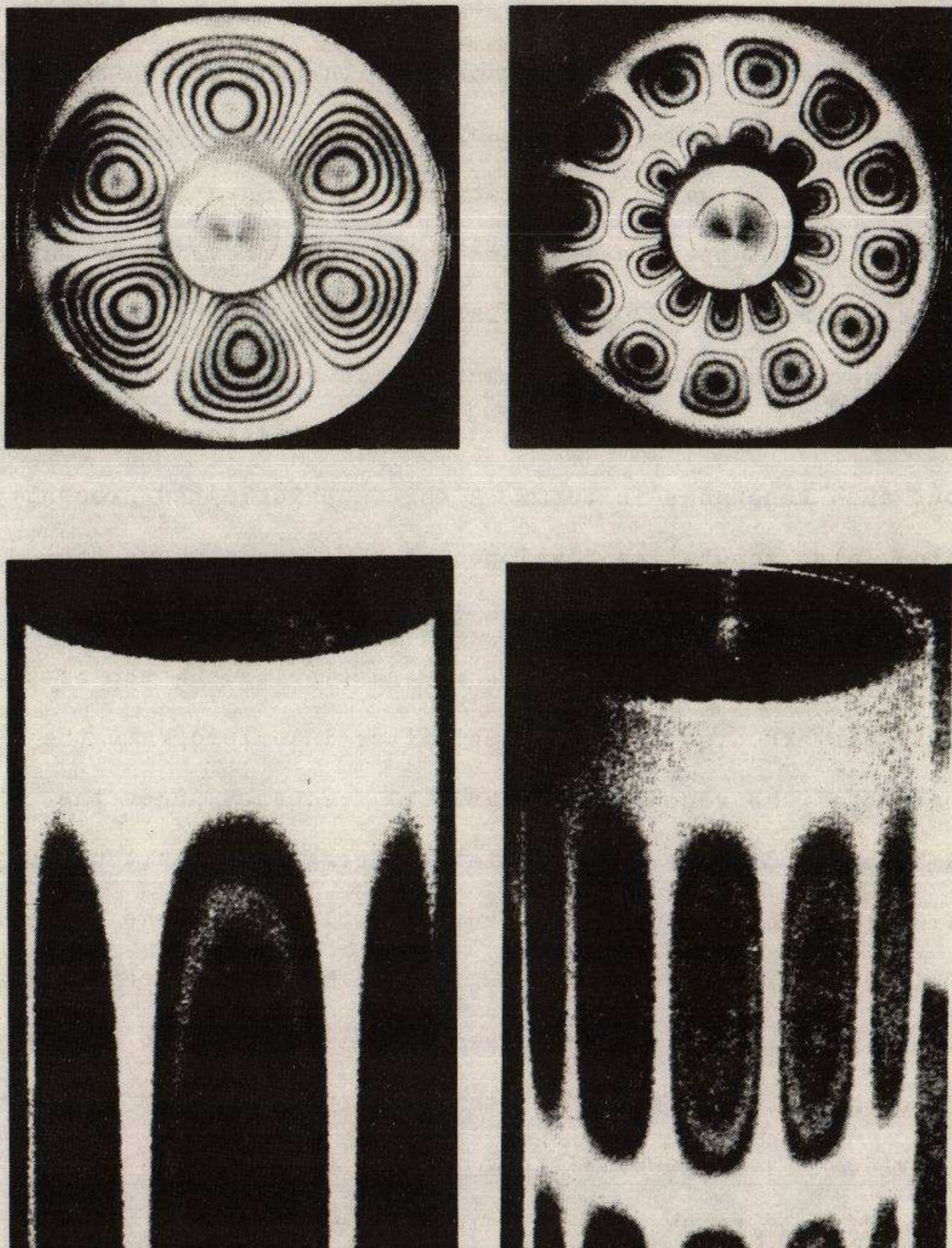
Vibrating cylinder sensors have been designed for various applications over the last decade and more. The essential feature is that a thin walled metal cylinder is maintained in resonance in a preferred radial hoop mode. The resonant frequency can be arranged to depend, with high stability on the physical properties of fluids brought into contact with either one or both cylindrical surfaces. The basic applications are for pressure measurement, where the hoop stress caused by a pressure difference across the cylinder wall causes an increase in resonant frequency, and density measurement, where the changing mass of fluid coupled to the maintained cylinder vibration on both sides of an open cylinder, causes a decrease in resonant frequency for increasing density.
The major design problem is to define a geometry for the cylinder element itself which will provide a range of resonant frequency change with applied fluid variable for a sensitive mode of resonance which is free from "crossings" of other resonant modes which may have very different sensitivities to the measured variable. When investigating the different mode frequencies under ambient air conditions, large separations in frequency may be achieved and a high Q of several thousand obtained on the preferred mode. However, when pressurising (or varying fluid density)

the frequencies of an interfering mode may pass through that of the preferred mode. If this happens the closed loop sensor may maintain on the interfering mode causing a discontinuity in characteristic or a sudden "flip" to the interfering mode may occur when the Q value of that mode exceeds that of the preferred mode. Alternatively, when the unit is first switched on, it may start up on the unwanted resonance mode on intermittent occasions and, once started, may lock onto that mode. Increasing viscosity of measured fluid may also cause degradation of system Q value to the point where non-preferred modes are equally likely to be excited as the preferred mode. Finally, even if "flipping" or discontinuities does not occur, a crossing mode may cause energy to be shared between two modes at one point in the range such that the maintaining system gain may not be sufficient to overcome damping and a "hole" in the characteristic can occur over a very narrow region indeed. This last effect may not be noticed in the early design stages and only comes to light under certain environmental conditions. The foregoing tales of woe point to the need to define all the possible vibration modes in the region of the preferred mode together with their sensitivities to the measured variable. The mathematics of cylindrical hoop modes of vibration has been explored by several authors (notably those by Arnold and Warburton) but, to my knowledge, the variation and sensitivity of these resonant frequencies to surrounding fluid conditions has not been carried out and does not lend itself to simple analysis. In addition, such factors as nodal rings at the ends of the thin cylinder sensing element play a significant part in some unwanted responses which may also involve the excitation of these coupled systems.

Crude experimental techniques such as the use of lycopodium powder, search coils, and tracking with pencil points can provide surprisingly good results. However, nothing can surpass the elegance of vibration interferograms such as those shown in the appended diagrams which were provided by workers at the N.P.L. in 1970. Initial photographs were taken of the cylinder sensing element direct, which was acoustically stimulated over the frequency spectrum of interest, picking out each resonance in turn. A more sophisticated presentation, also shown, was developed at N.P.L. and shows the interferometric pattern projected onto a conical matt dish beneath the cylinder with the camera viewing the top of the cylinder and dish. From these latter interferograms the nature of the resonant mode and its frequency under the ambient conditions was immediately recognisable without any fear that the measuring instrument would effect the system. This is certainly a problem with search coils or pencil leads! Coupling to end rings and mixed responses are also easily discernable. It is certain that the interferogram technique provides a very powerful tool in this design field which will be difficult to surpass in effectiveness, ease of visualisation and elegance of method.



VIBRATION INTERFEROGRAMS SHOWING DIRECT VIEWS AND PROJECTED PATTERNS OF TWO POSSIBLE CYLINDER VIBRATION MODES.