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IV. THE OSCILLATIONS OF QUARTZ CRYSTALS AS REVEALED
BY MULTIPLE-BEAM INTERFEROMETRY

By S. TOLANSKY.

**Sommaire.** — On forme des franges de Fizeau à ondes multiples entre un plan argenté et la surface argentée d’un cristal de quartz. Quand le cristal oscille, les franges donnent un tableau complet des nœuds et des vents et des amplitudes locales. On a étudié des fréquences entre 100 000 et 3 000 000 Hz pour différents types de coupe. En argentant les deux faces d’un cristal approximativement plan-parallèlement, on obtient des franges à l’intérieur du cristal oscillant. Par stroboscopie on peut obtenir les phases et les amplitudes locales. Les couches d’argent ne semblent pas affectées par les oscillations.

**Introduction.** — In this note a brief description is given of some striking experiments now being carried out by me, together with my assistant, Mr Bardsley. It was realized that it should be possible to employ multiple-beam Fizeau fringes to reveal the surface vibrations of an oscillating quartz crystal. Work was begun with some trepidation and doubts, for it was feared that the very vibration would prevent observation. When a fringe system is being employed in which a change of thickness of a few angstroms produces an appreciable shift, it would at first appear foolhardy to attempt observations on a rapidly vibrating system. It has, of course, been axiomatic in multiple-beam interferometry to avoid vibrations and disturbances at all costs, yet as will be shown the experiments have proved to be highly successful and have yielded already considerable information.

The technique has up to now been applied in various modifications to a number of crystals ranging in frequency from 100 000 to 3 000 000 vibration per second. It has, of course, revealed information about the oscillating crystals, but at the same time it offers a new procedure for studying thin films, for we have here for the first time the possibility of studying the dynamics of moving films.

**Experimental.** — A. **Surface studies.** — The technique is simple. The selected crystal is optically worked so that the surfaces have a good polish. The surface to be examined is left with a small residual curvature, and is silvered suitably for multiple-beam interferometry. It rests on a similarly coated optical flat. Contact is made to the electric oscillating circuit in one of several possible ways, all of which function. Thus one electrode rests on the silvered flat, which is larger than the crystal. For the other electrode one can use (a) a light open mesh wire grid above, but not touching,
are formed between the silvered crystal face and the silvered flat, and when the crystal is at rest, these show the contour of the crystal surface, as sharp fringes, and of course, their distribution is determined by the relative inclination of the two silvered surfaces.

As soon as the crystal is set into vibration, the fringes take on a remarkable appearance, and plates 8 and 9 are typical examples. The fringe pattern which appears is determined by the particular modes of vibration, which are fixed by the electric constants of the circuit and are readily altered by a variable condenser.

Without going into detail it is clear that the interference picture clearly reveals nodal regions and also one can readily calculate the exact amplitude of vibration at any position. The pictures are remarkably stable and remain unchanged for hours.

It is emphasised that there is no stroboscopic, only simple illumination, and it will be appreciated that the success of the experiments is in part due to deliberately keeping down the maximum amplitude of vibration to about at most 1.5 orders, say 4 000 Å.

A remarkable feature is the sharpness of the nodal regions which are certainly at rest to less than 50 Å, probably much less.

B. Body vibration. — Perhaps of equal interest to vibrations on the surface is the study of vibrations within the body of the crystal itself, and to do this a modified technique is required. A crystal was polished plane parallel (1.5 mm thick) and then one face deliberately worked into a slight curvature. With such a set-up, Fizeau fringes within the crystal were formed and because of the large separation of the two faces (1.5 mm) they are inevitably appreciably broadened.

The source to be used requires special consideration for the system is practically equal in resolving power to a corresponding Fabry-Perot interferometer, i.e. a resolving power of some 200 000 or so. Hence a water-cooled vacuum mercury arc suitable for hyperfine structure studies must be used and in fact, the hyperfine structure of the green line appears in the Fizeau fringes. The method has been found quite successful and has yielded information.

Stroboscopic technique. — A successful stroboscopic technique has also been developed. In this a fraction of the electrical energy of the vibrating system is tapped off and used to excite a discharge tube either with internal electrodes, or by high frequency electrodeless discharge. The end result is to illuminate the oscillating system with a source of the same frequency. The fringes therefore appear at rest. But they do not have the same shape as the surface contour when at rest, for they reveal the relative phase effects and indeed show which regions are moving in opposite directions.

A further advantage of the stroboscope method is that bigger amplitudes can be employed. Yet the direct steady illumination procedure is the more revealing.

Conclusion. — It need not be emphasised that we have here a very powerful weapon for the study of the oscillations of the crystals and this is of course being very actively pursued. Yet at the same time it is clear that the technique gives information (and can give much more) about the silver film. For clearly the film is also vibrating and when the surface shows multiple nodes some regions are quite at rest whilst nearby regions are moving through amplitudes perhaps 10 or 20 times the film thickness itself. Yet the reflectivity does not appear to suffer and this clearly indicates the non-continuous nature of the silver film. Since the fringes can be studied in reflection, it is possible to put a very heavy film on the crystal and investigate such films.

It is of interest to point out that even with a frequency of $10^8$ times per second, since the maximum amplitude may only be, say, 5 000 Å, the actual velocities are very slight indeed, and only of the order of cms per second and no question either of Doppler effect or refractive index changes due to pressure in the air film can at all influence the observations.
Intervention de M. Roig.

Les expériences de M. Tolansky sur la vibration du quartz utilisent des franges fines à faible différence de marche. Je veux signaler la possibilité d'une expérience de nature différente : si une radiation monochromatique se réfléchit sur un miroir de quartz animé d'un mouvement d'oscillation, les déplacements de la surface provoquent par effet Doppler une modification de la radiation réfléchie. Si \( N \) est la fréquence de la radiation incidente, \( \nu \) la modification de fréquence dans la radiation réfléchie, la distribution lumineuse obtenue sera

\[
I(\nu) = \frac{I_0}{\sqrt{\nu^2 - \nu_0^2}} \quad (-\alpha < \nu < +\alpha),
\]

\[
\alpha = 4\pi f \frac{\varepsilon_0}{\lambda} \quad \text{(pour l'incidence normale)},
\]

\( f \) est la fréquence d'oscillation du miroir, \( \varepsilon_0 \) l'amplitude d'oscillation, \( \lambda \) la longueur d'onde de la lumière.

Comme on n'a jamais de radiation incidente rigoureusement monochromatique on observera non pas les branches asymptotiques \( \nu = +\alpha \) mais deux maxima (fig. 3 b).

Le résultat est-il observable expérimentalement ?

Prenons \( f = 10^7 \), \( \lambda = 0.6 \mu \), le pouvoir de résolution nécessaire serait

\[
\alpha = \frac{2.3 \times 10^6}{\varepsilon_0} \quad \text{(si \( \varepsilon_0 \) est en microns)}.
\]

Il paraît difficile pour une fréquence de \( 10^7 \) de dépasser l'amplitude de \( 1 \mu \) sans amener la rupture du quartz.

Il semble que l'expérience soit possible, mais à la limite des réalisations expérimentales ; un pouvoir de résolution de plusieurs millions est réalisable avec un étalon de Pérot et Fabry ; une source donnant une raie incidente suffisamment fine pourrait être fournie par un jet atomique.