Frequency modulation of characteristic x rays and of beams of monoenergetic particles with the aid of moving crystals

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Relative motion of two identical single crystals having the same orientation in space, in a direction perpendicular to the atomic planes with respect to which anomalous passage of monochromatic x rays is observed according to Borrmann, makes it possible to effect frequency modulation of radiation. The possibility of using this method for RF and microwave modulation of a beam of x rays or monoenergetic particles is considered.

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During the last decade, a tendency has developed to use certain methods of x-ray interferometry for the measurement of very small linear and angular displacements.[1–3] By using the "Angstrom scale" proposed by Hart,[2] it was found possible to measure relative displacements of superimposed silicon single crystals with accuracy to 10^{-9} cm. An accuracy better by one order of magnitude was obtained by Deslattes and Henings [3] who combined x-ray diffraction with an optical Fabry-Perot interferometer. We shall show that analogous methods can be used for high-frequency modulation of the characteristic x rays and beams of monoenergetic particles.

Let two single crystals C_1 and C_2, identically oriented in space, be located one behind the other along a common axis $X—X$ (see the figure). We assume that the atomic planes, with respect to which anomalous Borrmann passage of monochromatic x rays is observed, are parallel to the XZ plane (schematically they are shown shaded on the surfaces of the crystals). The beam of monochromatic x rays is incident on the rear side of the crystal C_2 in the R direction, which is at the Bragg angle θ to the XZ plane. We assume also that the distance a along the $X—X$ axis between the crystals, as well as the distance between the crystal C_1 and the detector D, are small enough.

Assuming that the two single crystals are identical in structure, have no dislocations or other lattice defects, and their spatial orientation is the same, we consider two cases:

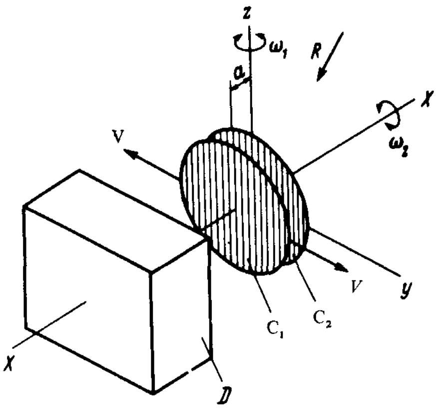

FIG. 1. Diagram of the method for frequency modulation of monoenergetic radiation with the aid of two moving crystals.

1. The crystals are located one behind the other, so that the atomic planes of one are continuations of the atomic planes of the other. Then they constitute, as it were, one single crystal, and the attenuation of the radiation incident on the detector is minimal.

2. We displace the crystal C_1 along the Y axis by half the distance between the atomic planes, $d/2$ (in the direction of the arrows V). In this case the atomic planes of the crystal C_1 overlap the spaces between the planes of the crystal C_2 and the intensity of the radiation incident on the detector becomes minimal.

If the crystal C_1 moves continuously with velocity V, the radiation frequency f is determined by the simpler relation $f = V/d$. It is easily seen that since d is small ($\sim 10^{-8}$ cm) the frequency of the signals modulated in this manner is 10^{10} Hz even at low velocities V, say 1 m/sec. Such a high oscillation frequency is at the limit of the resolution of modern recording systems (100 psec). However, by decreasing V to 1 cm/sec or 1 mm/sec we can easily change over to the megahertz frequency band, in which measurements are quite feasible.

The main difficulty in the practical realization of the proposed method is the need that the atomic planes of C_1 and C_2 coincide strictly. Simple estimates show that at a crystal height 1 cm an error of 10^{-3} seconds of angle in their mutual position makes frequency modulation impossible. To eliminate this limitation it is necessary, besides moving the crystal C_1 in the Y-axis direction, to vibrate crystal C_2 slowly in two mutually perpendicular directions—about the axes Z and X (the arrows ω_1 and ω_2). In this case there will always be an instant of time when the directions of the atomic planes coincide. If we use pendulum oscillations to obtain the required velocity V, then rotation about the X axis can be excluded. For a pendulum about 2 mm long, a situation is automatically produced wherein up to 1000 planes of the C_1 crystal are parallel to the analogous atomic planes of the C_2 crystal. An advantage of this method of frequency modulating the radiation is the possibility of using a "beat" technique for an exact measurement of the frequency. To this end, the electric oscillations produced at the output of detector D are compared with a standard frequency, e.g., that of a quartz oscillator. This makes possible precision registration of the oscillation frequency and measurement of the angular displacements of the crystal C_2 relative to C_1 accurate to thousands of a second of angle.

The principle considered above can be used not only for monochromatic x rays but also in experiments with monoenergetic beams of electrons, protons, and other particles for which bragg reflection from atomic planes of single crystals is possible. Once large and sufficiently perfect light-element crystals that slow down termal neutrons noticeably become available, then the possibility of using this technique for frequency modulation of monoenergetic beams of slow neutrons can likewise not be excluded.

[1] U. Bonse and M. Hart, Appl. Phys. Lett. **6**, 155 (1965).
[2] M. Hart, Brit. J. Appl. Phys. (J. Phys. D) **1**, 1405 (1968).
[3] R. D. Deslattes and A. Henins, Phys. Rev. Lett. **31**, 972 (1973).