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THE CATHODE-RAY OSCILLOGRAPH AS A MEANS OF DEMONSTRATING ELLIPTICALLY POLARIZED LIGHT

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ABSTRACT

The cathode-ray oscillograph may be employed for educational purposes in fields other than electrical engineering as, for example, the demonstration of the fundamental properties of elliptically polarized light. A method is here described whereby patterns may be produced on the oscillograph screen illustrating the composition, from plane polarized components, of the various forms of elliptically polarized light, and the underlying optical theory of this composition is discussed briefly.

Although the study of physical optics is not generally considered to be of the field of electrical engineering, the cathode-ray oscillograph has at least one interesting application as an educational means of demonstrating the mathematical properties of polarized light. With relatively simple auxiliary equipment, plane polarized light, circularly polarized light, and elliptically polarized light may be demonstrated on the cathode-ray screen. In fact, it is possible to produce on the screen of the oscillograph patterns representing every possible state of polarization of light (or of ultra-high-frequency radio waves) by merely manipulating three controls representing the three basic elements of a generalized ellipse, i.e., the magnitude of two perpendicular components and the phase difference between them.

The underlying advantage in using cathode-ray tube equipment to produce these patterns lies in the fact that such apparatus permits an easy adjustment of the basic elements in such a way that any one of the three may be varied alone without disturbing the other two. This ease of control is very difficult to obtain with mechanical models or similar apparatus.

OPTICAL PRINCIPLES

A beam of elliptically polarized light is usually most easily understood when it is considered as the resultant of the combination of two beams of plane polarized light, these components being oriented perpendicular to each other, and representing sinusoidal vibrations of the same frequency with a definite time lag or phase difference between corresponding points on the two waves. By purely electrical means it is possible to produce oscillograph patterns which possess geometrical properties identical to these same properties in a beam of

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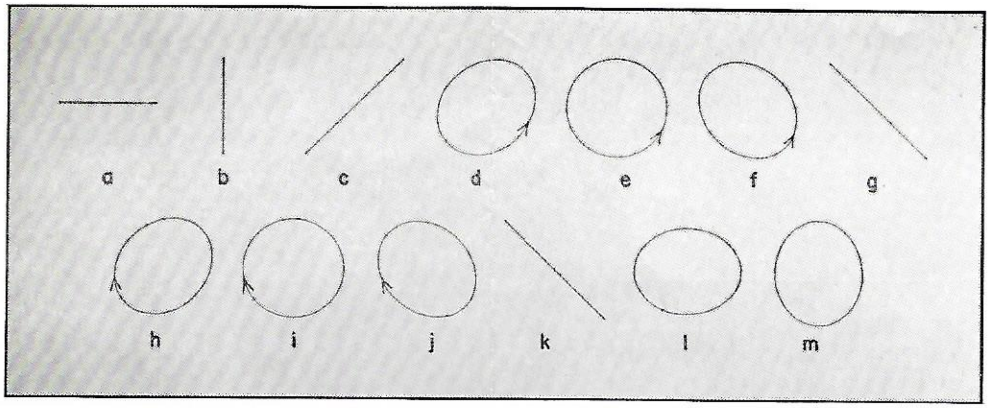

Fig. 1

polarized light and, for the purposes of this demonstration, these patterns may be taken as true representations of certain states of polarization. For example, if a sinusoidally varying voltage, such as the 60-cycle lighting source, is impressed on the horizontal plates of the oscillograph, the "spot" will move rapidly back and forth to produce a horizontal line, the length of which is proportional to the magnitude of the impressed voltage. Likewise a vertical line of controlled length may be produced if the voltage is applied to the other set of deflecting plates. Considering the oscillograph screen as a cross-section looking down into the beam of elliptically polarized light, then these two lines may be taken as representations of the two basic perpendicularly plane polarized components of the ellipse. (Fig. 1, a and b.)

If these two components are now combined, and if they happen to be of equal magnitude and of the same phase (or "in step"), they will produce as a resultant pattern a line at 45° to the two components, as shown in Fig. 1, c. If the magnitude of the two components remains the same, but their phase angle difference increases, the pattern on the screen successively changes to a left-handed ellipse with the major axis at 45° (1, d), then a left-handed circle when the phase difference becomes 90° (1, e). Further increasing of the phase difference results in a pattern consisting of a left-handed ellipse inclined at 135° (1, f) which degenerates into a straight line at 135° when this quantity approaches 180°. As the phase difference becomes greater than 180° these patterns are then repeated in the reverse order exactly as before, except that the direction of rotation is now right-handed (Fig. 1, h to k).

If a beam of plane polarized light enters, for example, a Kerr cell or a photoelastic specimen under mechanical stress, and if the polarization azimuth is at 45° to the lines of electrical or mechanical stress, then this beam will undergo a continuous change as it penetrates deeper into the stressed material. Neglecting absorption losses, it is apparent that these changes are caused entirely by a change in the relationship between the phases of the two components which are vibrating, respectively, parallel and perpendicular to the direction of stress, and the changes from patterns 1, c to 1, k will represent exactly what is happening to the beam as it penetrates the stressed material. This same series of patterns also represents the behavior of plane polarized light

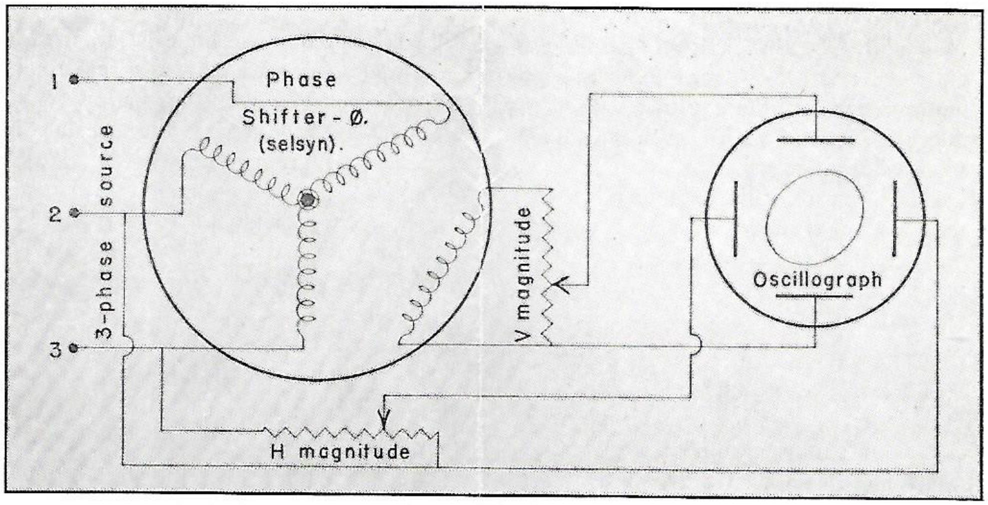

Fig. 2

traversing any birefringent medium, whether it is naturally in this condition or only attains birefringency under the action of electrical, magnetic, or mechanical stress. Cases where the azimuth of incident polarization is at an angle of other than 45° to the lines of stress are similar to the above, except that the horizontal and vertical components would no longer be equal, and this inequality would distort the patterns so that they would still represent actual conditions in the polarized beam.

By altering the magnitude of one or the other of the two components with the phase difference set at 90° or 270°, it is possible to produce ellipses inclined at 0° or 90° (1, l and m), and, by varying all three elements, it is possible to represent any imaginable state of polarization, and to note directly the magnitude of each component and the phase difference.

METHOD OF DEMONSTRATION

All the patterns previously described can be produced with quite simple electrical equipment such as is usually found in most physics laboratories. The principle item is the cathode-ray oscillograph which is preferably of the electrostatic-deflection type; for this purpose the Type 164 Oscillograph with a three-inch screen was found ideally suited. This oscillograph, with its built-in amplifiers, does not require continuous attention on the part of the operator and consequently more effort can be devoted to the proper demonstration of polarized light. The only other important piece of equipment is some sort of phase-changing transformer to be operated from a three-phase source so as to produce a voltage of constant magnitude and of controllable phase. Self-synchronous motors ("Selsyn", "Autosyn", "Synchrosyn", etc.) of even the smallest commercial sizes are readily adaptable to this purpose by fitting the shaft with a 360° calibrated dial and providing a knob and a light friction drag on the dial. From the wiring diagram in Fig. 2 it will be seen that the selsyn motor has its three-wire winding connected to a three-phase source of the proper voltage and its output winding connected via a potentiometer to the vertical-deflection plates of the oscillograph. Likewise one phase of the input is connected via another potentiometer to the horizontal-deflection plates. With a Type 164, or similar oscillograph, the built-in amplifiers and "V-gain" and "H-gain" controls will take the place of the two potentiometers and the equipment then reduces to just the oscillograph unit and a phase-changing transformer. The built-in amplifiers offer the further advantage that, for any ordinary selsyn voltage, they cannot be overloaded and hence the patterns on the screen are quite free of any artificially introduced electrical distortion.

If the source frequency is 50 or 60 cycles per second, the pattern-forming "spot" will move around the screen too fast for the eye to perceive whether the patterns are rotating left-handed or right-handed, and it will be necessary to resort to some sort of trick to demonstrate the transition from left-handed to right-handed elliptically polarized light when the phase angle passes through 0° or 180°. If motor-generator equipment is not available to produce small amounts of three-phase power at about 15 cycles per second, a satisfactory demonstration can be made by artificially introducing some "hash" into the incoming signals. No specific directions can be given for introducing this "hash" as the method will vary with each type of oscillograph. The author, in using a Type 164, found that excellent results could be obtained by connecting the external synchronizer control to either incoming signal and turning on the built-in sweep circuit and adjusting it to some multiple of the line frequency. The stability of the sweep circuit in this oscillograph is quite sufficient to keep the patterns in constant apparent rotation without any difficulty. Of course the direction of rotation of this "hash" is not necessarily the true direction of rotation of the spot forming the patterns, but since this direction reverses as the phase angle passes through 0° and 180°, the demonstration is fully convincing Similar results could probably be obtained by modulating the accelerating voltage in the cathode-ray "gun", but such a scheme has not been actually tried out experimentally.

APPLICATION

With the equipment described it is apparent that the two gain controls determine the magnitude of the two perpendicular sinusoidal (plane polarized) components, while the selsyn motor or phase-changing transformer alters the phase relationship of these two components without affecting the magnitude of either. By equalizing the magnitudes it is possible to demonstrate all the patterns in Fig. 1, c to 1, k with one rotation of the selsyn motor shaft, and the relationship of plane polarized light, with both left-handed and right-handed rotation, is quite evident. This, of course, leads to a more rapid understanding of the underlying mathematical relationship of these various states of polarization, which are the only states practically possible in physical optics.

With the DuMont Type 164 Oscillograph, a demonstration of the various generalized ellipse patterns was carried out simultaneously with the analagous polarized light experiments before a small laboratory section. With a somewhat larger oscillograph this demonstration was then repeated in a large well-lighted lecture room seating over 200 students.

EDITOR'S NOTE: *This paper is the second to be published under the rules of the Du Mont Cathode-Ray Symposium which was instituted by Allen B. Du Mont Laboratories to further the interchange of ideas on this type of indicating technique.*

Information regarding the Cathode-Ray Symposium and Prize Paper Contest may be obtained directly from our Laboratories.

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