Oscillograms and their Tests

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OSCILLOGRAPHS, as used in electrical laboratories, are divisible into two classes; namely, first, those that employ mechanical vibratory systems, and second, those that employ no mechanical vibratory systems. In the first class, are the great majority of electrical engineering oscillographs. In the second class are Braun cathode-ray tubes. The paper here presented deals only with the first class, or mechanical vibrators.

All mechanical-vibrator oscillographs behave differently to different frequencies, owing to their inherent elasticity and inertia. In other words, their specific deflections[1] and calibrations differ at different frequencies. These differences affect both magnitude and phase. An oscillograph calibrated at, say, 60~ must have a different calibration at other frequencies. In some instruments, the difference may be small, and for many purposes it is often negligible. In other instruments, or for other purposes, the difference may be very serious. But whether the error due to a change in frequency is small or large, it should be measurable, and the amount of it should be either known or determinable to the desired degree of precision.

When the oscillogram of a complex alternating wave form is analyzed, in one of the usual ways, for its Fourier components; *i. e.*, into a fundamental wave and its harmonics, these different harmonics call for their proper corrections, both as to amplitude and to relative phase position. It is not possible for the same calibration to apply to them all. If the instrument has been calibrated at, or near, the fundamental frequency, the apparent harmonic components require correction. The correction factors may be greater or less than unity. They may not be serious, but they should be capable of determination.

These errors of harmonic analysis in oscillograms have been known for some years, as the bibliography of the paper indicates; but no technique for determining the correction factors of an oscillograph at various impressed frequencies has yet been published, so far as the authors are aware.

The paper discusses (1) the theory of an oscillograph with relation to the purpose in view, (2) a device called an oscillograph-meter, which is an auxiliary compact vibrator for determining the resonant frequency of the tested oscillograph, and (3) a number of measurements obtained in this way upon oscillographs in the laboratory.

Theory. The paper points out that there is a complete and valuable analogy between an oscillographic vibrator, or the working part of an oscillograph, and a simple alternating-current branch circuit ($C\ L\ R$ circuit), containing a fixed capacitance C, a fixed inductance L, and a fixed resistance R, all in series across a pair of constant-potential mains, operated at variable impressed frequency. The capacitance C corresponds to the looseness or inelasticity of the mechanical suspension, the inductance L to the mechanical moment of inertia, and the resistance R, to the mechanical torque of frictional resistance to motion in the vibrator. Again, the alternating e.m.f. of the mains corresponds to the alternating torque imposed by a given r. m. s. current passed through the vibrator, and the alternating current strength in the $C\ L\ R$ branch to the angular velocity of the vibrating mirror. This analogy is helpful, because electrical engineers are more likely to be familiar with the electromagnetics of alternating-current circuits than with the dynamics of vibratory mechanical systems.

What the oscillographer desires to ascertain is the maximum angular displacement of the vibrating mirror under constant impressed vibratory torque, but with variable frequency. This displacement bears the same relation to vibratory angular velocity that alternating quantity, or electric displacement in the $C\ L\ R$ branch, bears to alternating current.

It is shown that just as there is the well known impedance Z to alternating current in a $C\ L\ R$ circuit, such that, by Ohm's law, $I = E/Z$; so there is also an impedance Z' to alternating electric quantity, or electric displacement, such that the maximum cyclic displacement is E/Z'. Attention is therefore directed to this "displacement impedance" in a simple branch circuit, which corresponds, in the mechanic analogy, to displacement impedance in the oscillograph.

Bluntness of Resonance. Any mechanical oscillograph, like any $C\ L\ R$ branch circuit, has a certain "bluntness of resonance" B. This quantity may be defined in various ways; but the definition selected in the paper is the ratio of the damping factor to the resonant angular velocity. A vibrator, or a branch circuit, has a bluntness of unity, when its resistance is just sufficient to make it critically aperiodic. If the bluntness is, say, 0.5, then the resistance is half that necessary for critical aperiodicity. Such a vibrator, or circuit, would have a "sharpness of resonance" of $1/0.5 = 2.0$. A bluntness of $B = 3$ would mean three times as much resistance as would be necessary for critical aperiodicity. An air-damped oscillograph ordinarily has a very small bluntness, or a large sharpness of resonance ($B = 0.01$ perhaps). A vibrator damped in castor oil may, on

1. The specific deflection of an oscillograph may be defined as the ratio of its deflection to the r. m. s. current producing the same.

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the other hand, have a bluntness greater than unity ($B = 1.2$ perhaps). The most suitable bluntness for an oscillograph, in order to operate with uniformity over a wide range of frequency, is probably near $B = 0.6$. The best value depends on the range of frequency to be covered.

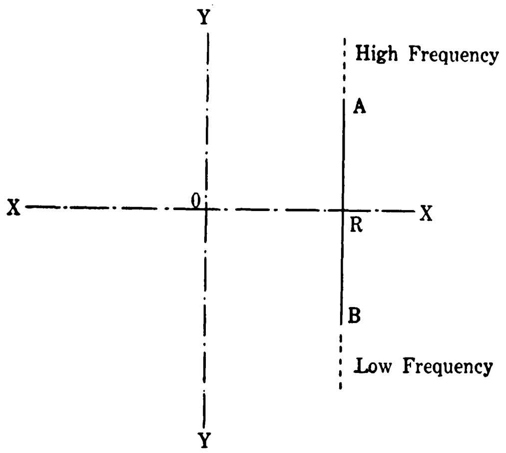

FIG. 1—VECTOR LOCUS OF IMPEDANCE TO ALTERNATING CURRENT IN A $C\ L\ R$ BRANCH, OR TO ANGULAR VELOCITY IN A VIBRATOR

If the resonant frequency f_0 of an oscillograph, and its bluntness B_0, are known, then its correction factor as regards amplitude and phase can be readily computed or tabulated for any or all impressed frequencies.

Displacement Impedance. Whereas the impedance Z of a branch circuit to electric current, at varying impressed frequency, is a straight line, $A\ R\ B$ Fig. 1, parallel to the Y axis, and passing through the point R on the resistance or X axis at the resonant frequency, the impedance Z' of the branch, to displacement, is a simple parabola $A\ B\ C\ D$ Fig. 2, having its axis on the real axis $X\ O\ X$. At zero frequency, the displacement impedance is $O\ A = 1/C$, and is equal to the reciprocal of the capacitance. As the impressed frequency increases, the vector displacement impedance is OB, OC, OD, and so on. At resonance, it is OC, along the Y axis. The focus F of the parabola lies below the point B, at which the tangent $t\,t'$ is equally inclined to the X and Y axes. Branches or vibrators of sharp resonance have a sharp vector displacement-impedance parabola, and the focus F lies to the right of the origin O. Branches or vibrators of blunt resonance, have a blunt displacement-impedance parabola, and the focus F lies to the left of the origin O. The ratio of the ordinate $F\ B$ through the focus, to the ordinate $O\ C$ through the origin, is equal to the bluntness B_0 of the branch or vibrator.

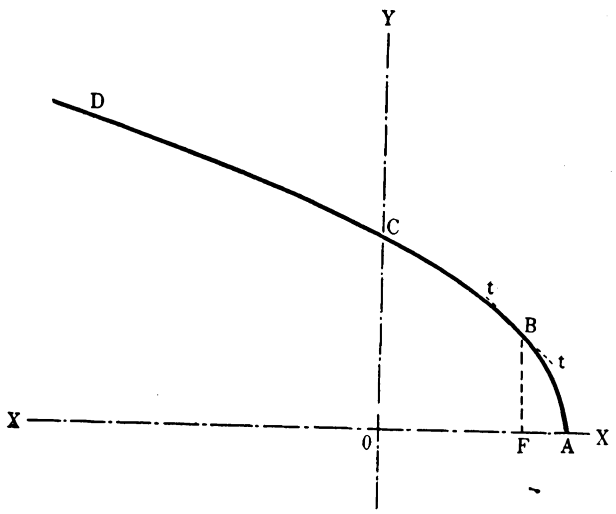

FIG. 2—VECTOR PARABOLIC LOCUS OF DISPLACEMENT IMPEDANCE IN A $C\ L\ R$ BRANCH CIRCUIT OR IN A VIBRATOR

Displacement Admittance. If we plot the reciprocal of the parabolic vector displacement impedance, we obtain a "displacement admittance" curve, or reciprocal of a parabola, which indicates the magnitude and phase of the displacement produced by unit impressed e. m. f. in the branch circuit as the impressed frequency is varied. A group of these curves are presented in Fig. 3, between the limits $B = 0.25$ and $B = 1.0$, for various ratios u of impressed to resonant frequency. From these curves, the behavior of any ordinary oscillograph can be read off, by inspection, when the bluntness B, and the resonant frequency f_0 of its vibrator are known. Thus, an oscillograph of bluntness $B = 0.3$, and calibrated at, or near, 60∼, would over-indicate in the ratio $1.24 \angle 22$ deg. at $0.5 f_0$, or at an impressed frequency half of its resonant frequency. Its maximum cyclic deflections would be 24 per cent too great at this frequency, and they would lag 22 deg. in phase behind the impressed torque. At $0.8 f_0$, it would over-indicate in the ratio $1.65 \angle 53$ deg., and so on, following the curve for $B = 0.3$.

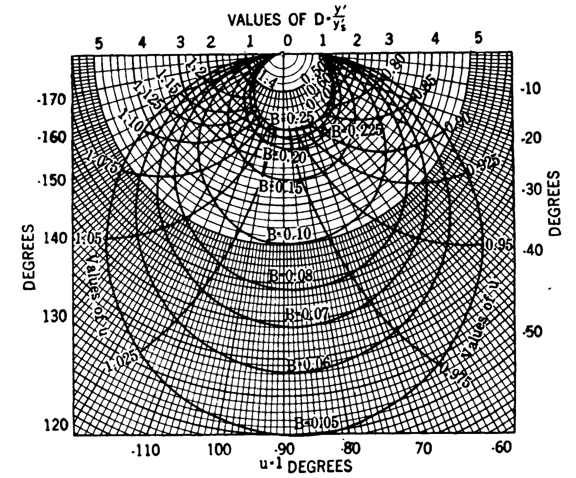

FIG. 3—PLANEVECTOR CHART OF THE DEVIATION FACTOR D FOR ANY OSCILLOGRAPH WHOSE BLUNTNESS LIES BETWEEN $B = 0.25$ AND $B = 1.0$, AND WHOSE RESONANT FREQUENCY IS GIVEN.

EXAMPLE: IF $B = 0.6$, AND $u = 0.3$, THEN $D = 1.022 / 21.6$ DEG.

Technique for Measuring f_0. In order to measure the resonant frequency, which, as indicated in Fig. 3, is not the frequency of maximum displacement, an optical method is used; *i. e.*, the method of Lissajous figures. An auxiliary permanent-magnet air-damped vibrator, shown in Fig. 4, is supported close in front of the tested oscillograph vibrator, as in Fig. 5. Both vibrators are connected to the same high-frequency source—a Vreeland oscillator or triode vacuum-tube oscillator. The frequency impressed from this source

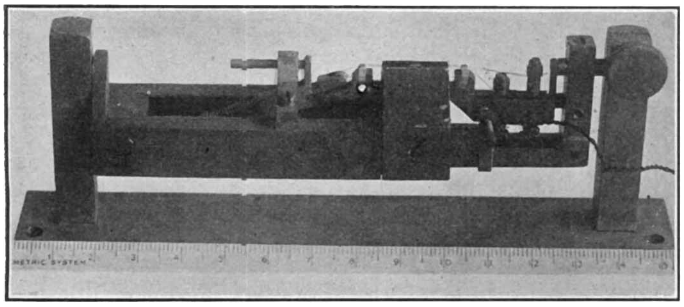

Fig. 4—Oscillographmeter or Auxiliary Vibrator, Length of Mirror 2.3 mm. Breadth 0.9 mm.

on the vibrators is raised, until the resonant frequency of the tested oscillograph is reached. Then, provided that the auxiliary vibrator is not also nearly resonant, the phase displacements of the two mirrors will be in quadrature. At resonance, the phase of a vibrator always lags 90 deg. behind the impressed torque. The auxiliary vibrator mirror, being air damped, and of very sharp resonance, will be very nearly in phase with

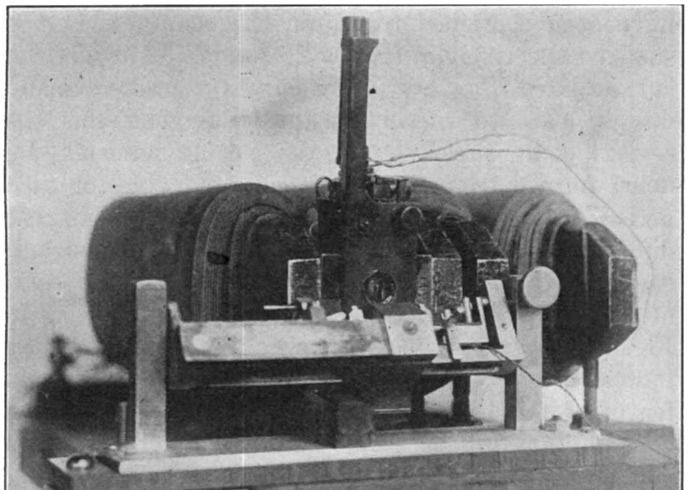

Fig. 5—Oscillographmeter Applied to Oscillograph for Test of Latter

the impressed torque until the impressed frequency is close to its resonant point. The condition of quadrature between the two vibrating mirrors is easily detected, by throwing a small arc-light beam, first on to the tested vibrator mirror, and then to the auxiliary vibrator mirror, and finally on a fixed screen, the two mirrors having their axes mutually perpendicular. The optical figure perceived on the ground glass or paper screen reveals the quadrature relation.

Technique for Measuring B. Having ascertained the resonant frequency f_0 for the tested oscillograph, as above described, the auxiliary vibrator is withdrawn, and the tested oscillograph is then calibrated at any very low frequency, such as $60\sim$, and again at its resonant frequency f_0. The ratio of the specific deflection at $60 \sim$, to twice the specific deflection at f_0 is then the bluntness B of the vibrator. This relation can be observed from an inspection of Fig. 3.

Having thus ascertained the fundamental constants f_0 and B of the oscillograph, its behavior at any impressed frequency may be ascertained, either by graphic approximation from Fig. 3, or by means of a formula given in the paper. These fundamental constants f_0 and B should be measured, whenever an oscillogram of a periodic wave form is secured for accurate work, and they may advantageously be recorded, for reference, on the oscillogram itself. Both constants are subject to variation with the temperature of the damping liquid; but, at constant temperature, they appear to be fairly permanent.

Results of Observations. The observations above described have been checked upon a number of vibrators, with satisfactory results. Oscillographic vibrators have resonant frequencies ordinarily lying between $1200\sim$ and $5000\sim$. Their bluntness B depends very largely upon the viscosity of the damping liquid. A vibrator, for example, which in air, had $f_0 = 2635\sim$ and $B_0 = 0.055$, developed in glycoline $f_0 = 1675\sim$ and $B_0 = 0.125$. In mineral oil, these values became $f_0 = 1614\sim$ and $B_0 = 0.288$; while in castor oil, they became $f_0 = 1196 \sim$ and $B_0 = 0.83$.

Tables and curves are presented in the main paper, giving the results obtained on various instruments in the laboratory.

SLAG AS AN AGGREGATE FOR CONCRETE

The results of the investigation made by the Bureau of Standards during the past two years on this subject are summarized as follows: Crushed slag as a coarse aggregate produced concrete of as high or higher strength than gravel. The tests have not been extensive enough to determine the durability of slag, but so far as they have gone, no signs of disintegration have been observed due to sulphide sulphur. Slag sand, because of its lack of fine material, does not produce easily workable concrete when used as fine aggregate. If it must be used, its working qualities can probably be improved by the addition of small amounts of fine sea sand, hydrated lime, or other similar material. In all probability, a larger amount of fine aggregate to replace some of the coarse aggregate would aid workability. Provisions in specifications for slag aggregates calling for a maximum sulphide sulphur content of 1½ per cent and a minimum weight per cubic foot of 70 pounds have been tentatively recommended.