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OSCILLOGRAPHER

THE OSCILLOGRAPH USED FOR DYNAMIC BALANCING

By WYLIE GRANT, Pioneer Mine, B. C.

Part 2

DERIVATION OF THE FORMULAE

While the motor is running in the forward direction two series of reactions take place simultaneously, and these may be studied with the aid of Figure 5. Here the abscissae represent time measured in degrees of rotation as registered by the pointer on the scale. Assuming that the pickup is mounted at the pointer, and that the overweight occurs at ω degrees, the distance between the overweight and the pickup, measured along the axis of the pickup as ordinate, is indicated by a sine wave (a). But if the pickup is mounted at an angle ϕ past the pointer, measured in the direction of rotation of the shaft, the conjunction of the overweight and the pickup occurs ϕ degrees later as is shown by (b). Resulting from this overweight movement are a motion of the frame in the same axis, an E. M. F. generated in the pickup, and a vertical motion of the cathode ray; all of which are similar to the first wave but may have a different phase relationship. We will assume that the vertical motion of the beam lags behind the motion of the overweight by the angle l as shown by (c) in the figure.

The other series of reactions begins with the synchronizing impulse (d) which controls the sweep voltage (e). The ordinate of (e) represents the horizontal position of the beam, so that the combination of the waves (c) and (e) gives the actual screen pattern (f). The value (s) represents the error of synchronization due to phase difference caused by the photo-cell amplifying system. It is assumed that the synchronizing impulse is properly centered and (s) is the same for both directions of rotation.

For reverse rotation the same description applies except that ω and ϕ are measured in the reverse direction.

The angles α_F and α_R are the distances in degrees of rotation from the starting edge of the fluorescent pattern to the peak associated with the conjunction of overweight and pickup. It is apparent from the figures that:

$$\alpha_F = \omega + \phi + l - S - 360^\circ \quad 1.$$

$$\alpha_R = -\omega - \phi + l - S + 360^\circ \quad 2.$$

Study of the figures show that for different values involved the last terms may change, but they will always be simple multiples of 360° (including zero and negative values.) The value of (l-s) may be combined as L. The formulae may now be expressed more generally:

$$\alpha_F = \omega + \phi + L + 360^\circ \times n$$

$$\alpha_R = -\omega - \phi + L + 360^\circ \times m$$

These equations may be used directly or they may be combined to give:

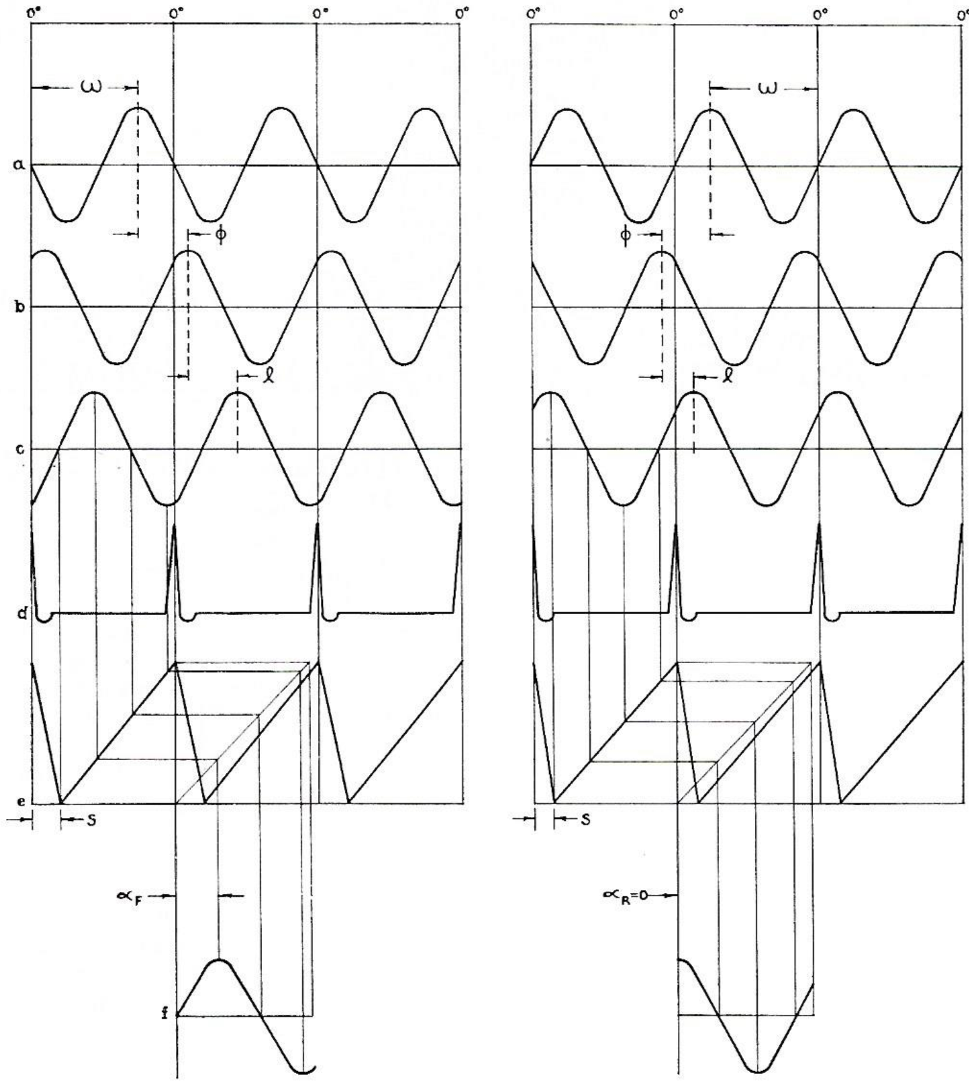

FIG. 5

$$L = \frac{\alpha_F + \alpha_R}{2} - (n + m) \times 180^\circ \quad 3.$$

$$\omega = \frac{\alpha_F - \alpha_R}{2} - \phi - (n - m) \times 180^\circ \quad 4.$$

From the definition of ω its value must be positive and less than 360°. (L) may be negative or greater than 360° but since it recurrs at intervals of 360° there is always a value within these limits. The formulae will still be valid if this value is chosen for the sake of convenience. It only effects the issue, then whether (n+m) and (n—m) are odd or even numbers. If they are odd 180° must be added, if they are even it must not. Both of these values have the same characteristics; if one is odd so is the other.

In commencing work on a machine it is first necessary to obtain the value of (L). This is done by a trial test. The values α_F and α_R are taken, the calculation for L and ω made assuming (n+m) to be odd or even. A trial correction is made and another test is run. The results of this test will indicate whether the assumption was right or wrong. Once the value of (L) is determined for a machine it serves as a guide in subsequent tests to show whether 180° must be added in obtaining ω. This trial test is not wasted since it affords evidence on which to estimate the amount of correction required.

From the foregoing it appears that when the machine under examination can be reversed, the term (L) can be determined (within the limit described.) However, if the machine cannot be reversed the formula (1) must be resorted to and a value for (L) must be found by some other means. Knowledge of the character of (L) is therefore necessary.

PHASE ANGLE OF FORCE AND DISPLACEMENT

The vibration of a rotating machine has some features which are well worth a more comprehensive study than can be attempted in this article. One of these which has an important bearing on the question can be briefly illustrated as follows: Consider again Figure 2, if the assembly rotates with the shaft held in immovable bearings, (O) will travel in a circle about (A). However, if the shaft is not fixed the tendency will be for the centre of gravity to remain stationary since there is no force to move it, and the axis (A) will revolve about it. In this case it is apparent that the displacement of the shaft is opposite to the position of the overweight on the shaft; they are therefore 180° out of phase. In practice the bearings are never entirely free to move and they exert a force which alters this phase relationship according to the amount of "damping" present in the mounting. As the speed of rotation increases the mass has less time to respond to the bearing force and the phase angle approaches 180°. It has been shown[1] that the phase angle is 90° lagging for all conditions of damping at resonant speed, and that above that speed it approaches 180° at a rate dependent upon the amount of damping present. It is desirable to operate a machine under test at a speed well above its resonant speed in order to obtain as stable a phase angle as is possible. If the machine cannot be reversed some method other than Equation 3 must be used to determine L for Equation (1).

$\frac{\omega}{\omega_n}$ is the speed of rotation relative to the resonant speed (ω_n). $\frac{C}{C_c}$ is the condition of damping relative to the critical damping (C_c). If Θ is the phase angle between the position of unbalance and the resulting unbalance, then

$$\Theta = \frac{2\frac{C}{C_c}\frac{\omega}{\omega_n}}{1-\left(\frac{\omega}{\omega_n}\right)^2}$$

and $L = \Theta - C$ where (C) is the constant characteristic of the testing equipment. This is discussed below.

The resonant speed of a motor may be measured approximately by adjusting the speed for maximum vibration. The oscillograph will serve in noting both the amplitude of the vibration and its frequency. The relative speed of the motor is then easily calculated. It may generally be stated that usual mountings have a narrow range of damping constants usually between 0.125 and 0.5; and if this is determined by the use of a reversible motor, or by any other method, on a similar base, the constant thus found may be used to obtain Θ for the motor under test.

OTHER PHASE ANGLES

Characteristics of the pickup also will effect (L). The usual type of construction resembles the well known dynamic speaker. The pickup coil (similar to a voice coil) is attached to the housing of the pickup, which is fastened to the vibrating machine, and it moves in the strong field of a magnet which is supported on weak springs so

[1]Den Hartog, "Mechanical Vibrations", McGraw-Hill, 1940 Edition, Chapter 15

as not to respond to the motion of the machine. Since the instantaneous E. M. F. generated in the pickup varies with the rate of motion of the coil across the field, a peak E. M. F. indicates a peak of motion rather than one of displacement. A little study reveals that the motion or pickup wave is 90° in advance of the displacement.

Care must be taken that the construction of the pickup provides an inherent frequency which is many times lower than that corresponding to the speed of the machine under test, otherwise a more than negligible error may originate here. This investigation leads to the conclusion that $L = \Theta - C$ where (C) is a constant characteristic of the testing equipment. By the determination of these factors, (L) may be found and used with formulae (1) for any machine which cannot be reversed.

AMOUNT OF CORRECTION REQUIRED

Most of the foregoing discussion is directed to finding the position and type of unbalance. Rather obviously the amplitude of the vibration is a direct indication of the amount of unbalance, and therefore, of the amount of correction which has to be applied to correct it. A direct calculation of the correction weight from the amplitude of the screen pattern would involve terms including sensitivity of the pickup, gain and phase delay of the amplifier, speed of rotation, relation to resonant speed, mass and rotational inertia of motor, distance of point of correction from centre, etc., which render the project impracticable. However, by the use of judgment and the trial test previously described, good results may be quickly obtained. The writer has found that only a very few trials will suffice to reduce the vibration below the level of that arising from other sources, which means that it is to all effects eliminated.

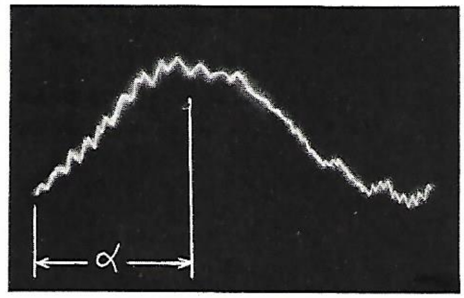

Illustration 2. Typical Oscillogram which shows alpha equal to approximately 140 degrees.

AN ACTUAL EXAMPLE

Correction of 30 h. p., 900 r. p. m. motor.

Test I $\phi = 0$

SIMPLE UNBALANCE

Ampl. = $\frac{3}{16}$″, $\alpha_F = 350°$, $\alpha_R = 150°$

DYNAMIC UNBALANCE

Ampl. = $\frac{3}{4}$″, $\alpha_F = 350°$, $\alpha_R = 150°$

THUS

$L = 250°$, $\omega = 100°$ or $L = 70°$, $\omega = 280°$

Correction for dynamic unbalance was made assuming L = 70°. Simple unbalance was considered sufficiently good.

Test II

DYNAMIC UNBALANCE

Ampl. = $1\frac{1}{2}$″, $\alpha_F = 180°$, $\alpha_R = 300°$

THUS $L = 60°$, $\omega = 120°$

Trial correction was based on correct value of L, but was about three times too much.

Test III

DYNAMIC UNBALANCE

Ampl. = $\frac{9}{16}$″, $\alpha_F = 330°$, $\alpha_R = 150°$

THUS $L = 60°$, $\omega = 270°$

Correction has been reduced too much. Adjusted.

Test IV

Dynamic unbalance wave was now indistinguishable from distortion. Amplitude all inclusive, $\frac{3}{16}$″.

Correction was considered sufficient since vibration was no longer apparent.

ALLEN B. DU MONT LABORATORIES, INC.
2 MAIN AVE., PASSAIC, NEW JERSEY

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