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MAGNETIC FLUX MEASUREMENT WITH A CATHODE RAY OSCILLOGRAPH

LELAND D. NORTON and JOHN H. TREVITT
Dictaphone Corporation, Bridgeport, Conn.

The determination of the distribution of the magnetic flux and the leakage paths in complicated magnetic circuits is a problem which generally cannot easily be solved by mathematical formulas. The calculation of leakage fluxes is never very accurate, as the exact length of the leakage paths is difficult to determine.

The cathode-ray oscillograph, in combination with simple search loops, provides a very convenient method of measuring the relative magnitude of the active flux and the leakage fluxes in a magnetic circuit. This permits the evaluation of the flux at different points in the magnetic circuit. The leakage fluxes can be obtained either by direct measurement, or where that is not possible, by the measurement of all other flux components, and then setting up the leakage flux as all that is not otherwise accounted for.

The search loops can be made of any convenient insulated wire which has sufficient stiffness to hold it in shape, or small enough to fit into the space available where that is a factor. When small leakage fluxes are to be measured, a preamplifier, in addition to the 2-stage amplifier in the oscillograph, must be used in order to get a readable deflection on the screen. If no preamplifier is available, a step-up transformer can be used to get a step-up in voltage. In this case, it is important to have the same total resistance for the search loop and lead. This is not important when the search loop is connected to the high impedance input of an amplifier.

The problem to be solved was to find a way to increase the pull on the armature of an electromagnetic clutch without increasing the power input or increasing the size of the unit. The construction of the magnetic portion of the unit is shown in Figure I. "A" is the clutch armature pivoted about "B" in the clutch bracket "C". The coil yoke "D" is fastened to the clutch bracket and supports the two clutch coils "E" with their iron cores "F" and the pole

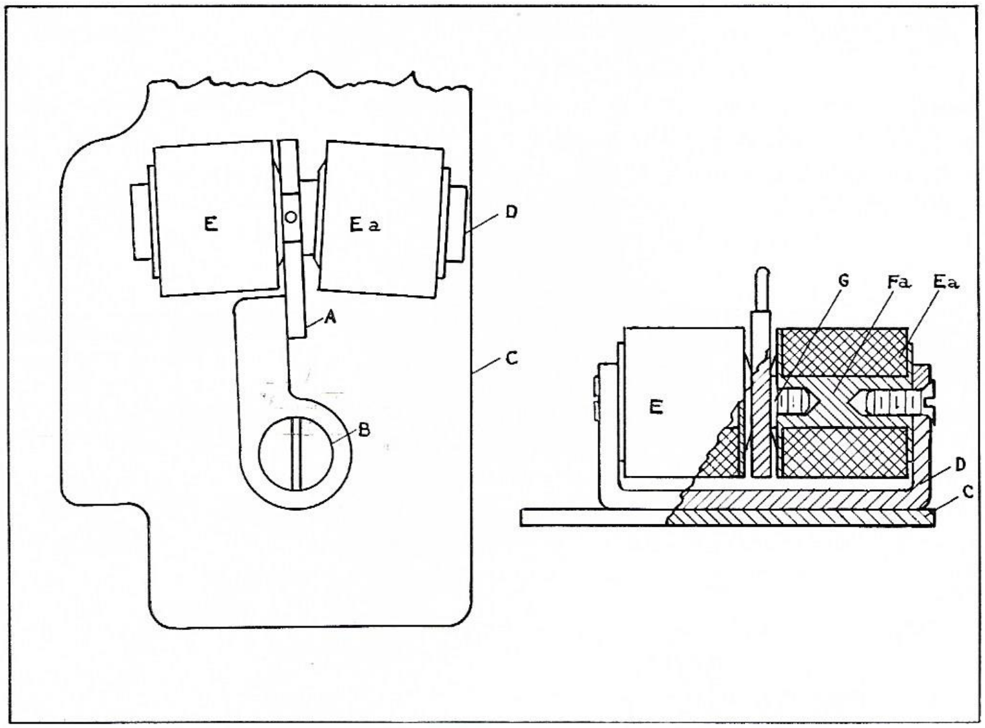

FIGURE 1.

faces "G". Thin rubber pads "H" cover the pole faces to reduce the noise and prevent actual metal to metal contact.

The clutch bracket "C" was originally made of brass, and the other parts of soft steel. An inspection of the clutch mechanism shows that the active magnetic flux passes from the end of coil "Ea" through the air gap on the armature "A", and from the armature across the small air gap to the coil yoke "D". Considerable leakage loss was expected to pass from the armature "A" to the pole face of the core "F" of the inactive coil "E", as the armature is separated from it only by the thin rubber pad, from whence it passes through the core of the inactive coil back to the coil yoke "D", and then to the other end of the active coil. Other leakage paths appeared probable in the air gap between the pole face of the active coil "Ea" and the coil yoke "D", between the active coil and the yoke, and through the air from one end of the active coil "Ea" to the other.

To explore all these possibilities, coils were placed at six different points in the magnetic circuit, as indicated in the photograph Figure II, and numbered from one to six. Single loops of enameled wire were formed around the perimeter of the coils in positions 1 and 3, around the yoke in positions 2 and 4, in the small air gap section with the loop sides parallel to the armature at 5, and a narrow loop in the air gap space between the pole face and the armature on the yoke at 6.

The leakage from the active coil to the yoke was not measured, but was determined as the difference between the maximum flux at 2 and the flux in the air gap measured at 1.

An alternating potential was induced in the search loops by sending an alternating current through one coil of the electromagnet. The ends of the six loops were consecutively connected with the vertical plates of the cathode ray oscillograph. The vertical height of the sinusoidal trace was adjusted to maximum for loop 2 where the flux was the greatest. The reading recorded was the sum of the deflection above and below the median line. The flux at the outer end of core "F" measured in position 1 was taken as a base because this was the total flux available for operating the armature together with all the leakage fluxes except the coil leakage. The other fluxes were expressed in percentages of this value. The flux passing across the small air gap, measured by the coil in position 5, was assumed to be the effective flux which produced the magnetic pull. On this basis, the following results were obtained:

Position 1	air gap	100 %
Position 2	active coil yoke	129.6%
Position 3	inactive coil core	40.7%
Position 4	inactive coil yoke	40.7%
Position 5	active flux	40.7%
Position 6	leakage, pole face to yoke	18.6%

It is evident from these measurements that the flux measured at position 3 and position 4 are one and the same thing, the leakage being small enough to be negligible. The other values give a picture of the magnetic flux distribution. An improvement seemed possible if the brass clutch bracket were replaced by a similar bracket made of steel. Then the magnetic reluctance through the return path, consisting of the armature and its pivot, would be decreased, and, consequently, a greater effective flux would be available for moving the armature.

This change was made, and after a brief magnetic survey, it was found that the flux distribution remained fundamentally the same. A new path was opened up for the active flux which could now pass along the whole length of the armature, through the armature pivot, and return through the steel bracket. Therefore, a new search loop 7 was inserted to surround this new flux path.

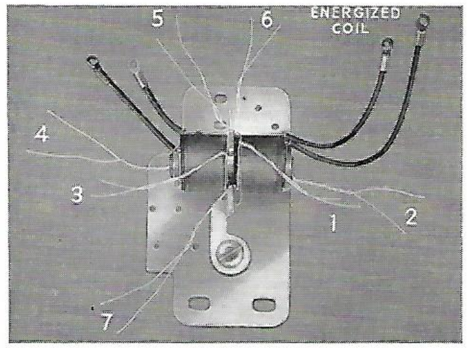

FIGURE 2.

Repeating the measurements in the same manner as before, the following results were obtained:

Position 1	air gap	111%
Position 2	active coil yoke	160%
Position 3	inactive coil core	22%
Position 4	inactive coil yoke	22%
Position 5	active flux	13%
Position 6	leakage, pole face to yoke	5%
Position 7	active flux	71%

The air gap flux is increased by 11% with the same voltage applied, and the active flux now has the value of 84% of the original basic flux, or an increase of 208% for the active flux obtained in the first design. The active flux, in this case, consisted of the sum of the fluxes in position 7 and position 5. The coil leakage was increased by this change in design, but nowhere near in proportion to that of the effective flux.

If possible, the measurements should be made under actual working conditions with the current that is normally used. However, if that is not possible, as it was not in this case, a lower current can be used. A final very short test was made at full current to see whether any saturation effects due to the higher flux densities needed to be considered.

This same method has been used extensively for the investigation of small universal motors to observe the flux and the armature reaction for different brush positions and different brush widths. In this case, one search loop is placed with its two sides in the geometrical neutral zones between the poles for the effective flux, and the other loop with its sides on the center lines of the poles for the cross magnetizing flux. A loop around the base of the field coil gives the maximum flux.

These measurements have indicated ways of increasing the torque and efficiency of these small motors, as well as improving the commutation.

The accuracy of the method depends on the careful choice of the positions of the search loops, the care with which the test loops are formed so that they link only the flux which should be measured, and the ratio of the thickness of the trace line to the maximum amplitude observed. The possible errors will be of the order of 5% of the maximum flux measured.

In most cases, compartive measurements such as those which have been mentioned are all that is necessary. However, if one wishes to go to the extra trouble, it is possible to actually determine the flux enclosed by the loops. The actual voltage applied to the cathode ray tube can be determined by calibrating the tube by any one of several methods, such as comparison with a standard, or the use of a potentiometer across a known higher and easily measured voltage, or other convenient methods. Then the flux can be determined from the following relationship:

$$\text{Maximum flux in lines} = \frac{10^8}{2\pi} \times \frac{\text{Maximum induced voltage}}{\text{frequency (cycles per second)}}$$

The maximum induced voltage is determined from the calibration. This relation holds for any wave shape.

The method which we have disclosed gives a very revealing picture of the magnetic flux distribution in complicated magnetic circuits. The accuracy of the method is quite satisfactory for most preliminary magnetic designs and investigations. The system can be used in many cases where mathematical methods either are much too complicated, or cannot be applied. In most cases, it will take much less time to determine experimentally the distribution of the flux than to try to calculate it. It is particularly applicable for equipment operated by alternating current, but the method is also applicable for magnetic circuits where direct current will normally be used. It gives a very clear picture of how various design changes affect the ultimate efficiency of the unit.

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

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