THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
RESEARCH DIVISION REPORT

To Mr. J.H. Waghorne
Director of Research

REMANENT FLUX IN CURRENT TRANSFORMERS

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Large amounts of remanent flux have been measured in relaying current transformers in service. This remanent flux may delay the operation of protective relays under transient fault conditions. Small air gaps in the cores of current transformers are suggested as a means of reducing remanent flux to a negligible value.

In the process of studying the performance of relaying current transformers, the effects of remanent flux on the output of current transformers were studied. The study consisted of measuring the remanence of relaying current transformers in service and of calculating the output of current transformers without remanence and maximum possible remanent flux.

This report gives the results of the as-found measurements of remanent flux of in-service relaying current transformers; explains the mechanisms by means of which remanent flux may be left in the core; gives typical transient output current wave-forms for current transformers, both with and without remanent flux; and suggests various steps that can be taken to reduce remanence in current transformers.

Survey of Remanence

As-found remanent flux was measured on 141 relaying current transformers in service. The transformers had been in service on Ontario Hydro's 230-kv system for periods of one month to a number of years. The sample included transformers both of the free-standing kind associated with air-blast breakers, as well as bushing current transformers mounted on oil breakers. The transformers, whose remanent flux was to be measured, were removed from service. A fluxmeter was connected across one portion of the transformer winding while a direct current was applied to another portion of the same winding. From the indication of the fluxmeter obtained while the direct current was applied in the forward and reverse direction, the remanent flux was computed. The table below summarizes the results of the survey.

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Remanent Flux (per cent of Saturation flux	Percentage of Transformers	
0 - 20	39	36
20 - 40	18	18
40 - 60	16	20
60 - 80	27	26
Total	100	1000

Mechanism of Remanence

There are many factors and conditions that influence the magnitude of remanent flux in a current transformer. For a transformer whose ratio, rating, and core characteristics are fixed, the remanent flux will depend largely on the flux in the core immediately prior to primary current interruption.

The flux in the core also depends on many factors. The most important ones are the magnitude of the primary current, the impedance of the secondary circuit and the amplitude and time constant of any offset transient. Since the impedance of the secondary circuit is fixed, the magnitude of remanent flux is governed by the magnitude of the symmetrical component of primary current and the magnitude of the offset transient prior to primary current interruption. Maximum remanent flux can be obtained under conditions where the primary current is interrupted while the transformer is in a saturated state.

Considered above were the operating conditions under which remanent flux can be left in a transformer core. There are also test conditions that can leave large remanence. Any procedure that requires direct current to flow in the windings of a transformer may cause remanence. For example, the measurement of the secondary winding resistance by a resistance bridge or multimeter, or a continuity check by a buzzer will leave almost maximum remanence in the core.

Once remanent flux is established in the core of a transformer it dissipates very little under service conditions. The voltage developed in the current transformer winding under normal operating conditions is not large enough to reduce the remanence except by only a very small percentage. In fact, it can be shown that a voltage in the order of 60 per cent of saturating value must be applied, if the remanent flux density is to be reduced to less than 10 per cent of saturation flux density.

The remanent flux will therefore remain in the core until the next occurrence of a large offset transient.

Output of Current Transformers with Remanence

Remanent flux in a current transformer core affects the burden and fault current capabilities of that transformer. When the remanent flux is of the opposite polarity to the flux due to the transient component of the fault current the burden or current capabilities of a current transformer are increased. They are reduced if the remanent flux is of the same polarity as the flux due to the transient component of the fault current. Since the reduction of transformer capabilities are most important, only it shall be discussed.

Shown in Figure 1 are three waveforms representing the output current of a current transformer with and without remanence. The waveforms in this figure belong to a 1200 to 5-ampere current transformer rated at 2.5L800, having a resistance of 0.6 ohms in the secondary winding. They were calculated with the aid of a digital computer. The fault current in each case is 24000 amperes with a transient having a 0.050-second time constant (X/R = 19), and maximum amplitude. Waveform A represents the output for the transformer loaded with an external burden of 2.0 ohms, resistive, and no remanent flux. Waveform B represents the output for the transformer loaded with an external burden of 0.7 ohms and 50 per cent remanence. Waveform C represents the output for the transformer loaded with an external burden of 0.05 ohms and a remanence of 75 per cent.

Note that the three output current waveforms are distorted to approximately the same intensity. Since the only variables in Figure 1 are the remanent flux and external burden, it can be concluded that for this particular example the burden had to be reduced from 2.0 ohms to 0.05 ohms to accommodate 75 per cent remanent flux.

An approximate formula that may be used for estimating the reduction in burden capability of a transformer with remanent flux is

$$B_r = \frac{(100-R)B_o}{100}$$

Where B_o = resistance of the secondary circuit of transformer with no remanence.

B_r = resistance of the secondary circuit of transformer with remanence.

R = remanent flux in core expressed in per cent of saturation flux.

Since remanent flux as high as 80 per cent of saturation flux can be obtained, and has been measured in cores of current transformers, the burden capability of a transformer with such high remanence has been reduced by a factor of 5. Since the resistance of the transformer secondary winding is a part of the total burden, the burden external to the transformer may have to be reduced to a very small value.

Shown in Figure 2 are three output current waveforms of a current transformer burdened with the same burden but with different magnitudes of remanence. The transformer ratio is 1200 to 5 amperes and rated at 2.5L800. The external burden is (1.0 + j 0.7) ohms which represents the lead resistance and the impedance of relays associated with the LH-1 line relaying scheme. The fault current is 24000 amperes with a transient of maximum amplitude and a time constant of 0.05 seconds.

It can be readily seen that there is an early loss or distortion of the output as the remanent flux is increased from zero to 50 and 75 per cent of saturation flux.

<u>Reducing Remanence in Current Transformers</u>

The only way of reducing remanence of current transformers that are presently in service is to demagnetize them by external means. Such demagnetization could be performed using power-frequency voltage or direct current. Demagnetization should be performed after each major disturbance in the station if the illustrated loss of performance is to be avoided (Figure 2).

Current transformers should be demagnetized after a continuity check or resistance measurement made by presently available equipment. The prevention of accidental saturation of current transformers by test instrumentation would require special continuity testers and resistance measuring instruments.

The remanence in new transformers can be controlled in a number of ways. These include the use of different grades of steel for the core, the use of air-gapped cores and the use of biased-core current transformers. These measures will be discussed in turn.

Cold-rolled, grain-oriented, silicon steel is the core material used for almost all relaying current transformers. This material can have remanence as large as 90 per cent of its saturation flux density. Hot-rolled silicon steel does not have as high a permeability or as low losses as the cold-rolled steel, but its maximum remanence are approximately half of the cold-rolled steel. If hot-rolled silicon steel were used for relaying current transformers, problems with remanence would be reduced.

The use of an air gap in the core of a current transformer has two effects on its performance. It increases the magnetizing current and reduces the possibility of remanence. It can be shown that the increase in magnetizing current due to a small air gap will have no affect on the relaying accuracy rating of a transformer but the remanence will be reduced to a very small value. Current transformers with large air gaps in their cores, sometimes referred to as linearized cores, have little or no remanence. These transformers draw large magnetizing currents causing large phase-angle errors. (The large air gap has been advocated to reduce the tendency of a current transformer to saturate in cases where the offset component of fault current is not needed in the current transformer output).

The biased-core current transformer consists of a core made up of two equal sections. By a suitable arrangement of bias windings and a dc power supply, one core section is magnetically biased to approximately 75 per cent of maximum flux density in the positive direction while the other core section is magnetically biased in the negative direction. The transformer operates as a conventional transformer except for the flux re-setting action of the bias windings. This re-setting action guards against any remanence being left in the core. The obvious disadvantages of this type of transformer are the bias windings and the requirement for a direct current power supply. It should be pointed out the failure of the dc power supply does not affect the operation of the transformer as such, but only its flux re-setting action. The transformer performance then reverts to that of a conventional current transformer.

Discussion

The survey of remanent flux revealed that about 27 per cent of transformers surveyed had remanence larger than 60 per cent and about 43 per cent of the transformers had remanence larger than 40 per cent. This means that under unfavourable system fault conditions the transformer's accuracy is degraded by approximately a factor of 4 and a factor of 2 respectively.

The poor current-transformer performance, due to remanence may result in a delay of protective relay operation or in the under-reaching of line relays. The delay is caused by the loss of output of the current transformer and is a function of the system time constant and the magnitude of the fault current.

The use of cores with small air gaps appears to be the best solution to the problem of remanence at the present time. There are other solutions but these would only be favoured under special circumstances.

Conclusion

Measurements of remanent flux of relaying current transformers in service revealed that large amounts of remanence are present in a large number of current transformers. This remanence may interfere with the speed of operation of protective relays. The use of small air gaps in the cores of current transformers will reduce remanence to negligible values.

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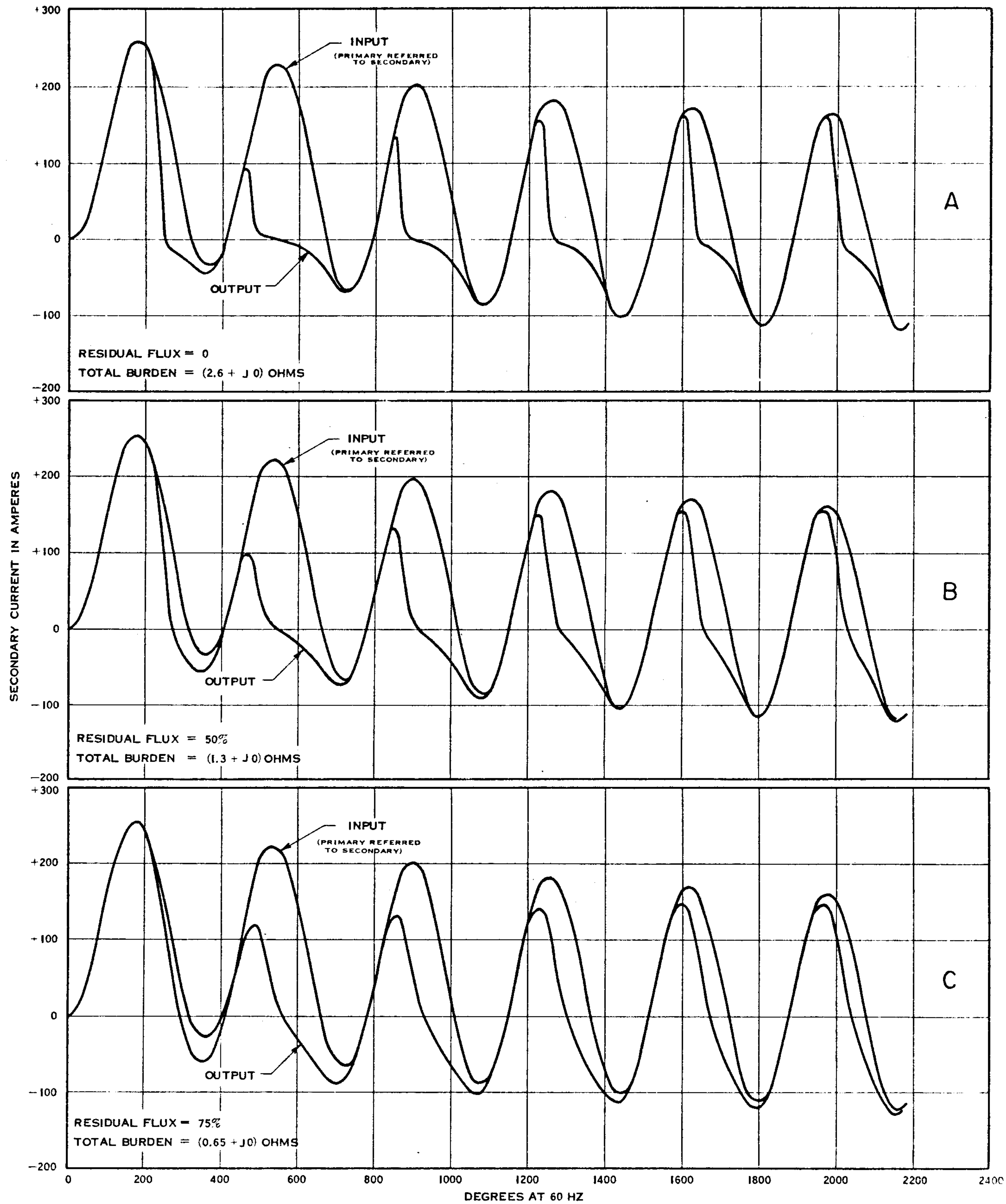

FIGURE 1

INPUT AND OUTPUT CURRENT WAVEFORMS FOR A CURRENT TRANSFORMER OPERATING UNDER TRANSIENT FAULT CONDITIONS VARYING DEGREES OF REMANENCE AND UNEQUAL BURDENS

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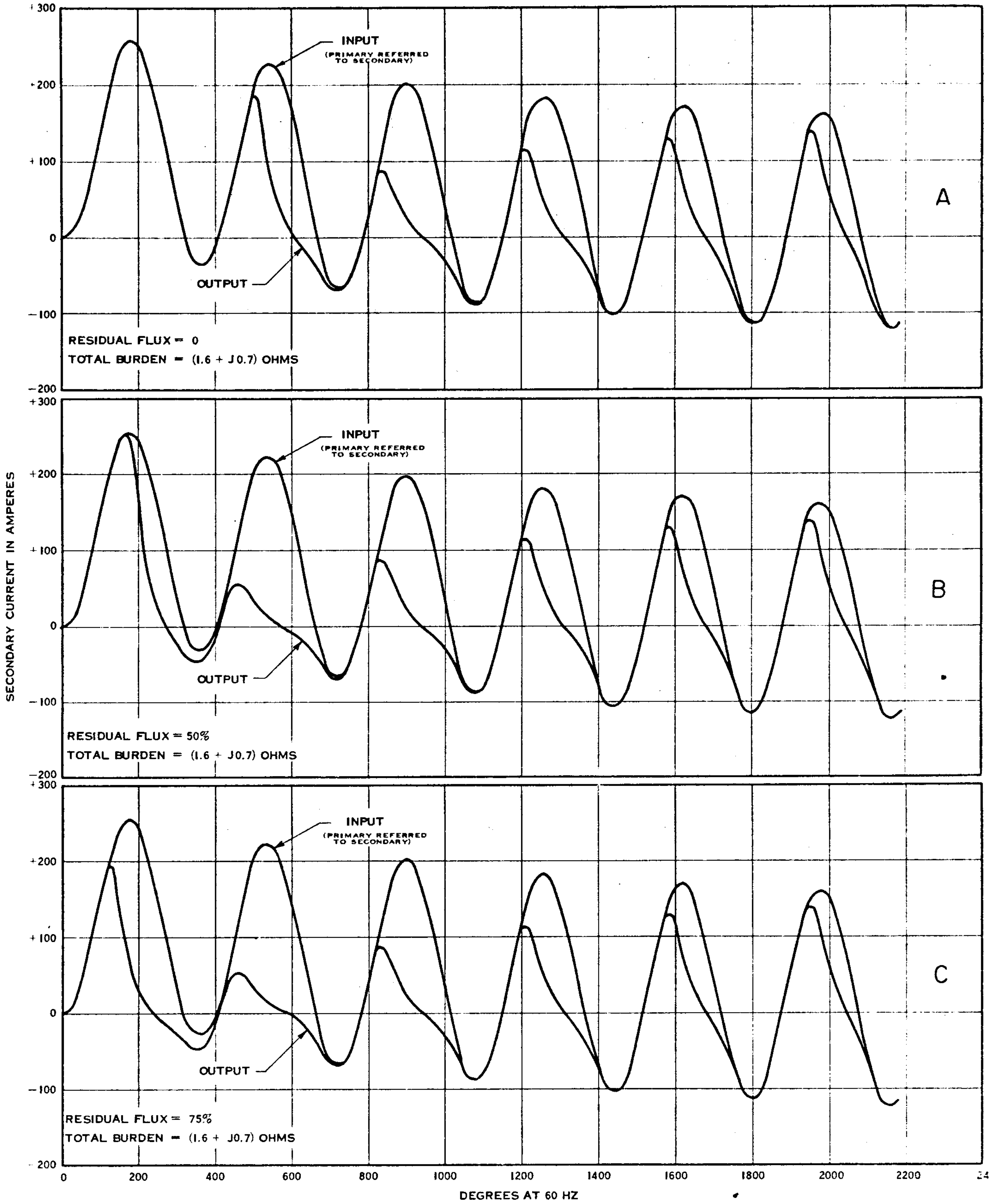

FIGURE 2
INPUT AND OUTPUT CURRENT WAVEFORMS FOR A CURRENT TRANSFORMER
OPERATING UNDER TRANSIENT FAULT CONDITIONS
EQUAL BURDENS AND VARYING DEGREES OF REMANENCE

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