DEVELOPMENTS IN DETECTING INTERTURN SHORTS IN GENERATOR ROTORS USING THE RSO TECHNIQUE

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INTRODUCTION

Various testing techniques are being developed for detecting the presence of shorted turns in generator rotors (1). One technique, the Recurrent Surge Oscillograph (RSO), involves applying a fast fronted step voltage to a winding and examining the terminal voltage waveform for reflections from shorted turns. An advantage for the manufacturer is that the test is quick and can be applied at different stages of coil winding to check integrity. However, the technique is very sensitive; it can detect turn to turn 'shorts' with resistances up to approximately 10 ohms. This has created an analytical problem because a satisfactory understanding of the mechanisms by which any reflections can occur has not yet been achieved. Minor trace differences may be indicative of high resistance 'shorts' or may be 'spurious'. An investigation has therefore been started into the causes of such minor trace differences and this has led to the realisation that the indications observed can only be understood using multi-conductor transmission line theory. Examples are given below of typical wave traces obtained from rotors with shorted turns and some giving spurious indications. Wave propagation is being studied theoretically and experimentally to develop a method of predicting waveshapes. Waveforms obtained at different positions in a coil are described together with those from a simple three turn simulated rotor coil set up in the laboratory. Initial comparisons with results from a computer model are made.

EXPERIMENTAL DETAILS

The cross section of a typical large generator rotor is shown in Fig. 1 to illustrate winding identification. The two pole windings are connected in series and normally have approximately eight turns per slot. Rotor diameter and length might typically be 1.2 m and 8 m respectively.

An RSO test on a rotor is performed by connecting a commercially available pulse generator as shown in Fig. 2. The generator alternately pulses each end of the winding approximately every 60 ms, and the measurement leads are electronically switched in synchronism to enable the terminal voltages to be viewed and compared on an oscilloscope screen. The rise time of the applied voltage pulse is 75 ns with the pulse generator open circuit.

Pulses for investigating propagation on a simulated three turn coil were derived from a different pulse generator. This supplies a 10 ns rise time pulse from a 50 ohms internal impedance source. Fig. 3 shows the model coil turn arrangement and dimensions.

RESULTS

Tests on rotors

Fig. 4 shows a series of oscillograms in which the position in the winding of an artificially introduced shorted turn is varied. The start of the resulting difference in the traces varies in time of occurrence and can be used to determine the position of the short. Real shorts have an appearance similar to those shown. As the resistance of the short increases the amplitude of the difference between traces decreases.

Three examples are given of 'spurious' indications. Fig. 5a) shows the trace from a 500 MW rotor which has consistently exhibited this form. No shorted turn has been detected by other techniques and no cause could be found when the winding was removed and carefully examined. Experiments indicated that changes to the trace at this time could be created by high resistance shorts placed near the centre of the winding which is much further into the winding than would be expected from the time delay, i.e. a fast travelling wave is implied.

Partially shorted damper strips were found to produce the indications shown in Fig. 5b) in a rotor without endcaps.

Colletts fitted to compress the endwinding conductors and insulation prior to fitting end caps have often been found to produce an indication of the type shown in Fig. 5c).

Tests on model coil

Fig. 6 is a series of oscillograms showing the voltage at each end and centre of both sides of the three coils of the model. Simple propagation as in a cable would lead one to expect that the waveforms would consist of a travelling wave progressing through the winding. However, it can be seen that the distribution of voltage spacially and in time is complex. The application of a fast rise time pulse to the beginning of the winding results in virtually instantaneous coupling of a portion of the front to the two lower turns. These reduced amplitude waves propagate in each direction from the point in the turn corresponding in physical position to the input lead. The multiple reflections resulting thereafter cause the waveshape to appear to have a longer rise time as it propagates to the end of the winding.

Theoretical considerations

McLaren (2) has studied surge propagation in motor windings to determine the voltage distribution in the first coil under impulse voltage conditions. His analysis treats the winding as consisting of connected transmission lines as shown in Fig. 7, with reflections occurring at each junction where there is an impedance mismatch. In addition the principal mode of propagation is between conductors rather than between a conductor and an earth plane as in a simple transmission line. An investigation has therefore commenced with the aid of McLaren to apply the program used for motor calculations to rotor windings. So far only a preliminary calculation has been attempted based on calculation of capacitance and inductance values appropriate to the rotor configuration. The mathematical program deals only with the first coil at present and will have to be extended to include the whole winding at a later stage of development. Fig. 8 shows the results of calculated compared with measured values. The general waveshape following the front appears similar in the waveforms from model and rotor. The reason for a slower rise time than calculated, however, is being investigated.

DISCUSSION

The RSO technique is a useful one in most instances where shorted turns exist on a rotor winding. When small trace differences are observed it is not yet possible to interpret them since they might result from a high resistance short or from other causes which affect the local capacitance or inductance of the winding. To gain a better understanding of how such effects result in trace differences a study is being made of pulse propagation based on multi-conductor propagation and a scattering matrix concept. Preliminary results are encouraging.

CONCLUSIONS

To progress with the development of the RSO technique for detecting shorted turns in generator rotors the most important part to resolve is the difference between high resistance shorts and other 'spurious' effects. One means of achieving this is to develop a mathematical model for a winding and this is being attempted.

REFERENCES

1. WOOD, J.W. and HINDMARCH, R.T. "Rotor winding short detection" Proc. IEE, Vol. 133, Pt B, No. 3, May 1986 pp 181-189.

2. McLAREN, P.G. and ABDEL-RAHMAN, M.H. "Modelling of large ac motor coils for steep fronted surge studies". IEEE IAS Convention, Denver, Sept. 1986.

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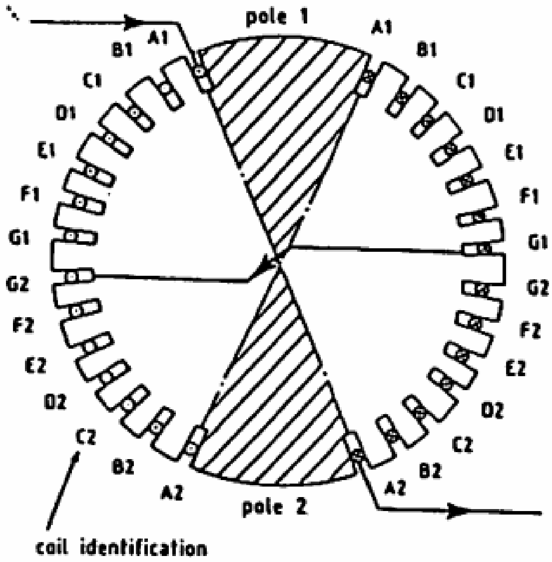

Figure 1 Cross section of rotor with identification of coils

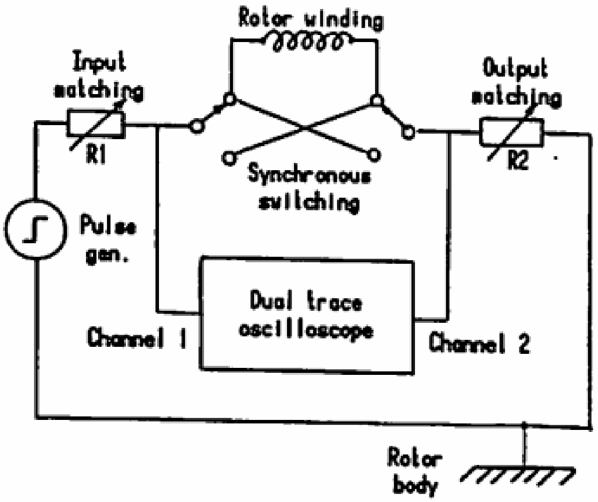

Figure 2 Rotor RSO test arrangement

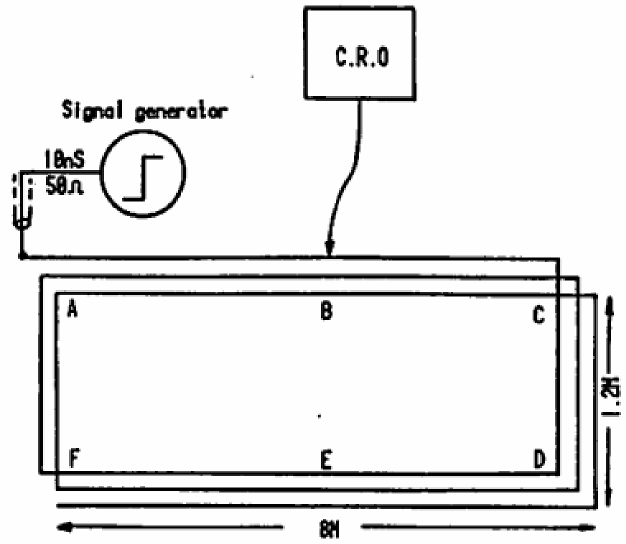

Figure 3 Experimental laboratory model dimensions

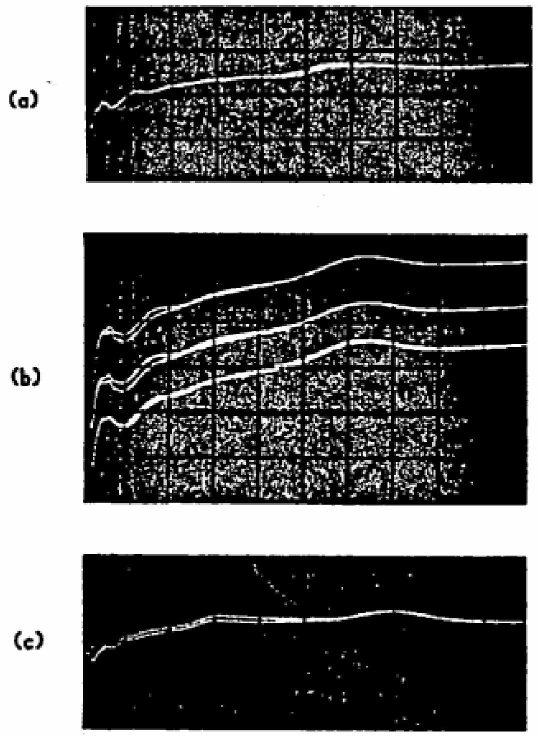

Figure 5 Examples of "spurious" indications

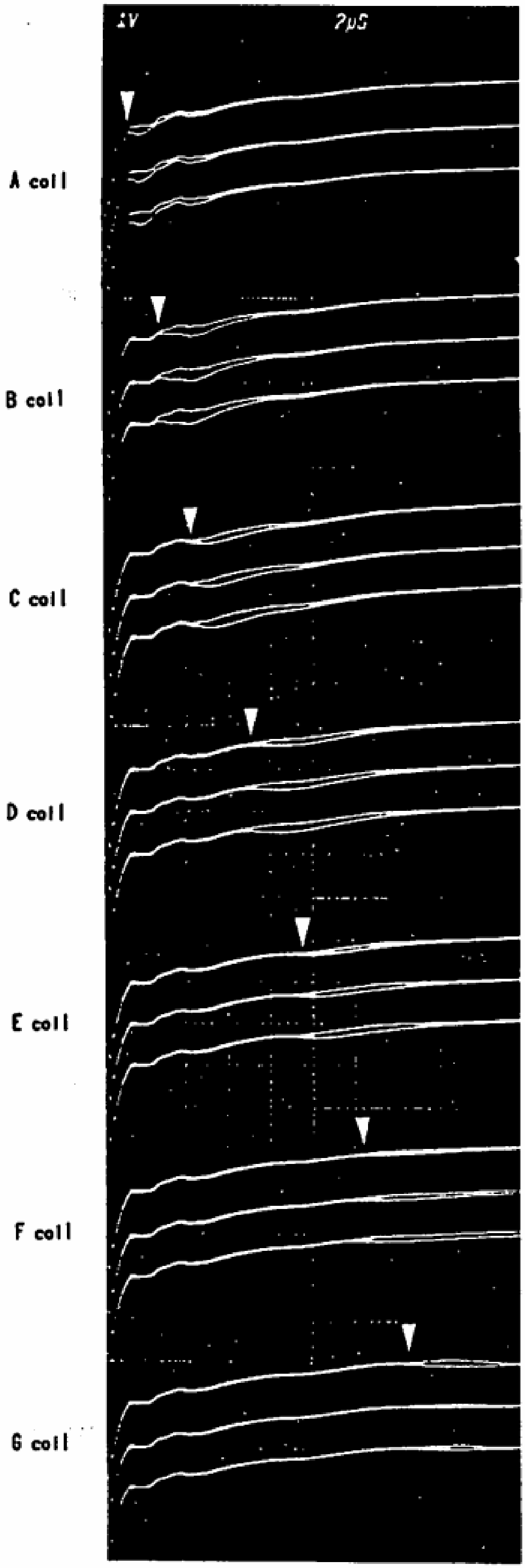
Top three turns of each coil with artificial inter-turn shorts of ~0.1Ω

Figure 4 Short circuits introduced at different positions in a winding

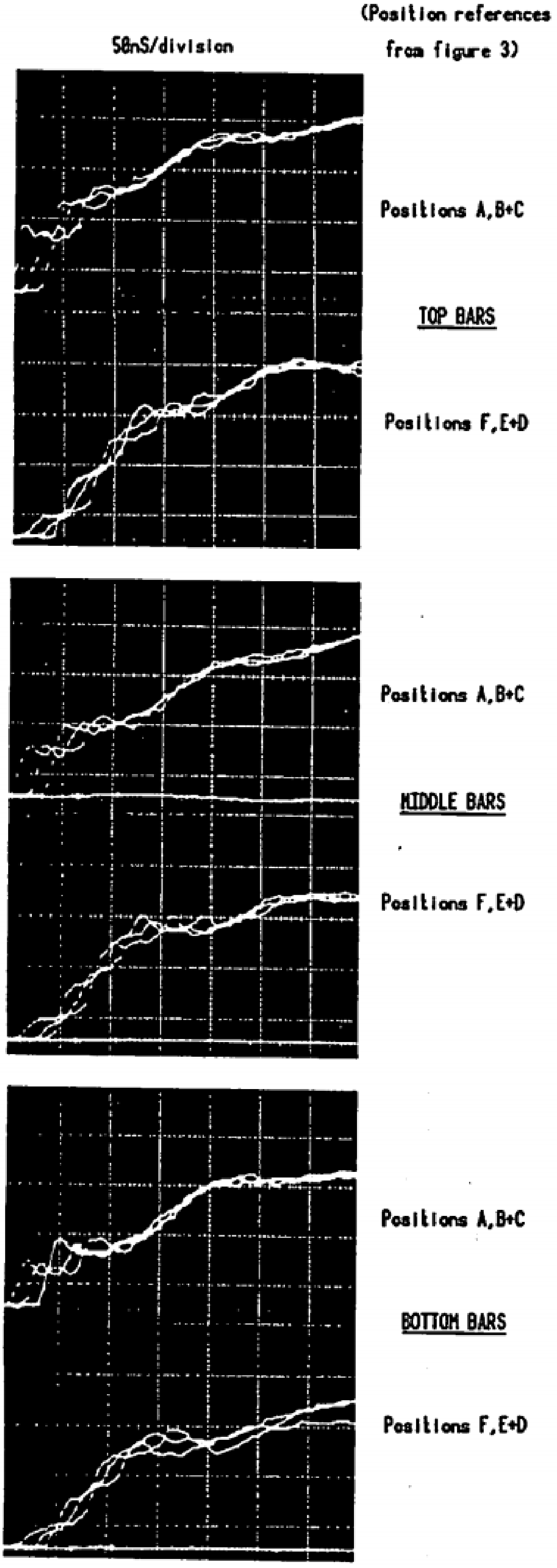

Figure 6 Voltages at different positions in simulated three turn coil

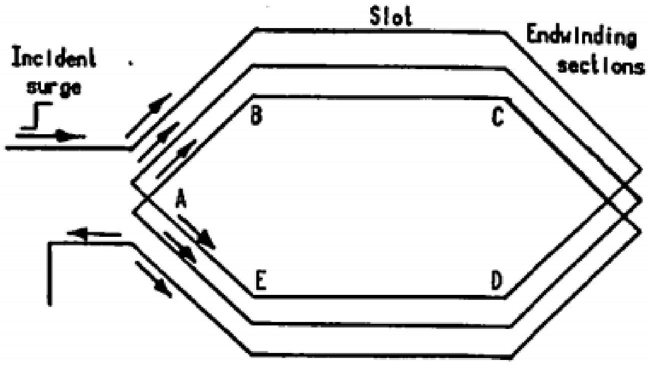

Figure 7 Division of surge at 'nose' of coil

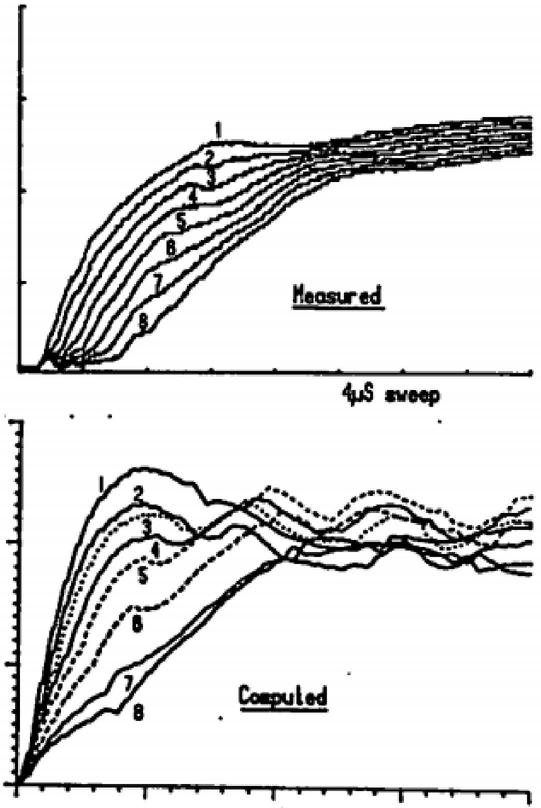

Figure 8 Measured and computed waveforms in turns of the first coil

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