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A STUDY OF THE PERFORMANCE OF THE 1000 KW MOTOR GENERATOR SET SUPPLYING THE CANBERRA HOMOPOLAR GENERATOR FIELD

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SUMMARY

Safety studies are described on the 1000 kW Motor Generator set used for exciting the field magnet of the Homopolar Generator. The studies were made by tests on the set, and analogue simulation of its behaviour. In some cases, analogue studies were first made onthe results checked by tests; these gave confidence that the analogue simulation was in fact reliable.

No attempts were made to deal with "commonplace faults", such as a partial or complete short circuit on the set, because the protective apparatus in the switchgear should handle them.

CONTENTS

1. GENERAL

This paper describes studies on the 1000 kW Motor Generator set used for exciting the field magnet of the Homopolar Generator. The studies were made by tests on the set, and analogue simulation of its behaviour. In some cases analogue studies were first made and the results checked by tests; these gave confidence that the analogue simulation was in fact carried out correctly.

To avoid confusion in the subsequent text the term "Generator" will be used to describe the Homopolar machine proper. The machine under study will be described as the "M G set" or just simply as the "set".

2. DESCRIPTION

A schematic diagram of the M G set is shown in Figure 1. The circuit used for analogue studies is given in Figure 2; this is in fact a simplified version of Figure 1. Appendix 1 gives equations used in the analogue simulation, and normal operating conditions of the set with permissible maximum values.

3. STUDY

3.1 Backing Oil Pressure

Referring to Figure 3, this shows interlocks in the pilot exciter field existing at the time of writing. This shows (among other things) that there can be no excitation of the pilot exciter, and hence the Generator field, when there is no backing oil pressure. For reasons which will be discussed later, it is desirable that this interlock should prevent the field being applied before the Generator is started, and that once the Generator is running, failure of the backing oil should not prevent field being applied. This is necessary because of course magnet field is necessary for shutdown of the Generator in some circumstances. Therefore the oil pressure interlocks are shorted by contacts of relays operated by the speeds of both top and bottom rotors (RL 54 and RL 55).

3.2 Magnet Field for Normal Working Conditions

Reference to Figure 3 shows also that an interlock in the pilot exciter field is derived from the "Run" circuit breaker of the M G set (see also Figure 1). This means that if the M G set is thrown off the supply the excitation will disappear. Some discussion of this interlock will appear later in Section 3.6.

3.3 Mains Failure to M G Set

For this argument it is assumed that the interlocks of Para. 3.2 do not exist, and that the pilot exciter remains on its supply when the set is thrown off the mains.

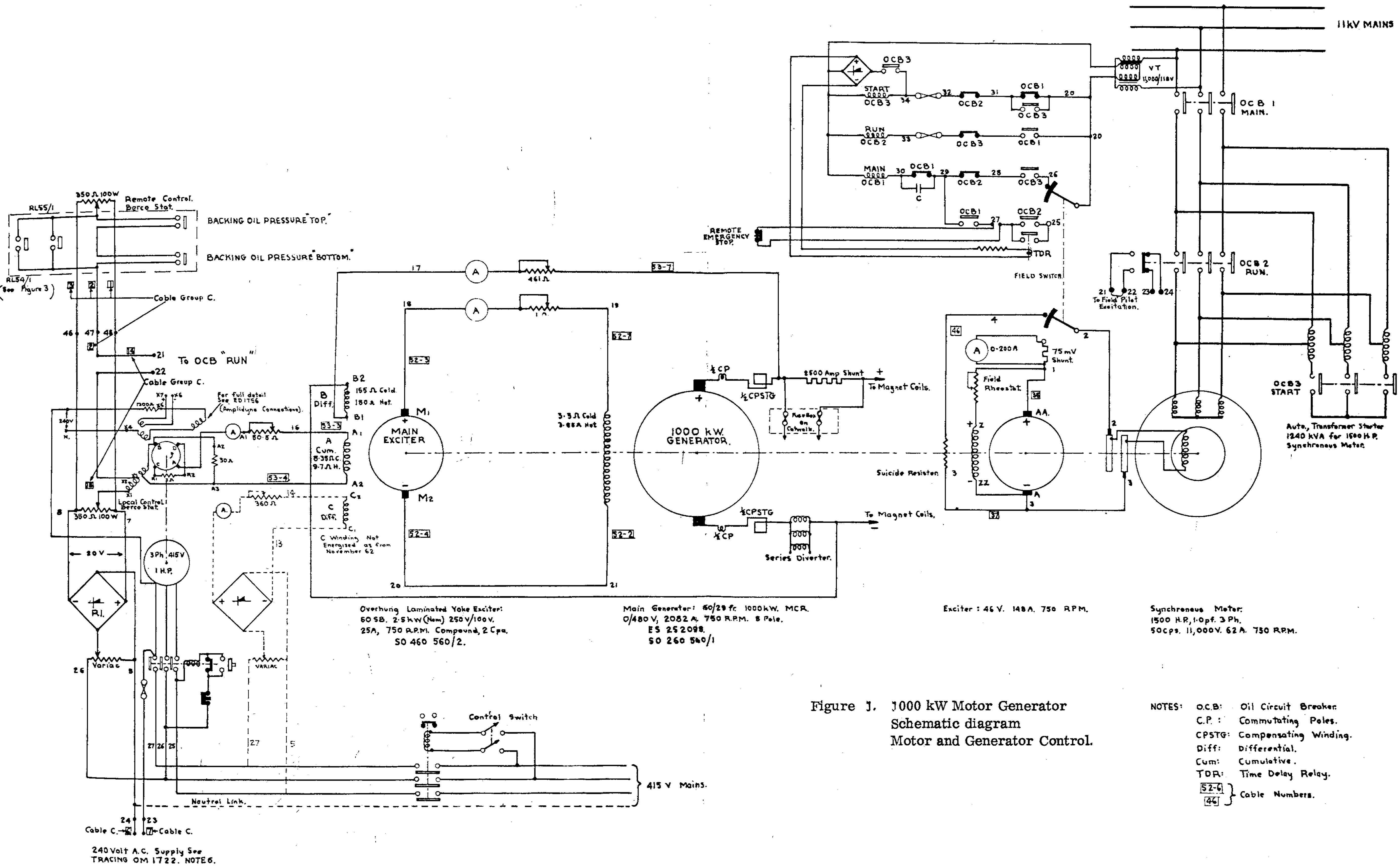

Figure 1. 1000 kW Motor Generator Schematic diagram Motor and Generator Control.

NOTES:
- O.C.B: Oil Circuit Breaker.
- C.P.: Commutating Poles.
- CPSTG: Compensating Winding.
- Diff: Differential.
- Cum: Cumulative.
- TDR: Time Delay Relay.
- 52-6, 46: Cable Numbers.

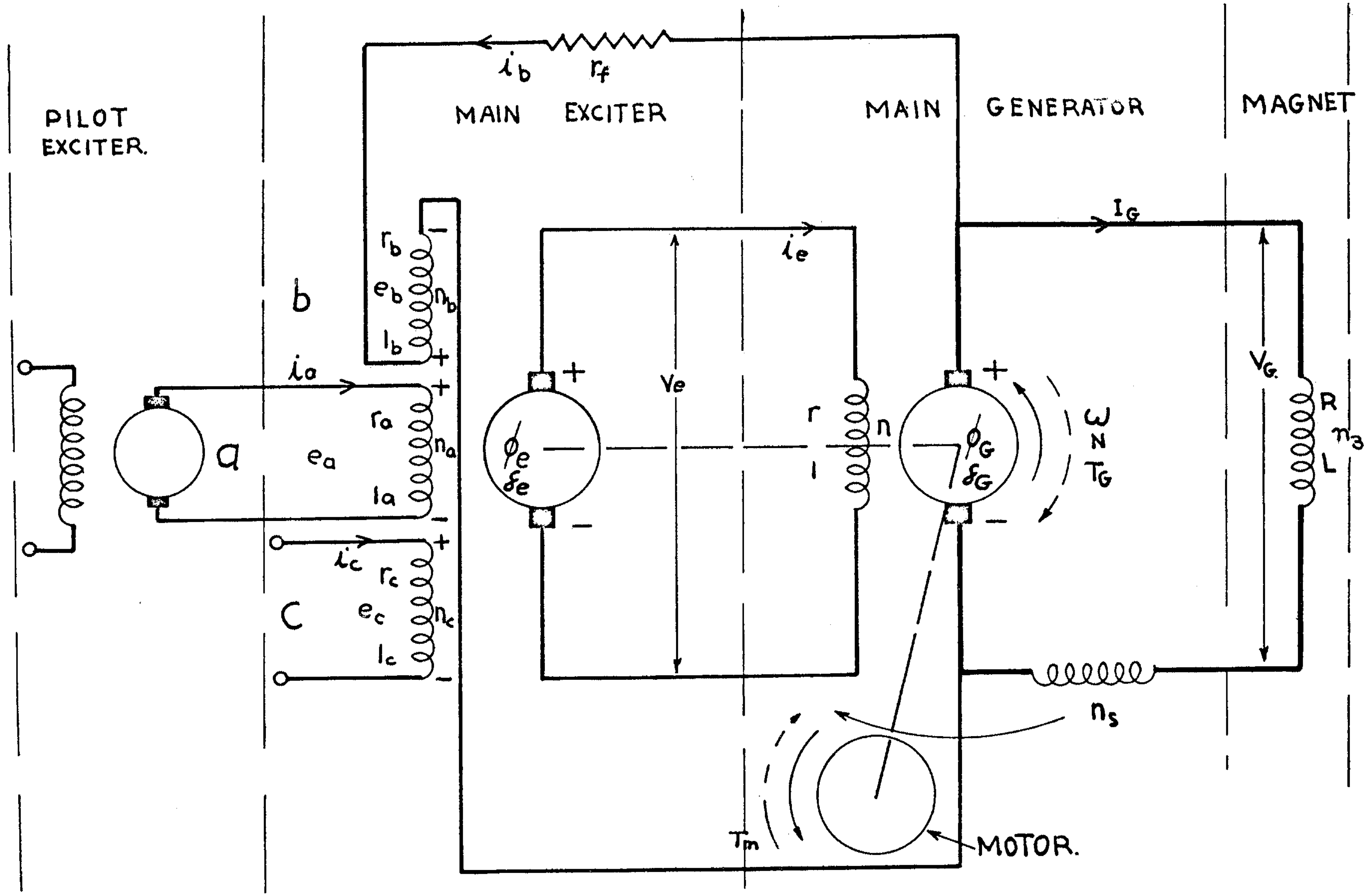

Figure 2. Simplified Motor Generator Diagram for Analogue Studies.

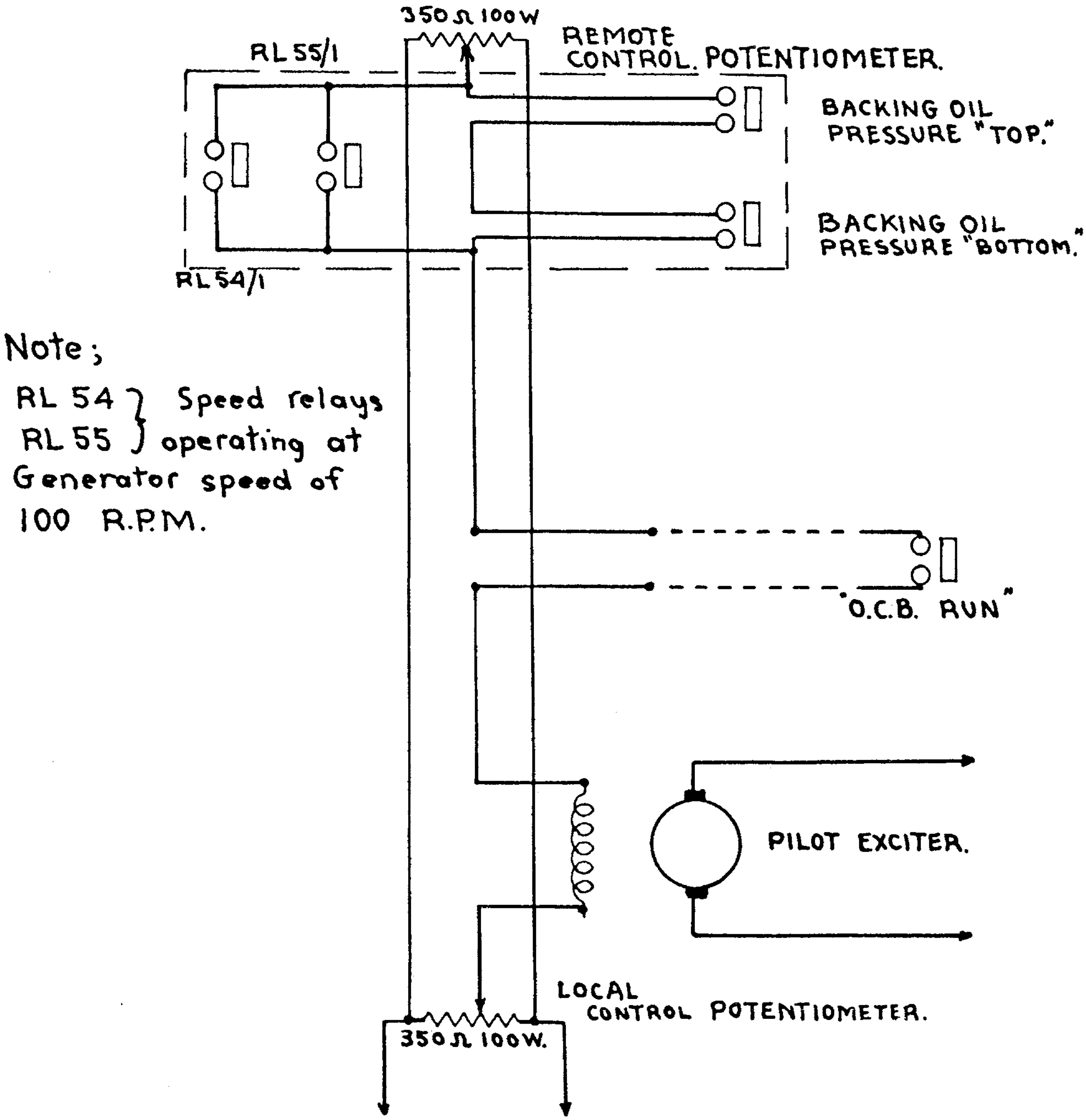

Figure 3. Interlocks in pilot exciter field.

The results of a test on the M G set are shown in Figure 5. These confirm very closely analogue studies made in the past. It is seen that for an initial field current of 2000 amps the speed falls quickly and the machine in fact reverses its rotation. This reversal is due to the time constant of the main field circuit of the set (V_e, i_e in Figure 2); when the machine reaches first standstill some field still exists.

These results demonstrate that in these circumstances a loss of mains failure is safe. The decay of magnet current should be noted. This does not decay in a manner very markedly different from the decay when the machine is running normally and all excitation of the M G set is removed (Figure 4).

3.4 Loss of Feedback Followed by Mains Failure

This condition is really an extension of 3.3. It is supposed that winding "b" on the main exciter (Figure 2) becomes open circuited when the machine is normally excited. The first result of this would be for the current to rise considerably in the magnet winding as the effect of winding "b" is to maintain negative feedback. The current in the magnet field would rise to about 3000 amps. It is assumed that when this happens the set is thrown off the supply due to the overloading or some other cause. The performance of the set under these conditions is shown in Figure 6. This performance is derived from an analogue study, but it is expected to be accurate, since comparison of analogue simulation and actual test was so good in 3.3.

It is obvious that even under these conditions performance of the M G set is safe.

3.5 Reversal of Excitation with Mains Failure

It has been customary in the past to force the field of the magnet to the reverse direction by fully reversing the pilot exciter field. There are some reasons for wanting to do this. First, the Generator may have to be slowed quickly by regenerative braking, and second a relatively quick way to remove magnet energy is to reverse excitation in this manner, and then cancel it as the magnet current goes through zero.

Indeed the simplest way to dissipate magnet energy is the way just described. When the pilot exciter is reversed quickly, the voltage Vg across the generator reverses while the current I_G maintains the same direction. (Figure 2). If at or about this time the set is thrown off the supply, then the magnet current will accelerate the rotor. The results derived by analogue means are shown in Figure 7.

This result is in one respect a simplified one since windage effect was not included in the computation - this would tend to lessen the maximum speed shown in the figure. Nevertheless, this fault is obviously very dangerous and cannot be tolerated. Even a partial reversal of excitation causing a small increase in speed is not desirable.

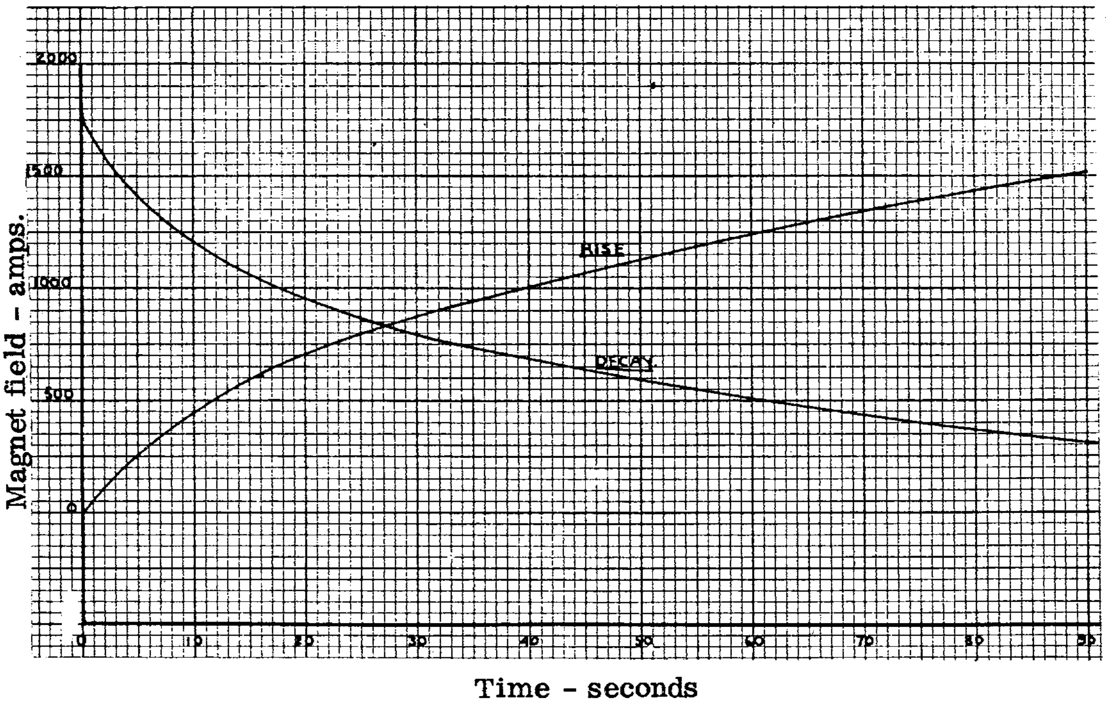

Figure 4. Recorded curves of magnet current on application and loss of excitation.

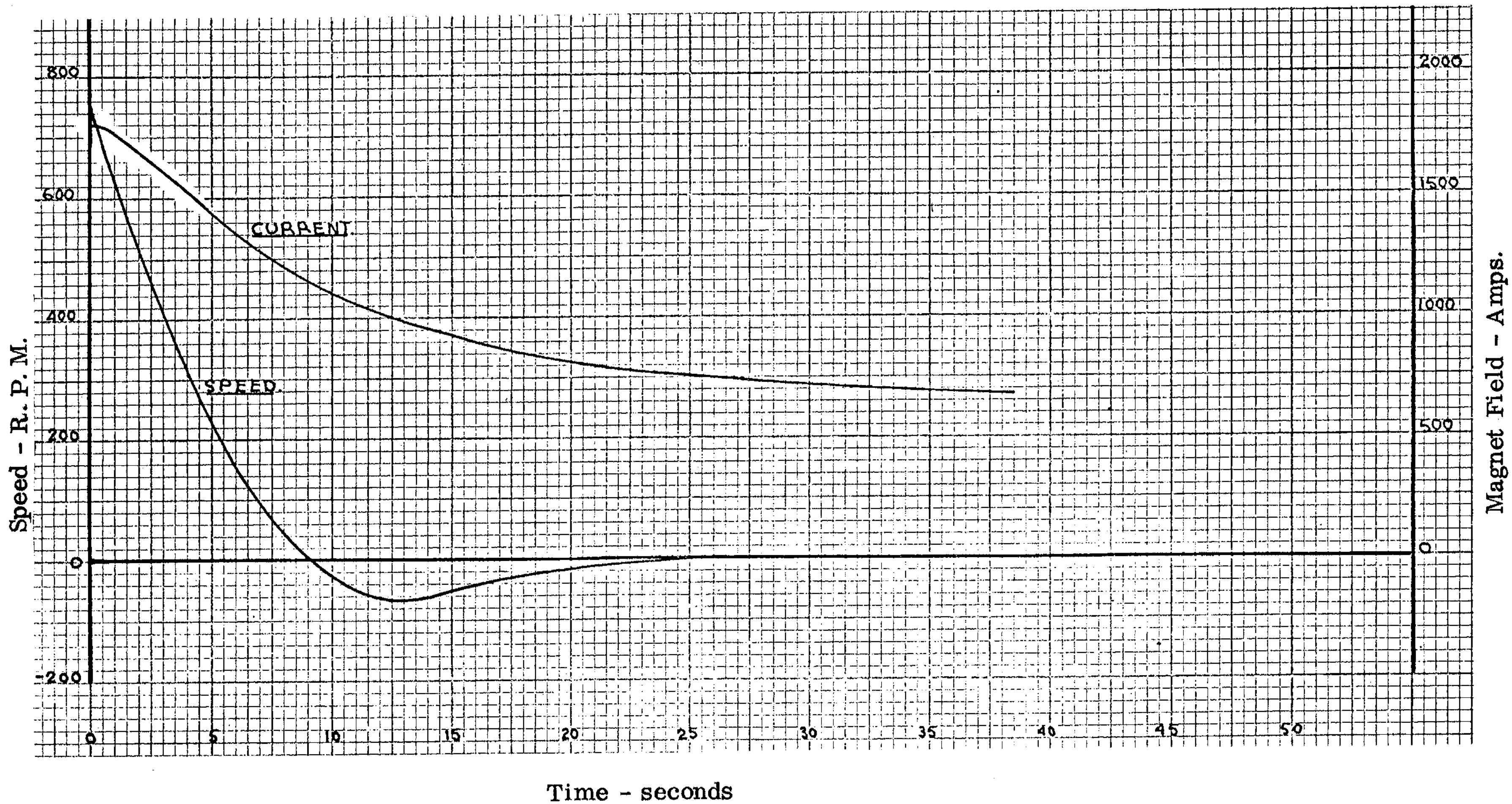

Figure 5. Loss of mains to motor generator set; recorded decay curves.

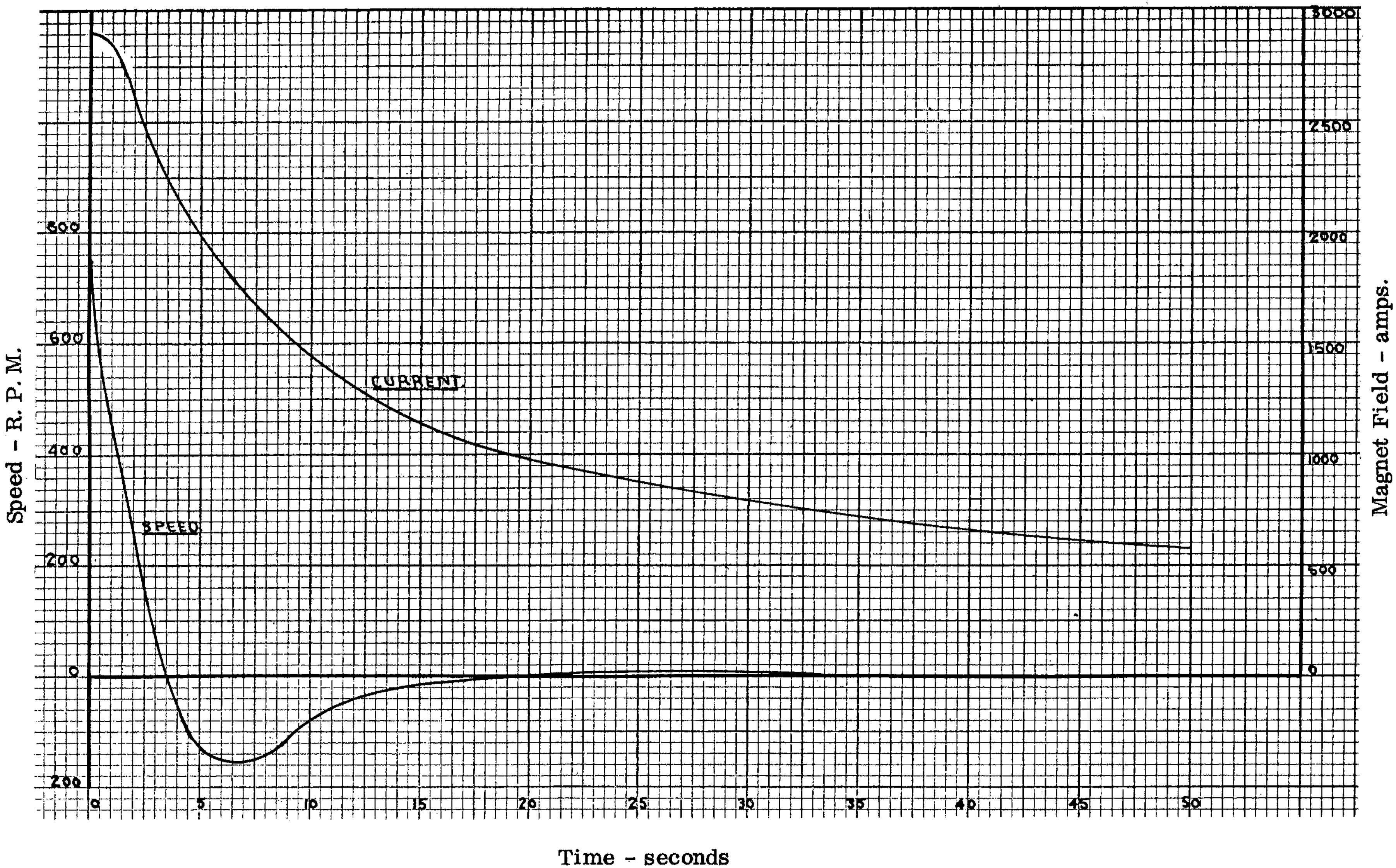

Figure 6. Loss of mains to motor generator set under forward excitation; Analogue study.

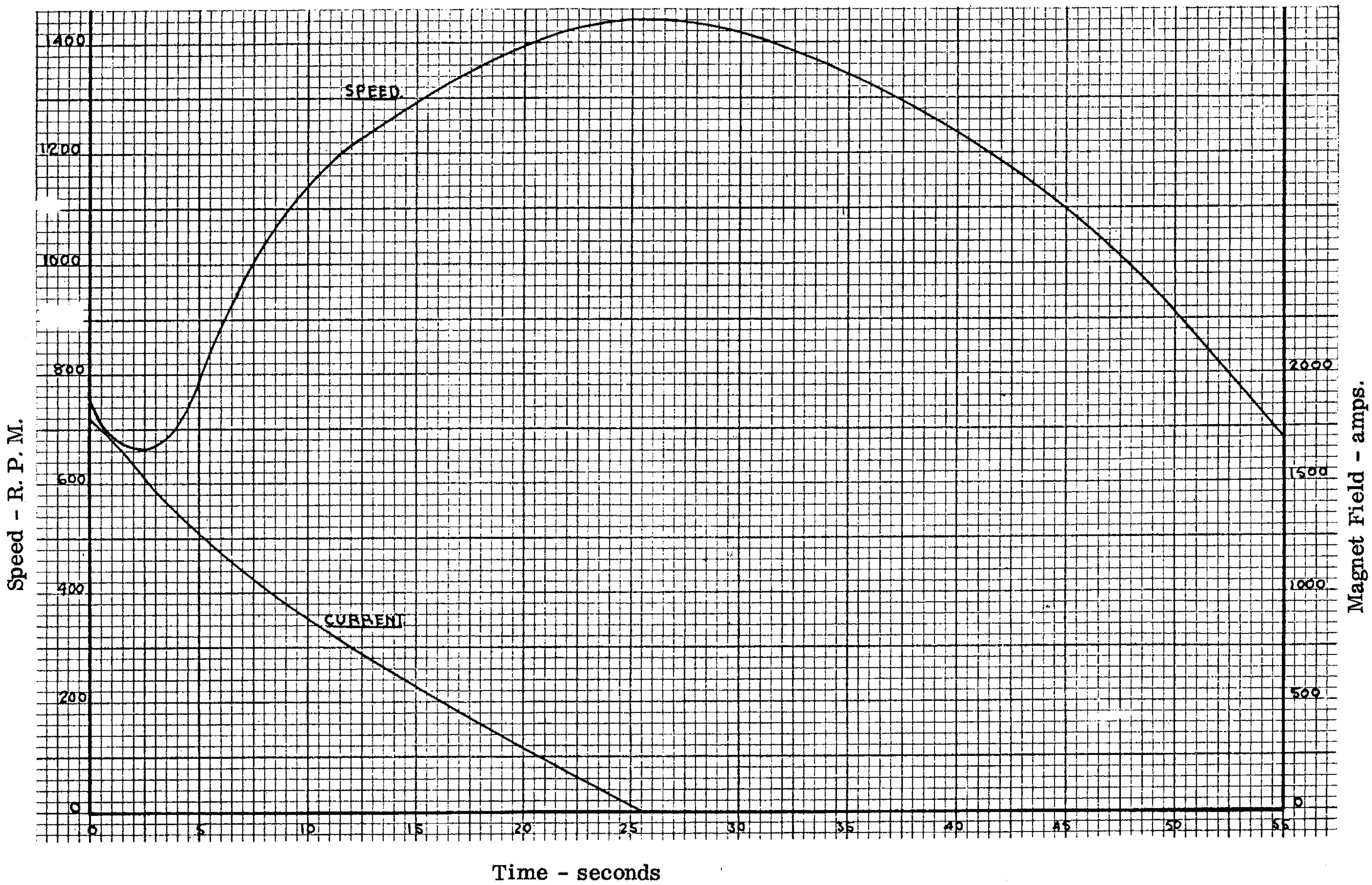

Figure 7. Loss of mains to motor generator set under reverse excitation; Analogue study.

Examination of the results shows a slight drop in speed at first. This is because the voltage Vg does not reverse immediately due to the time constant of the main field circuit (V_e $i._e$ as before).

It is now obvious that the main, if not the only, purpose of the interlocks described in Section 3. 2 is to prevent this fault occurring with the consequent destruction of the M G set. Faults described in Sections 3. 3 and 3. 4 have been shown to be safe.

Further reference to these results will be made in Section 3. 6.

3. 6 Magnet Field for Electrical Dump Load

We consider here means for maintaining field current so that the energy of the generator can be electrically "dumped" in the case of emergency. The desirability of such a method of dumping the energy is not discussed in this paper. We shall assume that it is in fact required, and that the means exist to absorb the generator energy even with partial magnet field.

There are four conditions to consider, these are:

1. The M G set running normally with the magnet field excited.
2. The M G set running normally with the magnet field not excited.
3. The M G set thrown off the supply but with the magnet field excited at this time.
4. The M G set thrown off the supply with the magnet unexcited at this time.

We shall consider these in turn in detail

1. This presents no problem, all conditions are normal and the energy of the generator could be dumped immediately.

2. In this case magnet field may be forced as quickly as possible and the energy of the generator dumped when the field has reached a tolerable value.

3. This results in the performance given by Figure 5. The magnet field decays leisurely and there is ample time available to take a pulse before the field has decayed to a small quantity.

4. Here the magnet field must be forced as the M G set is running down. Obviously the rotational energy of the M G set is transferred to the magnet field. Figure 8 shows actual tests carried out on the set. It can be seen that the current rises to about a quarter of full field strength. It is however fairly flat topped and persists for a considerable time. Considerable forcing is required to obtain this

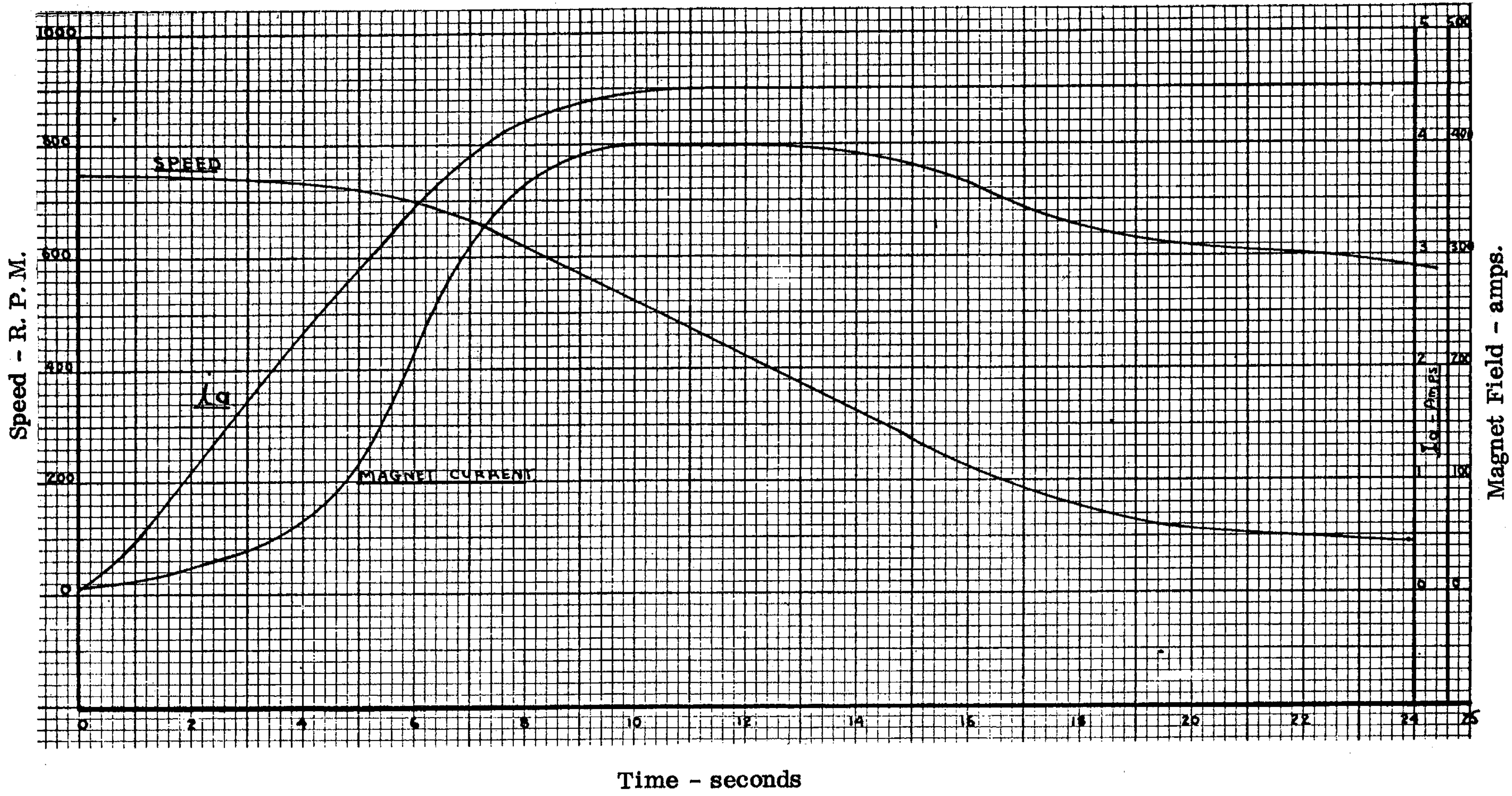

Figure 8. Loss of mains to motor generator set with forced excitation; Recorded values.

field current as can be seen from the curve of i_a in Figure 8, and in fact almost maximum excitation is applied to the pilot exciter. (Compare normal value of i_a in Appendix I.)

It follows that if method 4 is to be used in practice, then the interlocks shown in Figure 3 cannot be used, since these would prevent excitation being applied to the M G set and hence the studies of 3.3, 3.4, 3.5 can be held to apply. Interlocks are required which prevent the unsafe condition of para. 3.5 only; but these interlocks are not easy to apply as they must operate under some transient conditions. An easier solution might be to make it impossible to reverse the excitation on the pilot exciter quickly by a mechanical arrangement on the control knob. It would be possible to make such a device while still retaining the ability to increase the field quickly in either direction from zero, a quality which is essential if the demands of para. 3.6.2 and 3.6.4 are to be satisfied.

Such an application needs further thought.

Consider Figure 9, which shows the rundown of the M G set with no excitation. The purpose of this figure is for comparison with Figure 8, and to show that emergency apart, the magnet field may be forced some time after start of rundown because speed decays slowly.

4. FUTURE WORK

Some further work may be done on the characteristics of the set under the conditions of 3.5, but with partial instead of full reversal to determine what amount of field reversal, if any, is tolerable. This work would obviously have to be done on a computer at first and then carefully checked on the M G set.

It should be realised that even with the interlocks described in Section 3.2 (figure 3), a certain amount of danger exists with violent reversals of excitation. This is because of the time constant of the main field circuit. In other words, given a reversal, there may be an increase of speed before the generator voltage (V_g) is cancelled. This danger is eliminated at the time of writing by ensuring that the forward current does not exceed say 500 amps when field reversal is applied. This figure of current is rather arbitrary, but is considered safe; however, it ought to be verified by future study.

It is proposed in the future to install automatic control on the M G set either to control field current or generator voltage (Vg) or both. This paper is concerned with safety and not with stability as such, nevertheless the automatic control system must be compatible with any safety features or systems installed, and any circuit changes made in the interests of stability or quick response must be consistent with other desirable qualities of the M G set controls.

5. CONCLUSION

This paper deals with safety of the M G set with particular reference to its performance with the Homopolar Generator Magnet. No attempts have been made to deal with what might be called commonplace faults, such as a partial or complete short circuit on the set, because the protective apparatus in the switchgear should take care of this or similar conditions.

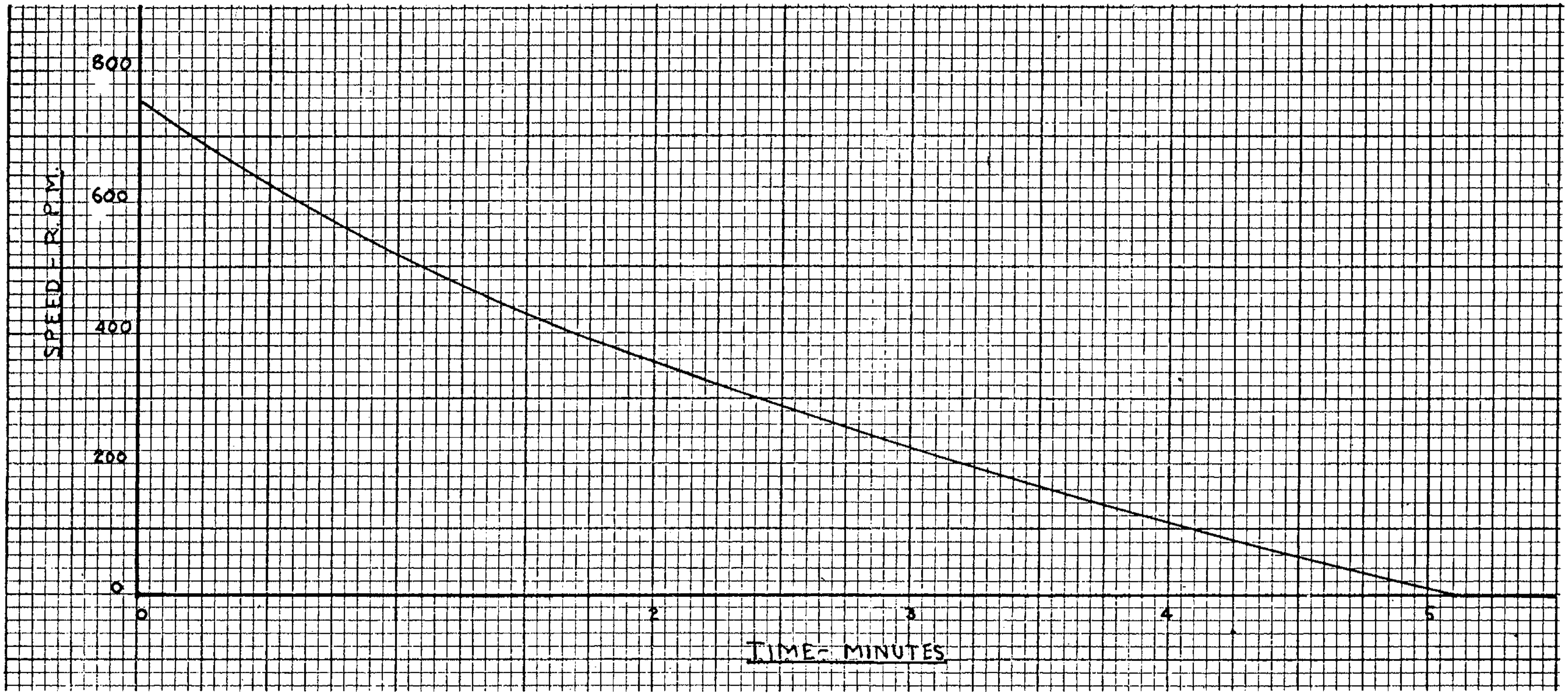

Figure 9. Motor generator set rundown; no excitation; recorded value.

APPENDIX I

1. Equations (refer to Figure 2)

$$V_e = N\phi_e = r\,i_e + 92{,}300\ \frac{d\,\phi_g}{d\,\delta_g}\ .\ \frac{d\,i_e}{dt} \qquad (1)$$

volts

Note $\delta_e = (n_a i_a + n_b i_b + n_c i_c)$ (2)

$= (500\, i_a + 1400\, i_b + 500\, i_c)$ amp turns (3)

with due regard to sign of currents.

now $$V_g = N\ \phi_g = 0.18\, I_g + 779\ \frac{dK}{d\,I_g}\ .\ \frac{d\,I_g}{dt} \qquad (4)$$

volts

note $\delta_g = (n\, i_e + n_s I_g)$ (5)

$= (280\, i_e + n_s I_g)$ amp turns

(see 2.2 of this appendix for value of n_s)

$$T_m = T_g + T_{Fw} + T_I + .00326\ M\ .\ \frac{dN}{dt} \qquad (6)$$

lbs. ft

where $T_{Fw} = 78.0 + .000498\ N^2$ lbs. ft (7)

(friction and windage torque)

$T_I = .0075\ i_e\ N$ lbs. ft (8)

(Iron loss torque)

Also $T_g = 7.03 \quad \phi_g I_g$ lbs. ft (9)

Hence $T_g \, . \, N = 7.03 \, V_g \, . \, I_g$ H.P. (10)

$$- V_g = (173 + r_f) \, i_b + 251 \frac{d \phi_e}{dt} \quad (11)$$

(note 173 ohms is the value of r_b)

and $V_a = r_a i_a + 90 \frac{d \phi_e}{dt}$ volts (12)

or $19 = 10 \, i_a + 90 \frac{d \phi_e}{dt}$ volts (13)

Notes:

1. $\phi_e (\delta_e)$ is the magnetic characteristic of the main exciter (not shown here).
2. $\phi_g (\delta_g)$ is the magnetic characteristic of the main generator (not shown here).
3. $K (I_g)$ is the H.P.G. field magnet characteristic (not shown here).

2. Normal Operating Conditions

(note - normal operating speed of the set is 750 r.p.m.)

2.1 Main exciter

i_a = 1.9 amps

i_b = -0.394 amps (negative sign indicates bucking current)

i_c = 0

V_e = 51 volts

i_e = 12.5 amps

2.2 Generator

V_g = 325 volts

I_g = 1800 amps

T_g = 5,480 lbs.ft

T_{Fw} = 358 lbs.ft

T_I = 72 lbs.ft

T_m = 5,735 lbs.ft

M = 15,000 lbs.ft^2

n_s = 0

note also r_f = 650 ohms

3. Permissible Maximum Values

3.1 Main exciter

i_a = 5.0 amps

i_b = 1.0 amps

i_c = 4.0 amps

V_e = 250 volts

i_e = 25 amps

3.2 Generator

V_g = 480 volts

I_g = 2,100 amps

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