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Reactor Training Simulator with Automatic Amplitude Rescaling

by

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Abstract

The present report describes a reactor-training simulator in which a simple resealing system is used to obtain a power range of many decades.

The reactor power and temperatures are computed by conventional analog methods, but the integrators used in the neutron flux computer are of a new design which makes it possible to change the amplitude scale of this computer automatically by a factor of 10 and 0.1.

Rescaling time is about 0.5 seconds. The sensitivities of the measuring channels are controlled by the resealing circuit in such a way that very little disturbance due to the rescaling is seen on the traces of the recorders in the control console. In the temperature and reactivity computers no rescaling is needed as the range of the operational amplifiers is sufficient.

The paper includes circuit diagrams of the resealing system and measuring channel records showing a "start up" and a "scram" of the reactor.

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Introduction

A reactor simulator is an analog computer programmed for solving the equations which describe the time variation of neutron flux, temperature, etc. under the different operation conditions of a reactor installation.

The computer includes a computer for neutron flux, which has to simulate a neutron flux in a range of 6-12 decades, depending on the type of reactor simulated. Since the normal operating range of analog computers is 2-3 decades only, special means have to be used in order to cover the neutron flux range. In the temperature computer an operating range of 2 decades is quite adequate.

When the flux N is simulated directly, it is necessary to change the amplitude scale several times during a reactor startup in order to cover the flux range. Normally this is a time consuming operation in an analog computer4 In a training simulator the resealing must be finished within a fraction of a second lest the proper "reactor feeling" should be disturbed.

The neutron flux range may be obtained by simulating 1/N dN/dt instead of the flux N itself, but the use of automatic rescaling is considered to be more accurate and to give better possibilities of changes in flux range and instrumentation.

This report describes a simulator with automatic amplitude resealing. The neutron flux computer has special integrator circuits with a resealing time of 0.5 sec. The simulator is provided with a control rod simulator and a safety system, but these will not be further mentioned in the present report. The resealing integrator has been developed in co-operation with K. Soe Hojberg on the Risø Analog Computer, and it is planned to examine the possibilities of using the circuit in this computer.

Lay-out of the Simulator

A block diagram of the computer is shown in fig. 1. Apart from the integrator circuits the neutron flux computer is of conventional design. It simulates the fission of U-235 with 6 delayed neutron groups. Owing to the resealing, active simulation of the delayed groups is used, and the flux computer contains 8 operational amplifiers, 7 as integrators and 1 as adder. In the figure is shown the change of different voltages during a reactor start-up.

The flux computer output is measured by two trigger circuits. When the output, N, is increasing and reaches a magnitude of 100 V, one of the triggers operates a relay sequence generator. This generator controls a change of the voltage of the capacitors in the flux computer by a factor of 1/10, activates hold relays in the temperature computer and in the measuring channels, and moves a "both way" selector switch one step forward. This selector switch step has the following purposes: It 1) decreases the neutron source voltage by a, factor of 10, 2) increases the sensitivity of the linear measuring channel and of 3) the temperature computer by a factor of 10. It also 4) adds a voltage corresponding to one decade change of flux to the output of the logarithmic measuring channel. When the flux is decreasing, and both N and the output from the 80 sec. neutron-group have passed 8 volts, a second trigger starts the relay sequence generator, which in this case changes the voltage of the capacitors in the flux computer by a factor of 10 and moves the selector switch one step backward.

The neutron source is only significant in the lower decades, and the temperature in the upper decades, and therefore their voltage dividers only give factors of 10 in these ranges.

The total resealing time is about 0.5 seconds. During steady state operation and slow power changes all operational amplifiers will operate within the voltage range 10-100 volts, which is not the case during fast power transients.

When a reactor "start-up" with a short period is simulated, the outputs from the slowest neutron groups will be low on account of repeated resealing with a factor of 1/io. This is not important for the computing accuracy, but it would cause the 8 V trigger to operate at an improper instant if this trigger was not controlled by both N and the output from the slowest neutron group.

On simulation of a reactor "scram", the flux, N, decreases rapidly, but a resealing is not possible until the output from the slow 80 sec. group is below 10 V, and to ensure stability a trigger level of 8 V is chosen.

This means that N may be low during such transients, but the resealing accuracy has proved to be sufficiently good down to 0.1 volt. After a "scram", the voltage simulating N drops back to a voltage roughly proportional to the inverse of the shut-down reactivity before resealing occurs. With $\delta k = -2\%$, this voltage is about 0.25 volt.

The recorder strips displayed (figs. 8-11) show the result of a simulated reactor "start-up" and "scram", and it is seen that very little disturbance arises from the resealing. Furthermore a noise generator will be added later on in order to simulate the reactor noise.

Adjustment of the simulator is very easy, the voltage steps to the logarithmic channel being the only adjustment which is not a normal measuring channel adjustment.

In this simulator we have used a flux range of 6 decades. This range can be 6xtendecl merely by utilizing more steps on the selector switch. As most log N instruments have a range of 6 decades only, switching to a separate log N instrument - a start-up channel - could be simulated in the decades added.

Rescaling Integrator,

The circuit diagram of the integrator used in the flux computer is shown in fig. 2. It is seen that, besides the normal integrator components, it comprises an extra capacitor, two extra relays, which may be common for several integrators, and a voltage divider 1:11 in the amplifier output. The circuit sequence for a change of the voltage of the capacitors by a factor of 10 is shown in fig. 3. Relay 1 is the normal hold relay which isolates the circuit. When relay 3 is activated, the output end of C_2 is connected to the voltage divider. The total capacitor charge will remain unchanged, and therefore it is easily seen that the voltage of C_1 will be changed by a factor of 10. Hereafter C_2 is charged between the amplifier output and the ground and placed in its computing position. When R11 is released, the resealing is finished. An 18 k resistor ensures that the amplifier is not overloaded during the charging of C_2. This is very important in order to ensure accurate resealing.

Rescaling by a factor of 1/10 is obtained by the reverse sequence. The capacitor C_2 is connected between the voltage divider and the ground by means of relays 2 and 3. It is then charged to 1/11 of the voltage of C_l, and when it is replaced in its computing position, the voltage of C_1 and C_2 will be 1/10 of the starting voltage.

The accuracy of the resealing is governed by the component accuracy and the ability of the amplifier to "hold' with a capacitor as small as 0.01 μF (i.e. the amplifier adjustment). The resealing accuracy is limited by the component accuracy in the range 1-100 V. Below 1 V the accuracy is more or less dependent on the adjustment of the "hold" drift of the amplifier. The amplifiers used are chopper stabilized and have the following data: DC-gain $3.5xl0^{7}$, input current $<5 \times 10^{12}$ A, and integrator drift < 5mV/min (lμF-lMΩ).

As shown in the appendix, it is possible, too, to integrate and rescale in three different time scales with this integrator circuit.

The Measuring Channels

Although it is possible to use real reactor instruments for the measuring channels if these are coupled to a voltage divider on the selector switch, as is the case with the temperature computer, we have simulated the channels by the use of operational amplifiers, as shown in the figures 4 and 5.

The log N channel, fig. 4, has a vacuum diode as log element. During steady operation and slow changes only one decade is used, 10^{-6} to 10^{-7} amps. During a reactor "scram", however, the flux voltage drops back to 0.1-1 volt, as mentioned earlier, and it is essential therefore to have a true logarithmic range from 10^{-6} to 10^{-7} amps. This is easily obtained as the log range for the diode 9004 is normally 6 decades.

The period channel is very sensitive to switching transients in the system, and to eliminate disturbances in the period reading, release of the "hold" relay in this channel has been delayed 10 sec. This will be unnecessary if noise is added to the measuring channels in order to simulate reactor noise. The time constants in the period channel are those normally used in period-meters.

The linear power channel is shown in fig. 5. It has four inputs with sensitivities of 1, 10, 100, and 1000 volts for full-scale deflection. These inputs are connected to the selector switch. During the resealing cycle this switch selects an input with a sensitivity one decade higher or lower according to the scaling factor. If the operator follows the power with the linear range switch, the channel will normally operate in the 100 V range on all reactor powers. Only during the power decrease following a scram, the higher sensitivities are used for longer time intervals.

The relay sequence generator and the trigger are shown in fig. 6 and fig. 7. The 8 V trigger operates relay Rl 4 and the 100 V trigger Rl 5. These relays operate the holding relays in the computer and relay Rl 2, which activates one set of the resulting relays. Furthermore Rl 4 and 5 select the proper coil on the selector switch and the proper set of rescaling relays to be operated by Rl 2. Rl 2 operates Rl 3, which is delayed about 150 mS. This relay operates the second set of resealing relays and disconnects Rl 2, which is released with a delay of about 150 mS. This releases the first set of resealing relays and, after a delay of 150 mS, relay Rl 3, which releases the second set of resealing relays. When relays 2 and 3 are released, Rl 4 and Rl 5 release and disconnect the holding relays. The resealing is then finished. Rl 6 defeats the triggers during resealing, to avoid improper action due to transient signals during the resealing time.

Appendix

The simulator normally operates in the true time scale, but the neutron flux computer can be used for start-up calculations in an accelerated time scale.

The time scale of an integrator is changed when the value of the integrating capacitor is changed. In the rescaling circuit this can be done by activating one or both rescaling relays during the integrating time. The circuit sequences giving resealing action for the different time scales are shown in fig. 12. The switching between the time scales can be done by simply switching in the control circuit of the resealing relays.

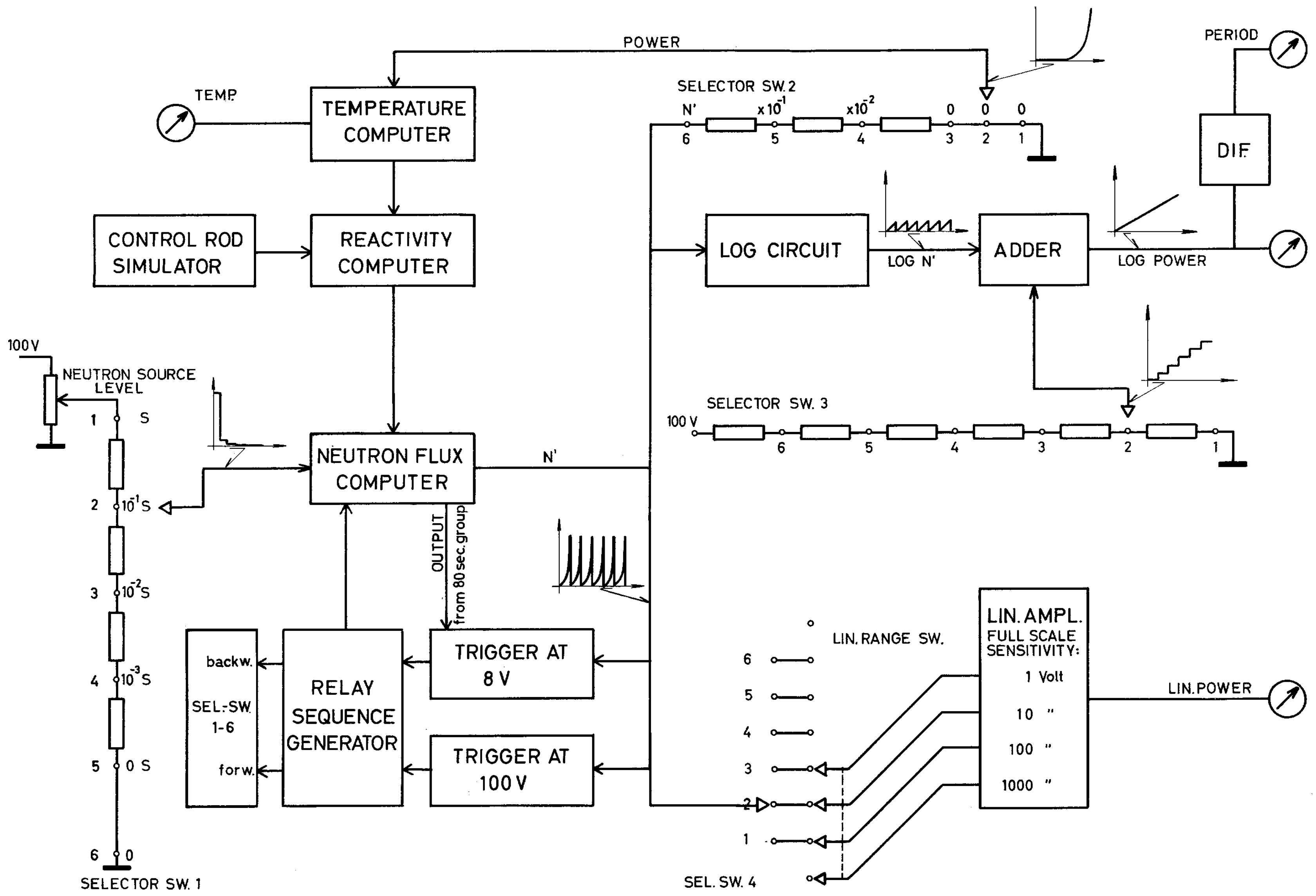


FIG.1. SCHEMATIC DIAGRAM OF SIMULATOR.

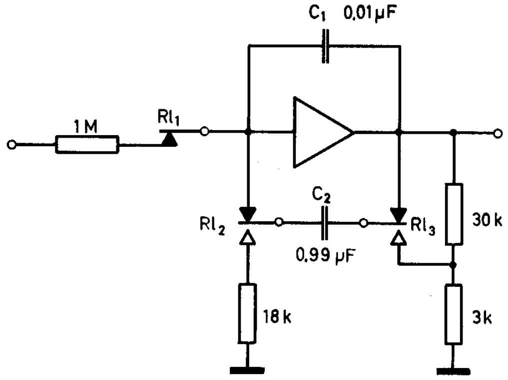
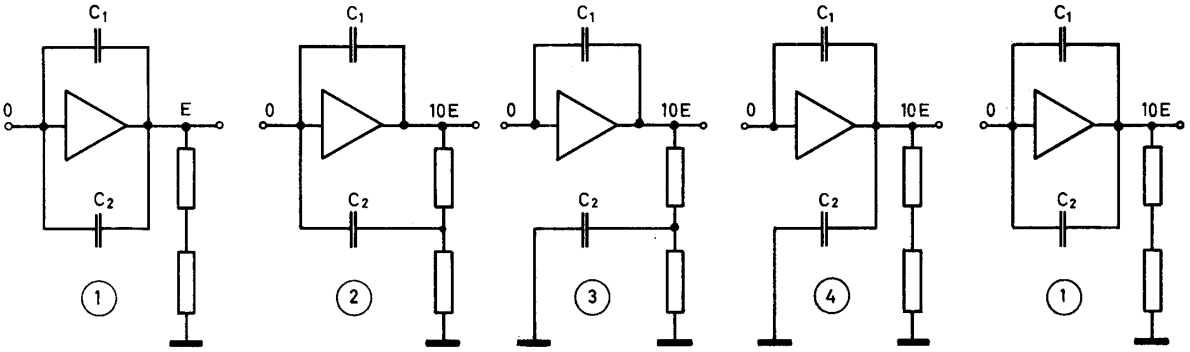


FIG. 2. RESCALING INTEGRATOR CIRCUIT.



Rl 1 activated. Circuit in "hold" condition.

Rl 1-3 activated. Voltage of C_1 changed by a factor of 10.

All relays activated. C_2 isolated from input.

Rl. 3 released. Voltage of C_2 changed by a factor of 10.

Rl 2-3 released. Circuit in "hold" condition.

FIG. 3. CIRCUIT SEQUENCE CHANGING THE CAPACITOR VOLTAGE BY A FACTOR OF 10.

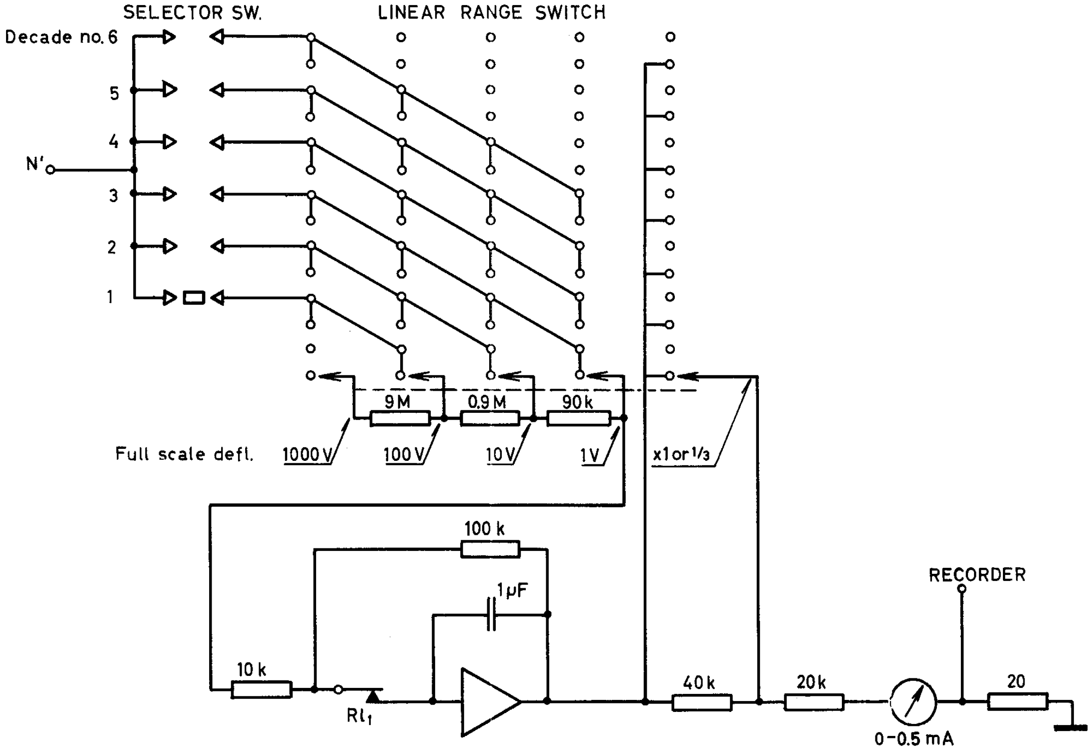


FIG. 4. CIRCUIT DIAGRAM OF LINEAR POWER-CHANNEL.

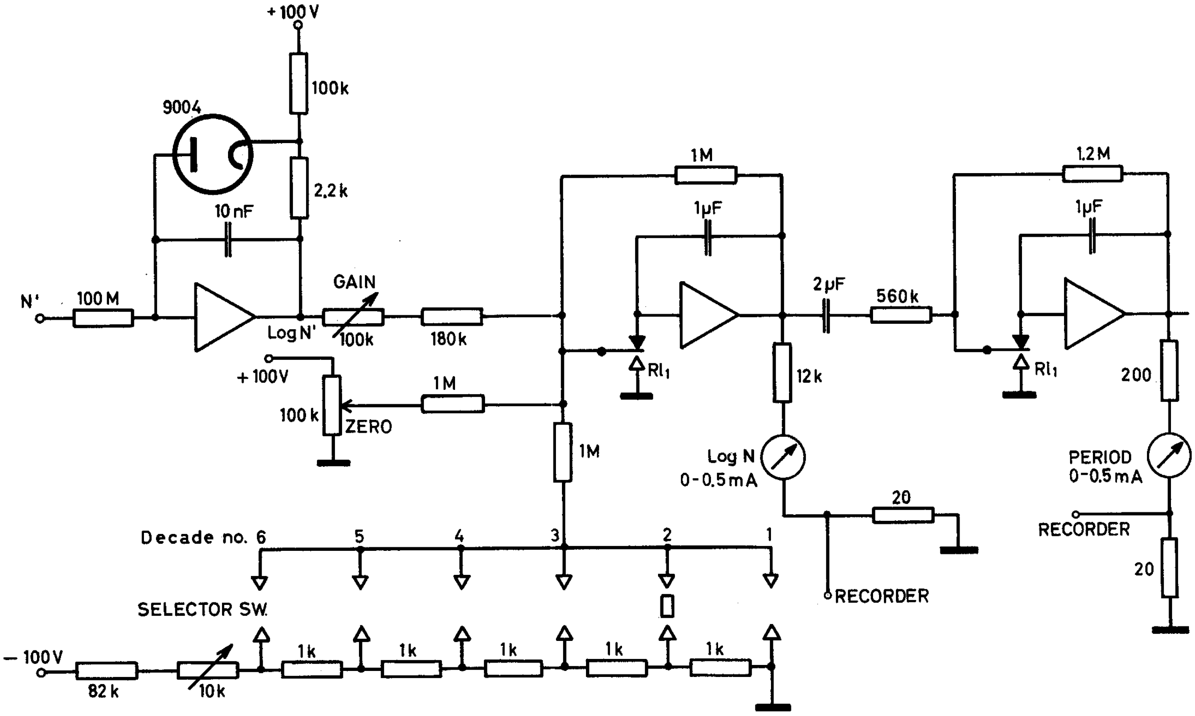
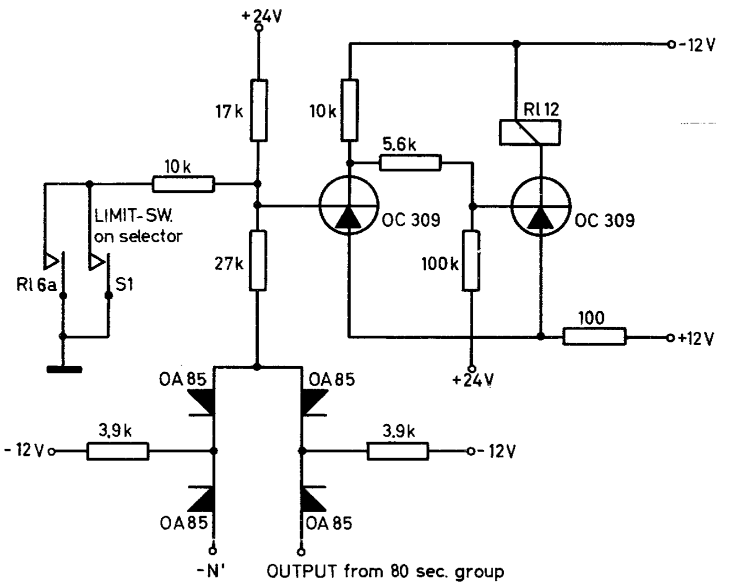
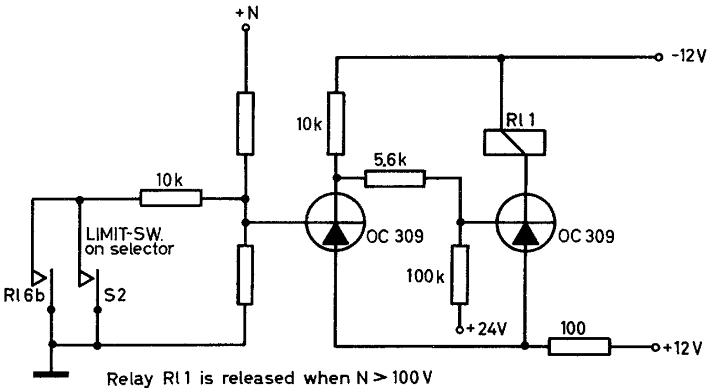


FIG. 5. CIRCUIT DIAGRAM OF LOG POWER AND PERIOD-CHANNEL.



Relay Rl12 is released when both N' and OUTPUT from 80 sec. group are < 8V



Relay Rl1 is released when N > 100V

FIG. 6. CIRCUIT DIAGRAM OF TRIGGER.

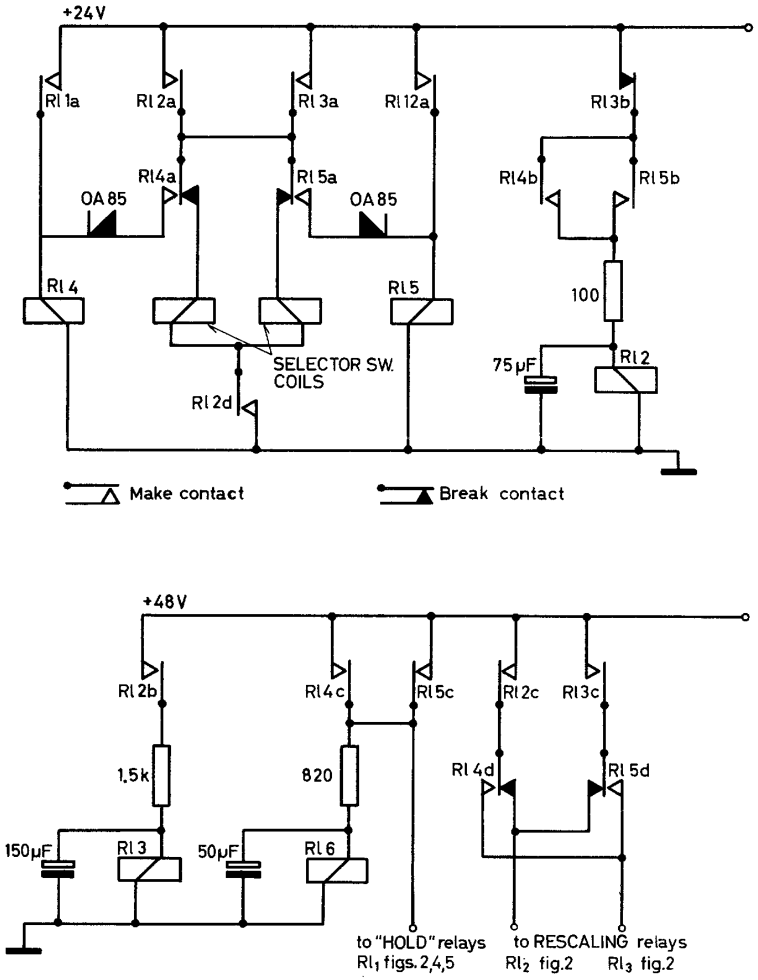


FIG.7. RELAY SEQUENCE GENERATOR.

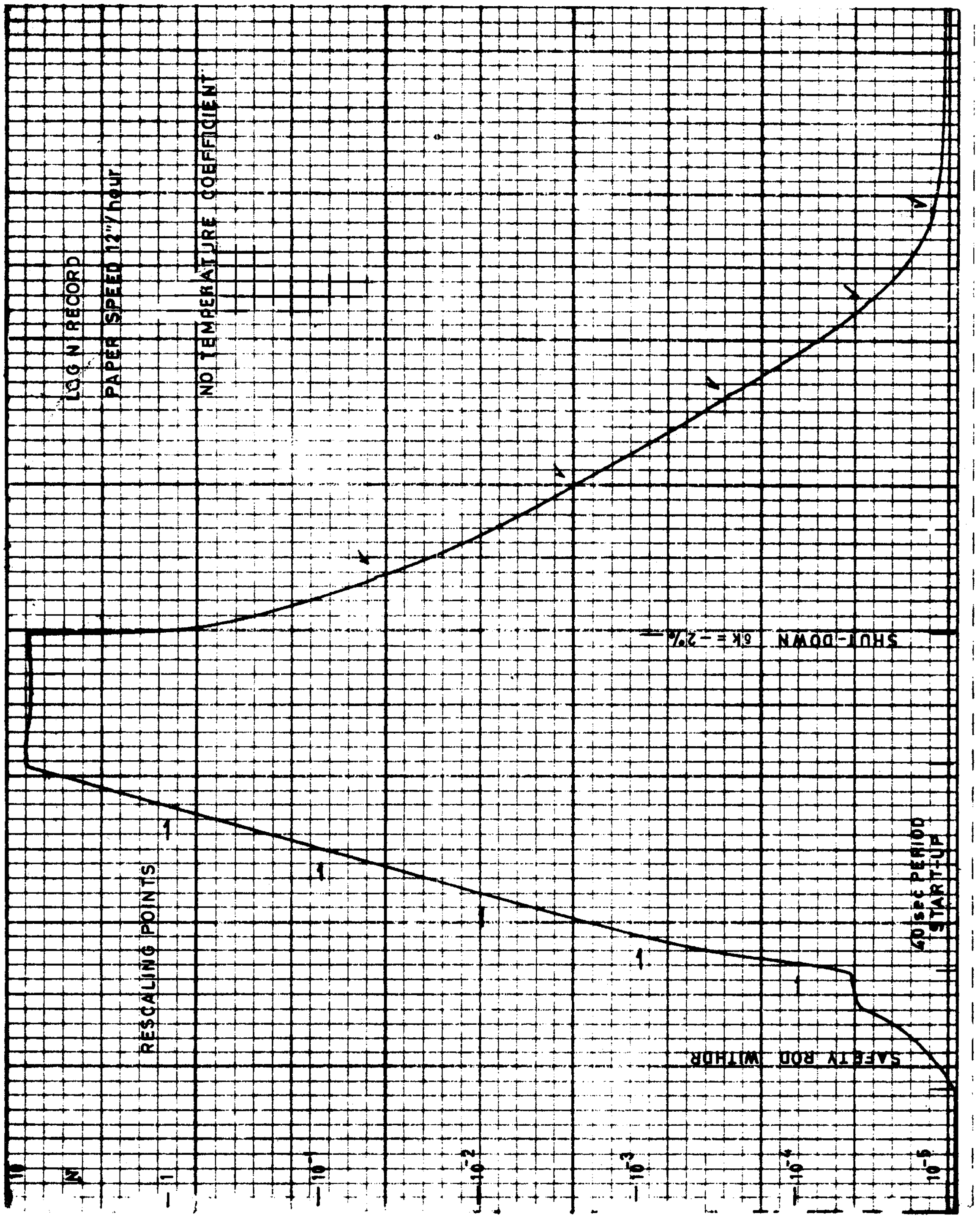


FIG. 8. LOG N RECORD FROM SIMULATED REACTOR START AND SHUT-DOWN.

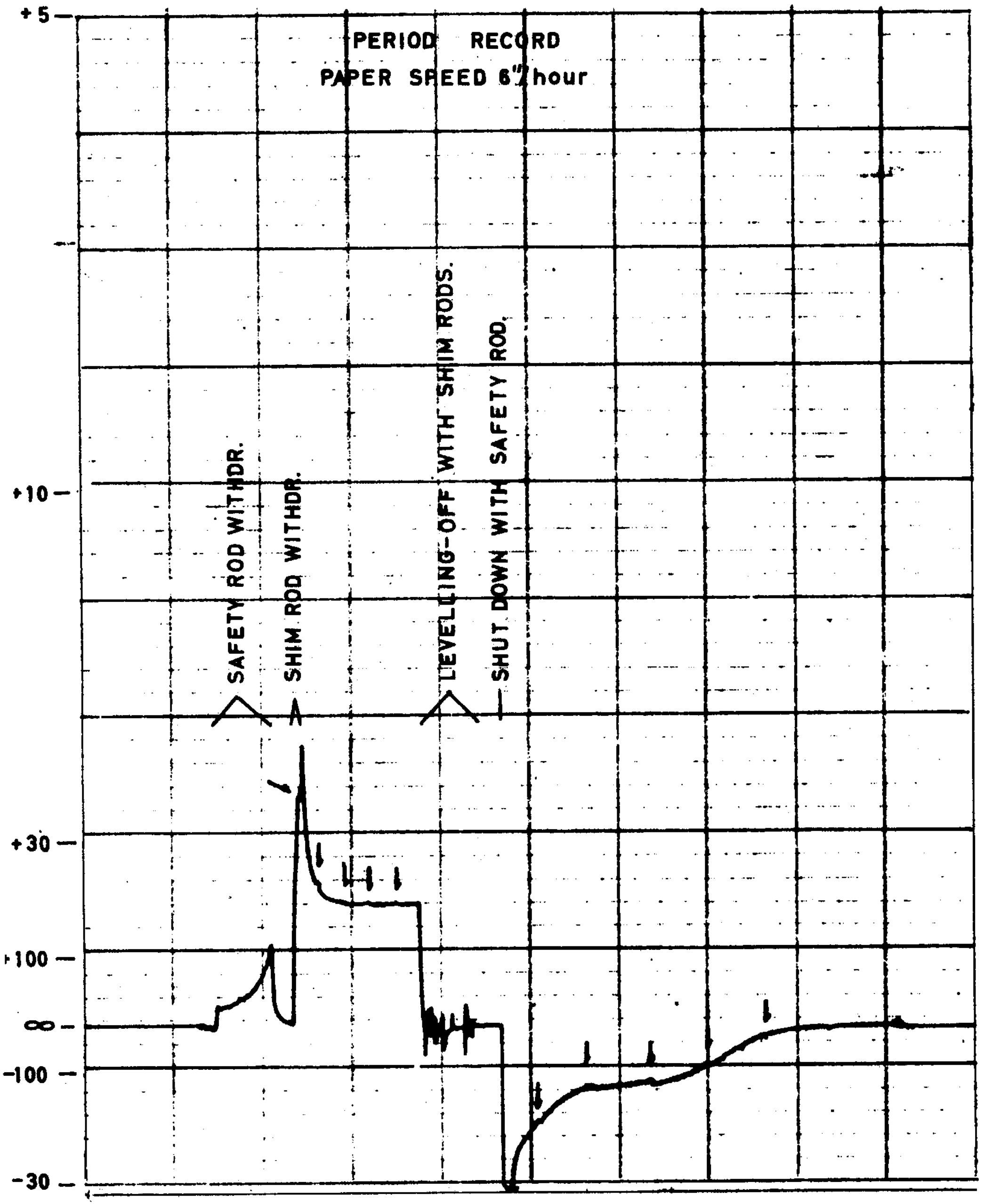


FIG. 9. PERIOD RECORD CORRESPONDING TO LOG N RECORD FIG. 8.

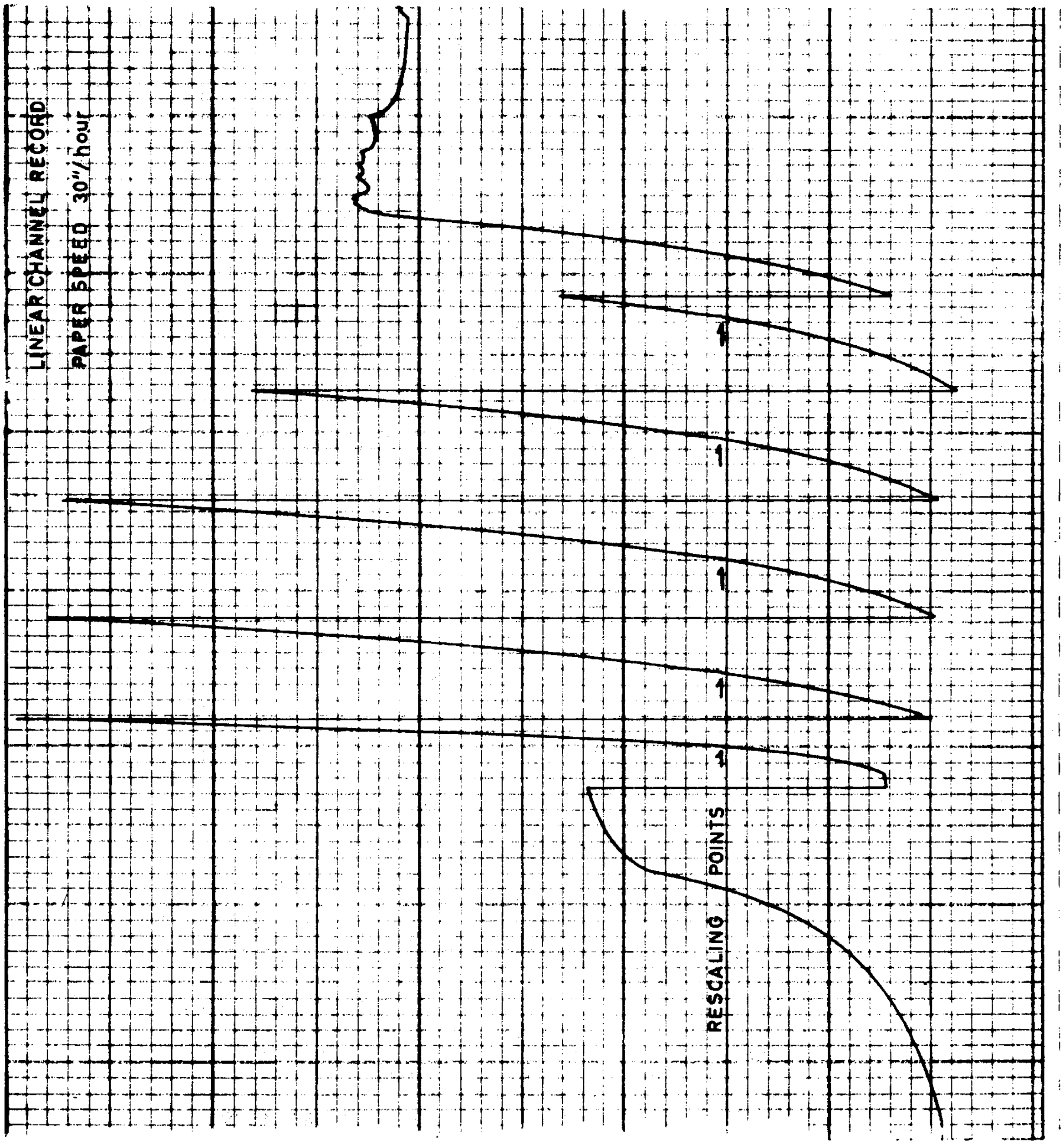


FIG.10. LINEAR CHANNEL RECORD OF REACTOR START-UP CORRESPONDING TO FIG.8.

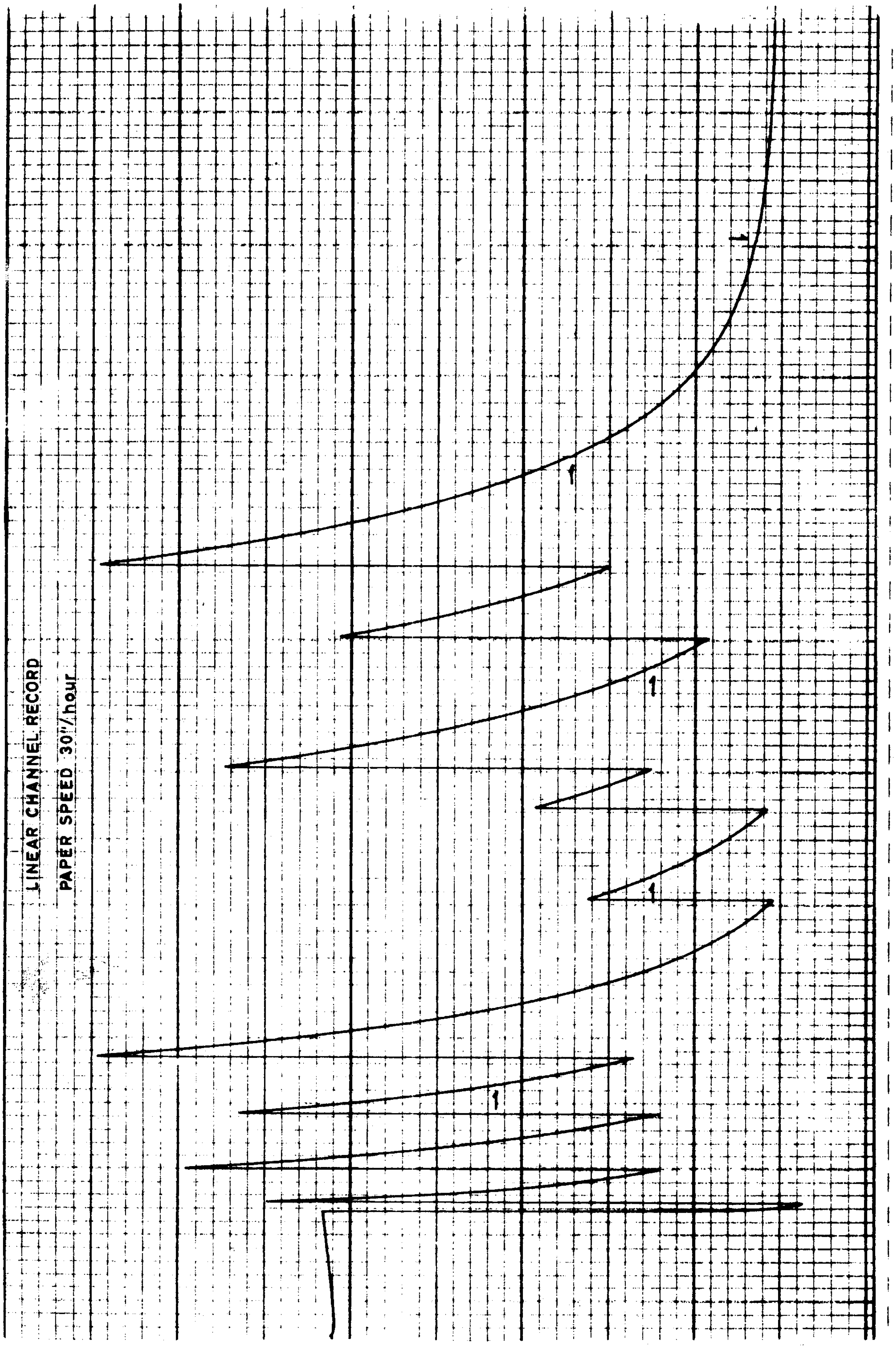
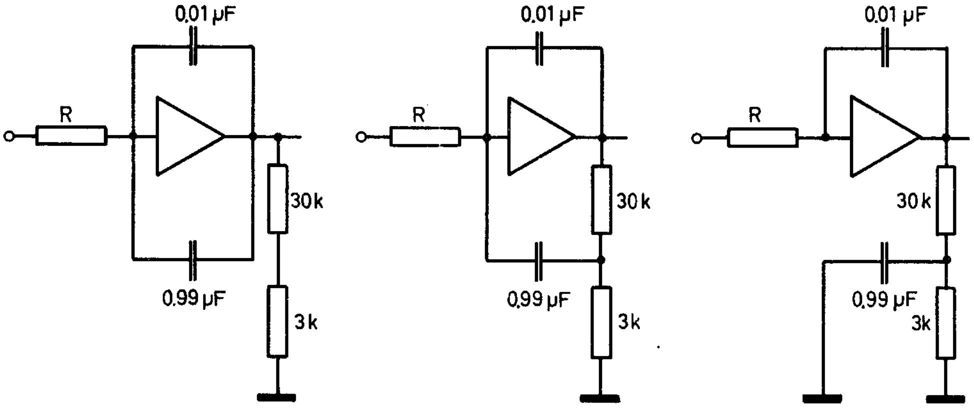


FIG.11. LINEAR CHANNEL RECORD OF REACTOR SHUT-DOWN CORRESPONDING TO FIG. 8.



TIME-SCALE	: NORMAL	x 10	x 100
Circuit during integration	: All relays released	relay 3 activated	relays 2-3 activated

TIME-SCALE	RESCALING FACTOR	CIRCUIT SEQUENCE Numbers of steps refer to fig. 3
x 1	10	1 — 2 — 3 — 4 — 1
	0,1	1 — 4 — 3 — 2 — 1
x 10	10	2 — 3 — 4 — 1 — 2
	0,1	2 — 1 — 4 — 3 — 2
x 100	10	3 — 4 — 1 — 2 — 3
	0,1	3 — 2 — 1 — 4 — 3

FIG. 12. CHANGE OF INTEGRATOR TIME-SCALE.
Circuit steps and relay numbers refer to figs. 2 & 3.