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METHOD FOR MEASURING FAST DECAY OF A NEAR-CRITICAL ASSEMBLY

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ABSTRACT

This paper contains a description of the apparatus and theories of the methods successfully used for determining the fast decay periods of near-critical assemblies.

The methods described are:

I. The modulation method.

II. The delayed coincidence or Rossi method.

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METHODS FOR MEASURING FAST DECAY OF A NEAR-CRITICAL ASSEMBLY

The time-dependence of a chain-reacting assembly is expressed by the factor $e^{\alpha t}$. The quantity α enters into the expression for the efficience as the square. It is therefore quite desirable to know α at the point where the assembly goes off, at say, around 3 crits. When the measurements were made it was impossible to measure α for more than one crit. What was done was to measure α as a function of mass for near-critical assemblies. This information could be used for extrapolating the α vs. mass curve and also as an integral check on the theory by which α is calculated.

The general features of the α vs. mass curve can be understood without any need of a precise theory. Fig. 1 shows

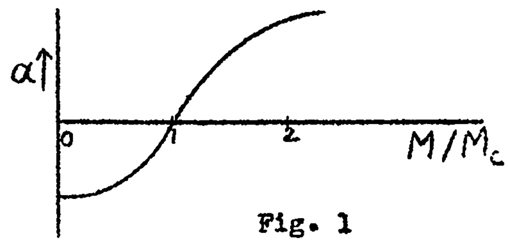

Fig. 1

what may be expected. The first part of the curve will be characteristic of the tamper because there is no active material present. α will of course be negative. It will have a finite value which is the reciprocal of the time of capture of a neutron in the tamper material. As active material is added, α will increase until it becomes equal to zero. This corresponds to infinite multiplication and this mass is called the critical mass M_c. If one were to continue to add material, α would continue to increase but would eventually level off at a value which is characteristic only of the active material. This will occur when nearly all the neutrons emitted by the fission process are captured in the active material without going out into the tamper.

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As soon as one goes into details, the situation is not so simple. We shall only mention one aspect which has an important bearing on our particular problem. We shall distinguish two kinds of α's, α_p and α_t. α_p, called α-prompt, is related to the fast multiplication and is the α which is significant for the efficiency calculations. α_t called α-total, is associated with the total multiplication. α_t differs from α_p in two respects. The small fraction of delayed neutrons enter into α_t, but not into α_p. Also, because of time absorption in the tamper, the tamper is less effective for the prompt multiplication. The problem discussed here is how to measure the slope of the α_p curve in the region when α_t is slightly less than zero.

The results of these measurements on both 25 and 49 have been previously reported.[1] This paper will describe the apparatus and the theory of the methods.

Two methods have been used successfully for determining α. They are the fast-modulation of the cyclotron and the delayed-coincidence or Rossi method. The theory of these methods is given in the appendix. At this point it will suffice to indicate briefly how these methods work to provide a background to better understand the experiments and apparatus.

THE MODULATION METHOD

The fundamental idea behind this method is that the time-dependence of the number of neutrons in chain-reacting assembly can be expressed as

$$N = A e^{\alpha t} \qquad (1)$$

1. Fast multiplication of 25 as a function of mass. LA-374
Fast multiplication of 49 as a function of mass. LA-479

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where A and α are function of the geometry and physical constants of the assembly. Theoretically this is not correct and the expression should be represented as a sum over a number of normal modes,[2] i.e.,

$$N = \sum_{i=1}^{n} A_i e^{\alpha_i t} \qquad (2)$$

However, it can be shown both theoretically and experimentally that if the assembly is close to critical and the method of excitation is reasonably chosen, then all the higher harmonics are negligible, and (1) is sufficiently accurate for our purposes. We shall defer to the appendix the question of delayed neutrons and take (1) with α_p as representing the time behavior of a near-critical assembly. If one introduces into such an assembly a source of neutrons S(t), then the number of neutrons at time t will be

$$N = e^{-\alpha_p t} \int_{-\infty}^{t} e^{\alpha_p t'} S(t)\, dt' \qquad (3)$$

If S(t) is zero after some time t_1, then one has that N is, after t_1, an exponentally decaying number. The measurement of α_p consist, then, in measuring the decay period.

In practice this is accomplished by modulating the cyclotron beam to give a pulse of neutrons approximately 0.5 μsecond long. When the beam is turned off, a gating circuit is triggered which records the pulses from an ionization chamber in ten definite time intervals immediately after the neutron pulse. These data, after being corrected for backgrounds, will immediately give the period of decay.

THE ROSSI METHOD

The principle behind the method is quite different from the modulation scheme. It relies upon the fact that a chain-reacting assembly actually

2. See: Effect of tampers on the time scale of sub-critical assemblies LA-194

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produces chains. If an assembly is near critical and a neutron is introduced into it, it has a very good chance of producing a chain of other neutrons. It is, in fact, the production of these chains which gives rise to the multiplication of the assembly. If in such an assembly one looks for pairs of neutrons which are separated by a short time interval, then it is highly probable that the two neutrons are related to each other by virtue of the fact that they are both members of the same chain. It is shown in the appendix that the time distribution of such pairs is $e^{\alpha_p t}$.

This distribution is measured in the following way. The assembly was provided with two ionization chambers. A natural source was used to introduce neutrons into the assembly. One of the chambers was connected to the gating circuit described above, so that whenever a pulse was recorded in it the circuit was in a condition to measure the time between this pulse and one recorded by the second chamber.

THE GATING CIRCUIT

The gating circuit is really the heart of the equipment. It is shown diagramatically in Fig. 2. Figs. 3 to 7 give the circuit constants for the component parts. Figs. 8 and 9 are photographs of the entire detecting equipment.

The principle of the circuit is as follows: the pulse from discriminator B fires a blocking oscillator (b.o.) in Gate 1; the b.o. pulse charges up a condenser in the cathode of 1/2 6 SN7; the b.o. pulse also goes down a delay line and fires b.o.2 in Gate #2; the pulse from b.o.2 does three things, (1) it shorts the cathode of the tube in Gate #1, thereby closing Gate #1, (2) it charges up the condenser in Gate #2, and (3) it sends a pulse down the delay line to trigger b.o.3 in Gate #3. This process continues down the chain of 10 gates, firing them in succession, but in

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such a way that no two are open at the same time. The duration of the gate is determined by the length of the delay line. The pulses which are formed in the different gates are mixed in the ten coincidence circuits with the pulse from discriminator A. To make this a little clearer, suppose all the gates in Chain B are 1 μsecond long. Suppose a pulse triggers discriminator B and 3 1/2 μseconds later a pulse triggers Discriminator A. In 3 1/2 μseconds, the pulse in B has reached Gate #4 so that when A is triggered a coincidence will be recorded in coincidence circuit #4 indicating that the two pulses were between 3 and 4 μseconds apart.

The widths of the gates could be varied individually from 0.1 to 1 μsecond. The resolving time of the component parts of the circuit was 1 μsecond and it could be run at counting rates up to 50,000/sec.

The circuit was also provided with a long gate (from 3 to 30 μseconds). This could be triggered at any time throughout the cycle and proved very convenient in determining backgrounds directly.

THE MODULATION EQUIPMENT

The beam from the cyclotron was snouted and focused on a small target about 10 feet outside of the water walls. The details of the magnetic focusing of the beam have been reported elsewhere,[3] and will not be given here. Fig. 10 shows the section of the snout between the target chamber and the focusing chamber. This section of the tube was provided at either end with adjustable slits. Also provided was a long set of deflecting plates. These plates were such that with 10 Kv across them the beam, which was defined by the entrance slit, was completely deflected across the exit slit. The modulation was accomplished by momentarily interrupting the deflecting vol-

3. LA Magnetic focusing.

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tage and permitting the beam to pass through the exit slit and strike the target. Fig. 11 shows the external part of the snout with the target imbedded in the WC tamper of the 25 assembly.

The modulation of the deflecting plate was accomplished by shorting the deflecting voltage to ground through a pair of 304 TH's. The 304's were driven by an 829 as a cathode follower which was in turn driven by a 828 blocking oscillator. The width of the pulse could be varied from 0.2 to 0.6 μsec. by varying the capacity in the grid circuit of the blocking oscillator.

OTHER ELECTRONIC EQUIPMENT

Crouch-Elmore amplifiers were used very successfully. A delay line clipper in the grid of the first stage of the amplifiers permitted clipping the pulses to 0.3 μsecond.

The discriminators, Fig. 3, were triggered uni-vibrators. Their resolving time was 1.5 μseconds. However, it was possible to remove the second tube, thus converting them into the more conventional flip-flop discriminator which had a resolvency time of .6 μseconds. The reason for using them as uni-vibrators was to make certain that the discriminators were the slowest part of the entire circuit.

The overall timing for the modulation was usually in a state of flux. The final and most satisfactory arrangement is shown in Fig. 12. The quadruple pulser was a self-triggered affair whose frequency could be varied from 10 to 10,000 cycles/sec. The four pulses could be arbitrarily phased with respect to each other. One of the pulses was used to trigger a sweep circuit, a second triggered the long gate. A third triggered the arc modulator of the cyclotron.[4]

4. It was found desirable to modulate the arc of the cyclotron ~~as well as the~~ beam in order to reduce the background from the tank walls.

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The fourth pulse triggered a delay time-controlled double pulser. The two pulses from this triggered the beam modulator and the B discriminator respectively. This latter pulser was necessary because any phase jitter at this point would have been quite serious. while it was not so important for the other parts of the setup.

None of this latter equipment was, of course, necessary when one used the Rossi method. Instead, another ionization chamber and amplifier were used to trigger B discriminator.

CALIBRATING OF GATING CIRCUIT

It was necessary to know accurately not only the widths of the gates, but also the time when each gate opened and closed relative to the time when Gate 1 opened. This calibration was made with a precision double pulser which was accurate to .01 μseconds. This pulser was calibrated against a crystal oscillator. Knowledge of the width of the gates was not sufficient since there was a little overlap in the gates. However, the widths were determined independently by counting random pulses and were compared with the widths as determined by the standard pulser. The agreement was quite satisfactory and served as a useful check on the overall behavior of the apparatus.

CHAMBERS

The chamber problem was greatly simplified since we are interested only in obtaining timing pulses indicating when an event is taking place. This means that the chambers did not have to have plateaus. All that was needed was high efficiency and fast response.

The chamber used for the measurements on 25 is shown in Fig. 13

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and 14. The square design was for convenience in stacking in the assembly. As shown in Fig. 13, it consisted of two separate chambers which could be used independently for the Rossi method or connected together and used as a single chamber for the modulation work. All the grounded parts of the chamber were coated with 80% 25 to a thickness of 1.3 mg/cm^2. The pulses were taken off the high voltage. It was operated at 10 lbs. gauge pressure with the Argon-Co_2 mixture.

The chambers used for the 49 work are shown in Figs. 15 and 16. Their design was also conditioned by the geometry of the assembly. It consisted of stacks of electrodes which are alternately grounded and at high voltage, the spacing between the electrode was 30 mils. Both sets of electrodes were coated with 80% 25 to a thickness of 2 mg/cm^2. Each chamber contained approximately 1 gm of oxide. It was operated at a pressure 100 lbs of argon and CO_2. The pulses were also taken off the high voltage.

METHOD OF TAKING AND HANDLING DATA

The general method for taking data by each method has already been indicated. There is little more that can be said. The counts in the ten different channels were individually corrected for backgrounds. These backgrounds were figured on the basis of the frequency and the total counts in A discriminator for the modulation method or on the total count in A & B discriminators and the time for the Rossi method. These counts were then reduced to count per unit gate width and plotted on semi-log paper against the time when each particular gate was open. These points always lay on a straight line within the statistics. The slope of these lines determined α_p.

These measurements of α_p were made for slightly different masses. The particular methods for changing these masses are reported elsewhere,[5] and

5. loc. cit. footnote 1.

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will not be given here. From this data it was possible to calculate the slope of the α vs. mass curve at a point near critical.

DISCUSSION

This report has dealt principally with the methods for measuring α_p rather than with the more important question of the measurement of $d\alpha_p/dM$. While this does not belie the title, it does represent a shortcoming. We have remarked rather glibly that we measure α_p for different masses. The difficulty is not in measuring the α_p or the different mass, but rather knowing just what the change in mass means. In the laboratory one changes the mass by actually removing some small piece of the active material. The problem, which is essentially a theoretical one. of evaluating the effectiveness of such a removal, is one of extensive difficulty and well beyond the scope of this paper.

The picture is much brighter on the question of determing α_p. The two methods described have been checked against each other and agree within the statistical errors. Each method has its advantages and disadvantages to recommend it.

The advantage of the modulation method is its greater intensity. This is particularly true when one backs off from critical by changing the mass. It can be shown that the counting rate varies linearly with total multiplication for the modulation method while it varies as the cube of the multiplication for the Rossi method.

The Rossi method excels in its simplicity. Although the detecting equipment is the same in both cases the simplicity of a natural source compared to a modulated cyclotron cannot be overemphasized. The Rossi method is also free of some spurious effects such as modulated backgrounds which can cause

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trouble with the modulated beam. Finally there is something inherently very nice about measuring a "dynamic" quantity by a "static" experiment.

Appendix I.

THEORY OF THE MODULATION EXPERIMENT

We shall start with the differential equation expressing the rate of change of the number of neutrons N in an assembly and taking into account explicitly the delayed neutrons and an external source.

$$\frac{dN}{dt} = -\frac{N}{\tau_o} + \frac{K(1-f)}{\tau_o}N + \frac{K f \beta}{\tau_o}\int_{-\infty}^{t} N(t')\, e^{-\beta(t-t')}\, dt' + S \qquad \text{(A1)}$$

Here:

τ_o	=	mean time for capture (loss of neutrons by leakage is equivalent to capture)
K	=	neutrons produced per neutron captured
f	=	fraction of neutrons delayed (sometimes called γ f)
β	=	assumed reciprocal period for the delayed neutrons
S	=	source strength in neutrons per second.

This equation says that the time rate of change of N is made up of four parts:

(1) The neutrons lost by capture; (2) the prompt neutrons produced by capture; (3) the delayed neutrons produced by capture; and (4) the neutrons supplied by the source. Upon multiplying the equation by $e^{\;t}$, differentiating, and rearranging terms, the following results:

$$\frac{d^2N}{dt^2} + \left[\beta + \frac{1-K(1-f)}{\tau_o}\right]\frac{dN}{dt} + \left[\frac{1-K}{\tau_o}\right]\beta N = \beta S + \dot{S} \qquad \text{(A2)}$$

If we use the following abbreviations

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$$a_p = \frac{1-K(1-f)}{\tau_0} \quad , \quad a_d = \frac{1-K}{1-K(1-f)}\beta \qquad (A3)$$

then, since $\beta\,(\sim 1)$ is negligible compared to $a_p(\sim 10^6)$ and in our experiment $a_d \sim 1 << a_p$ [see next page], we may write:

$$\left[\frac{d}{dt} + a_p\right]\left[\frac{d}{dt} + a_d\right] N = \beta S + \dot{S} \qquad (A4)$$

The particular solution of this equation is:

$$N = \frac{1}{a_d\, a_p} e^{-a_p t}\int_{-\infty}^{t} e^{a_p t'}\left[\beta S(t') + \dot{S}(t')\right] dt' + \frac{1}{a_d\, a_p} e^{-a_d t}\int_{-\infty}^{t} e^{a_d t'}\left[\beta S(t') + S(t')\right] dt' \qquad (A5)$$

This can be simplified by removing the $\dot{S}$ terms from under the integral sign by an integration by parts. In the range of K which is interesting (K nearly 1) and since $f \sim .007$, a_d is negligible compared to a_p. Using this fact we can write as a final result:

$$N = e^{-a_p t}\int_{-\infty}^{t} e^{a_p t'}\, S(t')dt' + \frac{K f \beta}{a_p^2\, \tau_0}\, e^{-a_d t}\int_{-\infty}^{t} e^{a_d t'}\, S(t')dt' \qquad (A6)$$

The result consists of one term with a very short period (approximately 1 μsecond) with a coefficient of unity plus another term with a long period (approximately 1 second) with a very small coefficient ($a_p^2 \tau_0 \sim 10^4$). This second term will integrate the source for a period of $1/a_d$.

Consider what happens if S is a periodic square pulse of duration $\delta \sim 1/a_p$ and unit intensity whose period if $T << 1/a_d$. We shall assume that S has been on for infinitely many cycles in the past and will measure time from the beginning of some arbitrary pulse. If $T >> 1/a_p$ then the first integral will only contribute from the immediate pulse under consideration. The last integral will average the source contribution for a time of $1/a_d$, the result is, then

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$$N = \frac{e^{\alpha_p \delta} - 1}{\alpha_p} \quad e^{-\alpha_p t} + \frac{Kf\beta}{\alpha_p^2 \tau_o} \quad \frac{S}{\alpha_d T} \qquad \text{(A7)}$$

What we have, then, is a rapidly decaying exponential superimposed on a continuous background. This background is caused by the delayed neutrons.

It is desirable that the background be sufficiently small for a good measurement of α_p. We might take as a criterion that the background be one-tenth of the counting rate of the exponential pulse after three periods.

This should permit a good measurement. Assume $\beta = .1 \text{ sec}^{-1}$, $t_o = 10^{-8}$ sec, and $\alpha_d = .01 \text{ sec}^{-1}$. This gives $K = .9992$; $\alpha_p = 8 \cdot 10^5$; and $\delta = 1.2 \cdot 10^{-6}$ sec. Our criterion is

$$\frac{(K f \beta / \alpha_p \tau_o)\ (\delta / \alpha_d\ T)}{(e^{\alpha_p \delta} - 1)\ e^{-3}} = 0.1$$

Putting in the numbers and solving for $1/T$ given a frequency of ~ 300 cycles/sec.

One might estimate the counting rates approximately as follows: if one assumes the deuteron beam to be 1 μ amp, which yields 10^{10} neutrons/sec, then one calculates from the above expression assuming a repetition rate of 300 cycles/sec that there should be $1.5 \cdot 10^5$ neutrons present in the assembly after three periods. Since the critical mass of the assembly is $\sim 3 \cdot 10^4$ gms and the chamber contains one gram then there should be $1.5 \cdot 10^5 / 3 \cdot 10^4 = 5$ neutrons per second making fissions in the chamber.

Actually these conditions are quite idealized. There is, besides the background discussed above, the general background from the tank wall, etc. This necessitates lowering the frequency somewhat. Also, since the chamber was placed in the tamper, the estimate of the efficiency is certainly optimistic. However, the estimated counting rates are so good that one can afford to take a bit of a licking on these other things.

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APPENDIX II

The Rossi Method

The Rossi method represents a different approach to this problem. It is essentially statistical in nature. Let P (t) be the probability that, if a neutron exists at time $t = o$ then a neutron will exist at time $t = t$. We may calculate P(t) directly. Suppose the initial t is subdivided into a large number of small intervals dt. We ask, what is the probable number of neutrons after a time dt? This probable change in the number of neutrons is given by the product of dt/τ_o, the probability of a captive in the interval dt, and $\left\{-1+K(1-f)\right\}$ (we are considering only prompt neutrons), the change in the number of neutrons if a capture takes place. Therefore, the probable number after a time dt will be the number existing at the beginning of the interval plus the probable change in the number during the interval.

Probable number after $dt = 1 + (-1 + K\ (1-f) \quad dt/\tau_o = 1 - \alpha_p\, dt.$

The probable number after a time t will be the product of the probable numbers of all the subintervals. There are t/dt of these intervals. Therefore,

$$P(t) = (1 - \alpha_p\, dt)^{t/dt}$$

$$= \left[(1 - \alpha_p\, dt)^{-1/\alpha_p dt}\right]^{-\alpha_p t} \qquad \text{(A8)}$$

In the limit of dt approaching zero, this becomes simply

$$P\ (t) = e^{-\alpha_p t} \qquad \text{(A9)}$$

From this we immediately have, for the probability of a neutron producing another neutron at a time t later and being captured in the time interval dt,

$$e^{-\alpha_p t} = dt/\tau_o, \qquad \text{(A10)}$$

since the probability that a neutron will be captured is just dt/ $_o$.

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As an immediate application of (A10) we may calculate the total number of neutrons that will be captured because a neutron exists at time $t = o$. This requires summing (A10) over all times.

$$\int_0^{\infty} e^{-a_p t} \, dt/\tau_o = 1/a_p \tau_o \qquad \text{(A11)}$$

The reason for emphasizing the capture of neutrons is because this is the same as detecting them. The detected neutrons are, among others, neutrons that are removed from the system.

Now, let D be the reciprocal period for the assembly including the delays. Then, in analogy to (A10), we have that the probability of producing a neutron at time t in the interval dt is βe^{-Dt} dt where β is the reciprocal lifetime for the delayed neutrons. We get then that the total probability of producing delayed neutrons is β/D in analogy to (A11). Now since it is impossible to distinguish a delayed neutron from a source neutron, these delayed neutrons will be multiplied promptly according to (A11). Therefore the total multiplication will be

$$(\beta/D) \quad (1/a_p \tau_o) \qquad \text{(A12)}$$

If we now take equation (A6) of Appendix I and interpolate it over all time assuming the source S to be unity, we find that, after dividing by τ_o, the number of neutrons present is $1/(1-K)$. If we equate this to the expression (A12) and solve for D, we find

$$D = \frac{\beta(1-K)}{a_p \tau_o} = a_d \qquad \text{(A13)}$$

This establishes the equivalence between the significant quantities of the Modulation and the Rossi Methods.

We shall now investigate the probabilities of counting pairs of

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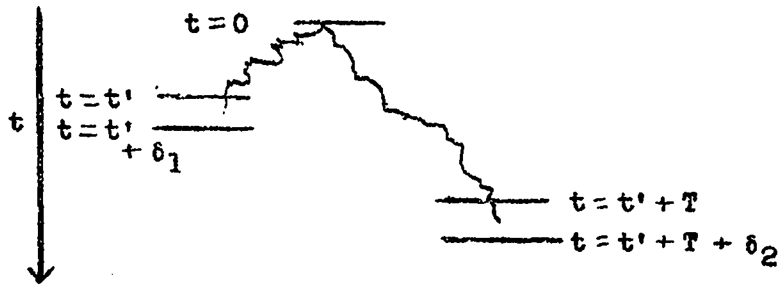
neutrons separated by a definite time interval T. We shall try to make this idea



somewhat clearer. Looking at the accompanying figure, suppose at time t = o a neutron exists. This neutron gives rise to a chain. There is a certain probability that, because of the existence of the neutron at t = o, a neutron will be captured in the time interval δ at t = t'. Similarly, there is a chance for one to be captured during the interval δ_2 at time T = t' + T. We wish to calculate the probability for counting the two neutrons separated by the interval T for all values of t'. We can simplify the calculation by calculating the probability that a neutron is captured at time t' and in the interval $\delta_1 + \delta_2$ at time t' + T. The result is

$$e^{-a_p t'} \frac{dt'}{\tau_0} \quad e^{-a_p (t'+T)} \quad \frac{\delta_1+\delta_2}{\tau_0} \tag{A14}$$

If we integrate this over all times t' we obtain the required result.

$$\frac{e^{-a_p t}}{2a_p \tau_0^2} \quad (\delta_1 + \delta_2). \quad ^{6)} \tag{A15}$$

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6. This expression is inaccurate in one respect. We have omitted any discussion of the fact that the number of neutrons emitted during fission fluctuate. A more detailed analysis of the theory of chain production shows that equation A15 should be multiplied by a factor usually called X_2 where

$$X_2 = \frac{\sum_{R=1}^{\infty} R(R-1) \text{ probability of emitting R neutrons per fission}}{}$$

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Hence, if one obtains the curve for the probability of counting pairs as a function of T, then this curve gives us a method of determining a_p.

If one uses a source of strength S, then the counting rate for pairs will be

$$\frac{S}{1-K} \quad \frac{e^{-a_p t}}{2a_p t_o^2} \quad (\delta_1 + \delta_2) \quad E_1 \; E_2 \qquad \text{(A15)}$$

When E_1 and E_2 are the respective efficiencies of the two chambers. The total counting rate in one chamber will be

$$\frac{S}{1-K} \; E_1 .$$

Hence the background of accidental counts will be

$$\left(\frac{S}{1-K}\right)^2 E_1 \; E_2 \; (\delta_1 + \delta_2). \qquad \text{(A16)}$$

We may estimate the expected results here as we did on the modulation method. We will first find what value of S we can use to keep the background down to one-tenth after three periods. That is

$$\frac{\left[S/(1-K)\right]/e^{-3}}{2\, a_p \;\; \tau_o^2} = .1$$

If we use the values of K, a_p, and τ_o of Appendix I, then we find that $S = 10^4$ Fission/sec which is easily obtainable with a natural source. If in (A15) we again take $E_1 = E_2 = 1/(3\text{x}10^4)$ and $\delta_1 = \delta_2 = 5\cdot10^{-7}$ sec as reasonable gate width S we find that the pairs/sec of three periods separation are counted at the rate of 1/sec.

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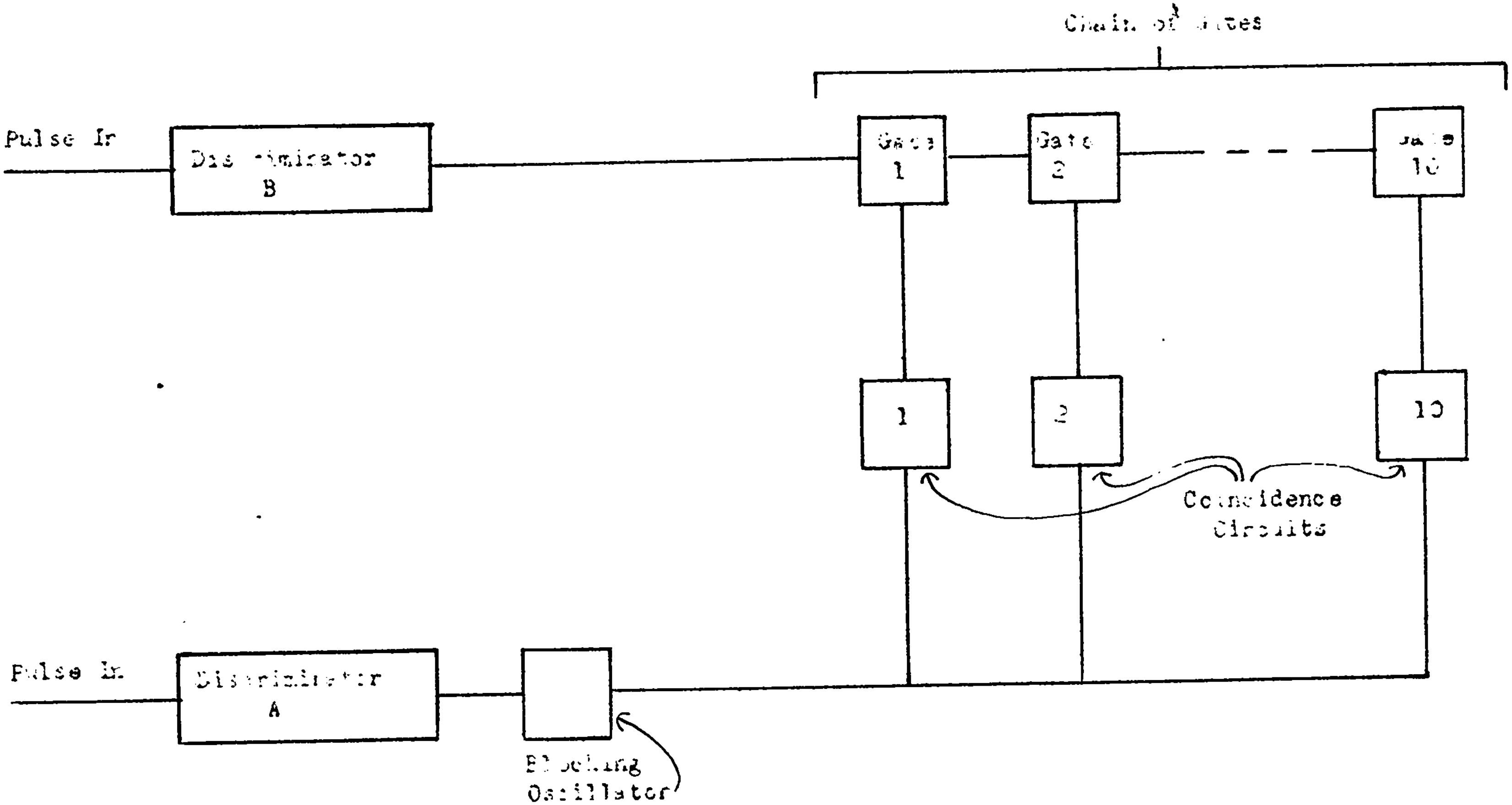

Fig. 2

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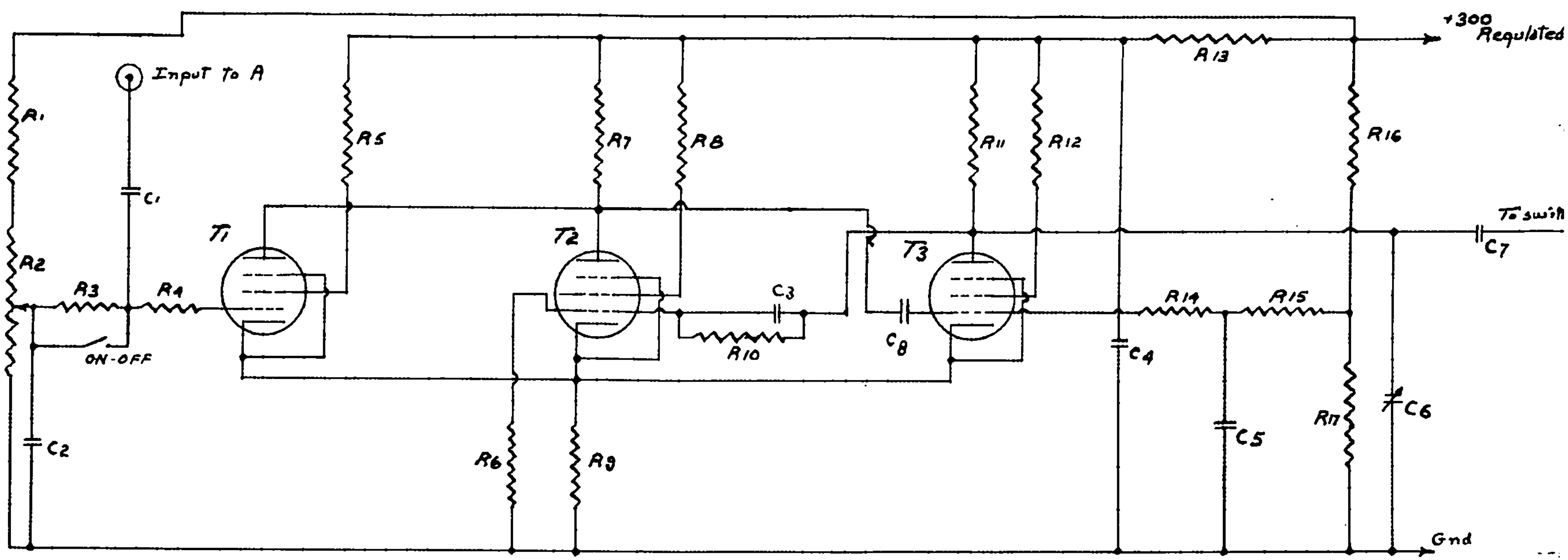
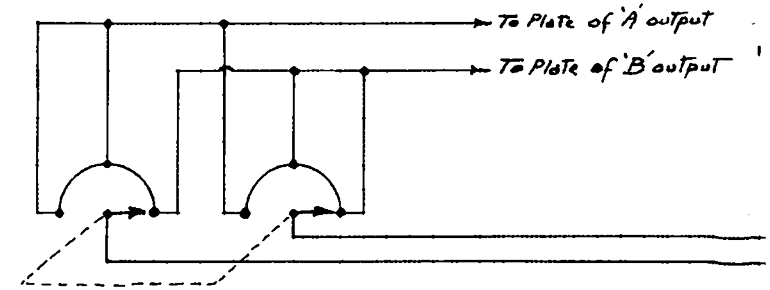
Drawing IV

Channel A (channel B the same)





R1 – 25K
R2 – 10K GR pot.
R3 – 50K ½w
R4 – 10K ½w
R5 – 150Ω ½w
* R6 – 30K 2w
R7 – 2K 2w
R8 – 150Ω ½w
R9 – 250K 2w
*R10 – 50K 2w.
R11 – 1.5K 10w
R12 – 150Ω ½w
R13 – 200Ω 10w
R14 – 10K ½w
R15 – 10K ½w
*R16 – 50K 10w
*R17 – 25K 10w

* accurate to 1%

C1 – .002 μfd
C2 – .1 μfd
C3 – 20 μμfd.
C4 – 4 μfd Tobe
C5 – .1 μfd
C6 – 5-50 μμfd
C7 – .001 μfd
C8 – 20 μμfd.

T1, T2, T3 } 6AG7

Fig 3

DISCRIMINATOR

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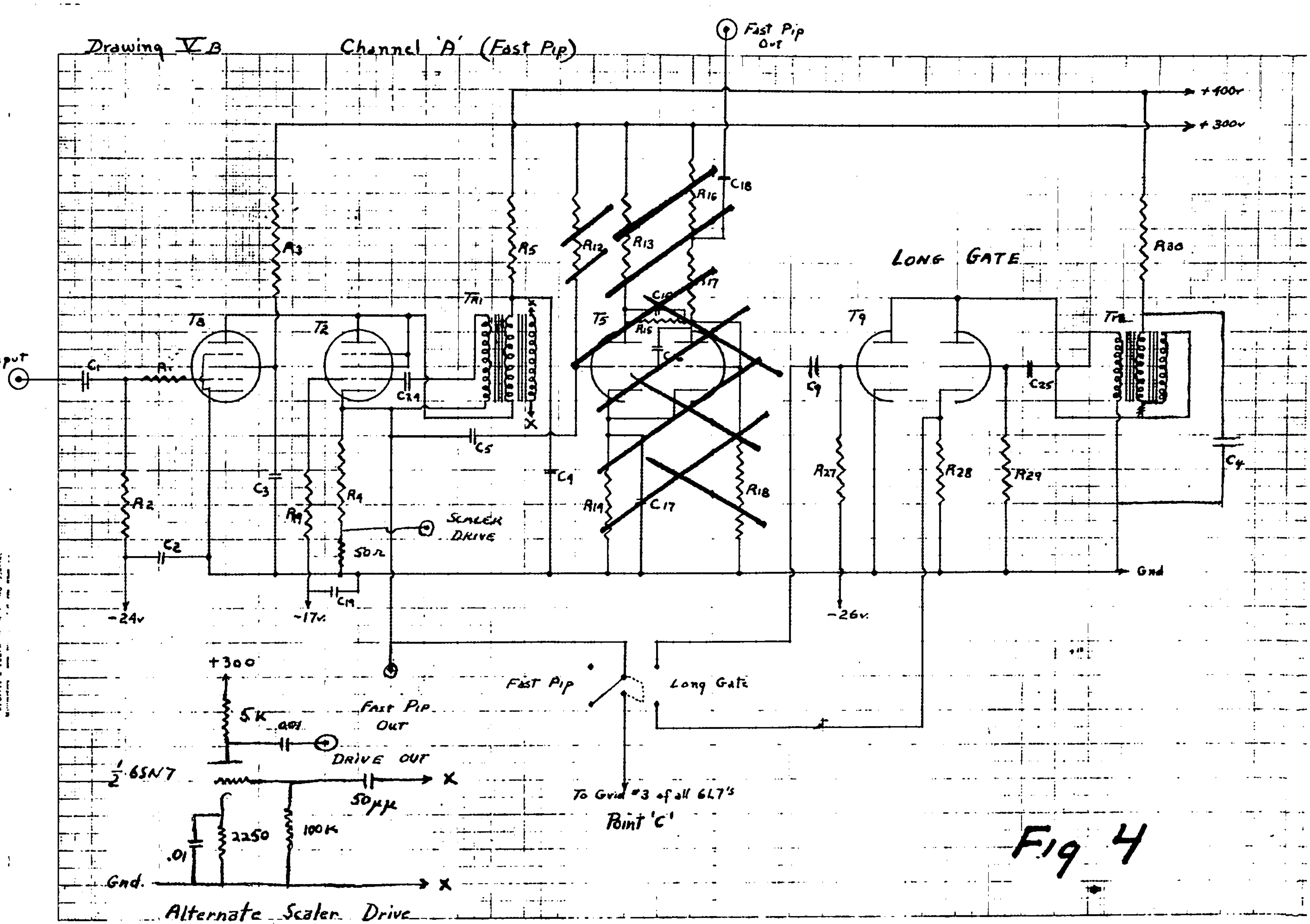

Fig 4

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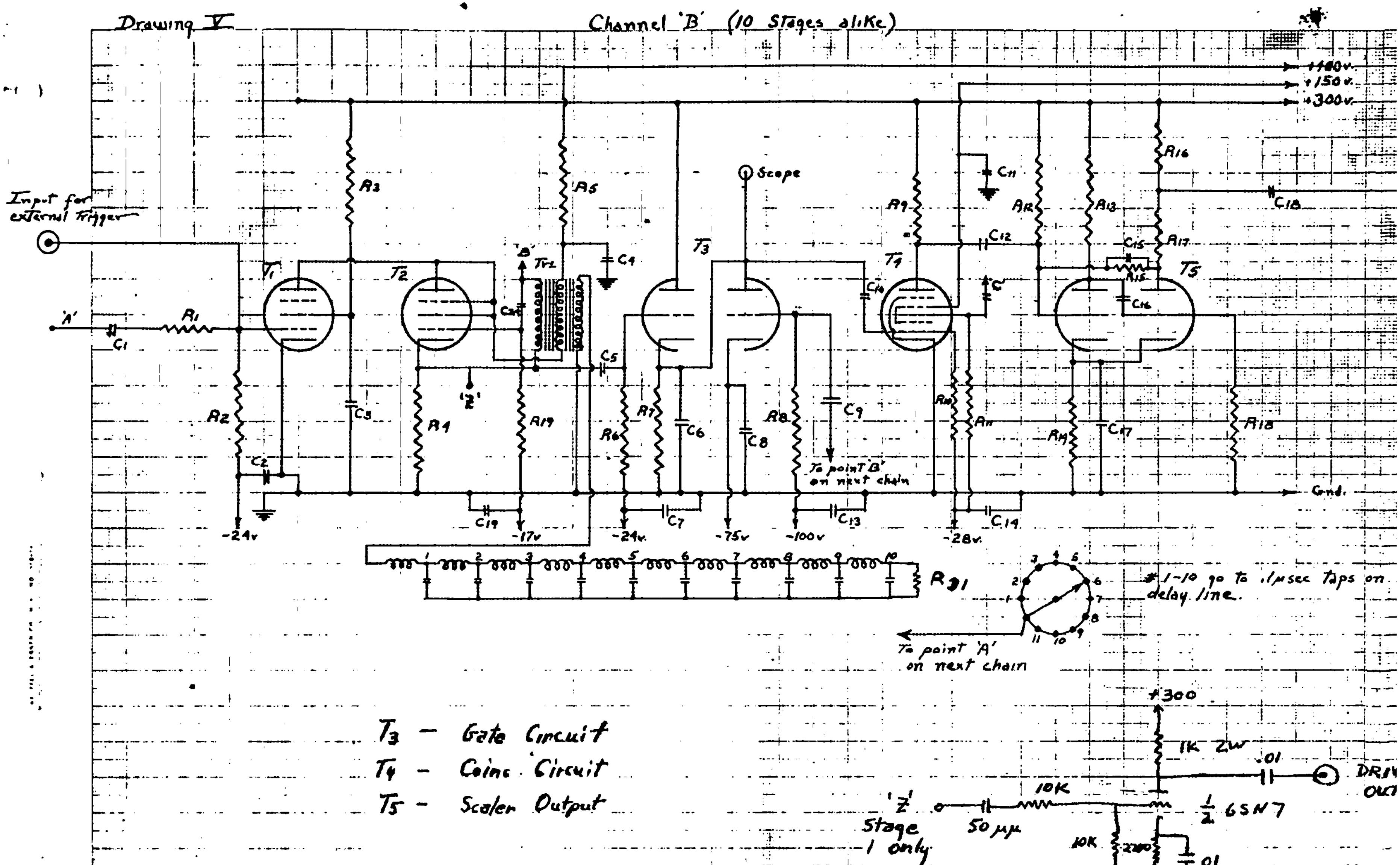

Fig 5

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Drawing V A

Channel 'B' Stage 11

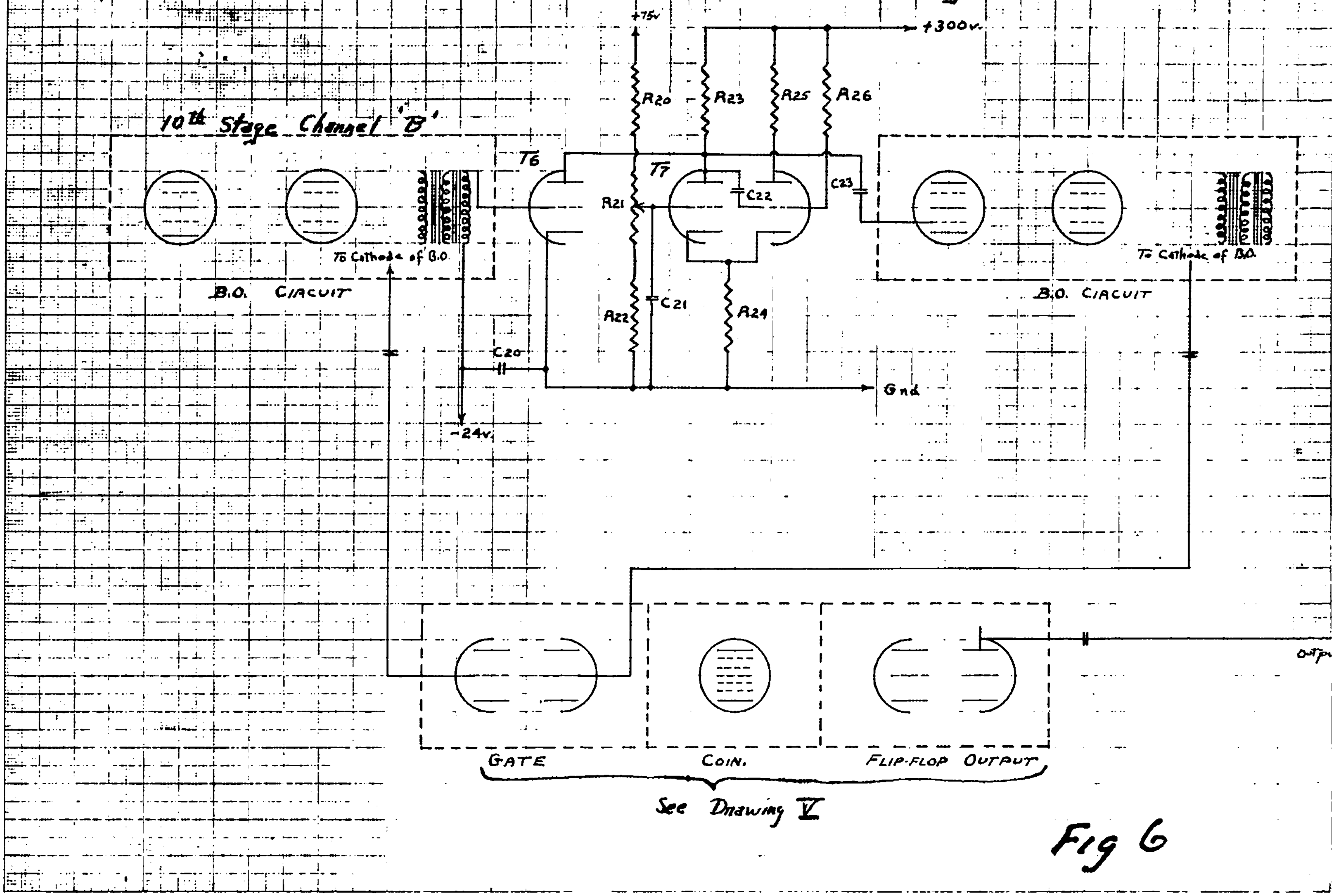

Fig 6

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Drawing V a

R1 – 2K ½w
R2 – 50K ½w
R3 – 2K 1w
R4 – ~~200~~ Ω 2w 200 Ω BW
R5 – 500 Ω 2w
R6 – 25K ½w
R7 – 100K 2w.
R8 – 7.5K ½w
R9 – 5K 1w
R10 – 100K ½w.
R11 – 100K ½w.
R12 – 200K 1w.
R13 – 20K 1w.
R14 – 11K 2w.
R15 – 75K ½w.
R16 – 12K ½w
R17 – 15K 2w.
R18 – 100K ½w
R19 – 50K ½w
R20 – 10K 1w
R21 – 5K 1w pot (Gate Control)
R22 – 1.25 K 1w
R23 – 10K 1w
R24 – 3500 Ω 10w
R25 – 10K 1w
R26 – 3 meg 1w
R27 – 20K ½w
R28 – 2K 1w
R29 – 12 K ½w
R30 – 1K 1w
R31 – 700 w

C1 – 500 μμfd.
C2 – .1 μfd.
C3 – .1 μfd
C4 – .1 μfd Tobe
C5 – .002 μfd.
C6 – ~~.1 μfd~~ 70 μμfd
C7 – .1 μfd
C8 – .1 μfd
C9 – .002 μfd
C10 – 150 μμfd
C11 – 1 μfd Tobe
C12 – .001 μfd.
C13 – .1 μfd.
C14 – .1 μfd.
C15 – 25 μμfd.
C16 – 50 μμfd.
C17 – .1 μfd
C18 – .01 μfd
C19 – .1 μfd.
C20 – .1 μfd.
C21 – .1 μfd
C22 – 75 μμfd
C23 – 100 μμfd.
C24 – 250 μμfd.
C25 – 250 μμfd .05

T1 – 6AC7 – {6AG7 in stage no 1}
T2 – 6AC7
T3 – 6SN7
T4 – 6L7
T5 – 6SN7
T6 – ½ 6SN7
T7 – 6SN7
T8 – 6AG7
T9 – 6SN7

Tr1 – 132 AW rewound
16 Turns on 1st winding
16 Turns on 2nd winding
10 Turns on 3rd winding

Tr2 145 EW

Fig 7

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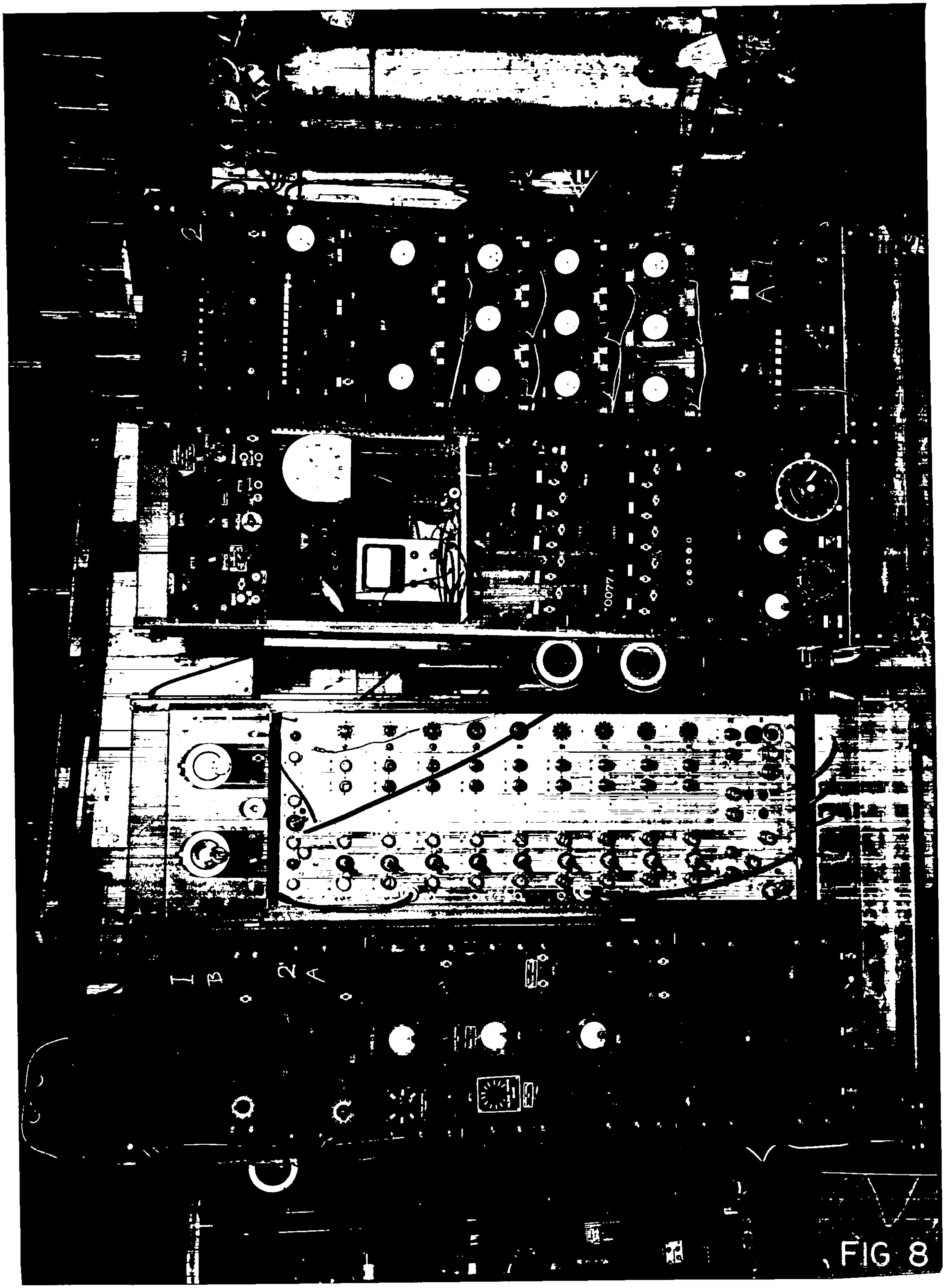

FIG 8

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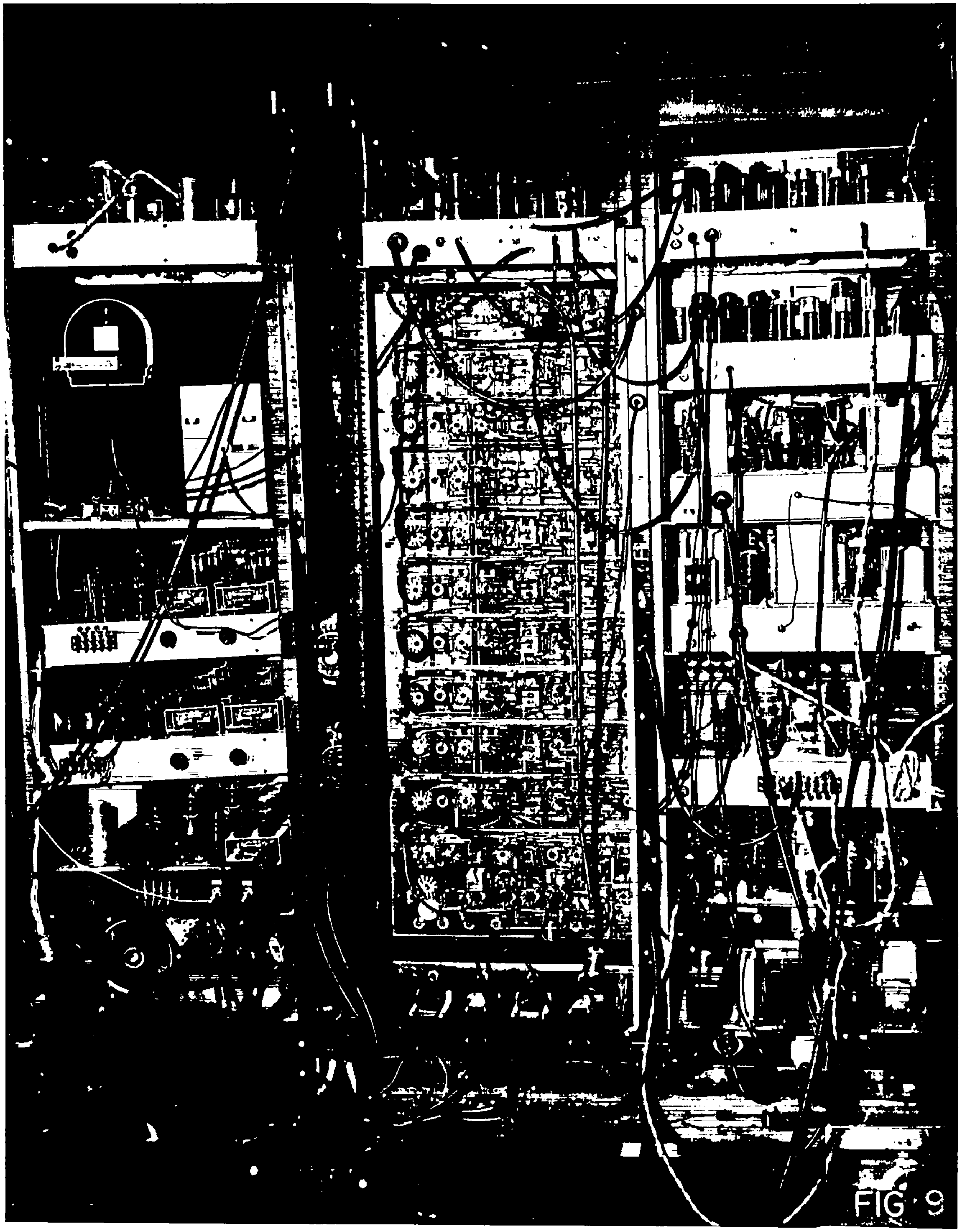

FIG 9

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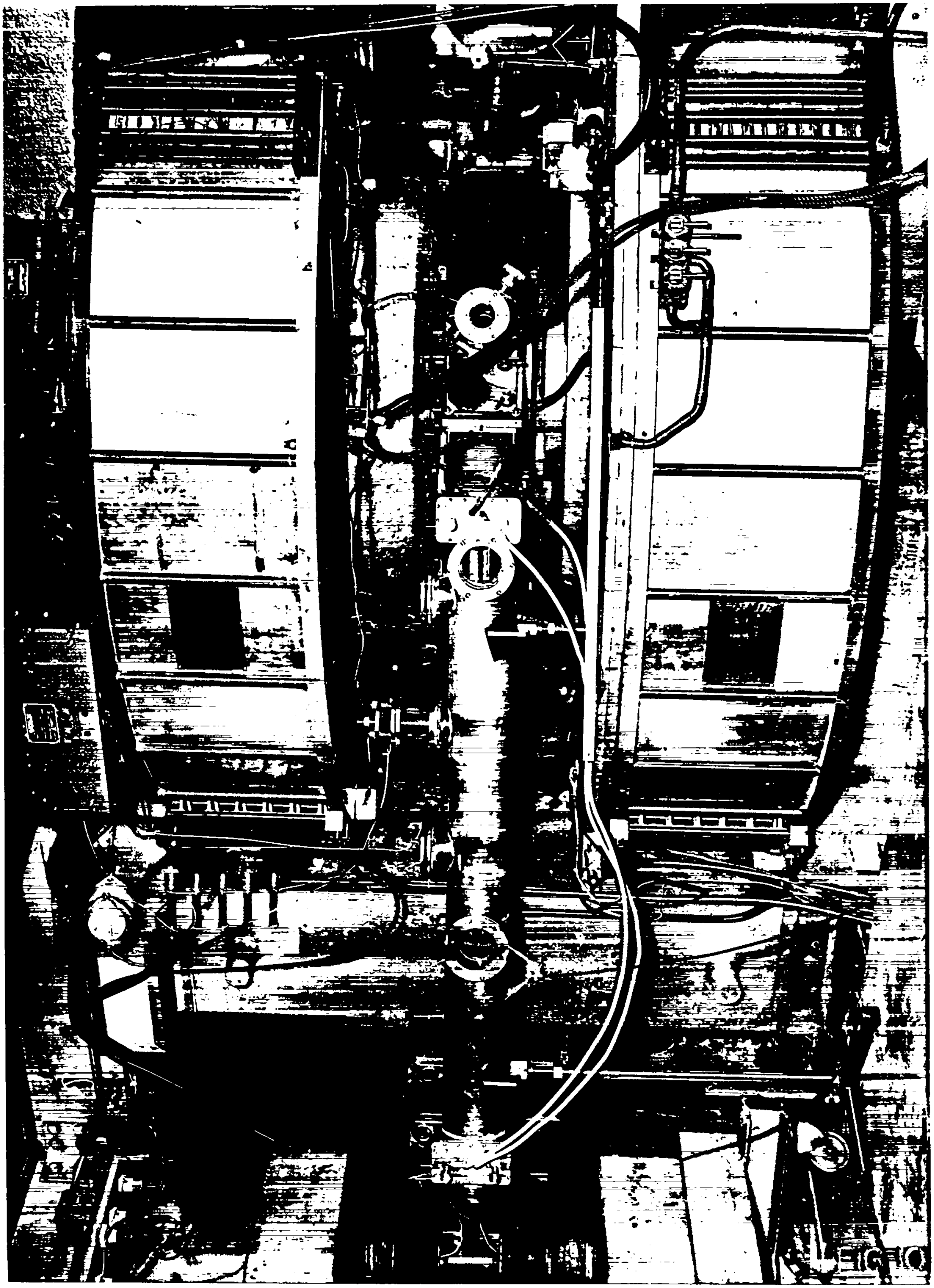

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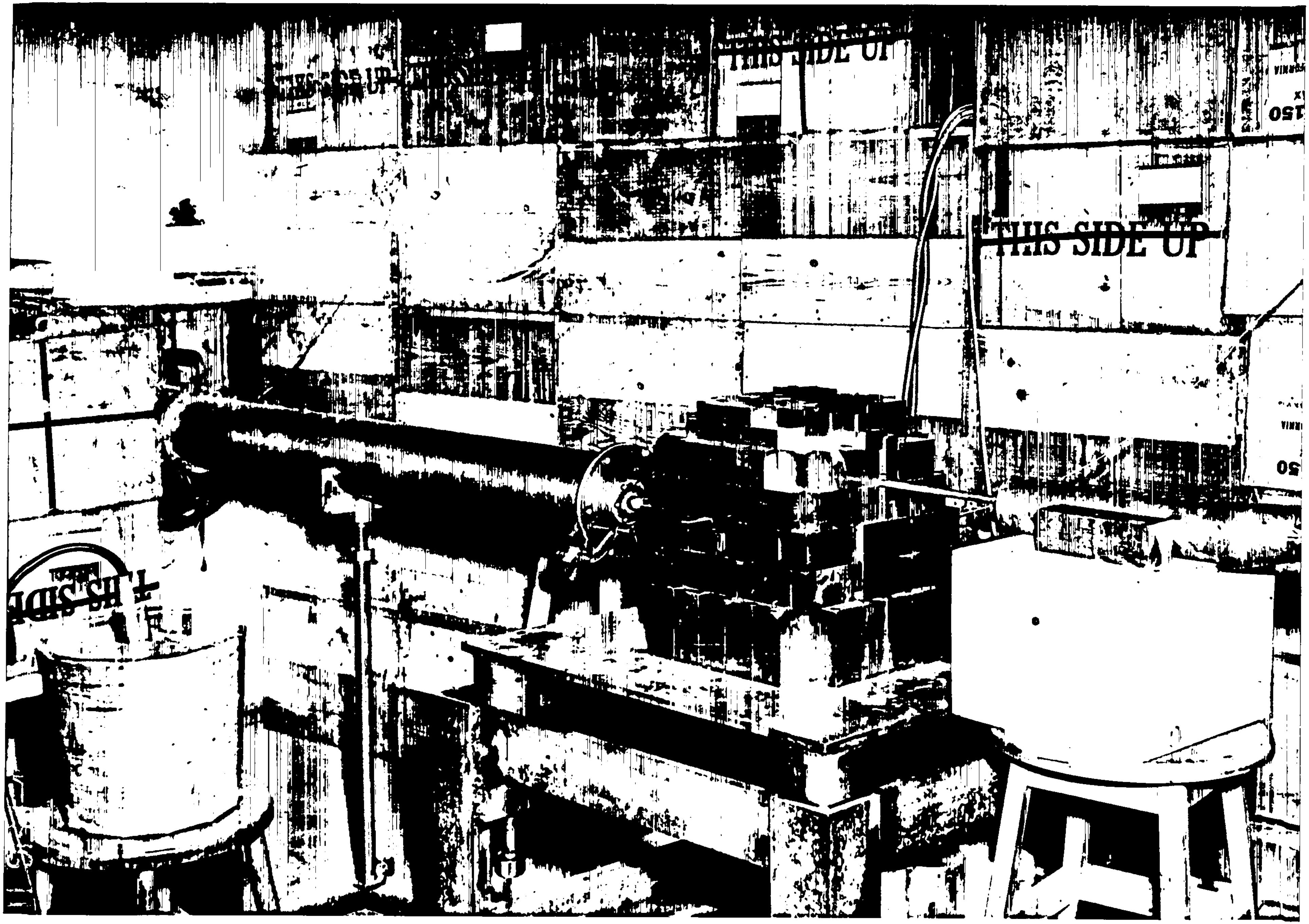

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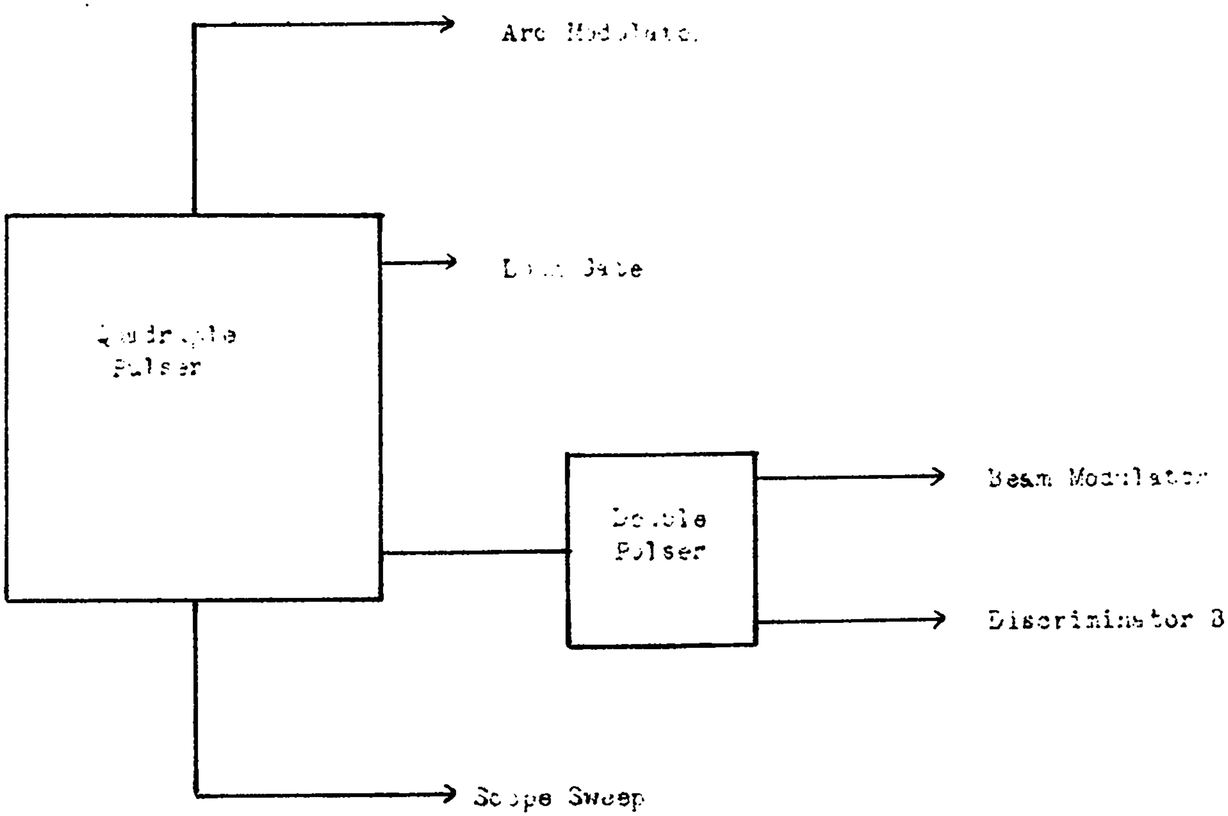

Fig. 12

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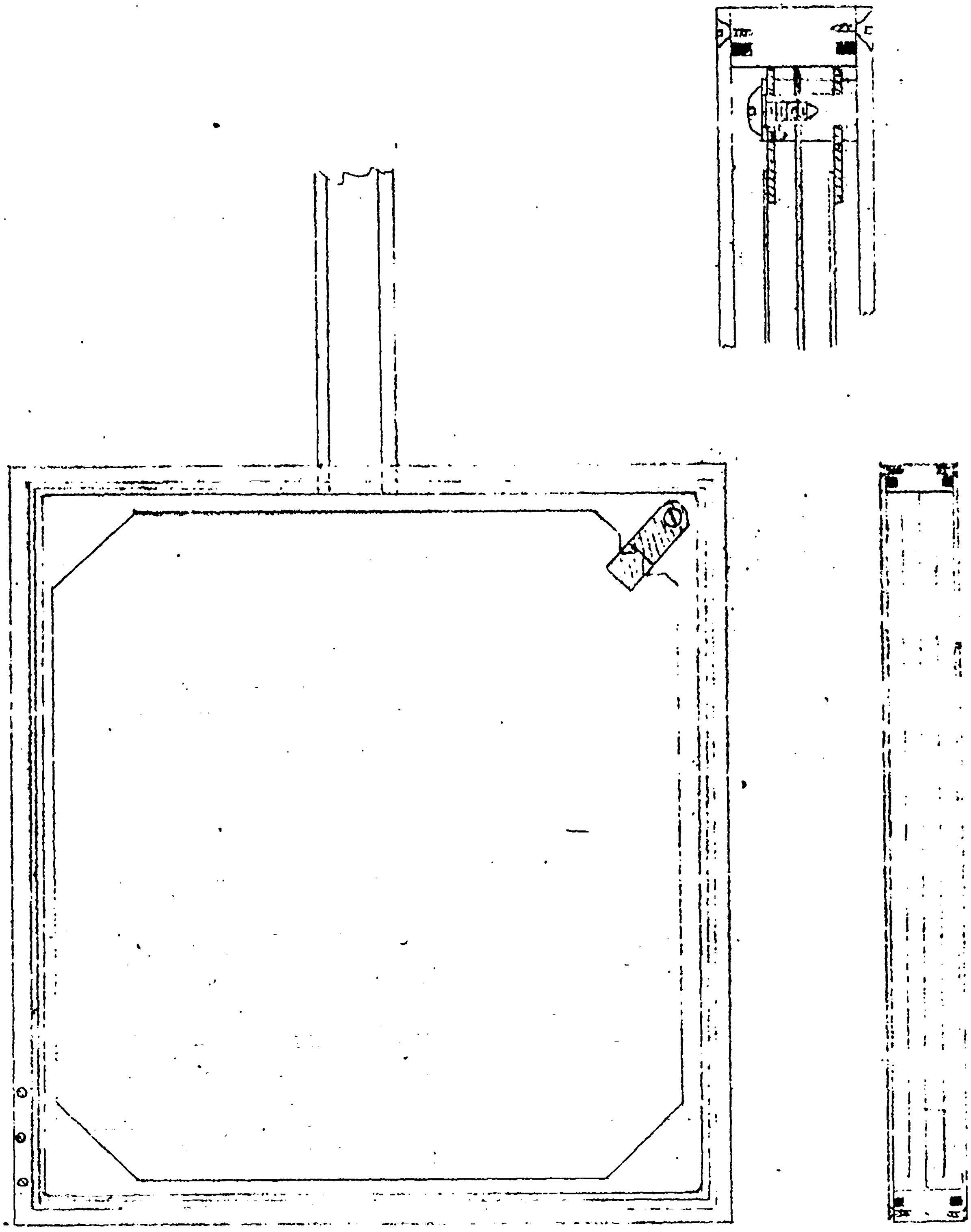

Fig. 13

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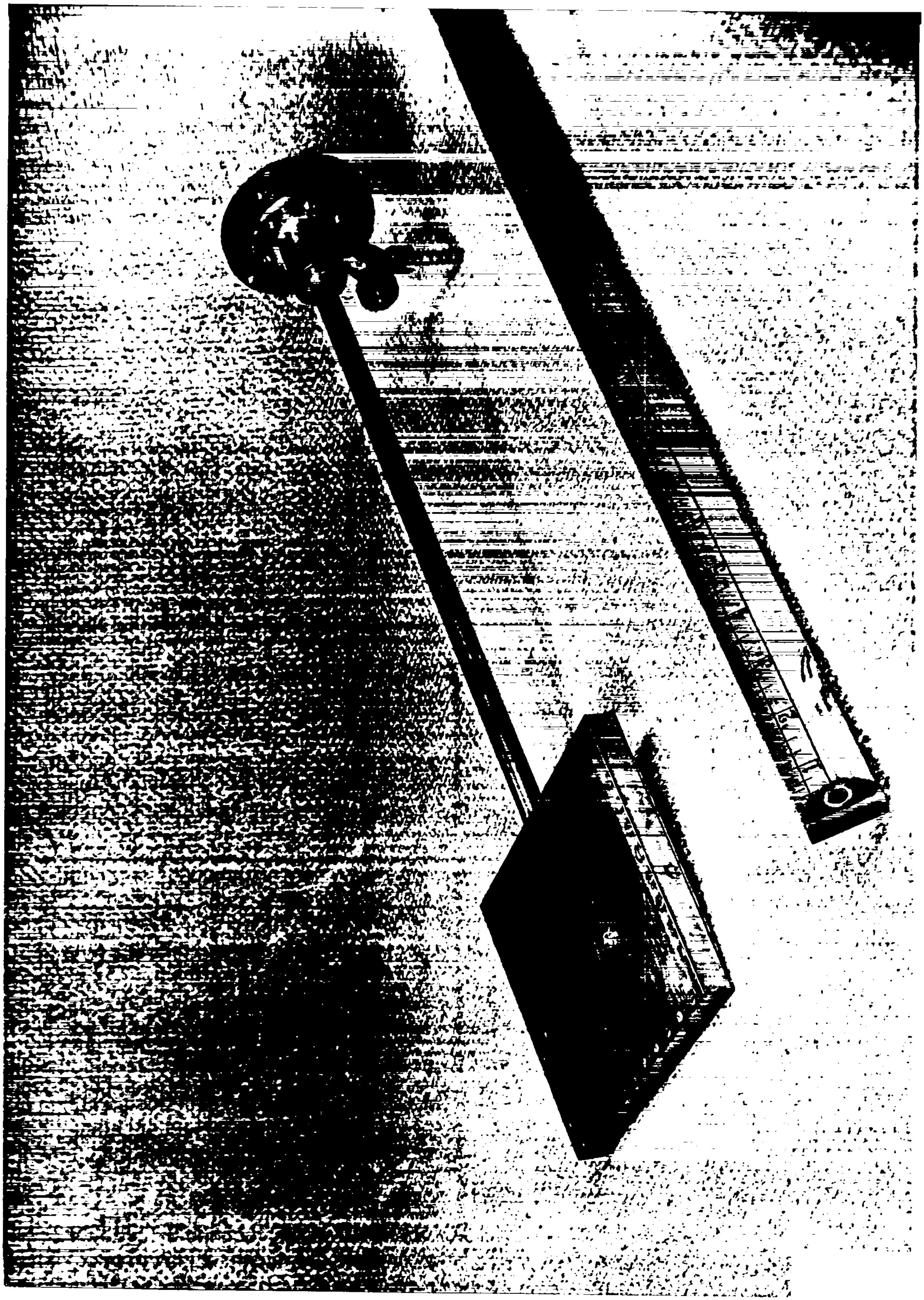

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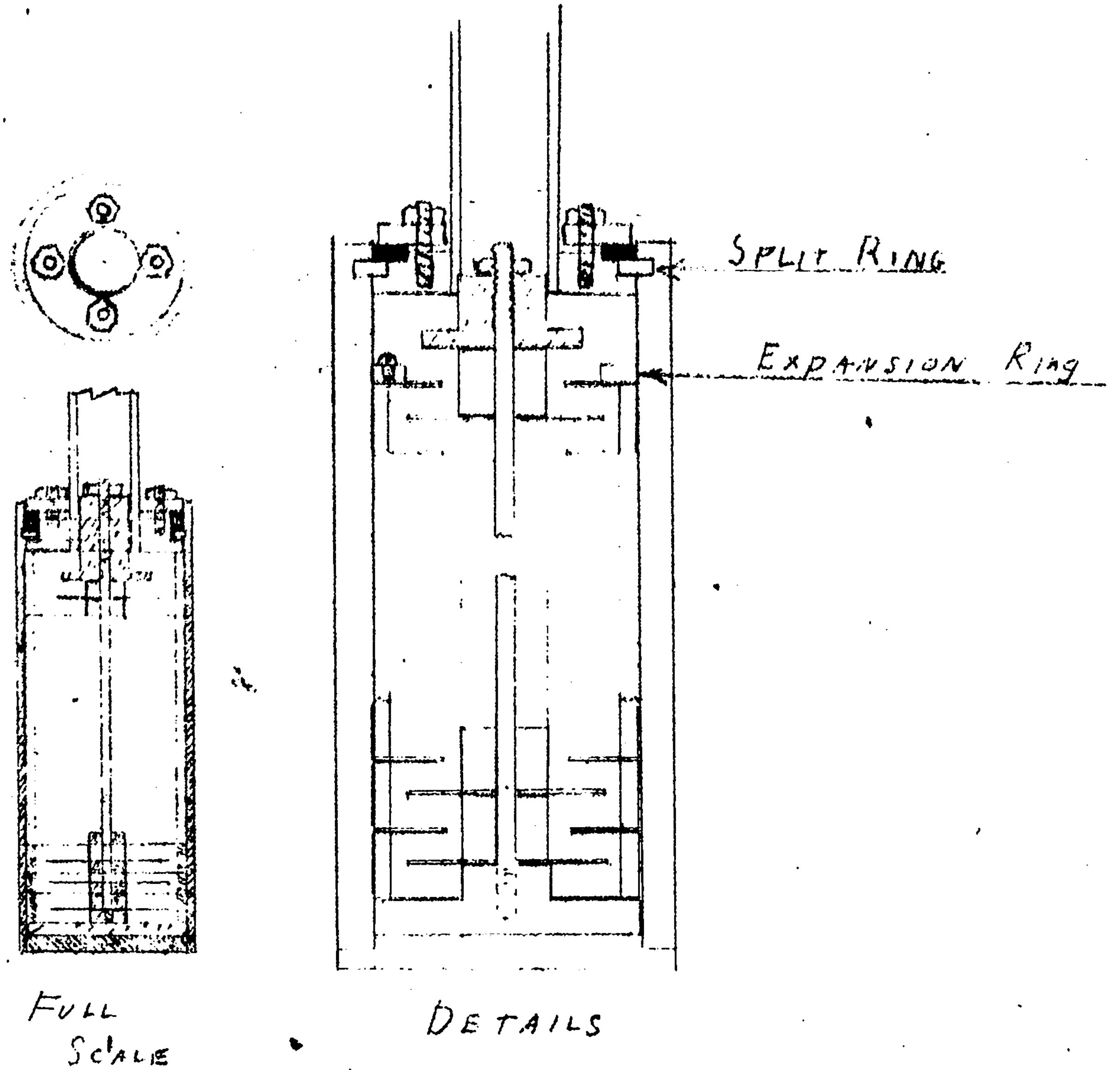

Fig. 15

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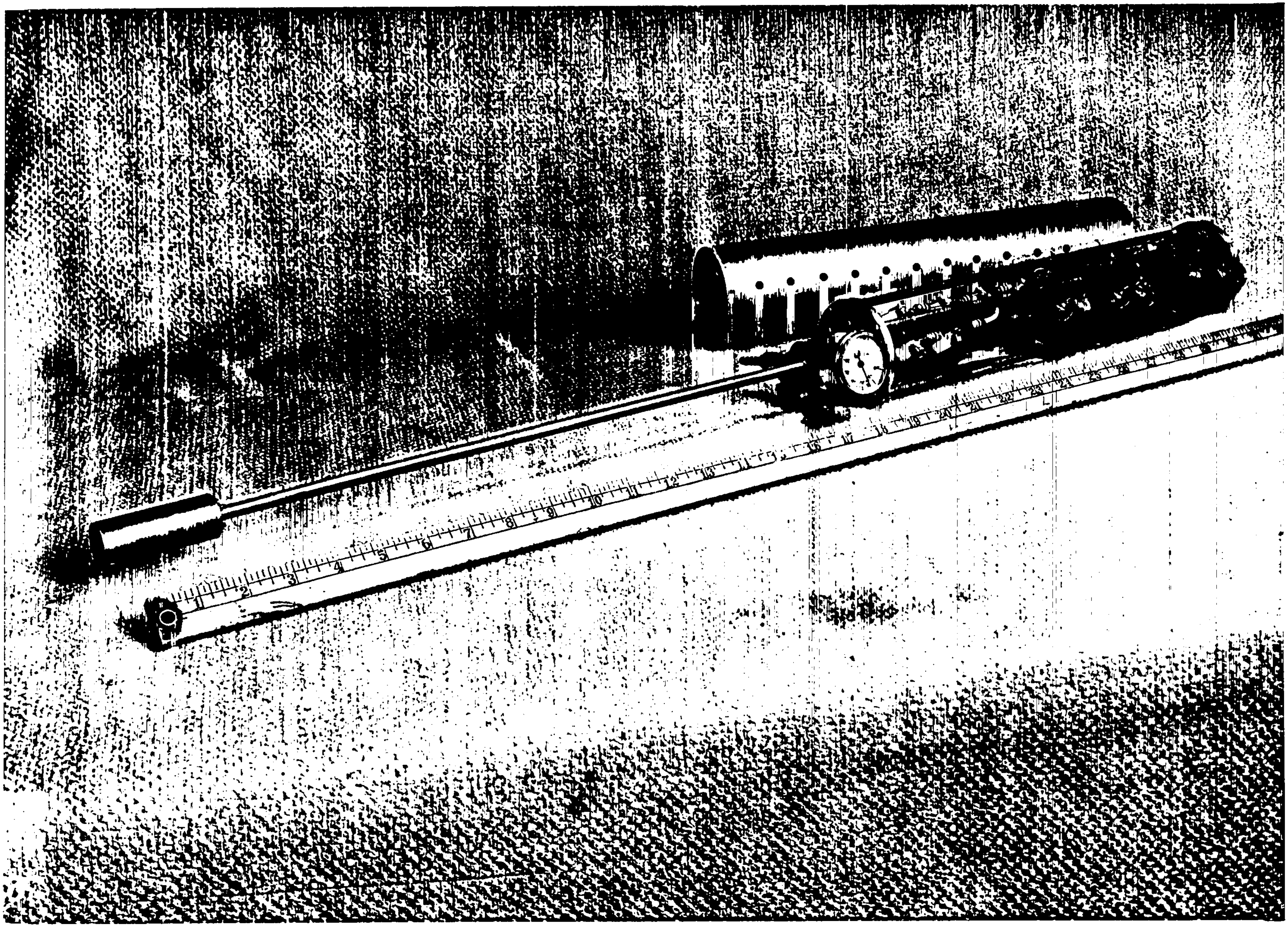

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