Der magnetische Inflektor (The magnetic inflector) by M. Swars.
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SLAC TRANS 11

THE MAGNETIC INFLECTOR

by M. Swars

A u t h o r ' s
E n g l i s h - l a n g u a g e   A b s t r a c t

The following article deals with producing a fast pulsed magnetic field for the DESY inflector. Hydrogen thyratrons were used to realize these pulses. Some problems of pulse measurement and amplitude control are described in detail.

C o n t e n t s

A) Basic considerations

The basic form of an inflector coil is the two-wire circuit, wherein an electron beam, guided between the wires of the current-carrying line, is deflected in the conductor plane. Since the homogeneous field-region inside such a single-wire arrangement (only conductors of one current direction being counted) is not very extensive, in practice we get more complicated arrangements, whose geometry guarantees a homogeneous field-region as large as possible in relation to the distance between conductors. In the present case (of the DESY synchrotron) a four-wire arrangement was found advantageous. With an injection energy of 40 mev and a coil length of some 1.70 m, for an inflection angle of 2.5°, we get with it an induction of 33 gauss, the current flowing through the conductors being 160 amp. Within a roughly circular cross-section having a diameter of 6 cm the field inhomogeneities amount to less than 1%. When the four wraps are connected in series, the coil inductance amounts to some 20 microhenries. Whereas the duration of the current-pulse leading edge is insignificant, when its crest lasts longer than one turn (1 microsecond), the trailing edge causes a gap in the ring filling. We are trying to keep this switch-off-time constant of the inflector coil as small as possible, by some intelligent economical means.

Translator's Note: From the standpoint of translation the subject dealt with here is sufficiently new that its (apparently not yet fully systematized) terminology is not yet fully findable in the bilingual and multilingual specialized dictionaries, and other reference books, in this field. It is always easy enough to report (in English) what the German "says," but what it "says" is very frequently not at all what it means. Where the translator has any twinge of doubt as to the most probable intended meaning, he explains the twinge in a Translator's Note (such as this).

For the above, for instance, the German is Abschaltzeitkonstante: "switch-off-time constant." In the English-language literature the translator has noticed the expression "pulse-off time," but has found no German equivalent, and does not know whether that is the intended meaning here.

If the conductor arrangement for the inflector coil has been decided, we still have to think about the face connections. Three possibilities present themselves:

a) all conductors in series, 4 wraps
b) every 2 conductors parallel, 2 wraps
c) all 4 conductors parallel, 1 wrap.

The field volume remaining constant, the inductance is proportional to the square of the number of wraps. In the first case we had 20 microhenries and a 160-amp coil current; in the second, 5 microhenries with 320 amp; and finally, with 4 conductors in parallel, 1.25 microhenry with 640 amp. Assuming a constant lead inductance of 1 microhenry in the pulse-generating circuit, and a time constant of L/R = 0.1 (microsecond), for the working voltages and pulse outputs in the discharge

Translator's Note: Translator's "working voltages" = (the German) Schaltspannungen = (literally) "switching voltages" or "circuit voltages."

circuit we get:

a) 210 Ω x 160 amp = 33.6 kv for 5.4×10^6 w

b) 60 Ω x 320 amp = 19.2 kv for 6.1 megawatts

c) 22.5 Ω x 640 amp = 14.4 kv for 9.2 megawatts.

In the case of a) problems of the circuit's dielectric strength play a role, whereas in the case of c) it is the currents to be overcome and the heating that pose problems---apart from the fact that in the first instance the coil's natural resonance would probably be too low to permit achievement of pulse steepnesses of 10^{-7} sec.

For the DESY inflector the compromise solution b) , with 2 wraps and 320 amp, has been selected. The coil's natural resonance of 8 mc still allows transmission of decay times of 10^{-7} sec. Here, of course, the magnetic field, as a factor of importance during the switch-off,

Translator's Note: Literal "switch-off" for the German Abschalten may mean "pulse-off." The translator is not sure.

is no longer strictly proportional to the current, whence, in addition to the simple current measurement, a direct field measurement is also advisable for observation of the inflector pulse (see Section E, Part 2).

B) Discharge circuit

In the designing, our first job is to select the proper switches for the 320 amp and 19 kv arrived at in Section A. Here we have the hydrogen thyratron, which has worked out so well in radar technology. True, it can be fired at a given instant, but unfortunately is not extinguishable with equal rapidity. Hence in thyratron circuits pulses can be generated only by means of transients. One well-known method of generating a rectangular pulse by means of a transient, with the aid of a chain-type delay line, always produces a certain ripple at the pulse crest in the presence of an inductive load, and therefore cannot be used, because a high amplitude-constancy of 1% (total) is required. We are left with the principle of using separate switches for the switching-on and switching-off of the current. The circuit for this is depicted in Figure 1. First the thyratron S_1 fires, and the capacitor discharge occurs via the inflector coil L_i and the

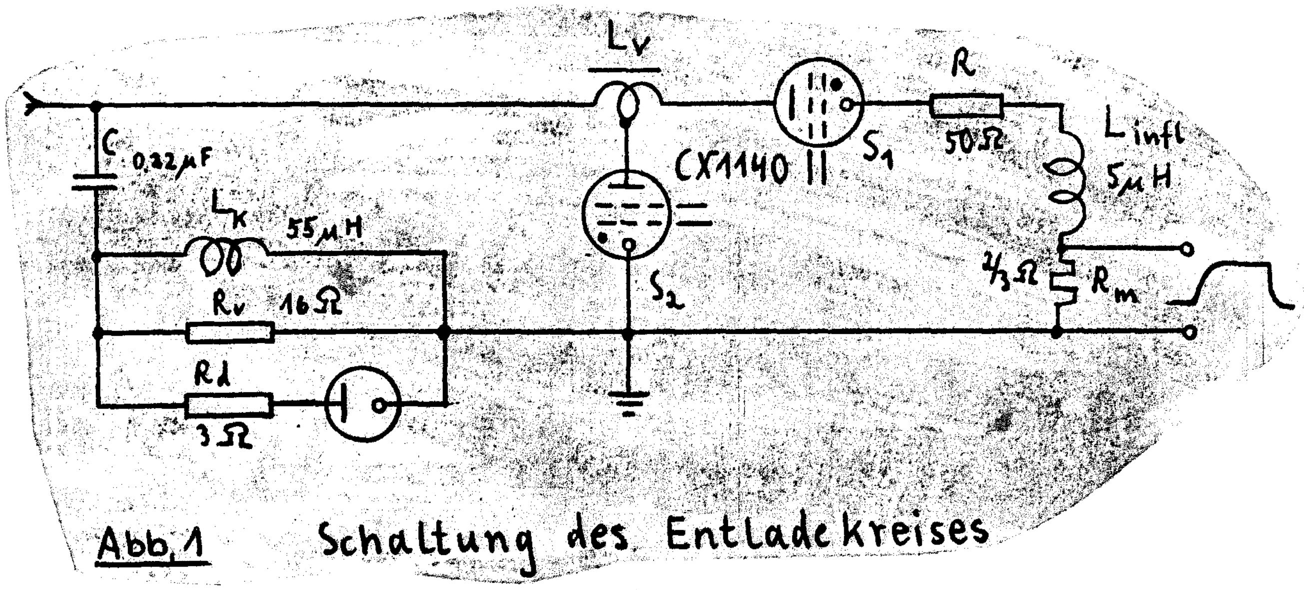

Figure 1: Diagram of discharge circuit.

resistors R and R_v . At the end of the pulse the thyratron S_2 is fired, and the branch with the inflector coil is therewith bridged, the capacitor discharging now only through R_v . Of course, the peak current in the switch-off circuit flowing through S_2 , being governed by the ratio R/R_v , at 1,000 amp (approximately) is much greater than the pulse current across S_1 . Here the dielectric strength of the thyratrons has to be 25 kv, because, added to the earlier-mentioned 19 kv at R , we now have the voltage drop at R_v . The thyratron tetrode used for this (the CX 1140) meets both the voltage and current requirements, and at the same time is a substitute type for the modulators of the linear accelerator.

The compensating coil L_k straightens the pulse crest (which

Translator's Note: The k in L_k is presumed to stand for Kompensation = compensating.

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otherwise, with a capacitor discharge, drops exponentially), and brings about the negative overshoot of the anode voltage, after the pulse, necessary for extinction of the thyratron. Naturally, to avoid misfires, the inverse voltage should not exceed several kv, for which purpose the damping resistor R_d and a diode are provided. From the compensation equation $L_k = R_v^2 \cdot C$ for $di/dt = 0$ at the pulse inception we get for L_k 55 microhenries.

Through a neat little trick, in the form of the peaking coil L_v, the decay steepness of the inflector pulse can be improved. As S_2

Translator's Note: The translator's "decay steepness" renders the German Abfallsteilheit (= literally "fall-off steepness"), which may mean instead (or as well) "trailing-edge steepness."

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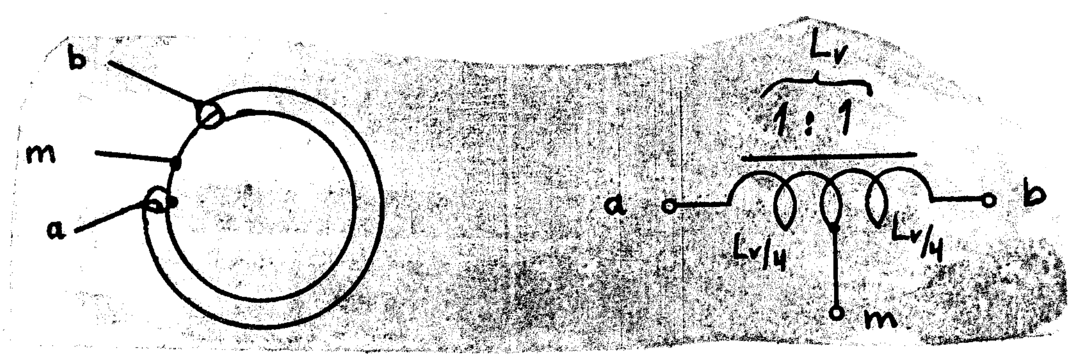
fires, through a 1:1 air-core transformer the reversed-polarity capacitor potential is incrementally coupled into the right-hand branch. Under the condition $L_v = 2L_i \times R_v/(R - R_v)$ this, theoretically, results in a halving of the switch-off-time constant existing without L_v .

Translator's Note: See Translator's Note re "switch-off"/"pulse-off" on page 4.

In this way we get a steepening of the trailing edge and a simultaneous leveling of the leading edge. The drop from 99% to 1% is thereby achieved in times of less than 0.2 microsecond (Figures 9 and 10). Decisive for the effectiveness of the method, however, are small inductance losses in the discharge circuit of the thyratron S_2 . The principle of the ultralow-leakage air-core transformer constructed specially for this purpose from a coaxial is shown in Figure 2.



mechanical design equivalent circuit

Figure 2: Principle of the peaking coil.

In the interest of completeness, be it added that, when L_k is an iron-core coil, operating on the pulse current in greater-curvature regions of the magnetization curve, the pulse crest can be linearized over a greater length of time than when air coils are used. The attainable pulse duration being the same, this makes possible a smaller capacitor and therewith a lowering of the installation's power requirement.

C) Charging circuit

After the discharge, which under steady-state pulse conditions lasts several microseconds, the capacitor needed as storage element for the pulsed output of some 10^7 watts has to be brought back to the old voltage during the 20-millisecond interval before the next discharge. This is done by means of an AC charging process, the principle of which is shown in Figure 3. There the LC circuit is tuned to the power

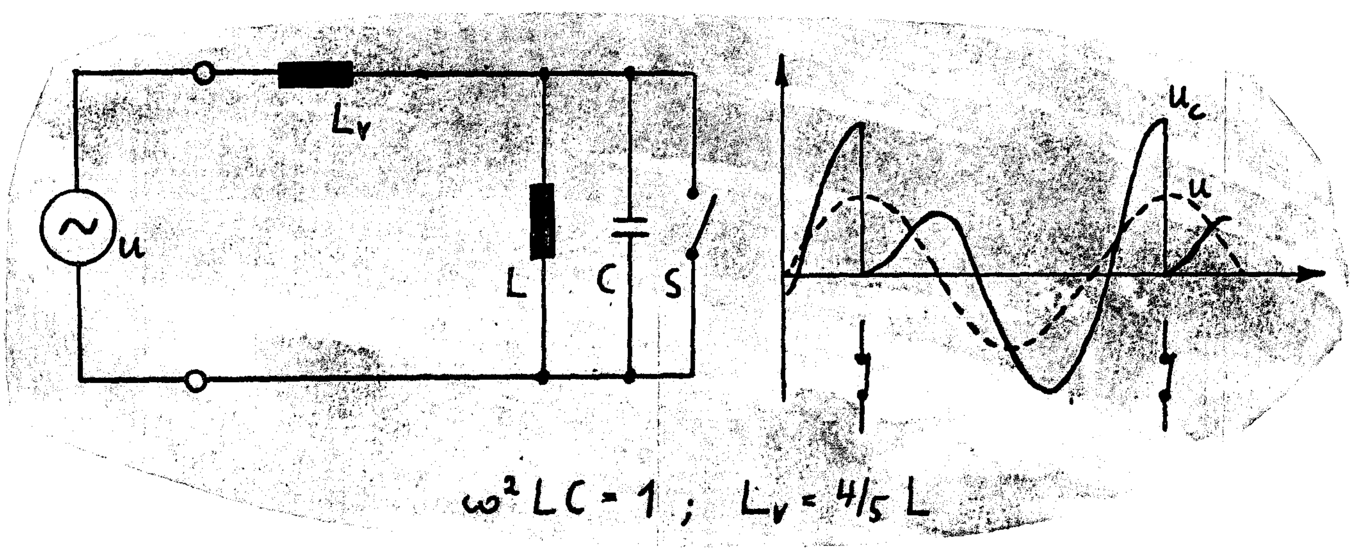


Figure 3: AC charging process.

frequency ($\omega^2 LC = 1$) so that, with the switch open and the losses neglected, no current is taken from the network through L_v. The periodic discharge through the thyratrons occurs at the crest of the line-supply voltage, symbolized by the switch, whose closing time is small in comparison to the length of a period. In this way, at the instant of firing, the system's original state is perturbed by a negative voltage jump at the level of the line-supply crest voltage $\hat{U}$ every time C is fully discharged. This results in the superposing of (?) a cosine transient $-\hat{U} \cos\omega_E t$ on (?) the natural frequency of the system

$$\omega_E = \frac{1}{\sqrt{\frac{LL_v}{L+L_v} \cdot C}} > \omega = \frac{1}{\sqrt{LC}} ,$$

determined by the parallel connection of L and L_v. L_v is

Translator's Note: The questioned "of" and questioned "on" (put in by the translator, because they seemed to make some sense to him) both stand in the German as <u>mit</u> (= "with"), which even in German seems (to the translator) not to make much sense.

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dimensioned such that $\omega_E = \frac{3}{2}\omega$. Then at the next instant of firing, after three half-periods, the amplitude of the transient has its positive crest value $+\hat{U}$. Since in the unperturbed state we also had $U_c = \hat{U}$ at the instant of firing, superposing the two phenomena results in a resonance rise to double the crest value of the line-supply voltage. For calculation of L_v we have

$$\omega_E^2 = \frac{L + L_v}{L L_v C} = \left(\frac{3}{2}\omega\right)^2 = \frac{9}{4LC}$$

$$1 + \frac{L}{L_v} = \frac{9}{4} ; \quad L_v = \frac{4}{5} L$$

The capacitor voltage was

$$U_C = \hat{U} \left(\cos\omega t - \cos \frac{3}{2}\omega t\right) \text{ für } 0 < \omega t < 2\pi \quad .$$

Translator's Note: (German) <u>für</u> = (English) for.

With $$i = \frac{\hat{U}}{\omega L} \left(\frac{5}{6} \sin \frac{3}{2}\omega t - \frac{5}{9\pi}\right) \text{ für } 0 < \omega t < 2\pi \ ,$$

notwithstanding the formal presence of the DC term, the current obtained from the network is pure AC, since integration of the AC term over the firing interval of 1½ periods yields an equally large positive DC component. The negative overshoot of the capacitor voltage amounts to 82% of the crest value $2\hat{U}$.

In practice the capacitor is placed at the secondary winding of a 1:40 high-voltage transformer whose primary inductance L is brought to resonance with the power frequency by means of an adjustable air-gap. The choke L_v stays on the low-voltage side. The capacitor C = 0.22

microfarad, charged to 25 kv, has a power of 69 watts. The active

Translator's Note: The author here apparently pluralizes the German abbreviation for "watt/s/," which is W, making it Ws (which, on its face, could be taken to mean "watt-second/s/."). But the translator infers from the context that the intended meaning is "watts."

power flowing in the discharge circuit is fifty times that amount, i.e., 3.4 kw---if we disregard the heating and thyratron-starter current. With an efficiency of 78% and power factor (no cos φ) of 0.80, the charging circuit takes from the 220-volt network 4.4 kw and 25 amp.

With a weight/power ratio of 50 kg/kw the high-voltage transformer turned out much larger than normal transformers having the same power, because a given primary inductance is achievable only with weakly saturated iron. With too great a magnetic load, the pulse amplitude---owing to nonlinear effects---would oscillate between two different values, to the rhythm of half the power frequency, rendering useful operation impossible.

D) Generation of firing pulses

With the thyratron tetrode CX 1140, in order to fire the plate circuit, we produce first a preionization by firing the grid adjacent to the cathode and, 0.75 microsecond later, triggering the second grid with pulses of 400-volt no-load amplitude. About 0.2 microsecond after the last trigger pulse we get the main discharge, which builds up in about 25 nanoseconds, so that between the triggering and the anode current 1 microsecond elapses. The current yield of the trigger wiring is 0.9 amp on short circuit. As compared with corresponding thyratron triodes, which all have to be fired with low-power hydrogen thyratrons, this small firing current is an obvious advantage of the tetrode arrangement. The charging of the firing electrodes occurs---without insertion of a pulse transformer---directly from a cathode-follower output-stage fitted with the EL 152 pentode. Here the no-load rise steepness of the trigger pulses is 3,000 V/microsec.

The fact that the firing is done with the power frequency is

Translator's Note: (Translator's) "power frequency" = (German) Netzfrequenz = (literally) "network frequency"---also variously called (in English) "line frequency" and/or "mains frequency."

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utilized to cut down the plate dissipation in the electronic system. The otherwise customary DC supply to the tubes being dispensed with, here the anode current is fed directly from the secondary winding of the power transformer with alternating voltage. Since, on the one hand, anode current can flow only in the positive half-periods of the power frequency, while, on the other hand, firing occurs at the crest of a sine half-wave, each of these circumstances results in a power saving by a factor of ½. Hence, with this mode of operation, the plate dissipation is only one quarter of what it is with a DC anode current.

During the inflector pulse the cathode of thyratron S_1, also the electronic triggering system direct-coupled to it, take on a high-voltage potential. This necessitated a high-breakdown-strength galvanic separation of the firing circuit from the leads. Hence the line-current supply to S_1 occurs via an inserted insulating transformer, while the control pulse for the electronic system, lasting only 3 microseconds, is coupled in through a corresponding air-core transformer with only a few wraps. The control pulses for thyratrons S_1 and S_2 are derived from the main trigger pulse of the linear accelerator via two time-delay elements (not further described here), the adjustable delay time of the second element defining the length of the inflector pulse.

E) Measurement devices

1) Current Measurement

In currently common practice of unbalanced HF engineering with coaxial cables the trivial and at the same time precise method of measuring the current as a voltage drop at a resistance assumes a measuring resistor with one side grounded, if acceptable results are to be achieved. It was necessary, therefore, to ground the inflector coil through the measuring resistor, so that the switch-on thyratron behind it had to be placed at a voltagewise "hot" spot. The resistance consists of a cage-type parallel circuit of several semiconductor resistors. One must keep in mind that with values below $10\,\Omega$ the self-inductance can start to interfere at high frequencies. That is why we have here 33 resistors each at $22\,\Omega$ equal to $2/3\,\Omega$ in parallel, which results nevertheless in a measuring voltage of 200 V.

2) Field Measurement - Integration Amplifier

In contrast to low-frequency measuring techniques, when an inductive signal is received by means of measuring coils in the inflector field, capacitive stray couplings from neighboring live conductors become a problem. The classical method of using a balanced measuring coil with a push-pull amplifier, wherein the interfering component occurs in push-push, and is thus knocked out, was not employed here, because with a magnetic field of over 30 gauss a readily shieldable single wrap will supply an adequate measuring voltage. An unbalanced measuring probe with a shielded wrap is relatively simple to design (as per Figure 4) by connecting the inner conductor of an open-end coaxial cable to its sheath. Here the inductive reactance of the loop, at the highest occurring frequencies, must still be small compared to the characteristic impedance of the cable.

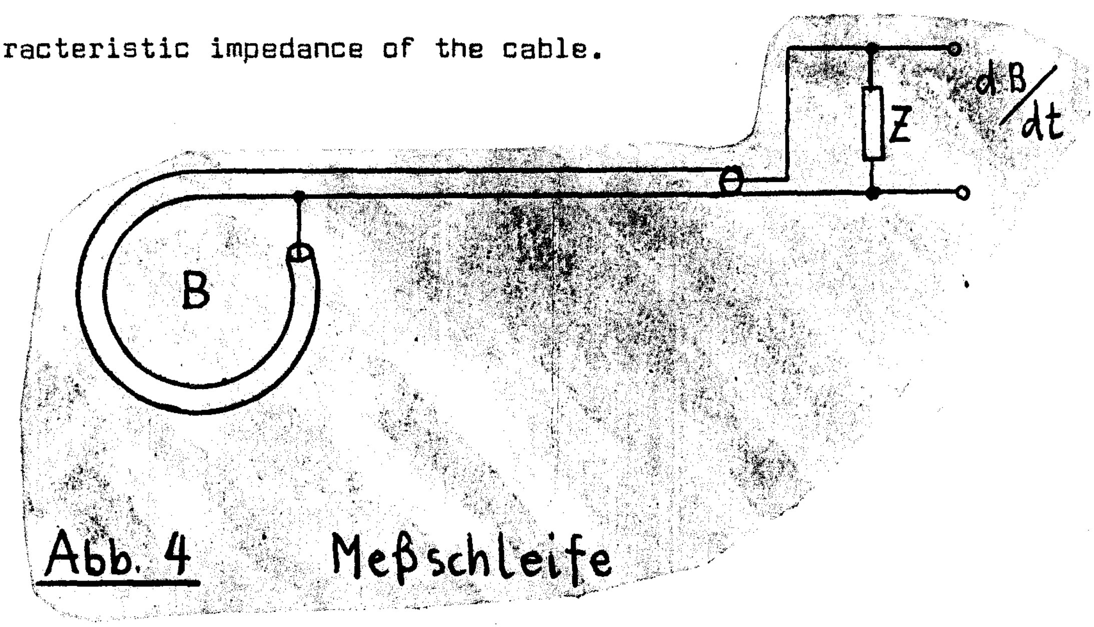
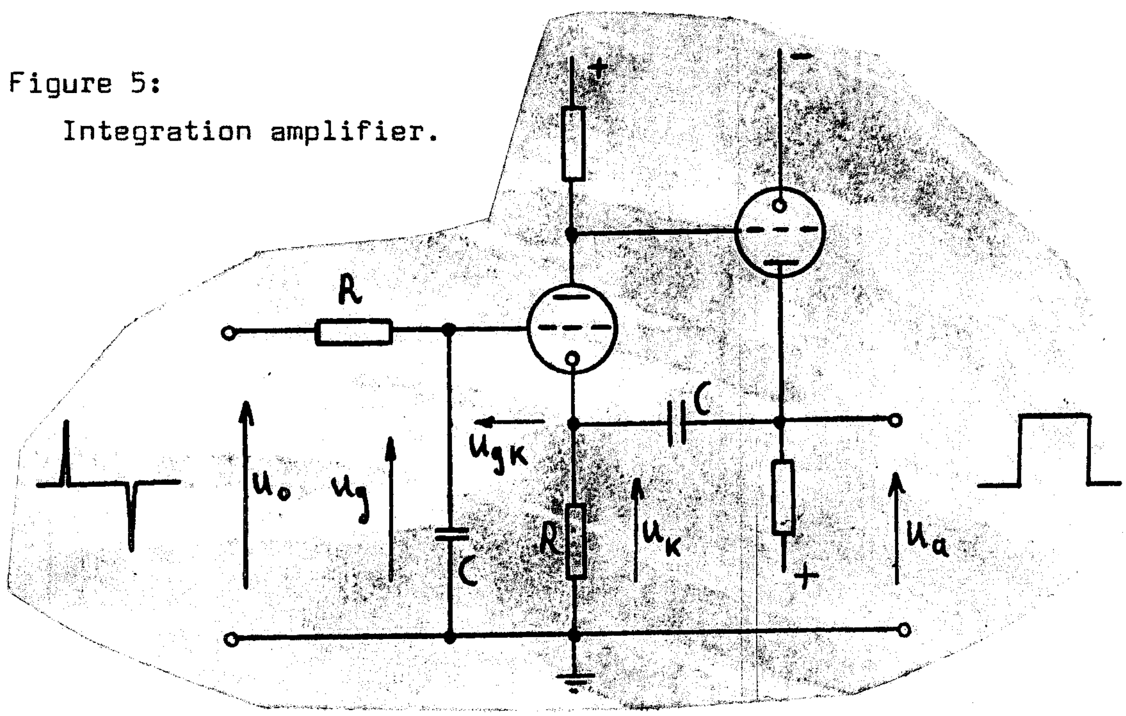


Figure 4: Measuring loop.

Of special importance is the distortionless reconversion of the measured signal dB/dt into the field component B through an integrator. In contrast to the practice (common in low-frequency applications) of using 180° phase-shifting integration amplifiers, we developed here a method of resolving the frequency spectrum into component-frequency ranges, wherein the input and output voltages are in the same phase position. As seen in Figure 5, connected in series to the amplifier itself is a low-pass element having the frequency response $U_g = U_o/(1 + j\omega CR)$. In the current-source equivalent circuit of the amplifier part that follows, with the transconductance S, the impressed current is $i = S \cdot U_{gk} = S(U_g - i \cdot R)$ or

Figure 5:
Integration amplifier.



$i = U_g/(R + 1/s) = U_k/R$. In the ideal case, with $S = \infty$, we get

Translator's Note: Not knowing whether S may be a standard international symbol, the translator points out that the German for "transconductance" is Steilheit (= literally "steepness").

$U_k = U_g$. We then have

$$U_a = U_g + i/j\omega C = U_g(1 + 1/j\omega CR)$$
$$= U_g(1 + j\omega CR)/j\omega CR .$$

From that we readily see that $\lim_{\omega \to \infty} U_a = U_g$.

Translator's Note: The translator is extremely reluctant to "monkey" with the author's notation---even when, as back on page 7, the subscript k (for Kompensation) seemed safely renderable with a c (for "compensating").

Hence in the high-frequency range, especially critical for electronic circuits, the amplifier component degenerates into a cathode follower. This is advantageous, since the latter circuit is reputed to have optimal transmission characteristics, particularly for high frequencies. Since in the forming of the product of the individual frequency responses the factor $(1 + j\omega RC)$ stands out, the over-all frequency response is simply $U_a = U_o/j\omega CR$, RC being the amplifier integration-constant.

Translator's Note: The German says literally that "...the factor $(1 + j\omega RC)$ lifts itself out," this reflexive-verb idiom usually meaning "...stands out" and/or "...is prominent," but there is no law preventing it from meaning (instead) "...is eliminated." The translator relies upon the reader to make the correct choice, and to know (since the translator does not know) why RC becomes CR.

The tube amplifier provides for integration of the low frequencies; the frequencies above $\omega = 1/RC$ are taken care of by the passive element. With this circuit design our integration constant comes out 0.13 microsecond, for a frequency overlap of 1.2 mc.

Translator's Note: The German says "overlap frequency."

F) Amplitude control

1) Principle

The design of the control system is governed by the degree of precision required, and by the factors that influence the pulse amplitude. The inflector is supposed to operate in the region of from 30 to 40 gauss with an amplitude constancy of $\pm$ 0.1%, insofar as possible. Without stabilization this constancy would be thwarted by the fluctuations of the line-supply voltage and variations in the temperature of the solid-carbon resistors in the discharge circuit. Owing to the high temperature coefficient of $-5 \times 10^{-4}(1/^{o}C)$ the latter reach their operating temperature at a resistance some 7% lower than in the cold state. Current is supplied to the linear accelerator and inflector through a separate generator, whose mass inertia screens out momentary fluctuations of the line-supply voltage, leaving to the control system the interception of only slow voltage-changes.

In normal control systems the control-loop time-constant---unwanted but necessary for stability reasons---has to be larger and larger, the greater the required precision. However, in the present case (of a pulsed system) this conflict between precision and stability can be circumvented with a storage capacitor, for in this special case it is possible, in a high-precision control system, to take care of rapid line-voltage fluctuations too. This is made possible by procedures which amount to separating the charging circuit from the discharge circuit after attainment of the desired capacitor voltage. They necessitate circuitry modifications on the high-voltage side, and are therefore relatively expensive. But if we dispense with the control of momentary fluctuations, we can get by with much less expensive modifications on the low-voltage side. Since, as mentioned earlier, we need expect here only slow fluctuations of the line-supply voltage, the inflector's pulse amplitude is regulated by the latter method through a final-control element intervening on the undervoltage side.

This element is controlled by a slowly variable direct-voltage potential (see Section F, Part 3). For this the measurand at the control-system output, as an inflector pulse of some 2 microseconds duration, must first be suitably converted (Section F, Part 2). The desired pulse amplitude is stipulated as the prescribed value through a potentiometer, and is compared with the measured pulse height. The thus determined deviation, converted into a direct voltage, guides the final-control element, whereupon the control loop closes. The still necessary indication as to whether the amplitude agrees with the stipulated value is afforded by three control lights, which evaluate the deviation (Section F, Part 4).

2) Measurand Conversion

The design of the measuring unit is governed by the amplitude and duty factor of the impinging pulses. When the current is measured through the measuring resistor and a cable line, we get at the end a voltage of about 100 V with a duty factor of 10^{-4}. In a suppressed-zero push-pull amplifier (reference stage, Figure 6) these pulses are compared with a fixed reference direct-voltage. The measuring resistor

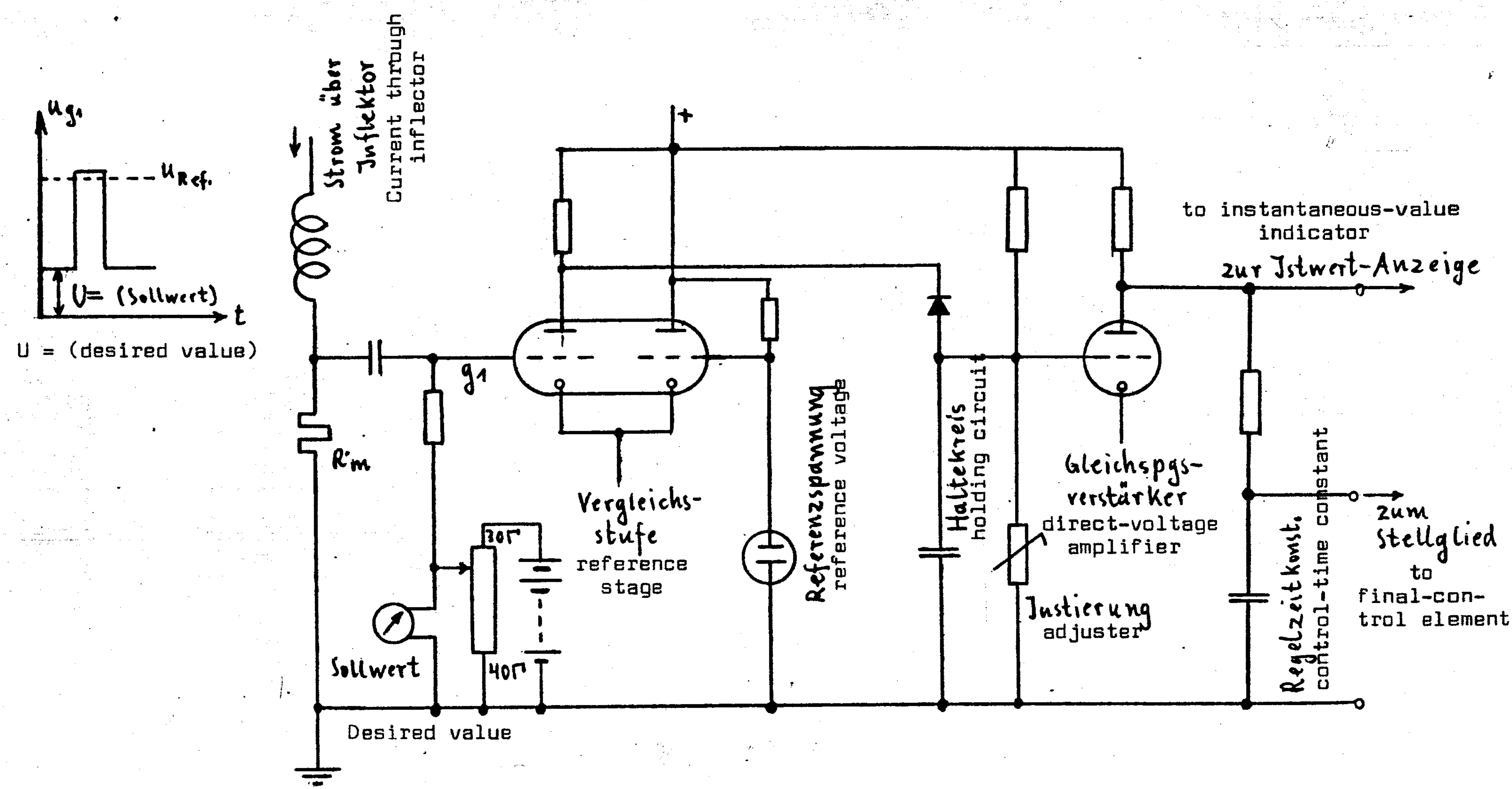


Abb. 6 Meßwertumformung (Prinzip)

Figure 6: Measurand conversion (principle).

is so adjusted that, when set at the maximum possible desired value of 40 gauss, the pulse amplitude will exactly equal the reference voltage, i.e., will equal the operating voltage of an ordinary industrial neon stabilizer (84 V). Then, in steady-state operation, we get during the inflector pulse a somewhat larger potential at the left-hand control grid than at the right-hand reference grid, and the anode-current pulse pulses the holding circuit, which is in the form

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Translator's Note: The translator uses the verb "to pulse" to express his understanding here of the German verb anstoßen, which translates literally as "to push," "to strike against," "to impinge upon," etc.

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of a point-contact rectifier whose control resolution is adjusted approximately to equality of potential of the pulse crest with the reference voltage. Hence the point-contact rectifier converts the deviation into a direct voltage, its response-time constant (at 0.3 microsecond) being smaller than the pulse duration, its discharge-time constant (at some 150 milliseconds) being large in comparison to the period of the power frequency. This extreme time-constant ratio of 5×10^5 was achieved by cascade connection of two holding circuits. The control voltage, then amplified by a factor of 15, is directed to the instantaneous-value indicator (Section F, Part 4), and in parallel to it is fed through a low-pass element (with a time constant of 7 seconds) into the final-control element. According to a rule of thumb, the built-in time constant must be larger than the product of the control ratio times the period between pulses, if hunting is

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Translator's Note: Where the translator says "hunting," the German says "control oscillations."

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to be avoided. Since here, with 12% network fluctuations, we measured an 0.1% amplitude variation, we calculate $T = 120 \times 20$ ms $= 2.4$ sec as self-excitation limit.

The reference stage is designed to respond only to a pulse crest value constant to within the deviation, wherein, with a capacitive coupling and the direct-voltage zero at the left-hand grid, we then get the total reference voltage as the pulse amplitude. Since with the small duty factor of 10^{-4} an almost exact adding of the pulse-crest voltage and direct voltage occurs, when a positive grid-bias is applied, we get an inflector pulse whose amplitude, compared to the full value, is diminished by the amount of the injected direct voltage. This is utilized for the desired-value adjustment. The desired value can be read off a line-scale instrument. 40 gauss correspond to its zero reading, 30 gauss to its full-scale reading.

3) Final-control Element

By intervening on the low-voltage side of the charging circuit (C) this control device influences the voltage of the charging capacitor at the instant of firing, therewith affecting the inflector's pulse amplitude. Dispensing with automatic control, one can adjust the amplitude manually through the final-control element. Figures 7 and 8 illustrate the operating principle. The overlap of the control voltage with an auxiliary alternating voltage leading by some 60° the line-supply voltage arrives at the input of a time-base stage something on the

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Translator's Note: "Time-base stage" is the translator's final weary guess as to the intended meaning of the German <u>Kippstufe</u>. The <u>-stufe</u> part means "stage;" there is nothing to worry about there. <u>Kipp-</u> is the stem of the German verb <u>kippen</u>, an everyday little verb meaning "tilt," "tip over," "upset," "incline," "flip over," etc. In electronics dictionaries <u>Kipp</u>- is variously rendered as "relaxation /scanning/," "sweep (or) relaxation /frequency/," "sweep /generator/," "trigger /relay/," "time-base /circuit/," etc., etc., etc.

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order of a Schmitt trigger circuit. This has a fixed sweep potential;

Translator's Note: Same problem. "Sweep potential" is the translator's guess-rendering of the German <u>Kippotential</u>.

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as indicated in Figure 8, the greater the control voltage, the sooner it is reached. When the stage flips over, a pulse transformer between

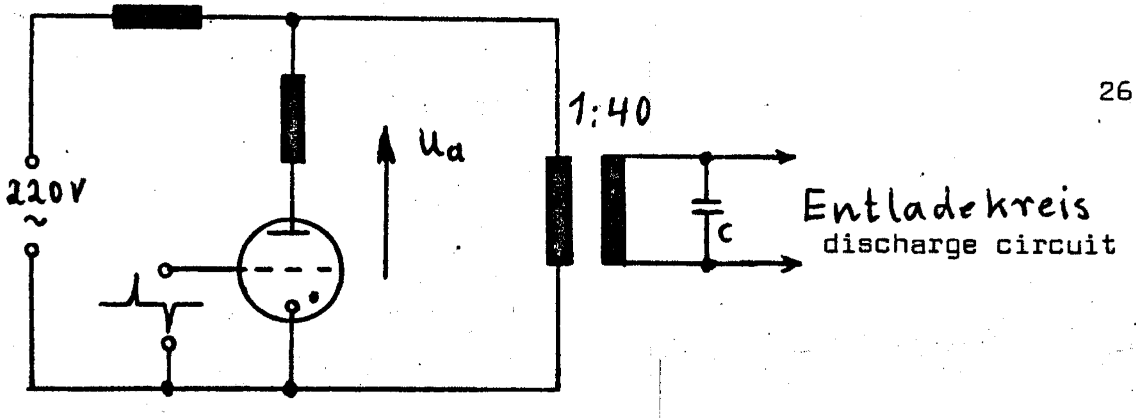
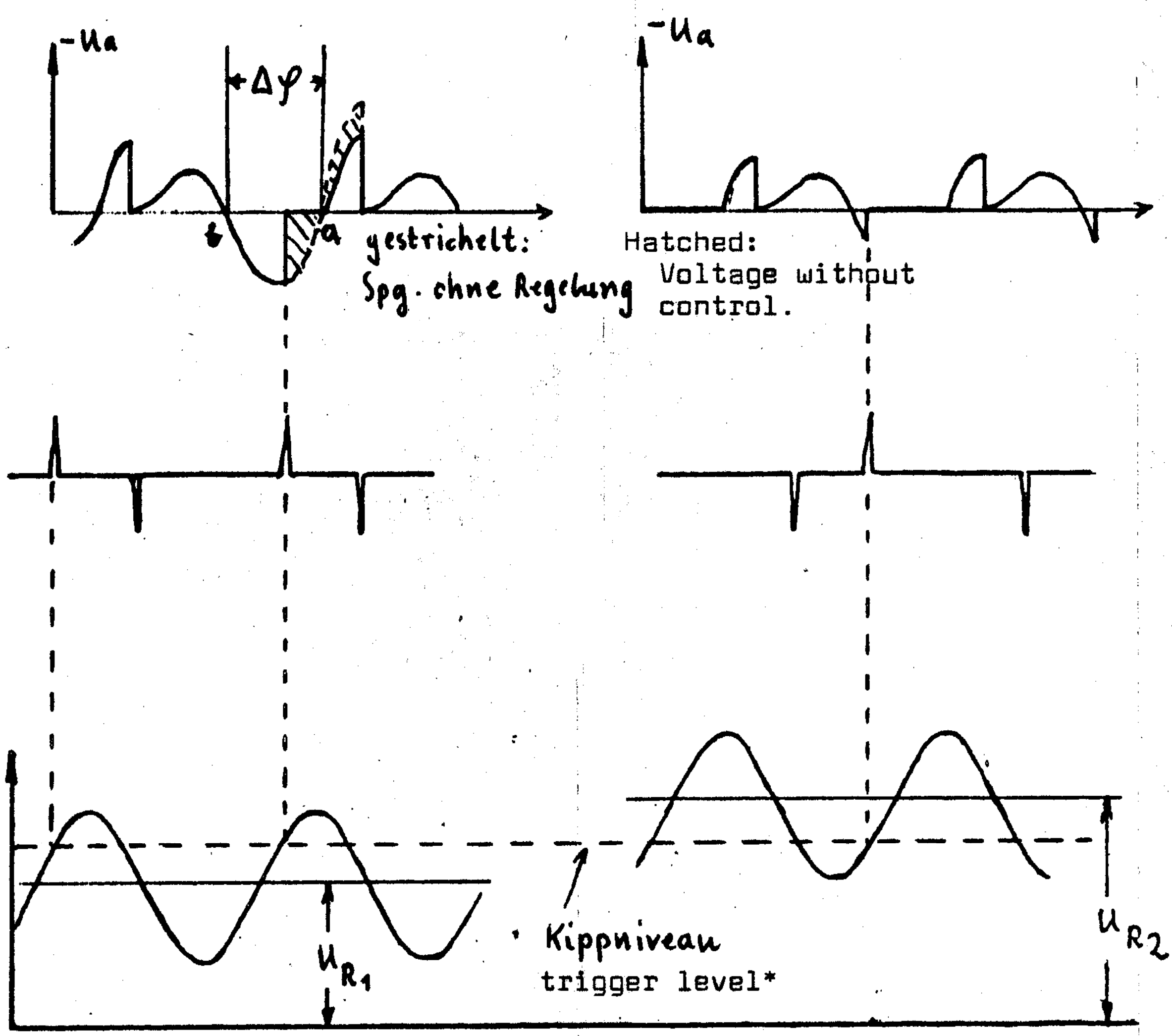


Abb.7 Ladekreis mit Stellthyratron

Figure 7: charging circuit with control thyratron



kleine Regelspannung
großer Puls
Small control-voltage
Large pulse

Abb. 8a

Figure 8a:

große Regelspannung
Kleiner Puls
Large control-voltage
Small pulse

Abb. 8b

Figure 8b:

* Translator's Note: See Translator's Notes on page 25 re Kipp-.

it and the control thyratron transmits pulse spikes to the thyratron

Translator's Note: "Pulse spikes" is the translator's guess rendering of the author's "needle pulses."

grid. With simultaneous presence of a positive anode voltage the positive grid pulses fire the thyratron; the negative peaks are meaningless. Through this firing-angle control the hatched piece is cut out of the voltage surface in Figure 8a. The result of this is that also the voltage jump at the end of the period, which indicates the discharge of the capacitor through the inflector, becomes smaller than without the firing of the control thyratron. The smallest inflector pulse is obtained when the firing occurs at point b . This operating point is unstable, however, because, when the firing pulse is advanced still further, the control suddenly ceases, for then the control thyratron's anode voltage is no longer positive at the instant of firing, hence can no longer fire the tube. Limiting the amplitude of the control voltage precludes this possibility.

The control thyratron's plate choke is so dimensioned that the inflector pulse can be down-regulated a maximum of 30%. Serving as thyratron are two inert-gas thyratrons PL 5545 connected in parallel through a saturable reactor (not shown here). The effective current-

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Translator's Note: "Saturable reactor" is the translator's best guess-rendering (arrived at by working from German through Russian into English) of the German Saugdrossel, which translates literally as "suction choke," and in various German-to-English technical dictionaries is rendered as "drainage coil," "series reactor," and "interphase transformer." But in the translator's SHORT GERMAN-RUSSIAN DICTIONARY OF AUTOMATION, REMOTE CONTROL, TELEMETRY, AND TELECOMMUNICATIONS (Moscow 1962) Saugdrossel = = Sättigungsdrossel ("saturating choke"). From this (via Sarbacher's ENCYCLOPEDIC DICTIONARY OF ELECTRONICS AND NUCLEAR ENGINEERING) the translator arrives at "saturable reactor."

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consumption of these, in the down-regulated state, is 2 × 7 amp. Here the total current consumption from the 220-volt network is 16 amp, as compared with 24 amp in the uncontrolled state.

4) Instantaneous-value Indication

Through observation of the control voltage, which represents the deviation of the inflector pulse from the desired value---the deviation being converted into a direct-current value and amplified---the agreement with the desired value can be deduced. For a large control-voltage (according to Section F, Part 3) the auxiliary-thyratron firing must be advanced, i.e., we need a small inflector-pulse amplitude, whereas for small control-voltages we need large amplitudes. When the control voltage drops below the value corresponding to the firing angle of point a in Figure 8a, we get the full uncontrolled amplitude value, which, even when the control voltage is diminished further, can increase no further. Conversely, when the control voltage corresponding to the firing angle of b is exceeded, the amplitude can be reduced no further; it remains fully down-regulated. So, with an 0.3% variation of the crest value "pulse + grid bias" in the reference stage, we span here the entire control range $\Delta\varphi$ (?) of the final-control element, which corresponds to a control-voltage variation of some 15 V. A pulse falling within this control-voltage range is defined as agreeing with the desired value, and is indicated by a green light. Smaller control-voltages are indicated by a white light (amplitude too small, control element uncontrolled), larger control-voltages by a red light (amplitude too large, control element overmodulated).

As a check on the functioning of this device the operating switch has three test steps, which, with the inflector pulse off, deliver to the input of the reference stage a chopper-generated test pulse with three amplitudes, each differing by 0.3%. If the apparatus is functioning

Translator's Note: Differing from what, is not stated.

properly, the three control lights light up one after the other.

need a preliminary warm-up of at least 15 minutes. This waiting time is imposed by an electronic delay element in that, not until 20 minutes after the inflector's electronic system has been turned on, does a relay contact, controlled by that element, unblock the switch-on of the high-voltage circuit.

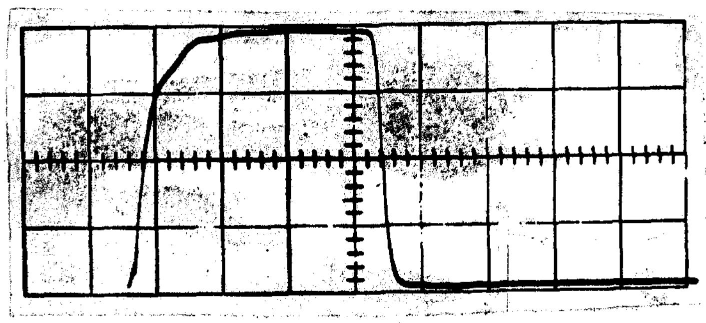

Figure 9: Inflector pulse 0.5 microsec/cm.

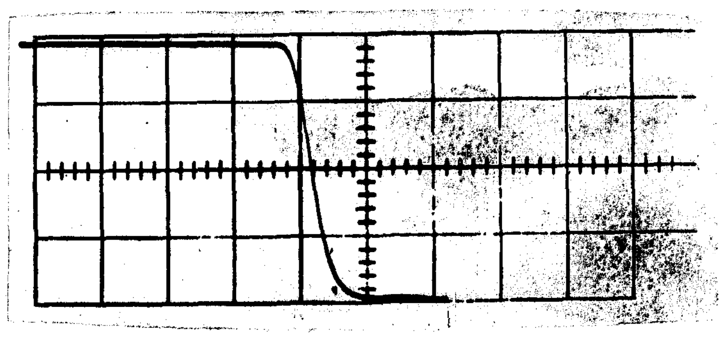

Figure 10: Trailing edge 0.2 microsec/cm.