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FAST Q - MEASUREMENT AT THE CPS

Addendum

by

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PS/8044

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ABSTRACT

In this second part of the report "Fast Q-Measurement at the CPS" the necessary control electronics is described.

It is shown by means of several photos how the installed system works.

The kicker creates coherent betatron oscillations with an amplitude of about 1 mm at 1 GeV. The beam can be kicked horizontally or vertically at any time of the machine cycle.

With the new installation the Q-measurement of the CPS can be accomplished more accurately and an order of magnitude faster than before. The error of the measurement due to counter resolution, filter adjustment and noise is of the order of 2 ‰ at low energies and about 3 ‰ at 19 GeV for a measurement time of 10 betatron oscillations.

The cost of the hardware (kicker, counter, H.V. power supply, control electronics and pulse generator) is less than 12,000 Sw. Fr.

4. DESCRIPTION OF THE CONTROL CIRCUITS

4.1 Control Chassis

Fig. M shows the schematic diagram of the control chassis. The inscriptions on the front panel (see Photo 6, part 1) correspond to those on the diagram.

The requirements are mentioned in paragraph 3.

A standard pulse sent to the trigger input triggers the blocking oscillator B01. Transistor T2 at the output of B01 serves as a gate. When the gate is open the positive 1 µs-pulse gets to pin 5 (B) of one-shot OS2. After a delay of 65 µs the positive going step at pin 1 ($\overline{Q}$) of OS2 is differentiated and triggers the blocking oscillator B02 (one-shot OS2 compensates for the counter delay (65 µs)). The output pulse at pin 4 is attenuated and gets to the trigger output which is connected to the trigger input of the kicker pulse generator.

To avoid contact damage of the relays in the kicker pulse generator, one-shot OS1 blocks 80 ms triggering of the kicker when the relays are switched by S1 or S2. When the position of S1 (pulse length) or S2 (horizontal/vertical) is changed, OS1 is triggered at pin 5 (B) via a differentiating network. The signal at pin 6 (Q) biases T2 positive at the base. During the one-shot time (80 ms) no trigger signal can get to the trigger output.

The variable Delay 1 permits to trigger the counter at the increasing slope of the filter resonance.

By potentiometer P2 the signal from the filter output (f_B) can be attenuated to a convenient level of the counter.

When the RF signal ($\approx$ 1 V pp) is connected to the "f_{RF} IN" jack, it is amplified by T3 with variable gain (P3). The signal can pass via emitter follower T4 either through a frequency doubler or through an attenuator and then gets to the output via emitter follower T5. It can be selected by switch S4, which excites the mercury relays H1 and H2. The peak to peak voltages of the two frequencies at the output are equal. The -3 db bandwidth of the amplifier is 15 MHz.

4.2 Counter Trigger Circuit

The circuit is shown in Fig. N. A standard trigger pulse at the input saturates transistor switch T1 and resets the counter. The condensor C4 was changed from 1 μF to 1 nF in order to decrease the delay.

Thus the delay between trigger pulse and counter gate opening was reduced about 60 μs.

4.3 H.V. Power Supply Overvoltage Switch

The voltage of the kicker pulse generator is limited at 630 V. The high voltage power supply (Fluke 412 B) has a short circuit protection which cuts the circuit off at I_{max} = 30 mA.

Fig. 0 shows the circuit which converts 630 V to 30 mA.

The tube 4379 fires at 340 V. At point P of the voltage divider R2/R1+R2 appear 340 V when the supply voltage U_o reaches 630 V. The current through the tube (≈ 4 mA) excites relay R. Relay R closes the contacts r1 and r2, causing a load current higher than I_{max} = 30 mA and the power supply switches off.

The circuit is mounted in the case of the kicker pulse generator (Fig. K, part 1).

5. RESULTS WITH THE Q-MEASUREMENT SYSTEM

Photo 7 shows on the right side the Q-measurement apparatus. From right to left: the kicker, the pulse generator, and in the middle of the photo: counter, control chassis and power supply one upon the other (the instruments on the left served to test the system).

The total system was tested for more than one week in the laboratory. During the machine stop of 15th/17th September, 1969, the kicker was installed in straight section 88 of the PS.

5.1 Radial and Sum PU Signals after Excitation of the Kicker

Photos 8, 9, and 10 show the sum- and radial signals of the even PU station 50 and the kicker current on the third trace at different proton energies.

The excited betatron amplitude is

at $T = 0.47$ GeV (B 50) $\approx$ 1.7 mm
$T = 2.3$ GeV (B 150) $\approx$ 0.5 mm
$T = 19$ GeV (B 910) $\approx$ 0.2 mm

(kicker pulse length $\tau = 4\ \mu s$,
peak current $I_p = 160$ A)

By extrapolation one finds for T = 1 GeV an amplitude

$$a_1 = a_2 \frac{p_2}{p_1} = 1.7 \frac{1.05}{1.7} \approx 1 \text{ mm}$$

as the amplitudes are inverse proportional to the momentum.

($p_2 = 1.05$ GeV/c at T = 0.47 GeV and
$p_1 = 1.7$ GeV/c at T = 1 GeV.)

(The difference of revolution time was neglected.)

5.2 Resonances at the filter output with kicker excitation

The first trace of Photos 11 and 12 shows typical resonances at the filter output. (T = 0.47 GeV, $J = 1.5 \times 10^{12}$ p/p, a = 40 db attenuation on filter input, $Q_f = 106$.) The second trace indicates the kicker current.

On photo 13, trace 2, it can be seen where the counter gate is opened for the Q-measurement.

Photos 14, 15, 16, and 17 show the influence of the filter frequency f_o. The correct filter frequency f_o = 95.6 kHz gives the maximum amplitude of the resonance (Photo 15). A smaller filter frequency f_o = 93.8 kHz (Photo 14) gives 40 % less amplitude and an error

$$\frac{\Delta N}{N} = \frac{1.3}{152.5} \approx 1\ \%$$

A higher f_o = 97.6 kHz gives with 40 % less amplitude an error

$$\frac{\Delta N}{N} = \frac{1.5}{152.5} \approx 1\ \%$$

An amplitude error of 4 % (10 times less) can be detected. With linear interpolation this would lead to an error of 1 ^{o}/oo due to filter adjustment.

5.3 Q-Measurement at Different Proton Energies

The following photos show the filter resonances on the first trace and the counter gate signal on the second trace. The gate time is 1 or 10 betatron periods (beam intensity 1.5 x 10^{12} p/p).

Photo 18, 19	at	T = 470 MeV	
20		T = 4.77 GeV	Transition
21		T = 7.51 GeV	
22, 23		T = 9 GeV	
24, 25		T = 19 GeV	

The corresponding counter indication N and the non integer part of the Q-value

$$q = \frac{40}{N} \qquad (12)$$

are always given.

At T = 19 GeV proton energy there was still a resonance amplitude of 0.9 V_{pp} with 20 db attenuation at the filter input. Yet, it should be noted that the signal to noise ratio is small. This causes supplementary random errors.

Photos 26 and 27 show that the kicker works horizontally as well as vertically.

5.4 q-Measurement Error Sources and Accuracy

Photo 28 shows 3 different measurements superimposed with various delays between kicker excitation and counter triggering (countergate signals trace 2, 3 and 4). The counter indication remained constant N = 155.6 in the 3 cases. Behind the maximum of the resonance an error could be noticed. This means the measurement can be done correctly at the increasing slope of the resonance from small amplitudes up to the first maximum.

In order to avoid errors it should be observed that the filter signal U_f corresponds to the counter input range. The range "x1" works from 0.2 V_p to 2 V_p correctly with zero-crossing. (Trigger threshold < 1 mV for counter HP 5325 B).

The error due to incorrect filter tuning ($\epsilon_f \approx 1$ ‰) is already mentioned in paragraph 5.2.

The error ϵ_c due to counter resolution depends on the number of periods p of the betatron oscillations which are used as time base and the q-value (see equ. 13 to 16).

$$\epsilon_c = \frac{1}{40} \frac{q}{p}$$

A further error source is the noise of the filter. The signal triggers the counter with a maximum phase error

$$\Delta \varphi = \frac{U_n}{U_s}$$

(U_n = peak to peak noise voltage
U_s = peak to peak signal voltage)

at the start and the stop instants.

This gives a maximum error due to noise

$$\epsilon_n = \frac{2 U_n}{U_s \cdot 2\pi \cdot p}$$

The error of the measurement electronics is the sum

$$\epsilon = \epsilon_f + \epsilon_c + \epsilon_n$$

$$\epsilon = \epsilon_f + \frac{1}{40} \frac{q}{p} + \frac{U_n}{\pi U_s p} \qquad (33)$$

The noise voltage U_n at the filter output depends on the position of the filter input attenuator. U_n was measured (with ΔR of old PU 83 connected)

attenuation	0	20	40	60	dB
U_n	200	40	20	20	mV

Exemples: $q = 0.25$

a) 470 MeV, 1 period, $U_n = 20$ mV, $U_s = 3.5$ V (s. photo 13)

$$\epsilon = 1\,\text{‰} + \frac{0.25}{40} + \frac{20 \cdot 10^{-3}}{\pi \cdot 3.5} \approx 1\,\%$$

b) 470 MeV, 10 periods

$$\epsilon = 1\,\text{‰} + \frac{0.25 \;=}{40 \cdot 10} + \frac{20 \cdot 10^{-3}}{\pi \cdot 3.5 \cdot 10} = 1.8\,\text{‰}$$

c) 19 GeV, 1 period, $U_n = 40$ mV, $U_s = 800$ mV (s. photo 24)

$$\epsilon = 1\,\text{‰} + \frac{0.25}{40} + \frac{40}{\pi \cdot 800} = 2.3\,\%$$

d) 19 GeV, 10 periods

$$\epsilon = 1\,\text{‰} + \frac{0.25}{400} + \frac{40}{\pi \cdot 800 \cdot 10} = 3.2\,\text{‰}$$

The counter needs for the measurement in case a)

at α) injection 26 µs
at β) top energy 8.4 µs

and in case b)

at a) injection 260 µs
at β) top energy 84 µs

The counter result N is a mean value of $\frac{40}{q}$ within the measurement time.

As in general the time derivative of Q, $\left(\left|\frac{dq}{dt}\right|\right)$, is maximum at the beginning of the acceleration, it is recommended to measure here with 1 period and later with 10 periods.

5.5 Cost

The following costs are estimated prices (except for the counter and the H.V. power supply) of the necessary hardware:

Counter		5,820	Sw.Fr.
H.V. Power Supply		2,060	
Kicker	<	500	
Control Chassis	<	2,500	
Pulse Generator	<	500	
Total	<	11,380	Sw.Fr.

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I thank Mr. W. Richter for the mechanical construction of the kicker and Mr. P. Opitz for the kicker glass tube.

I owe thanks also to Mr. J. Durand for his successful trouble-shooting in the control electronics.

Distribution: (open)

MPS Group Leaders
MPS/SR Scientific Staff
H.G. Hereward
P.H. Standley

and upon request

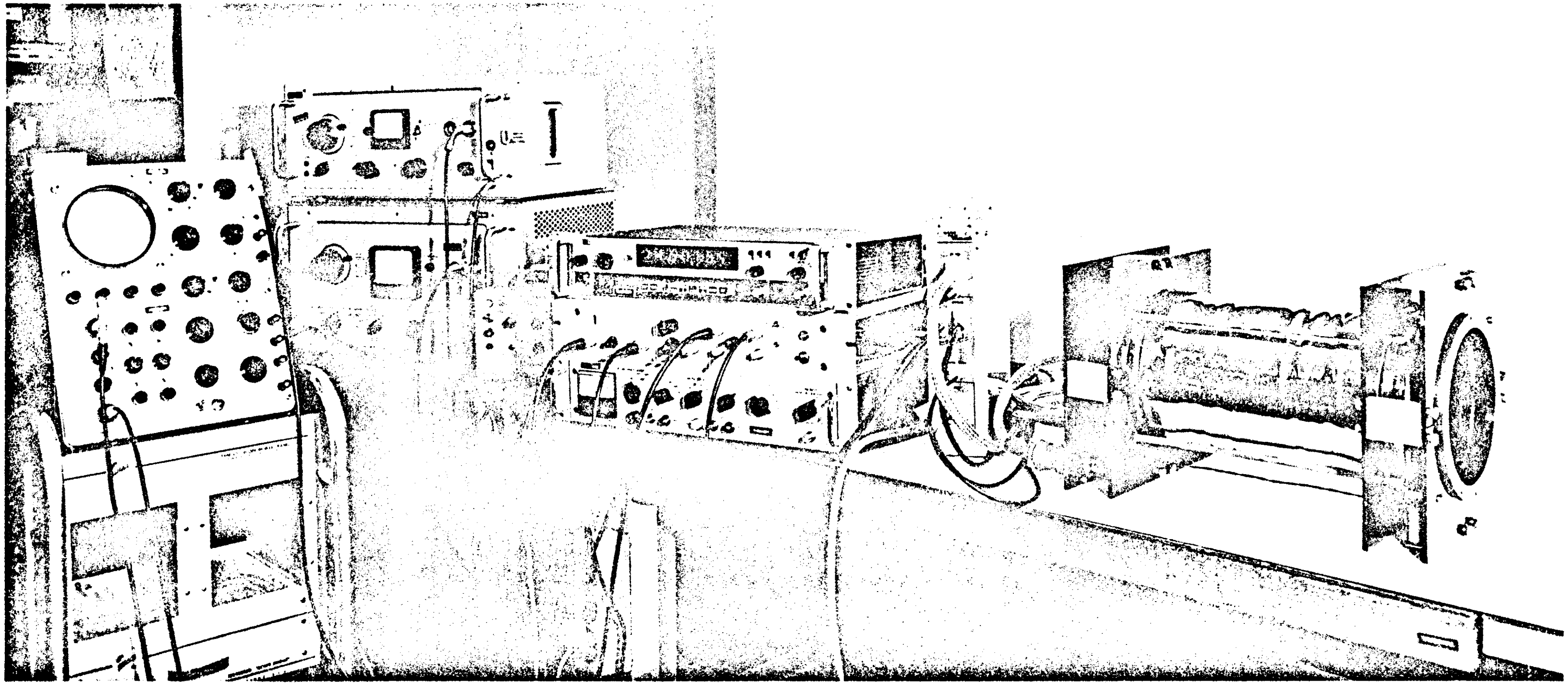


Photo 7 Q-Measurement Device in the Laboratory

Q - MEASUREMENT

1. Radial and Sum - PU Signals after Excitation of the kicker

beam intensity $J \approx 150 \cdot 10^{10}$ p/p

PU 50, Trigger B50 (T = 0.47 GeV)

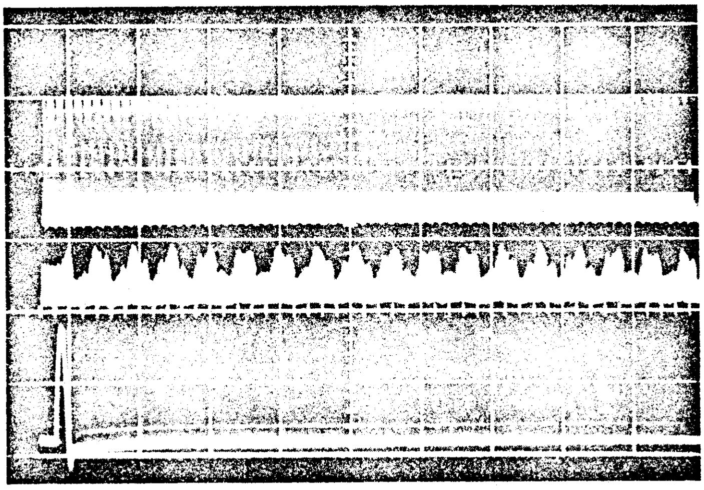


Photo 8

Sum 100 mV/cm

20 µs/cm →

ΔR 50 mV/cm
(Δr = 1.7 mm)

Kicker current J = 100 A/cm

Trigger B150 (T = 2.3 GeV)

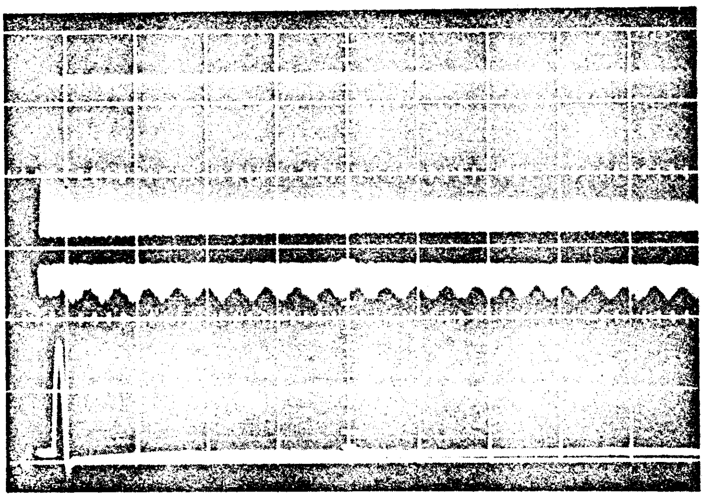


Photo 9

Sum 100 mV/cm

20 µs/cm →

ΔR 50 mV/cm
(Δr = 0.5 mm)

J_{kick} = 100 A/cm

Trigger B910 (T = 19 GeV)

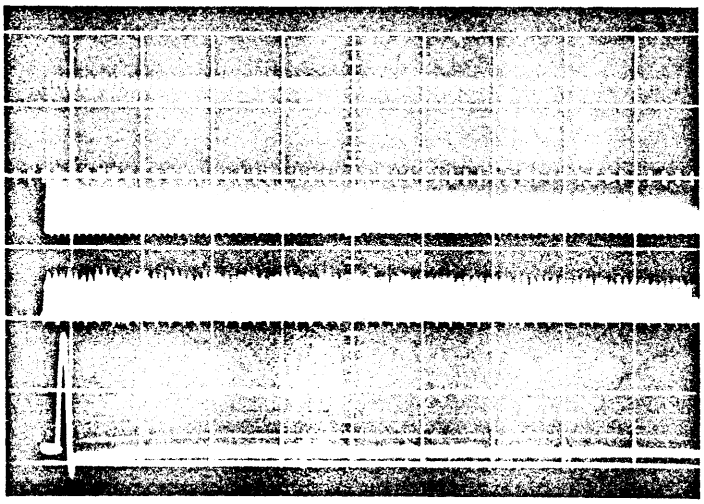


Photo 10

Sum 100 mV/cm

20 µs/cm →

ΔR 20 mV/cm
(Δr = 0.2 mm)

J_{kick} = 100 A/cm

2. Signals at the Filter Output after Excitation of the Kicker

$J = 150 \times 10^{10}$ p/p
ΔR of old PU 83
kicker pulse length 4 µs
filter $\begin{cases} Q_f = 106 \\ f_o = 95 \text{ kHz} \end{cases}$
atten. 40 db

Trigger B50 (T = 0.47 GeV)

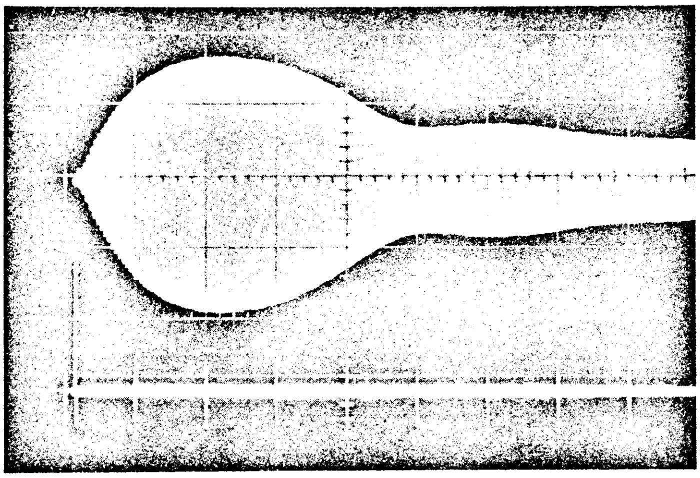


Photo 11

U_f = 1 V/cm + 40 db filter

J_{kick} = 100 A/cm

⟶ 200 µs/cm

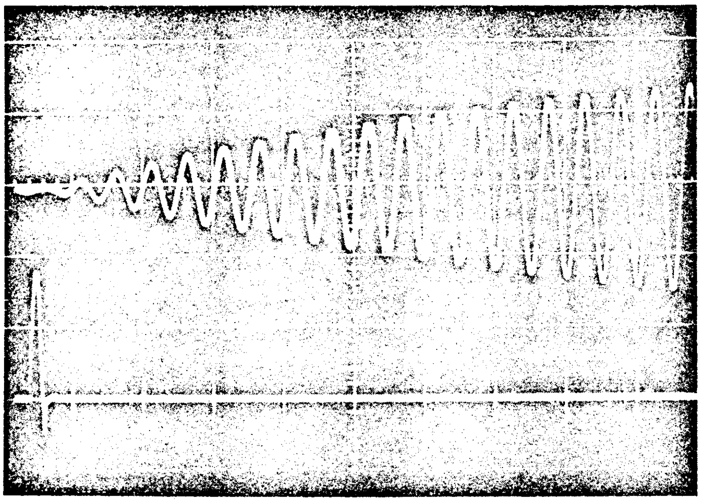


Photo 12

U_f = 1 V/cm + 40 db

J_{kick} = 100 A/cm

⟶ 20 µs/cm

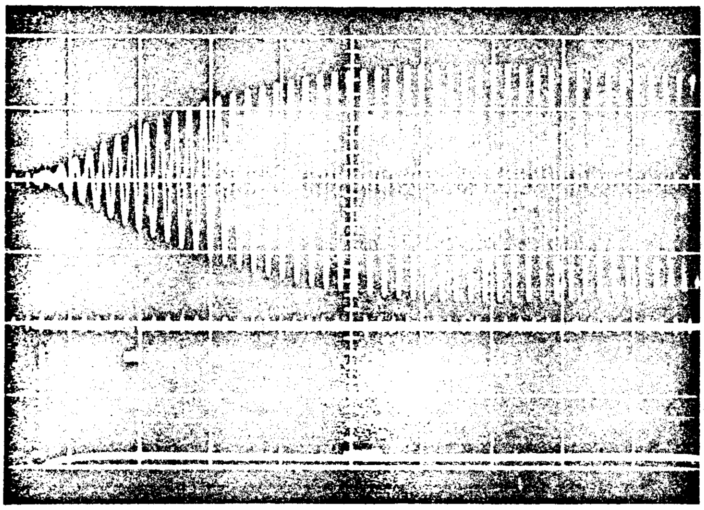


Photo 13

U_f = 1 V/cm + 40 db

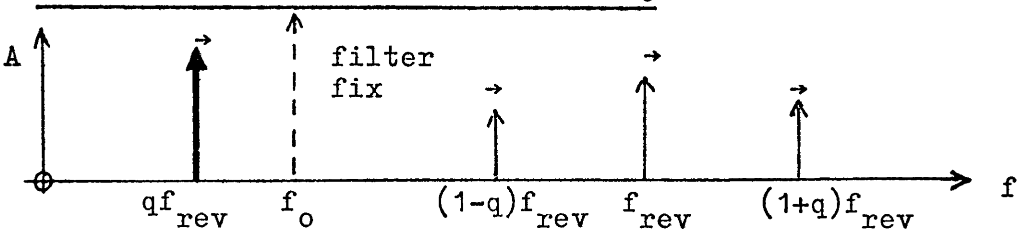
Counter Gate 10 V/cm
1 period

J_{kick} = 100 A/cm

$N = 151 \longrightarrow q = \frac{40}{N} = 0.265$

⟶ 50 µs/cm

Influence of the Filter Frequency f_o



B52

U_f 1 V/cm

U_G 10 V/cm

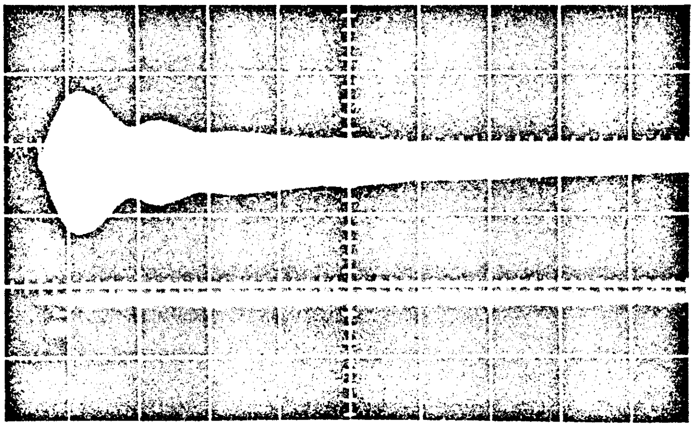


Photo 14

f_o too small

f_o = 93.8 kHz

N = 153.8

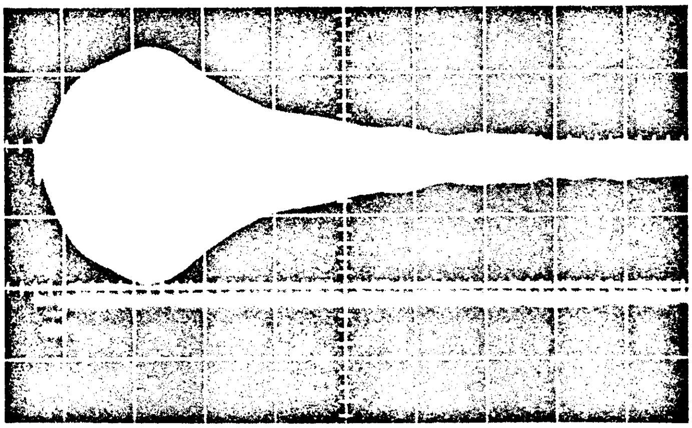


Photo 15

f_o correct
(maximum amplitude)

f_o = 95.6 kHz

N = 152.5

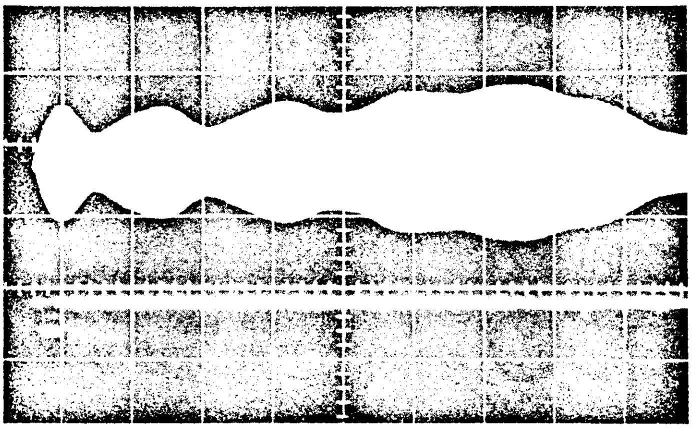


Photo 16

f_o too high

f_o = 97.6 kHz

N = 151

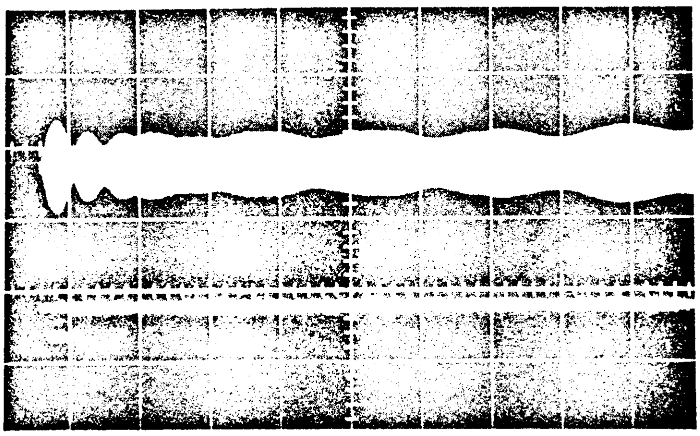


Photo 17

f_o too high

f_o = 99.8 kHz

N = 149.6

Trigger B50 continued

1 period

N = 142

q = 0.271

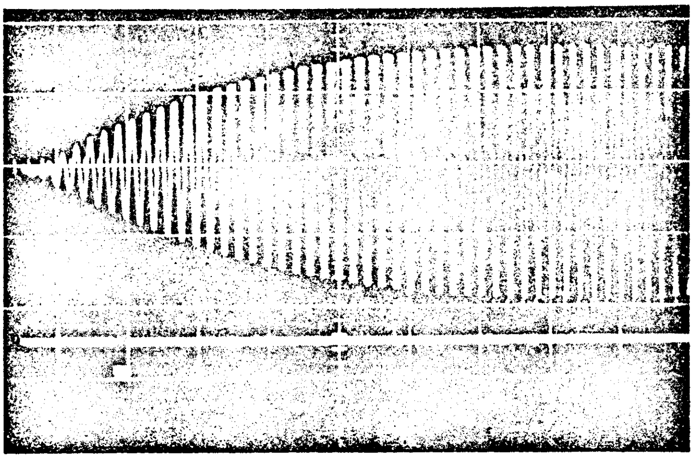


Photo 18

U_f = 1 V/cm
(+ 40 db at filter)

U_G = 10 V/cm

⟶ 50 µs/cm

10 periods

N = 142.0

q = 0.2715

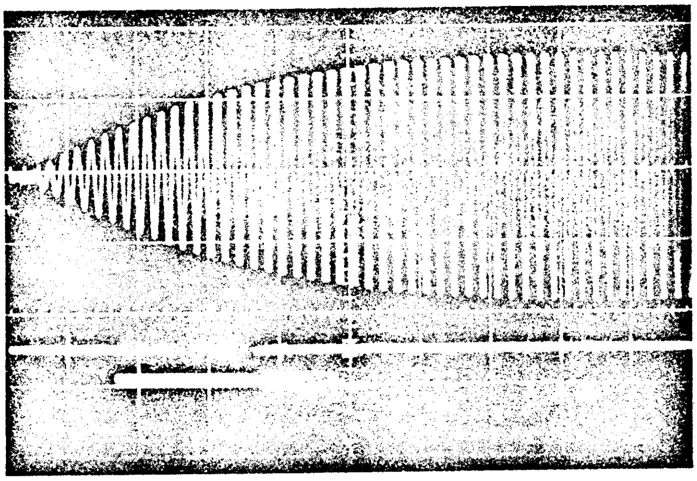


Photo 19

U_f = 1 V/cm
(+ 40 db at filter)

U_G = 10 V/cm

⟶ 50 µs/cm

Trigger B268 (Transition) T = 4.77 GeV

1 period

N = 149

q = 0.268

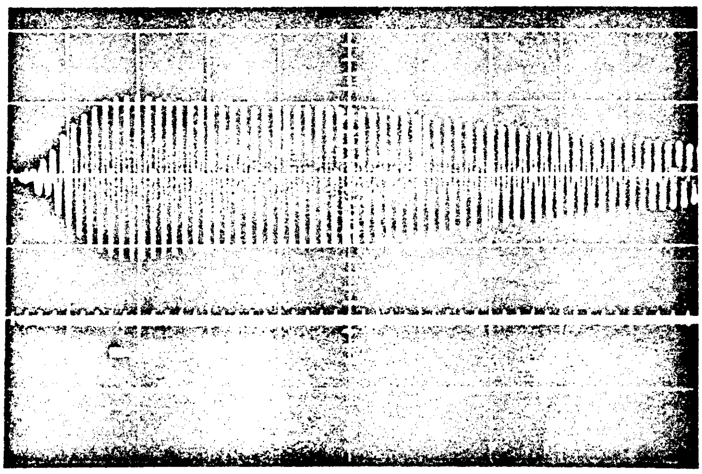


Photo 20

U_f = 1 V/cm

U_G = 10 V/cm

⟶ 50 µs/cm

Trigger B400 T = 7.51 GeV

1 period

N = 152

q = 0.263

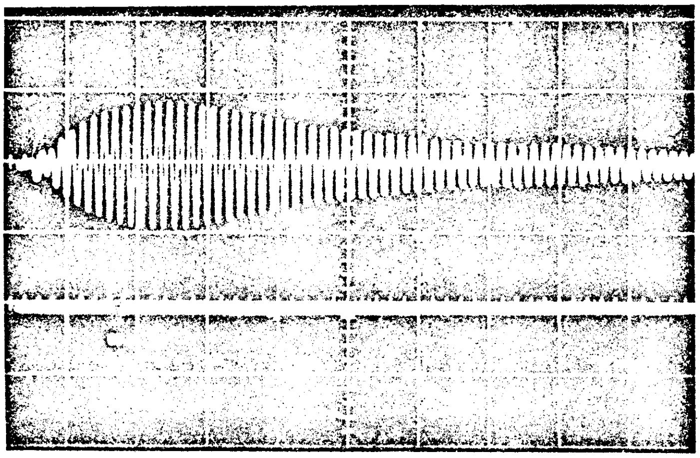


Photo 21

U_f = 1 V/cm

(+ 20 db at filter)

U_G = 10 V/cm

⟶ 50 µs/cm

Trigger B475 T = 9 GeV

1 period

N = 149

q = 0.268

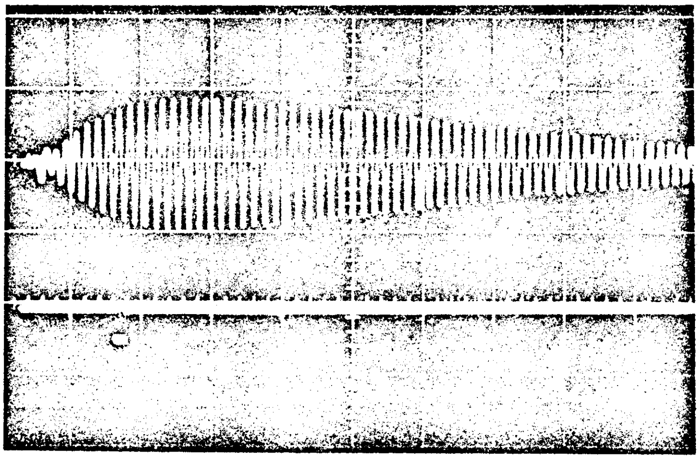


Photo 22

U_f = 1 V/cm

(+ 20 db at filter)

U_G = 10 V/cm

⟶ 50 µs/cm

10 periods

N = 150.5

q = 0.266

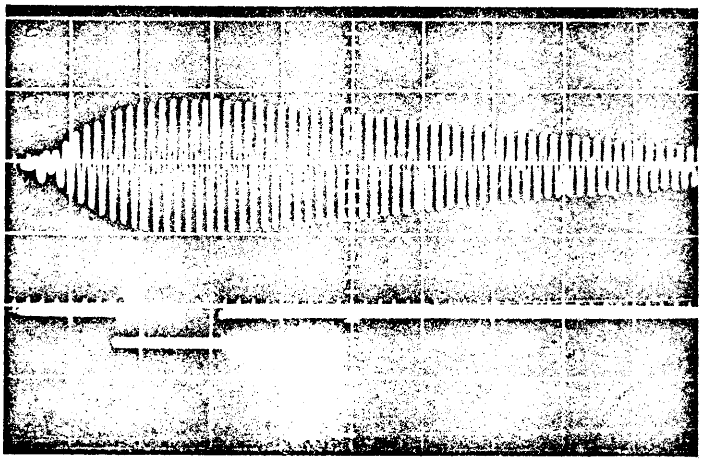


Photo 23

U_f = 1 V/cm

U_G = 10 V/cm

⟶ 50 µs/cm

Trigger B 955, T = 19 GeV

1 period

N = 140

q = 0.285

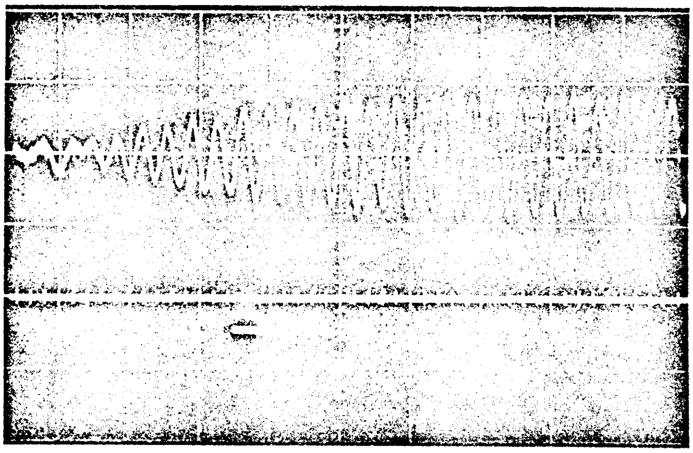


Photo 24

U_f = 0.5 V/cm

(U_G
U_G = 10 V/cm

⟶ 20 µs/cm

10 periods

N = 140.1

q = 0.2855

Photo 25

U_f = 0.5 V/cm

U_G = 10 V/cm

⟶ 20 µs/cm

Horizontal and Vertical Betatron Oscillations

(Kickerfield 90° changed)

(New P.U. 57 $\Delta R, \Delta V$, $J \approx 1.5 \times 10^{12}$ p/p)

Trigger B 355, T = 19 GeV

ΔR

N = 140

$q_r = 0.285$

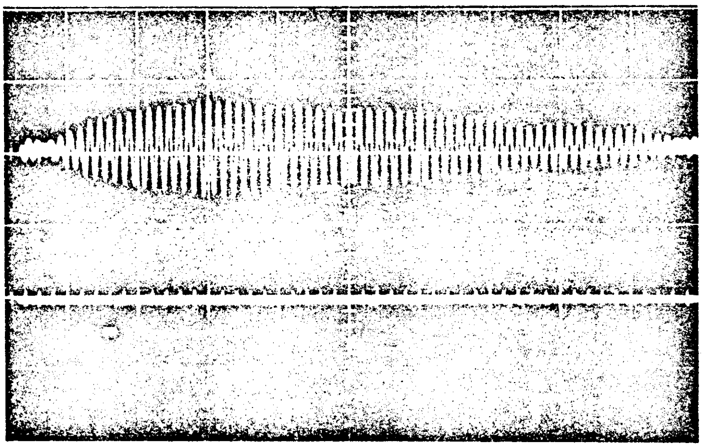


Photo 26

$U_f = 0.5$ V/cm
(+ 20 db at filter)

$U_G = 10$ V/cm

⟶ 50 µs/cm

ΔV

N = 145

$q_v = 0.276$

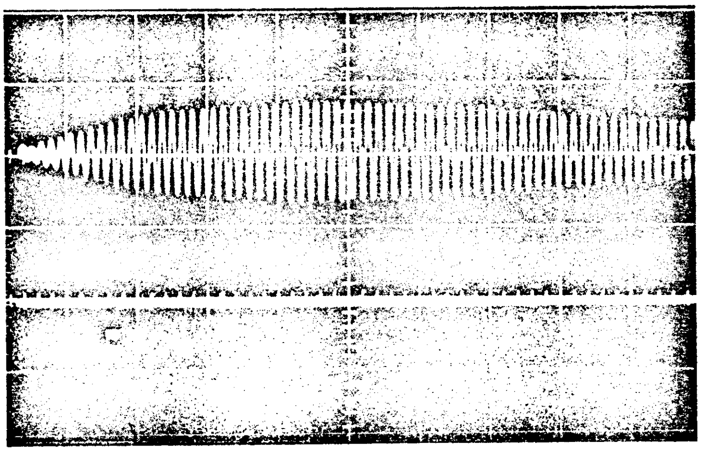


Photo 27

$U_f = 0.5$ V/cm
(+ 20 db at filter)

$U_G = 10$ V/cm

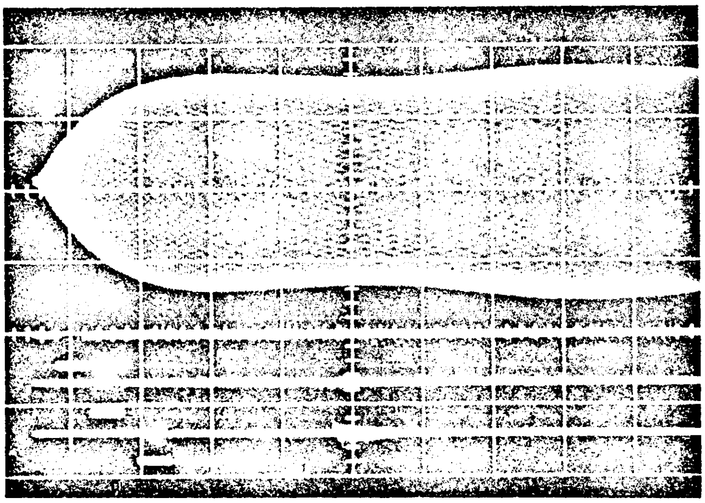
⟶ 50 µs/cm

Measurements at Different Times

on the Increasing Resonance Slope

Trigger B 100 (T = 1.36 GeV)

N = 155.6
N = 155.6
N = 155.6



U_f = 1 V/cm

U_G = 10 V/cm

q = 0.2571

⟶ 200 μs/cm

(3 exposures superimposed)

Photo 28

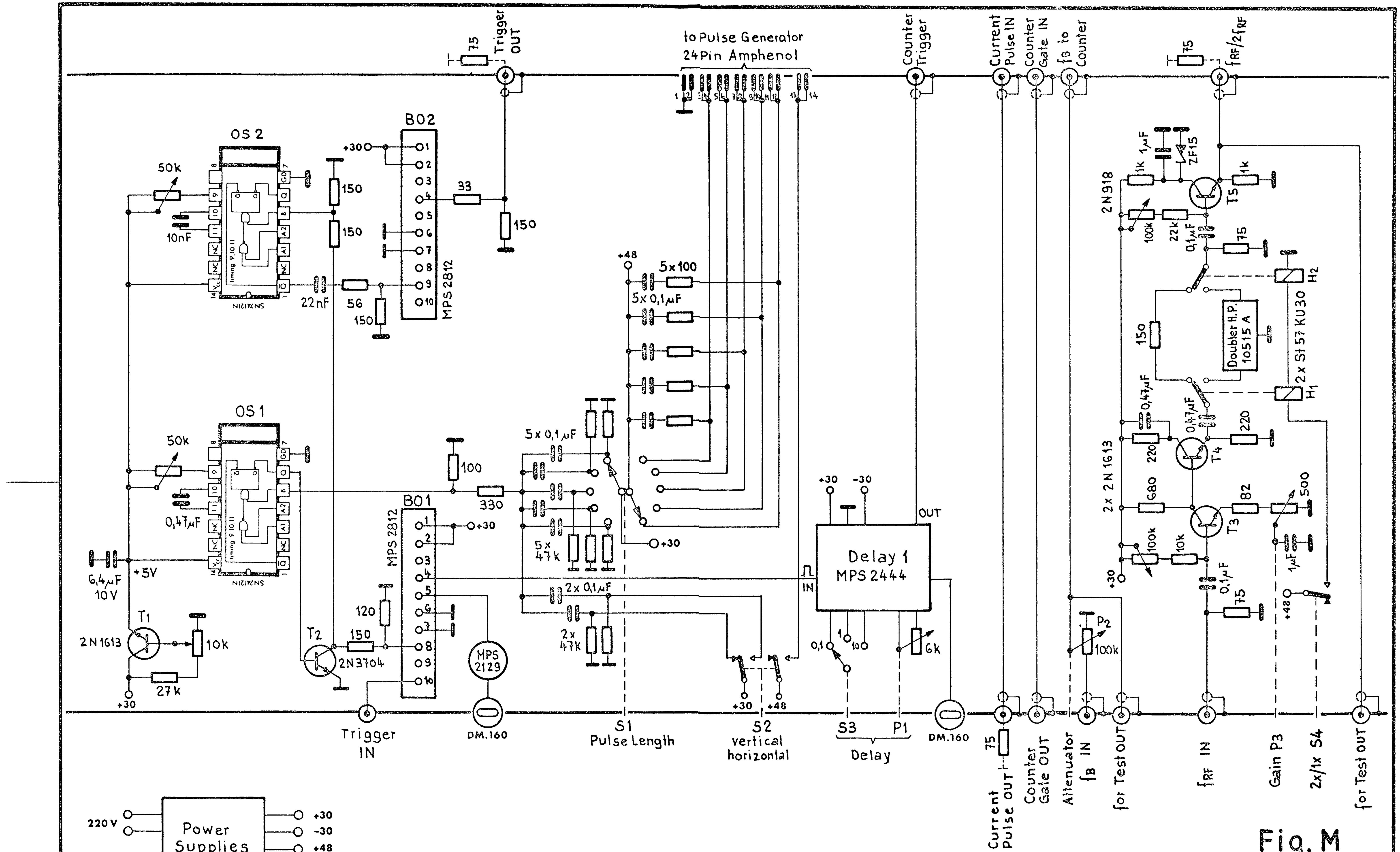
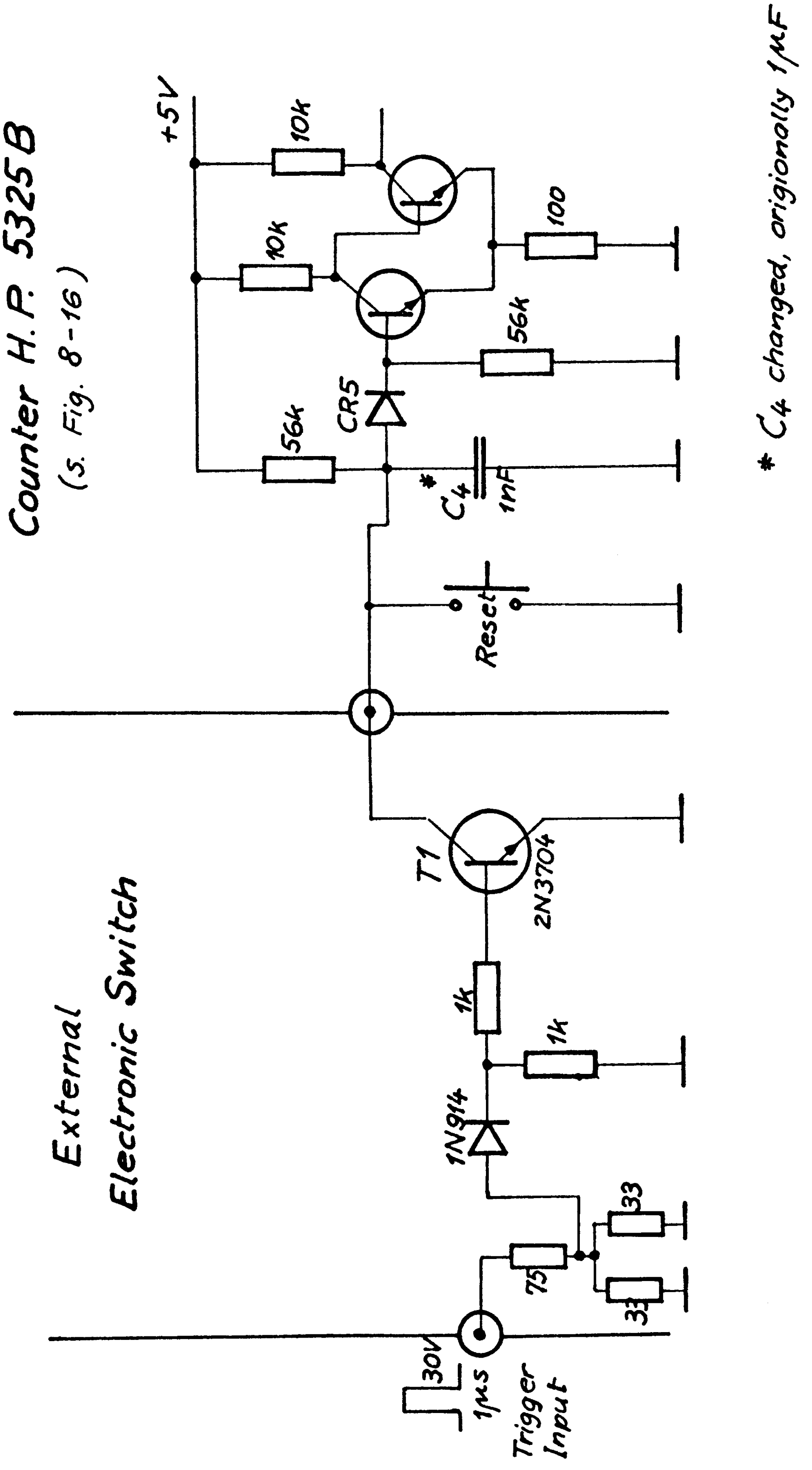
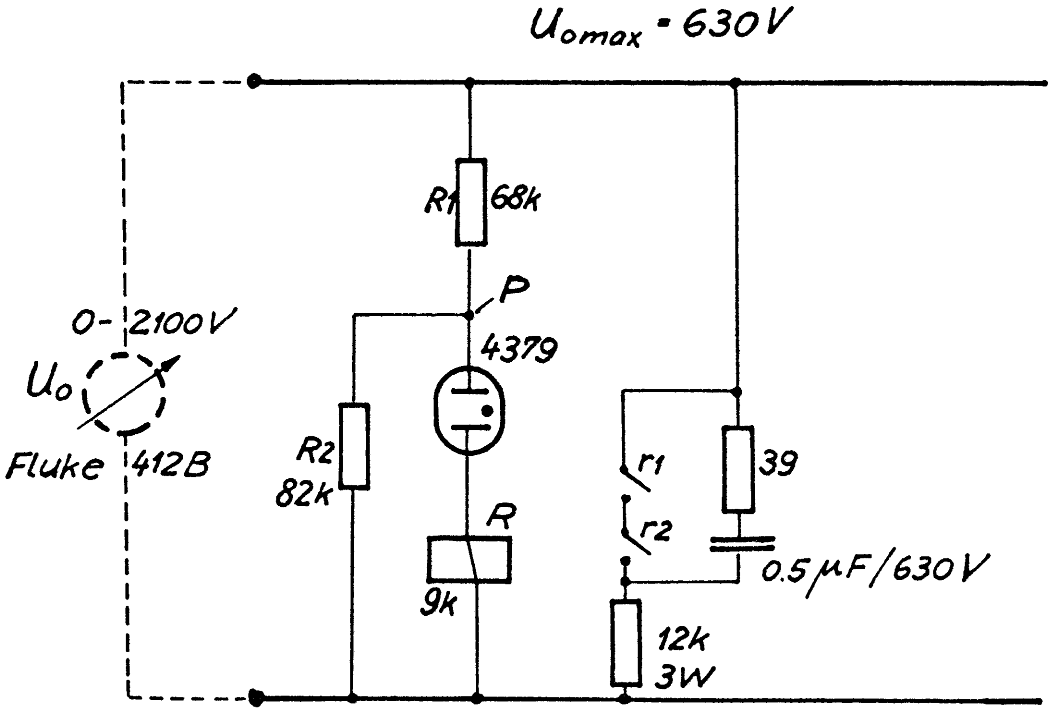


Fig. M

CERN	App. Q-Measurement	DATE	27. 10. 69.
		SIGN.	
MPS-SR	Title Q-Measurement Control-Chassis	7332-EL 1-3	



CERN	App. Q - Measurement	DATE	31.10.1969
		SIGN	Schneider
MPS-SR	Title Counter Trigger Circuit	Fig. N	



CERN	App. Q - Measurement	DATE	31.10.1969
		SIGN.	Schneider
MPS-SR	Title Over Voltage Switch	Fig. 0	