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Present, Near Future and Future Performance of the Fermilab Linac

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PRESENT, NEAR FUTURE AND FUTURE PERFORMANCE OF THE FERMILAB LINAC

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Abstract

The purpose of this write-up is to investigate possible upgrades of the Fermilab Linac. The aim is to increase peak current, beam pulse length and repetition rate above the present (Aug. 1995) performances. Today, for the needs of HEP, the Fermilab Linac can deliver 401 MeV H^- beam with 46 mA of peak current for a pulse length of $35\mu sec$ at 15 Hz.

ION SOURCE

Introductory Comments

The ion source is a direct extraction magnetron type of source. It was developed at Novosibirsk, Brookhaven and Fermilab and it has been operational at Fermilab since 1978. The design goal was 25 mA peak current with pulse length of $80\mu sec$ at 15Hz repetition rate. For more than 15 years the source has been delivering 50 mA peak current with a pulse length of $90\mu sec$ at 15Hz.

The average life time of the source is about four months, after which it must be removed and cleaned. Since August 1994, the peak current has been increased to 65 mA with no change in the quality of the beam or in the lifetime of the source.

Peak Current

The peak current of 65 mA is measured at the exit of the 750 keV acceleration column. To increase the peak current above the present value we are modifing the 90^0 extraction magnet to allow an increase in the extraction voltage from 20 to 25 kV and give a peak current of 70 mA or more.

Beam Pulse Length

Presently the beam pulse length is $75\mu sec$, (see Fig 1.), and is determined by the pulse length of the PFN used to create the arc voltage in the source. Longer pulse lengths may be possible, up to $\sim 110\mu sec$, with larger PFN.

Repetition Rate

The repetition rate of the whole system is 15 Hz. To increase to 30 Hz will require many modifications to allow for higher duty factor and gas loading.

Summary

It appears that the present source with minor modification can deliver a peak current of 70 mA, with pulse length of $95\mu sec$ at 15 Hz repetition rate. The longer beam pulse length will require new hardware for arc generation. The repetition rate of 30 Hz will require modification of most of the electronics. Evidence to support the belief that these improvements are possible is that the Brookhaven Linac runs a very similar ion source with a peak current of 65 mA, 650 μsec at 5 Hz.

Fig 1. H^- beam pulse, $\sim 90\mu sec$.

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Preaccelerator

Introductory Comments

Fermilab has two nominally identical preaccelerators. Each "preacc" consists of an H^- ion source inside a dome at a potential of about -750kV. At any given time one preacc is operational, while the other is held in reserve or undergoes maintenance. The two preaccs are called H^- and I^- for purely archaic reasons. The construction and operation of the two are virtually identical.

Peak Current

The H^- beam loads the accelerating column and produces a drop in high voltage. This drop occurs on both columns and is directly related to the peak beam current and beam pulse length. The present regulation loop can not correct for this. A bouncer circuit would be needed to correct for this drop. Table 1. summarizes recent measurements of the drop in high voltage as a function of the beam peak current

Extra. Voltage(kV)	20	19	18
Peak Current(mA)	65	58.7	47
Voltage Drop(kV)	7.3	6.7	5.8

Table 1. the beam pulse length is $\sim 95\mu sec$

showing a linear voltage drop on the time scale of $100\mu sec$.

Fig 2. High voltage drop, $\sim 8kV$ for beam $71\mu sec$.

Repetition Rate

The columns are run as DC devices and the high voltage drop recovers completely in 8 to 10 ms suggesting that a repetition rate of 30 Hz is possible.

Summary

To increase the beam current and beam pulse length will require a bouncer to remove voltage drop on the column. The design goal for the DC voltage stability for the preacc was 0.1 %. Today we see about 1.0 % voltage drop; cf. Fig.2.

750keV Transfer Line

Introductory Comments

The I- line is a simple transport line 4 meters long with a 3.25 in diameter. The H- is 10 meter long with two bends. This transport line was designed to be achromatic however it is tuned to get maximum transmission.

Peak Current

There are no known limits for the existing condition.

Pulse Length

There are no known limits for the existing condition.

Repetition Rate

There are no known limits for the existing condition.

Summary

All quadrupoles in the lines are DC powered so the lines can support arbitrarily long pulse length and repetition rates. From measurements the beam size is less than 3 cm at positions that simulations predict close to maximal value. So a moderate (100%) increase in the beam peak current should not be limited by the transfer line.

Low Energy Buncher

Introductory Comments

The Buncher is a single-gap cavity operating at the same frequency as the rest of the drift tube Linac. The cavity is made of two half drift tubes with 3 cm diameter for the beam. Presently 72 % of the DC beam is captured with the aid of the buncher.

Peak Current
It seems that the present regulation loops and available rf power can be used for peak currents up to the $\sim 100mA$.
Pulse Length
No hardware modification of the existing equipment is needed for beam pulse lengths up to $\sim 150\mu sec$.
Repetition Rate
Going above 15Hz will require major hardware modification.
Summary
The capture rate of 72 % can be increased to 85-90 % (in theory) by adding 15 % of the 3th harmonic. Since the buncher system is build around the rf system used in the drift tube linac a similar set of limitations applies.

Drift Tube Linac

Introductory Comments
The drift tube linac consists of five tanks which are driven by 5 MW of rf power at 201.24 MHz. The tanks are about 16 meter long except tank # 1 which is 7.4 meter long.
Peak Current
Initial design of the linac was for a 75 mA proton beam current. However a proton beam as high as 300 mA, only $2\mu sec$, was accelerated in the drift tube structure. Today we accelerate 49 mA to 116 MeV and a peak current of 90-100 mA seems possible with the existing hardware, Fig.3.

Fig 3. rf pulse(flat) and Modulator Voltage, $50\mu sec$/div.

Pulse Length
The existing linac was designed for a $100\mu sec$ beam pulse length. For HEP only $35\mu sec$ is used and $54\mu sec$ for Neutron Therapy. The rf is on and stable for accelerating more than $130\mu sec$, Fig.4.
Repetition Rate
Going above 15 Hz will require major hardware modification to the rf stations.

Fig 4. RF pulse, $50\mu sec$/div.

Summary
The existing drift tube linac is delivering a 116 MeV, 49 mA, $35\mu sec$ beam at 15 Hz repetition rate. It appears that 90 mA, 130 μsec can be accelerated with the existing hardware at a repetition rate of 15 Hz. It is important to note that Brookhaven accelerates 27 mA, $500\mu sec$ at 5 Hz and Los Alamos 18 mA, $900\mu sec$, at 120 Hz with the hardware which is similar to ours.

Transition Section

Introductory Comments
The 200 MHz drift tube linac operates with stronger transverse focusing and weaker longitudinal focusing than the side coupled linac which follows. Therefore, six-dimensional phase space matching is required to preserve the brightness of the beam. For longitudinal matching there are two sections; the 16 cell and the five cell sections. Today only the 16 cell section is effectively used.
Peak Current
This is probably the weakest point in the upgraded part of the linac. With todays 49 mA current the five cell section has no effect on the beam and higher peak currents may be beyond the possibility of the existing hardware.
Pulse Length
No hardware modification of existing equipment is

needed for beam pulse lengths up to $\sim 150\mu sec$.

Repetition Rate

Going above 15 Hz will require major hardware modification to the rf system.

Summary

It should be noted that Los Alamos has a very similar transiton energy (100 MeV) between the drift tube and side coupled structure and does not have a transition section.

Side Coupled Linac

Introductory Comments

The high energy part of the Linac is made of seven 804.96 MHz side-coupled cavity modules. Each accelerating module is powered with a 12 MW klystron-based power supply. The beam is accelerated from 116.4 to 401 MeV with 7.5 MV/m average axial field. The maximal surface field is 37 MV/m or 1.4 Kilpatrick limit. The design limits were 50 mA of H^- with a pulse length of $120\mu sec$.

Peak Current

The design goal of the upgrade was 50 mA of peak current. Traditionally the Fermilab linac has run not more than 35 mA of H^- beam and according to this tradition bridge couplers to the side coupled modules were cut for that peak current. However during September of 1994 the peak current was increased to 42 mA and today we run at more than 47 mA peak current without any problem. Regulation loops on the rf and the use of $\sim 9MW$ out of the 12 MW available give us confidence that 55 to 60 mA of peak current is not out of reach using existing hardware.

Pulse Length

The **quadrupole system** in the upgraded part of the linac is pulsed with about 15 % of a second harmonic, which makes quad currents flat for more than $400\mu sec$, Fig. 5.

The design specification for the **rf system** was $125\mu sec$. Due to the high sparking rate of the cavities at intial stage of the commissioning the rf pulse length was shortened to $65\mu sec$. As a test we have run some modules with rf pulse length as long as $90\mu sec$ and have not noticed any increase in the spark rate. The hope is that we can run with pulse lengths of $125\mu sec$ without any hardware modification, Fig 6.

Fig 5. Quads(Q01, Q02) Currents, $200\mu sec$/div.

Fig 6. rf pulse, PFN voltage(flat trace), $20\mu sec$/div.

Repetition Rate

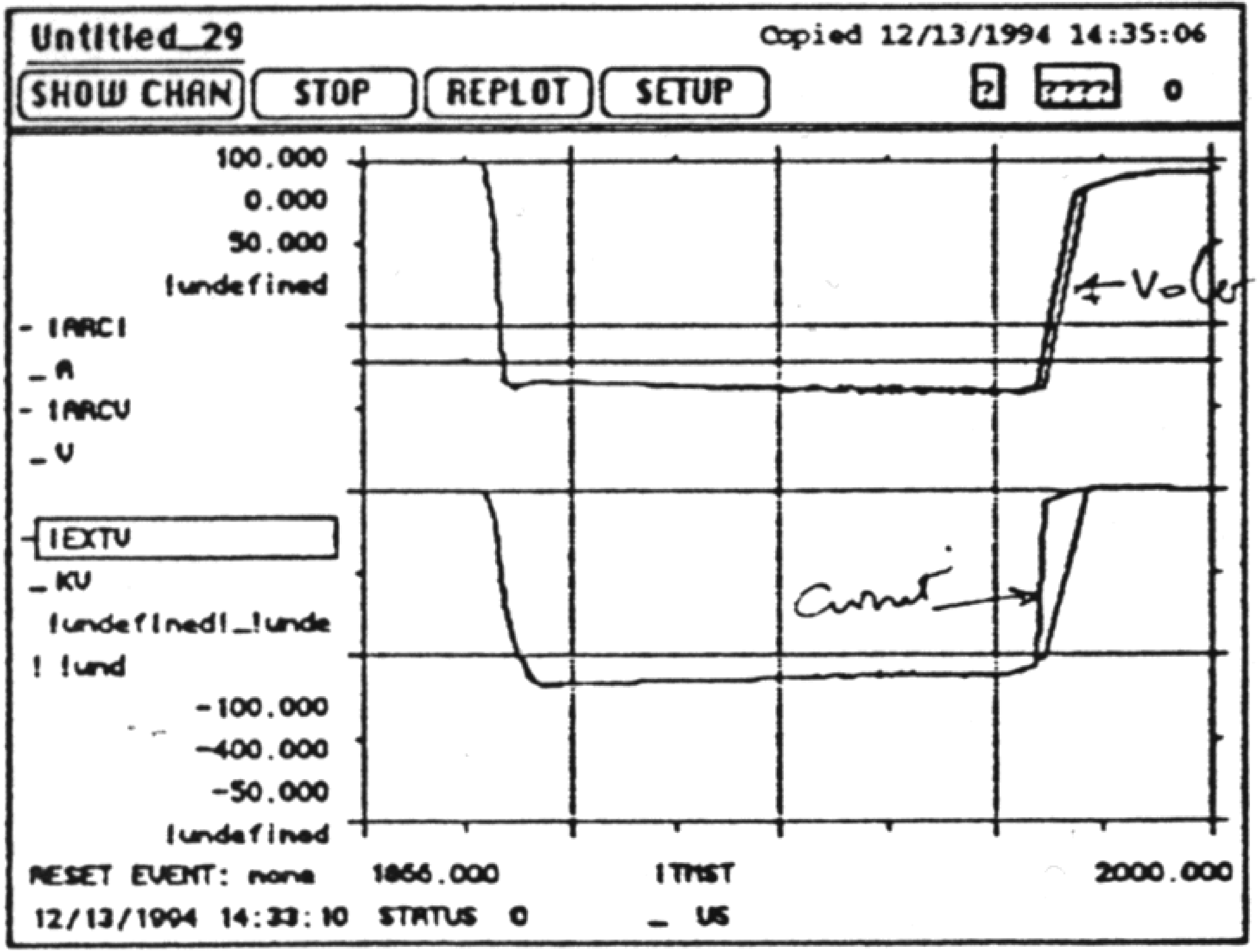
Going above 15 Hz will require major hardware modification.

Summary

The low spark rate for the whole side coupled cavity linac gives us confidence that a design limit of 50 mA, $125\mu sec$ at 15 Hz can be achieved with the existing hardware.

Conclusions

In this document we have analyzed only limits imposed by existing hardware and small modifications which can increase the Linac performace. There was no attempt to address limits imposed by the safety requirments. The general conclusion is that with existing hardware the system can deliver 48 mA, $80\mu sec$ at 15Hz. The hope is that with small modifications 55 mA, $110\mu sec$ at 15 Hz can be achieved.



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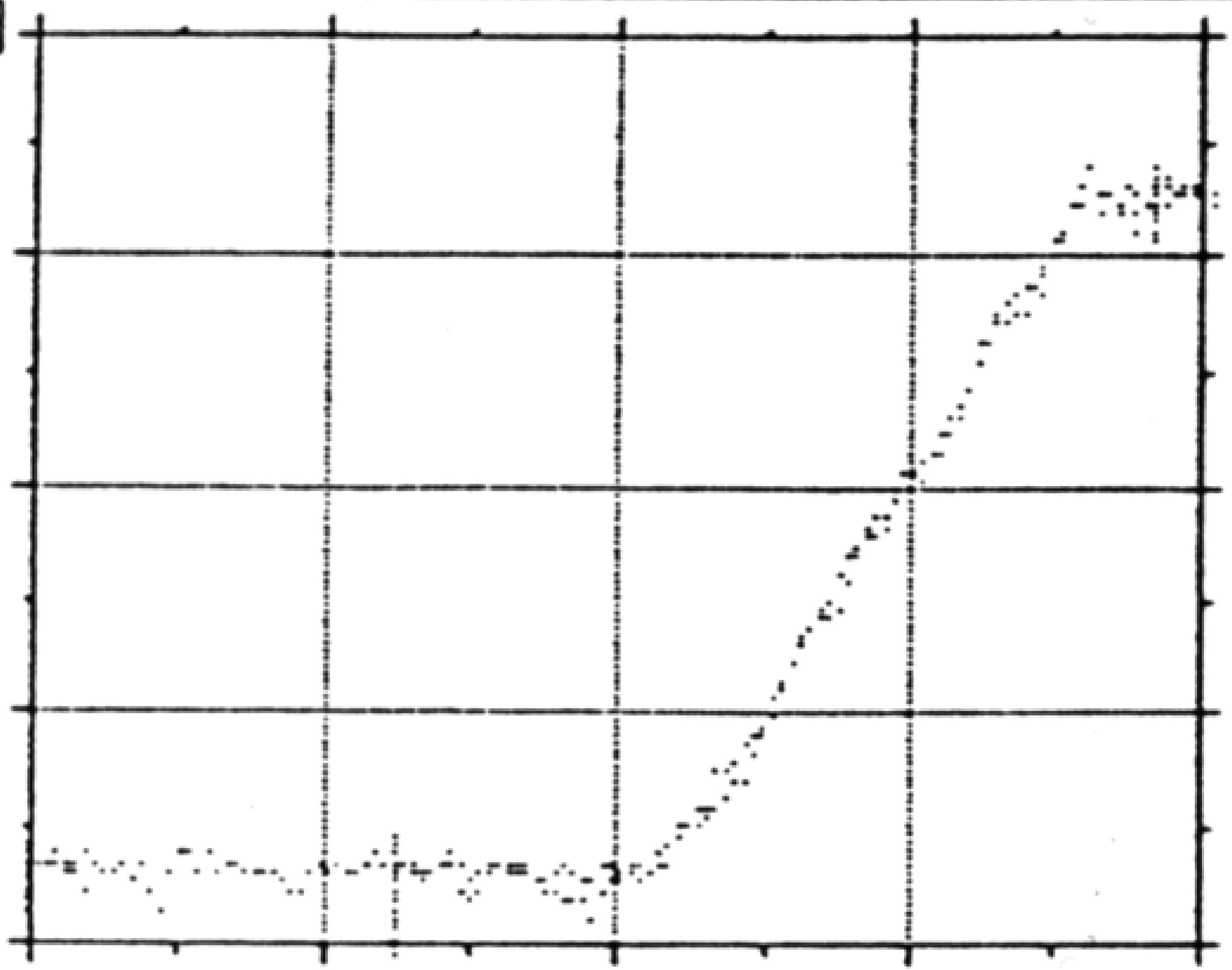

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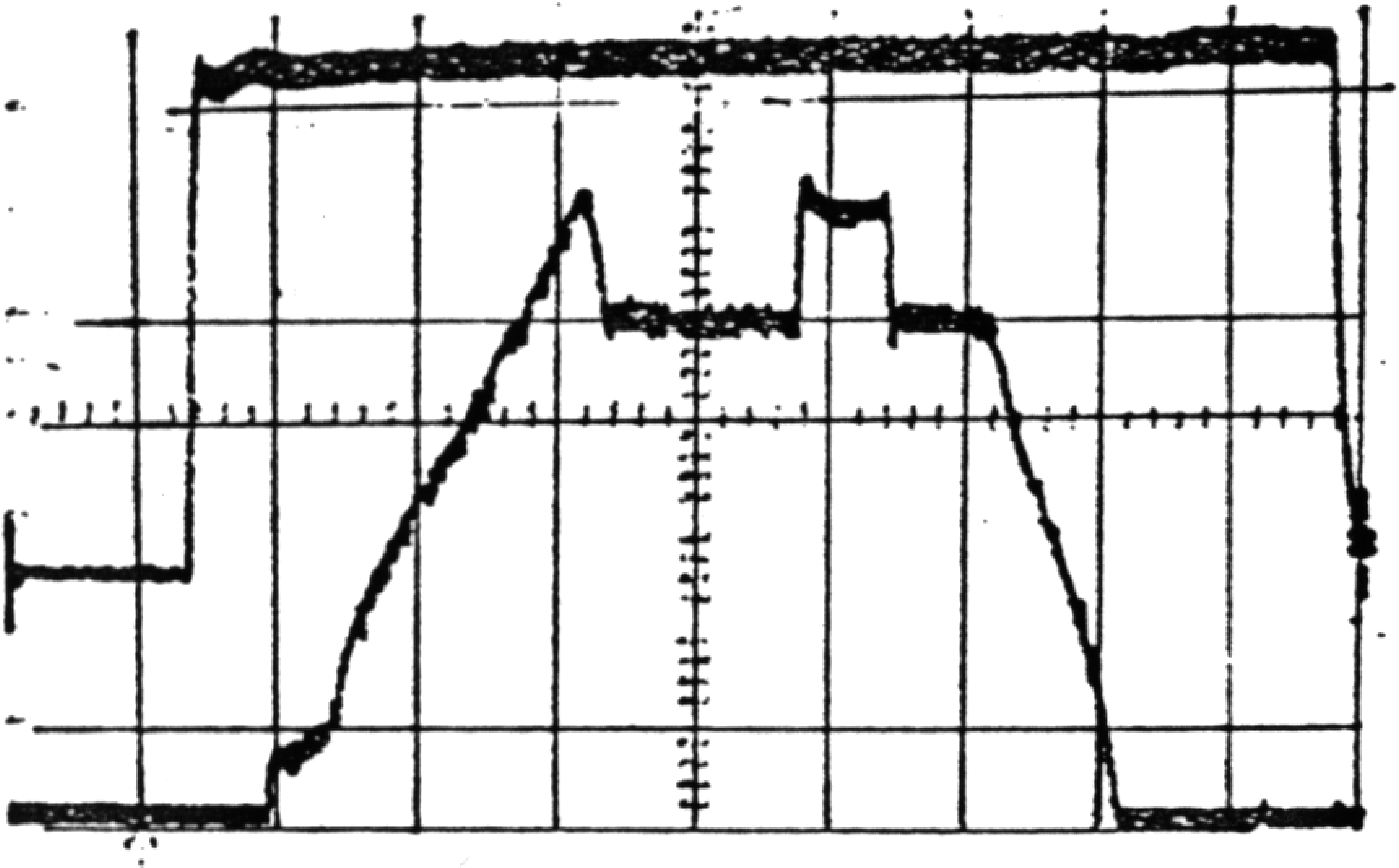

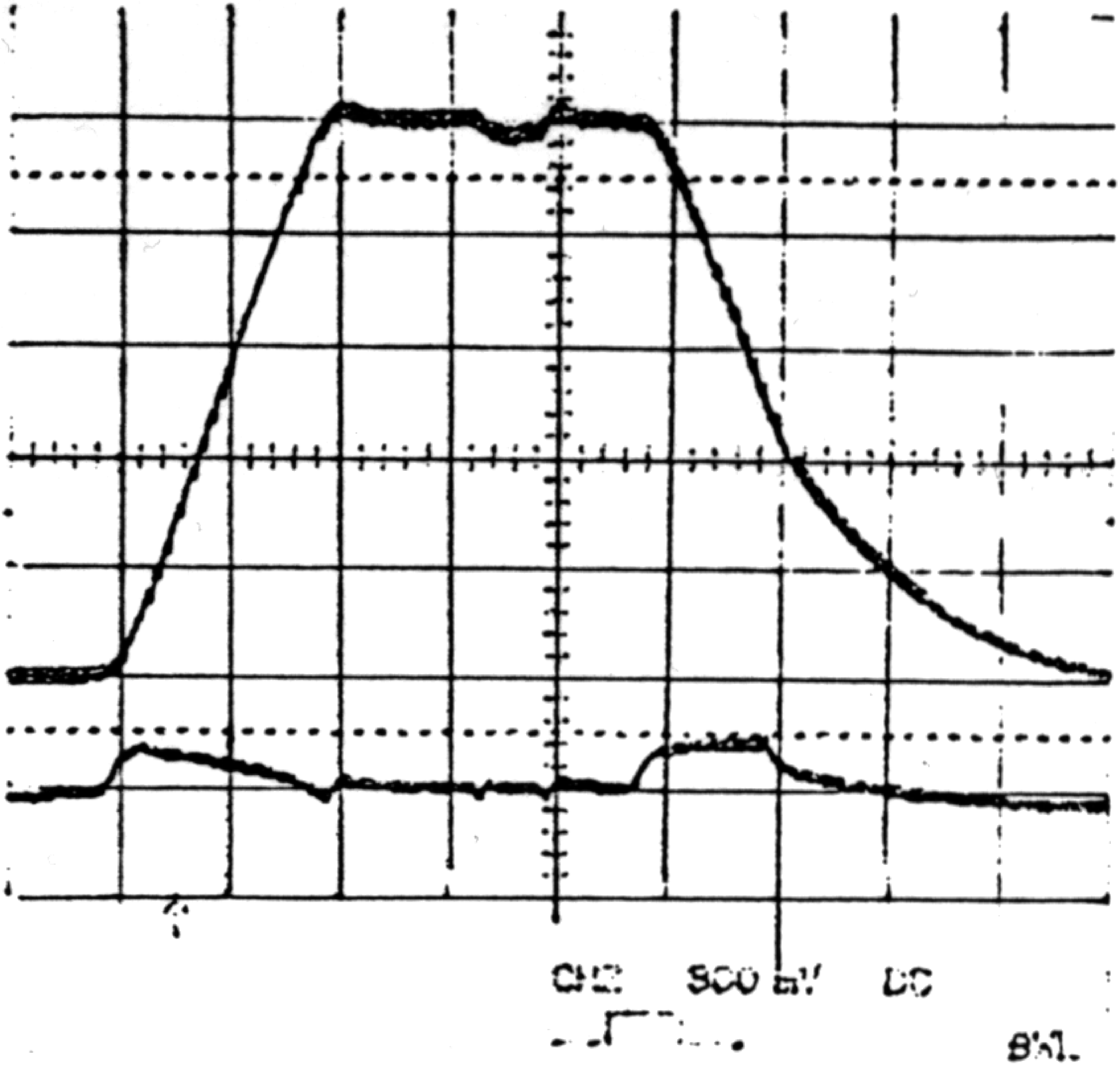
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