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INTERIM REPORT ON CONTROL OF SIEMENS GENERATOR VOLTAGE DURING PULSING

E. J. Rutan

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

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Siemens has provided several methods for the generator voltage control. These are described on pages 2 and 3 of their manual, "Description of Generator Control System" (received November 9, 1970). They, however, do not indicate which is the best method to use. In my discussions with the Siemens field engineer, before he left, he was unable to advise which was the preferred method. He stated he would have to try the several methods.

A voltage control method has been arrived at, after several trials, based on suggestions by the Siemens engineer and the Accelerator Department engineers. The adjustments concerned the no load voltage, rate of rise of current, and the control when changing to flat top. The present control seems adequate for successful pulsing of the main magnet so that a useful beam has been obtained at 28.5 BeV and 24.9 BeV. However, it is not known whether we are using the best method for controlling the generator voltage.

Some data has been taken with the present control method. Study of this data and the previous discussions with several Siemens engineers (1968-1970) indicates that improvements can be made. This report is being made to provide a better understanding of the control problem and to suggest a program of tests so as to obtain the maximum benefit of the control facilities provided by Siemens.

The report includes the following:

Part 1. Description and comments on the Siemens generator control methods as presented in their manual, "Description of Generator Control Systems" and also by them at conferences.

Part 2. Discussion of data obtained during March and April 1971, when pulsing the magnet at 28.5 BeV and 24.9 BeV. Indication where improvements can be made.

Part 3. Suggested tests to develop the best method of voltage control.

Part 1

After Siemens had been awarded the contract for the power supply, there were discussions of the methods of generator control. They recommended the maintenance of constant generator flux as the preferred method (meeting 4/10/68 Erlangen, Section 6 page 3). Subsequently other methods were proposed. Finally Siemens issued their manual in November 1970, "Description of Generator Control System" but did not recommend any specific method. The methods described in the manual are listed below A to D.

A) Control of generator voltage against a constant reference voltage.

B) Current-proportional control (droop) as a supplement to method A.

C) With method A, adding or subtracting constant values to the reference voltage when changing to flat top.

D) At the beginning of flat top changing from constant voltage control method A to constant excitation voltage control.

E) Constant flux control. A method which theoretically might be most advantageous, but never specifically described by Siemens.

A - This method utilizes a constant reference voltage against which the generator voltage is compared. The regulator attempts to vary the generator field voltage so that a constant generator terminal voltage is maintained. There are field winding and pole face winding time constants, and generator reactions due to the continuously increasing generator currents which cause slight deviations. This method was tried during the initial trial pulsing and as expected was not satisfactory. This method was designed to be combined with others described below.

B - Current-proportional control (droop). This is one of the supplementary procedures to method A. A signal is produced which is proportional to the increase in generator current. It can be applied to either increase or decrease the reference voltage as the generator current increases, thus raising or lowering the exciter voltage. This method has not been tried.

C - Adding or subtracting constant values to the reference voltage of method A at the beginning of flat top. This is the present method of operation. The reference voltage is increased at flat top. The magnitude of the voltage to be added to the reference voltage was determined by trial.

D - At the beginning of flat top, change from generator voltage control to constant excitation voltage control. During flat top the magnet current is maintained constant. It was felt a selected constant excitation voltage would produce a constant generator voltage and hence constant magnet current. This method was proposed in September 1969 by Siemens. The value of field voltage to be maintained would have to be determined by trial. This method has not been tried.

E - Constant flux control, which from the generator characteristics, seems to be the ideal, has never been outlined in detail by Siemens. It can probably be obtained by using current-proportional control method B. The current signal would add to the reference voltage to increase the field current to compensate for the mmf of the generator load current. It would have to be worked out empirically because the generator voltage should droop due to the leakage reactance drop. This is probably the reason the constant flux method was not described in the manual.

The adjustment required when changing from pulse to flat top can be controlled by either a change in reference voltage by method C or by switching to field voltage control, method D. Both adjustments would have to be determined by trial.

Part 2

Early in March 1971, the accelerator was operated at 28.5 BeV. The cycle timing was 600 milliseconds rise, 750 milliseconds flat top at a repetition time of 2.2 seconds. The no load generator voltage had been reduced from 7500 in several steps to 6000 volts (magnet dc voltage reduced from approximately 12,000 to 9600 volts) for initial beam control. The generator voltage control was by method A and C, that is constant voltage during pulse (rising current) and then a higher reference voltage during flat top.

When these adjustments had been made, the accelerator operated satisfactorily at the 28.5 BeV. Later with the same method of control the accelerator was operated at 24.9 BeV. These operations continued until shutdown at the end of April.

A series of measurements were made at both of these energy levels. Records of generator volts, generator current, field current and field volts were obtained. Because the recording instrument had only two channels, combinations of the above were taken so as to be able to make simultaneous comparisons.

The source of the measurements were as follows:

a) Generator volts - rectified secondary voltages of the three phase potential transformers.

b) Generator amperes - rectified secondary currents of the three phase line currents.

c) Field current - voltage drop across a shunt in series with the generator field.

d) Field volts - voltage at the field terminals.

For each energy level three records were taken:

1) Generator volts and generator current.

2) Generator current and field current.

3) Field current and field volts.

The results for the 28.5 BeV are shown on sheets 1, 2 and 3; those for 24.9 BeV are on sheets 4, 5 and 6. Since each set showed similar characteristics, only the 28.5 BeV on sheets 1, 2 and 3 will be discussed.

On sheet 1, the generator current (directly proportional to the magnet current) is approximately a triangular wave. The generator voltage has a slight droop. Sheet 2, which serves as a tie to establish timing between sheet 1 and sheet 3 does show the field current rises at a slightly different rate than the generator current. A rising generator current does have a self-exciting effect on the field system. The more important changes occur on sheet 3, field current versus field voltage.

On sheet 3, in addition to the measured field voltage a computed record of field ir drop has been drawn as curve A. Thus any departure of the measured field volts from curve A indicates field forcing. About one third through pulsing, field forcing starts actively and then levels off.

At the beginning of flat top (sheet 1) the generator current decreases to about 20% of the end of pulse value in less than 10 milliseconds. The sudden reduction in generator current reacts on the field circuit and causes a transient reduction in field current. This change is in the proper direction, but other effects take control. An increase in the voltage reference has been switched in so the regulator calls for an increase in generator voltage. On sheet 3 there are oscillatory changes in field current and field volts which take about 300 milliseconds to reach the steady values for flat top. After this time the field volts and curve A coincide showing no field forcing.

It should be noted that during the oscillatory period the field current which should be decreasing to the steady flat top value increases before decreasing. The desirable response at the change to flat top should have been a quick reduction in field current to the constant value required for flat top namely about 700 amperes. This may be where the Siemens proposal to transfer to constant field voltage would result in quicker stability. With the present limited data it is not known whether some other control would be better. It is evident however, due to periods of field forcing, the present operation is not at constant flux.

Because the more important periods for accelerator operation are the pulse and flat top not as much attention has been given to invert. During the change from flat top to invert there are similar oscillations (sheets 1 and 3). The sharp increase in generator current causes a dip in generator voltage. The field current and voltage go through oscillations seemingly in the wrong direction before decreasing to the no load value ready for the next pulse. The main interest in invert is to transfer the stored magnet energy back to the generator as quickly as possible and to arrive at the same no load voltage so the next pulse will be a duplicate of preceding pulses.

As a matter of interest sheet 7 is included which shows Siemens schematic comparison of several control methods for the change from pulse to flat top. It will be noted that their estimate of the constant flux control showed no oscillations in field current and generator voltage. As stated above, the constant flux control was never finalized by them.

Part 3

From the data on sheets 1 to 6 it is evident that during the pulse period, with the present voltage control, the generator is in a transient loading state, thus steady state analysis cannot be applied. The need, therefore, is to determine the status at the end of pulse. This will enable us to determine the desirable operating control into and during flat top.

A proposed program of testing would be:

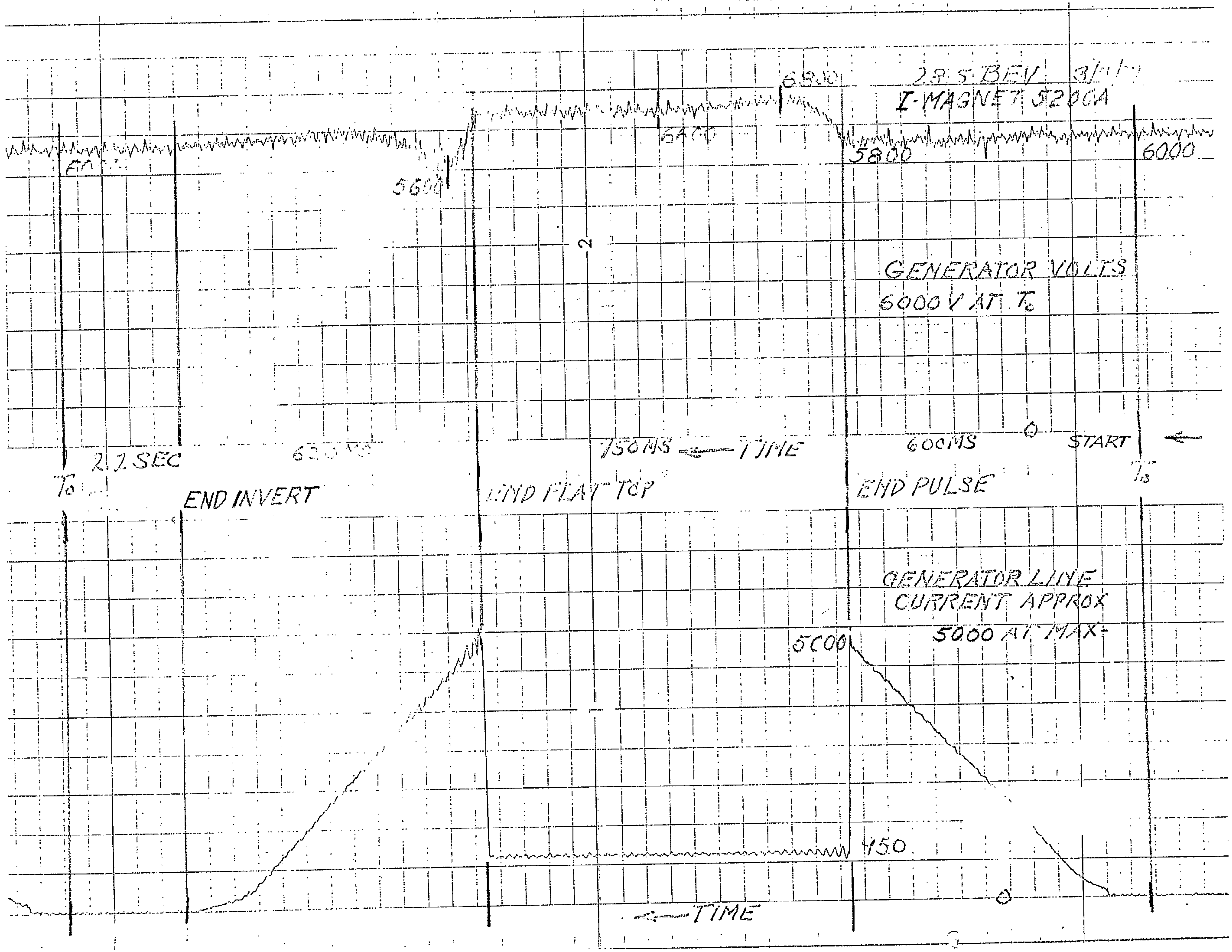
1) Set field current at no load, 7500 volt at generator terminals, and hold field voltage constant through a pulse, flat top and invert cycle. Take records of generator volts, amperes, field volts and amperes. Also magnet amperes from the pulse and flat top rectifiers.

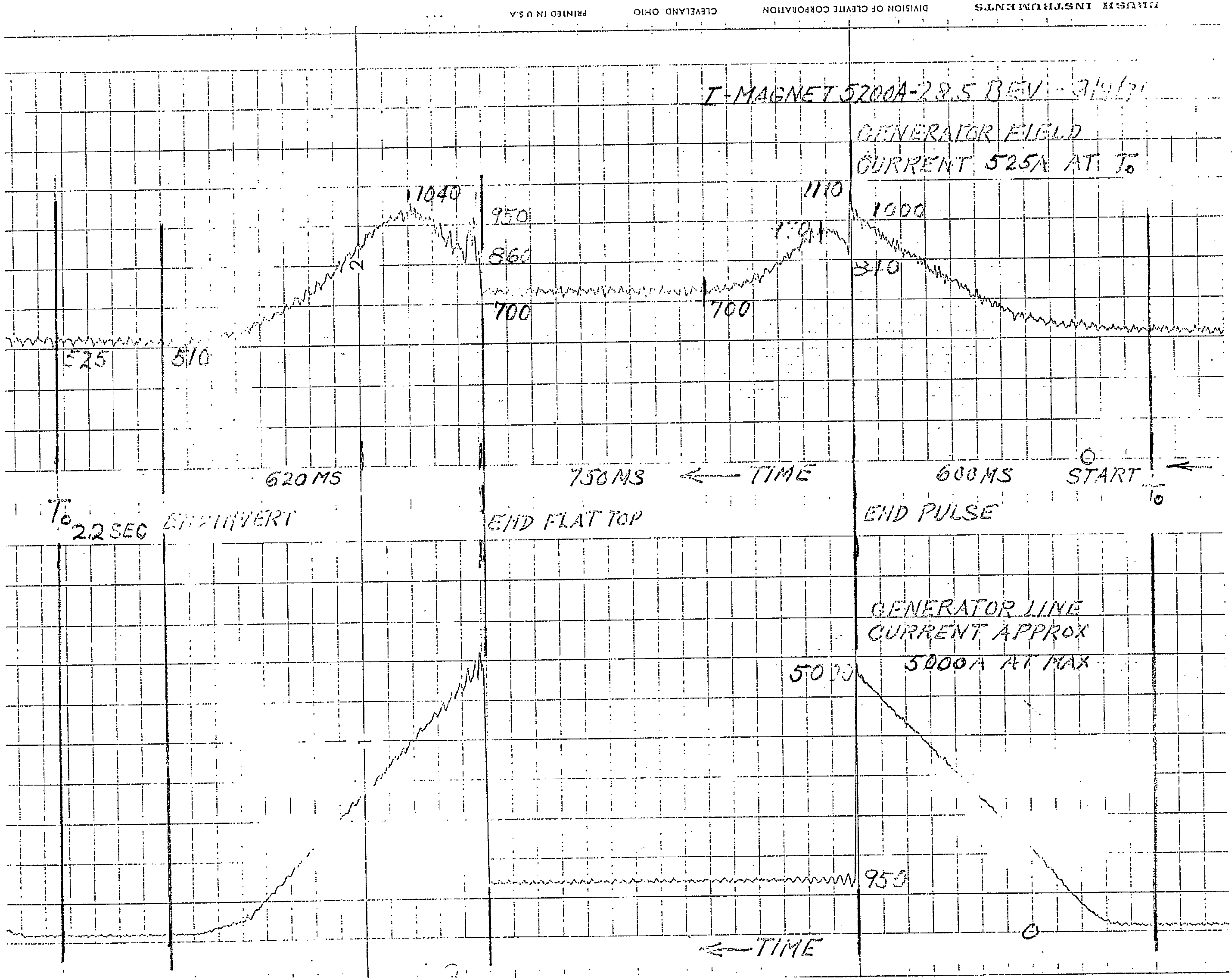
2) Use voltage regulator and introduce a negative droop (increase in reference with increase in generator current). At flat top this will lower total reference voltage due to reduction of generator current. Take same readings as in (1). Also record regulator signal to study especially the changes through flat top. This may give data for constant flux operation.

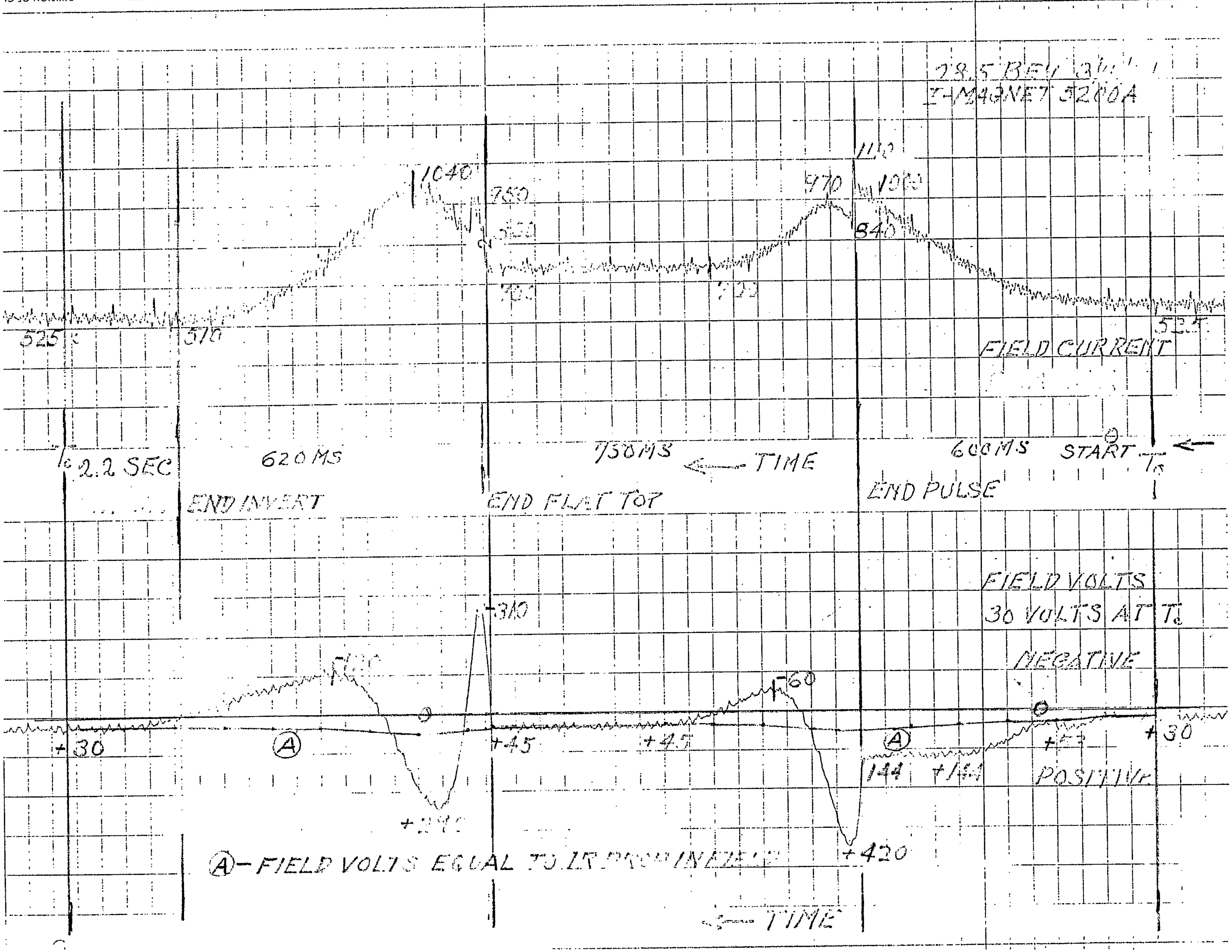
3) Repeat (2) but transfer to a constant field voltage at flat top.

A study of these results may lead to adjustments in (2) and (3) or may suggest other modes of operation.

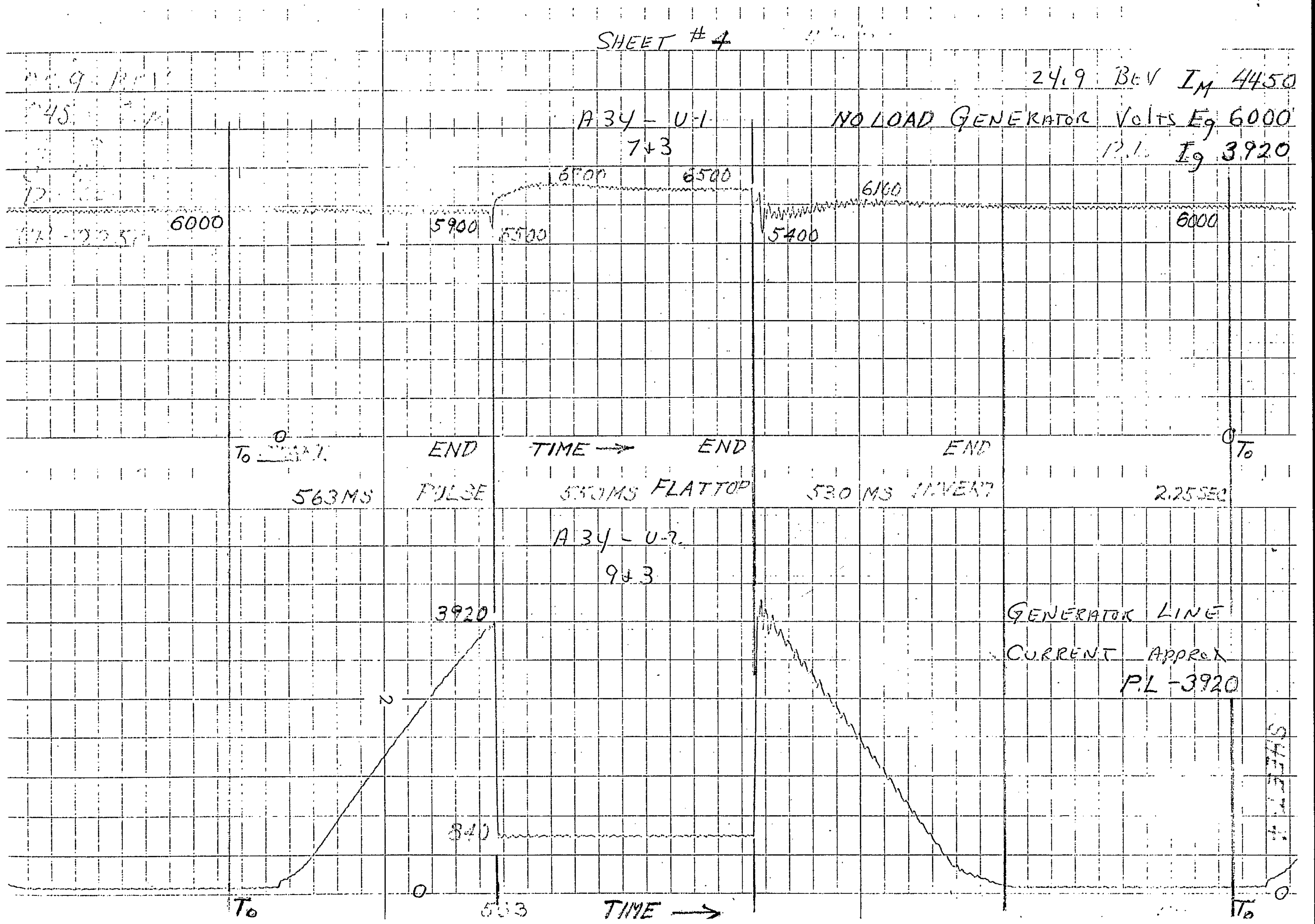
Distr: Department Administration
R. Adams
C. Anderson
D. Davis
A. Feltman
R. Gottschalk
J. Herrera
F. Humphry


28.5 BEV
I-MAGNET 5200A
6800
5400
5600
5800
6000
GENERATOR VOLTS
6000 V AT T_0
2.1 SEC
750MS ← TIME
600MS
0
START
T_0
T_0
END INVERT
END FLAT TOP
END PULSE
GENERATOR LINE
CURRENT APPROX
5000 AT MAX
5000
450
0
← TIME

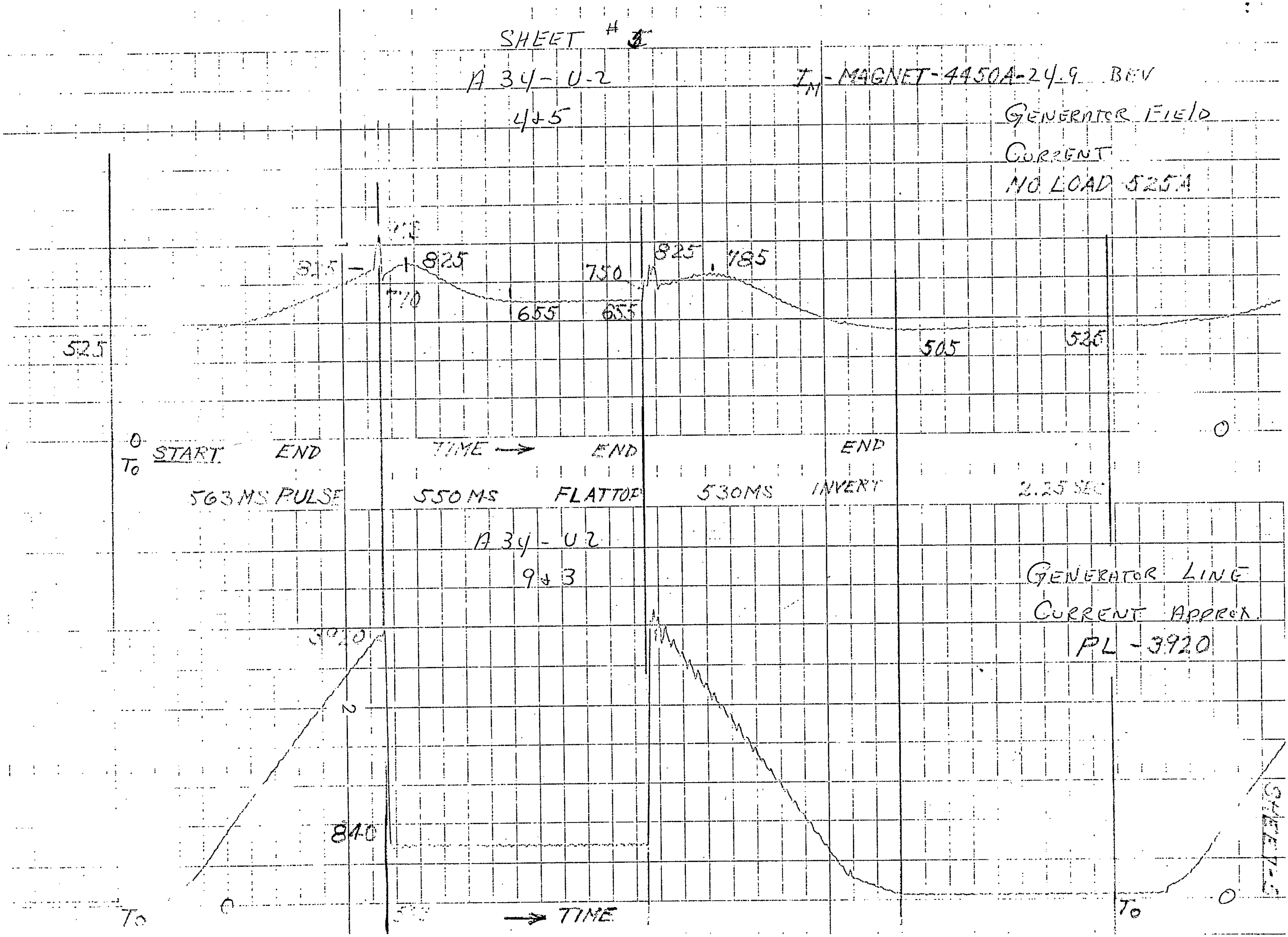

BRUSH INSTRUMENTS DIVISION OF CLEVITE CORPORATION CLEVELAND, OHIO PRINTED IN U.S.A.
I-MAGNET 5200A-29.5 BEV
GENERATOR FIELD
CURRENT 525A AT T_0
1040
950
860
700
1110
1000
810
700
525
510
620 MS
750 MS
TIME
600 MS
START
T_0
T_0
2.2 SEC
END INVERT
END FLAT TOP
END PULSE
GENERATOR LINE
CURRENT APPROX
5000A AT MAX
5000
950
0
TIME

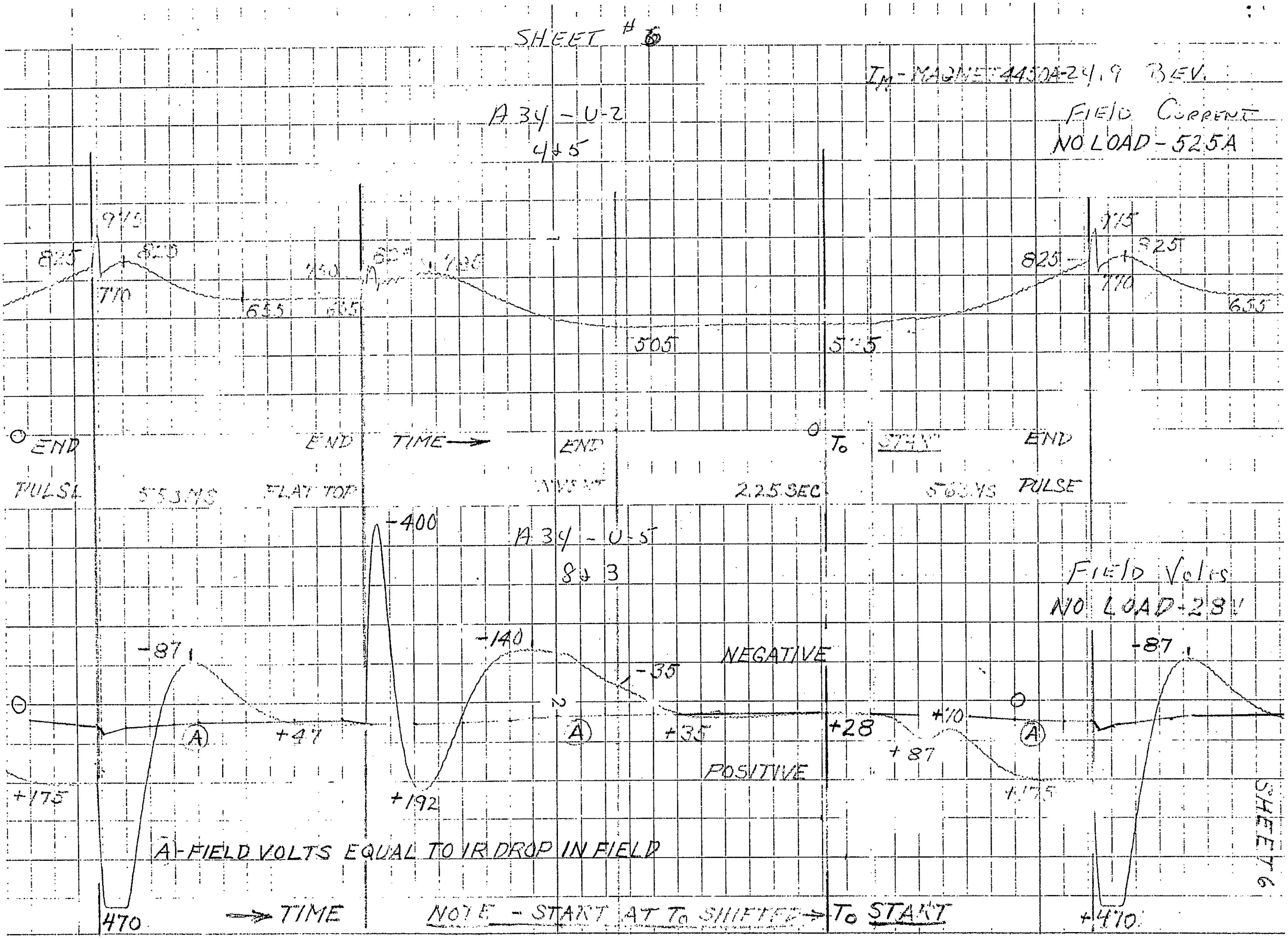

28.5 BEV
I-MAGNET 5200A
FIELD CURRENT
1040
750
970
1000
840
525
510
2.2 SEC
620 MS
750 MS
600 MS
START
TIME
END INVERT
END FLAT TOP
END PULSE
FIELD VOLTS
30 VOLTS AT T0
NEGATIVE
POSITIVE
310
60
+30
+45
+420
144
A - FIELD VOLTS EQUAL TO IR
TIME

3



SHEET #4
24.9 BeV I_M 4450
NO LOAD GENERATOR Volts E_g 6000
P.L. I_g 3920
A34 - U-1
7+3
6000
5900
5500
6500
6500
5400
6160
6000
T_o
END
TIME →
END
END
0
T_o
563 MS
PULSE
530 MS FLATTOP
530 MS
2.25 SEC
A34 - U-2
9+3
3920
GENERATOR LINE
CURRENT APPROX
P.L - 3920
840
0
T_o
TIME →
T_o
0


SHEET #
A 34-U-2
4+5
I_M - MAGNET - 4450A - 24.9 BEV
GENERATOR FIELD
CURRENT
NO LOAD 525A
815
825
770
750
825
785
655
655
525
505
525
0
0
To
START
END
TIME →
END
END
563 MS PULSE
550 MS
FLATTOP
530MS
INVERT
2.25 SEC
A 34-U2
9+3
GENERATOR LINE
CURRENT APPROX
PL - 3920
3920
2
840
0
To
→ TIME
To
0



SHEET # 6
BEV.
A34 - U-2
FIELD CURRENT
NO LOAD - 525A
825
820
770
655
505
825
770
655
END
PULSE
553 MS
END
FLAT TOP
TIME →
END
2.25 SEC
To
START
563 MS
END
PULSE
-400
A34 - U-5
8+3
FIELD VOLTS
NO LOAD - 28V
-87
-140
-35
NEGATIVE
-87
+47
+35
+28
+10
+87
POSITIVE
+175
+192
A - FIELD VOLTS EQUAL TO IR DROP IN FIELD
470
→ TIME
NOTE - START AT To SHIFTED → To START
+470
SHEET 6

FIG 2 MEETING NO 6 (7/29/68) 10/21/68

Bild 2: Verzögerte Kommutierung
CHANGE FROM PULSE TO FLAT TOP