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Test Results of BM109 Magnet Field Stability during Ramping

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Experiment E781.

This report presents results of the measured lag between the current ramp and the following magnetic field rise in BM109 magnets. The purpose of these tests is to choose identical ramping programs for PC4AN1, PC4AN2 and PC4AN3 magnets. The lag occurs due to the large eddy currents in the magnets' solid iron cores. The experiment requires a magnetic field stability of 0.1% during beam presence. Using existing equipment and a program slope of 100 Amp/sec starting at T1 yields fields within the 0.05% of set value. Add to this 0.05% for P.S. regulation to meet the required field stability of 0.1%. This program yields annual savings of $200,000 (assuming 100% usage). Additional savings can be made by using faster slopes, but this requires additional controls.

Ramping the current in the magnets is a very efficient way to save electricity, reduce the heatload, release system capacity and thus decrease the operating cost (1). The most important considerations for using a ramped current are magnetic field stability and mechanical stress experienced by the coils. For measuring the current and the magnetic field induction we used standard experimental area's data acquisition system. For the magnetic field sensing we used Metrolab group 3 Model DTM-141D gaussmeters and Hall-probes. For measurements on PC4AN1 and PC4AN3 meter #01040044 and probe #01141181 were used. For PC4AN2 we used #01040054 and #41055. PC4AN1 and PC4AN3 are BM109"MOD" type magnets with 4 coils in series and a 20" air gap, PC4AN2 is a BM109"MOD" with 2 coils in series and a 10" gap. Current settings were: 2500 Amp for PC4AN1 and PC4AN3 and 2700Amp for PC4AN2. Three different current slopes: 100Amp/sec, 200Amp/sec and 300Amp/sec were tried for each magnet. The long term current and magnetic field stability was monitored during the tests to make sure we had repeatable data since the monitoring system can only measure one parameter at a time: either the current or the field.

During the experiment some mechanical problems occurred. The PC4AN1 magnet coils moved up and down approximately 4 to 5 mm.

This problem was fixed by adding more shims. The coils of other magnets experienced some movement as well, but to a lesser degree. This difference could be explained by the way these magnets are assembled. Magnet PC4AN1 has a wooden spacer in between the coils of the same group (top pair and bottom pair), but other magnets have not. The test results for different slopes are presented on figures 1...3. The most interesting results obtained from the PC4AN3 magnet are shown on figure 3. As one can see from Fig. 3 the large current slope produces a magnetic field overshoot which results in an unnecessary coil stress. Supposedly the reason is improper adjustment of the power supply regulator. Comparing the current and the magnetic field behavior at about 10 seconds after current reaches the flattop, shows that the magnetic field flattop value comes within the needed 0.05% of the flattop value. With 12 seconds lead time of the current before the beam arrival, we are reliably within the specified margins for magnetic field. The beam spill during flattop is 23 seconds. Therefore the necessary current flattop duration must be 35 seconds.

There are two different ways to ramp the current. The first way is to use identical slopes, starting at T1. The second way is to use faster slopes, starting later than T1(see Fig. 4). The existing power supply control system for the magnet ramping can only be synchronized with the Main Ring control system events without any delays. It means that the current rise has to start at time T1 (the beginning point of every accelerator cycle). In this case the slowest possible rise time is the most beneficial. In our case this is about 100 Amp/sec. The ramping power losses in this mode, compared with the DC mode are:

$P_{100} = 70\% P_{DC}$, based on the easiest ramp program starting at T1 and shown in Fig. 5. If we would be able to add a variable delay to the T1, we could maintain the minimum current flattop duration of 35 seconds and use a faster ramp (see Fig. 4 and Fig. 5). Using a 200 Amp/sec ramp:

$$P_{200} = 63\% P_{DC}$$

Using a 300 Amp/sec ramp:

$$P_{300} = 61\% P_{DC}$$

Let's compare the power losses. With a variable delay we are able to save an additional 7% to 9% of P_{DC} but have to add the cost of either modifying the existing power supply control cards or adding extensions to them. To judge if this modification seems reasonable we have to estimate the expenses and savings. Estimate that the cost of 1 KWHr of power losses including the cost of cooling required to remove 1 KWHr is $0.08 (Ref.#1). From this we can calculate savings, based on the requirements for experiment E871 for the magnets, described above:

for PC4AN1 and PC4AN3 P_{DC} = 375 KW @ 2500 Amp

for PC4AN2 P_{DC} = 206 KW @ 2700 Amp.

For all three magnets together P_{DC} = 956 KW.
Using, for example, 100 Amp/sec current ramp we could save:

$P_{SAVE} = 0.3*956 = 286.8$ KW,

which yields $22.94 savings per hour. Using all three power supplies 24 hours a day we can save $550.66 a day. Assuming that we are going to use these magnets only 30% of a year we could save $60,297 per year. The same speculations for the 200 Amp/sec ramp speed give us an additional $14,000 savings a year. Using 300 Amp/sec slope we could save an additional $18,000 (compared with 100 Amp/sec). It is difficult to estimate the cost of the required power supply controls modification at this moment, but it seems to me that it would be less than $14,000 per three units. The final decision has to be made based on the projected schedule for the Fixed Target runs. I would suggest to investigate pros and cons of a modified control and test it.

REFERENCES:

1. A.T. Visser, Ramping of solid iron analysis magnets in experimental areas. BM109 preliminary results. TM #1509 9204.000, January 1988, Fermilab, USA.

ACKNOWLEDGEMENT:

Testing was set up by J. Lentz and PS Technicians.

$P_{DC} = I(f)^2*R_{LOAD}$, $P_{100} = I(100)^2*R_{LOAD}$.

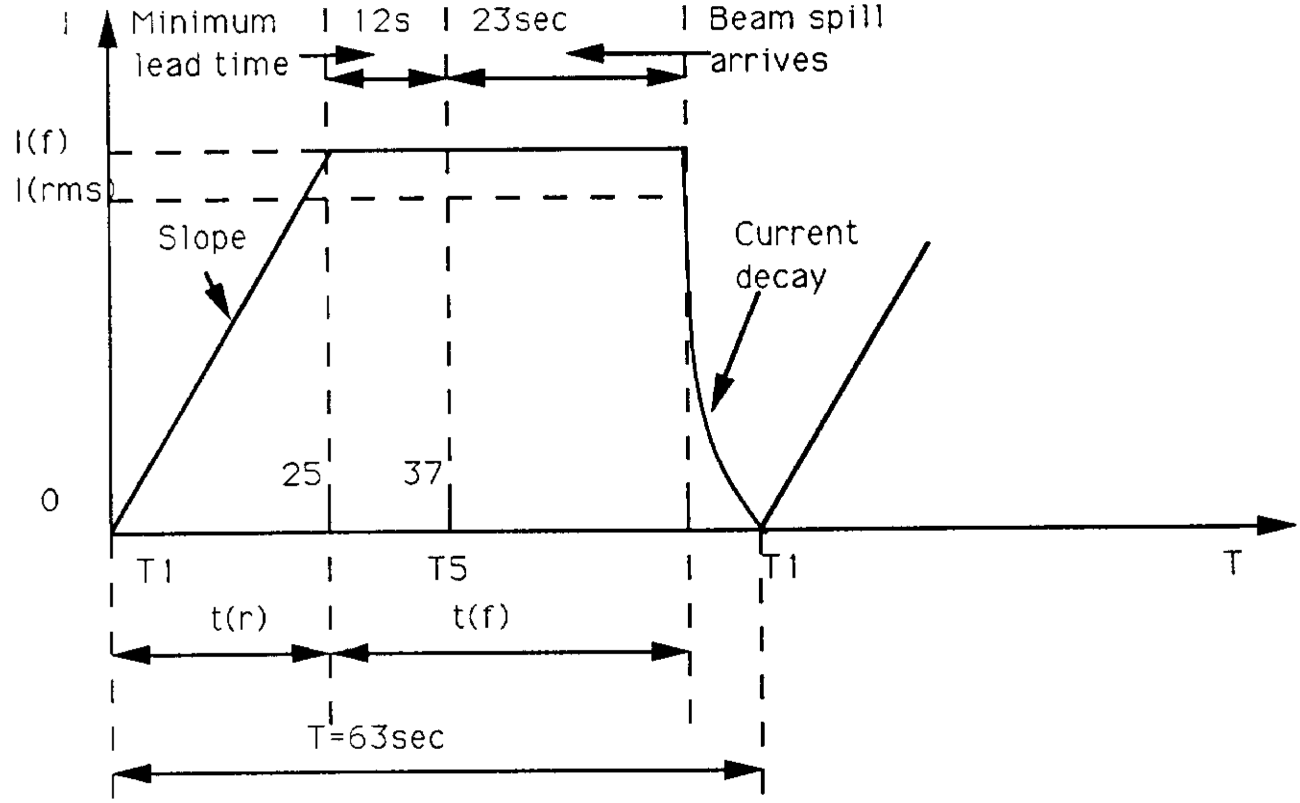


Fig. 5

Typical rampprogram for BM109.

T - pulse period

I(f) - peak flattop current

I(rms)-RMS current value of pulse train

t(r)-current risetime, depends on slope and I(f), 25 sec maximum

t(f)-flattop duration, fixed at 35 sec

τ - current decay time constant.

$$I(rms)=I(f)\sqrt{\frac{t(r)/3+t(f)+\tau/2}{T}}$$

I(100)- RMS current value of pulse with 100 Amp/sec slope

P_{DC} - DC power losses

P_{100} - ramped power losses with 100 Amp/sec slope.

For 100 Amp/sec slope and I(f) = 2500 A,

$$I(100)=I(f)\sqrt{\frac{25/3 + 35 + 0.5}{63}}$$

I(100) = 0.834*I(f)

P_{100}/P_{DC} = 0.695.

For 200 Amp/sec slope and I(f) = 2500 A we need 1/2*t(r) and

I(200) = 0.793*I(f),

P_{200}/P_{DC} = 0.629.

For 300 Amp/sec slope and I(f) = 2500 A we need 1/3*t(r) and

I(300) = 0.779*I(f),

P_{300}/P_{DC} = 0.607

100 Amp/sec

PC4AN1

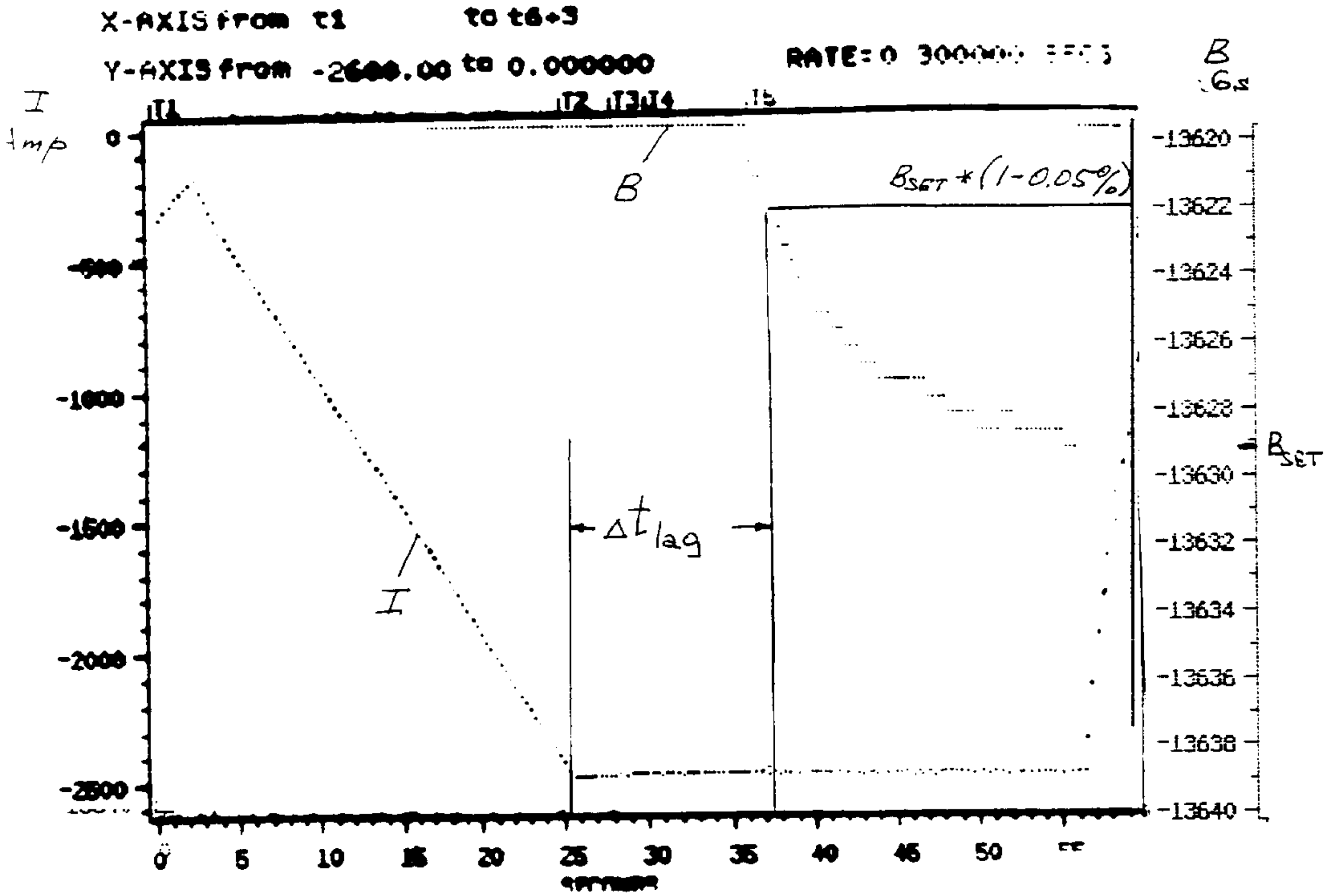


Fig. 1

200A/sec

PC4AN2

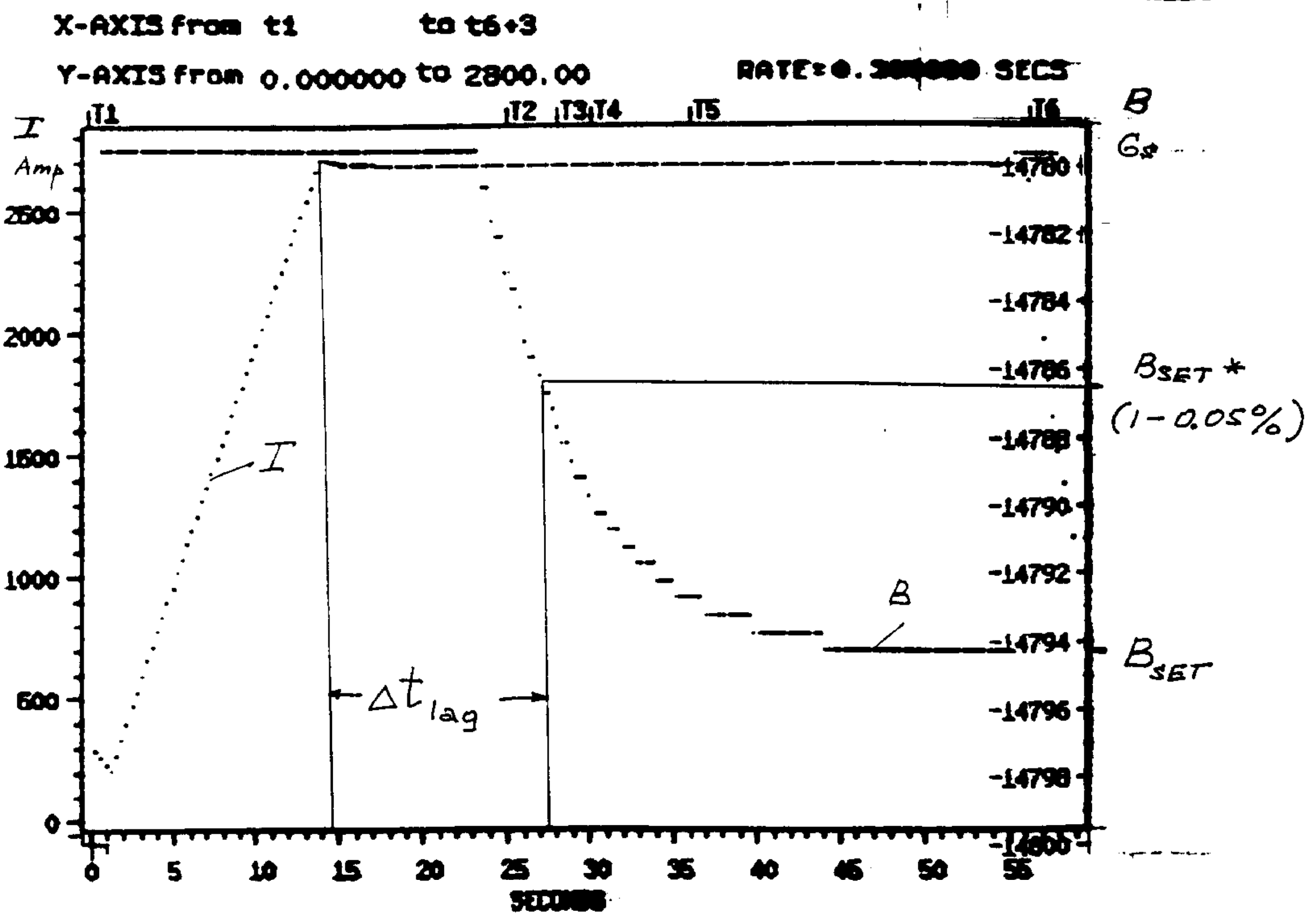


Fig. 2.

300 Amp/sec

PC4AN3

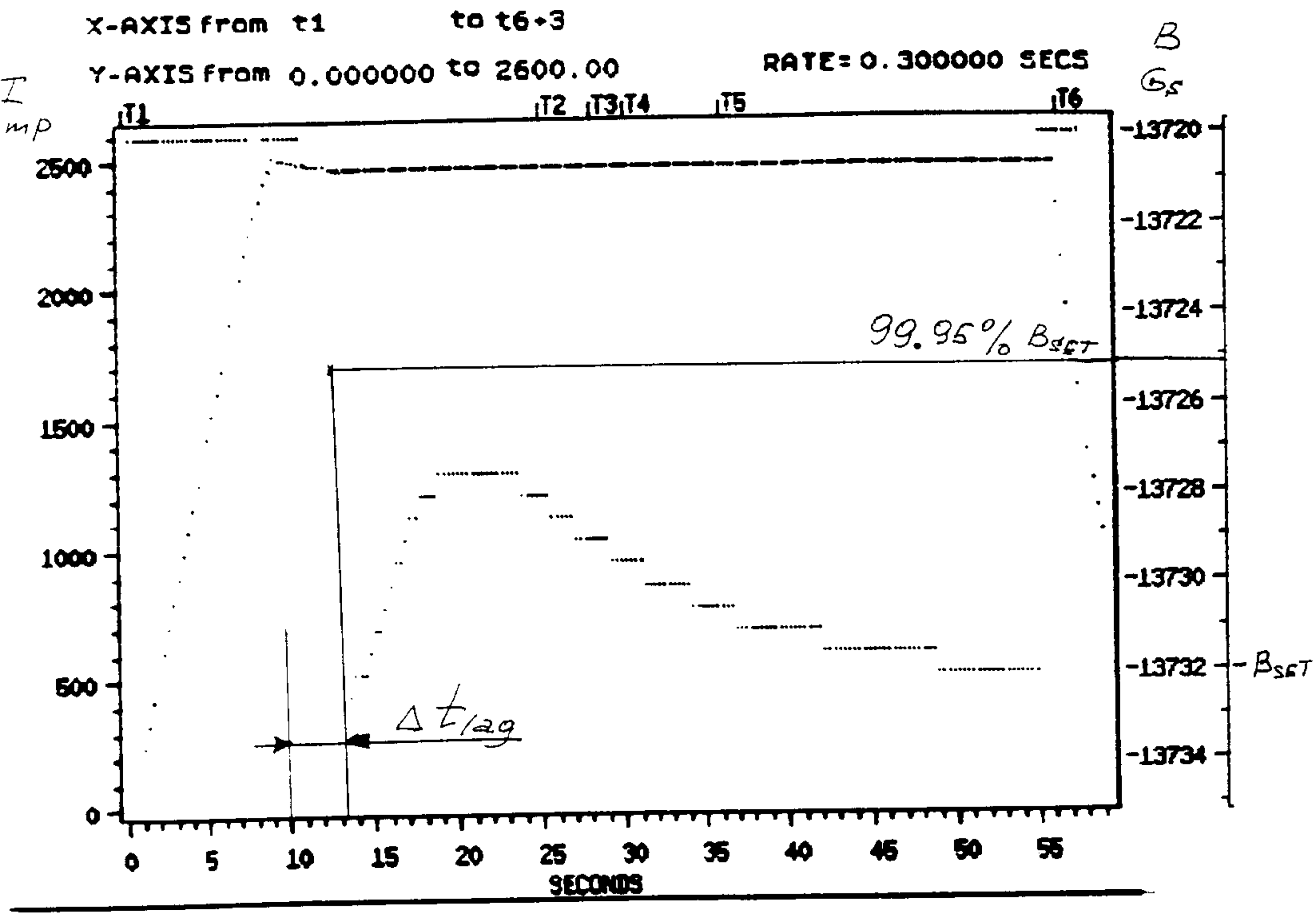
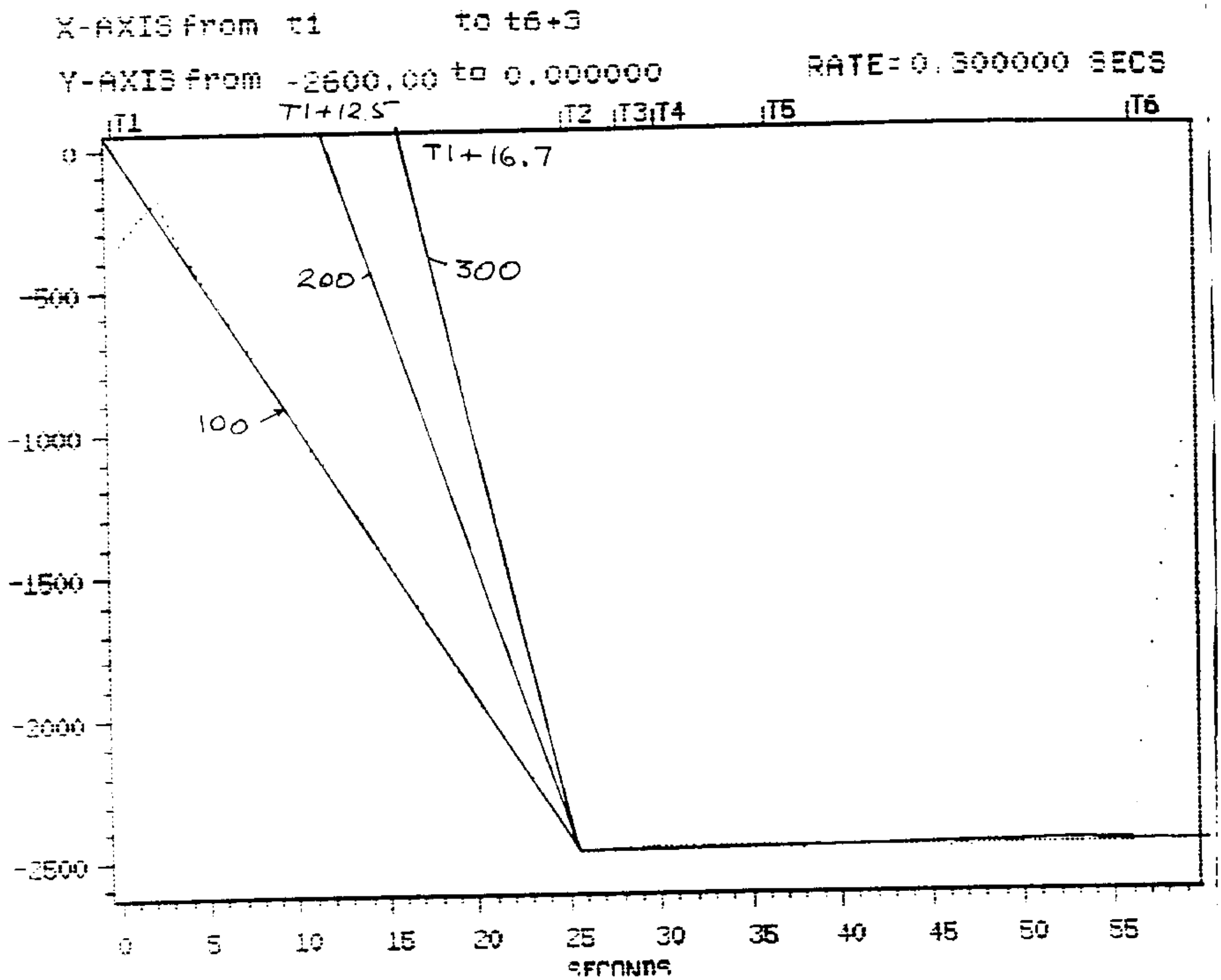


Fig. 3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Y-AXIS from -2600.00 to 0.000000
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T1
T1+12.5
T2
T3
T4
T5
T6
T1+16.7
100
200
300
0
-500
-1000
-1500
-2000
-2500
0
5
10
15
20
25
30
35
40
45
50
55
SECONDS

Fig. 4