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NEUTRAL BEAM WAVEFORMS

Real Time Systems Group

July 1982

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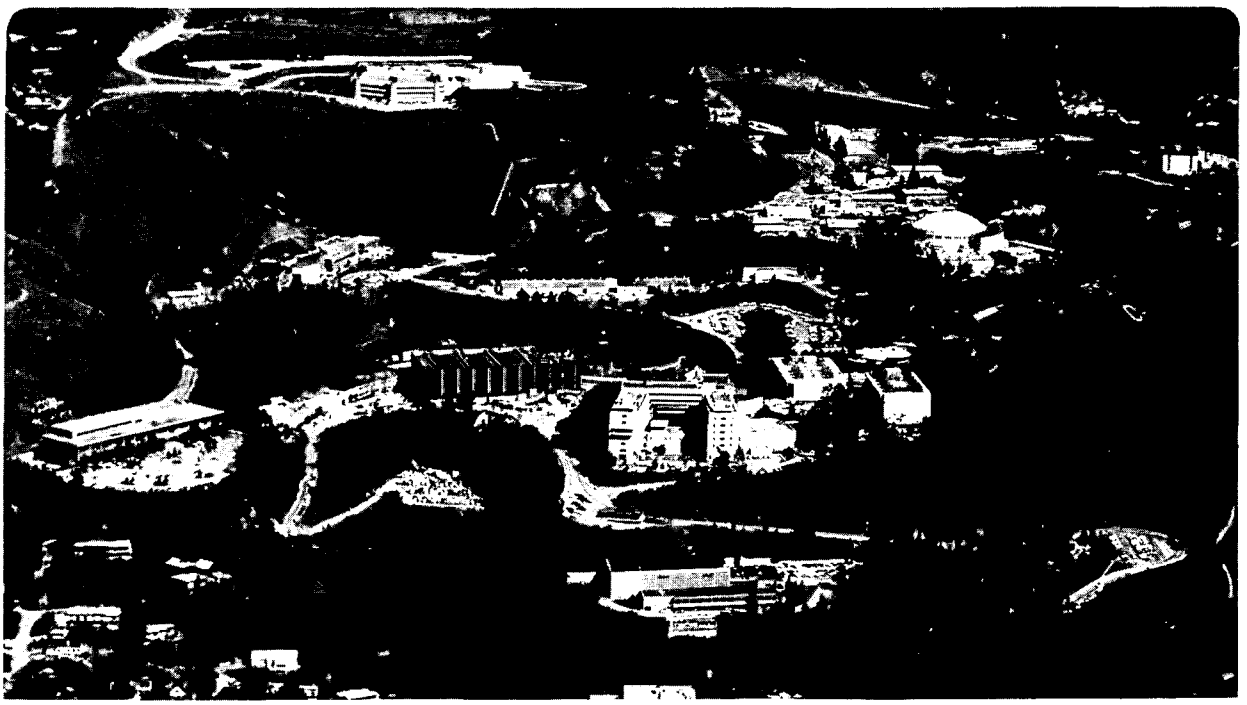

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Neutral Beam Waveforms

Real Time Systems Group

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Neutral Beam Waveforms

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1. Overview

The waveform data from a neutral beam can be divided into two classes: power system waveforms and source waveforms. The power system waveforms are unique to a particular power supply configuration and are generally supplied and used by the power system engineers or vendor. Source waveforms must monitor currents and voltages at the source. (Line losses, snubber effects, etc., generally make power supply waveforms useless for monitoring source behavior). The source waveforms are the primary monitors for both the operator, the fault detection system and the computer auto-conditioning, source modelling and power supply control programs. Since these monitors generally evolve thru neutral beam operating experience, there is a chance that some of them have been omitted in the PPPL system or are present in some early (and unsuccessful) form. Note especially that the computer control and auto-conditioning programs expect exactly the set of source monitors described here.

2. Source Waveforms

The source waveforms consist of:

- Accel current and voltage
- Total arc current to source (sum of all three anode currents) and average arc voltage (average of anodes 1 and 3).
- Filament current and voltage
- Gradient Grid current and 1st Gap voltage (V12 or the Gradient Grid voltage referenced to Vaccel).
- Suppressor current and voltage. The suppressor doesn't require high accuracy so its "slow" monitors (see below) are taken at the power supply.

- Plasma probe currents (from the eight Langmuir probes).

- Strobe (A "gate" waveform that indicates the "on" period for the beam. It is generated by some digital logic using, basically, the logical "and" of the Beamrequest timer and the complement of the Interrupt timer.)

The source behavior is looked at in two different ways: a "slow" digitizer is triggered at Arc turn-on and looks at all of the above waveforms with 1ms resolution for the entire shot (about 1 sec.). Two fast digitizers look at particular events and at most of the wave forms with about 1 microsecond resolution over a small window centered at the event (500 microseconds on either side). One of these digitizers is triggered at the first accel turn-on and is used to adjust the Arc Notch timing and shape so the accel and arc signals will be "matched". The other is triggered at the first turn-off (usually the first interrupt) and is used to determine the cause of the interrupt. The slow waveforms are used by both the operator and the computer programs, the fast waveforms are used only by the operator at present.

In general, the same transducer can't supply both fast and slow data and many of the source signals actually consist of two monitors, one for the "full shot" data (e.g., a current shunt) and one for the fast event data (e.g., a current transformer). The instances of duplicate monitors are:

- Gradient grid current: a hall-effect device looks at the "slow" behavior, a current transformer looks at the fast behavior.

- Supressor current: a shunt for slow data; a current transformer for fast data.

- Supressor voltage: a resistive divider for slow behavior; a capacitive divider for fast.

3. Problems

There have been two major problem areas for the waveform subsystem.

- Longterm Stability: the source models and computer controls require that their monitors be stable and repeatable to about 1% over a period of weeks or months. Gain and offset drifts in various stages (Signal conditioner, digitizer, telemetry, etc.) required the installation of an end-to-end computer controlled calibration system. This solved the problem.

- Poor Compensation: most of the high voltage transducers must be precisely compensated. If they are not, the overshoot or undershoot "fools" the waveform averaging and causes the resulting average to be dependent on the number of interrupts and the length of the shot. While we've made some improvements by shortening cable runs and changing transducers, this is an ongoing problem.

Finally, one early mistake was to assume that all the signals would be unipolar, and our hardware was set up accordingly. In practice, there are so many different "grounds" that any abnormal operation (e.g., a spark-off) can change the polarity of a signal. Thus, the hardware should be set for bipolar operation.

Waveform Averaging -- An Overview

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1. What It Is and Why It's Needed

By **"waveform averaging"** we mean the reduction of digitized waveform data from many thousands of values per shot to a small set of scalars that convey most of the essential information about the waveform. At NBETF, for example, 80 or more waveforms are acquired on each shot by the control computer through digitizers. These approximately 80,000 sampled values (1000 per waveform) can then be reduced to 240 scalars (three per waveform) by computing an average value and a "high" and "low" deviation from the average. The deviation numbers (expressed as a percentage of the average) then give an indication of the presence of ramping or spikes, while the average value is used in a variety of applications, as explained below. (Note that the claim is not made here that averaging satisfies the need to look at the full waveforms, a capability also supplied by the control system (Ref.1). Nevertheless, for many of the computer-assisted diagnostic and control functions, the three scalars suffice).

For a physicist or neutral beam operator used to receiving analog information (typically scope traces), the usefulness of - much less the need for - waveform averaging may not be readily apparent. In fact, it serves a variety of purposes, ranging from simple convenience to absolute necessity if certain functions, such as automated power supply control or computerized fault monitoring are to be accomplished. For example:

- The mere availability of these numbers on an ongoing basis serves as a useful and compact record for data logging. Figure 1 shows the averages of 10 important waveforms displayed with other information on a schematic of the beamline. This data refers to only one shot.

- If the averages are archived, trends and modes of operation can be identified. Figure 2 is a graph of the average values of the accelerator voltage for a sequence of 78 shots. The 78 associated waveforms would be almost impossible to deal with en masse, but the single graph quickly shows the principal trends

during those shots: starting at 90 KV, the accel voltage rose (shots 35-40) to 100Kv, then to 105Kv and so on. The ability to quickly and easily generate graphs like this one plays an important role in establishing source behavior, operational efficiencies and other matters of both scientific and budgetary interest.

- Certain computer generated operational aids need the averages. Fig 3 is a good example of an aid that had been performed manually prior to its automated version. In its manual mode, it slowed up the tuning process by perhaps a factor of 3, and was not as accurate or complete. Thus, waveform averaging in this instance is more than just a convenience; the reduction of data permits the quantification of beam behavior, the generation of accurate operator aids, and increases the number of shots per unit time, which itself can be translated into number of shots per dollar.

- The plasma probe diagnostic (fig. 4) is a similar example. In this case, the eight probe waveforms are reduced to the eight numbers plotted on the graph and listed in the table. Note the small vertical lines at each probe value on the graph. These are the "error" bars obtained from calculating the deviations from the average value. Their smallness indicates that the probe waveforms were relatively flat and not noisy during the averaging. Such graphs and tables have in the past been generated by hand, at the cost of significant operational time and accompanying inaccuracies.

- Generation of source model data (fig. 5) is clearly impossible without the waveform averages. That is, quantified information from the waveforms must be available to the models. Thus the entire source control scheme depends on the availability of the averages.

- Fault detection (anomalous conditions in waveforms) will depend in part on examining the averages and error bars of critical waveforms.

2. How Waveform Averaging is Accomplished at NBSTF

We decided that, rather than have the averaging take place on an adhoc basis in different tasks (programs) with different code, there would be a single waveform task. It can and is run several times during a single shot cycle. Some waveforms are always averaged (e.g., those on fig. 1), while others may be averaged only upon specific external request (e.g., pressing a menu button). Each time the task

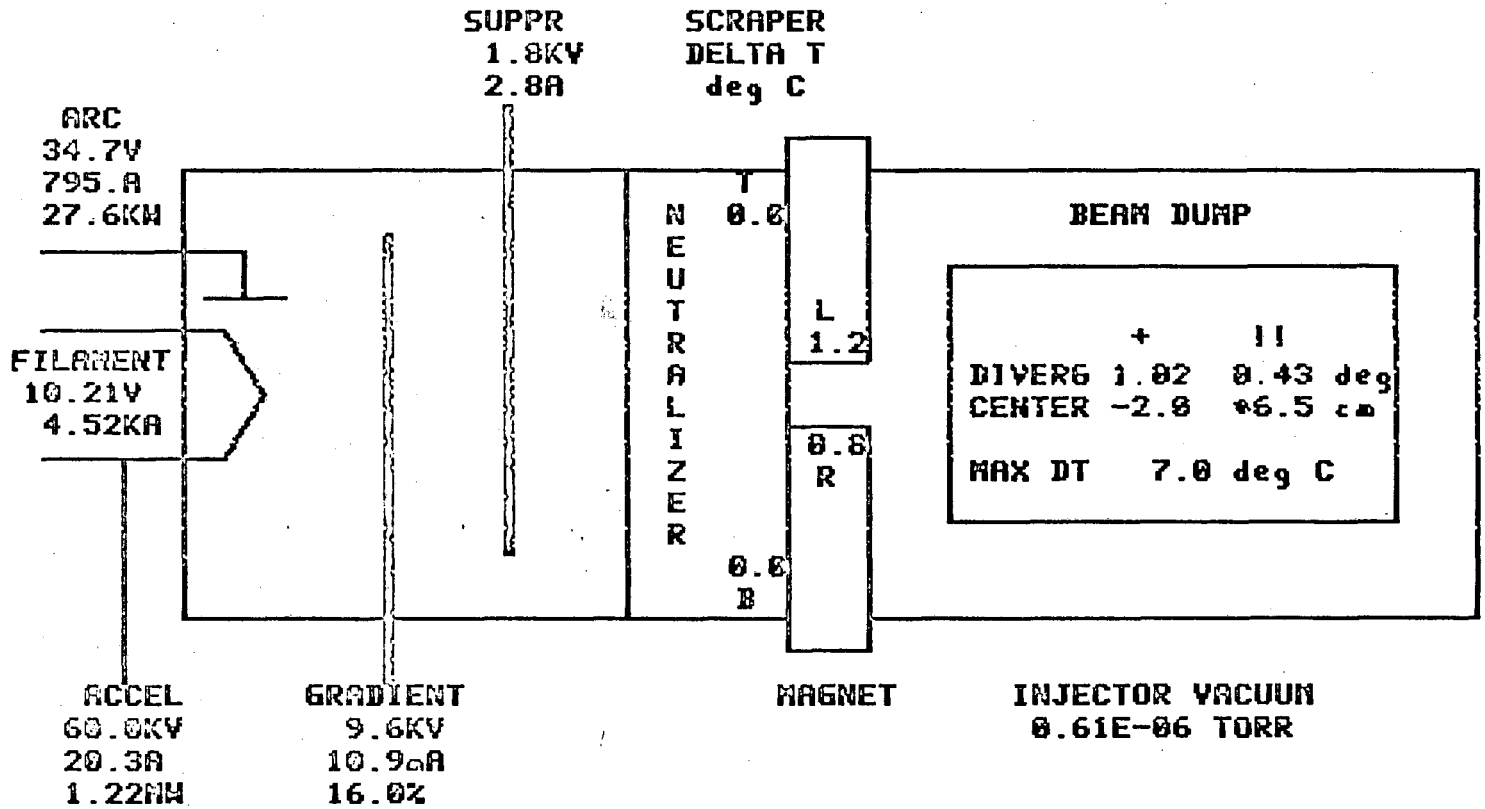
is activated, it uses its "wakeup" message to form the correct name of a file which contains the names of all the waveforms to be averaged at that time, as well as pertinent information about the wave form: number of digitized samples, sample rate, slope and offset for conversion to engineering units from raw values, etc.

The beam (and therefore many of the waveforms) is subject to interrupts. During the duration of the interrupt, typically 25 milliseconds, the waveform values drop to essentially zero. Thus, the interrupts are to be avoided during the averaging. We use a "gate" waveform ('strobe' for us), with a particularly clean signal (resembling a pulse train) to test when the beam is up or interrupted. While it's up, the waveforms are averaged. At the same time, an eight point moving average is kept. At the end of the process, the wveform average, X, and the highest and lowest of the moving average values expressed as percentages of X) have been calculated and stored in the data base for use by other tasks. The arithmetic involved is of course trivial. However, if many waveforms are to averaged during a shot, the amount of time involved may be significant and should be taken into consideration.

3. Reference

Neutral Beam Waveforms, in this volume.

SHOT #64741 SHOT SUMMARY 08/24/81 20:43



281.7mS BEAM ON TIME (100.% OF 281.7mS)
1 INTERRUPTS

Figure 1

V-ACCEL DURING AUTOCONDITIONING
August 14, 1981

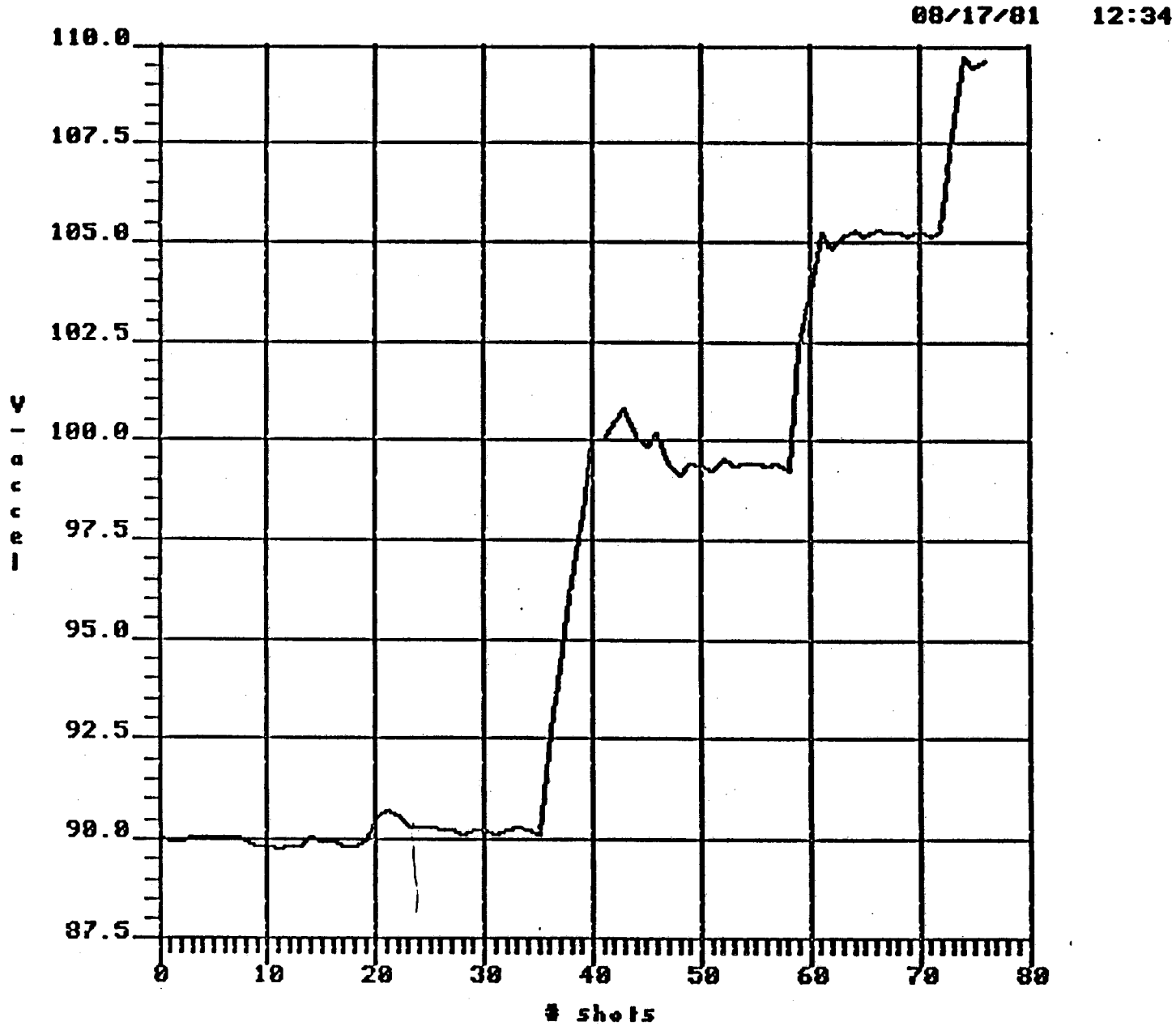
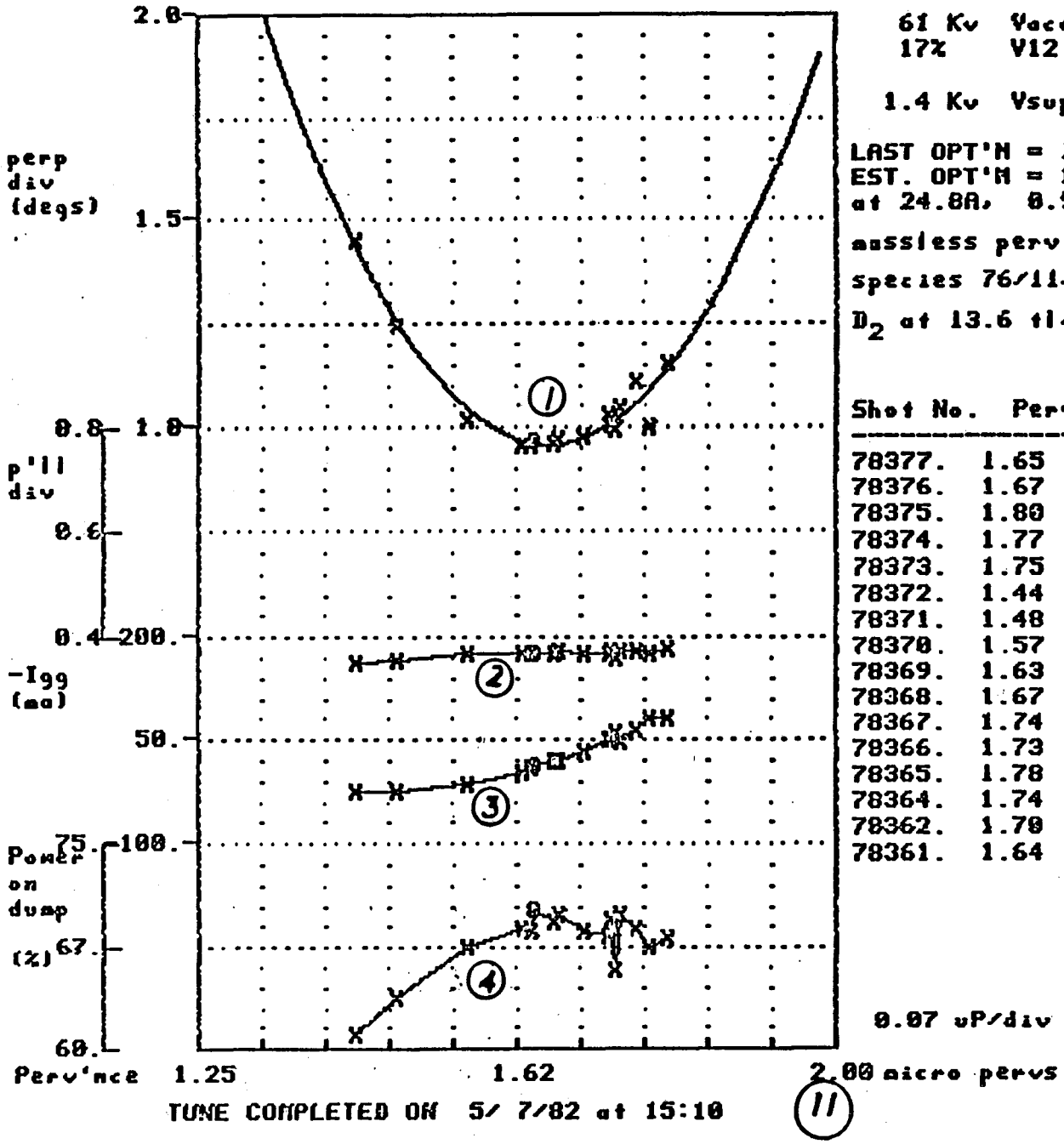


Figure 2

TUNING CURVES



61 Kv Vaccel
17% V12 (5)

1.4 Kv Vsupp

LAST OPT'N = 1.66 uP (6)
EST. OPT'N = 1.66 uP (7)
at 24.8A, 0.96 degs

massless perv 2.67uP (8)

species 76/11/12

D_2 at 13.6 tl/s (9)

Shot No.	Perv	Iacl
78377.	1.65	24.5
78376.	1.67	24.8
78375.	1.80	26.6
78374.	1.77	26.1
78373.	1.75	25.7
78372.	1.44	21.4
78371.	1.48	22.1
78370.	1.57	23.2
78369.	1.63	24.2
78368.	1.67	24.8
78367.	1.74	25.8
78366.	1.73	25.9
78365.	1.78	26.6
78364.	1.74	26.1
78362.	1.70	25.3
78361.	1.64	24.3

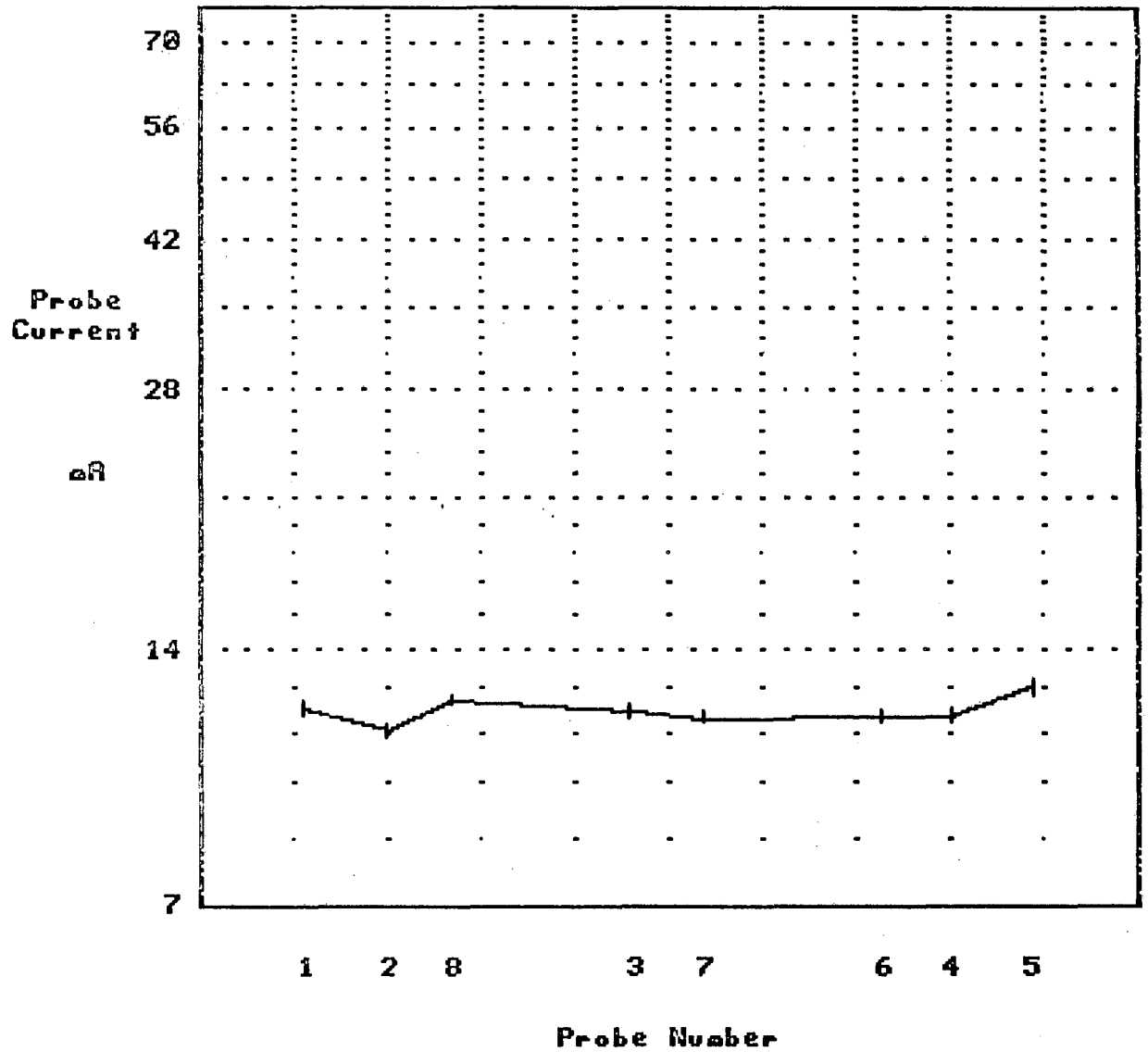
(10)

0.07 uP/div

TUNE COMPLETED ON 5/ 7/82 at 15:10 (11)

FIG. 3

SHOT #64741 **PLASMA PROBE PROFILE** 08/24/81 20:43



0	mA
1	12.0
2	11.2
8	12.2
3	11.8
7	11.6
6	11.7
4	11.6
5	12.6

Avg=11.8 mA

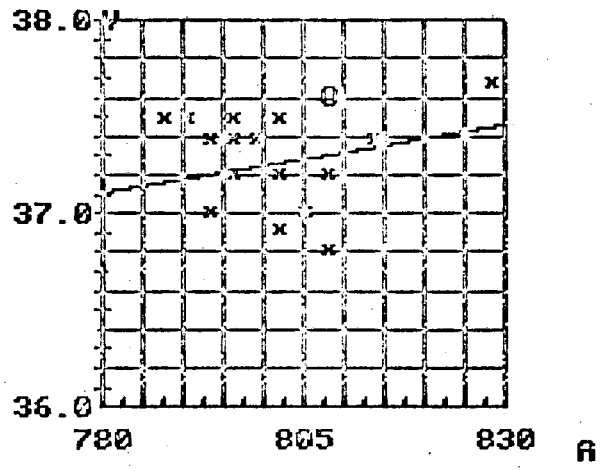
$$\frac{\text{Max}(5)}{\text{Min}(2)} = 1.12$$

Fig. 4

SOURCE MODELS

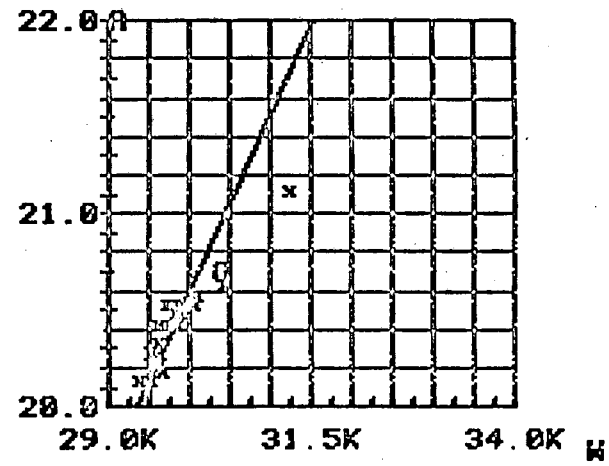
SHOT #44700 08/24/81 16:39

V-arc vs. I-arc



V-arc = 0.0071Iarc + 31.59

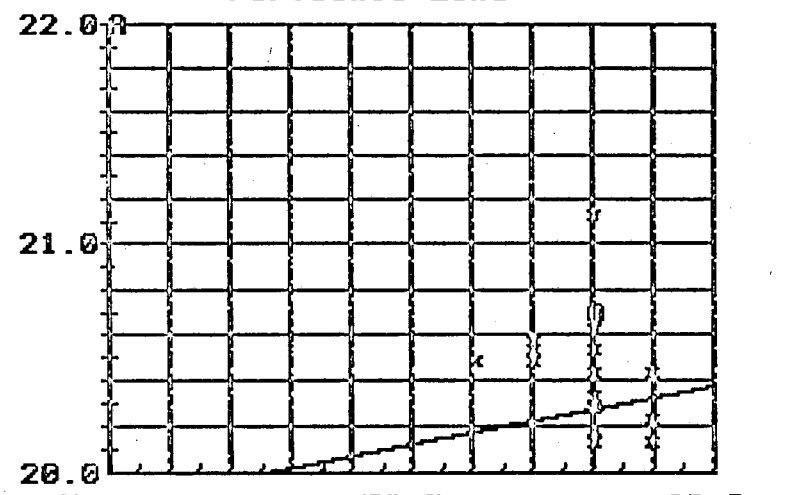
I-accel vs. Arc Power



Iaccel = 0.916E-03Parc + -6.903

I-accel vs. V-accel

Perveance Line



Iaccel = 1.39uP(Vaccel**1.50)

Fig. 5

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