SNS Extraction Kicker BPFN Output Current Waveform For Low ì Ferrite Magnet Current

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SNS Technical Note

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Abstract

A SNS proto type Extraction Kicker High Voltage Pulse Modulator (HVPM) has been built and tested. At this point it has been tested to 35kV at a repetition rate of 60Hz at 2.4 kA. This technical note will discuss the modulator pulse output waveform using a low ì ferrite magnet load.

Introduction

The SNS accumulate ring extraction section will utilize fourteen pulsed ferrite kicker magnets. Each of these magnets will be energized by its own high voltage pulse modulator. The basic configuration of the HVPM is a lumped element Blumlien pulse forming network (BPFN). The BPFN consists of two lumped capacitive / inductive networks simulating series transmission lines. The prototype BPFN is installed in an aluminum tank using silicone fluid as a dielectric and cooling agent. The high voltage and high current pulse is transmitted to a prototype low ì ferrite magnet by two 50 Ù coaxial cables connected in parallel. A capacitor charging power supply is used to charge the PFN to the correct operation voltage. An EEV (Marconi) thyratron is used as a high voltage switch to discharging the BPFN and produce a traveling wave in the Blumlien PFN which is than transmitted to the magnet load.

Extraction Kicker Current Waveform Requirement

1. Pulse rise time: 200nS from 1 to 95 %, 250nS from 1 to 99%

The beam extraction gap in the SNS accumulation ring will be approximately 250nS. In order to cleanly extract the proton beam from the ring the extraction magnet field must rise within the extraction gap during this 250 ns gap. The kicker current rise time from 1 to 95% is therefore specified to be 200nS. And the kicker current rise time from 1 to 99% is specified to be 250nS.

2. Pulse flat top width: 650nS

Because the accumulate ring RF system will operate at 1.188MHz; the beam obit rotation time is 841nS. Since the beam extraction gap is 250nS, the extracted beam's pulse length will be 591ns. In order to insure reliable extraction the BPFN was designed to have a 650ns flattop.

3. Pulse flattop ripple: less than 5% of the peak pulse current

BPFN First Article Waveform Tuning

In order to produce an acceptable output pulse and optimize performance the BPFN required tuning after assembly and during the testing process.

A saturating inductor was installed between the PFN output and matching resistor. The saturating inductor is consists of ferrite rings. The function of this saturable reactor is two fold, 1) it reduces the impedance the beam sees looking into the BPFN and, 2) it sharpens the high voltage modulator output pulse rise time. There is a trade off in how fast this reactor increases the rise time and the flat top ripple of the output pulse. The behavior of this reactor varies with the output current level so the system must be tuned near operating voltage and current. The prototype modulator was tuned at 35kV/ 2.4kA, the magnet design operating voltage and current.

The waveform tuning has to be done very careful and methodically. It is an iterative process that requires small changes being made and then retesting the system. This process is repeated several times before optimum tuning is achieved. The prototype BPFN was run in air between tuning adjustments in order to speed the process. In order to avoid thyratron damage during operations in air it was run at low pulse repetition rates (0.4 Hz) with good thyratron cooling.

An actual kicker prototype magnet was used as the high voltage modulator load. This magnet was made with very low ì ferrites. The kicker magnet was installed in a stainless steel vacuum vessel operating at around 1x 10^{-6} Torr. The kicker magnet inductance was measured to be 1.1ìH.

BPFN Tuning Waveform

The following waveforms show the result of the tuning process.

The magnet current waveform is shown in figure 1. The peak magnet current is 2.4 kA. The pulse rise time waveform is shown in figure 2. In this picture, the pulse amplitude is 100% from dash line to dash line. A 200 nS rise time was obtained from 1% to 95% of the peak current amplitude. Figure 3 shows the pulse flattop width of 750nS. The pulse flattop ripple waveform, which is less than 1 %, is shown in the figure 4. Figure 5 shows that the pulse current amplitude varies linearly with the BPFN voltage. Five current waveforms were measured with five different charging voltages of 15kV, 20kV, 25kV, 30 kV and 35 kV. These waveforms show that the pulse rise time increases 80 nS along when the charging voltage increases 20 kV.

These waveforms meet the specified requirements. The measured waveform parameter are listed:

Test voltage: 35kV

Pulse peak:	2.4kA
Pulse repetition:	0.4Hz
Load:	Low ì ferrite prototype magnet, 1.1ìH
Pulse rise time:	200nS from 1 to 95% of pulse peak amplitude Less than 250nS from 1 to 99% of pulse peak amplitude
Pulse flattop:	750nS
Flattop ripple:	less than 1% of pulse peak amplitude
Pulse fall time:	400nS

High Voltage Modulator Full Power Test

The high voltage modulator prototype was tested at full operating power, 35kV 60Hz repetition rate, and 2.4 kA for more than 100 hours continuous. The modulator was tested at 40kV, 60 Hz, and 2.8 kA for one day. The total accumulate hours at or above operating conditions has been over 200 hours.

The original scheme to cool the BPFN was to circulate water outside the tank through cooling tubes. This method proved inadequate. The present system circulates oil through an external water to oil heat exchanger and has worked very well.

The low ì magnet current waveform is shown in the figure 7. The pulse rise time is still the same (203 ns) as tuning waveform obtained in air. There is a small increase in flattop ripple between the tuning waveform and operating test waveform. In figure 8 it can be seen that the pulse flattop ripple has increased from less than + / - 1 % to approximately + / - 2%.

Next Step Test Schedule

The next series of tests will be to examine the modulator performance at increased voltages. The goal of these tests is to determine the operating margin of the modulator and to identify possible weak spots. These tests will be done in two stages, 1) the unit will be run at 40 kV at a 60 Hz repetition rate and will for one to two weeks, 2) The voltage will be increased to 45kV, but with low pulse repetition for approximately one week.

Acknowledgement

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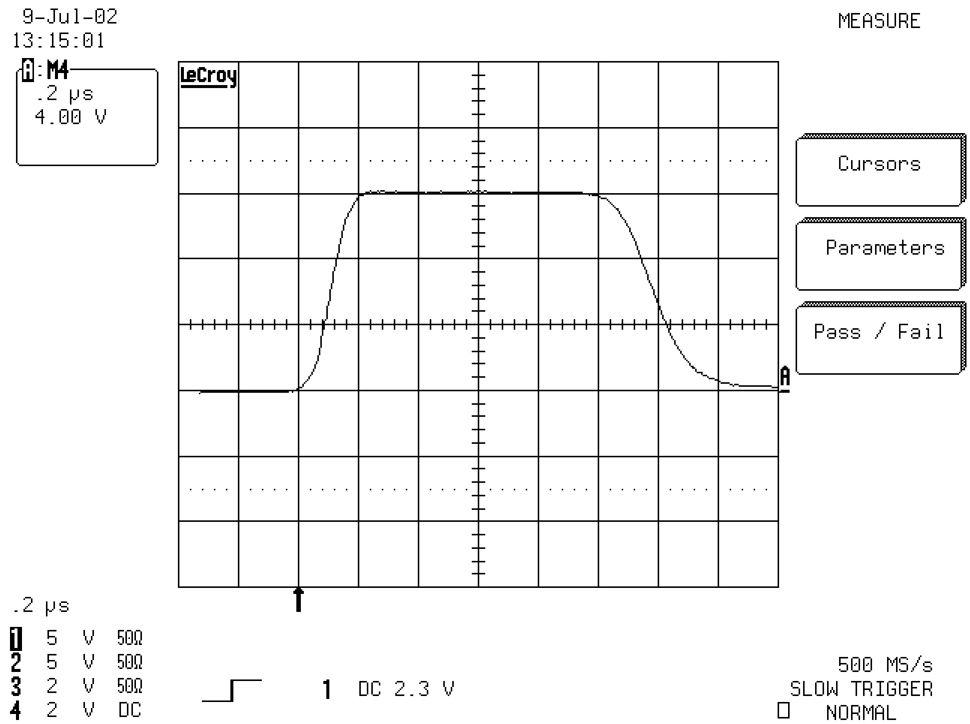

Figure 1. Magnet load current tuning waveform
Peak current 2.4kA (800A/div, 200nS/div)

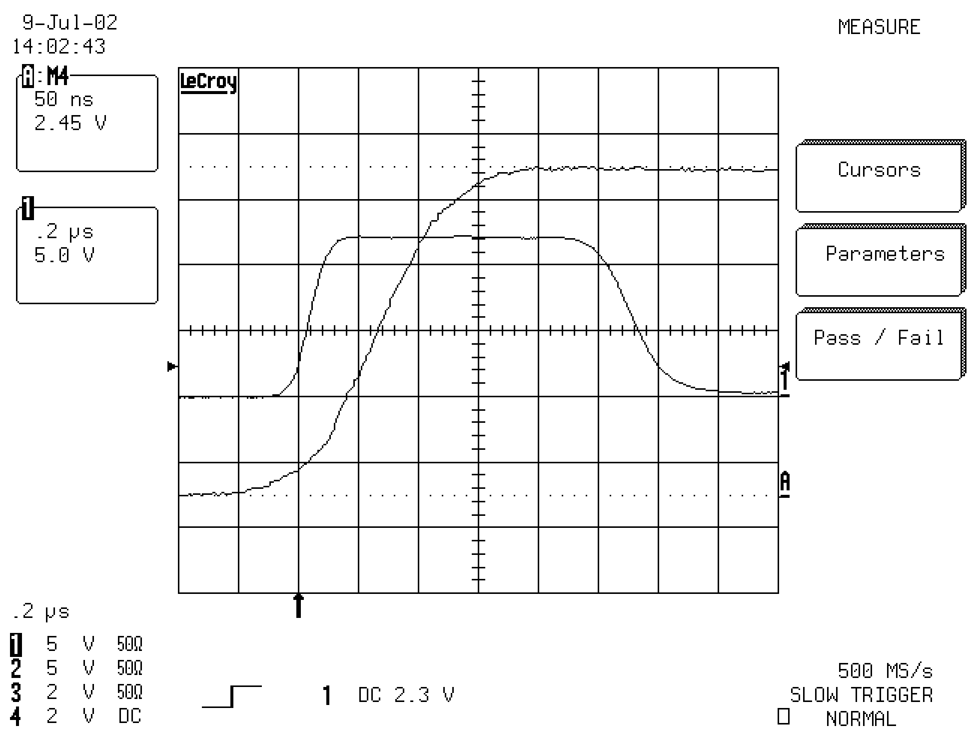

Figure 2. Pulse current rise time, 200nS from 1 to 95% (50nS/div)

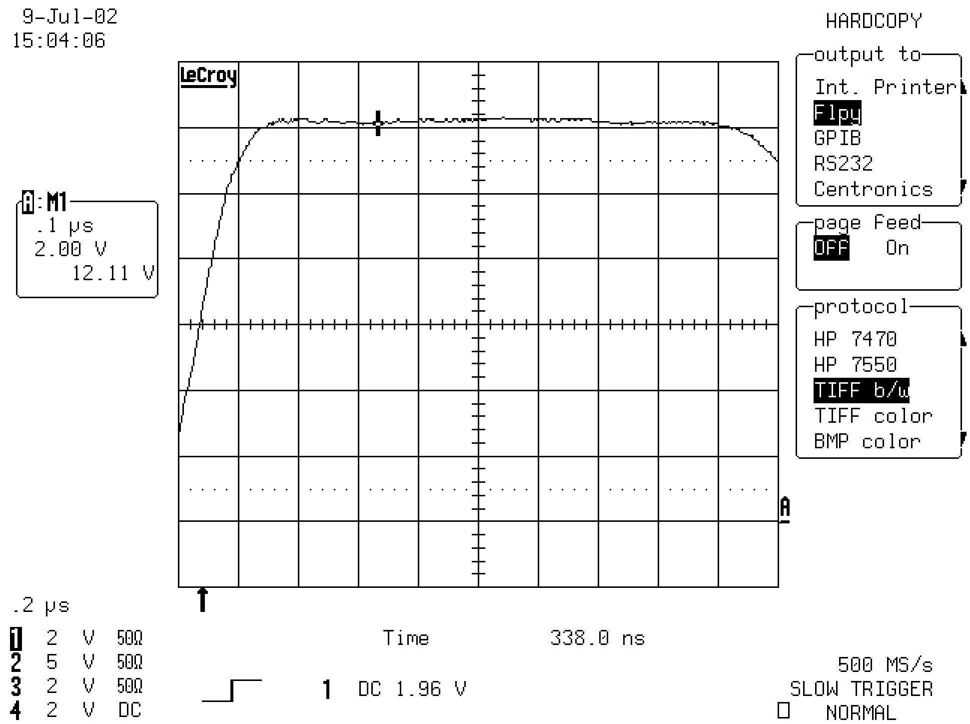

Figure 3. Pulse flattop width, 750 nS (100nS/div)

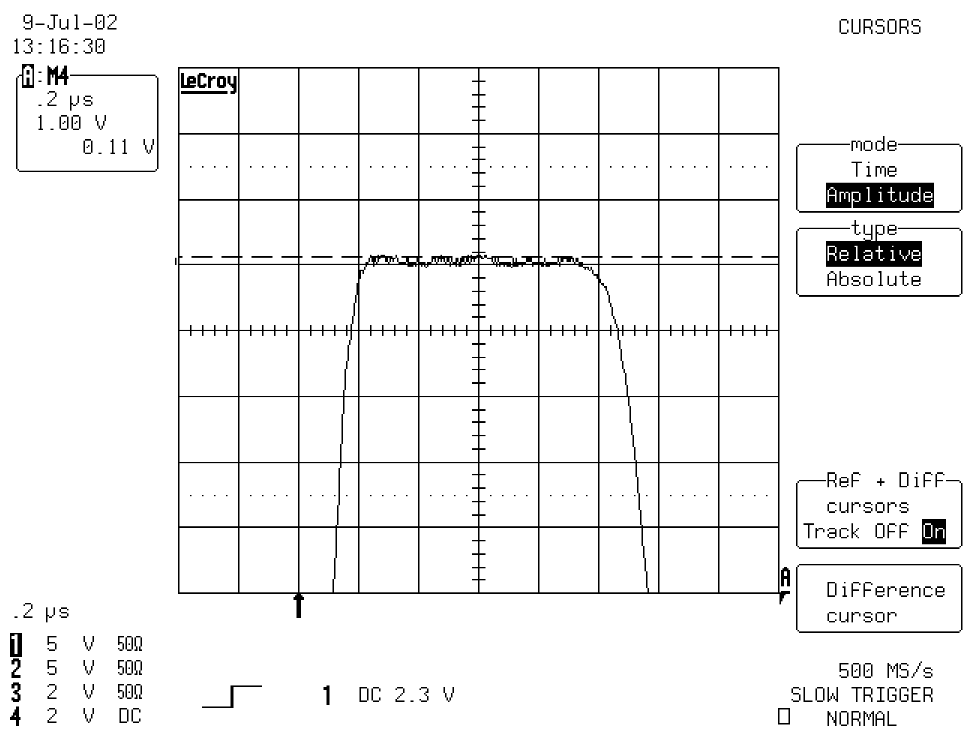

Figure 4. Magnet load current pulse flattop ripple waveform, flattop ripple less than 1% (0.11Vp-p, pulse peak is 12V, Peak current 2.4kA)

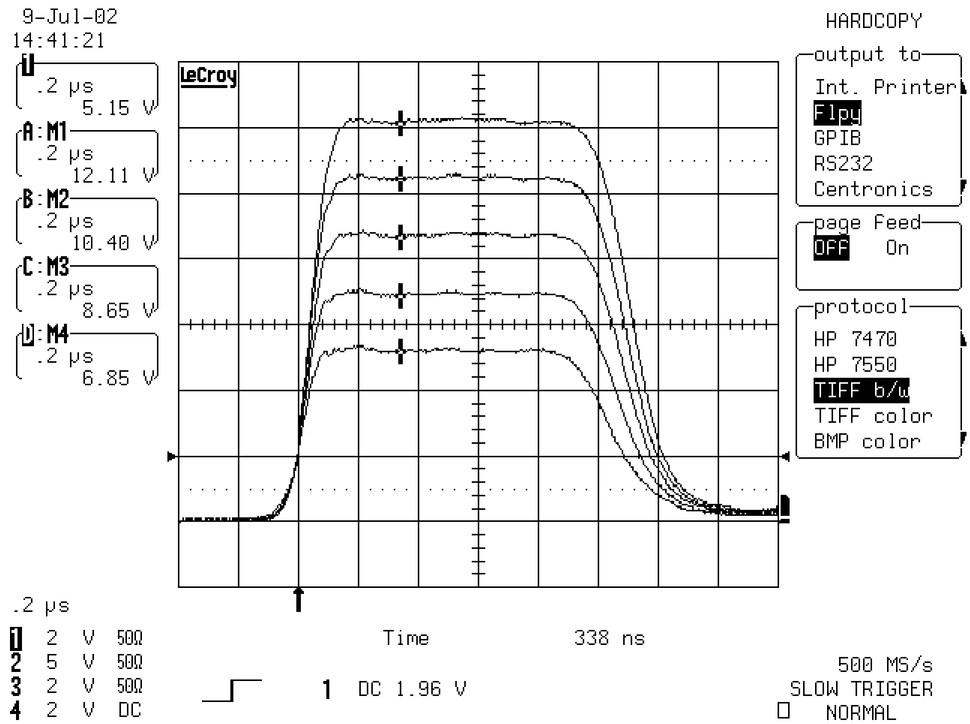

Figure 5. Magnet currents waveforms at different form HV, form 15, 20, 25, 30 to 35 kV

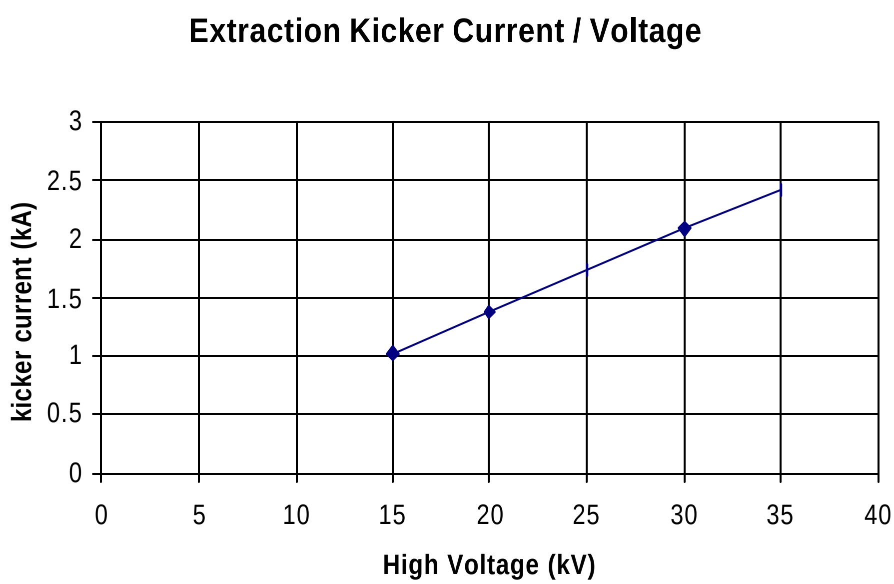

Figure 6. Pulse current amplitude varies with charging voltage.

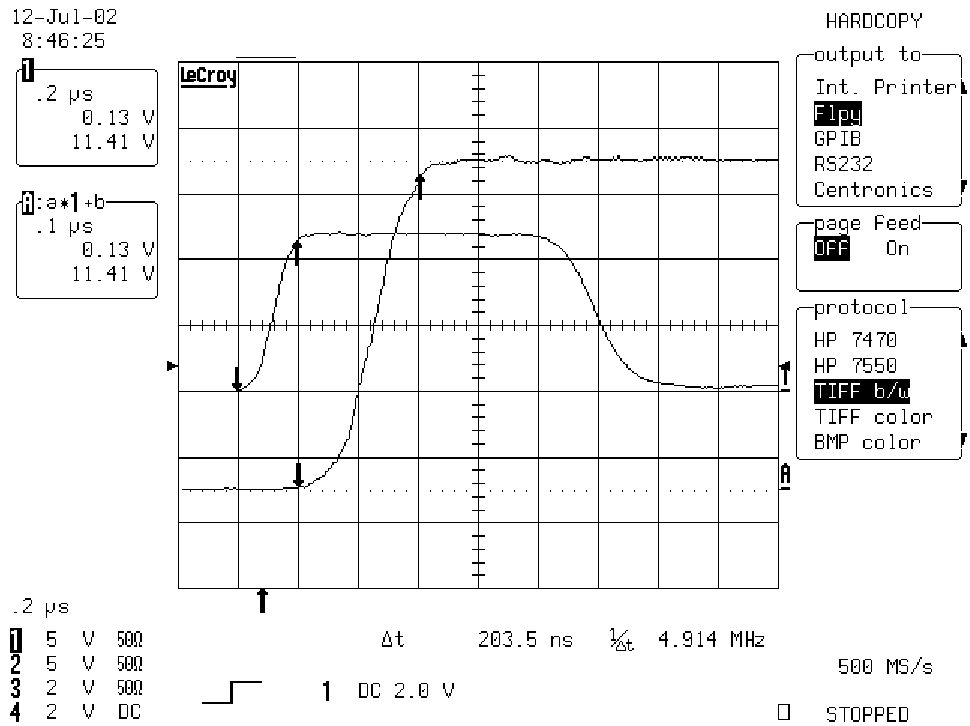

Figure 7. Magnet current pulse rise time waveform (BPFN in silicone tank)

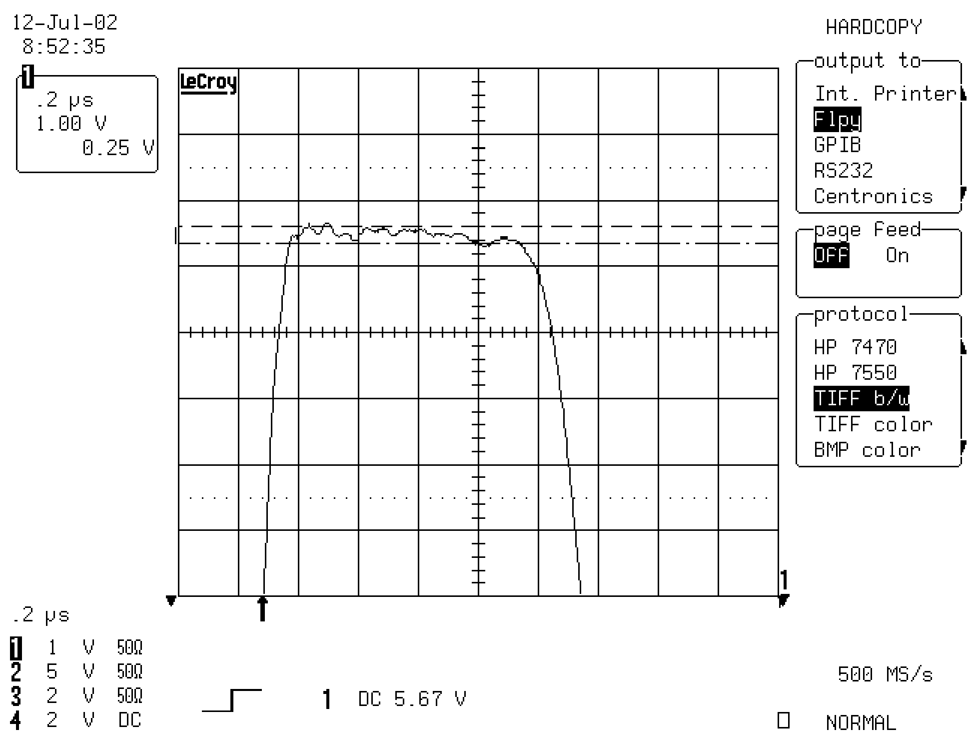

Figure 8. Pulse flattop ripple changes from 0.11Vp-p, to 0.25Vp-p (pulse peak is 12V)