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TEST RESULTS OF THE LOW-STORED- ENERGY 80-KV REGULATOR FOR ION SOURCES AT LANSCE*

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Abstract

The H- ion source at the LANSCE accelerator facility uses an 80 kV accelerating column to produce an H- ion beam. A regulated power supply maintains the source and support equipment racks at -80kV with respect to local ground. As the facility's H- beam currents have been increased, voltage droop on the regulated -80 kV power supply has become one of the limiting factors on beam current. The previous regulator used a standard 120kV DC HV supply and a high power planar triode in series to regulate the voltage down to 80 kV and to stop the flow of current during an arcdown of the -80 kV accelerating column. In 2018 we devised a method of using a pair of standard, 50 kV capacitor charging supplies to produce the required 80 kV with minimal stored energy and significantly better voltage regulation over the beam pulse. This configuration has been tested on the Ion Source Test Stand and is being considered for installation on the main LANSCE linac. We will present the design, modelling and measured results of the new system as compared with the performance of the previous system.

BACKGROUND

Current experiments at the Los Alamos Neutron Science Center (LANSCE) facility require an H- ion beam with a pulselength of 625µs and a repetition rate of 120 Hz. The H- ion source is located within in the dome of a Cockroft-Walton accelerator (C-W) which operates at -670 kV. Inside this dome a -80 kV DC accelerating column extracts and accelerates the H- ions from the source. The source and all its support electrical systems are kept at -80kV with respect to the dome interior. After leaving the dome, the beam enters a 670 kV accelerating column which brings the beam energy to 750 keV in the ground level of the Low Energy Beam Transport (LEBT). Then the beam is bunched and transported for injection into the first Drift Tube Linac (DTL) tank of the linac [1].

After the beam has been bunched, variations in the 750 keV beam energy translate into variations in arrival time (phase) at the entrance to the DTL which can magnify beam energy variations. The 750 keV beam energy is kept as constant as possible over the time of the linac beam pulse and from pulse to pulse. The original specifications for 80 kV voltage stability were written when the accelerator was designed in 1967 and revised in 1983. The total voltage droop could not exceed 300V and the variation during the beam pulse could not exceed +/- 50V while the source loaded the power supply with a 50 mA square pulse with 5µs rise and fall times. The supply current is much higher than the peak H- beam current due to electrons that are extracted with the H- ions and losses in the LEBT. Total output capacitance was limited to 30 nF and the energy delivered during an accelerating column arcdown was limited to 150 J [2]. Performance at peak currents higher than 50 mA was not required.

PESCHEL REGULATOR TUBE SYSTEM

The Peschel Instruments supplies procured under the 1983 requirements employed a -120 kV SCR controlled DC HV power supply in series with a regulator tube to produce the regulated -80 kV required by the source. Capacitors across the -120 kV supply output provided the current while the voltage across the regulator tube was adjusted during the pulse to counter the capacitor voltage droop and maintain a constant -80 kV output.

The Peschel supplies were reliable and met the performance requirements with only 76V of droop [3]. However, 30+ years later their reliability decreased dramatically as they approached the wearout age of their reliability bathtub curve. This resulted in many more frequent replacements of the 80 kV supplies.

All of the components were contained in a single 154 kg oil tank with all the components attached to the underside of the tank lid. The mass and physical size of this tank required that the C-W containing the LANSCE H- source be shut down for a day while the supply was craned out of the top of the C-W dome and enclosure. When the amount of beam downtime became unacceptable the Peschel supply was replaced with the LANSCE series regulator tube system.

LANSCE REGULATOR TUBE SYSTEM

The design of the LANSCE series regulator tube system began in 1988. In 1997 a prototype was placed in service on the Ion Source Test Stand (ISTS) [4]. This system used the same principle of operation as the original Peschel system, but the 120 kV supply was a commercial 25 mA Spellman unit and was physically separate from the oil tank containing the regulator tube. The regulator and interlock circuitry was also removed from the oil tank and placed on boards in NIM-BIN modules to make troubleshooting easier while remaining compatible with the standard interfaces used at the LANSCE facility. These improvements greatly reduced the Mean Time To Repair.

The original LANSCE series regulator tube system showed excellent performance at currents below 40 mA but above 40 mA the droop increased nonlinearly. This was blamed on issues in the control loop circuitry [4].

As the currents required by the LANSCE accelerator increased, the 80 kV voltage variation criteria were relaxed to only apply during linac beam operation when the

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droop affects the beam energy in the linac. Voltage droop that occurs before the linac beam begins was compensated for by running the -80 kV system at a slightly higher voltage so the voltage has drooped to the desired value by the start of the linac beam pulse. Figure 1 shows the voltage variation of the system at 46 mA of flat top current. Channel 1 is the output of a 20 MHz, 10,000:1 Ross voltage divider with a -8 V scope offset setting. The voltage droops 800 V during the 200 µs while the source comes on, but is stable to within 120V over the time of the linac beam pulse.

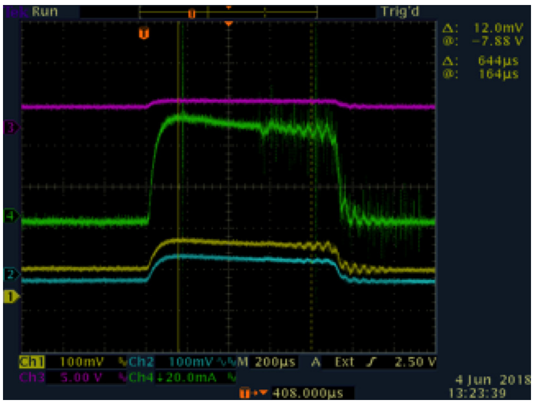

Figure 1: At 46 mA of flat top current (CH 4) there is 800V of droop and 120 V of voltage variation across the linac beam pulse.

As user current needs continued to increase, the currents drawn from the 80 kV system increased to almost 80 mA in normal operation and up to 100 mA during beam development experiments.

Despite many modifications to the control loops, the performance of LANSCE series regulator tube system did not meet goal of a constant voltage at flat top output currents above the original 50 mA design criteria. Eventually, this was accepted as the cost of higher current operation. Figure 2 shows the droop of the system at 76 mA of flat top current. Adjustment to the average voltage setting compensates for the 1.3 kV of voltage droop before the linac pulse begins. The 2.0 kV droop over the linac beam current pulse cannot be compensated for. In addition, linac pulse droop varied between 1.3 and 2.0 kV from pulse to pulse. When this was discovered in 2018, it was thought to be related to heater hum in the regulator tube because LANSCE beam pulses are synchronized with the 60 Hz power line. Adjustments to the regulator tube filament voltage improved the pulse to pulse consistency, but did nothing to reduce the droop during the beam pulse. For the last two months of the 2018 run cycle, the droop during the beam pulse ranged from 1 to 2.3 kV. At currents beyond 76 mA the droop increased nonlinearly to 8 kV at 100 mA. For these reasons we decided to install a new system in the H- dome for the 2019 run cycle.

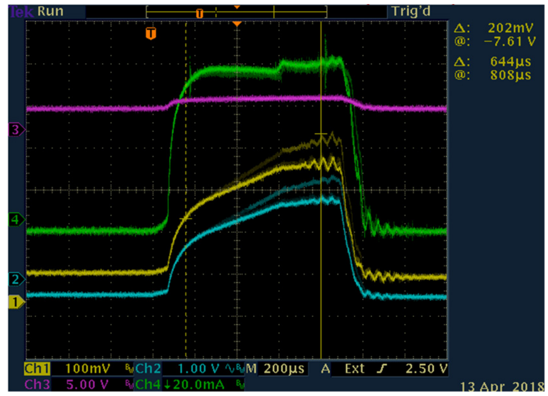

Figure 2: Performance of tube regulated system showing total voltage droop, droop across the beam pulse and pulse to pulse variation in droop at 79 mA.

CAPACITOR CHARGING SUPPLY SYSTEM

Design

The Capacitor Charging Supply (CCS) system leverages both improvements in high voltage switching power supplies and efficiency improvements in the low voltage power supplies that support the operation of the ion source. Low voltage power supplies in the floating 80 kV racks support the operation of the ion source. Upgrading the low voltage supplies to switching technology greatly reduced the AC power required in the floating 80 kV racks and left a surplus of power available from the racks' 75 kVA isolation transformer.

Capacitor Charging Supplies (CCSs) using resonant switching technology to reach up to 50 kV outputs have been available for many years. We could find no supplies of this type at the 80 kV output we needed, so we took advantage of the excess AC power that was available in the floating racks to put two 50 kV TDK-Lambda 402L CCSs in series.

Two sets of 25 nF capacitors are installed below the floating racks as shown in Fig. 3. A negative output, 50 kV CCS located at ground brings the connection point between the two pairs of capacitors to -40 kV with respect to the dome interior. A positive output, 50 kV CCS mounted in the floating racks brings its output to +40 kV with respect to the floating racks' common bus. This output is connected to the set of capacitors hanging below the racks, which brings the floating racks to -40 kV with respect to the connection point between the sets of capacitors. The voltage reversal protection diode and series resistors were included as per the CCS manufacturer's application notes.

Each CCS is rated to maintain its output voltage at 40 kV at average currents of up to 100 mA. The output capacitance in the CCS units is negligible compared to the capacitance of the capacitor array (25 nF), the isolation transformer (1.8 nF) and the stray capacitance of the floating racks (0.9 nF). At 80 kV the total stored energy of 80 J is well below the 150 J upper limit and the supply capacitance to ground is only 25 nF.

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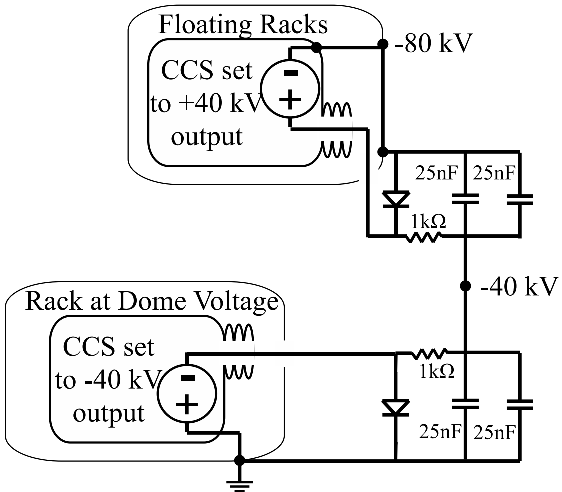

Figure 3: Design of the CCS system.

Modelling

Spice models of the CCS units were developed based on conversations with the manufacturer. The original models did not include the 1 kΩ series resistors. Modelling results predicted a 130V variation over the linac beam pulse.

Measured Results of CCS Prototype System

A prototype CCS system was tested on the ISTS in 2018. The current measured at the base of the capacitor bank/diode array was excessively noisy. The measured variation in rack voltage was 1 kV but seemed constant with respect to current. These results were improved enough to consider installation in the H- dome.

Measured Results of CCS Dome System

The CCS system installed in the H- C-W dome incorporated lessons learned from the prototype installation. A 1 kΩ series resistor was added at each CCS output. This reduced the noise on the supply current and improved the voltage regulation. The CCS control common conductor was isolated from the control system local common using to relays and isolation amplifiers. We encountered voltage spikes on the dome PLC control systems were mitigated by connecting all of the chassis in the floating racks to the racks' common bus through low inductance connections and through the addition of ferrite noise isolation on the inputs to the floating racks' control PLCs and at the CCS control port.

The performance of the CCS system is shown in Figs. 4 and 5. Figure 4 shows the voltage variation of less than 100 V when the current is 49 mA. The current signal is still noisy but averaging gives a clear, quantifiable reading. The H- beam current in the dome LEBT is given on CH 3 at 4 mA/V. This indicates that the noise on the CCS current signal does not transfer to the H- beam current.

Figure 5 shows the worst case pulse voltage variation at 62 mA, the highest current drawn by the source to date. The voltage variation increased to 360 V, but this is still much better than the performance of the LANSCE series regulator tube system.

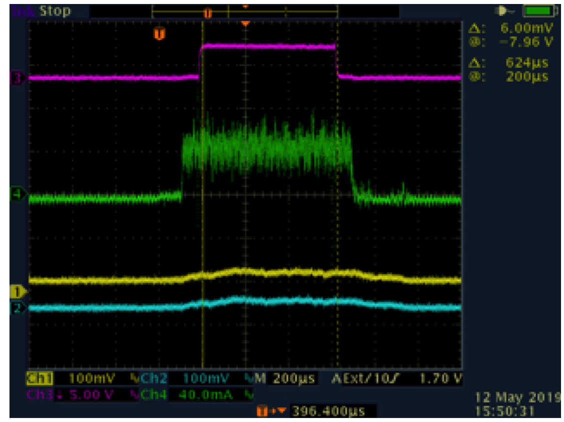

Figure 4: At 49 mA of flat top current (CH 4) there is <100V of voltage variation across the linac beam pulse.

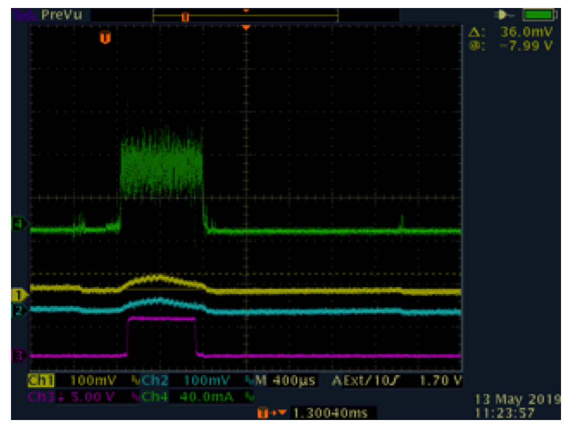

Figure 5: At 62 mA of flat top current (CH 4) there is <360V of voltage variation across the linac beam pulse.

CONCLUSIONS AND FUTURE WORK

The new CCS based 80 kV system has demonstrated improved voltage regulation as compared to the LANSCE series regulator tube system. The system has been tested at the highest currents presently drawn by the H- source and has greatly reduced the voltage variation.

Future work includes beam emittance measurements, extensive system reliability testing, investigation of the noise on the CCS current signal and further circuit modelling for further performance improvements.

REFERENCES

[1] C. Pillai *et al.*, "Performance of the LANSCE H- Source and Low Energy Beam Transport at Higher Peak Current", in Proc. 17th Particle Accelerator Conf. (PAC'97), Vancouver, Canada, May 1997, paper 6W021, pp. 2743-2745.

[2] University of California, "Specifications for 100 kV Power Supply", MP-11-67, Rev A, 1983.

[3] Peschel Instruments, Test data Model RPS100-20-0.1LX, SN 7993, 1983.

[4] E. G. Jacobson, R. L. Haffner, W. B. Ingalls, B. J. Meyer, and J. E. Stelzer, "Low-Stored-Energy 100-kV Regulator for Ion Sources at LANSCE", in Proc. 19th Int. Linac Conf. (LINAC'98), Chicago, IL, USA, Aug. 1998, paper TU4094, pp. 621-623.