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LANSCE CCL KLYSTRON HIGH-POTTING INVESTIGATION AND IMPROVEMENTS*

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Abstract

LANSCE uses 44 805 MHz klystrons to power the Coupled Cavity Linac (CCL). Modulated anode tubes such as the 1.25 MW LANSCE klystrons need high voltage testing and processing prior to full operation. This not only verifies the klystron can hold-off HV but also allows the klystron to process out some internal imperfections prior to being pulsed by the modulator for the accelerator. The LANSCE accelerator is a relatively long pulse machine, and improper processing can lead to premature degradation in the performance of the tube. This paper describes recent improvements to the 1.25 MW 805 MHz klystron HV check and conditioning process through the development of a new high-potting test stand. High-potting setup and techniques that were historically used are contrasted with the new implementation. Our goal is to improve LANSCE operations by accelerating the high-potting process and reducing expert time and dependence. The new test stand will optimize legacy processes by improving diagnostics, automating control and reducing inconsistencies and process invariability due to human factors. Analysis and automation efforts for this critical process are discussed along with current benefits and future work.

CURRENT PROCESS

Goal

The goal of the high-potting process is to test the voltage hold-off strength of the klystron and carefully recondition the tube if it cannot hold-off required HV. The main indicators used for evaluation of this step are the hold-off voltage (V_{HO}), leakage current (I_{Leak}), and the vacuum ion pump current (I_{IP}).

High Voltage Testing

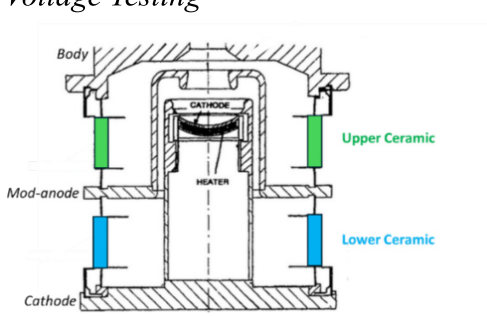

Figure 1: Internal klystron gun structure showing the different sections for high-potting (derived from R. Kowalczyk SLAC "RF Source Vacuum Tube Cost," May 2017).

Klystrons are high potted to check the hold-off voltage between the (see Fig. 1) two different ceramic insulators: mod-anode to the cathode and mod-anode to the body. For high-potting the lower ceramic, HV is connected to the cathode, and the mod-anode is grounded. For the upper ceramic, the cathode is connected to the mod-anode, and the body of the klystron is held at ground potential. The benchmark is for the klystron to reasonably hold-off 110 kV on the lower ceramic and up to 120 kV on the upper ceramic with little to no arcing for approximately 1 hour. Once this is achieved the klystron is high-potted with the modulator tank as a final check. These three test conditions allow us to isolate different parts of the electron gun and test them individually for their ability to withstand high voltage.

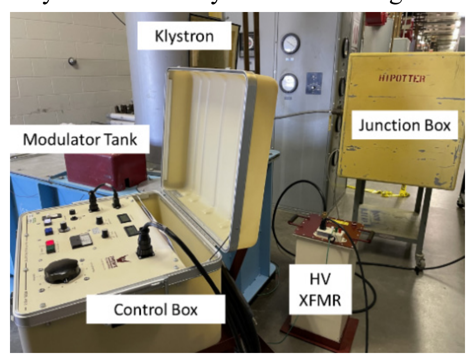

Figure 2: Existing HV testing and processing setup.

If the klystron fails to meet these hold-off voltage benchmarks or has excessive arcing, the tube is slowly processed with HV attempting to improve the electron gun voltage stress points on high field surfaces.

High Voltage Processing

HV processing allows the operator to condition out breakdown issues within the vacuum tube which allows the klystron to run for longer with a reduction in arcing and related issues leading to eventual failure. Improvements are typically characterized by an increase in hold-off voltage and reduction in leakage current and ion pump current.

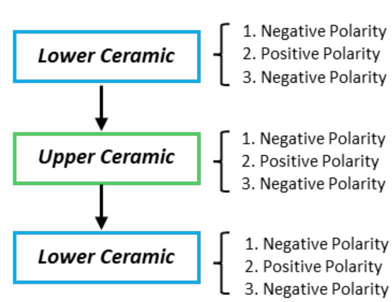

Figure 3: Typical high voltage processing procedure to reduce arcing and improve hold-off voltage.

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High voltage processing is reliant on the response of the tube to the two main techniques used to improve the hold-off voltage. These techniques presently are:

1- Time at voltage
2- Transient Processing

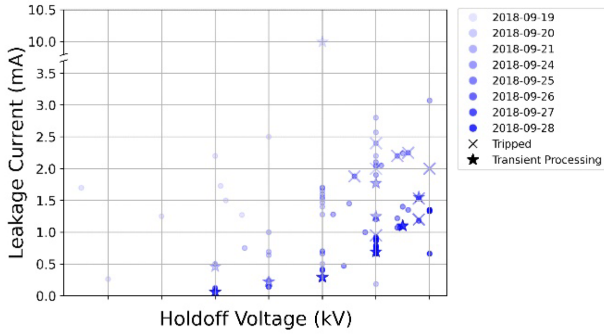

Figure 4: HV processing data for lower ceramic processing showing decrease in leakage current with additional processing.

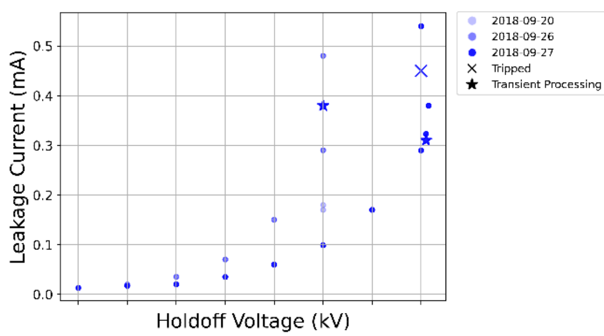

Figure 5: HV processing curve for upper ceramic showing improvements after each day of HV processing.

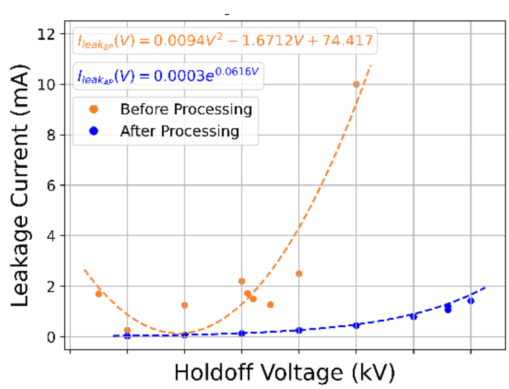

Figure 6: Final HV curve for klystron lower ceramic showing a drastic improvement in leakage current. The initial results are shown in orange to the final shown in blue.

The time at voltage method relies on reducing arcing as a function of time spent at a set voltage. This method involves setting a target voltage and a holding voltage. The holding voltage is just slightly less than the target voltage and serves as the potential difference the klystron is held for a short period of time to sustain the target voltage. Both the target and hold-off voltages are incrementally increased until the target voltage reaches 110 or 120 kV.

In the transient processing method, the holding voltage is increased in small transient bursts above the target voltage. Typically, the maximum transient voltage is 5 kV higher than the target voltage. It is essential that the operator understands that transient processing is a stressful process to the klystron [1] and can lead to adverse results and permanent damage without sufficient expertise [2].

After successful processing (as per Figs. 2 and 3), the klystron tested in Figs. 4, 5 and 6 was able to hold-off higher voltage with less arcing. This can be seen as the leakage current drops down to a fraction of its previously observed values.

Arc Discharge Waveform

The discharging current emanating from high-potting can be observed in Fig. 7. This is the current that flows out of the klystron ceramic to ground during the HV arc. This manifests as an exponential decay and is on the order of 1 to 10 microseconds. The more powerful the discharge the longer the decay and the higher the jump in the klystron vacuum ion pump current observed during high-potting.

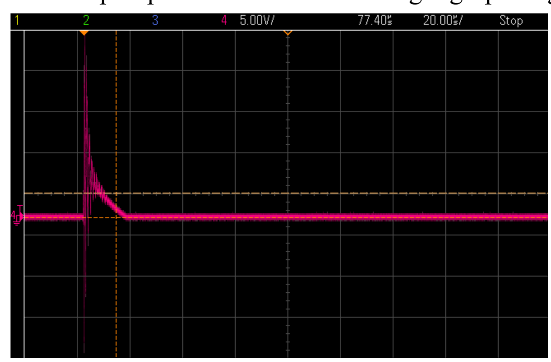

Figure 7: Discharge current curve after HV arc during high-potting.

High-potting Circuit

To investigate the discharge current observed the set up was analyzed as a lumped element circuit (Fig. 8) with the klystron being modeled as a voltage holding capacitor.

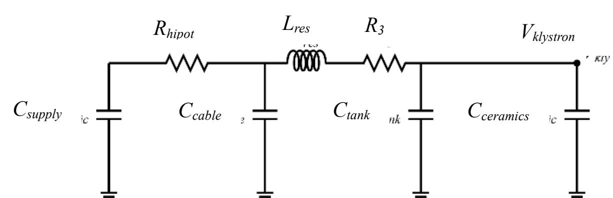

Figure 8: Lumped element model used for analyzing discharge current behavior observed during high-potting (where C_{supply} represents the power supply capacitance, R_3 represents the inline series resistance, $V_{klystron}$ is the hold-off voltage and $C_{ceramics}$ represents the specific klystron electron gun section connected during high-potting).

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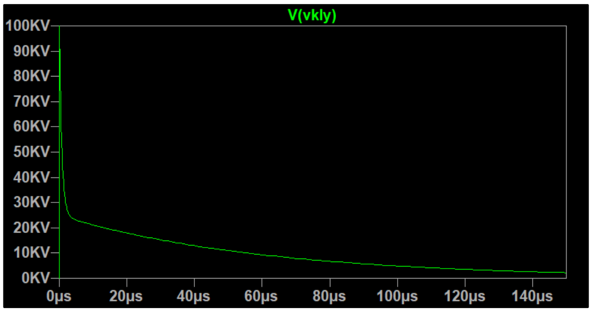

Figure 9: Simulated discharge current based on the lumped element model resembling the observed discharge current during klystron HV trip.

The simulated discharge (Fig. 9) was found to be a second order decaying exponential that can be used to approximate the discharge observed during real life high-potting. Extrapolating the observed discharge waveform to an equation would allow us to obtain theoretical values for any given klystron during high-potting. This would further enable capturing of ideal values for leakage current and hold-off voltages optimizing the process.

During a fault in normal operations a similar discharge phenomenon can be observed when a klystron arc trips the capacitor room power supply. This can be seen in Fig. 10. High-potting test data is currently being analyzed with additional data collected to investigate hold-off voltage and other klystron insights using observed arc discharges.

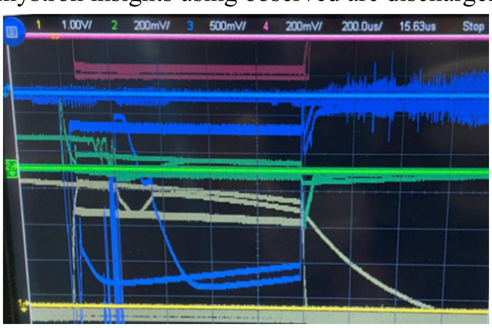

Figure 10: Discharging seen in klystron modulator waveforms as a result of a klystron arc tripping the capacitor room power supply during linac operation.

NEW HIGH-POTTING TEST STAND

Figure 11: Developed high-potting test stand.

Currently the high voltage testing and processing can take up to 2 weeks per klystron. This is partly because the modulator needs to be re-arranged in several different configurations by a team of 2 people. Manual high voltage control and active monitoring by experts (Fig. 2) places an additional time commitment on personnel.

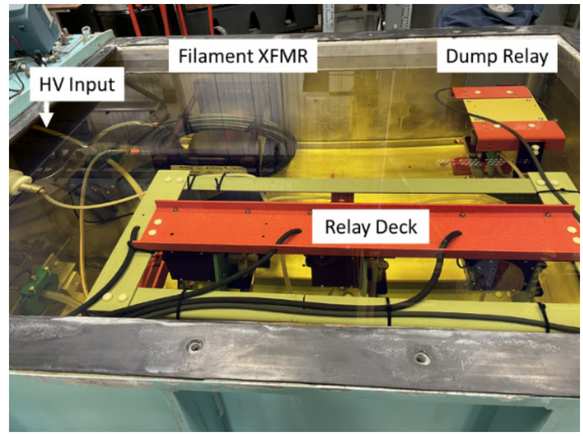

Figure 12: High Voltage Testing and Processing (HVTP) test stand tank HV relay setup for automated connections.

We are working to automate the both the high voltage testing and processing steps (Fig. 11). A HV relay system has been built that can automate the HV connections process (Fig. 12). Work is currently underway to automate HV control according to the captured data and presented analysis. Improved diagnostics and controls are also being explored. The final high-potting system will take into account V_{HO}, I_{leak}, I_{IP} and captured arc waveforms to quantify improvements in-situ and actively perform the high-potting process.

CONCLUSION

Klystrons are the backbone of LANSCE's beam infrastructure. Ensuring that the klystrons can deliver high power RF to the linac is paramount to the consistent operation of LANSCE and its five experimental areas. Improved understanding of klystron behavior and the high-potting process as a whole will result in less time and money spent on repairs or diagnostics leading to higher beam up time for the users.

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