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IMPROVEMENTS TO THE LANSCE CCL KLYSTRON EVALUATION*

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Abstract

This paper describes the existing procedure for LANSCE 805 MHz klystrons testing and evaluation and realized avenues for improvement. Each of the 1.25 MW klystrons used for driving LANSCE CCL (side Coupled Cavity Linac) are tested during first installation or following a fault in operations. The executed testing process includes high potting, pulsing, and full power RF testing. Generated testing data is used for evaluation and certification of spare units for the linac. In this paper, we hope to breakdown this expert-dependent, lengthy 1–2 month process and examine improvements which can accelerate time to evaluation. The goal of this paper is to fully capture the current procedures and investigate improvements to modernize our legacy systems and processes.

INTRODUCTION

LANSCE uses 44 modulated-anode style klystrons for driving the CCL cavities. To verify proper operation during first on-site testing and for evaluating suspicious behavior these klystrons need to be tested as per the process shown in Fig. 1. Currently there are only two test stands dedicated to testing klystrons and evaluating their performance. These test stands are equipped with the diagnostics and controls required to perform all the necessary steps and gather sufficient testing data for evaluation purposes. The goal of the evaluation process is to certify klystron -modulator spares required to keep beam production running.

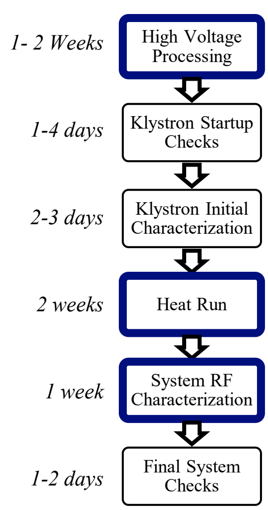

Figure 1: Current LANSCE 805MHz klystron-modulator testing and evaluation process.

As LANSCE struggles to keep up production level beam due to equipment obsolescence and legacy equipment reaching end of life [1], the testing and evaluation process needs to be re-evaluated and accelerated. This will ensure faster evaluation of spare units increasing the beam uptime for the accelerator and upholding mission-critical 800MeV energy levels. This paper describes the different steps part of the CCL production klystron testing process, data generated during klystron testing, and metrics used for klystron evaluation. Improvements that are currently being investigated to advance evaluation metrics and increase overall system reliability and performance are also presented.

TESTING PROCESS

The typical testing process undertaken to test each klystron is shown in Fig. 1. This process is highly dependent and inherently slow because it depends on the feedback from the klystron itself. Some units perform better than others and some need to be further investigated to make a complete evaluation. The typical timeline for a full evaluation is typically 1-2 months with the steps highlighted in blue from Fig. 1 taking the longest.

High Voltage Processing

In the first step, klystrons are high-potted to check the hold-off voltage between the two different ceramics insulators: mod-anode to the cathode (lower ceramic) and mod-anode to the body (upper ceramic). If the operator can reasonably achieve 110kV on the lower ceramic and 120kV on the upper ceramic with little to no arcing for approximately 1 hour, then this check is said to be complete. If sufficiently high hold-off voltages cannot be established or if the tube demonstrates excessive arcing the tube must be processed to meet these hold-off voltage requirements as per Fig. 2.

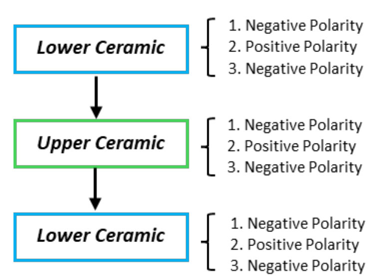

Figure 2: Typical high voltage processing procedure to reduce arcing and improve hold-off voltage.

HV processing allows the operator to condition out breakdown issues within the electron gun of the vacuum tube [2] 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 a

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substantial increase in hold-off voltage and reduction in leakage current and vacuum ion pump current.

Startup Checks

After step 1, the klystron is installed in the modulator system to be pulsed. Startup refers to the klystron being properly installed and subjected to HV for the first time. This includes completion of all the necessary steps needed for getting the pulsed klystron system to produce RF. Major steps for this process are shown in Fig. 3.

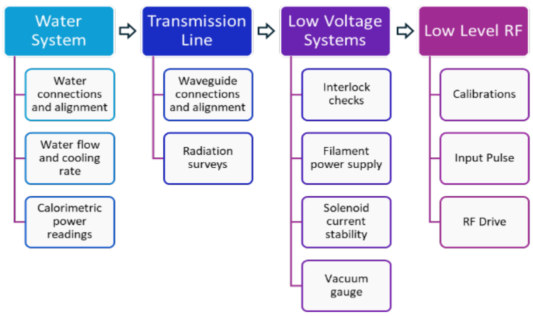

Figure 3: Major steps during klystron startup sequence.

Initial Characterization

Following the klystron startup checklist, the klystron modulator is connected to the capacitor room HV power supply and brought to operating voltage. The pulse generator is connected and waveforms checked for any discrepancies. This is illustrated in Figs. 4 and 5.

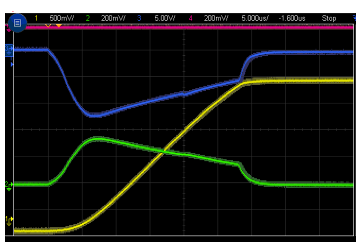

Figure 4: Typical waveforms for a klystron-modulator showing the main waveform channels.

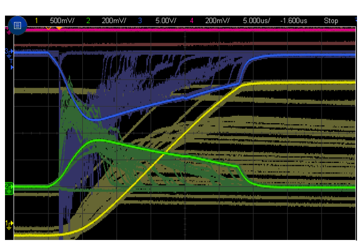

Figure 5: Irregularities captured leading to further investigation through observed waveforms.

If no anomalies are found in the pulsed waveform signals (cathode current, modulating anode signal and switch tube current) the RF drive is connected, and the RF output is checked for stability. The output power is compared against drive power and calorimetric RF power levels. The repetition rate is gradually increased from 10Hz to its nominal 120Hz with the pulse width also increased from 300us to its typical 1 us. If no issues are found during this period, then the testing moves on to the heat run phase.

Heat Run

The heat run refers to an extended period on the test stand where the klystron-modulator is run at maximum voltage and output level to catch potential issues (Fig. 6). Currently this period lasts for 2 weeks when the spare is run continuously and any faults tripping the test stand off are thoroughly investigated. Faults caught during this stage typically involve the switch tubes, fiber-optic driver system and other modulator components responsible for pulsing the klystron.

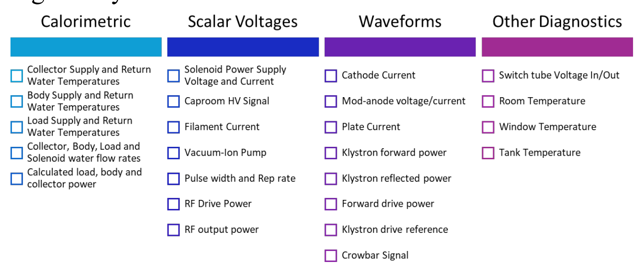

Figure 6: Data collected during klystron testing.

System Characterization

To determine the initial cathode filament and beam settings, emission curves are performed for the klystron and switch tubes along with power transfer curves for the klystron.

The power transfer curve (Fig. 7) measures the output power, gain, saturation point, and RF stability of the klystron. Input power is swept by 10 dBm and output power is recorded. This test is performed at a beam voltage of 80kV, 82kV and 84kV with the capacitor room power supply held within ±0.1kV of a given beam voltage. The knee point obtained from the power transfer curves optimizes the amplitude set point in low level RF preamplifier and control system.

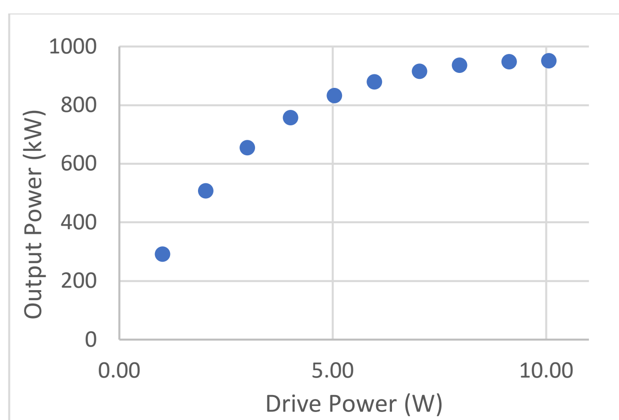

Figure 7: Klystron power transfer curve used for determining saturation point and optimal drive level.

Emission curves (Fig. 8) allow us to run the klystron and switch tubes right at the space change limit, maximizing vacuum tube lifetime.

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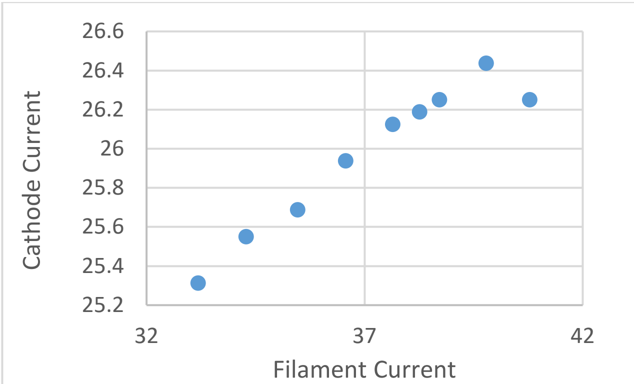

Figure 8: Klystron emission curve needed to set initial set points. Insufficient control and limited data capturing for the characterization process is responsible for inaccuracies.

Final System Checks

After the system characterization is complete and the spare has run at maximum output level, the system is shut down and a datasheet is generated for the most optimal settings. Everything from steps 2 and 3 (Fig. 1) is checked again and the spare is certified as a good spare if it completes the entire process.

ACCELERATING EVALUATION

To accelerate time to klystron health evaluation and CCL spare readiness the testing process needs to be improved. High-potting (step 1) and heat run and characterization (step 4 & 5) take the longest because they require expert time and knowledge. Automating these steps may lead to 25 to 50% savings in time. This involves process optimization and improvement through extensive data collection and monitoring.

Controls for the test stand have remained fully manual in the last 50 years and place a huge time and expertise burden. Legacy data acquisition scheme involved manual data entries twice a day with limited data capturing introducing variabilities. Irregular behavior may have been recorded but not caught and rectified immediately due to prior system limitations.

An effort to accelerate the evaluation process through improvement in diagnostics, control and monitoring is currently underway. Data monitoring and achieving of various diagnostics, listed in Fig. 6, used throughout the evaluation process have been incorporated into the LANSCE Control System (LCS). Waveform capturing has been implemented with microsecond resolution as shown in Fig. 9. Virtual controls that allow automation of characterization curves have started to be added. The team is working to add low and high voltage power supply controls so that they can be adjusted algorithmically.

Anomaly detection is being incorporated to detect irregularities in the captured data points along with waveforms (Fig. 10). Alarms can now be set during testing to call experts if certain data points go beyond their nominal value. Analysis is also being done to incorporate generated system data for training a prediction model.

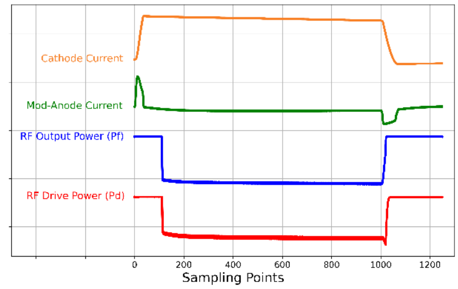

Figure 9: Captured waveforms on the new data archiving system.

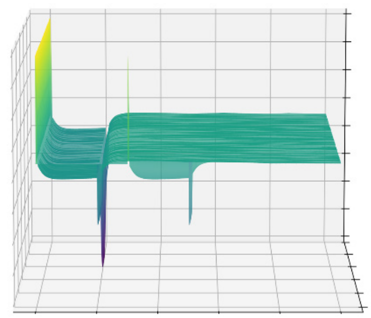

Figure 10: Captured waveform anomaly through the newly developed system.

CONCLUSION

Improvements to the klystron-modulator evaluation process better equip LANSCE for supporting mission critical needs. Modernized test systems and processes allow tools such as anomaly detection and machine learning to be used on the generated data. The new capabilities set the stage for investigative efforts on worsening system reliability and klystron failures.

REFERENCES

[1] A. Waghmare and J. Valladares, "LANSCE 805 MHz klystron reliability analysis", in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 1486-1488. doi:10.18429/JACoW-IPAC2024-TUPR28

[2] A. Waghmare *et. al*, "LANSCE CCL Klystron High Potting Investigation and Improvements," presented at NAPAC'25, Sacramento, CA, USA, Aug. 2025, paper WeP084, this conference.