RECENT PERFORMANCE, LIFETIME, AND FAILURE MODES OF THE 5045 KLYSTRON POPULATION AT SLAC*

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Abstract:

The 65 MW S-Band klystrons (5045) used to power SLC have been in service for over seven years. Currently, 244 of these tubes are in place on the accelerator, operating full power at 120 pulses per second. Enough tubes have now reached cathode end of life, or experienced other failures to allow a good analysis of failure modes, and to project average lifetime for this type of tube. This paper describes the various modes of failure seen in klystrons returned from SLC service, and pro–vides data on expected lifetime from current production based on accumulated SLC operating experience.

Introduction

Over seven years ago, the first 65 MW klystrons, Fig. 1, were installed and started operation at SLAC. Since that time, almost 600 klystrons of this design have been manufactured. A number of these klystrons that failed and were removed from service produced the initial failure analysis of References 1 and 2. Some of these failed klystrons were remanufactured and returned to service. Presently, 244 klystrons are operating continuously in SLC service at full power and 120 Hz repetition rate. The average age of installed klystrons has increased to over 23,000 high voltage operating hours, but the failure rate has accelerated with 120 Hz PRF operation. Most failure mechanisms that produced premature failure have been identified and corrected so that now failures are mostly due to end-of-life processes such as cathode depletion and anode barium deposits that cause arcing and gassing in the tube. The lifetime is directly related to operating cathode temperature with 50,000 hours projected for a "good" low-temperature operating cathode and less than 15,000 hours for a "poor" cathode requiring initial operation at a high temperature. Overall, operation of these klystrons has produced very stable RF for the SLC with little beam downtime due to klystron malfunctions.

Klystron System Faults and Failure Modes

Klystrons are assembled on pulse tanks, and undergo a full power system test in the Klystron Test Lab before being transported to the SLC Gallery for installation. Any failure in the klystron, or the pulse tank system necessitates the removal of the klystron assembly from the SLC gallery and return to the test lab for repair and retesting. In Reference 2, the principal causes of failure were listed as window failure, high voltage seal puncture, RF output faults including regenerative instability (Ref. 3), RF output gap breakdown, gassy cathodes, and various mechanical, water, and pulse tank problems. At the writing of that paper, we had experienced very few end-of-life cathode failures.

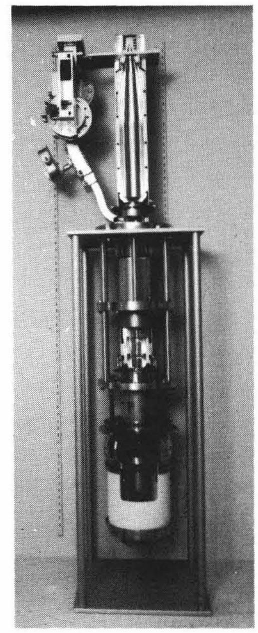

Fig. 1. 65-megawatt klystron.

During the last seven months of intensive full-power 120 PPS SLC running, we have been removing an average of six klystron assemblies per month from gallery sockets for various faults including klystron failure. Twenty-five of the removed tubes, upon retesting in the test lab, were failed; the rest were repaired, retested, and returned to gallery service. Several of the tubes returned to service were close to end-of-life. All but three of the failed klystrons were failed for reasons associated with the end-of-life of the cathode. One tube, an early model, failed for an unrepairable water leak, and a second non-cathode failure was attributed to a hot window, although it was almost at end-of-life on the cathode. Excessive RF breakup was the reason for the third failure.

Figure 2 shows the emission characteristics of five selected klystrons removed from the gallery, and retested in the test lab. The first three tubes had "good" to "excellent" cathodes, have given long service, and are still in operation. The last two examples started out with "marginal" cathodes that required

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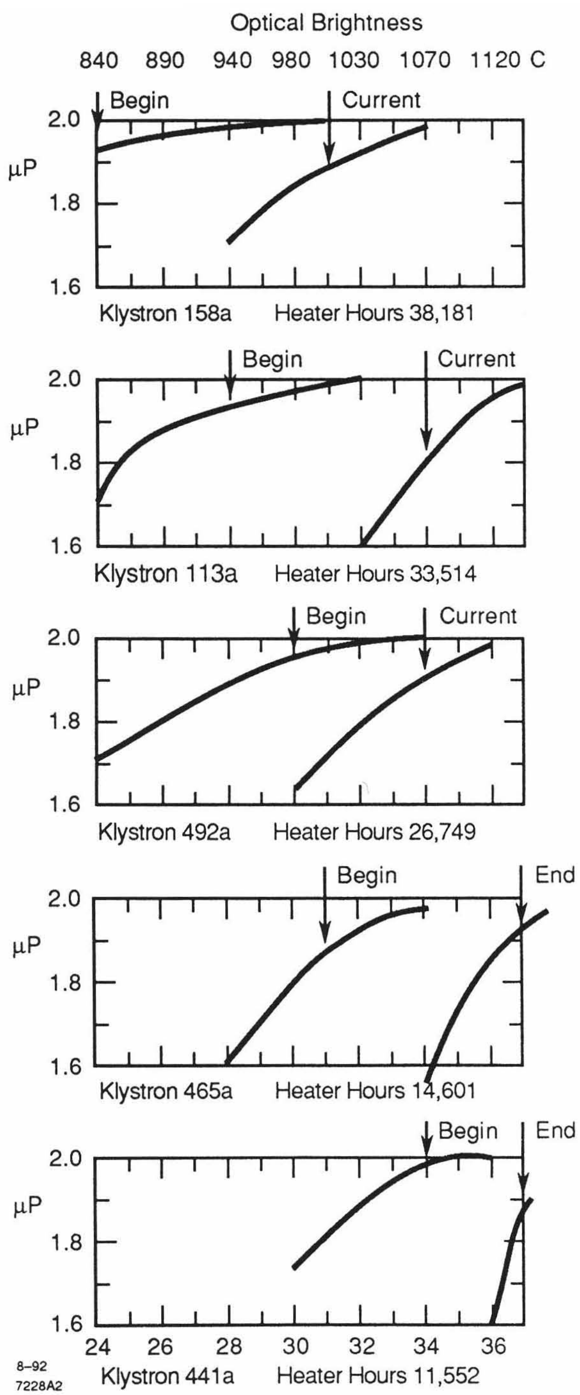
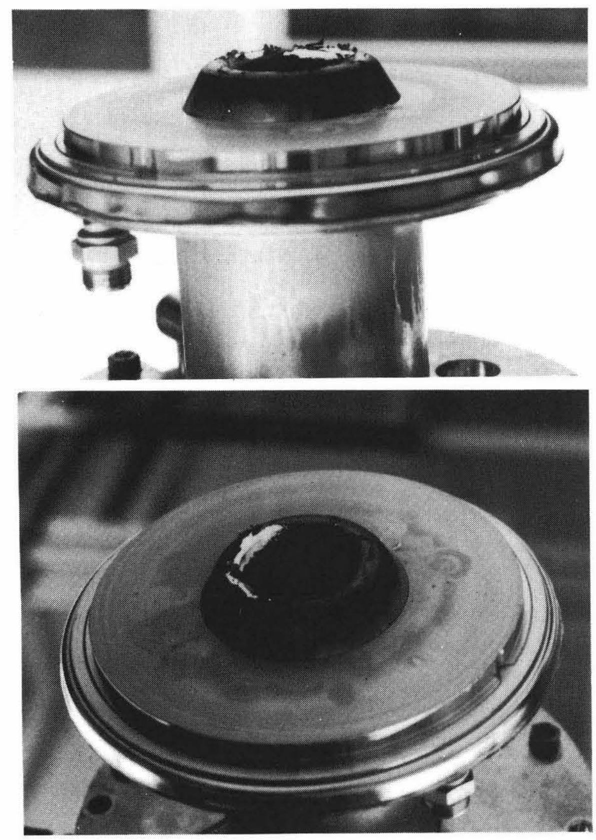


Fig. 2. Beginning and ending emission characteristics for klystrons with "good" to "bad" cathodes.

initial high temperature operation. Both failed due to end-of-life symptoms at rather low operating hours. The pictures in Figures 3 and 4 show the annode surface of one of these failed tubes. The failure mode was arcing and gassing in the tube. Note the barium compound buildup on the anode surface, and the flaking. Most of this flaking happens after the tube is cut open, but any small break in the barium buildup tends to arc in the high-voltage gradient between the cathode and anode, and causes a massive gas burst. The barium buildup is accelerated by high operating cathode temperature. On a few high operating hour tubes that failed for reasons other than cathode problems, very little barium buildup was in evidence during autopsy. The dominant mode of failure of klystrons now operating in SLC service is cathode depletion, and the associated arcing and gassing from anode barium buildup.



Figs. 3 and 4. Barium buildup on klystron anode.

Figure 5 is a graph of cumulative high voltage hours for klystrons that have been, or are currently in operation. There is a large group of tubes that is approaching 40,000 hours of life. Most of the "infant mortality" type failures occurred during the initial installation phase seven years ago. Currently, tubes passing test lab tests do not show any serious "infant mortality" problems when put into SLC service. The average age of failed tubes returned from SLC service is 19,000 hours of high-voltage running time. The average age of operating tubes in SLC service is 23,000 high-voltage hours, and 29,000 hours of cathode heater time. The mean time between failure of SLC service klystrons is presently 52,000 hours. The history chart of these numbers is shown in Figure 6. In a random-population, steady-state-system, these three averages should converge, but even with seven years of operation, this convergence has not occurred for the SLC klystron population. During this time, operational conditions have changed, and we have modified the klystron design to reduce early failure mechanisms.

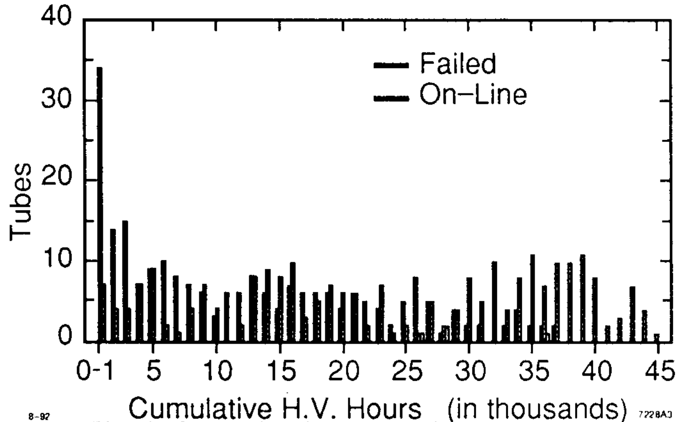


Fig. 5. Graph showing cumulative H.V. hours of online and failed 5045's.

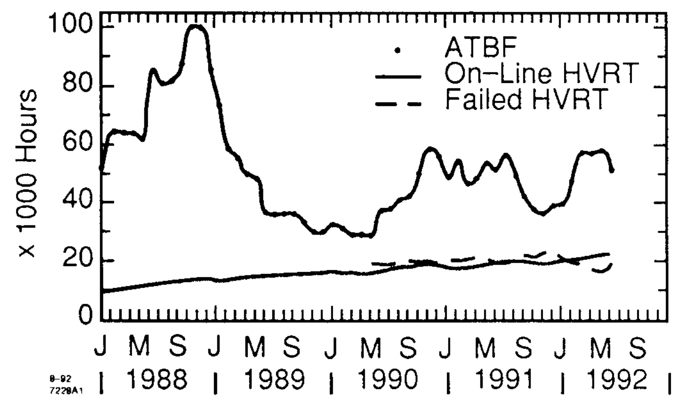


Fig. 6. 12-month average time between failures, average HVRT of failed 5054 klystrons, and average HVRT of online 5054 klystrons.

References

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