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**TITLE:** RELIABILITY AND OPERATING EXPERIENCE OF THE LAMPF 805-MHZ RF SYSTEM

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# RELIABILITY AND OPERATING EXPERIENCE OF THE LAMPF 805-MHZ RF SYSTEM*

Paul J. Tallerico

## ABSTRACT

Over 850,000 hours have been accumulated on the klystrons and modulators that constitute the LAMPF 805-MHz rf system. The 1-1/4 MW klystrons, the floating-deck modulators and the modulator triodes are described. The operating data are summarized and the fault and failure modes are tabulated for the three major components of the system. The high-voltage processing and other maintenance required to keep this 86-kV system operating reliably are described. The tube failure rates, tube fault rates and modulator fault rates are presented. The mean time to failures is > 56,500 h for the klystrons and > 40,600 h for the modulator triodes. The steps taken to produce such good reliability are discussed.

## INTRODUCTION

The Clinton P. Anderson Meson Physics Facility (LAMPF) in Los Alamos, New Mexico is a high-current proton linear accelerator which is capable of accelerating 1 mA of protons to 800 MeV. The facility is powered by two rf systems which operate at 201.25 and 805 MHz. The 805-MHz rf system is comprised of 44 1-1/4 MW klystrons and their modulators. This system usually operates at 86 kV, with a 500 μs rf pulse length and a 120-Hz rate. The facility is operated for ∿ 5000 hours per year and over 850,000 socket hours have been accumulated on the rf system.



The klystrons are operated in seven sector buildings, with either six or seven klystrons in each building. Each sector building has a single 86-kV, 30- or 35-A power supply. The floating-deck modulator tank supports the klystron and its focusing solenoid. The tank is filled with transformer oil, weighs ∿ 3200 kg and is capable of being moved on an airpad by two men. A complete spare rf module (klystron and modulator) is located in each cluster building, and the spare module can be installed in ∿ 2 h by the accelerator operations crew. Defective rf modules are transported via a fork lift to the Electronics Testing Laboratory (ETL) where diagnosis, repair and testing are done on the modulators, switching triodes and klystrons.

The modulators are of the single-triode, floating-deck type which have only to switch the ∿ 500 pF capacitance of the klystron's modulating anode and the associated circuitry. The modulators have been described in some detail [1]; however, the basic circuit is shown in Fig. 1. The LPT-44 switching triode is a 120-kV version of the ML-8495 which is normally rated at 160 kV maximum. The meter, M1, indicates any interpulse current through the LPT-44, and when this current exceeds ∿ 4 mA, the triode is replaced. A small, hinged lid on the modulator's main lid is opened to replace the triode. This operation is performed with the module in the cluster building. The causes and cures of this interpulse current will be described below.

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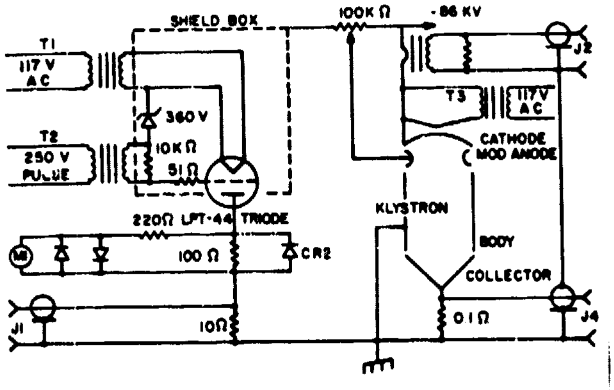


Fig. 1. The essential components of the modulator circuit.

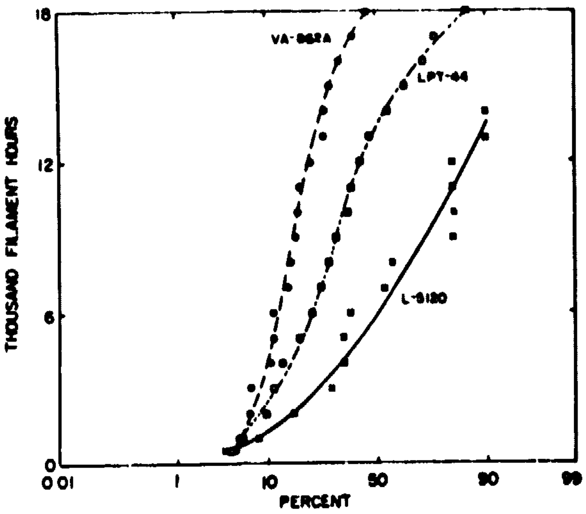


Fig. 2. The klystron cumulative survival curve.

The klystrons have 5 cavities, ∿ 50 db of gain and 1-1/4 MW of peak output power at a maximum duty factor of 12%. Two types of klystrons are used: the L-5120 and the VA-862A. Both klystrons have a modulating anode and operate in the same focus solenoid, although the filament voltages and sockets are different. The electrical and mechanical parameters of the L-5120 have been presented in Ref. [2]. Both types of klystrons have a 50% dc to rf conversion efficiency at saturation.

KLYSTRON RELIABILITY

As of June 1, 1976, the VA-862A klystrons have accumulated 734,900 filament hours (fh) and 666,900 high-voltage hours (hvh) with a total of 12 failures, while the L-5120 klystrons have accumulated 133,900 fh and 114,300 hvh with 9 failures. A failure is defined as a serious fault which requires that the klystron be taken apart and rebuilt to effect a repair. A fault is defined as a condition whereby the klystron is inoperable, but the repair is easily made by high potting or operating the tube at reduced power levels. The cumulative survival probability for the two types of klystrons and the modulator triodes are plotted in Fig. 2. The data presented here includes seven rebuilt L-5120s and nine rebuilt VA-862As. From Fig. 2, the estimated life of the VA-862A is ∿ 18,400 fh, three times that of the L-5120. The number of faults per 10,000 hvh and the average age of the installed klystrons are shown in Fig. 3 for the past 17 calendar quarters. A summary of the current statistics for the klystrons and the modulator triodes is shown in Table I. The average fault rate of the VA-862A is ∿ 3.59 faults in 10,000 hvh, while the L-5120 has ∿ 6.26 faults per 10,000 hvh. The corresponding mean times to failure (MTTF) are 56,533 and 22,323 fh, respectively. The fault rate is almost twenty times the failure rate.

The faults are usually due to one of two causes: either a water leak occurs and water seeps into the modulator or the klystron arcs and damages the modulator. There is a crowbar circuit on each capacitor bank to protect the klystron, but it does not always protect the modulator. The entire rf module is sent to the ETL for repairs and testing, and the klystron is charged with a fault.

TABLE I

SUMMARY OF KLYSTRON AND TRIODE STATISTICS AS OF 1 JUNE 1976*

| Tube Type | Total fh | Number Failed | Average Age in Service | Average Age of Failed | Mean Time to Failed | Mean Time to Fault | Number Rebuilt |
|---|---|---|---|---|---|---|---|
| VA-862A | 734931 | 13 | 14689 | 6011 | 56533 | 15977 | 9 |
| L-5120 | 133938 | 9 | 6065 | 3626 | 22323 | 4465 | 7 |
| LPT-44 | 853208 | 21 | 10836 | 4144 | 36581 | 4268 | 139 |

*The triodes are reprocessed rather than rebuilt.

There have been a total of 21 klystron failures to date, out of 84 new and 16 rebuilt klystrons. The combined histogram for both types of klystrons is shown in Fig. 4. The crosshatching indicates failed klystrons.

The failure causes are listed in Table II. The two leading failure causes are the inability to hold off high voltage properly and cracked high-voltage ceramics due to water in the oil. No LAMPF klystrons have ever failed because of a defective rf window or low emission from the cathode. This is probably due to the fact that the current densities and power densities are rather low in these klystrons. None of the klystrons which have been cut open for rebuilding have shown any evidence of copper grain growth. Except for a few arc marks in the output cavity gap, the body and collector of a rebuilt klystron appear as good as new.

THE KLYSTRON MODULATOR

The modulator is a simple, single-triode, floating-deck circuit, emmersed in a large (1- x 1- x 2-m) oil tank. The large tank is necessary because a substantial portion of the modulator operates at 96 kV dc. The modulators are capable of 1-ms operation, but the usual rf pulse length is 500 μs.

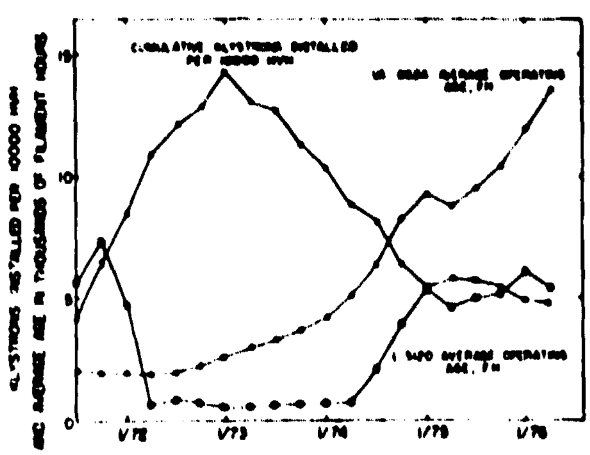

Fig. 3. Klystron fault rate and average installed age as a function of time.

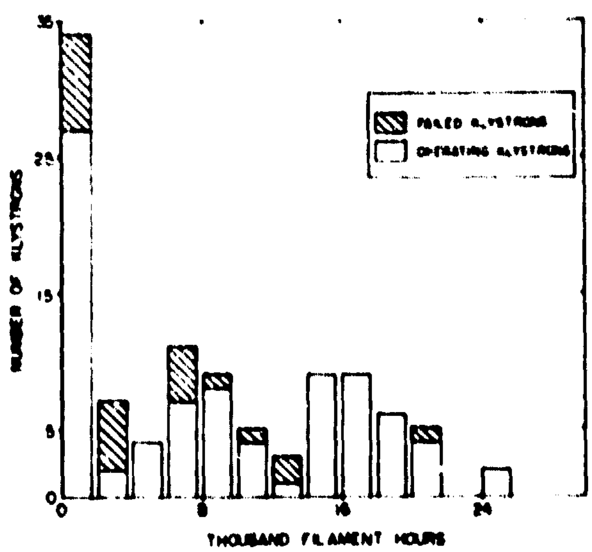

Fig. 4. Histogram for failed and operating klystrons.

TABLE II

KLYSTRON FAILURE SUMMARY

| | |
|---|---|
| High Voltage Problems | 8 |
| Gun Ceramic Failure | 7 |
| Vacuum Leaks | 3 |
| System Errors | 2 |
| Poor Rebuild | 1 |
| Total | 21 |

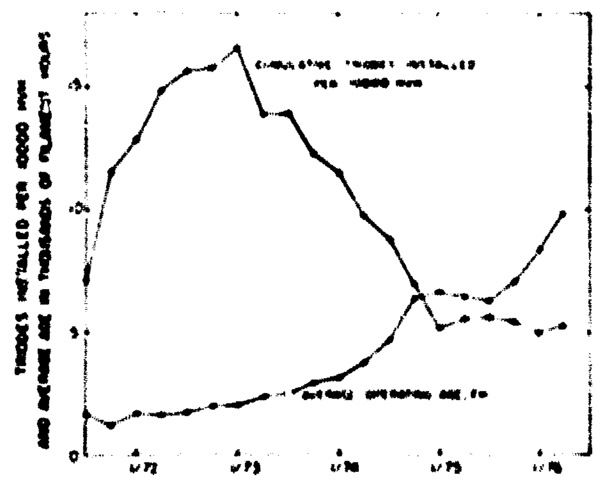

Fig. 5. Triode fault rate and average installed age versus time.

The reliability of the modulator is not directly measured since defective modulators are almost always caused by arcing klystrons or water in the transformer oil. The modulator is damaged when the klystron arcs from the modulating anode to the cathode, as this places 86 kV across ~ 15 kΩ of the 100 kΩ resistor. This type of arcing often damages the LPT-44 triode.

MODULATOR TRIODE RELIABILITY

The LPT-44 modulator triodes have accumulated 853,200 fh and 768,200 hvh with a total of 21 failures. The failures are irrepairable malfunctions, such as the triode losing vacuum or its filament breaking. There have been 180 faults which were repaired by reprocessing the triodes. The cumulative survival curve for the LPT-44 is shown in Fig. 2, and the expected life from the figure is ~ 13,400 fh. The fault rate and average age of the installed LPT-44 triodes are shown in Fig. 5. The most common fault is interpulse current, and there are at least two modes of this occurring: grid emission from cathode material deposited on the grid, or field emission from the grid because the grid surface is roughened by an arc. An extreme case of a rough grid is illustrated by the photograph in Fig. 6. The long strands at the bottom of the grid structure are pieces of the platinum grid cladding up to 1-cm long, which were peeled from the molybdenum grid wire by an arc. Triodes with grid damage as bad as this example have been successfully reprocessed.

The hold-off capability of the triodes is usually restored by heating the grid with ~ 300 W and high potting the triodes with a 0.04-μF capacitor connected across the triode ("spot knocking"). These procedures are outlined in [3] and are more fully described in an internal memo, [4]. The average age of the operating LPT-44s is 10,836 fh and the average age of the failed triodes is 4,144 fh. The triode histogram is shown in Fig. 7.

Some analysis of the triode fault problem has been performed. The expected time to the first fault in a new triode is 3,400 hvh. After the triodes are reprocessed, the expected time to the next fault is only 1,150 hvh, and after the second reprocessing, the expected time to

Fig. 6. An example of cladding peeling from a grid wire of an LPT-44 triode.

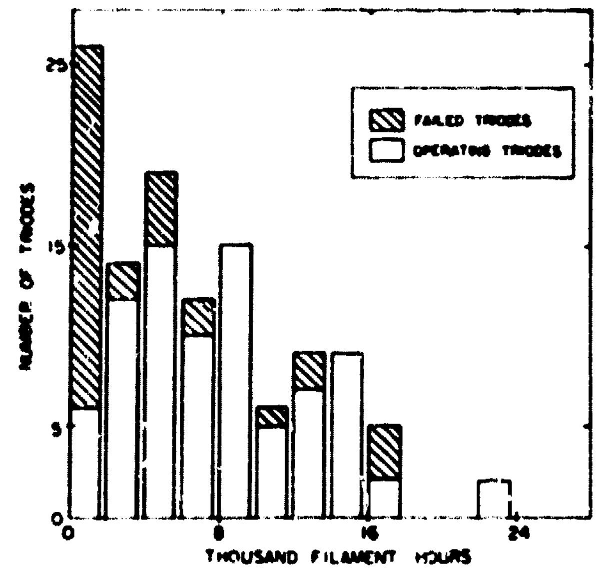


Fig. 7. Histogram of failed and operating modulator triodes.

next fault is 1,425 hvh. It is economically worthwhile to reprocess these modulator triodes as only ~ 1/2 man-day is required to process and test one triode. It is suspected that the triodes are damaged by klystron arcs. The arc damage is partially repaired by the reprocessing, but the grid never becomes as smooth as a new grid; thus, the triode may fault again.

## SUMMARY AND CONCLUSIONS

The level of reliability achieved by the klystrons and modulator triodes at LAMPF is acceptable for accelerator applications. The fault rate for the three types of tubes are all less than 12 faults per 10,000 hvh, and for the most reliable klystron, the VA-862A, this rate is 3.6 faults per 10,000 hvh. The cumulative fault rate was highest for a few quarters after the accelerator was first turned on, then decreased for about two years and now appears constant, (Fig. 3). Thus, no indication of any wear-out mechanism has yet been found. The observed failures occur at random times due to arcs or vibration and an exponential probability distribution seems to fit the limited data better than a Wiebull distribution. The observed failure rates are indicative of what can be expected from high-power tubes in similar applications.

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