SLAC–PUB–6543
December 1994
(A)

A HISTORY OF THYRATRON LIFETIMES AT THE STANFORD LINEAR ACCELERATOR CENTER*

David B. Ficklin Jr.
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Abstract

The Stanford Linear Accelerator Center (SLAC) has been in almost continuous operation since the middle 1960s, providing a remarkable opportunity to amass thyratron data. This paper reviews the history of this thyratron usage, focusing primarily on data collected during the last ten years of accelerator operation.

There have been two distinct operating conditions during the history of operation at SLAC. Prior to 1985, the fundamental thyratron operating points were 46 kV anode voltage (Epy), 4.2 kA peak current, 3.8 μs equivalent square pulse (esp), with a maximum repetition rate of 360 pulses per second (pps). The accelerator was upgraded during 1985, and the thyratron operating points are now 46 kV Epy, 6.3 kA, 5.4 μs esp, with a maximum repetition rate of 120 pps.

The SLAC high-energy physics research program requires that each of the available modulator klystron units provide a stable microwave energy source. Within these constraints, this paper explores historical thyratron lifetimes at SLAC, reviewing the available data to determine how long these thyratrons can be expected to operate before failure currently or recently used in the 243 accelerator modulators.

INTRODUCTION

The Stanford Linear Accelerator Center functioned for many years as originally designed. In early 1985, there was a major upgrade to accommodate the newly developed 50 Megawatt pulsed S-Band Klystron. This rework of all linear accelerator (linac) modulators altered the thyratron operating condition to an Epy of 46kV at 5,600 amps into a 1:14 pulse transformer to drive the new klystrons.

Prior to and during the conversion of the linac modulators, concern was expressed about the existing ITT F143 and Wagner CH1191 thyratrons being capable of operating at the higher required power. Therefore, 48 of the 243 modulators used in six sections of the accelerator were modified to use two thyratrons each. After additional testing, the existing Wagner CH1191s and the ITT F143/CH1191 rebuilds were found to be fully capable of operating the new modulator configuration, so all of the dual thyratron modulators were eventually reconfigured back to single thyratron operation.

During the period of the linac upgrade, it was found that the new 5405 klystron could operate at 350kV, with 60 megawatts of power out. This required modification of all 1:14 pulse transformers to 1:15, increasing the peak primary current through the thyratron from 5,600 to 6,100 amps. With this change, we could continue to use the diminishing thyratron inventory while actively engaged in a search for new thyratrons that would operate the new 5045 klystrons.

Initial checkout of the modulator systems was accomplished at 10 pps. Most of the accelerator commissioning work done through 1990 was accomplished at 60 pps or less. During part of the conversion process, the accelerator continued to operate particle beam experiments with the pulse rate limited to 10, 30 or even 60 pps. No experience was available to establish or reliably project thyratron lifetimes. Even limited operation at 120 pulses per second for a month did not establish any benchmarks. The prediction of the rate of consumption of thyratrons in the linac modulators was therefore based on conjecture. Modulator reliability in the Stanford Linear Collider (SLC) configuration is discussed by A. R. Donaldson et al., "SLAC Modulator Operation and Reliabiltiy in the SLC Era" in the1992 20th Power Modulator Symposium, IEEE Confrence Record CH3180-7/92/0000-0152.

The linac commenced operation at 120 pulses per second in July 1990. In July, 11 thyratrons were changed in the linac modulators, followed by 18 in August, 4 in September, 19 in October and 10 in November, when the run was completed. During this run cycle, the initial symptoms of premature thyratron failure due to internal problems with Grid 1 appeared. During the three years of SLC operation at 10, 30 or 60 pps, the average replacement rate was 4.5 tubes per month. From 1988 through 1991, running at 60 pps, the replacement rate increased to 7.5 tubes per month. Running at 120 pulses per second, the replacement rate is 14 tubes per month. These rates include thyratron changes for any reasons.

An extensive testing program was established in March 1991 to verify the status of all thyratrons removed from operation in the linac. Of all thyratrons undergoing failure verification testing, 10% are recertified for operation in the linac modulators. This program provides hard data that is shared with the vendor to improve the reliability of their product.

The nature of the operational cycle at SLAC includes periods of time when the power is turned off for installation work, repairs, and upgrades. During the initial start up following an extended maintenance period, thyratron replacements run above average. The actual number of changes varies, without correlation to time turned off, or prior operating conditions. During a recent holiday down time, the thyratron filament, reservoir, and dc keep-alive circuits were left on in an attempt to reduce replacements. This decreased the number of replacements, but required operating 243 power supplies at 121 kilowatts. At three weeks, cost of power is cheaper; at five weeks, power costs are greater than savings.

Of the 440 thyratron replacements in the linac that occured during the three years since September of 1991, the earlier internal problem with the Grid 1 failure was a significant cause. Originally appearing in the F241s, this type of failure mode also appeared in other models, and will be discussed as part of the data presented for each thyratron model. The large number of changes has significantly altered lifetime profiles.

We look at current lifetime profiles and age profiles, grouped by specific thyratron model. This data is dynamic. Here, it is presented in a static format. All mention of hours refers to the thyratron high-voltage running time recorded by electromechanical meters on the front of each modulator. The age and lifetime profiles are extracted from the thyratron data base and may be viewed on computer. These graphs are based on run-time meter readings taken approximately at the end of each month. Data current as of May 31, 1994, was used to generate the hours history plots shown for the thyratrons models presented. Filament run-time data is also recorded, but is not included in this discussion.

* Work supported by Department of Energy contract DE–AC03–76SF00515.

Presented at the 1994 21st International Power Symposium Advanced Program West in South Coast Plaza Hotel in Costa Mesa, California, June 27–30, 1994

Litton Model 4888

The thyratron high voltage run time hours for Litton's model 4888 thyratrons are in the range of one to six thousand hours, from a sample statistically small compared to other vendors. Design work, and prototyping produced the first tube in June 1993, with production deliveries started August of 1993. Litton is still in the post development stage of production, correcting of minor problems, improving and optimization testing procedures.

The first thyratron was installed into the linac in June 1993. Today there are 16 in use. During a maximum 8750 hours of high-voltage running time, the earlier problem with Grid 1 failure has been seen in only one thyratron to date. Due to the very short period of time available to collect meaningful lifetime data, it is too soon to project an accurate lifetime.

OmniWave Model 1002

Production or rebuilding of the Wagner carcasses started in late 1984 with the first deliveries beginning in January 1985, and ceased nearly 6 1/2 years later after approximately 250 tubes had been rebuilt. The Thyratron Age Profile graph (Figure 1) plots quantity versus age for the 10% of the total model 1002 thyratrons which are still in active service. Most of the 15 thyratrons centered in the bell of the distribution curve at 20,000 hours were produced late in the production. The two oldest thyratrons have close to 50,000 hours.

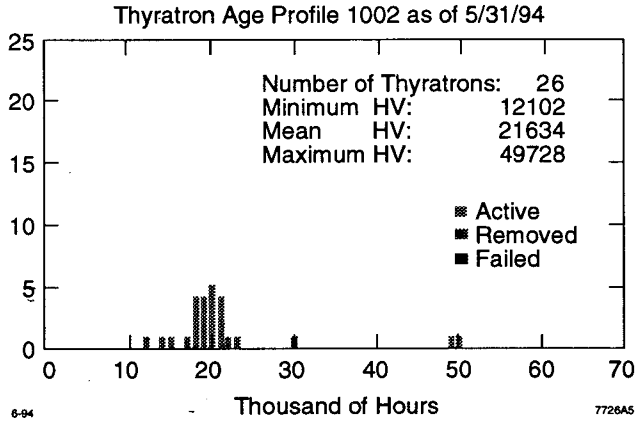

Figure 1. The quantity of tubes versus the high-voltage running-time hours. One thyratron failed at 30,000 hours since the readings.

Examination of the Thyratron Lifetime Profile in Figure 2 shows that almost half of the 145 thyratrons failed with 5,000 hours or less. One significant failure mode for this model was the rapid rise in required reservoir voltage. A second failure mode is the tripping off of the modulator power supply on a high voltage over current fault. This is likely to be a result of vaporized metal being deposited on the ceramics in the vicinity of the electrode gaps. Seven of the OmniWave model 1002 failures have been due to Grid 1 problems. Fourteen thyratrons have failed since passing the 20,000 hour mark. Figure 1 shows that OmniWave did have the ability to produce a rebuilt thyratron with the capability of 20,000 plus hours of operation.

English Electric Valve Ltd. Model CX1836A

Fifty-four model CX1836As were delivered, starting in October 1992, through May 1993 to fill a serious need for spare thyratrons. The design of the CX1836A enabled the tube to be an identical replacement.

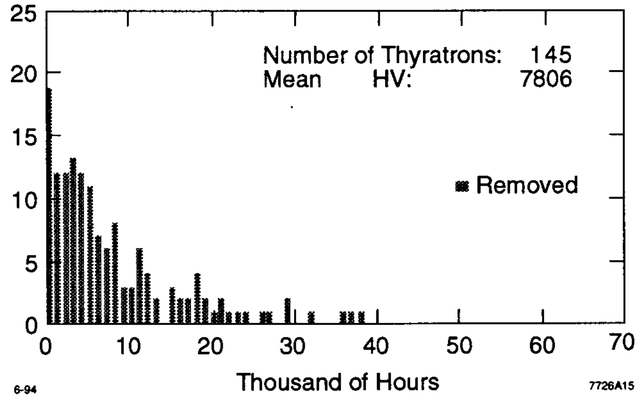

Figure 2. The quantity of tubes verus the high-voltage running time hours at the time of removal from the linac modualtor. There were 19 failures with less than 500 hours of high-voltage running time.

Fifteen of the CX1836As currently active in the linac. A problem manifested as external arcing from Grid 1 to ground reduced the number of CX1836A thyratrons active in the linac. A fix was found by working closely with English Electric Valve, and all of the removed CX1836As have been modified and recertified for use. The CX1836A is the only thyratron model that has not suffered from the Grid 1 problems prevalent with all other models used in the linac modulators.

English Electric Valve Ltd. Model CX2410

The CX2410 is the result of a SLAC request for a six-nch diameter thyratron with an oxide cathode. Deliveries started July 1992 and ran through July 1993. Outgrowth of this particular design is the CX2412, which supports and brings Grid 1 through the ceramic in the same fashion as Grid 2. The CX2412 is currently operational in a linac modulator with 4,500 hours of high-voltage run time. There are three tubes in active service, and a fourth tube that was removed from service after 3,200 hours and verified as failed due to Grid 1 problems.

ITT Model F143

Deliveries of just over 220 ITT rebuilt Wagner carcasses started in March 1974, and proceeded through October 1981. There are three remaining active thyratrons, with a fourth that was removed at 55,000 hours. Retesting has yet to be done.

Going back seven years to June 1987, Figure 3 displays the Thyratron Age Profile graph for the half of the linac modulators that were utilizing the F143 thyratron.

The decrease in the population of F143s with less than 2,000 hours is due to depletion of the F143 spares. In June 1987, 28 of the active thyratrons had exceeded the 20,000 hour point, and 25 thyratrons had been removed with 20,000 hours or more. There is an apparent randomness in high-voltage hours for the thyratrons removed from the gallery. Here again, with enough time, is proof that a thyratron can be manufactured or rebuilt that has the capability of providing over 20,000 hours of high voltage run time.

Figure 4 is a presentation of theThyratron Lifetime Profile of total high-voltage hours for all of the F143 thyratrons that have been removed from use in the linac modulators. The bar on the left edge in the range of 0 to 500 hours indicates there were nine thyratrons that failed prior to 500 hours. This small quantity is a direct result

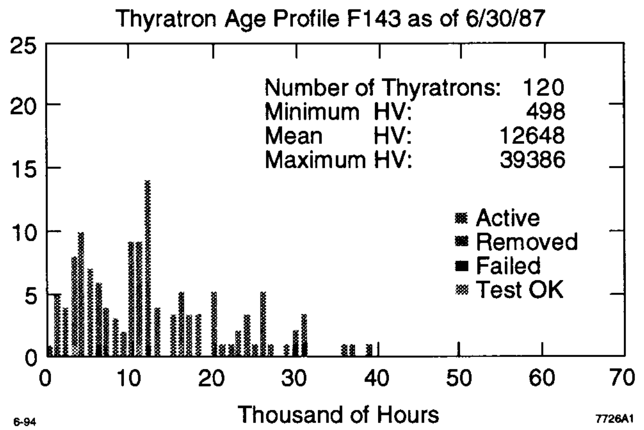

Figure 3. The quantity of tubes versus the high-voltage running-time. Five thyratrons failed during the month, three others were removed and recertified for operation and later used. This represented the largest quantity of the model F143s used in the linac modulators.

of the acceptance testing program, although not all of the infant mortality failures were caught. SLAC rejected 28 F143s—some were reprocessed by ITT and returned, others were simply replaced. There is a peak in the number of failures at 26,000 to 27,000 hours. Here is effective proof that 20,000 hour thyratrons can be produced in quantity. The predominate failure mode for the F143 has been unstable operation or due to high-voltage power supply over current faults. Only seven F143s have been documented with the Grid 1 internal failure problem.

ITT Model F241

First delivery of ITT's model F241 started in July 1985 and continues today. Over 400 model F241s have been received and tested and of those, over 340 have been utilized in the linac modulators.

Figure 5 shows the Thyratron Age Profile for 58 active F241s in service at the beginning of June 1994, with two removals at six and nine thousand hours. The low quantity of thyratrons recently installed is due to there being a selection of five different models to choose from. Two thyratrons with 33,000 high-voltage hours are still in operation. One of these is on loan to SLAC for lifetime testing of a dispenser cathode.

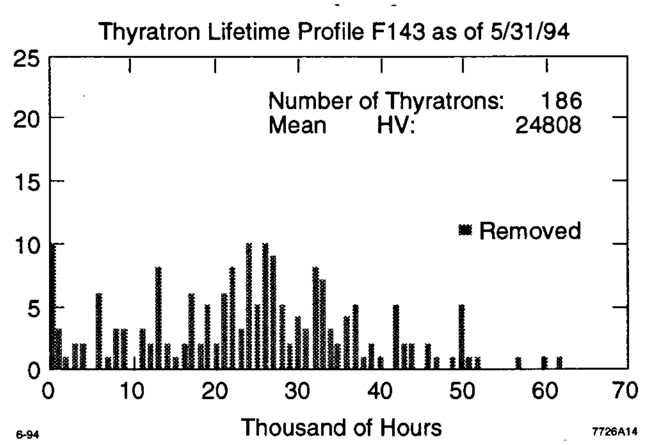

Figure 4. The quantity of tubes versus the high-voltage running-time hours at the time of removal from the linac modualtor. Only 10 failed with less than 500 hours of high-voltage running time.

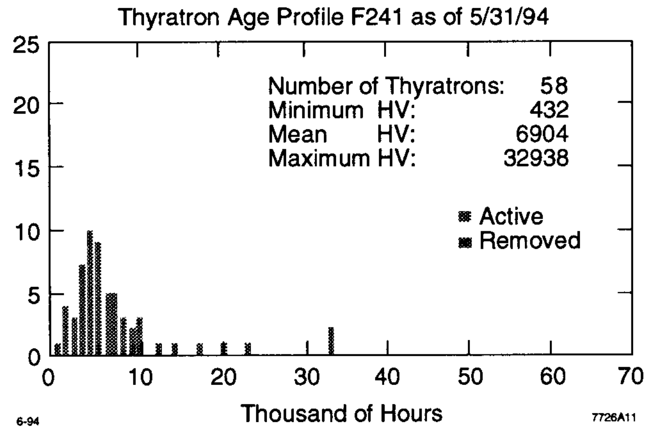

Figure 5. The quantity of tubes versus the high-voltage running-time hours. Two were removed, one with 5,000 hour and the second with 9,000 hours. Failure verification has yet to be done.

During the last three years, SLAC experienced significant losses in the F241 population, primarily due to the internal failure in Grid 1. The Grid 1 failure mode was first effectively documented by the F241 failures. Figure 6 displays the Thyratron Lifetime Profile. A large failure rate at six to seven thousand hours is predominately due to the Grid 1 problem. Diagnosis showed that there were two separate types of failures. In the first, part of Grid 1 developed a short to the cathode ground. The second type of failure was nonconduction from the cathode to Grid 1. This was only found upon attempted operation of the thyratron. Thyratron autopsies revealed serious erosion of the top of the cathode structure and disintegration of the Grid 1 element. Engineering discussions with ITT resulted in a change in design, and the F241 thyratron continues to be a stable workhorse for operational requirements of the linac.

ITT Model F310

When it became evident that the recent utilization of the failed Wagner carcasses was not a viable process, a switch was made to rebuilding the failed model F241 thyratrons. Operationally and physically, the F310s are identical to the F241. Deliveries of the rebuilt tube, now

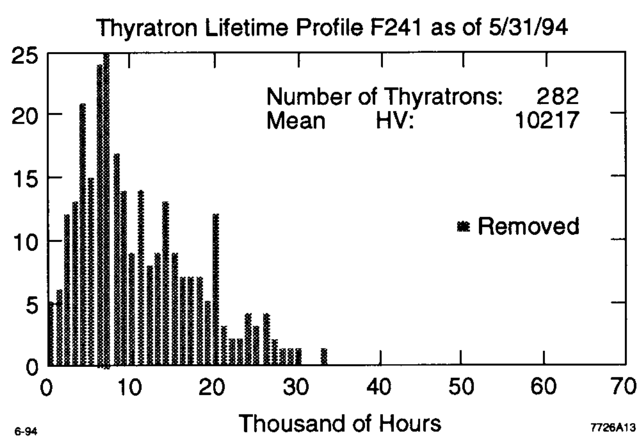

Figure 6. The quantity of tubes versus the high-voltage running-time hours at the time of removal from the linac modualtor. Five failed with less than 500 hours of high voltage runing time. The large peak at 6,000 to 7,000 hours can directly be attributed to the failures associated with the Grid 1 problem.

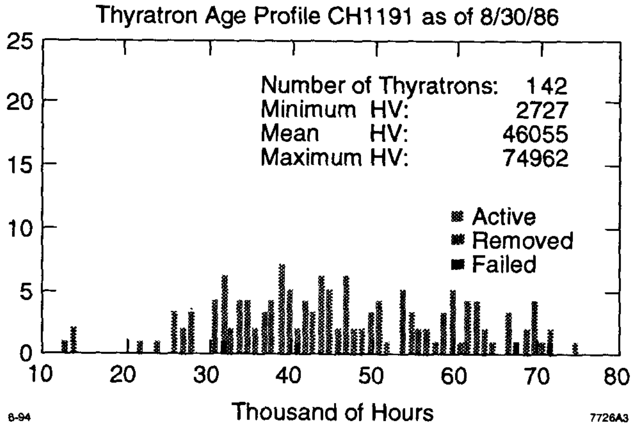

Figure 7. The quantity of tubes versus the high-voltage running-time hours.

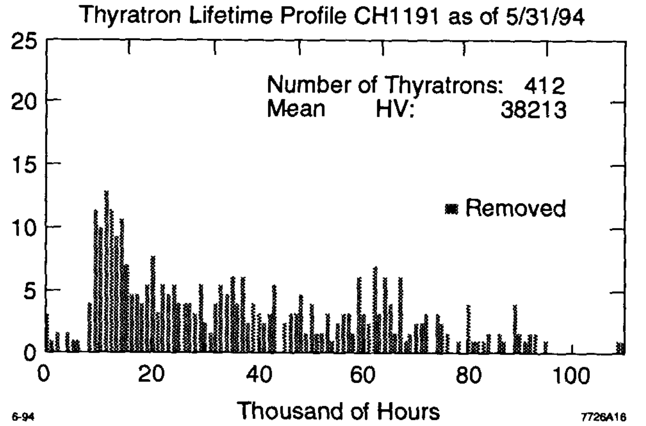

Figure 8. The quantity of tubes versus the high-voltage running-time hours at the time of removal from the linac modulator.

called F310, started in August 1992. Over 140 F310s have been in service in the linac modulators to date. Model F310s also suffer from losses caused by the Grid 1 problems. Experience indicates rebuilding the F310s from the F241 carcasses is viable and cost effective.

Wagner Model CH1191

Production delivery started in September 1964, starting a long run that delivered approximately 1600 thyratrons and rebuilt an additional 125. Not all of the CH1191 thyratron data exists in the computer files—approximately 35% is currently available from the last part of the production. The conversion of the linac to SLC type operation during the summer of 1985 came ten years after the last thyratron delivery from Wagner. Meanwhile, 20 thyratrons are still in service in the linac, with hours ranging from a minimum of 75,000 hours to top of 120,000 hours. This grouping provides exciting data for product lifetime. The remaining 20 thyratrons currently in service are considered to be at the high end of the distribution curve. These veterans create a tough benchmark for comparison. In this group, Wagner serial number 7RE 513, received February 1, 1974, was installed in Sector 27 Modulator 8 on February 25, 1974. This thyratron has been in continuous service since that date and has 119,225 hours as of May 31, 1994. This is the very top end of thyratron lifetimes recorded at SLAC. The last rebuilt CH1191 was installed in a linac modulator in 1982.

Looking back in time to August 1986, Figure 7 shows the Thyratron Age Profile at that point in time when there were 142 of the CH1191s in active service. Evidence was beginning to mount that the CH1191s had the ability to operate for long periods of time. Even later, in January 1989, when the oldest of the OmniWave model 1002 thyratrons reached the 20,000 hour mark, there were still 70 CH1191s active in the linac modulators, with lifetimes ranging from a minimum of 30,000 hours to a high of 84,000 hours.

The Thyratron Lifetime Profile (Figure 8) shows only 35% of the CH1191 thyratrons used at SLAC. Much of the very old data, pre-1985, only exists in paper log form and has yet to be entered into the computer. This means that below 30,000 hours, the actual population is much larger than shown. Reviews of the log book indicate lifetimes much shorter than 20,000 hours, with one old failure report from the late 1970s stating, "Longest One Yet" for a CH1191 that lasted more than 20,000 hours.

Summary

While the longevity and history of the various thyratron models varies widely, all of the current models have been modified, revised, or created within the last two years. Much of this data is difficult to apply or project for use with the revised models now in use. With the changes that have been made, all of the lifetime history clocks have been effectively reset.

Many other interesting tidbits of information have been unearthed in the research for this paper. Based on models F143, F241, and the F310, ITT has provided a total of over 8.7 million tube hours operation. The ITT thyratrons, even with the rediscovery of the Grid 1 problem, have been a reliable work horse in the linac modulators. OmniWave, including the tubes that were accepted and used, has provided over 1.7 million tube hours of high-voltage operation for the linac. Wagner, with the 35% of CH1191 thyratron data available, has provided over 17.5 million tube hours of operation. And the linac is sill running!

Acknowledgments

The author is indebted to R. Hanselman, N. Tarvid and R. Ecken for their direct support in continuing the existing information system and providing foundation for further development. Thanks is given to C. Olsen, B. Bradford, and others who kept past records. The staff of the Accelerator Maintenance West group, who perform timely diagnosis, make the replacements of the thyratrons, and document the changes, deserve credit for all of their efforts. The author greatly acknowledges the test technicians charged with the task of performing all of the acceptance tests, and the retesting of all the thyratrons. The author thanks R. Koontz for his support, as well as George Caryotakis, Department Head, Klystron and Microwave Department, for his interest in this project.