THE LANSCE 805 MHZ RF SYSTEM HISTORY AND STATUS*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) linear accelerator runs at 201.25 MHz for acceleration to 100 MeV. The remainder of the acceleration to 800 MeV is at 805 MHz. This is done with 44 accelerator cavity stages driven by 805 MHz klystrons. Each klystron has a peak power capability of 1.25 MeV. Originally, 98 klystrons were purchased, which was 70 from Varian/CPI and 28 from Litton. The 44 RF systems are laid out in sectors with either 6 or 7 klystrons per sector. The klystrons in each sector are powered from a common HV system. The current arrangement uses the Varian/CPI klystrons in 6 of the 7 sectors and Litton klystrons in the remaining sector. With that arrangement there are 38 CPI klystrons installed and 1 spare klystron per sector and 6 Litton klystrons installed in the final sector with 2 spares. The current average life of all of the operating and spare klystrons (52 total) is >112,000 filament hours and >93,000 HV hours. That is three times the typical klystron lifetime today for other similar klystrons. This paper summarizes the details of the LANSCE klystron history and status and a summary of the predicted failure rate.

LANSCE SETUP

The 805 MHz section of LANSCE accelerates the beam from 100 MeV out of the 201.25 MHz section to the final energy of 800 MeV. There are a total of 44 805-MHz RF stations laid out in 7 sectors (labeled sector B through H). Each sector has either 6 or 7 klystrons [1]. Sectors B and E-H have 6 klystrons each, and sectors C and D have 7 klystrons. The 6-klystron sectors have capacitor banks with 48 capacitors, and the 7-klystron sectors have capacitor banks with 56 capacitors. The capacitors are arranged with 2 levels in order to meet the voltage needed for the klystrons. The stored energy is approximately 225 and 260 kJ for the two different banks. Approximately 7% of the stored energy is used on each pulse. Each bank has a crowbar system to protect the klystrons in the event of a fault. The system typically operates at 120-Hz, but lower repetition rates are also used depending on the experimental needs. LANSCE can operate with pulses of H+ and H- intermixed.

The klystrons were originally estimated to have a lifetime of approximately 25,000 hours. This lifetime has been exceeded by a very large amount, but significant rebuilds and replacements will be needed in the near future. The current average life of all of the operating and spare klystrons (52 total) is >112,000 filament hours and >93,000 HV hours.

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Figure 1: Operational Varian Klystrons

ORIGINAL PURCHASES

In the original LANSCE klystron purchases, the interactions went on with Varian and Litton. Varian did not bid on the first set of 1.25 MW klystrons, so Litton was given the first order. They made 4 prototypes, but none met the specifications (these were s/n 1001-1004), and they were salvaged. When the production contract was first out, both Varian and Litton bid, and Varian was awarded 5 prototypes (these were s/n 101-105). For about 9 months, the first Varian klystron was too unstable to meet our specifications, but the designer, Oscar Lundstrum, looked for all kinds of oscillations. Based on his detailed studies, he came up with the idea of running the klystron with many magnet power supplies. This was a break from previous systems and allowed more adjustment and versatility of the focusing fields. The klystron became stable for many shapes of focus field, and Oscar saw that he could get a good shape by a series/parallel connection of the individual focus coils. For example, the output cavity needed more ampere-turns than the original design. The klystron was stable under this configuration and passed our specifications. LANL ordered 55 production klystrons from Varian. LANL then placed an order with Litton that required that they make a klystron that operated in the Varian solenoid, and they needed to make their drift tubes much larger in diameter. They tried these changes on their last prototype, and it came close to meeting spec. They were close enough with the prototype that they could likely make klystrons that met our spec, and Los Alamos ordered 28 production klystrons from Litton, s/n 2007-2034. We were then given "production spares" money from DOE, and we used it to buy 10 more Varian klystrons, s/n 301-310.

Thus from Varian we ended up with 70 klystrons (counting the prototypes which met our spec), and from Litton we had 28 klystrons (not counting the prototypes which were salvaged), giving us the 98 total.

The klystrons had reasonably long lifetimes, and facilities were set up at LANL for minor repairs. Given that, and given the large number of original purchases (98) versus the number needed in operation (44), LANSCE is still operating on those original klystrons. The problem now is that virtually all of the klystrons have a large number of hours, the number of available spares is small, and LANSCE cannot operate without all 44 stations operational.

KLYSTRON LIFETIME

The original 98 klystrons, given their generally good lifetime, are the klystrons that LANSCE is still using. Of the original 98, 3 are no longer accountable. One was converted to 850 MHz for a previous program, and 2 have been loaned or destroyed (not certain). The remaining 95 klystrons are available and accountable. 40 klystrons are on their first operational cycle. The plot below (Figure 2) shows the operational hours of the klystrons that are either installed are available as spares.

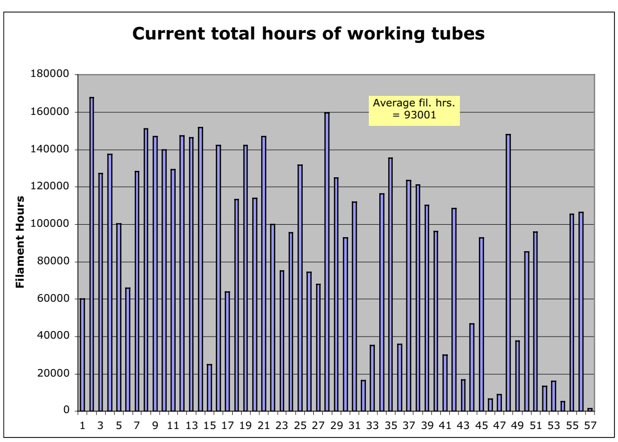

Figure 2: Total hours for all working klystrons.

Of the klystrons shown in the graph above there are 40 that have not been rebuilt. They are shown in the separate plot (Figure 3). The interesting note is that their average number of filament hours is over 100000.

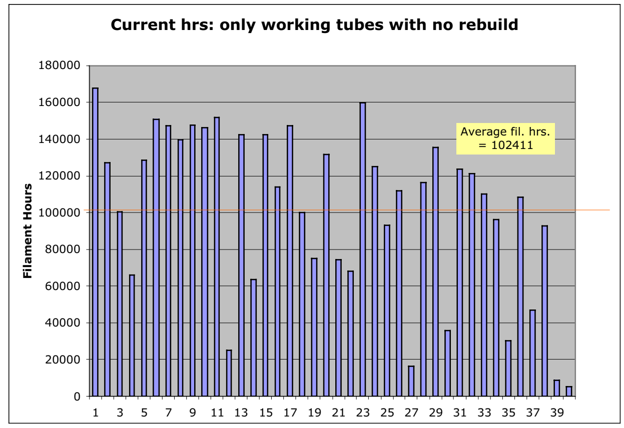

Figure 3: Total hours of all working klystrons that have not been rebuilt.

Probability of near term failures of operational tubes

A Weibull distribution has been applied to the filament hours, and all data under 10,000 hours was discarded to eliminate infant mortality and focus on wear-out failures. The Weibull fit was much better than a constant failure rate fit.

The results are that the expected life is 128700 hours per klystron, and the failure rate is 1.138*10^-5 per hour. Thus with 44 klystrons, and 4000 hours per year, we expect 2.003 klystron failures per year, and twice that in two years. The probability of n failures in 1 or 2 years is in the graph in Figure 4.

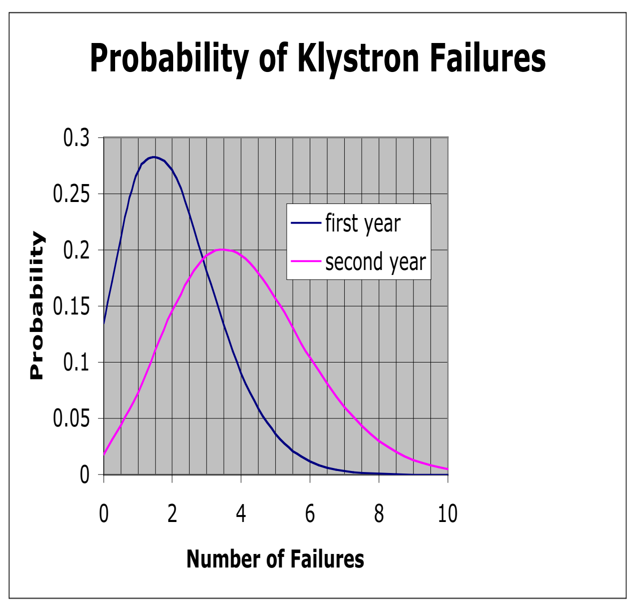

Figure 4: Probability of failure of currently operational klystrons in the first and second year.

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Given that we have a total of 57 operational klystrons, and we need a minimum of 44 to operate, the above statistical analysis is very serious. It shows that it is likely that up to 2 klystrons will fail in the coming year and 4 klystrons in the year after that. That would leave us with a total of 7 spares. Our current operational setup uses 1 spare in each of the 7 sectors except the sector with the Litton tubes. The current arrangement uses 2 spares in that sector.

NUMBER OF REBUILDS OF THE ORIGINAL KLYSTRONS AND THE CURRENT STATUS

Rebuilding failed klystrons is an option, but it has risk and cost associated with it. A summary of the rebuilds done to date is shown in Figure 5. The quality of the results varied considerably.

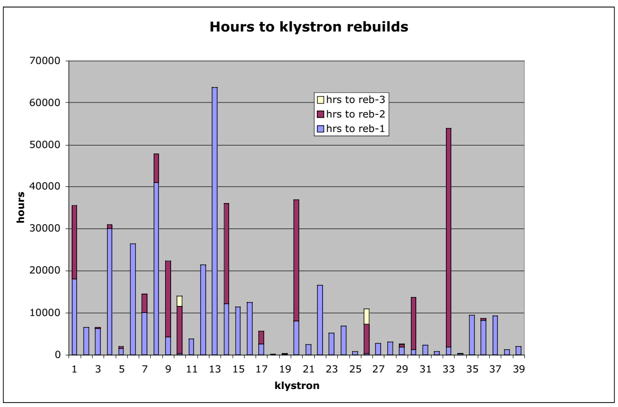

Figure 5: Hours to rebuild of all 39 klystrons that have been rebuilt, showing the hours to rebuild1, then rebuild 2 (in 18 cases), and then rebuild 3 (in 4 cases).

Of the original 95 klystrons currently accounted for, 56 have not been rebuilt, and of those 56, 40 are still operational. Thirty-nine of the 95 klystrons have seen rebuild number 1. Of those 39 tubes, 18 have seen rebuild number 2. Of those 18 tubes, 4 have seen rebuild number 3. Of the 21 tubes seeing only rebuild number 1, 11 are still operational. Of the 14 tubes seeing only rebuilds number 1 and 2, 5 are still operational. Of the 4 seeing rebuilds number1, 2, and 3, 1 is still operational (klystron number 26 in figure 5). That particular tube failed the first time after only 330 hours, the second time after only 6,924 hours, and the third time after 3,699 hours. Since the third rebuild, however, it has provided 85,000 hours of operation and is still a working tube.

EXAMPLES OF KLYSTRON PARAMETERS AND EXPERIENCES

Of the 95 klystrons there is an assortment of experiences. Klystron 101 (the first Varian prototype) went just over 18,000 hours before needing to be rebuilt. It then went about 17,500 hours before needing rebuild number 2. It then only lasted a little over 1,200 hours before failing again. It has not been rebuilt a third time. Klystron 104 (another Varian prototype) is still operational with almost 168,000 hours and no rebuilds.

Similar experiences occur in the Varian and Litton production tubes. Klystron 222 (a Varian production tube) has been rebuilt 3 times and has failed again (a 4th time), and it has a total number of hours of just over 16,000. As mentioned above, there are 40 operational tubes that have never been rebuilt, and their average lifetime at this point is over 100,000 hours. Of these 40, 38 are Varian tubes – a much different result than tube number 222. As noted below, the 2 Litton tubes that have not been rebuilt have seen limited hours, unlike the Varian tubes. Klystron number 231 (number 13 in Figure 5) provided almost 64,000 hours to its first failure and has not been rebuilt.

In the Litton tubes, number 2016 has been rebuilt 3 times with a total number of hours at the 3rd failure of only 11,000. Since the third rebuild however, it has operated 85,000 hours and is still operational. In another example, tube number 2013 needed to be rebuilt after only 6,900 hours. It then failed again after only 5,900 hours, and that is its current status. Klystron number 2026 (33 in figure 5) provided only 1,800 hours to its first failure, but then provided another 52,000 hours after being rebuilt. Klystron number 2028 (34 in figure 5) provided only 346 hours to its first rebuild, then only 45 hours to its second rebuild. However, it has now provided a total of 106,000 hours and is still operational. There are only 2 Litton tubes that are operational and have not been rebuilt. They both have less than 10,000 hours, however, so that may be the reason a rebuild has not been needed yet.

PLANNED KLYSTRON UPGRADE

The plan for the future is to ultimately replace the klystrons with diode type tubes [2]. This requires a different high voltage system than the HV capacitor bank used now. But the klystron design and manufacturing is greatly simplified. The hope is to get long-lived tubes without the huge variation that we experienced with the tubes discussed in this paper.

REFERENCES

[1] K.C.D. Chan, et al, "Evaluation of LAMPF Upgrade for High-Power Operation," Final Report to the Defense Nuclear Agency, October 31, 1994

[2] D. Rees, et al, "LANSCE RF System Refurbishment," PAC"05, Knoxville, May, 2005. http://www.jacow.org