LANSCE 201 MHZ AND 805 MHZ RF SYSTEM EXPERIENCE*

J. K. Young, G. Bolme, J. Lyles, M. Lynch, E. Partridge, D. Rees
LANL, Los Alamos, NM 87545, U.S.A.

Abstract

The LANSCE RF system consists of four RF stations at 201 MHz and forty-four klystrons at 805 MHz. In the LANSCE accelerator, the beam source is injected into the RF system at 0.75 MeV. The beam is then accelerated to 100 MeV in four drift tube linac (DTL) tanks, driven at 201.25 MHz. Each 201 MHz RF system consists of a train of amplifiers, including a solid state amplifier, a tetrode, and a triode. After the DTL, the beam is accelerated from 100 MeV to 800 MeV in the forty-four coupled cavity linac (CCL) tanks at 805 MHz. The machine operates with a normal RF pulse width of 835 microseconds at a repetition rate up to 120 Hz, and sometimes operates with a pulse width up to 1.2 milliseconds at 1 Hz. This RF system has been operating for about 37 years. This paper summarizes the recent operational experience. The reliability of the 805 MHz and 201 MHz RF systems is discussed, and a summary the lifetime data of the 805 MHz klystrons and 201 MHz triodes is presented.

201 MHZ RF SYSTEM

201 MHz RF System Description

An overview of the 201 MHz RF system is shown in Figure 1. The typical operating peak RF power levels produced by the amplifiers for DTL #1, 2, 3, and 4 are 350 kW, 2.9 MW, 2.3 MW and 2.7 MW, respectively. The energy of the beam is 5.4 MeV at the output of DTL #1, and then increases to 41.3 , 72.7 and 100 MeV at the output of each DTL, respectively. The RF window consists of a coaxial Rexolite disc, mounted between two copper platted stainless steel flanges. The vacuum seal is made with o-rings outside of the RF field.

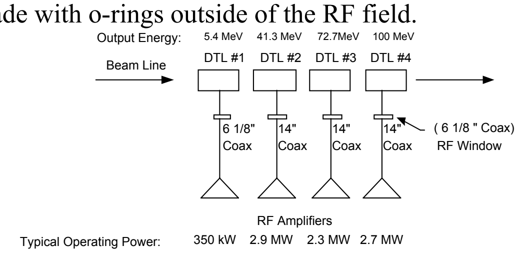

Figure 1: Overview of the 201 MHz RF System Layout.

The RF amplifier consists of a low-level interface amplifier which feds into a solid-state amplifier, capable of up to 5.5 kW. A nominal 3.5 kW is fed into a tetrode Intermediate power amplifier. The output of the tetrode is typically 130 kW. This power drives the triode final power amplifier; the output of the triode is coupled into the DTL through the window to a loop coupler in vacuum. A schematic of the 201 MHz RF source is shown in Figure 2.

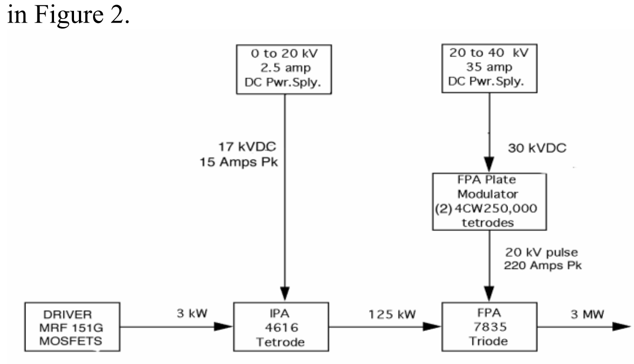

Figure 2: Schematic of the 201 MHz RF Amplifiers.

Recent 201 MHz Operational Experience

The current 201 MHz RF system has been in operation for about 37 years. The most common failure point in the system is the triode final power amplifier. We have a record of sixty-two triodes between 1968 and 2007. Of these tubes, twenty-three have failed because of ceramic failures, six due to vacuum problems, one due to a bad contact, eleven due to arcing, seven due to emission or power slumping, and five due to unidentified low output, as shown in Figure 3. Three were removed from service because they were weak, probably due to age. Presently seven triodes are operational. Figure 3 also shows the number of filament hours at the time of failure, along with the type of failure.

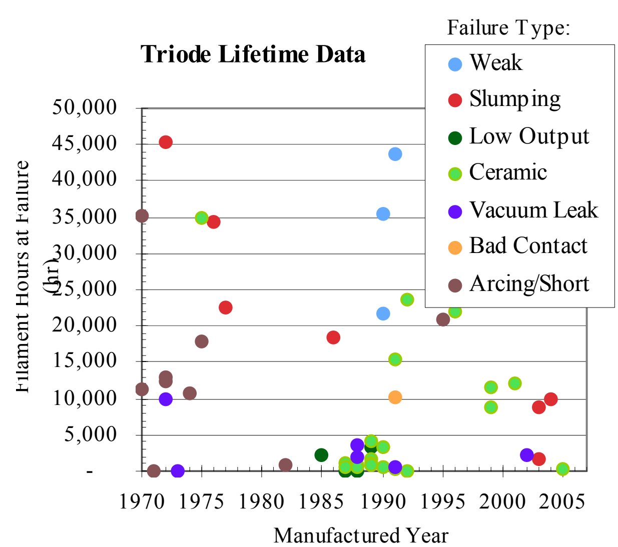

Figure 3: Summary of Triode Failures.

In the past two years, we have seen three failures due to "emission slumping". These failures are described in detail in an internal report by J. Lyles [1]. Emission

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slumping a condition where the peak output power drops while the anode voltage, driver power, and filament power remain constant. Emission slumping can sometimes be overcome by increasing the filament temperature, by raising the filament current. This is thought to burn-off whatever may have poisoned the cathode/emitter, from excess gas or other contaminants within the tube envelope. Increasing the high voltage and increasing the RF drive can compensate for a low emission tube, to a degree. However, these fixes all cause other problems: Filament emission lifetime is reduced by operating the filament at elevated temperatures. Increasing the HV and driver power beyond certain values will eventually cause arcing and failures in those subsystems. A specific test procedure has been developed to process through an emission slumping condition and is somewhat successful.

In 2006 one triode failed due to sudden low power output. Early in the teardown process, an oil leak was found in a worn bellows in the input circuit, over the tube. The oil had dripped and burned onto the ceramic insulator between the cathode and the grid. After the tube was cleaned and reassembled, it was tested to 2.93 MW at a low duty factor in a short time. Unfortunately, when the duty factor was increased, emission slumping was noted. Attempts to increase the filament current demonstrated d that this triode had a low emission problem, probably unrelated to the oil leak. This tube was considered a failure, unusable on DTL's 2, 3 or 4. This tube had 13,767 filament hours at the time of its failure [1].

A second example of a triode failure due to low emission was seen last year. This tube was transferred from BNL to LANL in February 2004 with 366 filament hours. At BNL it has been successfully tested and stored as a spare for the AGS injector linac. Once at LANL, it was successfully tested in a test amplifier for 71.9 hours and then put in service on DTL # 2. It operated at a high duty factor (10%) for a short period of time and then worked well at the DTL at lower DF for over a year. In July of 2006 it began emission slumping. The filament current was raised to the maximum permissible level. A sudden increase in filament current to maintain acceleration fields in DTL #2 was seen at the end of life of the tube. This tube was removed from service with 9926 filament hours.

A third recent example of a triode emission failure on a young tube was observed in 2005. A rebuilt tube was tested and showed signs of emission slumping. It was fully conditioned by processing through the emission slumping and installed on DTL # 2. Twenty-four days later, it had to be removed with only 1750 filament hours elapsed. It could not maintain acceleration fields, regardless of filament current, drive power or anode voltage.

201 MHz RF System Upgrades

A new 201 MHz RF system is being developed in LANSCE-R. This new system will improve the reliability, reduce the water and power consumption, eliminate the large anode modulator, and reduce the number of gridded tubes from twenty-four to seven. A Thales TH781 tetrode will be used as the intermediate amplifier. The final power amplifier will use a Thales TH628 Diacrode instead of the problematic triode. The details of the new 201 MHz RF system are discussed in the reports by Lyles, *et al*, and Rees, *et al* [2,3].

805 MHZ RF SYSTEM

805 MHz RF System Description

The beam is accelerated from 100 MeV to 800 MeV in the 805 MHz coupled cavity linac. The 805 MHz RF system includes forty-four RF stations or modules which consist of a klystron with focusing solenoids, an oil filled modulator tank, and the control racks for the klystron, modulator tank, and beam line components. The modulator tank contains the switch tube, HV isolation transformers, voltage divider, and other required components. These klystrons drive a coupled-cavity linac without a circulator for reflected power protection. The 805 MHz RF stations start at module five on the LANSCE accelerator and continue through module forty-eight. The forty-four klystrons are laid out in seven sector buildings. Five sectors contain six klystrons and two sectors contain seven klystrons. The first six sectors contain Varian/CPI klystrons and the remaining sector contains Litton klystrons. Each sector is powered by a power supply charging a capacitor bank that stores up to 260 kJ of energy for each pulse. The klystrons operate at a nominal voltage of 82 kV and a nominal beam current of 29 Amps. The klystrons provide up to 1.25 MW of peak RF power with a nominal power of .7 to 1 MW, depending on the CCL, at 120 Hz and an 835 microsecond pulse length.

805 MHz Reliability

The klystrons have outlived their expected lifetime. At time of purchase in 1968 the average lifetime of the klystrons was predicted to be 25,000 hours. As of October, 2006, the average number of filament hours was 123,969 hours for the klystrons installed on the linac. Figure 4 shows that the klystron with the largest number of elapsed filament hours is module 5 with 194,675 hours. This chart shows the number of filament hours since the last rebuild, as some klystrons have been rebuilt. The number of years since the klystrons were installed on the linac is shown in Figure 5. Six of the forty-four klystrons have been installed, online and operating for over twenty years, while four klystrons were installed in the last year.

A detailed report discusses the history and failure rate of the 805 MHz klystrons[4]. Originally ninety-eight klystrons were purchased. Seventy klystrons were purchased from Varian and twenty-eight from Litton. Of these original klystrons, thirty-four have not been rebuilt and are still in use, forty-two were rebuilt a total of sixty-one times (fifty-eight of the rebuilds were done in–house). One was modified to run at 850 MHz, and two were given to another laboratory. Of the forty-four klystrons on line, thirty-one have not been rebuilt, seven have been rebuilt once, three have been rebuilt twice, and three have been rebuilt three times. Currently there are ten spare klystrons, four that need further testing, and thirty seven that need to be rebuilt. Using thirty-five years of historical data, a Weibull distribution was applied to predict the probability of failure for the klystrons[4]. The expected lifetime of the klystrons from this analysis is 128,700 hours, which is within 5000 hours of the average age of the klystrons presently installed on the linac. Thus, sometime during the 2007 run cycle, the average number of filament hours of the klystrons installed on the linac will surpass the predicted lifetime.

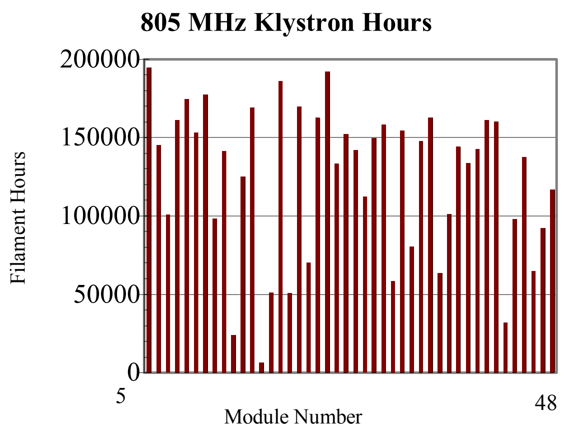

Figure 4: Klystron Filament Hours.

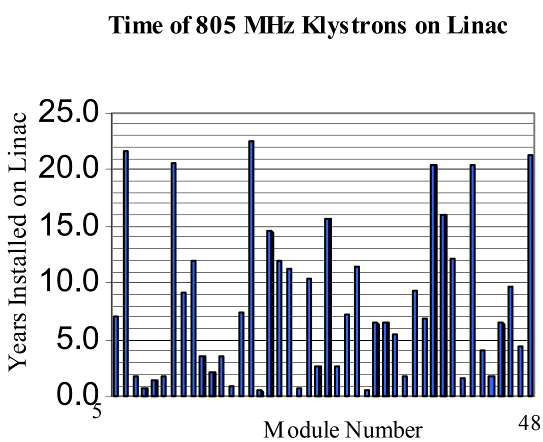

Figure 5. Time of klystrons on linac since installation.

Other than the failures of the klystrons, water leaks into the oil filled modulator tank have recently been the dominating reason that klystron/modulator assemblies have to be removed from service. Typically, the leaks occur at the quick disconnect fittings that are used to connect the cooling water circuits on the klystron /modulator assembly to the building water systems. The leaks are attributed to leaking seals in these fittings due to mineral deposits over time.

805 MHz System Upgrades

In the LANSCE-R project thirty-five klystrons are being replaced in five and a half of the sector buildings. Four of the seven sectors of klystrons are being replaced with high efficiency klystrons that will operate at 95 KV. These new klystrons will save approximately $650 k per year in electricity costs for the four sectors. Circulators and circulator loads will be installed with the new high efficiency klystron systems to protect the klystrons from reflected power. The high voltage systems and capacitor banks are also being replaced in these four sectors. In addition to the four sectors of new high efficiency klystrons, one and a half sectors are being replaced with a new version of the klystrons originally purchased for LANSCE, produced using modern manufacturing methods. Thus, thirty-five of the original klystrons will be available as spares for the remaining nine original klystrons on line. The details of the LANSCE-R project are discussed in the report by Rees, *et al* [3].

CONCLUSIONS

Both the 201 MHz and 805 MHz RF systems at LANSCE have operated very successfully for 37 years. Their performance has outlasted original expectations. The installation of the new Diacrodes in the 201 MHz system will remove the problematic triodes, reduce the power consumption, simplify the RF system and increase the reliability of the plant. For the 805 MHz plant, the reliability of the klystron RF power systems has been exceptional. With their increasing age, however, an increasing number of klystron failures are being seen as we approach the end of the bathtub curve. The LANSCE-R project will incorporate improvements in technology with the new high efficiency klystron systems, and will provide many spare klystrons for the existing system. With the LANSCE-R project the reliability of both the 201 MHz and 805 MHz RF systems will continue to be high over the next few decades.

REFERENCES

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