Klystron Modulator Operation and Upgrades for the APS Linac*

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Abstract

The Advanced Photon Source (APS) linac requires five 100-MW modulators to achieve its required energy. In-house construction of these modulators was under an extremely compressed time schedule and, while the original design was successful, it had a few shortcomings. The operation of the modulators was hindered by excessively sensitive controls and overheating during the hot summer months. The system underwent minor changes that resulted in major improvements. Additionally, improvements have been made to the high voltage circuits to improve the rise time of the output pulse shape, reduce the initial ringing of the pulse, and enhance the reliability of the system. This paper will outline the changes and explain the results of the improvements.

I. SYSTEM UPGRADES

There were three primary changes made: repackaging of components, changes to the control electronics, and elimination of cabling connecting the thyratron switch to the pulse forming network (PFN). All these changes have been executed on the five modulator systems used for the APS linac.

A. Repackaging of Components

The system was repackaged to improve cooling of the components, high voltage performance, and maintainability of the modulator. Seven control chassis were removed from the cabinet that housed the main power supply for the modulator. These chassis generated a constant 4-5 KW of waste heat within the cabinet, occupied a large amount of space, and restricted the airflow through the cabinet. By removing several substantial heat sources and improving the airflow within the modulator, the air temperature was reduced by approximately 25-40° C. The amount of actual temperature reduction depends primarily upon weather-related factors.

The removal of these heat sources also allowed more room for the remaining components. With the additional space it was possible to increase cooling of critical components by increasing airflow. This, in turn, allowed removal of insulation sheets which collected dust, required downtime to clean, and represented a source of fuel in the case of fire. As an added benefit, several system control chassis were now more accessible since they were outside the high voltage cabinet.

B. Changes to the Control Electronics

The second purpose for the upgrade was to eliminate many of the unnecessary modulator controls. The first change made during the upgrade was to replace the existing interface with a more robust interface. In the initial design there was insufficient filtering and clamping of the input signals to the control system. During the upgrade, additional filtering and clamping were added to the input circuits. This simple change decreased failure and false alarms by 15-20%.

The original philosophy of the system was reevaluated. Initially the response of almost any slight irregularity was to trip the modulator to a state where operator intervention was required. Presently the system shuts off only if the system that is out of tolerance would cause damage to equipment or would present an operation that is unsafe for personnel. In many cases all that is issued is an alert message for the operator to notify the engineering staff.

The klystron focus current and heater power are both excellent examples of this change. The focus current was required to be above a set minimum to prevent damage to the klystron and below a maximum value to protect the current capacity of the focus magnet. Initially, the focus supply was controlled to within ±5%. The system was changed to only trip when the current went too low, and the focus magnet was protected by a set of fuses. Since this change was implemented, there has not be a single failure or trip. The same rethinking process resulted in a different result in the filament supplies. In that case very little damage can occur if the filament is slightly low but the life of the various tubes are severely reduced by exceeding the rated power of the heaters. Therefore, if heater power is low, the system only generates an alert to the operators who log the alert. Engineers can then assess the problem without bringing down the modulator. If the heater power is too high, a fault is generated and an immediate response is required.

The first two categories of upgrades resulted in improvements in operational reliability. Previously, operation was dominated by the false alarms or noise generated by the control system. Currently, the false alarms from the control system have been nearly eliminated and the system is exceeding the reliability requirements of the project more than 99% of the time. This is up from previous statistics of about 90% reliability, which was unacceptable.

C. Elimination of Cabling

The final issue that was dealt with was the output pulse. In three of the five modulators, the output of the klystron feeds a pulse compression device. The gain of the pulse compression device is partially determined by pulse width of the signal feeding the unit. Any pulse width that is wasted by a poor rise time will reduce the gain of the compression unit. The rise time of the output pulse is greatly affected by three parameters. The first two are the inductance and stray capacitance of the

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interconnecting cables and the system, and the third is the leakage inductance of the main pulse transformer. There is very little that can be done to eliminate the leakage inductance of a transformer. Neither is stray capacitance within the cabinet easily changed since the cabinets already exist and presently fill the available space. Therefore, the only practical solution was to eliminate some cables.

In the original configuration, coaxial cables (RG-220) were used to connect the main switch tube to the PFN. These cables were eliminated by mounting the thyratron within the PFN cabinet. This change resulted in an improved rise time from more than 1.2µs prior to the upgrade to about 0.8µs after the upgrade. This is a widening of the pulse of more than 10%. As an added benefit, there are now two fewer cables that might fail. In the past, these cables contributed substantially to the failure rate. Figures 1 and 2 compare the output pulse before and after the upgrade.

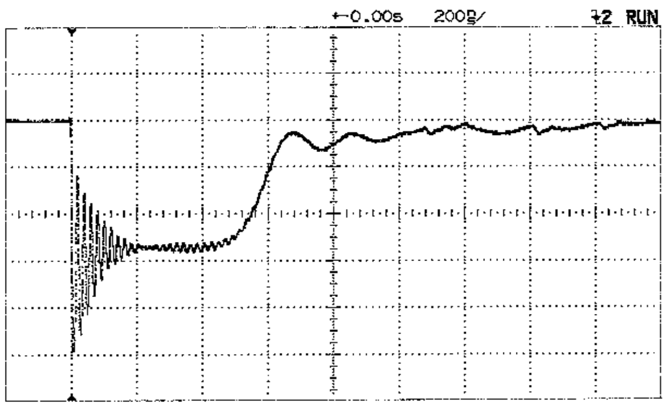

Figure 1: Original PFN Pulse

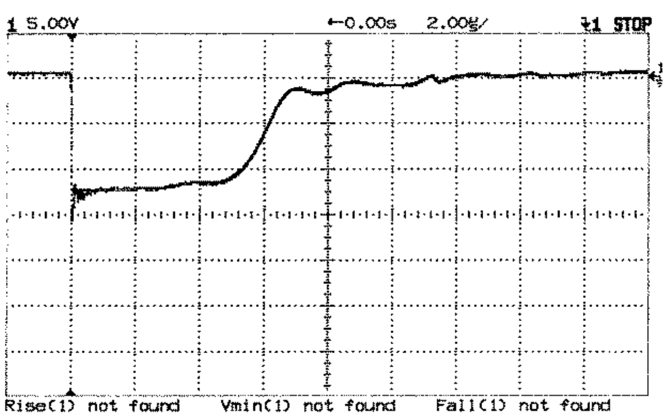

Figure 2: Improved PFN Pulse

The pulse width was also increased by simply changing the configuration of the inductors in the PFN. The PFN was rewired so that the magnetic field of the coils aided the next coil to increase the inductance within the PFN. This resulted in an increased pulse width of about 0.5µs to 0.7µs.

As noted in Fig. 3, the initial overshoot of the pulse is 100%. A simple RC filter network was designed and installed directly across the primary of the output transformer. The ringing of the output pulse of about 20% as configured is shown in Fig. 4. This additional circuit was modeled with great detail using SPICE and the model results matched nearly exactly to the implemented results. It should be noted that there are very few detrimental effects on the rise time of the output pulse.

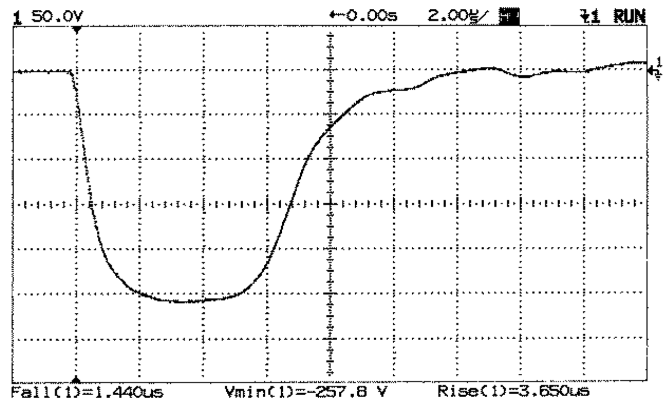

Figure 3: Original Klystron Pulse

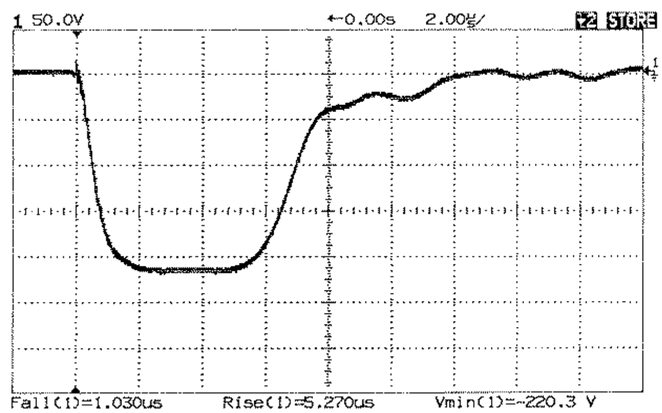

Figure 4: Improved Klystron Pulse

II. CONCLUSIONS

Great improvements have been made to the klystron modulators in the APS linac. Reliability of the system has improved from an initial availability of 90% to better than 99%. The pulse rise time has improved while at the same time the overshoot has been reduced. In addition, maintainability has improved with the increased accessibility of the system.

III. ACKNOWLEDGEMENTS

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