PERFORMANCE OF THE ELECTRON LINAC FOR RACE AT UT AUSTIN

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A 20-MeV LINAC, constructed at the Idaho Accelerator Center at the Idaho State University, was installed in a beam port of the 1.1 MW University of Texas at Austin (UT Austin) Mark II TRIGA research reactor. This installation was part of a Reactor-Accelerator Coupling Experiments (RACE) Project to examine the sub-critical multiplication of a reactor core driven by a LINAC. The performance of the LINAC, as measured by the observed reactor power, degraded over the three-month experiment period. Performance of the LINAC on any single day was observed to be approximately constant. Another power supply was included as part of the installation to help increase the power output of the LINAC. The immediate effect of the new power supply was to increase the maximum observed reactor power, but once again the reactor power continued to decrease with time. Several components of the LINAC were tested and monitored to determine the cause of the decreasing performance. One of the suggestions for the loss of beam was an over-working RF driver. However, due to time constraints, the RF driver was not re-tuned while at the UT Austin facility. Lessons learned from these experiments demonstrate the need for full-time, experienced accelerator operators for beam diagnostics and greater time available for diagnostics.

I. INTRODUCTION

A 20-MeV electron linear accelerator (LINAC), modified by accelerator engineers of the Idaho Accelerator Center (IAC), was installed in beam port 5 (BP5) of the 1.1 MW University of Texas at Austin (UT Austin) Mark II TRIGA research reactor. Staff members of the Nuclear Engineering Teaching Laboratory (NETL), undergraduate and graduate students of UT Austin assisted IAC accelerator engineers with the installation. This facility was part of a reactor-accelerator coupling experiment (RACE) to examine sub-critical multiplication of a reactor core driven by a LINAC. UT Austin's main priority was to develop and test instrumentation for the experiment. The main instrumentation was the neutron monitors to observe the low neutron flux in the sub-critically fueled core and the instrumentation response as the pulse rates of the LINAC were varied. Ideally, small variations in the neutron flux (sub-critical feedback) could be observed with each pulse regardless of pulse rate. Finally, another goal for UT Austin was to examine the target (eighty weight percent tungsten and twenty weight percent copper) as a material choice for photoneutron production. During the experiments, UT Austin accelerator operators observed inconsistent reactor power readings at specific pulse rates caused by unknown sources.

II. EXPERIMENTAL

A concrete cave built of cinder blocks was constructed around the LINAC as a biological shield. The target was fixed to the end of a five meter long, stainless steel beam guide that extended from the end of the LINAC into BP5 of UT Austin's Mark II TRIGA reactor. Polyethylene supports were fashioned around the beam guide within the beam port to prevent bowing over the length of the guide. Since the target was situated near the center of the reactor and surrounded by the beam port, traditional means for determining the beam position and focus were unavailable. A photograph of the entrance to the beam port with the target installed is shown in Fig. 1.

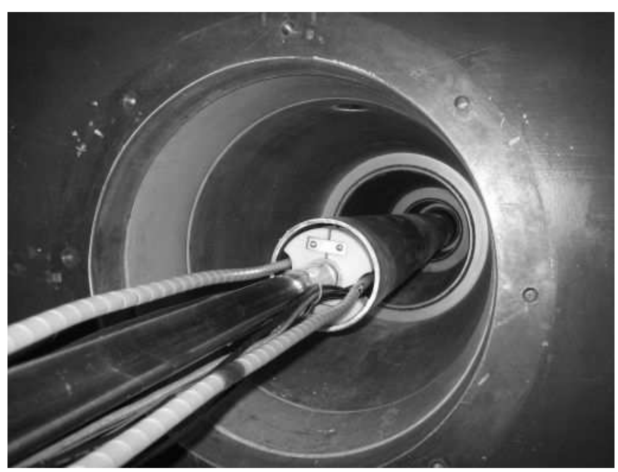

Fig. 1. View of beam guide into beam port five.

Initially, beam position and focus were determined by optimizing the response of several instruments including the reactor power meter, radiation area monitors, and four thermocouples soldered to the target. At first, a large increase in target temperature as measured by the thermocouples was considered advantageous since it meant there was beam on target, but it did not necessarily reflect the same response in reactor power. It was determined that a lower beam quality contributed to more energy deposition in the form of thermal heating than it did with photoneutron production resulting in high target temperatures with low reactor power readings. As mentioned, the greatest beam energy would be 20-MeV, but the beam, despite being perfectly tuned, still had a spectrum of electrons with energies less than 20-MeV. Also, the target temperature would decrease which suggested the beam was off target. However, the temperature fluctuations were discovered to come from the cycling of the target coolant chiller. It was therefore essential to have multiple sets of instruments monitoring beam performance to ensure the best quality beam.

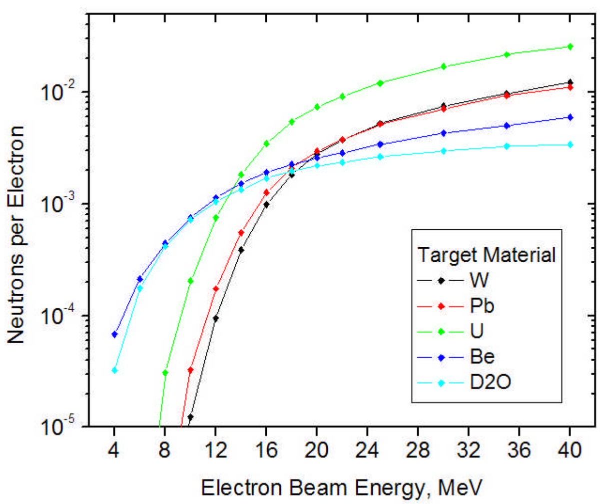

Fig. 2. Chart illustrating how a low quality beam significantly decreases photoneutron production[1,2].

Other required non-RACE operations at NETL required the LINAC to be removed from its position. Removing the LINAC from the beam port allowed for visual inspection of the target and beam guide. Inspection revealed radiation damage to plastic tie straps along the length of the beam guide and a large darkening of an area on the target itself showed that at times during first operation a great amount of scattering of the electron beam occurred. If the beam were perfectly aligned and focused down the beam guide, damage to the tie straps would not have occurred. This fact supported the concern that at times the beam was not directly on target and scattered greatly within the beam port. Additionally, it suggests that the beam was not always fully focused which led to poor neutron production and subsequently low observed reactor powers.

After a new target with the same composition was installed, three new tools for beam steering were installed and implemented. These tools included the Position Indicating Split Toroid (PIST), two Resistance Temperature Detectors (RTDs), and using the target as a Faraday Cup[3]. Each instrument was monitored to determine maximum response by the reactor from the injected beam by steering it with the LINAC controls. The PIST became a vital tool in determining beam position because it allowed for direct steering of the beam in two dimensions. The RTDs replaced the thermocouples for target temperature measurement that were located near the entrance and exit of the cooling loops on the target. Isolating the target for use as a Faraday Cup also allowed for direct measurement of the current reaching the target. With the addition of these instruments, confidence was restored that beam alignment was not an issue but beam quality was the only thing affecting the reactor power at each pulse rate.

From the beginning, observed reactor power was significantly less than calculated at particular pulse rates. In addition, accelerator operators noted quickly that the reactor power at each of these pulse rates was not constant from day to day as seen in Fig. 3. Accelerator operators and experimenters were determined to discover the cause of the changing power levels and what appeared to be an overall decrease of the maximum power in time.

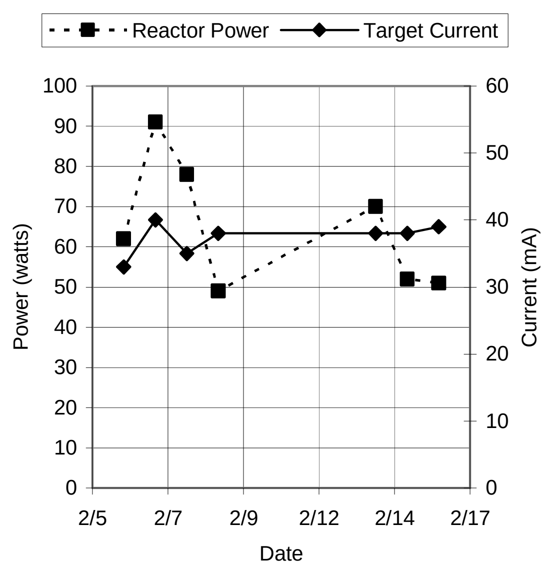

Fig. 3. Measured maximum reactor power at 170 Hz.

The first suggestion by IAC engineers was to vary the injected current. The injected current was varied until optimized to improve power output. From Fig. 4, this value was determined to be 300 mA. As shown, an increase in injected current beyond 300 mA did not increase the reactor power. However, the power recorded by the reactor neutron detector still indicated lower power levels than anticipated. NETL staff members were still determined to increase output of the LINAC to the calculated levels.

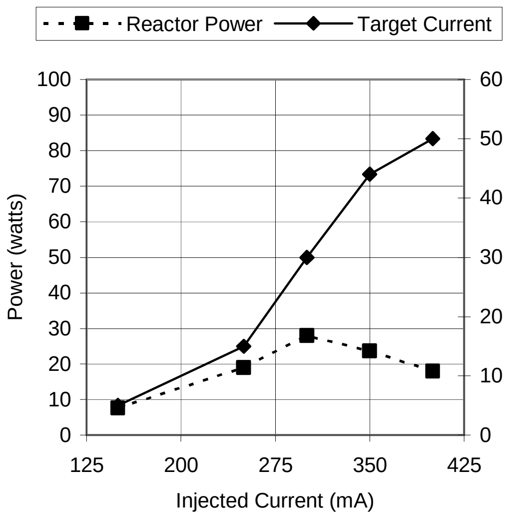

Fig. 4. Plot of reactor power and target current versus injected current.

Another suggestion by IAC accelerator engineers to improve LINAC output was to increase the pulse forming network (PFN) high voltage (HV). The PFN HV was increased within the operation capacity of the module and showed an immediate improvement in reactor power. However, the observed reactor power at certain pulse rates began to decrease after this adjustment as seen in Fig. 3.

Another peccadillo of the LINAC was the seemingly slow corresponding response time to reaching a steady state reactor power level after increasing the pulse rate. For example, an increase from 5 Hz to 170 Hz would result in a sharp, initial increase in reactor power (and target temperature), followed by a much slower rise to a steady state power level (on the order on ten minutes). Not knowing the exact power level that would be reached at particular pulse rates made it difficult for the accelerator operators to know if the slow increase in power level was due to beam steering or if the power level was just not going to reach the same, expected maximum power level from a previous day.

The addition of a second capacitor-charging power supply (CCPS) was intended to allow for higher pulse rates and, therefore, higher reactor power. Sadly, UT Austin accelerator operators discovered that increasing pulse rates much above what was currently achievable with one CCPS (170 Hz) only contributed to LINAC issues. The cooling system for these power supplies and other LINAC components could not adequately remove heat resulting in EMS power supply trips. However, data was still acquired for pulse rates above 170 Hz for short operating periods with promising results. See Fig. 5.

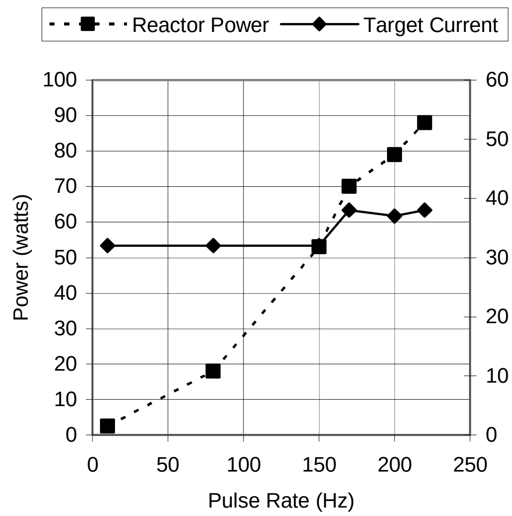

Fig. 5. Increase in pulse rate with addition of second CCPS.

Accelerator engineers from IAC also suggested monitoring the klystron for abnormal readings. Klystron readings throughout experimentation revealed no significant deviation from initial or expected values. During this time, observed reactor power levels with LINAC operation at the same pulse rates continued to fluctuate or decrease with no determinable cause.

III. RESULTS AND DISCUSSION

No obvious cause for the varying reactor power readings at specific pulse rates over the course of experimentation was finally determined. Altering the injected beam current up to 300mA provided the best beam for experimentation as evidenced by a temporary increase in reactor power. Increasing the high voltage on the PFN also provided a boost in reactor power briefly. The full response of the LINAC with the additional CCPS was not realized due to the inability of the cooling system to sufficiently remove heat from the LINAC. However, the additional CCPS seemed to provide promising results.

The cooling loop for the LINAC was not modified due to timing issues with other reactor experiments at NETL.

Near the end of the experimentation period at UT Austin for the RACE project, accelerator engineers from IAC determined that the RF-driver had been operating outside of an optimal range. Due to restraints on reactor usage, there was not enough time to properly optimize RF-driver inputs and parameters before the LINAC facility had to be removed. It was expected that this optimization would provide the greatest increase in photoneutron output and therefore reactor power.

IV. CONCLUSIONS

Determining the root cause of the unpredictable and deteriorating LINAC performance was not fully realized. Future work to solve inconsistent LINAC behavior and increase reactor power could include adjustment of the RF-driver and running the CCPS units on NETL facility chilled water while keeping the remaining components of the LINAC on the current cooling system. A redesign of the biological shield for the LINAC at UT Austin would provide additional space for an adjusting magnet to be installed on the LINAC. This would allow for better beam tuning and providing greater confidence in beam quality while potentially assisting in troubleshooting efforts by the accelerator operators. Lessons learned by this experiment include the need for full-time, experienced accelerator operators for their diagnostic abilities and more time available during the experimental program for beam diagnostics. In the end however, the LINAC did provide adequate photoneutron production for acquisition of sub-critical multiplication data.

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