IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

THE EVOLUTION OF THE LAMPF HIGH POWER PION PRODUCTION TARGET MECHANISMS*

Mahlon T. Wilson, Linas L. Thorn, Lloyd O. Lindquist, and Donald L. Grisham
Los Alamos Scientific Laboratory, University of California
P. O. Box 1663, Los Alamos, New Mexico 87545

Summary

The Los Alamos Clinton P. Anderson Meson Physics Facility's (LAMPF's) beam contains 800 kW of power and passes through three pion production targets in series before being deposited into an isotope production section and beam dump. The first two targets are rotating graphite rings that are radiatively cooled. The third pion production target is a water-cooled graphite slug.

Beam Conditions

LAMPF intends to attain a proton beam current of 1 mA at 800 MeV. This beam is focused to pass through three pion production targets in series. The first target (A-1) provides π^+ and π^- particles for two vertical bend channels, and requires a beam spot size of the order of 1 mm high by 5 to 10 mm wide. The second target (A-2) provides large numbers of π^+ and π^- particles for a high energy pion channel and a stopped muon channel, and requires a beam spot size 2.5 mm high by 5 to 10 mm wide. The third target provides large numbers of π^- particles to a vertical bend biomedical channel (A-5) and requires a beam spot that is 5 mm in diameter. The beam has a macrostructure dictated by the power-dissipating capability of the rf power tubes.

The beam is on for 0.5 ms, at a planned current of ~17 mA, then off for 7.83 ms (6% duty factor). Therefore, the power in the beam, while it is on, is expected to be 13 MW. This surge of power is delivered 120 times/s and thermally shocks materials. The problem of targeting at LAMPF is that of devising a method to pass the proton beam through targeting materials at instantaneous beam power levels up to 100 MW/cm^2.

History

Target development was underway in 1965, under the direction of Donald R. F. Cochran. This work involved the transfer of heat from an electrically heated graphite rod to an annular, axially flowing water coolant. Heat transfer rates of about 2.5 kW/cm^2 at burnout were obtained. Electrical heating tests continued on graphite rods throughout 1966. Sleeves of BeO survived heat transfer rates of 1 kW/cm^2 across the wall thickness when heated internally by a graphite electrical resistance rod and cooled externally by axially flowing water. Graphite heating element failure limited testing.

The year 1967 was occupied with preparing an irradiation station and test targets for the Electron Prototype Accelerator's (EPA's) 20-MeV, 1-mA, 6% duty factor, electron beam. Brazing and coating techniques for graphite targets were developed.

By mid-1968, EPA was ready for use in the target development program, and targets were tested with electron beams until the end of 1971 when EPA was shutdown. Figure 1 indicates the concept of the water-cooled cigarette shaped target that evolved. The use of EPA in target testing was fraught with frustration, since it was difficult to keep the electron beam properly centered and defocused. Moving the beam off center would cause excessive jacket temperatures, and a focused beam was capable of vaporizing the target. In mid-1970, Karl L. Meier joined the target development effort and enhanced the calculational and experimental programs.

Serious consideration of the design of the experimental areas was begun during 1968. Despite the fluid nature of the design of the beam lines, it was possible to combine requirements for shielding, remote handling, utilities, and beam line components into a unified, compatible system.[1] One facet of this system concerned target mechanisms. It was expected that targets would require frequent replacement; therefore, the target-holding mechanism was visualized as extending from the beam line out through sufficient shielding so that utilities and vacuum-sealing interface could be maintained by hand. As indicated in Fig. 2, targets were to be mounted between two water lines, much as the rungs of a ladder. The water lines extend through a shield plug. Vacuum seals and a drive system are located at the top of the plug. The targets are positioned by raising or lowering the water lines. The targets are replaced by removing the shield plug and transferring it in a shielding cask to a hot cell.

The secondary beam line designs were firming up during 1969-1971, and it became possible to consider what the optimum target configurations should be. There was a general desire to have a higher density than graphite, with no material between the beam and the secondary channel. There was concern that the small spot size at the first target could cause leakage problems due to beam missteering, whch had so often happened during the EPA testing program.

Various new targeting concepts were advanced. Those that progressed into prototype hardware included (1) a flat ATJ graphite rectangle, canned in stainless steel with water flowing over the top and bottom surfaces, provided a beam-spot-shaped target, minimizing material not in the flat beam spot. Electrically heated targets failed because the water coolant flow separated from the target's flat surfaces, causing hot spots. (2) Another target assembly resembled a band saw with the blade acting as the target and the drive wheels as a heat sink. A target of this nature would provide a secondary particle source that is thin on one dimension. Interest in this scheme declined when attempts to develop a radiation-resistant rotating seal failed.

(3) The band-saw concept involved blade cooling by both radiation and conduction to the cooled-drive wheels. The amount of heat conducted across the interface between blade and wheel is a difficult quantity to estimate, and one tends to rely more on the radiation losses. This led to wrapping the blade in a circle and attaching it to a hub with spokes--similar to a bicycle wheel. The wheel must rotate to spread out the input power, and it needs

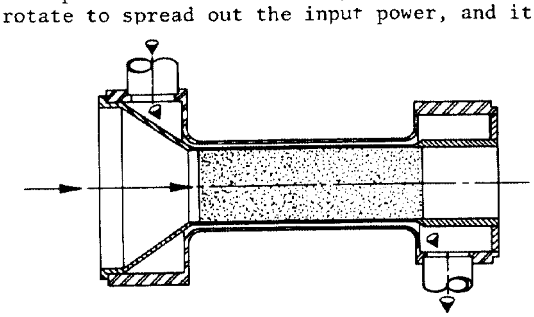

Fig. 1. Water-cooled cigarette-shaped graphite target.

*Work performed under the auspices of the US ERDA.

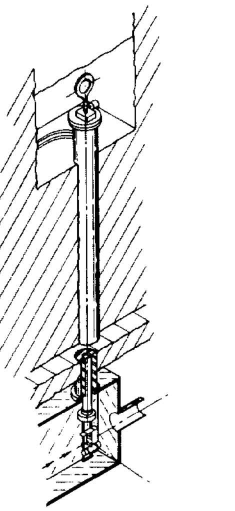

Fig. 2. Original concept.

some size to provide sufficient radiator area. Calculations for a wheel made of 99% molybdenum alloy (TZM), rotating at 84 rpm and dissipating 15 kW of energy to the target box walls, indicated an average temperature of 2150°K.

Wheel targets of molybdenum and graphite, 12 cm diam, 2-mm-thick rims, supported on four spokes, and rotated at 160 rpm, were tested in the electron beam of EPA in 1971. The helical gears driving the wheels consistently gave trouble, and prevented any meaningful results. The drive system was rebuilt using bevel gears [one of Ampco 18 (aluminum bronze alloy), the other of cast iron, and both lubricated with a mixture of MoS_2, Sb_2O_3, and a polyimide binder]. A graphite wheel was irradiated by the EPA beam for 30 h, and attained temperatures from 1450 to 1600°K.

The EPA served its primary purpose of providing design input for the LAMPF accelerator, and it was shutdown at the end of 1971. At that time it was felt that two targeting schemes had been shown to be capable of being used as LAMPF's pion production targets. They were (1) water-cooled graphite, cigarette-shaped targets and (2) radiation-cooled, rotating, graphite wheel targets. The wheel targets were favored, and preliminary designs of mechanisms to support and rotate the targets were prepared for each target station.

The construction of the LAMPF accelerator had progressed to the stage that it was possible to use a 100-MeV proton beam for target development; a facility was developed for this work in 1972. An ambitious program of target irradiations was planned with three targets poised to be tested. These were an ATJ graphite radiation-cooled wheel for use at A-1 and two water-cooled, cigarette-shaped, graphite targets, which were now proposed for A-5 at the biomedical facility. Due to tight scheduling of the 100-MeV proton beam and interference with continuing accelerator construction, only the wheel target was tested. Irradiation with an average current of 310 μA of 100-MeV protons lasted for 30 h, and produced target temperatures in excess of those anticipated for the 1-mA, 800-MeV pion production targets. The target wheel appeared to be undamaged.

Target Mechanism

The first two pion production targets are radiatively cooled rotating graphite wheels. The wheels have an outside diameter of 30 cm, and are handled by a fork attached to their hubs. A requirement existed in 1972 to have at least three targets of various thicknesses and compositions poised for rapid placement into the beam. The targets are conveyed in a sled through a channel formed in the shielding by driving aside two long shielding bars. The fork on the target is seated into a socket on the mechanism by the pushing action of the sled. The socket is rotated, thereby lifting the fork and the target out of the sled, which is then withdrawn back through the shielding.

The A-1 target mechanism was designed to handle the targets much like a nickelodeon, and it became known as "the juke box" (Fig. 3). Three target fork-holding sockets were threaded onto a rod. The targets were delivered by sled to the position of the right-hand wheel (Fig. 4A). To put that target into the beam required the 180° rotation of its socket (Fig. 4B) and then a horizontal translation up beam onto the rigidly mounted drive spindle (Fig. 4C). Sufficient translation distance is available to permit putting any of the three targets onto the drive spindle (Figs. 4D-E). The mechanism is 40 by 40 by 430 cm, and weighs 7 tons. The A-1 targets have a maximum required beam direction thickness of 3 cm. The A-2 target wheels have a parallelogram cross-sectional shape, with beam direction width of 2 cm and a length of 6 cm. The acute angles are 20°, giving the parallelogram a length of 12 cm and requiring a fork width 4 times greater than that required for the A-1 targets. This would require an A-1 type mechanism 160 cm wide, taking entirely too much space along the beam line.

The A-2 target mechanism has its three target fork sockets mounted on the perimeter of a drum. This arrangement resembles a Ferris wheel (Fig. 5). The drive spindle is translated down beam to rotate the active target. The unit is 64 by 41 by 790 cm, weighing 14 tons.

Both the A-1 and A-2 mechanisms are rolled into vacuum chambers that extend through the stacked shielding and attach to the proton and secondary beam lines. The vacuum seals, drive motors, and cooling connections are accessible for hands-on maintenance. Motions are obtained by rotating shafts that have universal joints or flexible cables to accommodate the steps in the radiation shielding. The targets were to be inserted into the conveyor sled through a vacuum interlock, since it was predicted that beam pump-down time would be too long to allow venting to atmospheric pressure. Schedule and budgetary constraints precluded the acquisition of the vacuum interlock components. Actual pump-down times of only 4 h obviate any time advantages of vacuum interlock transfers; there is no plan to institute them.

The A-5 target mechanism was of the type proposed in 1968 (see Fig. 2). A biomedical treatment was visualized to require frequent turning off of the proton beam during the insertion and removal of targets. This was expected to cause a problem with the users of the other beam lines, and a 3-s beam-off goal was requested. This meant that a few hundred pounds of pipe containing water tubing and shielding had to be lifted 20 cm in 3 s. An electrohydraulic stepping motor, 8-hp capacity, was used to provide an adequate amount of power and precise position control. Additional target travel was provided to raise the targets a sufficient distance to clear the gate of a horizontal vacuum valve. Closing the valve would allow removal of the whole mechanism without disturbing the beam line vacuum. The inability to find a rugged and dependable radiation-resistant vacuum valve and concerns about radiation heating of the thermally isolated gate of the valve resulted in its elimination.

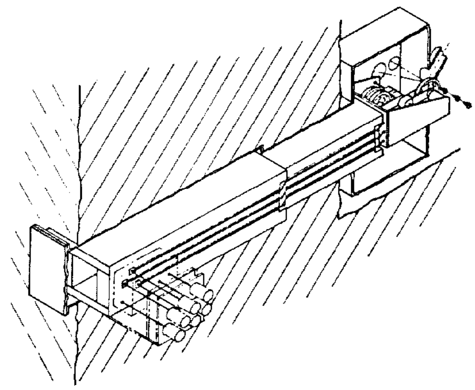

Fig. 3. The A-1 target mechanism.

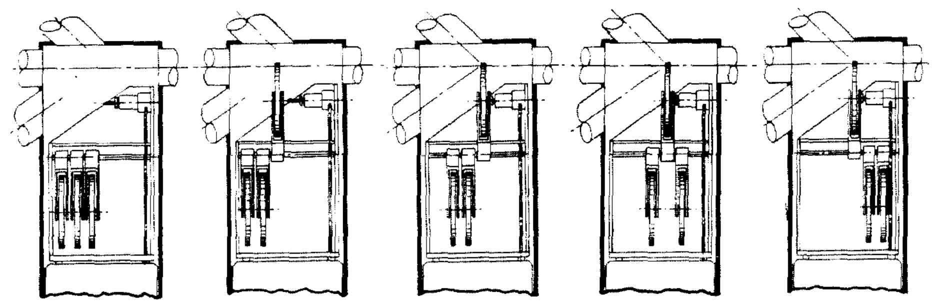

Fig. 4. Target shifting sequence.

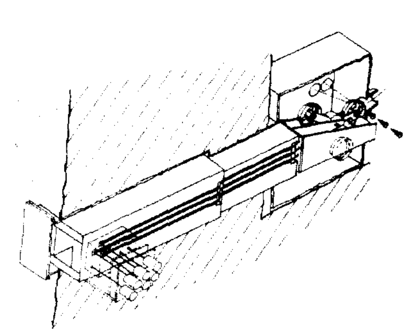

Fig. 5. Target mechanism.

Operating Experience

The A-1 target mechanism was installed during September 1973; one of its typical drives consisted of a motor, clutch, rotary vacuum seal, 7 universal joints, 2 pairs of bevel gears, and 1 flexible shaft - mounted on several stainless steel ball bearings. The running friction was greater than calculated, and larger drive motors were required. The accidental opening of a vacuum valve sent an air shock wave past a target, bending it so badly that it could not be rotated into the sled for remote removal, and necessitating the removal of the whole mechanism. The initial flexible shaft failed after 120 h of use, due to overflexing, and a U-joint seized after 360 h, causing a drive shaft to fail. The method of actuating the indicator switches caused distortion of the metal-ceramic switches, resulting in their failure to perform reliably. Minor fixes kept this mechanism operating until December 1974, when LAMPF shut down for facility upgrading. A new target mechanism was installed in March 1976, and has run to date (March 1977) with only one flexible shaft failure (the shaft may have been defective). A 100-μA beam striking the nonspinning 3-cm-thick ATJ graphite target for about 800 h resulted in only minimal visual alteration of the target. The new mechanism had larger drive motors, some of the U-joints were replaced with flexible shafts, the socket 180° rotate worm gear was replaced with a rack and pinion, the socket sliding motion was roller mounted, and the position switches were fitted with actuating linkages.

The A-2 target mechanism was completed late, and flag targets of Ta, ATJ graphite, and Al_2O_3 were used for the 1-2 μA initial LAMPF beams. The Ferris wheel target mechanism was installed in January 1974, and operated until December 1974, with only a shaft-binding problem (fixed with the addition of a bearing). A new target mechanism was installed in March 1976, incorporating the same improvements as for A-1. The first target used with the new mechanism experienced hub failure due to rubbing, caused by either improper dimensions or assembly. The failure was not detected, and attempts to cycle to another target caused component bending. The high induced radioactivity levels of the mechanism required it to be placed in hot cells for remote repair. Only some of the functions were restored, and operation was limited to use of one wheel. While the second mechanism was being repaired, the first one was used; clutch failure was experienced due to excessive drag of the spin drive. Its target remained stationary for 1000 h of 100-μA operation, resulting in a crack along the beam path and a white coating over the heated zone (probably caused by the oxides of the graphite impurities). An earlier test run of a 6-cm-thick Al_2O_3 wheel with a 35-μA beam resulted in a brown discoloration and fracture of the wheel.

A recent failure of two of the four target wheel support spokes (one melted and one had a brittle fracture), caused a reevaluation of the wheel design. A solid flanged wheel, resembling a railroad car wheel, is undergoing trial tests as a pion production target.

Both the A-1 and A-2 target systems may now be controlled at the LAMPF Central Control Room by pushing the appropriate instruction button on a card programmable function panel.[2] If a sequence failure develops in the mechanism, a message is displayed explaining the problem; thus, operating personnel do not have to learn the intricacies of each mechanism.

The electrohydraulic stepper motor driving the A-5 biomedical target had considerably more internal fluid leakage than claimed, requiring almost continuous operation of the rather small hydraulic pump that powered the circuit; excessive pump wear and system degradation resulted. The system has been improved with a larger pump and motor rebuilding. The water-cooling circuits for the target have only recently been extended to the target system. Initial attempts to use water-cooled targets were abandoned when the metallic water seals leaked, probably because the seal surfaces on the mechanism had been damaged during the previous three years of use (holding radiation-cooled targets). A 2-cm-diam by 8-cm-long pyrographite cylinder supported by Mo wires was used with up to 35-μA beams. A 2 by 8 by 20 cm pyrographite slab is now being used at currents up to 200-μA.

Future Plans

The problems experienced with the intricate mechanisms required to provide a fast three-target interchange capability has resulted in an operations' decision to utilize only one target wheel, mounted on a positive drive system (probably chain), with the ability to move the target out of the beam. There is no longer a speed requirement for the biomedical target and the electrohydraulic stepper motor will be replaced by an a.c. gearmotor. The A-5 target will be a single graphite slab, conducting its heat to water tubes.

References

1. Mahlon T. Wilson, "Remote Maintenance Concepts for The Los Alamos Meson Physics Facility," Proc. Natl. Particle Accel. Conf., Washington, DC, March 5-7, 1969, Vol. NS-16, No. 3, 588-593.

2. B. L. Hartway, "A Compact Programmable Control Panel for Computer Control Systems," Proc. Particle Accel. Conf., San Francisco, CA, March 5-7, 1973, Vol. NS-20, 531-533.