MECHANICAL AND MAGNETIC ALIGNMENT TECHNIQUES FOR THE RADLAC-II LINEAR ACCELERATOR

D. J. Armistead, D. L. Bolton, and M. G. Mazarakis
Sandia National Laboratories
Albuquerque, New Mexico 87185
and
R. Peredo
Air Force Weapons Laboratory
Albuquerque, New Mexico 87117

Abstract

The RADLAC-II beam line, which includes nine accelerating cavities, 25 solenoidal magnets, and a nine-cryopump vacuum system, is suspended from the top of a water tank by 60, 0.5 cm-diameter, stainless steel rods. There are seven swiveling joints providing beam line flexibility (similar to that of a spinal cord). We have developed a technique to mechanically align the ~ 12-meter-long accelerator vacuum pipe to within a fraction of a millimeter. A high accuracy microprocessor-equipped theodolite is being used with a television camera, monitor, and hard copier for observation ease, comparison, and documentation. Three illuminated lucite targets with cross hairs are utilized to align the beam line which comprises vacuum pipes of three different I.D.s. For the in-situ magnetic alignment of the solenoids, a new technique is currently being developed and will be presented.

Introduction

Mechanical and magnetic alignment is of great importance for any charged particle accelerator. A carefully aligned beam line with a focusing element axis, coinciding with the vacuum pipe axis, is necessary to insure 100% beam transport and superior beam quality throughout the accelerator. These requirements become even more crucial in the case of RADLAC II. RADLAC II is a linear induction, electron accelerator which produces a high current beam (~ 40 kA).[1] The beam is produced and transported in a strong guiding, solenoidal magnetic field. At the end of the device the beam is extracted from the vacuum and magnetic field and propagates into the air. An off-axis beam striking the vacuum pipe can be disastrous! It can drill holes in the vacuum walls and destroy the solenoidal coils that produce the magnetic field. One pulse of a misaligned beam could be enough to cause such damage. However, we cannot tolerate even smaller misalignments. A beam axis 2-3 millimeters off the geometric and magnetic axis can induce significant beam instabilities and quality deterioration during acceleration and transport. In addition, a beam exiting the accelerator with a small offset from the axis can become unstable and exhibit wild oscillations at the extraction point. This results from the forces applied on the beam by a non-axisymmetric radial component of the solenoidal fringing field.

In this paper we will describe a technique we developed to precisely align the beam line of the RADLAC-II accelerator and present results of the beam behavior after alignment. A magnetic alignment technique currently under development will also be presented.

The RADLAC-II Beam Line

In the present configuration, the accelerator beam line with the vacuum pump system, composed of nine cryopumps, is suspended from the top of the water tank by 60, 0.5 cm-diameter stainless steel rods (Figure 1). During operation the injector and entire beam line are immersed in deionized water which serves as a dielectric medium for the device. At the extraction side, right-hand end of Figure 2, the beam line comes out of the water through an opening in the tank wall. A rubber bellows is fastened on the tank wall surrounding the circular opening. The other end of the bellows is attached to the outside cylindrical wall of the beam line. Both joints are water tight. The bellows prevents water from escaping from the tank and, most importantly, mechanically decouples the beam line from the tank wall. Thus, the beam line is free to oscillate. The main beam line comprises the injector, seven post-accelerating cavities and gaps, and eight diagnostic packages (Figure 3). The upstream side of each accelerating cavity is connnected with the beam line via a swiveling joint which provides a degree of beam line flexibility. Thus, the entire beam line is

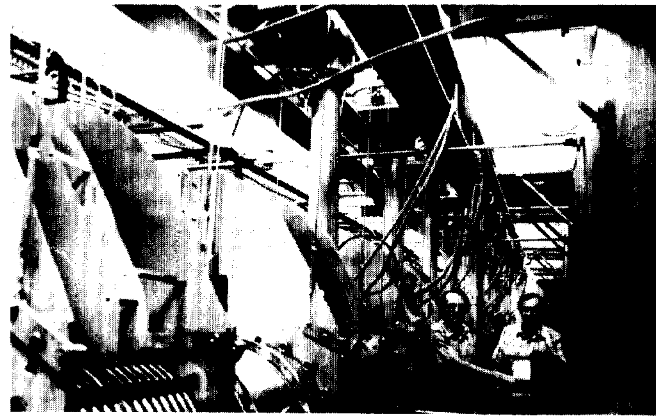

Figure 1. RADLAC-II beam line. The graded accelerating cavities and the stainles steel rods by which the entire beam line is suspended are shown. During operation the tank is full of water.

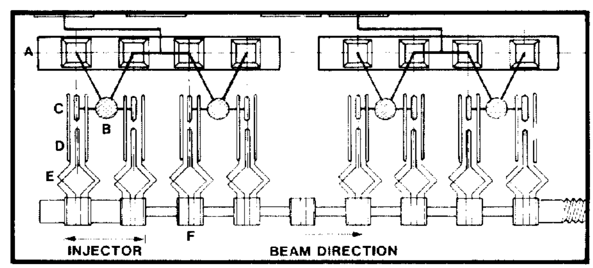

Figure 2. Top view of RADLAC II: (A) intermediate store capacitor, (B) laser-triggered gas switch, (C) pulse forming line, (D) transmission line, (E) convolute, and (F) accelerating cavity.

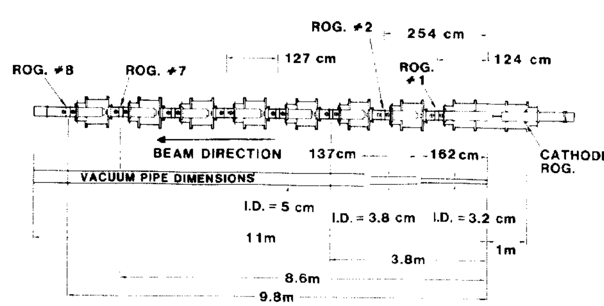

Figure 3. The RADLAC-II beam line.

composed of 34 individual straight segments, including the cathode shank, requiring proper alignment to a common axis. To make things more challenging, the beam pipe I.D. varies and, in addition, the accelerating gaps are not square. A flared gap design was adopted to reduce beam radial oscillations.[2,3]

Starting from the injector, the first section, which extends downstream to the first post-accelerating gap, is made of a 3.2 cm I.D., stainless steel pipe. The middle section, stretching between the first and second accelerating gaps, is made of a 3.8 cm I.D. pipe, and finally the last section is made of a 5 cm I.D. pipe. The first and second post-accelerating gaps are "step gaps," that is, the upstream side of the gap has smaller diameter openings than the downstream side.

The accelerating cavities are ~ 50 cm in diameter and ~ 50 cm long. They are composed of metallic and plastic grading rings[2] and serve a dual purpose. They act as high voltage insulators as well as an interface between the outer water-dielectric and the vacuum. The inner vacuum voltage distance is a few cm (accelerating gap) and is defined by the two extensions of the beam pipe into the accelerating cavity. These cylindrical extensions (field shapers) have the ends shaped in accordance with the prescriptions of reference 3. The downstream field shaper is tightly attached to the cavity's end plate. However, the upstream field shaper is attached to the other end plate through the swiveling joint which provides some alignment freedom. The vacuum pipes are surrounded by solenoidal coils. The coils are enclosed in a 20 cm I.D., stainless steel pipe. This pipe protects the coils from the water and forms a pressure vessel for the 8-psi SF_6 required to electrically insulate the coils from the pipe walls. There are 25 coils powered by five capacitor banks. A 17 kG peak magnetic field is achieved when the coils are energized.

There are no independent alignment "knobs" for the magnetic field. The solenoidal coils tightly surround the vacuum pipe. It is assumed that the mechanical alignment of the coil axis will provide alignment of the magnetic field axis. Hence, the goal is to verify that the magnetic and geometric axes of the beam line coincide.

Mechanical Alignment

We developed a technique to mechanically align the accelerator vacuum pipe to within a fraction of a millimeter. A high accuracy theodolite was used coupled with a television camera, a television monitor, and a hard copier. Three illuminated lucite targets with cross hairs were utilized to align the three pipe sections. Figure 4 indicates the alignment set up. The targets were parked at various locations inside the vacuum pipe and their cross hairs were compared with the theodolite cross hair in the field of view. The optical axis of the theodolite defines the desirable beam line axis. All the beam line segments were adjusted so their axes coincided with the theodolite axis.

The following step by step alignment procedure was pursued. Before starting the alignment each accelerating cavity, with its downstream field shaper rigidly attached, was freed from the pulse transmission lines and from each other. The cavities with the attached cryopumps are the heaviest modules of the beam line. Our goal was to align the entire beam line in its free hanging stable equilibrium position, similar to that of a pendulum. This way the beam line will return to its equilibrium position following any lateral oscillation caused by the water shock. We started with a rough alignment of all accelerating cavities. Then we proceeded with the fine alignment starting from the downstream end of the device and going upstream. The axis of the cavities and all the

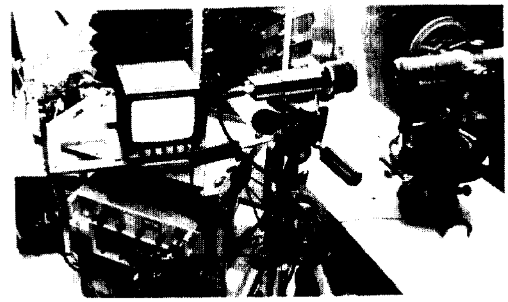

Figure 4. Beam alignment set up.

other beam line sections were brought on line by adjusting the lengths of the 60 hanging rods. A turnbuckle on each rod was our "knob" for the fine tuning. First, we aligned the ninth and eighth cavities, then the beam line section connecting these two cavities. Next, we aligned the seventh cavity; then the section connecting cavity seven to cavity eight, and so on all the way to the injector. A hole bored through the cathode shank axis helped the exact positioning of the foilless-diode cathode on axis.

Special care was taken for the alignment of the pipe sections upstream and downstream of each accelerating gap. This was the most difficult and tedious task particularly for the "step gaps" and required many iterative target positionings and sightings upstream and downstream of the gap. Every newly aligned section was tightly attached to its downstream neighbor using the available flanges and retention clump shells (for the swiveling joints). This was done under constant monitoring of the alignment by having parked a lucite target in the location of the operation. No bolt was turned without watching the cross hair of the target as compared with those of the theodolite on the TV monitor. Having the monitors inside the device tank and actually observing in real time the effect of every mechanical adjustment on the beam axis was a real breakthrough. It greatly facilitated the effort and reduced the time required for aligning the entire accelerator. An alignment from ground zero now takes only 3-4 days with most of the first day spent in precisely positioning the theodolite and defining the beam axis.

To assure that no lateral forces are applied on the aligned beam line, we modified the transmission line sections connected to the accelerating cavities making them more flexible. Thinner stainless steel plates were used which were connected to the convolutes and accelerating cavities via flexible joints (hinges). It is interesting to note that although we aligned the beam line in air, the water buoyancy forces on the beam line do not affect beam alignment. This was checked repeatedly with the theodolite.

Figure 5 illustrates and summarizes the alignment technique. The left frame is a photograph of the illuminated target through the theodolite. This photograph was taken using the television camera and hard copier. The target is positioned at the exit end of the accelerator. The cross hairs of the theodolite perfectly overlaps that of the target. The right frame is a photograph of the smaller target at the foilless diode anode, ~ 10 m upstream. The beam line indeed appears very well aligned.

Our effort in precisely aligning the RADLAC-II accelerator were justified by the obtained beam results.[4] Following alignment, we got a very stable beam exiting the accelerator and well centered on axis (Figure 6). This is also shown in the open shutter photograph of the extracted beam (Figure 7). X-ray framing camera results[4] verified the open shutter photograph beam stability.

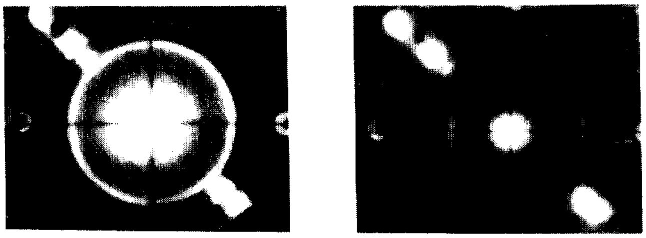

Figure 5. Photograph of the lucite targets inside the accelerator beam line during the alignment process. In the right frame, the target is at the foilless diode anode pipe. In the left frame, the target is located at the exit of the accelerator. In the latter, the target and theodolite cross hair are not rotated relative to each other and completely overlap.

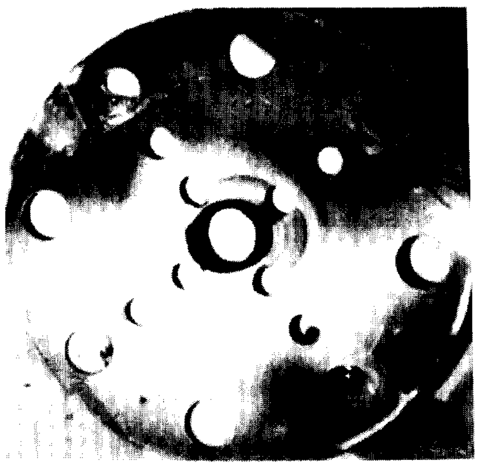

Figure 6. The beam drills a hole precisely on axis into the 0.013-cm tantalum, x-ray converter plate placed outside the extraction foil.

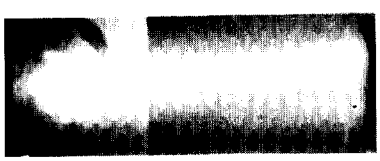

Figure 7. Open shutter photograph of the extracted beam following precise alignment of the accelerator beam line.

Magnetic Alignment

The proposed magnetic alignment technique is essentially the same as the one for the mechanical alignment. Only the target design changes. Instead of the solid lucite targets, a glass vacuum tube is being used (Figure 8). The outside diameter of the tube is precisely machined to follow the inside diameter of the beam line vacuum pipe. The tube length is ~ 25 cm. One end is fitted with the electron gun of a television

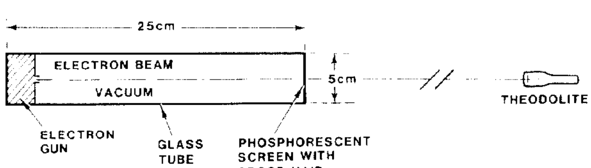

Figure 8. Magnetic alignment electron gun tube.

tube[5] (RCA, CE74W), and the other end has a phosphorescent screen with a cross hair. The electron gun is precisely positioned to produce an electron beam on the axis of the glass tube. During magnetic alignment, the solenoids of the beam line are activated with a low DC current. If the magnetic axis is parallel to the pipe axis, the image of the electron beam striking the phosphorescent screen should appear on the center of the cross hair.

The target-tube can be moved upstream and downstream along the beam pipe sampling the magnetic field alignment of the entire beam line. The position of the electron beam spot relative to the cross hair is again followed and precisely measured with the aid of a theodolite and TV camera. If the electron beam does not strike the phosphorescent screen on axis, this signifies that there is a misalignment between the magnetic and geometric axis.

This technique is being proposed for the magnetic alignment of RADLAC-II; however, it can be utilized in any accelerator with focusing or beam guiding solenoidal coils.

Conclusion

We have developed and implemented a very precise alignment technique for the RADLAC-II accelerator. The 12-m long beam line was accurately aligned with a maximum offset between injector and exit pipe axis less than one millimeter. The precisely aligned RADLAC II produced a very stable (non-oscillating), well-focused beam emerging from the accelerator on axis of the 5 cm vacuum pipe. A similar alignment technique for the magnetic field axis is currently under development.

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