IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

# MECHANICAL TECHNOLOGIES FOR PIGMI*

L. Hansborough, V. Hart and E. Bush, Jr.

University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

## Summary

PIGMI (Pion Generator for Medical Irradiations) is a compact linear proton accelerator designed for a hospital environment. The prototype of the low energy section of PIGMI has been designed and is being fabricated at the Los Alamos Scientific Laboratory. It is an accelerator design which makes use of several advanced or innovative technologies. The PIGMI Prototype consists of a 250 keV injector, a double harmonic buncher, a tape-wound 13 kG solenoid magnet, and four accelerator tanks with a total of 63 drift tubes of which 18 contain strong focusing quadrupoles of permanent magnets. The accelerator tanks are mild steel, copper-plated using a bright acid leveling technique. Drift tubes are stainless steel, fabricated using electron beam welding, shaped in a lathe and then copper plated. Drift tubes loaded with permanent magnets are sealed using laser welding. The samarium cobalt magnets are shaped by cutting and grinding techniques developed at Los Alamos.

## Introduction

The objective of the PIGMI project is to demonstrate the feasibility of a relatively inexpensive, easily maintained and operated linear accelerator to produce pions for use in a hospital environment. Pion cancer therapy is now being done at the Los Alamos Meson Physics Facility, and the initial experiments have been very encouraging. To achieve low costs, new technological approaches and accelerating structures are exploited. The accelerating structure is described in Ref. 1, and the general mechanical design is described in Ref. 2. A prototype of the low energy portion of PIGMI is being built at LASL; Fig. 1 illustrates that first 2.48 meters of the Pigmi Prototype.

## Injector Technology

The 250 keV injector is shown in Fig. 2 and described in detail in Ref. 3. The injector is a small, simple, cantilever design with no corona rings, and it utilizes a spherical Pierce geometry to produce a converging beam. Eight 38.7 cm o.d. x 34.9 cm i.d. alumina rings bonded to .5 mm thick titanium washers and a thick stainless steel flange at each end compose the accelerating column. The bond with the titanium washers is with polycarbonate, and the bond to the end flanges is with Torr-Seal. The column is surrounded by a cantilevered Lucite jacket which contains 3 psig of $SF^6$ insulating gas. Oil-free injector operation is critical, and pumping for the system is provided by 550 ℓ/s magnetically-levitated-rotor turbopump. This pump maintains a $1 \times 10^{-7}$ torr base vacuum in the column and operates at $2 \times 10^{-5}$ torr with a hydrogen gas flow of 1.5 atm cc/min. The turbopump exhausts through a refrigerated cold trap and a molecular sieve to a mechanical forepump. Because the turbopump motor is convectively air-cooled, the requirement for an uninterrupted cooling water supply is eliminated, and this pump, unlike most turbopumps, pumps hydrogen very well (485 ℓ/sec). The attitude of the injector may be fine-tuned and mechanically locked by means of six bolts on each side of the vacuum manifold. The column is aligned to produce the proper beam direction; no steering magnets are used.

## Solenoid Magnet Technology

A tape-wound solenoid magnet is used in the beam guide to prepare the beam for injection into the linac. This magnet was designed to minimize overall size, particularly beam line length. It has an overall length of 18.0 cm, a diameter of 42.8 cm, an aperture of 4.8 cm, and a field strength at the bore of 12.9 kG with a current of 387 A. The two electrical coils are edge-cooled, tape-wound coil sections, each having 115 turns and connected in series. The coil conductors are 1.27 mm thick x 6.76 cm wide copper strips with 0.76 mm thick Nomex (Nylon) paper as the insulator. Three coated (arc-sprayed $Al_2O_3$) cooling plates are held in mechanical contact with the coils while thermal contact is enhanced by a silicone heat sink compound.

## Accelerator Tank Fabrication Techniques

One aim of the PIGMI program is to be able to assemble and align the accelerator structure prior to shipment and installation at a hospital site. Therefore, a low cost and rigid accelerator structure is desirable. Mild steel was selected as the tank material, plated using bright acid leveling copper plating. This technique results in exceptionally good copper surfaces, is inexpensive, and has been successfully tested in a vacuum and rf environment in the PIGLET rf test cavity.[4] The plating thickness may be varied, but that used on PIGMI components is about 0.1 mm thick, and it has resisted bakeout temperatures to about 480° C.

The PIGMI Prototype contains four tanks: the Alternating Phase Focused (APF) tank, the Quad Ramp tank, the Phase Ramp tank and the Drift Tube Linac (DTL) tank. The APF tank is 63.3 cm long and contains 28 drift tubes, none of which contain quadrupole lenses. The Quad Ramp tank is 61.8 cm long and contains 16 drift tubes, every other one of which contains a quadrupole lens. Both tanks have a 46.0 cm i.d. and are similar in construction. The tank material is normalized seamless AISI 1010-1020 mild steel tubing. The tanks are thick-walled (2.54 cm), which provides rigidity and adequate material to machine drift tube stem seats in the tank wall. In the APF tank, odd-numbered drift tubes are rotated 60° about the axis because drift tube spacing is otherwise too close to allow installation of stem terminations. Figure 3 shows the APF tank with the drift tubes installed. In the Quad Ramp tank, the drift tube spacing is sufficient to allow all drift tubes to be in the same orientation with one vertical stem.

The Phase Ramp and DTL tanks are similar in construction. The Phase Ramp tank is 95.5 cm long, 45.0 cm diameter cavity containing 16 drift tubes. It is very similar in construction to the PIGLET cavity

* Supported by the National Cancer Institute of the Division of Cancer Research Resources and Centers of the U. S. Dept. of Health, Education, and Welfare.


0018-9499/79/0600-3770$00.75 © 1979 IEEE

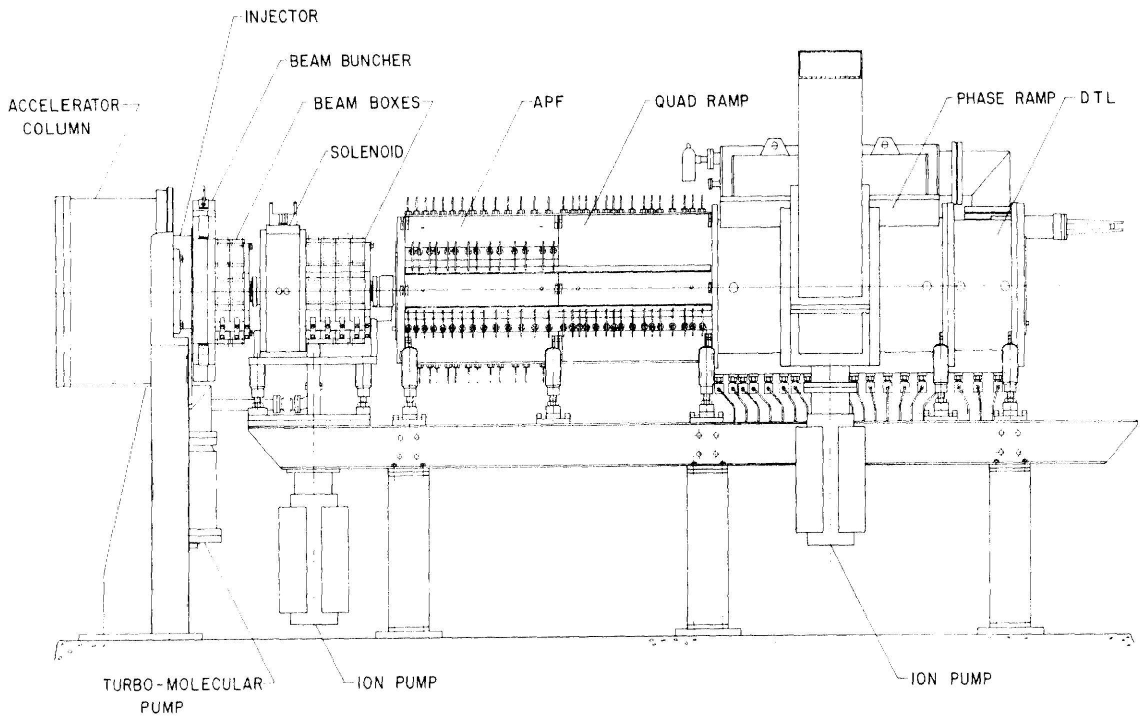


Fig. 1. The PIGMI Prototype showing all major components.

shown in Fig. 4. The tank wall material is .95 cm thick 1010-1020 mild steel which is annealed after welding and prior to finish machining. The DTL tank is 27.6 cm long, 44.0 cm diameter cavity containing three drift tubes. Drift tubes in these tanks are single-stemmed, and every other drift tube contains a permanent magnet quadrupole lens. These tanks exploit the technological innovations developed on PIGLET which are (1) welded steel tank construction with a heavy saddle for mounting drift tubes, (2) drift tube alignment by means of close machining tolerances on the drift tube stem holes and a controlled-crush copper interior stem seal, (3) a copper rf tuning slug which doubles as a vacuum pumping port and provides access to the tank interior when removed, and (4) rf input through an iris.

## Drift Tube Fabrication Techniques

There are 36 three-stem drift tubes and 9 single-stem drift tubes which do not contain permanent magnet quadrupole lenses in the PIGMI Prototype, plus 8 magnet-loaded three-stem drift tubes and 10 magnet-loaded single-stem drift tubes. The heat load on each drift tube is on the order of 5-10 watts. All drift tube bodies are 304 stainless steel, and fabrication of each type is relatively similar. An inner cylinder containing the cooling passages is electron-beam welded to an outer concentric cylinder. Electron-beam welding is desirable because the welds are reliable, repeatable, and deep penetration is required on some drift tubes. Following welding, the external shape is machined on either a numerically-controlled lathe or a tracer lathe, and then the drift tube stems are brazed to the body.

The three-stem drift tubes use .30 cm diam. 304 stainless steel hypodermic tubing for the stem material. During brazing operations, the stems are cooled to minimize the annealed region of the stem. The single-stem drift tubes use a 1.27 cm diam. 304 stainless steel stem. Machining in the stem termination region following brazing assures proper drift tube alignment. Following brazing and machining operations, the drift tubes are copper plated using the bright acid leveling technique.

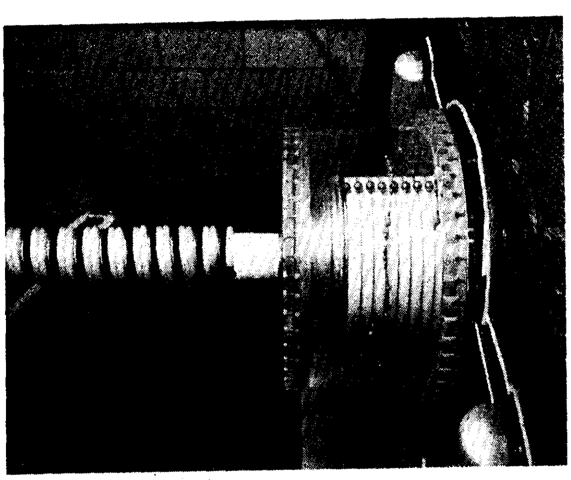

Fig. 2. Overhead view of the PIGMI injector.

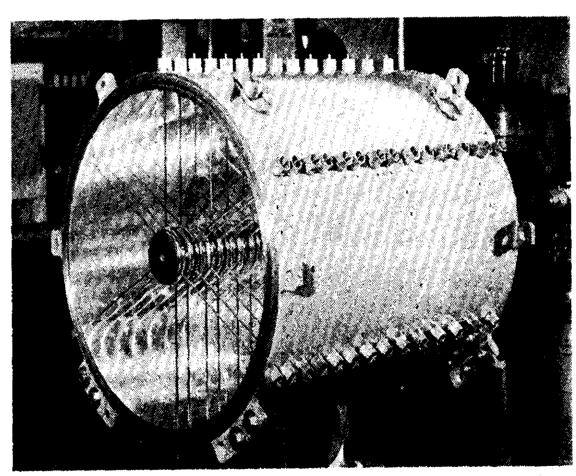

Fig. 3. APF cavity with drift tubes installed.

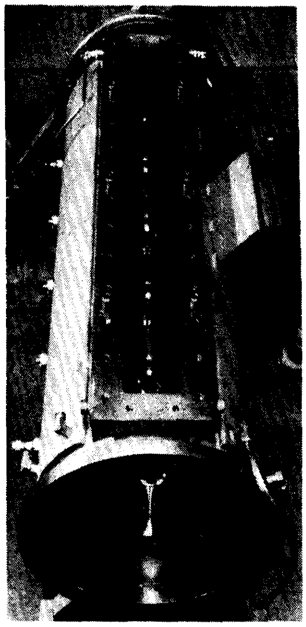

Fig. 4. PIGLET cavity with drift tubes installed and rf inlet on right side of tank.

Fabrication of the magnet-loaded drift tubes is similar to that of the unloaded drift tubes through the drift tube body profile machining and stem brazing. However, the drift tube body is then bored for the yoke, the yoke is installed, and then the holes for the permanent magnets are bored. Following installation of the magnets, a cover plate is laser welded (in an argon atmosphere) in place, and then the cover plate is profile machined. The drift tubes are then copper plated.

Installation of the single-stem drift tubes is straight-forward; however, installation of the three-stem drift tubes requires that the stems be bent. Each stem must be bent about 1.9 cm over its 19.0 cm length, and one must be careful to bend the stems only in the region which is unannealed to avoid putting a set in the stem.

## Permanent Magnet Quadrupoles

The use of permanent magnets for the quadrupole lenses is a major technological innovation for PIGMI. A simple arrangement of four magnets in an iron yoke was chosen although more powerful (and complicated) arrangements are possible. The permanent magnets are samarium cobalt HICOREX 18 for all drift tubes except for three where the more powerful HICOREX 22 is used.[4] Both are made by Hitachi Magnetic Corporation. The field of the quadrupole is tuned by the shape of the magnets. Magnet length is limited by space inside the drift tube, and magnet proximity to the beam is limited by the bore. Fine tuning of the magnets is done by grinding a flat on the bore side of the magnet, and it is very important that the flat be accurately ground with the proper alignment. Figure 5 shows the grinding attachment with a magnet in place. Insertion of a keeper against the magnet flat insures retention of proper magnet orientation in the drift tube. One limitation caused by the use of permanent magnets is that a temperature in excess of about 200°C may cause irreversible changes in the magnetic characteristics; however, an advantage is that magnet cooling is not required as for an electromagnet.

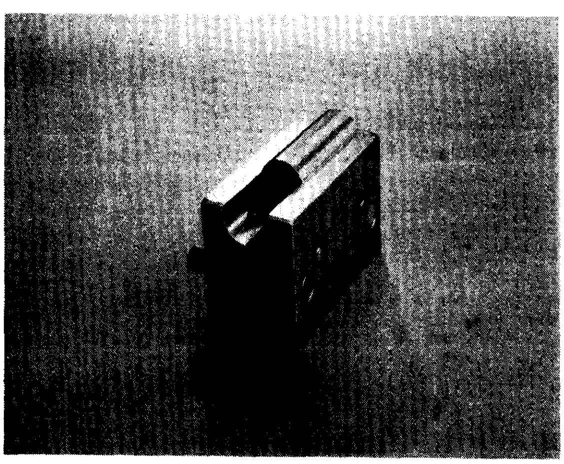

Fig. 5. Permanent magnet in grinding fixture showing ground fine-tuning flat.

## Conclusions

Several fabrication techniques and technologies somewhat new to the accelerator field are being exploited in the design and fabrication of the PIGMI Prototype. These techniques may have a very beneficial application to future accelerator designs if proven on the PIGMI Prototype.

## References


1. D. A. Swenson and J. E. Stovall, "Low-Energy Linac Structure for PIGMI," Proc. of the 1977 Particle Accel. Conf., Chicago, 1977.

2. L. Hansborough, E. Bush and V. Hart, "Mechanical Description of PIGMI," Proc. of the 5th Conf. on the Use of Small Accel., North Texas State Univ., 1978.

3. R. Hamm, R. Stevens, D. Mueller, H. Lederer and J. Leavitt, "A compact 250 kV Injector System for PIGMI," Proc. of the 5th Conf. on the Use of Small Accel., North Texas State Univ., 1978.

4. N. Saito, E. Bush and D. Swenson, "Development of Sameriun-Cobalt Quadrupole Lenses for Particle Accelerator Applications," Los Alamos Scientific Laboratory Report LA-7232-MS, 1978.