ALIGNMENT PHILOSOPHY, DESIGN AND TECHNIQUES USED AT LAMPF*

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Abstract

This paper will describe some of the more important alignment philosophies and techniques used to build the LAMPF Accelerator. The laser equipment used for alignment, the establishment of the 2,600 foot accelerator axis, the Alvarez section drift-tube alignment and some of the off-axis alignment techniques used will be discussed.

I. LASER EQUIPMENT

When the initial discussions on possible accelerator tolerances were held, the decision was made that the required tolerances could be held using standard optical alignment techniques and equipment. The tightest tolerances were on the drift tube positioning in the 201.25 MHz Alvarez section and the quadrupole doublets in the 805 MHz side-coupled linac. It turned out that our longest module, or our longest line of sight, was about 60 ft so transverse tolerances of ±0.005 in. were reasonable. It was also decided a gradual tilt could be tolerated in the overall accelerator axis as long as there were no steps or sharp deviations. This allowed a line extension technique to be used without having an absolutely straight line over the 2,600 ft distance.

Following the decision to use standard optical tooling, the first of the commercial tooling lasers came on the market. Two of these systems were procured and were used to align some of the early linac models as well as the Electron Prototype Accelerator (EPA). These lasers were fairly successful and both standard and homemade detector targets were used. The chief drawbacks to these lasers were: (1) they were not completely interchangeable with optical tooling components; (2) they were susceptible to air currents on the laser barrel itself; and (3) most important, the detectors were bothered by incident ambient light.

When the time came to pick a system to use in the LAMPF Accelerator alignment, a study was made of the existing laser alignment systems available and the system shown in Fig. 1 was selected. The primary considerations in selecting this system were: (1) the modulation of the laser beam and detector targets which made the system impervious to external light sources, (2) the continuous ground barrel which made the laser itself more interchangeable with respect to standard optical tooling components, and (3) the position of the laser beam with respect to the barrel. Figure 1 shows a detector target, a standard tooling sphere, a see-through detector, a detector readout unit and the tooling laser.

The PERT schedule for LAMPF required continuous installation, with the 201.25 MHz Alvarez linac and the side-coupled linac being installed simultaneously. We acquired two complete laser systems for this reason and later a third to use as a spare. We also set up a complete overhaul and calibration facility to keep the lasers operating, since returning them to the factory required several weeks. We fabricated several special detectors to use with this system. At least 95% of all alignment on the LAMPF accelerator was accomplished with the laser system.

II. ESTABLISHMENT OF THE ACCELERATOR REFERENCE LINE

Initially our biggest problem in trying to establish the accelerator reference line was getting on the site. The building construction schedule was such that only short lengths of the beam channel were accessible for long periods of time. The 201.25 MHz linac sector became available first. This portion is shown in Fig. 2. This initial sector was about 225 ft long. At first, the only reference survey monument was the upstream end which we called Station 0.00. The next reference survey

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monument was 400 ft away and because two different building contractors were involved, a locked temporary plywood barricade kept us out.

We did some initial alignment monument installation using nominal measurements from walls and the floor. This allowed us to experiment with our laser system in place. Figure 3 shows a typical on-axis laser and target monument in place. At this time, we recognized the problems with the myriad of openings in the channel, each one contributing to an air turbulence, which greatly affected our laser reference line. We put a large tarp over the upstream end of the beam channel, taped or covered all other openings we could find, and finally began to get good stability in our reference line over the 200 ft shooting distance.

Due to some fortunate circumstances, when the next short section of beam channel became available, approximately 400 ft, we were also able to have doors put in the contractor's temporary barricades so we could shoot the 2,600 ft to the far reference survey monument. The weather conditions were almost perfect and we worked several nights using the laser beam to check the walls and floor of the beam channel. We were able to judge the conditions under which we were shooting by observing the laser beam on the 2,600 ft target. The laser beam is about 1 cm diam at the laser and was about 10 cm diam at 2,600 ft. If there were perturbations due to temperature differences, airborne particles or such, the laser beam lost its size, shape and steadiness. Under bad conditions, the laser beam became a rapidly moving, undefined red area on the target. If conditions were good, we felt we could determine the center of the laser beam on the 2,600 ft target within 1/8 in. So, centering the laser beam on the target at Station 0.00 and pointing it to the target at 2,600 ft, we set our first permanent alignment monuments in the first 600 ft of beam channel. We had access to the 2,600 ft target for only a few weeks when construction closed our access. We did install a temporary target at the 800 ft station.

With a good start on our 2,600 ft long accelerator axis reference line, we extended our line by a leap-frog technique. We had primary instrument monuments at both Station 0.00 and Station 220.00. The beam channel design, as described in V. E. Hart's[1] paper, and the very rigid accelerator support structure design allowed intermediate alignment monuments to be bolted directly to the support structure. Figure 4 shows a typical target monument used on the 201.25 MHz linac support structure and Fig. 5 shows the monuments used on the 805 MHz linac support piers. The support structure was bolted to the steel plates set in the floor. These plates had been located and welded to the rebar in the floor before the concrete floor was poured.

Figure 6 shows schematically our leap-frog line extending technique. With the laser in one position, pointing downstream, we were able to set four to six target monuments. These monuments were 50-60 ft apart. Each target could be set to an accuracy of 0.002 to 0.010 in., depending on the distance from the laser. The laser was then moved downstream one monument distance, and bucked in using the target that had been the far reference target as the new close reference target. The closest of the newly set targets was used as the far reference target. We could then check all other targets that had been set and could set one new target. This process was repeated for the whole length of the beam channel. This procedure maintained our criteria of allowing a gradual deviation in the straightness of the reference line while maintaining a few thousandths of an inch tolerance over any 200-300 ft distance. We also made long-distance shots at frequent intervals, including shots through the entire beam channel as it became available.

III. DRIFT TUBE INSTALLATION

The 201.25 MHz linac tanks were aligned and assembled on their mounts as described in Hart's[1] paper. To prepare for drift tube installation, the first operation was to check the distance from the mounting surface on the tank saddle to the accelerator reference line. This was to ensure that there was sufficient adjustment capability without any special machining. This measurement was made by using an alignment scope and an inverted optical tooling scale.

The laser was then bucked in on the reference line and the machined spiders were put in the machined counterbores at each end of a tank section. Each spider had a target position on the centerline so a continuous check could be made during drift tube installation. We had decided to use special steel tooling tapes to position the drift tubes axially.

These tapes had the theoretical position of each drift tube scribed on it and each drift tube had a corresponding line. The spiders contained the pulleys and vernier adjustments to locate the tooling tape. Figure 7 shows the spiders installed with the tooling tape and tension weight in place. In the longer tanks, several temporary tape supports were put in the tank until each drift tube could support the tape.

Figure 8 shows a typical drift tube with the bellows assembly which has the high-vacuum sealing flange on the top. Also shown is a tool steel mirror which has the reflecting surface perpendicular to a shaft which fits the drift tube bore. The self-centering drift tube target with an adjustable stop is next to the drift tube.

The drift tubes were completely fabricated at ETL Building and transported by truck to the beam channel. Special containers were built which held five drift tubes in a closed wooden box built on a forklift pallet. Protective covers which supported the bellows and protected the sealing surface were built for each drift tube. As each drift tube was finished at ETL, it was given a final cleaning, the bellows assembly protective cover installed and the drift tube put in a plastic bag and sealed. When each container of five drift tubes was full, they were transported to the beam channel. Figure 9 shows the drift tube, the protective cover on the bellows and the shipping box.

After final cleaning, all handling of the drift tubes was done wearing white gloves to keep the high-vacuum surfaces of the drift tube as clean as possible.

When a particular drift tube was to be installed, it was taken out of the plastic bag and the protective cover removed from the bellows assembly. The high-vacuum sealing surface was examined for any imperfections that might affect the vacuum seal. If necessary, the surface was repolished and cleaned. The metal O-ring was then installed using aluminum foil and masking tape on the low vacuum side as shown in Fig. 10. The bellows assembly protective cover was then reinstalled to protect the bellows and seal while the drift tube was rolled down the tank.

Due to the small diameter of the 201.25 MHz linac tanks and the location of the optical tooling tape just off the tank axis, no provisions were made for personnel transportation. A cart was designed to transport the drift tube down the tank to the required position. This cart had a 100 lb capacity jack with a turntable on top. The drift tubes were set on the cart with the drift tube bore 90° to the linac axis. The stem lay over in a V-block and the cart pushed into the tank. Figure 11 shows the cart with a drift tube being loaded. Ropes were attached to both ends of the cart so it could be pulled either direction in the tank.

As the drift tube on the cart approached the technician inside the tank, he removed the bellows protector, made a visual check of the metal seal, and carefully bent the spring fingers on the drift tube to insure electrical contact when the drift tube was installed. He also visually checked the sealing surface on the inside of the tank saddle to insure a vacuum seal could be made and, if necessary, he polished and cleaned it.

When the drift tube stem was inserted in the bore in the tank saddle, the turntable allowed it to be rotated 90° and the drift tube was jacked into position using the built-in jack on the cart. Figure 12 shows the technician guiding the stem and bellows assembly into place so the studs on the metal seal flange mated to a clamp ring. The drift tube was then raised approximately 1 in. higher than its final position to allow the split retainer rings to be put in place. The drift tube was then lowered on the jack until the drift tube was supported by the tank. The mirror was placed in the drift tube bore and the drift tube rotated in the split retainer until the drift tube bore was parallel to the linac axis. This was accomplished by auto-reflecting the laser beam with the mirror. The split retainer clamp ring was then tightened which rigidly mounted the drift tube to the top block. All further motion of the drift tube would be made by moving the top block.

The drift tube top support block had been previously installed on a trial set of shims. With the drift tube bore parallel to the laser beam, achieved by auto-reflecting with the mirror, the drift tube laser target was adjusted so the detector cell would be positioned on the vertical axis of the drift tube, and the target put in the drift tube bore. A reading was taken of the X-Y position of the drift tube and angular errors about the X and Y axis noted. The simple adjusting fixture, shown in Fig. 13, bolted to the tank saddle and allowed adjustments in the X and Z direction and rotations about the Y axis. So, using the laser target, the drift tube was put on the linac axis; using the mirror, the rotation was checked, and using the optical tooling tape, the axial position was set. We were now ready to make a determination of the final shim stack. With the three-point mount on the top block, as noted in Fig. 13; by changing appropriate shims, we could effect changes in the Y direction, as well as rotation about the X axis and Z axis. After the correct spacer stack was obtained, the adjusting fixture, laser target, mirror and tooling tape were again used to locate the drift tube in its correct position.

The final operation inside the tank was to position the bellows assembly to insure no bare steel was exposed while the high-vacuum seal was being made. The technician inside the tank then applied helium to the seal inside during the final leak check. After the drift tube was vacuum tight, all water manifolds were installed and checked, and the final position readings taken and recorded.

IV. OFF-AXIS ALIGNMENT

Since our primary alignment scheme for both the 201.25 MHz and 805 MHz linac portions of the accelerator was on beam centerline, it required the alignment monuments to be removable or new off-axis monuments provided. In the 201.25 MHz linac area, the 6 ft tall monuments were made so the top 2 ft section could be removed and replaced when needed. This does, however, require removal of either quads or beam diagnostic gear.

In the 805 MHz linac area, a quadrupole doublet had to be located approximately every 25 ft, a total of 103 doublets. It was decided to depend on these doublets to provide a base for checking accelerator alignment. The doublets were manufactured with very close tolerances, and with a set of dowel pin holes on the horizontal centerline of the outside of the yoke. A set of fixtures was made which located a parallel line 16 in. off the centerline of the doublet. Spacer bars were also made which fit the bore of the side-coupled linac modules or the monuments we had previously set when establishing the accelerator reference line. Figure 14 shows a typical quadrupole doublet on its mount with the alignment fixture containing a laser. The spacer bar is shown in front with a laser detector target in one end. The electronic level is used to level the spacer bar as well as set the rotation of the quadrupole doublet. Figure 15 shows a spacer bar set to establish the 16 in. parallel line from a monument. Note the laser target and precision level. Figure 16 shows a doublet being installed with the alignment fixture attached to the doublet. Figure 17 indicates the method of using a previously aligned doublet as a reference monument.

ACKNOWLEDGMENTS

L. M. Kelly for 201.25 MHz support design and tank installation supervision.

E. D. Bush, Jr. designed and fabricated the 201.25 MHz drift tubes and supports.

R. Harrison, C. Welch, J. Sherwood, E. Weiler, G. Roybal and V. Martinez all worked to make the alignment schemes actually work.

REFERENCE

1. Valgene E. Hart and Elbert W. Colston, "Installation and Alignment of LAMPF 201.25 MHz and 805 MHz Linac Tanks", to be published in the Proceedings of this Conference.

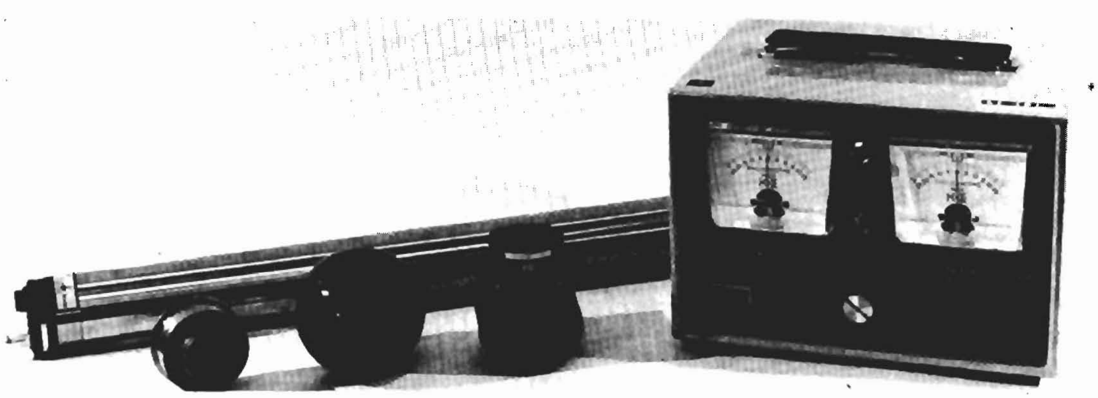

Fig. 1. Commercial tooling laser system used to align LAMPF.

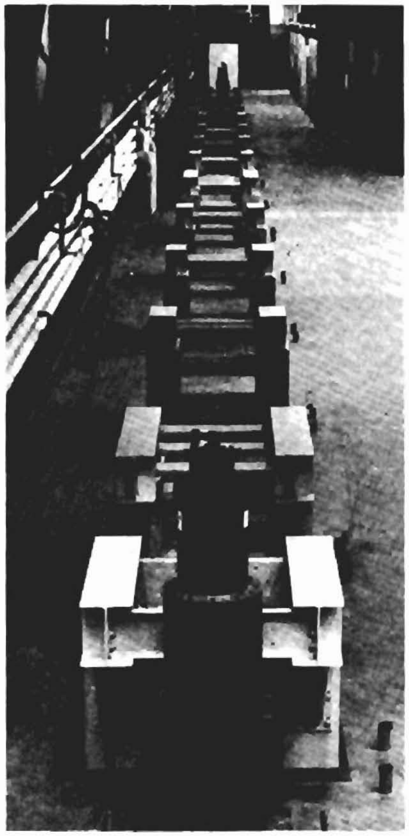

Fig. 2. 201.25 MHz Alvarez linac beam channel with support structure.

Fig. 3. Primary alignment monument station at Station 0.00.

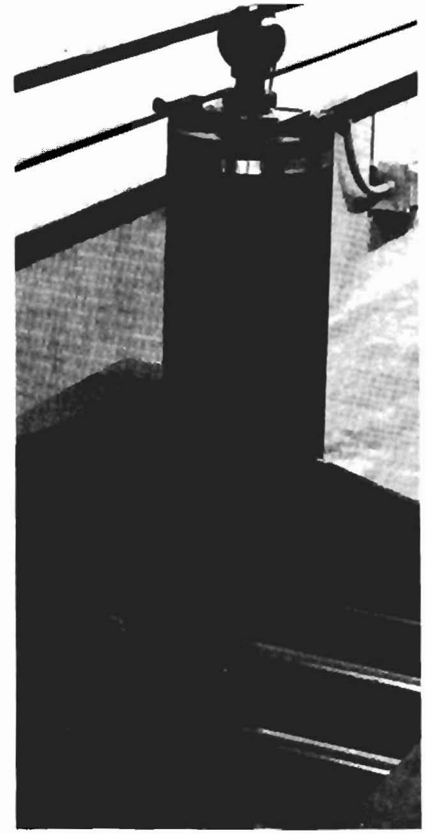

Fig. 4. Intermediate target monument used on the 201 MHz linac support structure.

◄Fig. 5. Laser and target monuments used on the 805 MHz linac support structure.

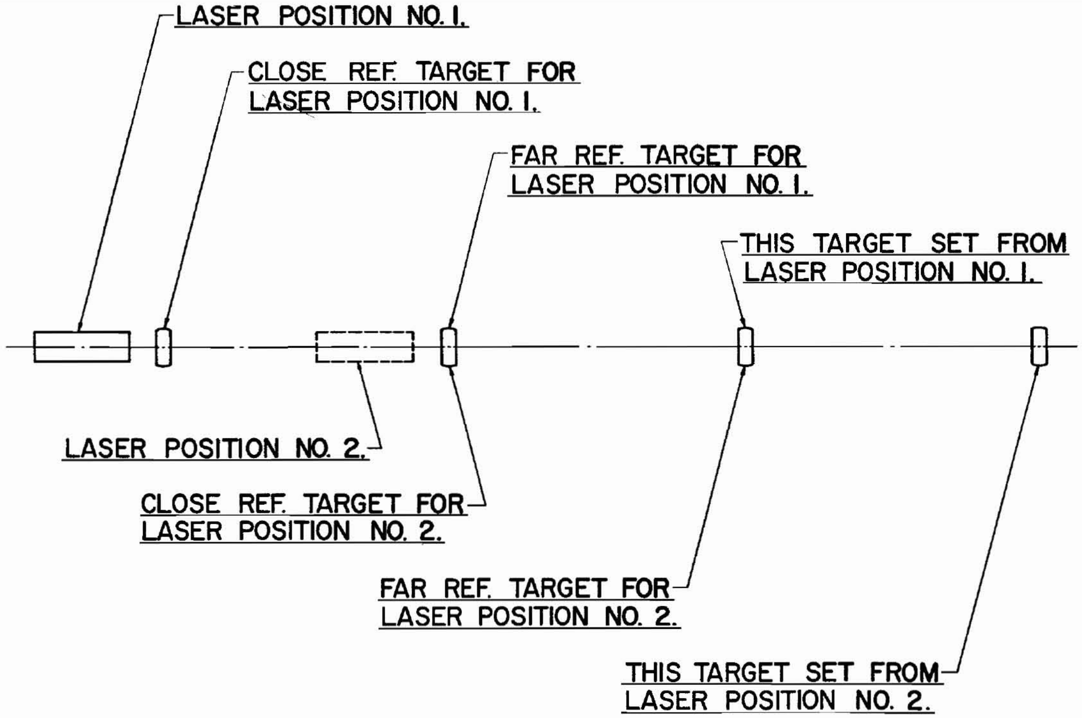

Fig. 6. Schematic of line-extending technique.

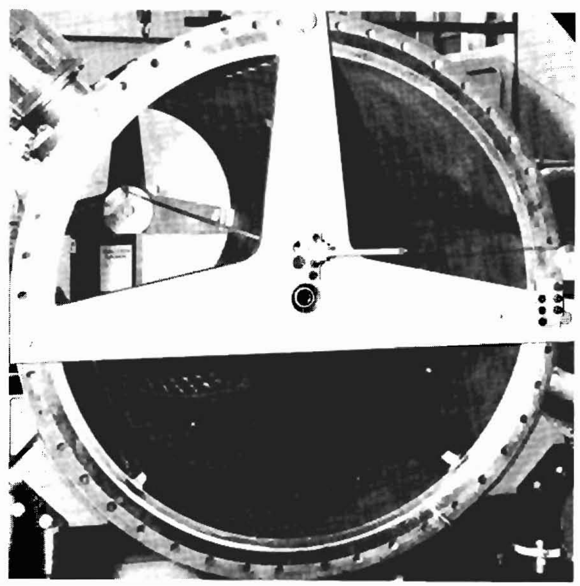

Fig. 7. 201 MHz Alvarez linac tank with machined spiders and drift tube tooling tape installed.

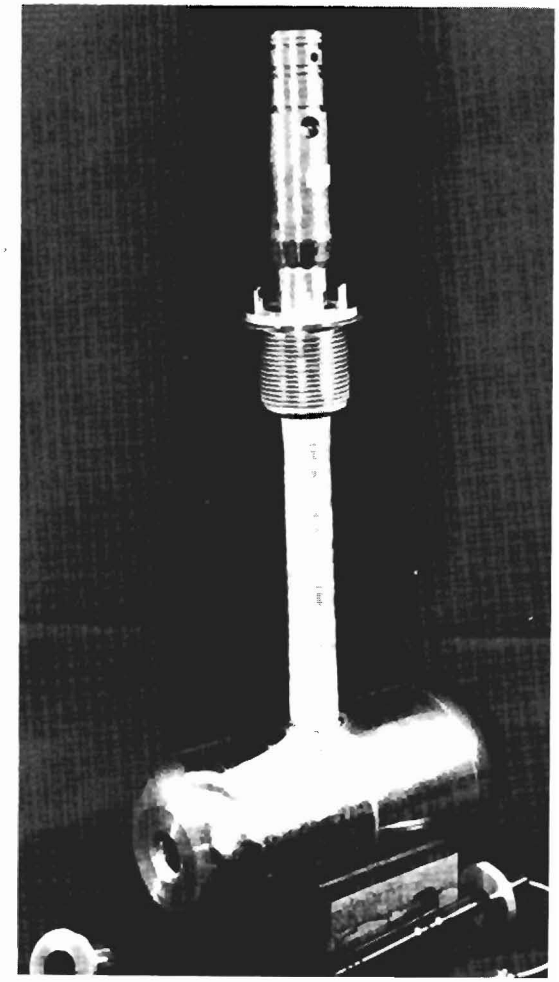

Fig. 8. 201 MHz Alvarez linac drift tube with laser detector and auto-reflecting mirror.

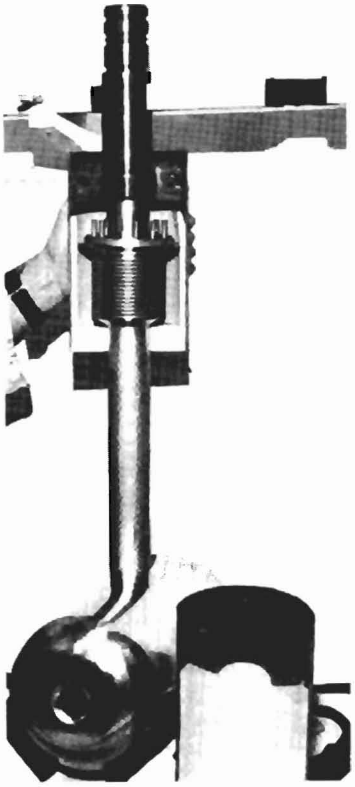

Fig. 9.
Drift tube with protective cover for bellows assembly shown in shipping container.

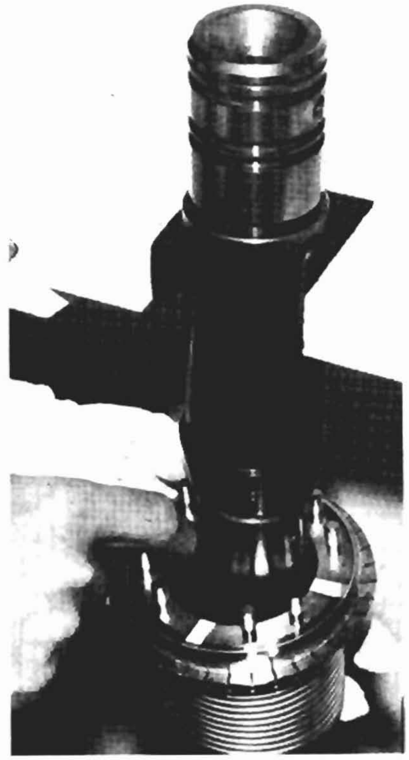

Fig. 10.
Metal seal being installed on drift tube.

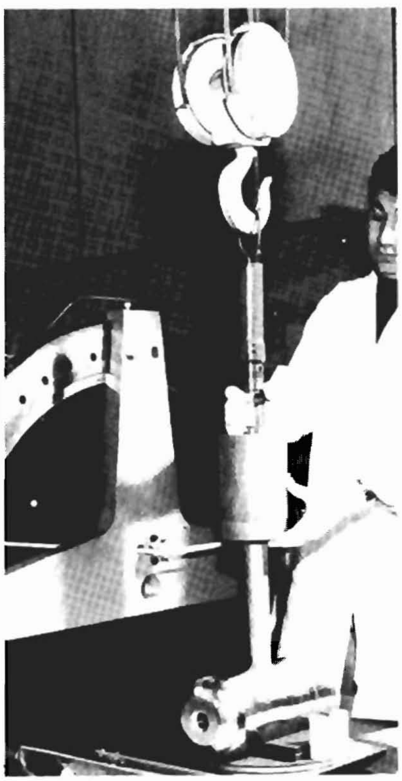

Fig. 11.
Drift tube being loaded on special cart.

Fig. 12.
Drift tube being put in position in 201 MHz Alverez linac. Note optical tooling tape.

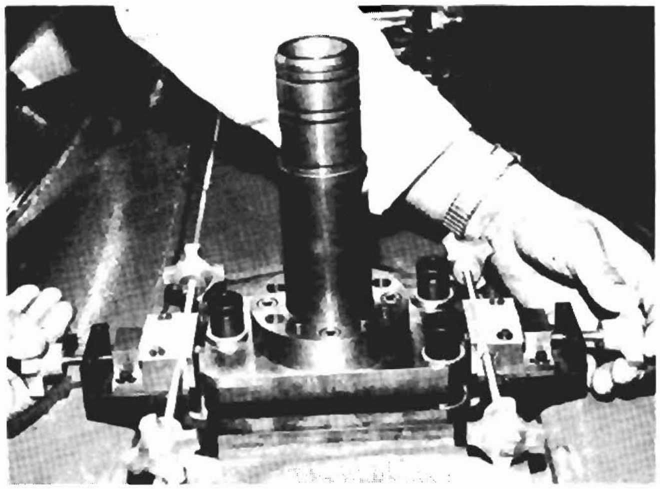

Fig. 13. Drift tube adjusting fixture used on top of 201 MHz Alvarez linac tank.

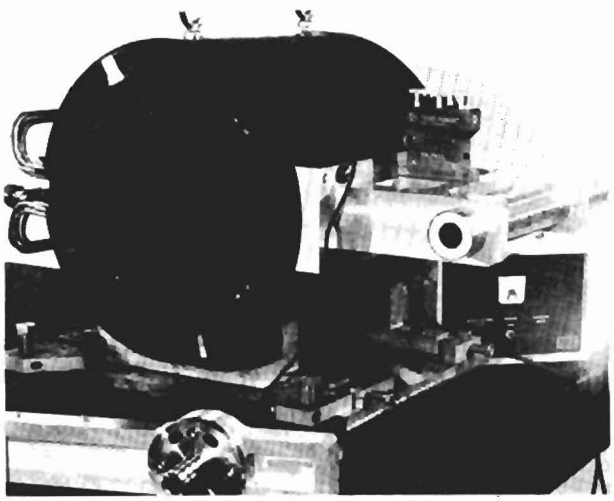

Fig. 14. 805 MHz linac quadrupole doublet with laser alignment fixture and spacer bar.

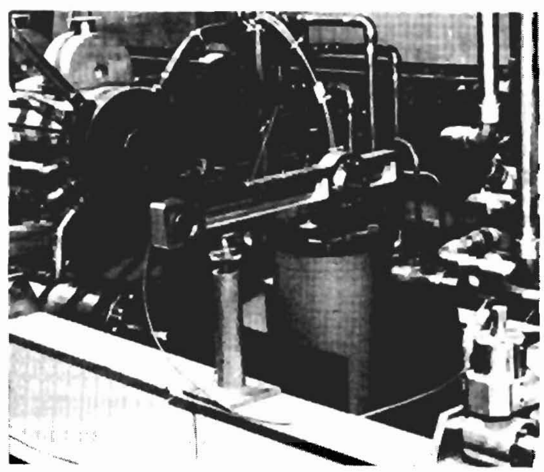

Fig. 15. Spacer bar used to set offset parallel reference line for 805 MHz linac quadrupole doublet installation.

Fig. 16. Installation of quadrupole doublet between 805 MHz linac modules. Laser fixture is shown on doublet.

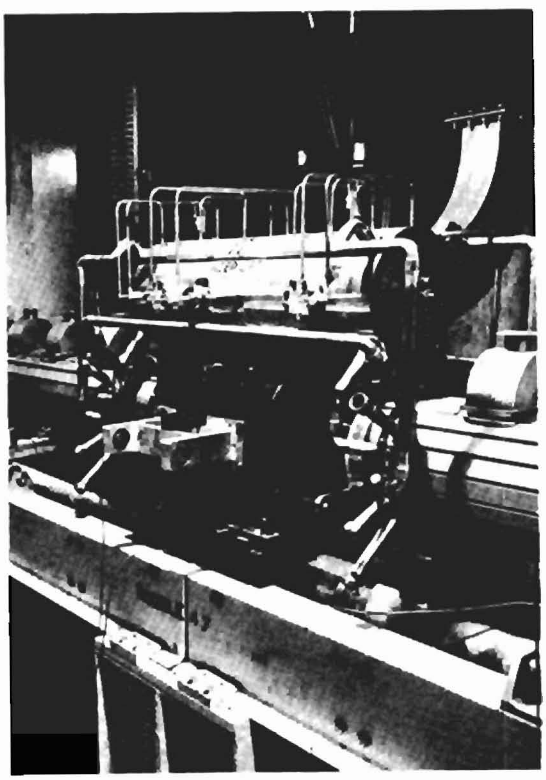

Fig. 17. Laser fixture used as reference monument on previously installed quadrupole doublet.

DISCUSSION

Blewett, BNL: You have stated that the accuracy of these measurements is a few thousandths of an inch in 200 feet. Do you have an independent method of checking these measurements?

Colston, LASL: No, we used the laser system to recheck the leap-frog technique by turning the laser around and repeating the measurements.

Miller, SLAC: Were the centers of the quadrupole doublets determined magnetically or mechanically?

Colston: Mechanically. The mechanical and magnetic axes are identical.