DRIFT TUBE ALIGNMENT EXPERIENCE ON THE AGS LINAC INJECTOR

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The orbit dynamics of the proton beam in the AGS injector was calculated by L. Smith,* who showed that for the transverse oscillations:

$$(\text{amplitude})_{rms} = 16\ \delta_{max}$$

where δ_{max} is the maximum error of a square probability distribution. A number of different error patterns were calculated and plotted and in most of these the rms value of amplitude was close to 16 δ_{max}. However, in one case this value was 22 δ_{max}, showing that for some types of error distribution the amplitude may be considerably increased.

The drift tubes fabricated for the AGS linac were manufactured and corrected so that before their installation in the linac the three orthogonal axes of the drift tube were accurately set up in the proper angular relationship. The horizontal position, vertical position and axial position were to be measured when installed and positioned accurately by the use of shims. This was done by using an optical target installed in one end of the drift tube bore and sighted on by an optical alignment telescope directed along the axis of the linac. The bore used to locate the target in the drift tube was machined to be concentric with the axis of the bore locating the quadrupole focusing magnet. The bore at the other end of the drift tube is not as accurate because it is part of the drift tube end cover which is soldered in place after the quadrupole was installed and the clearance for the solder joint is .005" on the radius. Thus the possible radial inaccuracy at this end could be $\pm$.005". On the longer drift tubes there is a possibility of con-

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siderable error in the position of quadrupole magnet center if the drift tube axis is not parallel to the line of sight. This is a result of the axial distance between the target location and the center of the quadrupole which multiplied by the angular error produces a radial offset. By locating a target in both ends of the longer drift tubes it recently became evident that greater errors were present than had been expected. This error in radial offset has been as much as 0.008".

As a result of vacuum leaks between the rough vacuum on the inside of the drift tube and the high vacuum inside of the linac tank, there have been three shutdowns of the linac during which time various drift tubes have been removed for repair. After reinstallation of the drift tubes the alignment of these was checked and a spot check made of other drift tubes along the tank. During the present shutdown, for adding the conjunction section for the new target area, a vacuum check of the drift tubes showed leakage between the linac tank walls and the drift tube stems. This has necessitated the removal of all 123 drift tubes and their replacement and alignment. By having these opportunities to check the drift tube alignment a better idea has been obtained as to what the actual alignment of drift tubes becomes at some time after the drift tubes are initially aligned by the optical techniques.

The first alignment of the drift tubes was done on a tank-by-tank basis as each 10 foot section was positioned on the supporting pile system. This was especially necessary for the axial position as this was done by using length rods from the end faces of the tank. The optical alignment telescope and the target at the opposite end are supported by stands anchored to the tank support pile caps at the low energy and high energy ends of the linac tank.

After all the tanks were in position the vertical and horizontal location was finally set by measuring the drift tube position and cutting shims of the proper thickness to place the drift tube bore on the optical axis. Shims are also used to position the drift tube axially.

Based on the report mentioned above an rms error of location of .010" would produce an rms amplitude of oscillation of the beam of .160" or a diametral beam of .320". This beam would have to pass through a bore of .500" in the first drift tubes. However, from some optical tests that were performed it became apparent that the targets and drift tubes could be located to within ±.003". Therefore the drift tubes were located to this accuracy in the initial alignment.

During one of the shutdowns for repairs, when a check was made of the drift tube alignment, the spread in the random error of position was found to have increased, and also a smooth curve passed through the scatter of points of position showed a deviation from a straight line. The maximum deviation was .010" in the case of two drift tubes. These were relocated to be within an envelope ±.006" from the smooth curve.

During the recent shutdown a check was not made of the drift tube positions before removing them from the tank. When the drift tubes were reinstalled with the original shims a check was made of the drift tube locations. This showed a change in the vertical baseline of .030" which was probably due to a shift in location of the alignment telescope support. The horizontal baseline was essentially centered. A smooth curve passed through the average of the vertical drift tube positions showed a maximum deviation occurring at tank 3 with the curve going down .018" at tank 1 and down .006" at tank 11. The horizontal smooth curve showed a maximum deviation at tank 6, the middle of the linac, going to the east .010" at the low energy end and .004" to the east at the high energy end.

Since the drift tubes were removed from the tank without measuring their location the long term stability and the relocation is not known. Previous measurements indicate that the random positioning may have been off by ± .010"; considerably more than the initial alignment precision. However, upon installing the drift tubes the shim system provided an initial positioning of ±.015". A short period of alignment and shim grinding brought the drift tube alignment accuracy to ±.005" from the smooth lines indicated above. The axial alignment was spot checked and found to be within .010" of the proper position.

The reason for the smooth variation of drift tube position is not clear because the only surface available for precision measurement is the drift tube bore. It is probable that the gross shift in position is due to a movement of the linac tank or the pile system that supports it. From the viewpoint of the beam dynamics, rather large smooth variations in drift tube positions are allowable without affecting the beam intensity. Since there are no fiducial marks to measure to after assembly it is impossible to determine the actual cause of the shift in position. Future machines of this type should incorporate target positions which will allow for determining accurately what is happening to the intermediate support structure. Hardened steel balls have been installed on the AGS linac at the tank flanges and their location determined for future reference.

The random shifting of the drift tubes has the largest excursions in the vertical direction. This is probably due to the fact that the vertical drift tube stem which determines the vertical position is restrained in position by the weight of the drift tubes. However, the radiofrequency connection to the tank wall, and the vacuum seal from high vacuum in the tank to rough vacuum in the drift tube stem boxes is made by means of copper bellows which upon installation may be stressed. As a result, the low energy drift tubes which are light may move slightly and not return to their original position upon changes in temperature or slight tremors in the floor or foundation system. Clamps are being provided for the vertical drift tube stems, and new bellows of greater flexibility will be available for any future shutdowns.

Although the accuracy of location of the drift tubes perpendicular to the axis was initially determined to ± .003" it is known that after a time some of the drift tubes deviated by as much as .010" from the tank axis before the present shutdown and possibly more. From this evidence, and from discussions with personnel from other linac installations it would appear that the stability of drift tube positions is considerably worse than the precision of the measurement system used for the initial location. If the stability of the support system could be increased, the accuracy of the initial drift tube alignment could be decreased and still retain a better long time drift tube alignment accuracy.

One final point is that from what evidence is available many of the drift tube linacs with quadrupole focusing have been operating for long periods of time without a check of the drift tube alignment and with no evidence of deterioration of beam intensity due to alignment. From measurements that have been taken on the AGS linac, and from estimates of alignment on some machines, it would appear that the actual alignment is considerably worse than the initial alignment, perhaps as much as 5 times worse. If this is true, the accuracy specifications for initial alignment may be too strict and can be relaxed by a factor of two or three.