Modification & Alignment of Beam Line of 10 MeV RF Electron Beam Accelerator

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Abstract: A 10 MeV, 10 kW RF industrial Electron linac designed and developed at BARC is installed at the Electron Beam Center Kharghar, Navi Mumbai. The entire RF accelerator assembly consists of Electron gun, RF source, RF linac structure, Beam diagnostic chamber, Drift tube, Scanning magnet, Beam sensing aperture, Scan horn, and is spread over two floors at EBC. The paper discusses in detail about the alignment procedure adopted for the equipments of 10 MeV RF beamline. The complete electron beamline will be maintained under ultra high vacuum of the order of 10⁻⁷ torr. The paper discusses about the present problem of alignment, measurement technique of alignment, reason for misalignment, possible ways to solve the problem, equipment used for alignment, supports & arrestors, verification of alignment under vacuum.

1. Introduction:
A 10 MeV, 10 kW RF Electron linac for industrial application has been installed at EBC Kharghar, Navi Mumbai. 50 keV Electrons produced by a LaB₆ cathode based electron gun will be injected into the on-axis coupled cavity standing wave linac, which will accelerate them to energy of 10 MeV. A 2.856 GHz klystron based RF power source will be used to establish the required electric field inside the linac. The complete linac assembly consists of Electron gun, linac cavity, BD (Beam Diagnostic) chamber consisting a FCT, drift tube, bellow, scanning magnet, beam sensing aperture, scan horn, Ti beam extraction window, beam dump. The complete beam line will be maintained in a vacuum of approximate 10⁻⁷ torr with the help of three sputter ion pumps (SIPs). A rotary backed Turbo molecular pump does initial evacuation.

2. System & its supports:
The complete system (Fig. 1 & Fig. 2) consisted of a beam-line and an auxiliary vacuum line. A central I-beam, which was welded to EP on the first floor ground, supported the beam line and auxiliary line. The beam line of the system was supported at three places: BD-I chamber, BD-II Chamber and Scan horn. The scan horn was supported on a MS support structure, which was welded to EPs on the ceiling of the ground floor. The TSIPs were also supported.
The complete system was installed and aligned by using plumb line to ~ 1 mm. The complete linac system as per original design had the anode flange of electron gun and top flange of linac cavity (anode linac distance) was ~ 700 mm. The beam line sequentially consisted of electron gun, focusing chamber, BD-I chamber, steering magnet, GV-1, Linac, GV-2, BD-II chamber, rectangular pipeline (for analyzer), GV-3, T-port, bellow, beam sensing aperture, scan magnet chamber and scan horn.

2.1 Reason for misalignment:

The DN 150 bellow connecting the main line to the TMP didn’t have arrestors. Also, there were no arrestors to locate the linac and BD chambers. Due to this, when the system was pumped, the bellow shrunk, thereby pulling the beam-line and disturbing the alignment. The system was misaligned by about 6 mm in both x and y directions.

2.2 Measurement of misalignment in system using the electron beam:

Irradiation of glass plate resulted in a black band of width ~ 50 mm on glass plate (with scanning), and indicated a beam shift of ~ 18 mm along the width of scan horn, the band being uniform along its length. Beam current becomes zero when the magnetic fields of the analyzer are –53 gauss and + 35 gauss. Changing the magnetic field of analyzer improved the beam current by only 1 mA, indicating some beam loss due to this misalignment. Thus there was a misalignment in the system.
2.3 Modification in system to increase output beam current:

In order to increase the output beam current and hence the output power, the anode-linac distance was reduced from \( \sim 700 \text{ mm} \) to \( \sim 45 \text{ mm} \). For achieving this some modifications in the system, between the gun and linac, were made. The focusing chamber, BD-I chamber and the X-Y steerers were removed. The modified system (Fig. 3) consists of electron gun, water-cooled slit flange, Linac, GV-2, BD-II chamber, rectangular pipeline (for analyzer), GV-3, T-port, bellow, beam sensing aperture, scan magnet chamber and scan horn. The system was pumped by only 2 TSIPs (SIP-2 & SIP-3).
3. Analysis of misalignment of the modified system:

In the assembled structure of 10 MeV beam line, misalignment was analyzed and pointed out the following reason:

1) Lower portion of the accelerator that is scan horn, scan magnet, sweep magnet etc were fully rigid hence there was no scope for alignment. The scan horn was supported from bottom, which restricted its motion in all the three directions (x-y-z). The tolerance of the gap between the scan magnet chamber & magnet poles was only 2 mm.

2) The scan magnet was very heavy (Approximate weight 300 kg) and it was rigidly fixed by bolts. There was no provision for its movement in the x-y directions.

3) There were no arrestors to locate the linac and BD chambers.

4) A DN 150 bellow connecting the main line to the TMP didn’t have arrestors. Due to this, when the system was pumped, the bellow shrunked, thereby pulling the beam-line and disturbing the alignment. This misalignment persisted even in the modified assembly.
Our existing system was as per Fig: 3. We started our modification and alignment after this stage. This report deals with the details of modification and alignment of the system, which was carried out during end of May-2007.

4. Threats to alignment works:
The human eyes always prompt to error. One can judge two lines looks parallel form one angle but at the same time he can also deny that lines are parallel if he looks from other angle. It concludes that the best can never achieve unless we used some modern aligning instruments.

5. Different stages of misalignment observed during dismantling of 10 MeV Beam line structure:

(1) The scan horn was supported from the bottom, as per original design. This hindered the removal of the scan horn foil holder. New support arrangements for the scan horn were made (Fig. 4). 4 nos. of SS threaded block are welded to scan horn bottom flange and M16 bolts are engaged which is rested on support structure. Therefore scan horn load is imposed on supporting structure through these bolts and foil holder can be removed. Using the 4 M16 bolts of the scan horn, it can be moved up and down and also tilted slightly. 6 nos. of M10 bolts were provided for adjustment of scan horn along width. Alignment accuracy is more critical along width, which is taken care by these bolts.

![Diagram of scan horn support arrangement](image)

**FIG:-4**

4 nos. of M16 bolt provided for scan horn support and 6 nos. of M10 bolt provided for adjustment of scan horn along width side

(2) Electron gun, rectangular pipeline (for analyzer) and the scan horn foil holder were removed.
(3) In the first stage, plumb line was used from top flange of cavity to bottom of BD-II. It was observed that (Fig. 5) the plumb end was touching the linac cavity towards klystron side.
(4) In the second stage, plumb line was used from top flange of the T-port to bottom of scan horn. It was observed that (Fig. 6) the plumb end was off towards klystron side by 35 mm.
(5) In the third stage, plumb line was used from top flange of the cavity to bottom of scan horn. It was observed that (Fig. 7) the plumb end was off by 20 mm towards klystron side and by 10 mm towards stair case side.
6. Alignment & provision made for readjustment and locking of 10 MeV Beam line structure:

For aligning of the whole assembly it is divided into two sections:

(a) From top of cavity to BD-II end flange
(b) Remaining lower portion upto end of scan horn.

After analyzing the offsets and the structure flexibility it was decided that the scan horn section should be assembled and aligned first and then alignment should proceed towards top.

(1) The supporting structure of scan magnet-scan horn assembly (Fig. 8) was rigid, as it was welded to EPs on the ceiling of the ground floor. Also the scan magnet was rigidly fixed to this support structure through 2 C-clamps and 6 M10 bolts. There was no clearance in the holes provided for these M10 bolts. Hence the scan magnet could not be moved in x- directions. Therefore all six nos. of existing M10 bolt was replaced by M6 bolts and the scan magnet was slightly shifted towards klystron side. In doing so one had to take care of the 1 mm tolerance in the gap between the magnet yoke and the scan magnet chamber.

(2) The auxiliary vacuum line was modified by removing parts B & C (Fig. 9). Part C was removed, as SIP-1 was not used in the system. Pumping of the system is to be provided by only 2 TSIPs (SIP-2 & SIP-3). Part B was modified by connecting the GV7-TMP combination to the T-port vacuum chamber, thus bringing them closer to the beam-line (Fig. 10). Part A (DN 100 CF bellow) was removed.
(3) The scan horn was slightly aligned visually by adjusting the 4 M16 bolts and 6 M10 bolts.

(4) The rectangular pipeline (for analyzer), which was removed earlier, was replaced by a cylindrical drift tube (Fig. 11). This enlarged the beam traveling section and avoided any beam loss in the rectangular width of the rectangular pipeline.

(5) The plumb line was used from top flange of drift tube to bottom of scan horn. It was observed that the plumb end was approximately at the center of the scan horn along the width and off by 10 mm along the length towards the stair case side.

(6) The leveling of top flange of drift tube was done using 3 nos. of arrestors provided in the bellow. It also retains the position of bellow by not allowing it to shrink on evacuation. Spirit level (20 µm/m) was used. Level achieve was A-side +40 micron and B-side +120 micron (Fig. 12).
(7) After leveling the drift tube, offset was checked using plumb line from the top of drift tube to the base of scan horn. The offset value was found to be 1 mm towards klystron side and 10 mm towards staircase side (Fig. 13).

(8) After leveling and aligned the lower section it was decided to make it rigid by their support (Fig. 14).

(9) Again, offset was checked using plumb line from the top of drift tube to the base of scan horn. The offset value was found to be 1.5 mm towards klystron side and 8 mm towards staircase side.

(10) A support for He-Ne laser instrument was made to use the laser for alignment purpose. The laser instrument was used to measure the offset at the end of scan horn flange by using calibrated graph paper stuck to scan horn flange end. The laser assembly was put on top of drift tube flange. The offset found by was 8 mm towards klystron side and 5 mm towards the staircase side. The difference in reading is because in the simple laser alignment instrument, the surface leveling may not be very accurate. This problem was later on sorted out by using 3-D self-aligned laser instrument.

(11) The linac along with the BD-II chamber was removed.

(12) The support for the BD-II chamber was connected and it was found that the BD chamber had to be shifted horizontally, for alignment. This support structure consists of two C-shaped frames. The concavity of the C-shape had to be increased to fit the BD chamber. Also, the holes for the bolts for holding the BD chamber support structure to the main support structure were elongated for maximum flexibility. 4 nos. of brackets with locking bolts was welded to BD chamber support structure (Fig. 15A & 15B). This gave the provision for positioning the BD-II chamber in horizontal plane.
(13) The linac along with the BD-II chamber is assembled again. After assembly, alignment was checked by plumb line from top of linac to scan horn end flange. The offset observed was 1 mm towards klystron side and 4 mm towards stair case side (Fig. 16). For achieving this, adjustments were made to locate the BD-II chamber. Scan horn angle was adjusted using the 4 M16 bolts, scan horn side was adjusted using the 6 M10 bolts.

(14) Temporary arrestors and packing material were put to hold the linac top flange in position. With this the plumb line thread was visually at the center of the beam-sensing aperture and offsets at the end of scan horn were 0.5 mm towards klystron side and 4 mm towards stair case side.

(15) The BD chamber was illuminated using a bulb. The plumb line was from top of linac to scan horn end flange. On observing from beneath the scan horn an offset of ~ 4 mm towards the klystron side was attained at the end of the linac. Using spirit levels at the top of linac showed that the side (towards klystron) had to be made up by 0.25 mm. The cavity straightness had to be assured.

(16) The cavity was removed and the centerline flange to flange offset was checked. Cavity was supported from bottom flange using 3 nos. of M8 bolt and the top flange was leveled to an accuracy of 30 micron in RF window side and 40 micron in perpendicular direction. A 3-D self-aligned laser (from SAMEER) was used for alignment. The self-aligned laser was put on the top flange center point and a calibrated graph paper was pasted to the center of bottom flange. Laser spot observed was almost at the center of graph paper. The cavity was assembled over the BD-II chamber. Four arrestors with locating screws were connected to locate the top flange of linac for alignment purpose. Offsets were measured using both the plumb and the self-aligned laser. Final offset measured using plumb line and self align laser was 1 mm towards klystron side and 3 mm towards stair case side (Fig. 17).
(17) The DN 100 bellow (Part A in pt.2) was reconnected along with retainers. The 1m long DN 63 hose was also connected.

(18) An acrylic blank flange was connected to the bottom of scan horn with rubber gasket as sealant. Graph paper was stuck below the acrylic sheet. On top of the linac top flange a lead glass window was connected with rubber gasket as sealant. The complete system was evacuated to 9.7 x 10^{-1} mbar.

The self-aligned laser was put on top of the linac exactly at its center. The laser spot at the bottom of the scan horn was observed for offsets. The spot was within 1 mm at the center of the scan horn along the width and off by \( \sim 3 \) mm along its length towards the staircase side. As we are scanning the electron beam along the length of the scan horn, an offset by 3 mm is acceptable.

The scan horn foil holder was connected and the electron gun was connected. Irradiation on glass plate showed that there is no offset along the width of the scan horn.

Thus the complete system was aligned within 1 mm at the center along the width of scan horn and within \( \sim 3 \) mm along its length.

(19) The new sketch of 10 MeV RF electron beam line as shown below (Fig. 18).
Conclusion:
1. Final offset measure was 1 mm towards klystron side and 3 mm towards stair case side.
2. Plumb line and self-aligned laser reading are almost coinciding. Therefore self aligned laser is more reliable then simple laser instrument.
3. In future adjustment provisions are there at different locations like scan horn, FCT, bellow, etc.

References:
[1] Proceedings of the Fourth International Workshop on Accelerator Alignment (IWAA95), Nov. 14-17,1995, KEK, Tsukuba.