# MECHANICAL DESIGN OF CERN NEW LINAC ACCELERATING STRUCTURE

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## Summary

This paper outlines the mechanical engineering design philosophy and gives a short description of major components, assembly methods and performance of the Alvarez structure for CERN's new 50-MeV proton linear accelerator now in operation as the injector for a complex of high energy machines. It replaced the old linac which could no longer satisfy the demands for a proton beam of higher peak current and better quality.

Some of the design details mentioned in this paper, such as drift tube demountable girders and the alignment method, were first tried on the 3-MeV experimental linac built at CERN.[1] Some production technologies, like copper clad steel, have been used on existing linacs. However, there are several new features incorporated in this Alvarez structure which are novel in the field of linac design.

## Basic Parameters

The accelerating structure of this linac (Fig. 1) is composed of three cavities with two intertank sections for beam diagnostics at 10 MeV and 30 MeV. All cavities are rf stabilized using post couplers. The full drift tubes are suspended on a single stem, the half drift tubes are incorporated in the tank covers. All drift-tubes, including the half drift tubes, house pulsed quadrupole magnets. The nominal frequency is 202.56 MHz, the peak current is 150 mA, the pulse duration is of 70-200 µs with a maximum repetition rate of 2 pps.

The following table[4] gives some basic parameters.

| | Tank 1 | Tank 2 | Tank 3 | |
|---|---|---|---|---|
| Input energy | 0.75 | 10.35 | 30.48 | MeV |
| Cavity ID | 0.94 | 0.90 | 0.86 | m |
| Cavity length | 6.939 | 12.958 | 13.359 | m |
| Intertank length | 0.15 | 0.20 | | m |
| Number of cells | 52 | 44 | 32 | |
| Number of posts | 25 | 21 | 31 | |
| Drift tube OD | 0.18 | 0.16 | 0.16 | m |
| Bore hole ID | 20.25 | 30 | 30 | mm |
| Stem OD | 28 | 40 | 40 | mm |
| Cavity rf power | 0.60 | 1.12 | 1.17 | MW |
| Rf power (150 mA) | 1.44 | 3.02 | 2.93 | MW |
| Total heat loss | 0.83 | 1.02 | 0.95 | kW |
| Drift tube loss | 0.59 | 0.64 | 0.59 | kW |

The average heat losses are given for a $0.6 \times 10^{-3}$ duty cycle, although the cooling capacity was designed for a maximum duty cycle of $2.2 \times 10^{-3}$.

For fine frequency tuning, there are ten piston tuners of 10-cm diameter. Five rf feed loops are used, one for the first tank and two for each of the following tanks. All loops are motor driven.

The tanks are also provided with a number of glass thimbles for monitoring loops and five observation windows opposite the feed loops.

The components are positioned around the circumference at different angles (Fig. 2) to avoid unwanted rf field couplings and to provide good accessibility.

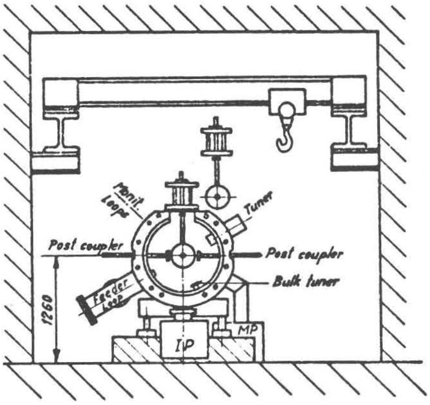

Fig. 2 Cross-section of tank in tunnel (schematic)

## Design Philosophy

With more severe demands on both the performance and the reliability of linear accelerators, it is of great importance that the design concept concerning mechanical hardware fulfills as closely as possible the specified needs. The main reason for this is that the criteria for high reliability, on the one hand, and high performance on the other, may easily be in conflict. In such a situation, it is a good design philosophy to follow the rule that the proven "sufficient" is better than the unspecified "best", for both technical and economical reasons. This rule was applied wherever it was possible in the design of all major components.

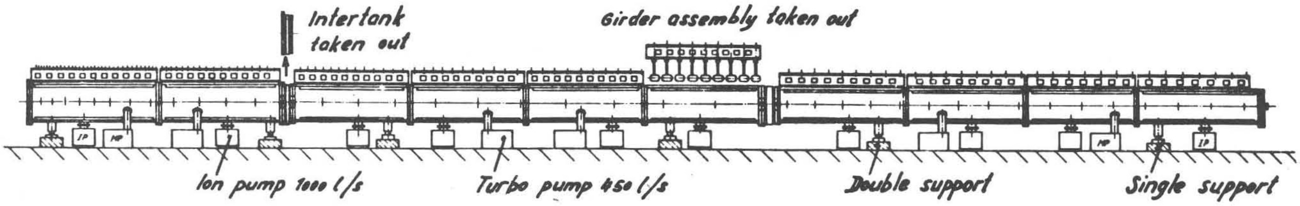

Fig. 1 Side view of the accelerating structure (simplified)

The tanks are made of copper-laminated steel, allowing relatively large tolerances for the inner diameter; the errors in frequency are to be corrected with bulk tuners. This production technique is safer and simpler than the copper plating technique, where the inner diameter has to be machined and polished after welding. The tanks are water cooled via tubes glued on the outside walls, which is quite sufficient for the small heat losses; welding channels for water-cooling on the tank walls would only cause more stresses and make the repair of leaks more difficult.

The drift tubes are of the sealed type with the quadrupoles open to air. This type has been successfully used on many linacs because the degassing rate in the critical region for sparking is relatively small. The low heat dissipation rate makes it possible to cool the drift tubes via the demountable water-cooled stem, thus excluding water leaks inside the tanks.

The vacuum seals made of aluminium wire provide, with few exceptions, the rf contacts. Compared with standard spring contacts, an aluminium vacuum joint, with correct inside flange geometry, makes a more reliable and better rf contact.

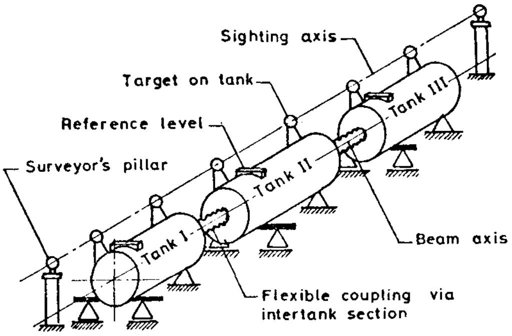

Fig. 3 Support and alignment system for structure

The support system for the tanks is shown in Fig. 3. The main reason this system was chosen is that a tank supported in a statically determinate manner, will not deform or receive additional stresses if the foundation moves. For this support system, flexible intertank sections are essential. These sections being axially compressible allow the tanks to be inserted (or removed for repair) independently into the structure.

For good operational reliability, it was assumed that an easy exchangeability of structural parts, and above all a possibility to measure and quickly correct the alignment of the drift tubes, is more important than trying to achieve long term geometrical stability. This concept resulted in :

a) The girder drift tube concept permitting the introduction of the drift tubes into the tank from the outside, contrary to the present practice on existing linacs, where the drift tubes are installed from the inside. The girder drift tube system offers a quicker, cleaner and safer (irradiation) alignment and maintenance procedure.

b) The drift tube suspension design (Fig. 5) allows the quadrupole positions to be measured directly on the drift tube body and/or on the stem at the top of the girder; it consequently allows the realignment of the drift tubes from the outside, without disturbing the vacuum in the cavities.

c) The external alignment system, which uses the girders to align the drift tubes to the tank and optical targets on the tanks (Fig. 3) to align them to a reference axis parallel to the proton beam. The reference (sighting) axis is defined by surveyor's pillars (monuments) mounted on the tunnel floor.

## Tanks and Girders

For production and handling reasons, a tank is divided into several sections of varying lengths. Each section carries a girder.

The tank's section is a cylinder rolled from a copper clad steel sheet(15 mm steel + 2 mm copper), with heavy flanges welded at both ends and several flat steel profiles welded all along the cylinder, providing flat surfaces both at the top and at the bottom of the tank. On top of the tank there is a long slot which is partially cut into the end flanges. The section is sufficiently rigid torsionally and in bending with the slot open. With the girders bolted and dowel-pinned over the slots, the tank will only deform negligibly due to atmospheric pressure load.

Aluminium wire seals are used throughout the structure. The wire is backed by spacers (sheets or plates). These spacers, and not the wire, determine the distance between the sealing surfaces.

The tank manufacturing procedure included heat treatment for stress relief after welding and prior to machining. The final operation was welding the copper inserts to the copper cladding in order to extend the copper surface to the wire seals. Smaller holes for post couplers, piston tuners, etc., were left unlined; the small amount of steel exposed to rf fields increases the losses only slightly. The copper surfaces were neither machined nor ground after welding.

The specified tolerances for the tank diameters were +0.5 mm/-0.0 mm, with roundness tolerances ±2.0 mm in any plane along the length, and ±0.5 mm in planes inside the flanges. The tolerances for perpendicularities were 0.25 mm, for surface flatness 0.1 mm. The surface roughness for copper is 5 μm ($R_a$). The copper was specified as oxygen free with 99.95% Cu and 0.03% P.

The tank sections are water-cooled via tubes glued on the outside cylinder wall. The gluing compound is an epoxy resin mixture filled with 200% aluminium powder and has a heat conductivity of $\sim$ 0.8 kcal/m-h-$^0$C.

The girder is a closed profile, made of mild steel, with a copper plate bonded to the bottom flange by epoxy resin. This plate completes the copper lining of the cavity. The girder has several functions: it closes the cavity, carries the drift tubes with their adjustment mechanism and acts as a straight edge for the alignment.

The machining tolerances were: straightness <0.2 mm, parallelisms between reference faces 0.1 mm, perpendicularities 0.1 mm, drift tube hole centers ± 0.1 mm, cumulative over the whole length ± 0.25 mm.

The inter-tank section (Fig. 4), comprises two tank covers and cavity with ports for beam diagnostic equipment. Figure 4 does not show the ring used to center and compress the inter-tank section prior to introduction between tanks. The possible movements are: radially ±3 mm, torsionally ±10 mrad, longitudinally ± 4 mm.

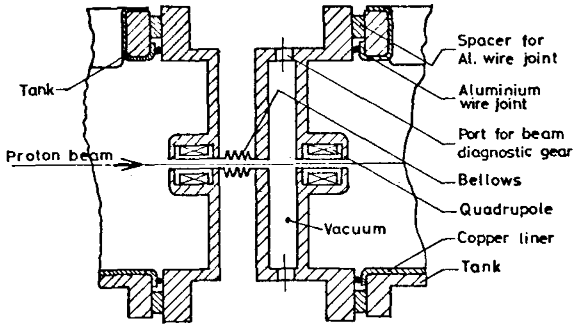

Fig. 4 Inter-tank section

### Tank assembly procedure

The first assembly of the tank sections and girders is to determine the thickness of the spacers needed to correctly deform the aluminum wire seals. The second assembly is to measure and possibly correct the alignment of the girders. This finished, and everything reassembled, the relative positions of the girders (empty) concerning alignment, spacing and tilt.

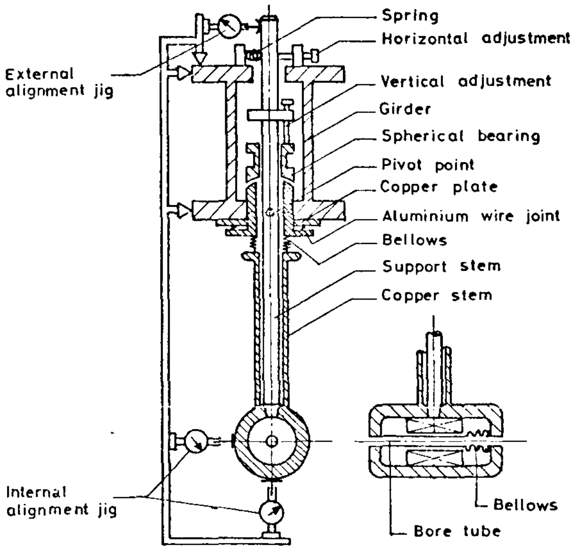

Fig. 5 Drift tube suspension (schematic)

The excessive errors for tilt and alignment are corrected by repositioning the tank sections. The alignment error of the girders on the first tank was negligible. For the two other tanks the errors were up to ± 0.2 mm and 0.25 mrad. These errors were taken into account when the drift tubes were aligned.

Some tank sections showed local indentations of up to 0.25 mm deep on the machined steel surfaces near the welds and unfortunately under the copper inserts in the region of the seal. This was probably caused by insufficient thermal treatment after welding. The problem was solved by placing shims underneath the copper liner. Some sections developed small air leaks (up to $10^{-4}$ Torr-l/s) on the copper liner welds, which were acceptable.

### Drift Tubes

The drift tube body with the stem and bore-tube is a vacuum tight structure, with the inside open to air (Fig. 5). The materials used are: forged oxygen free copper for the body, stainless steel for the bore-tube, standard grade copper for outer stem. The bellows on top of the stem is of special brass. The manufacture of the drift tubes included diamond machining of the copper body (outside surfaces), vacuum furnace brazing, electron beam welding and induction brazing in vacuum. There have been some problems with electron beam welding the stainless steel bore-tube to the copper body of drift tubes for Tank 1. The production errors were up to 0.20 mm on the length of the drift tubes.

Heat generated in the drift tube body is transferred by conduction to the support stem which is closely fitted into the drift tube body. With this cooling method, a typical drift tube in a $2.2\times10^{-3}$ duty cycle operation (about 40 W heat dissipation) would have an average body temperature of 4.3°C above the cooling water temperature, which results in a frequency change of $\sim$15 kHz.

With the suspension method schematically shown in Fig. 5, it is possible to make all movements needed for the positioning of drift tubes except the rotation around the stem axis, which is fixed once the vacuum seal between the drift tube stem and the girder is made. The precision achieved is 0.04 mm in horizontal plane (measured on the drift tube body) and ± 0.01 vertically. In case the drift tube is accidentally knocked, the support stem would jump out of the spherical bearing and automatically fall back in its original position with the precision given above; this protects the stem from damage during assembly. This suspension system has good damping characteristics against unwanted vibrations.

### Rf Feed Loop

As shown in Fig. 6, the loop is inside the tank exposed to vacuum. The **teflon rf** window is placed at a distance $\lambda/2$ from the short circuit end of the loop. The vacuum sealing is made directly on the teflon window by means of lip seals. A hydro-formed bronze bellows on one side and a sliding contact made of a silver plated helical spring on the other side of the loop, allow the displacement. The unit is cooled by heat conduction into the tank walls. No water cooling is provided.

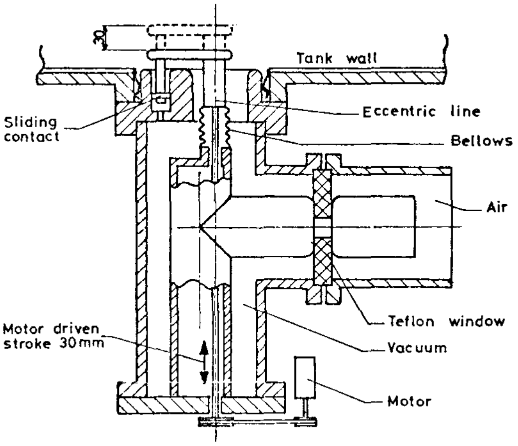

Fig. 6 Rf feed loop (schematic)

The massive 230 mm rf coaxial line is flexibly connected to the unit in order to minimize external forces on the tank.

## Water-Cooling System

The closed circuit cooling system for tanks and drift tubes uses ordinary water. This circuit is cooled via a heat exchanger by town water. The total flow rate in the closed circuit is 16 $m^3/h$ with 4.5 bar head loss for a maximum heat load of $\sim$10.3 kW. The nominal water temperature is $20^0$C, matching the air temperature in the linac tunnel. The water temperature is controlled to ± $0.25^0$C by a commercial thermostat unit.

## Vacuum System

The three cavities form a common vacuum system with a volume of 21 $m^3$ and 140 $m^2$ of copper surface. The system includes ten 1000 l/s triode ionization pumps; for roughing, six sets of 450 l/s turbo-molecular pumps backed by 30 $m^3/h$ rotary pumps. The final pressure in the system is $2x10^{-7}$ Torr. It is not significantly affected by the rf or proton beam. Dry nitrogen is used when the cavities are opened to atmospheric pressure. The pump-down time with conditioned tanks is $\sim$90 min to reach a pressure of $2x10^{-6}$ Torr. In a few hours the final pressure is established.

## Assembly and Alignment

Each tank was completely assembled, tuned, low energy rf tested, aligned and leak tested in the assembly hall near the linac tunnel. This finished, the tanks were split in the middle (except Tank 1) for transport to the tunnel. There the tanks were reassembled, placed on supports and aligned to the proton beam. Inserting the inter-tank sections was the final operation.

A simplified version of the assembly procedure in the hall is as follows :

a) The bare girders were fitted to the tank and aligned as already described. Straight edges, spirit levels and micrometers are used.

b) The girders were removed from the tank and placed on stands for the drift-tubes to be installed, correctly spaced and aligned to the reference faces on the girders. Special jigs were used for the alignment (Fig. 5) and micrometers for the drift tube spacings.

c) The complete girder assemblies were bolted on the tanks. Then the half drift tubes (on the end covers) were aligned to the drift tubes, and the covers keyed and bolted to the tank. For this alignment an outside caliper jig was used.

d) Finally the optical targets were installed at both ends of the tank. For this, the reference faces on the girders were used once again.

Note that the alignment of a tank has been carried out without optical instruments. The precision that can be achieved using this method is better than 0.1 mm between the drift tubes and about 0.2 mm over the whole length of the tank. This is valid both for the alignment and the spacing of the drift tubes. The final alignment of the structure in the tunnel, where optical methods must be used, reduces the overall alignment precision to ± 0.25 mm all errors included.

## Performance in Operation

The linac became operational at the beginning of September 1978. Since then, there have been no mechanical failures except for some trip-outs caused by the flow switches for the water cooling circuits. These were quickly repaired.

The rf conditioning of the cavities took about one day. Now the cavities can run 20% above nominal field levels without spark breakdowns.

The initial drift tube alignment was sufficiently accurate for a 150 mA beam. However, recent alignment checks show that movements have occurred between the tanks and building as well as between drift tubes and the tanks, none of which warrant realignment at the moment.

## References

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4) D.J. Warner, "Accelerating Structure of the CERN New 50-MeV Linac", CERN/PS/LIN 76-5, Chalk River Conference, Canada 1976.