

CSNS DTL PROTOTYPING AND RF TUNING

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Abstract

The 324MHz Alvarez-type Drift Tube Linac (DTL) for the China spallation neutron source will be used to accelerate the H^- ion beam of up to 15mA peak current from 3 to 80MeV. It consists of four independent tanks, of which the average length is about 8.6 m. Each tank is divided into three short unit tanks about 2.8 m in length for easy manufacture. A full-scale prototype of the first unit tank with 28 drift tubes containing electromagnetic quadrupoles has been constructed to validate the design and to demonstrate the technology. The overall features of the prototype in both key technology and RF tuning are presented. In particular, the influence of the post couplers was studied in the ramped field DTL.

INTRODUCTION

The China Spallation Neutron Source (CSNS) Linac mainly consists of an H^- ion source, a LEBT, a 3 MeV RFQ, a MEBT and an Alvarez-type Drift Tube Linac (DTL) as shown in Figure 1[1]. The DTL will accelerate H^- ion beam of up to 15mA peak current from 3 to 80 MeV in 4 accelerating cavities over a length of 35m. These four RF cavities operating at 324MHz and at 1.05 duty cycles are 560mm in diameter. Several new features have been incorporated in the basic design, leading to many technical difficulties, especially in the low energy section. A 2.8m long full-scale prototype thus has been built to validate the design principles. RF low-power measurements were performed to verify the electromagnetic properties of the cavity and to define the most appropriate tuning strategy.



Figure 1: CSNS Linac layout

RF STRUCTURE

The Prototype RF structure includes a single tank, 28 drift tubes accommodated with electromagnetic quadrupoles, end walls, slug tuners, and post couplers. See Figure 2 for a general layout of the prototype Model.

Tank Fabrication

The tank is a vacuum vessel that provides a RF envelope and a mechanically stable platform for the array of drift-tube assemblies, post couplers, and slug tuners. It is made of a carbon steel tube with copper plated in the inner surface to increase its electrical conductivity. It

contains 9 large ports for tuners, vacuum, and approximately 60 small ports for drift-tubes, post couplers and pickups. Tank inner surface and all ports were coated with Oxygen-Free Copper (OFC) applying successfully the Periodic Reverse (PR) copper electroforming technology.

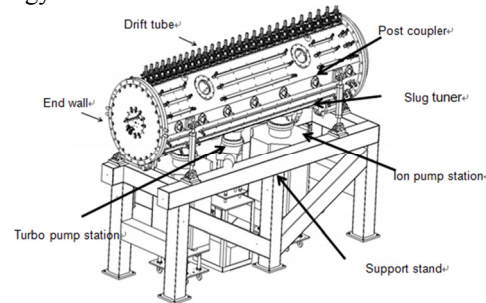


Figure 2: CSNS prototype DTL

Figure 3 shows the tank prototype module after electroforming. The inner copper surface has been polished and the ports have been finish machined for high accuracy and high flatness. The measured inner surface roughness is between 0.26 and 0.29 μ m. The average copper thickness is 0.2 mm (design 0.15 mm).

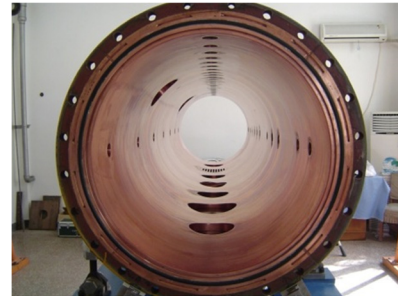


Figure 3: Internal view of DTL prototype

Drift tube

Each drift tube assembly is comprised of a body and stem, see Figure 4. One of the main features of the CSNS DTL is the use of OFC in all parts of DTs. Long-term deformation test has been done which convinced us of the material selection and design.

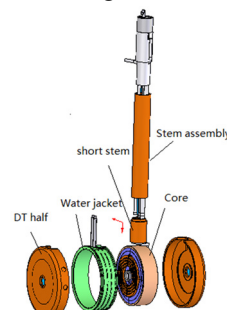


Figure 4: View of a typical Drift tube

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ISBN 978-3-95450-122-9

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The fabrication process is complex and time consuming accompanied with many kind of tests. All parts of the DT and the stem (34 mm in diameter) are fabricated by the electron beam welding (EBW) after the installation of the EMQ into the DT. The space around the magnet in the DT is filled with the epoxy resin by a vacuum impregnation method.

The magnetic field is measured several times by a rotating coil measurement system during the DT fabrication process [3]. Modifications have been introduced to make the rotating coil system more accuracy. Figure 5 shows the records which compare the deviations of the mechanical centre from the magnetic field centre before and after the measurement system upgrade. It can be found that most of the deviations (round one) fall into the tolerable area $\pm 30 \mu\text{m}$ after the measurement system upgrade compared with those (squares) before the upgrade. The average deviation decreases from 28.6 to $14.5 \mu\text{m}$, approximately 51%. Correspondingly the ratio of the dipole component and the quadrupole component becomes less than 0.05% at the magnetic centre compared with 0.3% before the upgrade. Higher-order multi-pole components are also sufficiently small at the field centre.

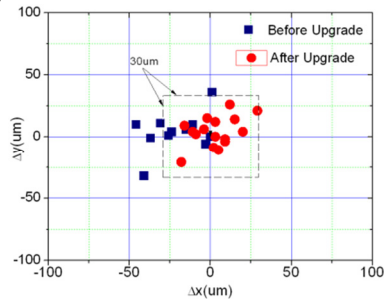


Figure 5: Deviation of the mechanical centre from magnetic field centre before and after upgrade.

Other Components

Some aluminium cold models needed in the low power tuning of prototype DTL cavity include post couplers and slug tuners, have been developed. The vacuum grill and tank end wall containing a half DTL also have been fabricated for test.



Figure 6: Aluminium cold models: post coupler (a), slug tuner (b), vacuum grill (c) and end wall (d).

ACCELERATING FIELD

The tuning of the DTL tank basically includes three items, namely resonant frequency tuning, field profile

tuning and stability tuning against perturbations. A bead perturbation method was chosen for field distribution measurement. Normally, it's required an aluminium bead, monofilament fishing line, a motor to step the bead through the cavity, and a network analyser to measure the phase changes due to bead. The space resolution was about 1mm per data point.

The general technique to tune the cavity is as follows [3]:

- Using the slug tuners, with the post couplers removed. Tune the cavity fields so that the fields follow the design field.
- After the fields are to within a few percent of the design field, insert the post couplers to establish the stabilization.
- Orient the post couplers to tune the fields and adjust the length of post couplers to maintain required tile sensitivity.

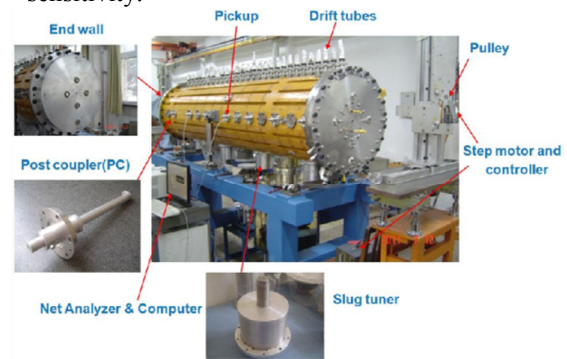


Figure 7: Tuning setup for DTL tank

Adjustment of the Tuners

The prototype DTL tank has 4 slug tuners for resonant frequency and field tuning. Firstly, the field with all the slug tuners penetrating into the cavity to an identical penetration depth has been measured, about 20% maximum deviations from the design value. The frequency sensitivity for each slug tuner has been obtained in advance. After adjustment of the slug tuners, the electric field distribution along the beam axis is within $\pm 2\%$ as shown in Figure 8.

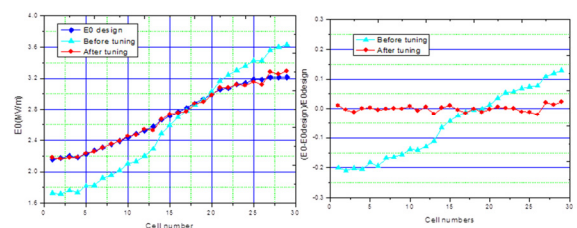


Figure 8: Slug tuner adjustment.

Adjustment of the Post-couplers

The post-couplers are used in DTL cavities to create a secondary coupled resonator system, which is then coupled with the main resonator system, formed by the accelerating cells resonating in the TM_{01} mode. The purpose of the PC is to stabilize the accelerating field in

case of local frequency errors. This can be done by tuning the dispersion curve of PC band and TM_{01} band such that the stop band between these two curves to be very small. The PCs are expected to have a negligible effect on the nominal accelerating field, and we start with all PCs inserted into the cavity as far as possible to get a lower enough frequency for PC mode. For the field stabilization of the TM_{010} , the mode with the highest resonant frequency in the PC band (PC1) should locate in the symmetric position in the frequency spectrum to the TM_{011} mode in most cases. However, in the prototype DTL design, the average accelerating field linear ramp from 2.2 to 3.1MV/m and then keeps constant. When the post-couplers inserted into the cavity, the field distribution and the resonant frequency change by quite a bit according to the measurement. The Q value of the accelerating mode as a function of the post-coupler insertion depth also has been investigated, see Figure 9. While the stop band between the dispersion curve of the PC mode and that of the TM-band was adjusted to be zero by means of gradually pull out all PCs, the Q value of the TM_{010} decreased by a factor of two at a PC-DT length of about 3cm. It has confirmed us that the conventional tuning method for flat field will not work in the ramping field structure. Unlike the flat field structure, the PC influence on the single cell differs significantly from the others in the ramping field cavity, especially in the low energy section, results in unsymmetrical locations between PC1 and TM_{011} . On the other hand, the loss in the aluminium material is bigger compared with that of copper, leading to a negative impact on Q value. Therefore, we modified the post-couplers shape and material in order to increase the cavity Q value and better understand the PC stabilization mechanism in the ramping field cavity.

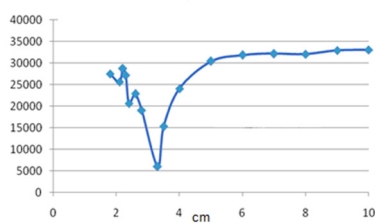


Figure 9: Unloaded Q value of TM_{010} versus PC-DT gap length

After adjusting the PC-DT gap to define the region where the Q value appeared to be insensitive to the PC penetration length, we get the tilt sensitivity directly by making two repetitive bead-pull measurements. The initial adjustment of the post-couplers has been done by keeping up the PC-DT length constant within the limited region. The axial field profile has been measured before and after frequency perturbation of the two end tuners. A considerable number of tests with finely adjusting the PC-DT gap have been undertaken to make the tilt sensitivity less than $\pm 100\%/MHz$, some individual PC adjustment results in a smooth TS curve. At this stage, the orientation angles of all the post-couplers keep constant. It is noticed that small TS fully compatible with the design value do

not guarantee that the fields are at the design value. Achieving the fields to be at the design value requires that the post couplers be rotated. Rotating the post coupler in a particular direction will reduce the fields in that particular direction. Since the fields are generally only locally perturbed by rotating the post coupler, the field tuning can be done step by step. Once the fields are flat from rotating the post couplers, the fields should be checked for tilt sensitivity. This tuning procedure is basically iteration process. Figure 10 shows the field profile after stabilization. The overall RF properties of the prototype DTL are listed in Table 1.

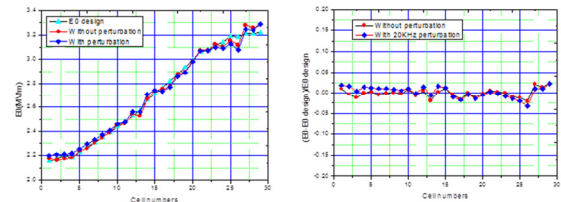


Figure 10: Field profile after post-couplers adjustment.

Table 1: RF properties of prototype tank

	Design	measurement
Resonant frequency	323.9@20°C	323.923@26°C
Unloaded Q	>80% calculation	81.9% calculation
Field flatness	$\leq 2\%$	-2%~1%
Tilt sensitivity	$\leq 100\%/MHz$	99%~68%/MHz

CONCLUSION

The prototypes of the tank and the DT containing 28 EMQs for 324 MHz DTL have been developed in IHEP for the CSNS project. The RF properties have been measured for this prototype DTL. The tuning scheme and the procedures for ramping field DTL tank are established and the prototype was successfully tuned to meet the tuning requirement. The CSNS DTL will be constructed based on the experienced gained in the manufacture, assemblies and test of this prototype cavity.

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