LOW POWER RF TUNING OF THE CSNS DTL*

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Abstract

The China Spallation Neutron Source (CSNS) is an accelerator-based neutron source being built at dongguan, Guangdong province in China. A conventional 324MHz Alvarez-type Drift tube linac (DTL) is utilized to accelerate an H- ion beam from 3 MeV to 80 MeV. The RF field tuning of DTL is necessary for compensating the unexpected error caused by manufacturing and assembling. For reasons of RF power saving it is convenient to build a long DTL tank, but this choice involves risks of accelerating field instability. This problem can be fixed by using the resonant coupling stabilization method and equipping DTL cavities with a series of post-couplers. A practical tuning method was proposed, an acceptable field distribution with a good stability was achieved for CSNS DTL-1.

INTRODUCTION

The CSNS accelerator complex utilized the Alvarez-type DTL as the main accelerator in the linac section. It consists of four independent tanks, of which the average length is 8.6m. Each tank is divided into three short unit sections for ease of fabrication and assembly. This study mainly focused on the first DTL tank since the structure is the most complicated one among all four tanks of the CSNS DTL. The DTL-1 has 63 full drift tubes and 2 half drift tubes to provide longitudinal acceleration, 31 post-couplers to stabilize the accelerating field, 12 fixed tuners and 2 movable tuners to adjust the resonant frequency. An iris type RF input coupler is equipped at the middle of the tank to drive the DTL cavity with a 2 MW peak power. The installation of the first DTL tank is completed on April 2015, with an accuracy of ±0.05 mm in both longitudinal and transverse direction. The Low power RF tuning was started right after the assembly.

To operate DTL effectively, basic parameters such as the resonant frequency, field flatness and tilt sensitivity need to be tuned. The tuning objectives are listed as follows [1]:

- Resonant frequency within 323.9 MHz ± 20 kHz in air.
- Field distribution within ±2% of design.
- Fields stable against frequency perturbations.

RF FIELD TUNING

The accelerating field profile can be measured by the bead-pull method based on the Slater's perturbation theorem. It is required to have a bead, monofilament wire, and a motor to step the bead through the cavity to measure E-field. Figure 1 shows the schematic diagram of bead-pull measuring system [2].

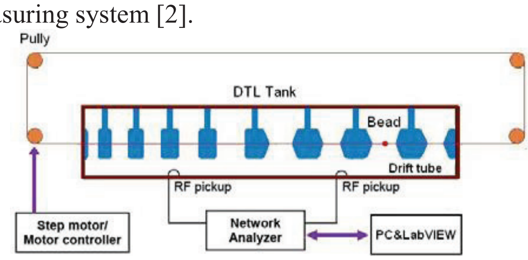

Figure1: The schematic diagram of bead-pull measuring system.

To ensure the accuracy and repeatability, the ambient temperature and humidity in the test hall should be strictly controlled; the wire should have enough tension in the line such that the sagging in the middle of the cavity is not more than a few percent of the size of the bead. Typically, the tension in the wire is 4-5 kg, and the corresponding sagging in the middle of the 9 m tank is less than 0.5 mm which is acceptable since the diameter of the bead is 7 mm. In principle, the field profile in the DTL tank can be obtained simply and accurately by using Eq. 1, but measuring the frequency shift for such a long cavity generally takes long time, and accordingly it may contain large errors due to the transient effects of environmental changes such as the ambient temperature change and humidity change. To reduce the errors caused by the transient effects, measuring time should be minimized. In our case, the frequency shift was obtained from the measured phase shift which can be performed very quickly. On the other hand, the phase shift is very sensitive to the testing environment, results in a 0.5 degree phase zero-shift during the 100 seconds measuring process. It brings a 3~5 percent errors especially in the low energy section of DTL-1 where the signal was relatively weak. To avoid any systematically errors, the initial phase adopted in the data processing at each cell is different and was in correspondence with the average phase while the bead was shielded in the drift tube, accordingly the phase zero-shift can be eliminated. Hollow aluminium sphere traverses the cavity at constant speed while a network analyzer under Lab View control records the resonant phase at regular intervals.

$$\frac{\Delta\omega}{\omega_0} = -\frac{3\Delta V\varepsilon_0}{4U}|E_0| \quad (1)$$

The initial field distribution of TM_{010} without tuners and post-couplers is shown in Fig. 2 (red curve). It can be easily found that the measured field profile has a large

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discrepancy with the design field for about ±80%. Both manufacturing and assembly errors are responsible for this large divergence between designed and measured results. During the RF tuning, all the 12 fixed tuners are replaced by the cold movable tuners with RF contactors. The resonant frequency shift is linearly proportional to the insertion depth of the slug tuner at the range of 10~80mm, which is perfectly agreed with the 3D simulation result. The initial field profile indicates that the frequency should be decreased in the Low energy end (LE) by extracting the slug tuners nearby, while in the high energy (HE) section, the frequency should be increased by inserting the slug tuners nearby. Usually, the tuning of frequency and field is an iteration process and may take several times to achieve the objective. The blue curve in Fig. 2 shows a ±2.5% field deviation after slug tuner tuning.

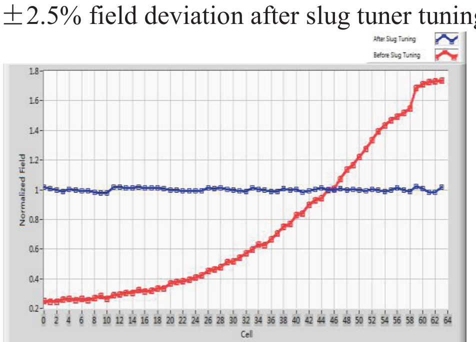

Figure2: The field distribution before and after tuner tuning.

STABILIZATION TUNING

Alvarez DTLs operate in the zero modes resulting in the same direction of the electric field in all accelerating gaps as shown in Fig. 3(a). Since the group velocity $v_g =$ ty $v_g = \partial\omega/\partial k_z$ of this mode, which is proportional to the slope of the dispersion curve, is zero, the electric field distribution is very sensitive to small frequency perturbations in the cells. For the π/2 mode on the other hand, the tangent on the dispersion curve becomes maximum, yielding a high group velocity and making this mode the most stable mode of operation for any cell-coupled accelerating structure. Since the π/2 mode would be very inefficient for acceleration, one tries to change the slope of dispersion curve at the location of the zero mode by introducing a 2^{nd} resonator band which is then coupled to the TM_{01} band. This can be done by inserting the post couplers in the horizontal plane placed in correspondences to the drift tube centres. The post couplers are then tuned such that the frequency stop band between the two dispersion curves becomes very small. Maximum stabilization is achieved at confluence for a vanishing stop band [3].

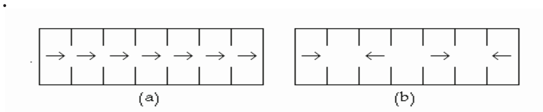

Figure 3: (a) Electrical field of the zero mode (b) electrical field of the 2/π mode.

In general, a critical parameter used to describe the stability of the RF cavity is tilt sensitivity factor, the definition is as Follows:

$$TS\left[\%/_{MHz}\right] = \frac{E_{perturbed} - E_{unperturbed}}{E_{unperturbed}} \frac{1}{\Delta f[MHz]} \times 100 \quad (2)$$

Bead-perturbation measurement without post couplers tuning shows tilt sensitivity of ~ ± 1300 %/MHz as shown in Fig. 4, which means the electric field would change 13% with 10 kHz frequency perturbation. Normally, the cavity should have to withstand several kHz frequency shift at operation, result in a required TS parameter of less than 100%/MHz.

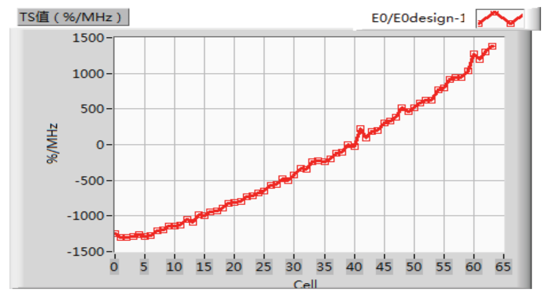

Figure 4: Initial TS distribution in each cell without post-coupler tuning.

Typically, from a dispersion curve point of view, the stability can be achieved by closing the stop band between post-coupler mode and TM_{01x} mode in the RF cavity as mentioned above. In the meanwhile, the highest PC mode and TM_{011} should be located symmetrically against TM_{010} with similar field profiles, so that the accelerating field perturbation induced by these two modes can be cancelled [4]. However, this method is approved to be unsuitable in the RF tuning of CSNS DTL prototype [2]. Given that a good symmetry has been obtained in the frequency spectrum, it turned out much difficult to increase the similarity of the PC_{01} and TM_{010} .A new tuning method was proposed aim at directly finding zero TS slope. The post-coupler insertion length was simply determined by viewing the TS slope curve during the tuning process. It is noticed that the resonant frequencies of the PC modes are increased with larger gaps between PCs and DTs. A positive TS slope indicates the PC-DT gap is not enough, while a negative TS means the gap should be decreased. At the beginning, all the post-couplers were fully inserted into the cavity to keep a uniform minimum PC-DT gap. This adds 100 kHz of the resonant frequency which has been taken into account during the tuner tuning process. Based on the above analysis, all the PCs were gradually extracted with identical insertion length, it turns out the low energy section was over-tuning with a negative TS slope while the high energy section still kept under-tuning. As the tuning of the post-couplers with uniform length did not succeed, the PC-DT gap length was divided into five groups and varied along the beam axis according to the TS slope distribution. The adjusted PC-DT gap is summarized in Fig. 5 and the TS factor after PC tuning improved to ± 70%/MHz which is 20 times better than before, and the TS slope was approached to zero. In that case, the frequency spectrum is also measured as shown in Fig. 6. The frequency interval between PC_{01} and TM_{010} is slightly smaller than the interval between TM_{011} and TM_{010}. After the stabilization tuning, the field was slightly changed, and fine tuning by using PC tips was performed to optimize the field distribution. Eventually, the field deviation was less than ±2% as the resonant frequency was 323.901 MHz.

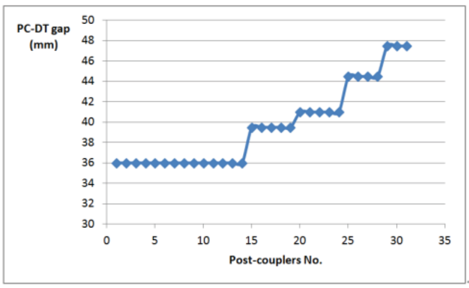

Figure 5: Final PC-DT gap of DTL1.

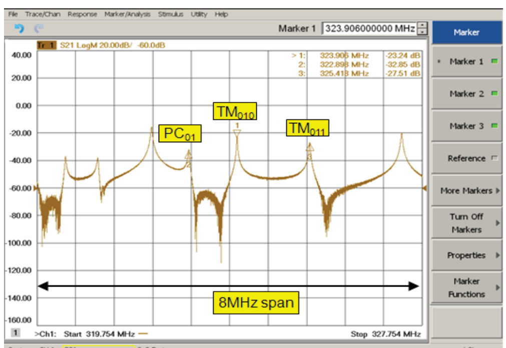

Figure 6: Frequency spectrum.

In order to check the current stability of the RF cavity, two movable tuners were used to provide frequency perturbation. Each movable tuner can cause a 60 kHz maximum frequency shift, then the accelerating field profile was measured with different movable tuner insertion length, Fig. 7 shows an acceptable field change under this circumstance. It is safe to say that the DTL-1 is now very stable against perturbation with proper PC-DT gaps.

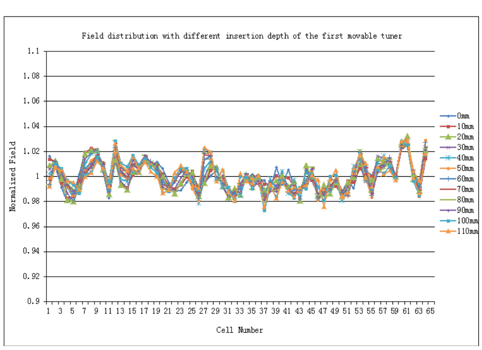

Figure 7: field profile with different insertion length of the 1st movable tuner.

CONCLUSION

The Low power RF tuning of the CSNS DTL1 has been successfully accomplished. The tuning objective was achieved, with a ±2% field distribution to the design, less than ±5kHz of design frequency. A practical stabilization tuning method was proposed and was demonstrated by the measurement. The cavity shows a good stability even under relatively large frequency perturbation which would guarantee a stable performance at operation.

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REFERENCE

[1] C. Deibele et al., "Low Power RF Tuning of the Spallation Neutron Source Warm Linac Structures," in *Proc. Of Linac 2004,* 2004, pp.760-762.

[2] X.J Yin, et.al. "Preliminary Study on the RF tuning of CSNS DTL," *Chinese Physics C*, vol. 38(2), p. 27002-027002, 2014.

[3] N. Alharbi, F. Gerigk, M. Vretenar, "Field Stabilization with Post Couplers for DTL Tank1 of Linac4," CERN, Geneva, Switzerland, CARE-Note-2006-012-HIPPI, 2012.

[4] Francesco Grespan, "Study of DTL Stabilization with Post Couplers for the SPES Driver Linac," Ph.D. thesis, faculty of mathematics, physical and natural phd in physics, astrophysics and applied physics, University of Milan, Italy, 2009.

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