

# MEASUREMENT AND TUNING OF THE RF FIELD FOR THE CSNS DTL\*

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## Abstract

The CSNS DTL accelerates negative hydrogen ions from 3 MeV to 80 MeV with resonant frequency of 324 MHz and peak current of 15 mA. The CSNS includes four DTL cavities with diameter of 56.6 cm and each length of 9 meters. RF properties research and measurement have been done to make sure the design and manufacture validate for beam operation. A new automatic system has been developed for measuring field distribution. The secondary derivation method is used to calculate the amount of the tuners to tune axial field flatness. The tilt of TS curve is used to judge the gap between the post couplers and drift tubes to achieve stability. At last the tanks have good flatness and strong stabilization, the field deviation is 2% with the standard deviation of 0.96%, and the maximum TS parameter is 65% /MHz. After the low power RF tuning experiment, the four tanks have been installed in the tunnel, and have gotten good results of high power test and beam acceleration experiment.

## INTRODUCTION

The CSNS consists of an 80 MeV linac, a 1.6 GeV rapid cycle synchrotron and a target station. An Alvarez-type DTL has been employed to accelerate the ion beam from 3 MeV to 80 MeV, with 15 mA peak beam current, in 324 MHz resonant frequency [1]. It consists of four independent tanks, of which comprised of 3 short unit tanks (3m in length), with the diameter of 56.6 cm. Because of the errors in design, machining and assembly of the cells structures that make the field distribution is not the same as the design one, the RF tuning includes resonant frequency, axial field flatness and stabilization. A bead pull system has been used to calculate the average electrical field distribution. In the tuning process, 12 fixed tuners are used to adjust the resonant frequency and field flatness, and that the post couplers are applied to tune the field stability. The tuning target includes 2% field deviation and 100% /MHz tilt sensitivity parameter [2]. The

low power RF tuning is very important for the manufacture and research of the DTL, especially the stabilization part. The four tanks have been tuned successfully.

## AUTOMOTIVE MEASUREMENT PLATFORM

The Slater's perturbation theorem has always been used to measure the longitudinal electric field distribution of a DTL. If a small bead has been inserted into the cavity, the perturbation at any bead position causes a frequency shift that is proportional to the square of the local field. The field distribution can be calculated through the phase shift in the low power RF measurement. The newly designed measurement system is shown in Fig. 1.



Figure 1 : RF measuring platform of the CSNS DTL.

While the motor drives the bead moving, the phase shift perturbed by the bead can be synchronously measured through the vector network analyzer. Through data transmission and processing, the final results are displayed in the program interface which has been developed by us in LabVIEW platform. The whole measurement and data processing can be done within one minute that can reduce the measurement time and the measurement is more efficient. The most important thing is the measurement accuracy, which is affected by many factors, such as the uniform speed of bead's movement, the number of acquired points, the measurement time, stable environment, data processing and so on. After all the efforts have

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been done, the measurement accuracy of the system is 0.3%. Figure 2 shows the initial phase shift when the bead moves along the cavity's axis before tuning. There are about 32000 marker points at a step of 0.3 mm in the first tank. All the measurement work has been done automatically by the program mentioned before, which can save work time and avoid the manual operation mistake.

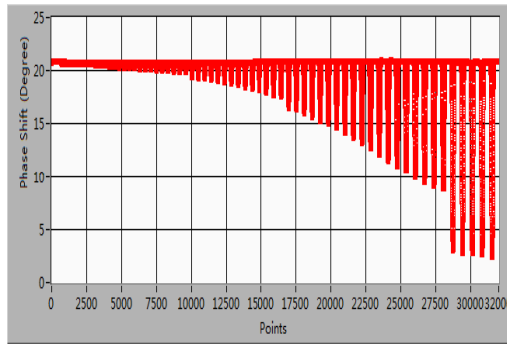


Figure 2: The raw data of the phase shift along the beam axis before tuning (TM010 mode, with the same length tuners and no post couplers).

### ADJUSTMENT OF THE TUNERS

The DTL tank has 12 fixed tuners with diameter of 150 mm and 2 movable ones with diameter of 90 mm. The fixed tuners are uniformly distributed along the tank and the movable ones are in the third of the cavity respectively. During tuning, the fixed tuners are replaced by the aluminum movable models, the length of the fixed tuners has been adjusted to attain the required frequency as well as the uniform axial electric field distribution. In the low power tuning, the movable tuners keep the same insertion depth of 50mm, they are used to tune the cavity's frequency in high power operation. The equation of Normalized field is the measured field  $E_z$  to the design one  $E_{0design}$  as shown below:

$$Normalized\ field = \frac{E_z}{E_{0design}} \quad (1)$$

Because the first tank has maximum drift tubes (63 drift tubes), each with different size, it is difficult for producing and aligning. For design, machining and assembly error, the initial maximum deviation is -75%~70% without post couplers, which is bigger than the other tanks of CSNS DTL. A special program according to the second derivation algorithm has been written for the field flatness tuning and it worked well. Besides, we should ensure some tuners not inserted too deep to affect the stabiliza-

tion because of the coupling of slug tuners with drift tubes and post couplers [3]. Finally, comparing with the initial one, the field flatness has been rough tuned less than 2.5% at first step (see Fig. 3, the blue curve shows the initial field, the red one shows the normalized field after rough tuning with tuners).

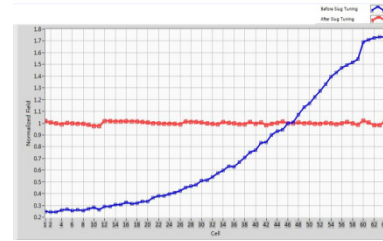


Figure 3: Initial field distribution and the field after tuners' rough tuning.

### ADJUSTMENT OF THE POST COUPLERS

After the field's flatness requirement is satisfied, every post coupler has been installed for each two drift tubes, starting at the second DT in DTL-1. They mount on the wall and point at the center of the DT, with a gap between them. The stability field should satisfy three demands [4]:(1) PC1 and TM011's frequency spacing is symmetrical or nearly symmetrical between the TM010, (2) PC1 has the similar field profile to the TM011, (3) Tilt Stability is less than 100% /MHz. The Tilt Sensitivity (TS) value is the most important parameter in tuning process, to test cavity's stability parameter by the equation (2). Making 20 kHz perturbation to the cavity at high energy end and -20 kHz at low energy end with the head and end tuners, fine adjusting post couplers by group to make sure the perturbed field the same with the unperturbed one. At the same time, paying attention to the highest PC mode and TM011 frequency, making them nearly symmetry to TM010 mode.

$$TS_i = \frac{|E_p|_i - |E_u|_i}{|E_u|_i} \times \frac{1}{\partial f_i} \times 100\% \quad (2)$$

Where  $|E_u|_i$  and  $|E_p|_i$  are measured field distribution before and after tuners' perturbation,  $\partial f$  is amount of frequency perturbation. Usually, extracting or inserting the post coupler length according to  $|E_u|_i$  and  $|E_p|_i$ , it's the first time to propose the tilt of TS curve for the PCs' grouping and adjusting. Negative value of TS' tilt means

this structure is under coupling, these post couplers should be pull out more, as well, the positive means over coupling and should be inserted more, zero value means these post couplers can stay the same. For DTL-1, the initial tilt sensitivity of the cavity without post couplers is  $\pm 1370\%$  /MHz, and reduces to  $\pm 65\%$  /MHz when the post couplers 36~47 mm away from drift tubes, as shown in Fig. 4. This result equal that the electrical field changes less than 0.65% with maximum 10 kHz local frequency perturbation, caused by the local temperature perturbation and the beam loading during beam operation. The case with uniform PC length has not achieved the basic requirement of the cavity's stability in operation. So we divided them into about 5 groups to get the good result, the length of each PC shows in Fig. 5.

For the field stabilization, the frequency of the PC1 is 322.71 MHz, the TM011 is 325.265 MHz. As shown in Fig. 6, they are nearly symmetrically distributed on both sides of the TM010, which is 323.894 MHz. Dispersion relation at the stabilization is shown in Fig. 7. The system composed by the TM and PC bands, they joined together for coupling resonance, to get a bigger group velocity of the accelerating mode [5]. The group velocity defined as a derivative of the measured dispersion curve. The mode separation between TM010 and TM011 increased from 0.4 MHz to 1.37 MHz at the stabilization compared with all the PCs inserted in the cavity.

This dispersion curve is another judgment of the stabilization. As well, both modes have the same field distribution on the axis. As a result, it has been confirmed by the measurement that the field has good ability against perturbation.

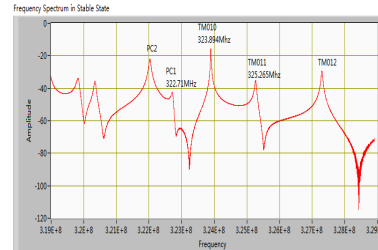


Figure 6: Measured resonant modes mode at the stabilization.

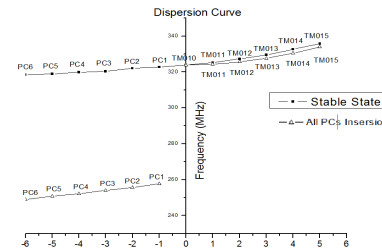


Figure 7: Measured dispersion relation at the stabilization and all PCs inserted.

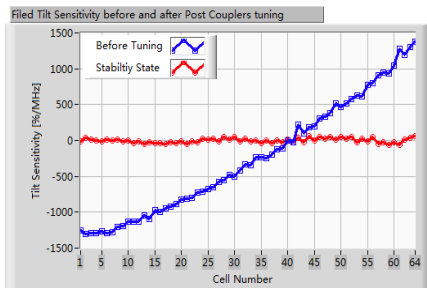


Figure 4: Tilt Sensitivity of the Stabilization comparing with initial state.

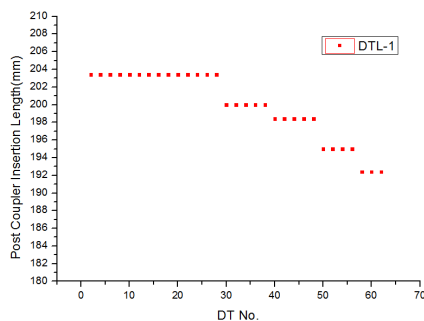


Figure 5: Insertion length of all post couplers for DTL-1

The field's deviation is about 8% with the post couplers in the stability position. To achieve the design one, a stub is attached at the end of each post coupler and should be rotated. When the stub rotates in a particular direction, it will increase or decrease the frequency, thereby changing the field. The final flatness tuning result is shown in Fig. 8, that the deviation is less 2% to the design value.

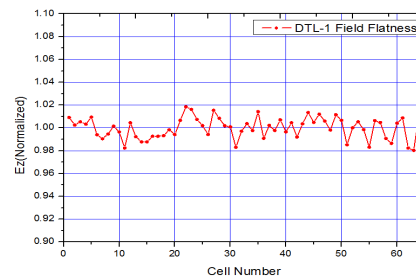


Figure 8: The final accelerating field for each cell for DTL-1.

After the low power tuning experiment has been finished, the tanks were installed in the tunnel as shown in

Fig. 9. Following high-power RF conditioning has been carried out successfully, and the beam operation is under measurement and tuning.



Figure 9: Four tanks of CSNS DTL installed in tunnel.

## CONCLUSION

These four tanks' RF properties research and measurement of CSNS DTL has been successfully finished. A new automotive field-measuring apparatus and data processing program based on the Slater's perturbation theorem were set up, getting more accuracy comparing the platform of preliminary tank of CSNS. The main tuning procedure includes frequency, field flatness and stability tuning. At last the tank has good flatness and strong stabilization, the field deviation is 2% with the standard deviation of 0.96%, the maximum TS parameter is 65% /MHz. has been carried out successfully, and the beam operation is under measurement and tuning.

## REFERENCES

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