RF TUNING OF A S-BAND HYBRID BUNCHER FOR INJECTOR UPGRADE OF LINAC II AT DESY

Y.C. Nie#, C. Liebig, M. Hüning, M. Schmitz, DESY, Hamburg, Germany

Abstract

LINACII at DESY currently provides 450 MeV electrons for the synchrotron radiation source PETRAIII. The injector upgrade of it aims to improve its reliability and mitigate the radiological activation due to electron losses at hundreds of MeV. Therefore, a 2.998 GHz hybrid buncher has been developed and will be installed in between a pre-buncher and LINAC II. It comprises a 1-cell standing-wave (SW) section for rapid acceleration and a 13-cells travelling-wave (TW) section for further bunching and acceleration. This paper focuses on its RF tuning procedure. The tuning strategy combines a non-resonant bead-pull measurement of complex electric field and a linear model for local reflection coefficient calculation. The tuning result is satisfying. Field unflatness of the TW section has been improved from ±9% to ±4%, and field in the SW section has been enhanced significantly. By using ASTRA simulation, it has been verified that the residual detuning of the structure is acceptable in view of beam dynamics performance.

INTRODUCTION

LINAC II at DESY accelerates electron bunches to 450 MeV before they are injected into PIA and DESY II. DESY II provides 6.0 GeV beam for the third generation radiation source PETRA III [1]. Moreover, LINAC II has promising potential to provide 800 MeV electron bunches for the Helmholtz distributed ARD facility SINBAD [2]. A new injector of LINAC II has been constructed and is being tested in parallel to the old injector. In the new injector, the old DC diode gun was replaced by a triode gun, and a hybrid buncher was inserted after the pre-buncher to mitigate the radiological activation problem due to electron loss at hundreds of MeV. The detailed upgrade plan can be found in [1]. The performance of the new injector has been verified by using ASTRA simulations [3, 4].

In this paper, we focus on the RF tuning of the 2.998 GHz hybrid buncher, one of the most critical components in the new injector. A hybrid structure combines the advantages of both SW regime and TW regime. The detailed RF design of the hybrid buncher was reported in [1]. The structure and the simulated electric field using CST Microwave Studio [5] of the hybrid buncher are shown in Fig. 1. Each cell can be tuned by the deformation of the cylindrical holes in the outer wall, the so called tuners. All the tuning holes can only be pressed inwards the cavity gently by hammering a copper rod with a spherical head, and the deformations can hardly be recovered. It means that we can only increase the structure's frequency during tuning. So the buncher was manufactured at a frequency several MHz lower than the operating frequency of 2.998 GHz.

#yuancun.nie@desy.de

The most used tuning strategy was derived from a non-resonant perturbation theory of C. Steele [6] and a linear model of T. Khabiboulline et al [7]. They were used for the overall bead-pull measurement of the complex electric field, and the derivation of each cell's (local) reflection coefficient, respectively. Such a method has been complemented during its applications to the tuning of the 12 GHz X-band TW accelerator of CLIC at CERN [8], and the 5.712 GHz C-band prototype for SPARC photo-injector upgrade [9], etc. We used the similar method, while paying special attention to enhancing the field in the SW cell to ensure its beam capturing capability.

TUNING PRINCIPLE

According to the non-resonant perturbation theory, the relationship between the reflection coefficient and the electric field can be expressed by the following equation at a given frequency $\omega=2\pi f$:

$$2P_i \Delta S_{11} = 2P_i (S_{11p}-S_{11a}) = -j\omega k E_a^{\,2}\,, \tag{1}$$

where P_i is the input power, S_{11p} is the reflection coefficient in the presence of a perturbing object, S_{11a} is the value in the absence of it, k is a constant depending on the electric property and the geometry of the perturbing object, and E_a is the electric field at the perturbed position. It means that the field amplitude is proportional to the square root of the amplitude of ΔS_{11}, and its phase is half to the phase of ΔS_{11}.

Required tuning for each TW cell can be represented in terms of local reflection coefficient, which can be derived via T. Khabiboulline's linear model. In the center of a cell, the field can be considered as a superposition of forward and backward waves, provided that the cavity is lossless. For a regular TW n-th cell, its local reflection S_{11}^n can be calculated approximately by:

$$S_{11}^n = \frac{B_n - B_{n+1}e^{-j\varphi_n}}{A_n}\,, \tag{2}$$

where A_n is the forward wave in the n-th cell, B_n and B_{n+1} are the backward waves in the n-th and (n+1)-th cells, respectively, and φ_n is the phase advance between (n+1)-th and n-th cells. They can be calculated from the measured complex field. Normally φ_n is close to the nominal phase advance $\varphi_0 = 2\pi/3$. For better distinguish, the local reflection coefficient calculated using φ_0 is denoted by $S_{11}^{n(0)}$. In principle, if the imaginary part of S_{11}^n

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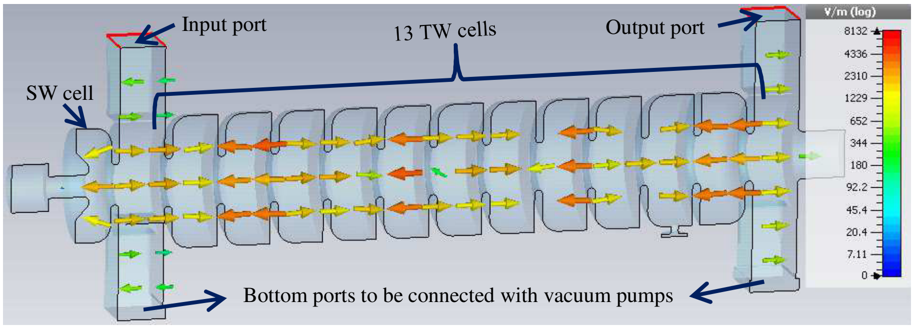

Figure 1: Structure of the hybrid buncher with the SW cell coupled in π mode and the following 13 TW cells in $2\pi/3$ mode. The simulated electric field mode is shown as well. There is a 180° phase jump between the two sections.

is negative, i.e. Imag.S_{11}^{n}<0, it means the frequency of the n-th cell is lower than the integral frequency and correspondingly it has lower field than average. Therefore, its tuners should be pressed inwards to decrease the cell's volume and thus increase its frequency. The cell's field will be thus enhanced and the field unflatness will be reduced. During this process, the integral frequency of the structure is upshifted. For the output coupler, its reflection can be reduced by tuning of the coupler cell itself and its adjacent cell. Usually, the input coupler is tuned at the end, for the purpose of minimizing the global reflection.

Tuning of a structure aims to make its frequency be exactly the working frequency, and at the same time its field as flat as possible. Take into account the differences in structure temperature T_{str}, air-temperature T_{air}, air-pressure P_{air}, and air-humidity H_{air} between laboratory and operating conditions, the tuning target frequency can be calculated by certain empirical formulas. Under a typical condition where T_{air} = 23.0 °C, P_{air} = 1016.9 mbar, H_{air} = 39.6%, T_{str} = 40.4 °C, the target frequency is 2997.1 MHz.

For our hybrid buncher structure, wall deformation of the SW cell or a TW cell will influence the overall field distribution pattern, due to their interaction. With respect to that the SW cell should have sufficiently strong field to capture incoming electrons, it should be tuned with higher priority. A compromise needs to be considered between the field strength of the SW cell and the remaining frequency margin for the following TW cells' tuning. The tuning procedure is concluded as follows:

1. Establish all the positions of shortcut plates and stub tuners for minimum reflection from bottom waveguide ports and output port;
2. Tune the SW cell to enhance its field strength in comparison to the TW section;
3. Tune the regular TW cells from output side to input side;
4. Tune the output coupler and input coupler to make field flat and reflection small;
5. Check and assure the increment in frequency during steps 2-4 is around 500 kHz;
6. Repeat steps 2-5 until the structure's frequency reaches the target frequency where the global reflection is small and the field flatness is satisfying.

TUNING RESULTS AND ANALYSIS

Figure 2 shows the experimental setup of the tuning. The perturbing object used was a cylindrical needle, with a diameter of 1 mm and length of 4 mm, fixed on a nylon string. Geometrical sizes of the perturbing object and string were chosen for the best signal to noise ratio.

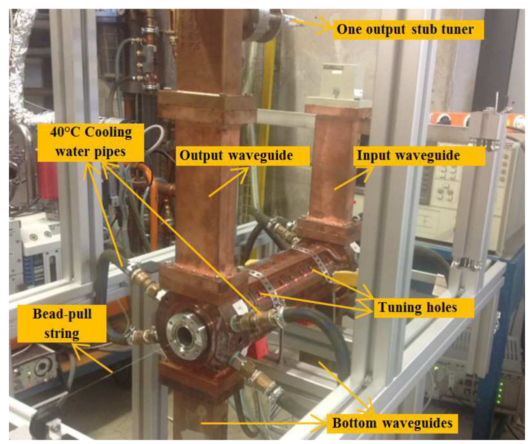

Figure 2: Tuning experiment.

Figures 3 and 4 are the measurement results for the target frequency 2997.1 MHz before and after tuning, respectively. From Fig. 3(a) it can be seen that the field unflatness is about ±9% for the TW section and the field of the SW cell is 35% lower than the mean value of the TW cells. It also shows that Imag.S_{11}^{n} varies on the same trend as the field, which gives us direct idea about which cell should be tuned and in which direction. The differences between Imag.S_{11}^{n} and Imag.$S_{11}^{n(0)}$ are obvious, since the phase advances between adjacent cells are not exactly 120°. Almost all the Imag.$S_{11}^{n(0)}$ locate under 0, indicating that the structure should be tuned by increasing its frequency. Figure 4 (a) shows that the field flatness has been improved from ±9% to ±4% for TW cells and the field of the SW cell becomes 20% lower than the mean value of TW cells. |Imag. S_{11}^{n} | has been reduced apparently, and the differences between Imag. S_{11}^{n} and

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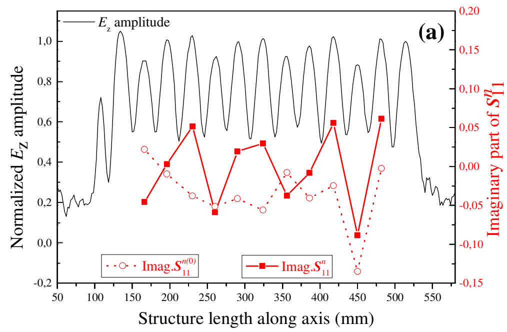
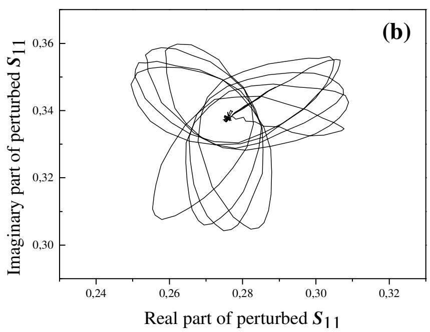
Imag.$S_{11}^{n(0)}$ are no longer as much as before, since the deviation of the phase advances has been improved from the range ±5° to ±2°. As for the phase diagrams of the perturbed global S_{11}, the segments in Fig. 4 (b) are much better overlapped than those in Fig. 3 (b). Meanwhile, the global S_{11} was improved from -17 dB to -38 dB.

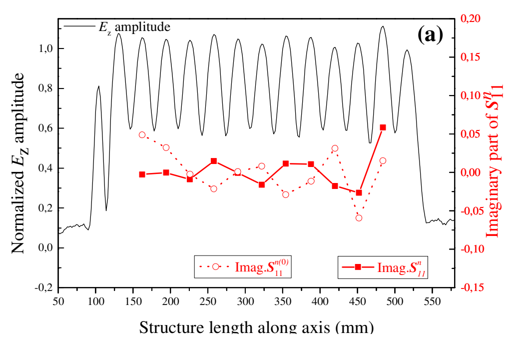


(a) Field amplitude and imaginary part of S_{11}^n

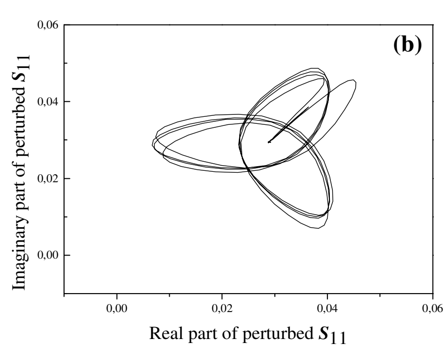


(b) Perturbed S_{11} in phase diagram

Figure 3: Measured results before tuning at 2997.1 MHz.



(a) Field amplitude and imaginary part of S_{11}^n



(b) Perturbed S_{11} in phase diagram

Figure 4: Measured results after tuning at 2997.1 MHz.

The residual detuning is acceptable, which has been verified by ASTRA simulation in view of beam dynamics performance. Table 1 lists the comparisons of the rms bunch length σ_z, mean momentum P_z, bunch charge Q and momentum spread $\Delta P/P$ at the buncher exit between the ideal (flat) field case and the tuned (unflat) field case. The unflat field degrades the output bunch length and energy spread by about 7%, whereas the momentum and charge are only slightly influenced.

Table 1: Beam Dynamics Comparisons

	σ_z	P_z	Q	$\Delta P/P$
Ideal field	2.35 mm	5.3 MeV/c	1.63 nC	2.8%
Tuned field	2.52 mm	5.4 MeV/c	1.61 nC	3.0%

SUMMARY

We have presented the tuning procedure of the S-band 2.998 GHz hybrid buncher developed for the new injection system of DESY LINAC II. The field in the SW cell is very sensitive to the size of the coupling iris, which leads to the different field strengths between the two sections. The residual detuning of the structure is still visible but tolerable, which has been verified by ASTRA simulation in the viewpoint of beam dynamics performance. An even better field distribution would depend on: a) higher machining precise, and b) more sophisticated tuners. However, both of the two ways need more cost, therefore a trade-off should be considered.

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