A NEW TUNING METHOD FOR TRAVELING WAVE STRUCTURES

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At DESY S-Band accelerating structures are under development since 1993. Fourteen 5.2 meter long sections have to be replaced in the injector linac (LINAC II)[1] and overall four 6 meter long sections have to be build for the S-Band test facility at DESY[2]. A new tuning procedure for the accelerating structure after brazing has been developed which uses bead-pull field distribution measurements instead of a detuning plunger. Amplitude and phase of the field are measured simultaneously along the structure without touching the surface on a 13 meter long horizontal bench.

I. INTRODUCTION

To decrease the cost for cavity production the dimensional tolerances are relaxed by oversizing the resonators and tuning after brazing. The resonance frequencies of the cells after brazing of the section are lower by 200-1500 kHz compared to the operating frequency. Four tuning holes are machined with 10mm diameter and 1mm thickness in the wall of each cup (fig. 1.1).

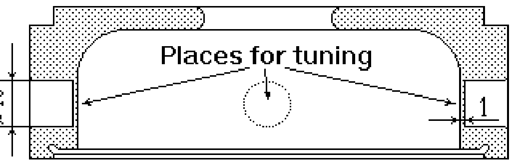

Figure 1.1. One of the cups.

For the measurement of the traveling wave field distribution (amplitudes and phases in the center of the cells) a bead-pull method is used in the section. The tuning method is based on the calculation of the field distribution of the scattered wave from each cell of the structure. During the tuning procedure the amplitudes of the scattered waves are minimized.

II. BEAD-PULL FIELD DISTRIBUTION MEASUREMENTS

The traveling wave field distribution measurement is based on a non-resonant perturbation theory [3]. In this technique the measurements of the reflection coefficient **S11** are measured at the same frequency with and without a perturbing object placed at the point at which the field parameters have to be determined. On the axes of the section the magnetic component of the field is zero and the dependence of the reflection coefficient from the electric component of the field is expressed by the following formula:

$$2\mathbf{P}_i\,(\mathbf{S11}_p-\mathbf{S11}_a)=-j\omega k\mathbf{E}_a^2 \qquad 2.1$$

with $\mathbf{P}_i$ - the input power, $\mathbf{S11}_p$ - the reflection coefficient in the presence of a perturbing object, $\mathbf{S11}_a$ - the reflection coefficient in the absence of the perturbing object, k depends on the electric parameters and the geometry of the object and $\mathbf{E}_a=A\mathbf{e}^{j\varphi}$ - the electric component of the field. The perturbing object being used was a metallic needle with a diameter 0.4mm and a length 5mm (fig. 2.1), oriented parallel to the axis of the section. The needle can be moved along the axis of the section using a step motor with a step size about $\Delta\mathbf{L}$=0.14 mm.

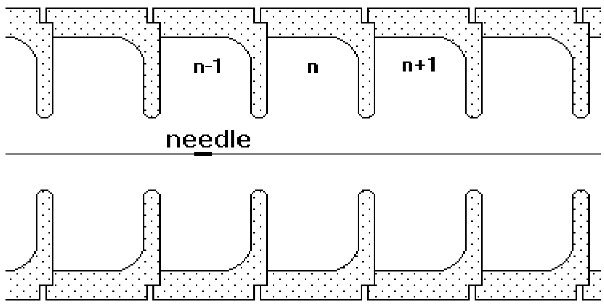

Figure 2.1. Bead-pull measurement.

In the centers of the cells the longitudinal gradient of the phase is smallest with $|\Delta\varphi/\Delta z|$<0.9°/mm. The transverse gradients, for deviations not larger than $|\Delta x|$ < 2 mm and $|\Delta y|$ < 2 mm from the axis of the section, are of the order of $|\Delta\varphi/\Delta x|$<0.03°/mm and $|\Delta\varphi/\Delta y|$< 0.03°/mm for the phase, $|(\Delta A/A)/\Delta x|$<0.05%/mm and $|(\Delta A/A)/\Delta y|$<0.05%/mm for amplitude**.**

To decrease the required time for one measurement of the 150-180 cell section the field distribution is measured only in the center of the cells. For precise determination of the position $\mathbf{Z}_1$ of the first cell center and distance $\Delta\mathbf{Z}$ between the centers the complete field profile is measured in the 3 first and 3 last cells of the section (with the exception of coupler and load cells). After data processing the accuracy for positioning in the first cell center is approximately 0.1 mm and for cell to cell length ≈0.002 mm for the 5 m section. The minimal step $\Delta\mathbf{L}$ given by the step motor for bead positioning is not small enough (≈0.14mm) and therefore the field is measured in 2 positions ($\mathbf{Z}_{n1}$=int($\mathbf{Z}_n$ /$\Delta\mathbf{L}$)$*\Delta\mathbf{L}$ and $\mathbf{Z}_{n2}=\mathbf{Z}_n+\Delta\mathbf{L}$), close to the optimum position $\mathbf{Z}_n=\mathbf{Z}_1+(n-1)\Delta\mathbf{Z}$. The amplitude and the phase in the center of n-th cell are approximated with the formula:

$$\mathbf{A}_n=(\mathbf{A}(\mathbf{Z}_{n1})(\mathbf{Z}_{n2}-\mathbf{Z}_n)+(\mathbf{A}(\mathbf{Z}_{n2})(\mathbf{Z}_n-\mathbf{Z}_{n1}))/\Delta\mathbf{L}, \qquad 2.2$$

$$\boldsymbol{\varphi}_n=(\boldsymbol{\varphi}(\mathbf{Z}_{n1})(\mathbf{Z}_{n2}-\mathbf{Z}_n)+(\boldsymbol{\varphi}(\mathbf{Z}_{n2})(\mathbf{Z}_n-\mathbf{Z}_{n1}))/\Delta\mathbf{L}. \qquad 2.3$$

III. A LINEAR MODEL OF THE FIELD DISTRIBUTION IN THE SECTION

With the bead-pull method we can measure and calculate amplitudes and phases of the field in the centers of the cells: $A_1\mathbf{e}^{j\varphi_1}$, $A_2\mathbf{e}^{j\varphi_2}$, $A_3\mathbf{e}^{j\varphi_3}$, ... For two neighboring cells with number n-1 and n, let us consider this values as a superposition of forward and backward waves: $a_n\mathbf{e}^{j(-2\pi/3(i-n)+\psi_n)}$ and $b_n\mathbf{e}^{j(2\pi/3(i-n)+\phi_n)}$, which has passed through n-th disc (between cells n-1 and n).

$$A_{n-1}\mathbf{e}^{j\varphi_{n-1}} = a_n\mathbf{e}^{\,j(2\pi/3+\psi_n)}+b_n\mathbf{e}^{\,j(-2\pi/3+\phi_n)} \qquad 3.1$$

$$A_n\mathbf{e}^{j\varphi_n} = a_n\mathbf{e}^{\,j\psi_n}+b_n\mathbf{e}^{\,j\phi_n}. \qquad 3.2$$

The solutions of these two complex equations are:

$$a_n\mathbf{e}^{j\psi_n} = (A_{n-1}\mathbf{e}^{j(\varphi_{n-1}-\pi/2)}+A_n\mathbf{e}^{j(\varphi_n-\pi/6)})/\sqrt{3} \qquad 3.3$$

$$b_n\mathbf{e}^{j\phi_n} = (A_{n-1}\mathbf{e}^{j(\varphi_{n-1}+\pi/2)}+A_n\mathbf{e}^{j(\varphi_n+\pi/6)})/\sqrt{3} \qquad 3.4$$

From formula (3.4) we can find the amplitude b_n and phase ϕ_n of the backward wave which passed the n-th disc (between cells n-1 and n). For the next (n+1) disc we can use the formula (3.4) to calculate the backward wave:

$$c_n\mathbf{e}^{j\eta_n} = (A_n\mathbf{e}^{j(\varphi_n+\pi/2)}+A_{n+1}\mathbf{e}^{j(\varphi_{n+1}+\pi/6)})/\sqrt{3} \qquad 3.5$$

Let us calculate the difference of these two backward waves in the plane of the n-th diaphragm. The phase shift per cell is about $2\pi/3$ and if attenuation can be neglected we can write:

$$S_n\mathbf{e}^{j\theta_n} = b_n\mathbf{e}^{j\phi_n} - c_n\mathbf{e}^{j(\eta_n-2\pi/3)}. \qquad 3.6$$

This value is used to characterize the performance of the n-th cell. S_n and θ_n are the amplitude and phase of the wave scattered from n-th cell. In the process of tuning the amplitudes S_n should be decreased. This procedure was tested on a 50-cell constant gradient test section [4]. Figure 3.1 shows the values $S_n\mathbf{e}^{j(\theta_n+\pi/2)}$ before and after tuning.

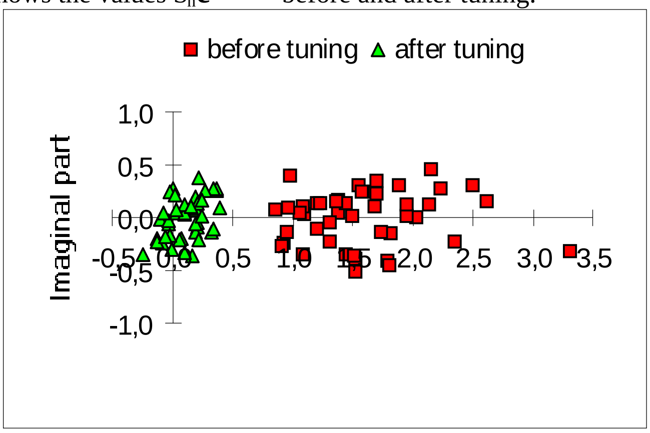

Figure 3.1. $S_n\mathbf{e}^{j(\theta_n+\pi/2)}$ before and after tuning of 50-cell constant gradient section.

By definition, pressing the tuning holes of the cell, the frequency of this cell is increased, the real part of $S_n\mathbf{e}^{j(\theta_n+\pi/2)}$ is decreased and the reflection coefficient **S11** in the input of the section is changed. This effect is used for the automatization of the tuning process.

The process of the tuning is controlled in real time by a computer code. Before tuning of each cell, a computer receives from the Network Analyzer (NWA) the reflected wave value $\mathbf{S11}^0$. While tuning the reflected wave value **S11** is analyzed, so that the calculated value of $|\mathbf{S11} - \mathbf{S11}^0|$ should be achived:

$$U_n = |\mathbf{S11}\text{-}\mathbf{S11}^0| = \mathrm{Re}(S_n\mathbf{e}^{j(\theta_n+\pi/2)})*K_n \qquad 3.7$$

where K_n - is a coefficient to correlate the calculated and measured values for the cell number n:

$$K_n = |\mathbf{S11}^*|/a_2*C_n \qquad 3.8$$

The $|\mathbf{S11}^*|$ - amplitude of the reflected wave from the structure measured after detuning of the input coupler cavity, characterizes the amplitude of the input power from the NWA. C_n - is the loss factor or attenuation coefficient of the wave, which traveled from n-th cell to the beginning of the structure.

If we take into account the nonuniformity of the amplitude distribution in the structure the expression (3.8) can be rewritten for a constant impedance structure:

$$K_n = (|\mathbf{S11}^*|/a_n)*(A_n/a_3)^2 \qquad 3.9$$

For the constant gradient structure:

$$K_n = (|\mathbf{S11}^*|/a_3)*(A_n/a_n)^2*\Gamma_n \qquad 3.10$$

where Γ_n ($\sim V_{gr}^n$ - group velocity for the n-th cell) is the reflection coefficient measured at the input of the structure for the wave reflected (for full reflection) from the n-th cell.

The results of the test tuning of a 50-cell section was sufficient (σ_{ph}=0.17° for the phase distribution along the section) and wedecided to use this method for the tuning of the first 156 cell constant gradient accelerating structure of the LINAC II at DESY.

IV. TUNING OF THE LINAC II SECTION

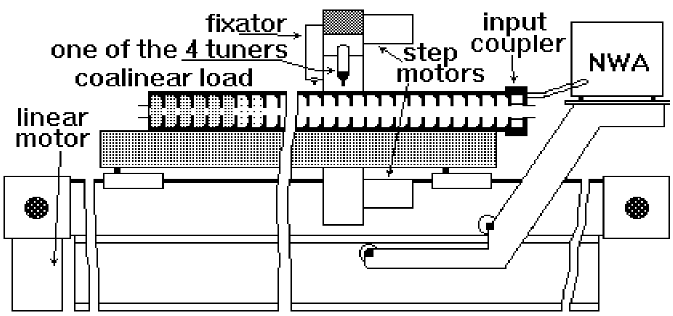

Figure 4.1. Tuning bench.

The structure was installed on a horizontal 13 meter long tuning bench (fig. 4.1) and connected to a water thermo-stabilization system. To be careful, the tuning of the structure was carried out in 3 steps: a) tuning to the frequency $F=F_{oper}$ - 900kHz; b) tuning to the frequency $F=F_{oper}$ - 400kHz; c) tuning to the frequency $F=F_{oper}$. For the calculation of the operating frequency F_{oper} (F_{vac}= 2998 MHz in the vacuum and 40°C temperature of the structure), T_{str} - the temperature of the structure, T_{air} - the air temperature, H_{air} - the air humidity and P_{air} - the air pressure was taken into account[5]:

$$F_{oper} = F_{vac}/(1+1.7*10^{-5}(T_{str} - 40))/\varepsilon^{1/2}$$

$$\varepsilon=1+P_{air}/T_{str}*(211+P_0*H_{air}/P_{air}*(10160/T_{str} - 0.294))*10^{-6}$$

$$P_0 = 10^{(7.45*(Tstr-273)/(Tstr-38.3)+0.656)}$$

One step of tuning includes the field distribution measurement, the calculation of the parameters U_n , tuning of the integrated load (last eight cells, nr.: 149-156) and automatic tuning of cell 4-148 in the tuning machine. If the reflection from the load is very large for some reason, the load cells have to be tuned first. In figure 4.1 the field distribution in the section before tuning is shown. There are a lot of reflections from different parts of the section and in addition a large reflection from the load. The graph corresponds to a SWR in the structure of 1.5÷1.8 after brazing.

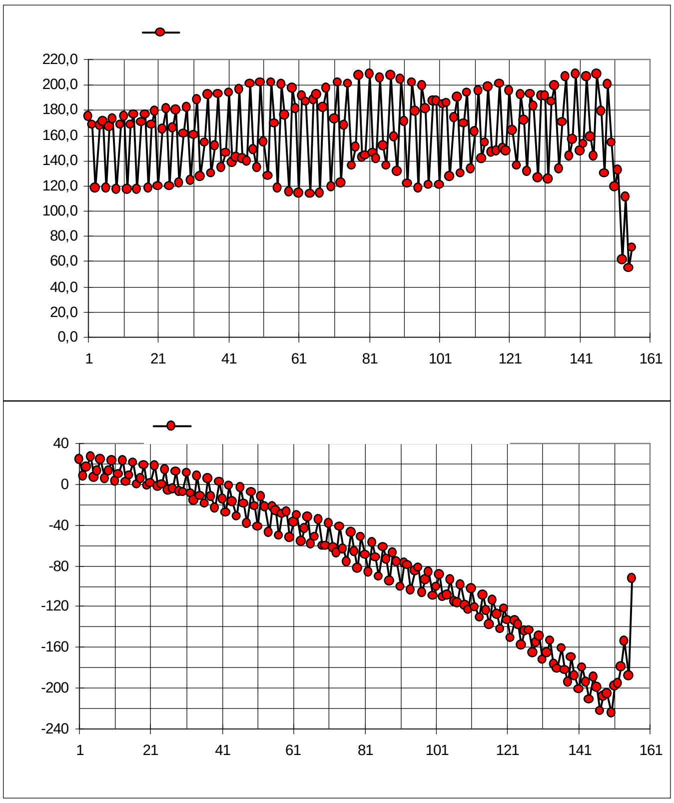

Figure 4.1. Field distribution in the section before tuning.

Figure 4.2 shows the field distribution in the section after three steps of tuning as described before. The field distribution in front of the integrated load is sufficient with a SWR smaller than 1.02. For the phase distribution a σ of 0.3° has been achieved. A small phase error in the load could not be tuned due to a dimensional error in the resonator diameter.

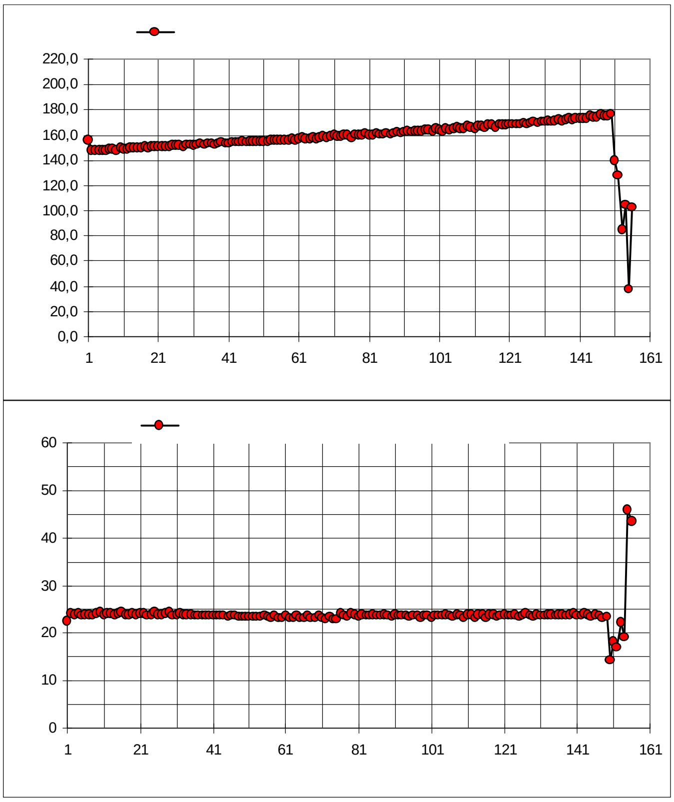

Figure 4.2. Field distribution in the section after tuning.

SUMMARY

It has been proven, that the bead pull measurement being presented in this paper is well suited for the tuning of long (many cell) traveling wave accelerating structures. The results for the tuning of a 156-cell traveling wave constant gradient accelerating structure (σ=0.3° for the phase) has been presented.

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