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STABILIZING CHARACTERISTICS
BETWEEN THE POST-COUPLED AND THE MULTI-STEM STRUCTURE

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ABSTRACT

In order to make sure of the equivalent circuit analysis of the post-coupled and the multi-stem structure, we made a cold model cavity which could be used as both structures. The typical differences predicted by the analysis between the two stabilizing elements were recognized experimentally. Within the frequency region of the coupling elements in this experiment, there was no contradiction to the analysis. That is to say the multi-stem structure has no harmful frequency of the coupling element at which the accelerating field is definitely distorted. And the multi-stem is more insensitive to the resonant frequency of the coupling element than the post-coupled.

INTRODUCTION

In a linear accelerator, especially of the low energy section, the stability or homogeneity of the accelerating field is essential to reduce the beam loss and the unexpected emittance growth. But the inhomogeneity of the accelerating field due to fabrication errors is unavoidable. Moreover it is preferable that the accelerating field should be free from the effect caused by the intense beam such as beam loading.

In the Alvarez type linac, that is the typical structure to accelerate protons from about 1MeV, the post-coupler or the multi-stem is the most popular as the element to reduce the fabrication errors and compensate the crucial effect induced by the beam.

Most papers[1] explaining the stabilizing mechanism use bi-periodic linear chain model. They say that the stability is accomplished by the "confluence" of the two pass-band which correspond to bi-periodic elements respectively. Then confluent two pass-band make one pass-band and the accelerating mode shifts to the center of the pass-band. In other words, the accelerating mode becomes the pi/2 mode which has a finite group velocity and is stronger against perturbations than 0 mode.

But originally, this bi-periodic model was applied to the stabilizing mechanism of a side-coupled or alternating periodic structure, in which we are able to define easily two kind of element. On the other hand, it is not so easy in the post-coupled and the multi-stem structure. Because the bi-periodic model analysis cannot explain the fact that all of the cells do not need the post-coupler to achieve the stability. Other problem is that the length of a post-coupler must be the value around $\lambda/4$. The λ is the wave length of the accelerating mode. Moreover in some case the post-coupler distorts the accelerating field.

In the previous paper[2], we provided another approach to the analysis of the stabilizing mechanism of the post-coupled and the multi-stem structure. That analysis was based on the equivalent circuit[3] as shown in Fig. 1. The post-coupler and the multi-stem were introduced as the impedance tuner between a drift-tube and the outer wall. When we adjust these elements to have the infinite impedance, the accelerating field is stabilized. But if we misadjust these elements to have the zero impedance, it is distorted more harmfully than the case without such stabilizing elements.

This approach showed some interesting features to be mentioned in the next section. So we made a cold model cavity which could be used as both the post-coupled and the multi-stem structures. Then we measured the resonant frequency of the coupling element and the accelerating cell, and the field distribution to compare the values predicted by the analysis.

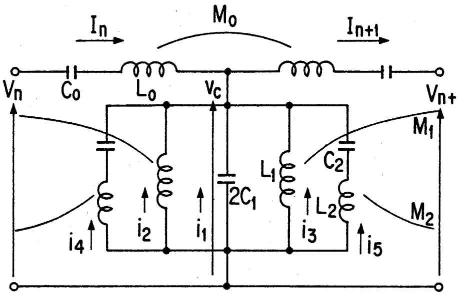

Fig. 1 Equivalent circuit for the Alvarez type linac with stem and post-coupler.

EQUIVALENT CIRCUIT ANALYSIS

Figure 2 shows the dependence of the impedance on the resonant frequency of the post-coupler and the multi-stem. And Fig. 3 shows the dependence of the field inhomogeneity on the post-coupler frequency when the accelerating frequency of one side cell is detuned to +f and the other side to -f. In this figure, Dx means the sum of the difference from the uniform field[4]. If we could obtain the completely flat field distribution among all of the cells, Dx should become zero.

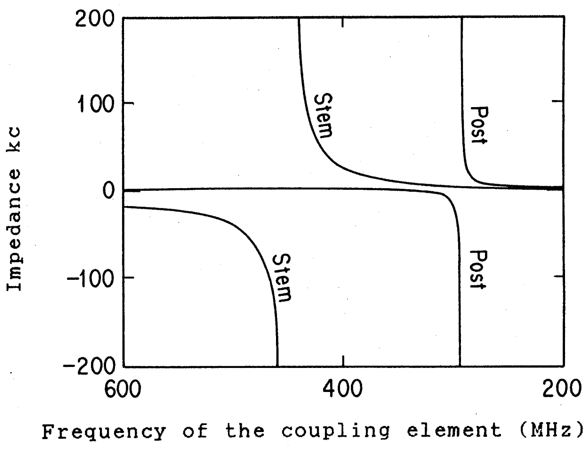

Fig. 2 Impedance kc dependence on resonant frequency of the multi-stem or the post-coupler. The kc of the multi-stem is represented as

$$1/2k_c = L_0\{L_1(1 - k_1^2)\}^{-1}\{\omega^2/\omega_1^2(1 - k_1^2) - 1 + k_1\cos\theta\}$$

and kc of the post-coupled as

$$1/2k_c = L_0\{L_1(1 - k_1^2)\}^{-1}\{\omega^2/\omega_1^2(1 - k_1^2) - 1 + k_1\cos\theta\}$$

$$+ L_0L_2^{-1}(\omega_2^2/\omega^2 - 1 + k_2\cos\theta)\{(\omega_2^2/\omega^2 - 1)^2 - k_2^2\}^{-1}$$

where

$$k_1 = 2M_1/L_1\ ,\quad \omega_1 = (L_1C_1)^{-1/2},$$

$$k_2 = 2M_2/L_2\ ,\quad \omega_2 = (L_2C_2)^{-1/2}$$

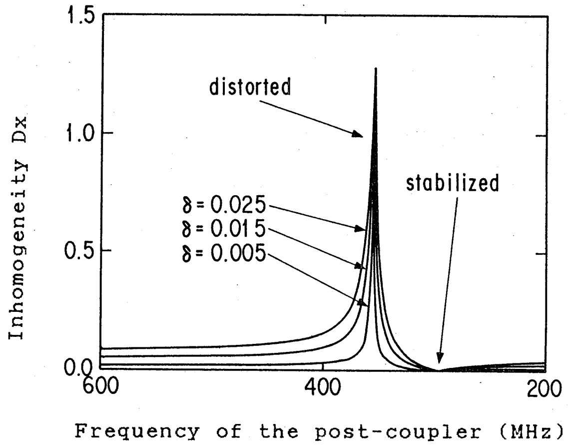

Fig. 3 Field inhomogeneity Dx dependence on the frequency of the post-coupler derived from the equivalent circuit analysis. The δ means the value of the perturbation (ref. 2).

In Fig. 2, we can recognize the two different features between the post-coupled and the multi-stem structure. First, the impedance of the multi-stem changes more slowly than that of the post-coupler. This makes the different frequency region between two in which the impedance becomes higher than some constant value. In other words, it is necessary for the post-coupled structure to adjust the resonant frequency more accurately than for the multi-stem. Because the field homogeneity is more sensitive to the resonant frequency of the element in the post-coupled. Second, there is no zero crossing point in case of the multi-stem. Although the post-coupled structure has the harmful frequency of the post-coupler at which the field is definitely distorted, the multi-stem structure does not have that one. Moreover the sign of the impedance corresponds to the slope of the field as shown in Fig. 4. So in the post-coupled structure, there are two frequencies at which the slope changes, but in the multi-stem, only one frequency. In addition to that, in the distortion, the frequency jump of the accelerating mode is predicted by the analysis as shown in Fig. 5.

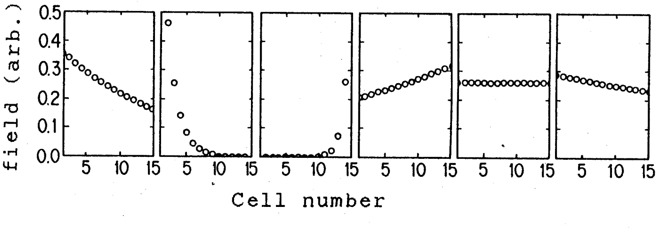

Fig. 4 Accelerating field dependence on the post-coupler frequency. From the left, before the distortion, slightly before the distortion, slightly after the dirtortion, before the stabilization, at the stabilization, and after the stabilization.

EXPERIMENT

Frequency of the Coupling Element

To compare with the equivalent circuit analysis, it is necessary to know the resonant frequency of the coupling element. If we are able to measure all the frequencies of the coupling modes, which make a dispersion curve, it is easy to know, assuming that there is only the nearest neighbor coupling among each coupling elements. But in an actual experiment, the identification of these modes is not easy. Because there is a couple of modes which can not be excited in the imposed configuration.

Usually, the resonant frequency of the coupling element is lower than that of the accelerating element and it becomes a cut-off. In other words, this resonance in the center of the cavity is rarely affected by the boundary conditions. So we measure the resonant frequency when only one coupling element is inserted into the cell located at the center of the cavity. Figure 6 shows the dependence of the resonant frequencies of a post-coupler and a multi-stem in a single cell on the lengths of a post-coupler and the number of a multi-stem.

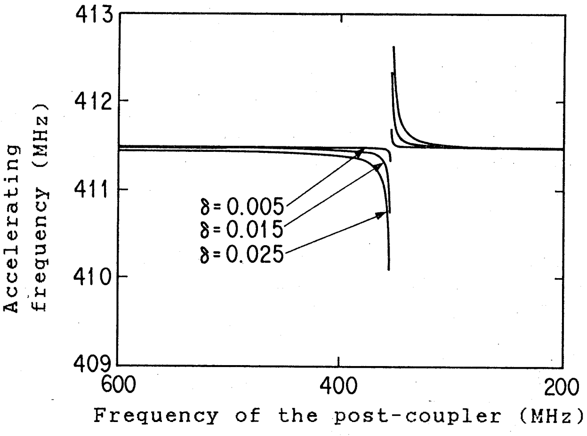

Fig. 5 Shift of the resonant frequency of the accelerating mode on the post-coupler frequency. The δ means the value of the perturbation (ref.2).

Field Distribution

The accelerating field distribution was measured by the bead perturbation method. In the experiment, we took the gap length between a drift-tube and the outer wall in the post-coupler or the number of the multi-stem as a parameter. Then these parameters were converted to the resonant frequency with comparing the values in Fig. 6. The inhomogeneity of the distribution was shown with the distortion parameter Dx mentioned in the previous section.

Figure 7 shows the dependence of the Dx on the resonant frequency of the coupling elements. In the case of the post-coupled structure, this distortion curve agrees with the one predicted by the analysis except for the absolute value of the post-coupler frequency. The accelerating field was stabilized at about 340 MHz of the post-coupler frequency and distorted at about 355 MHz. The slope of the field changed at these frequencies. In the multi-stem, there seemed to be the stabilizing frequency between 300 MHz and 340 MHz, which corresponded to three and four stems per cell. In these cases, the field distribution had opposite slope and this also indicated the existence of the stabilizing frequency in this region.

In the higher frequency side, Dx of the multi-stem became large. In this experiment, we could not know if there was the distortion even in the multi-stem. But the Dx changed more slowly than the post-coupled and this result supported the analysis.

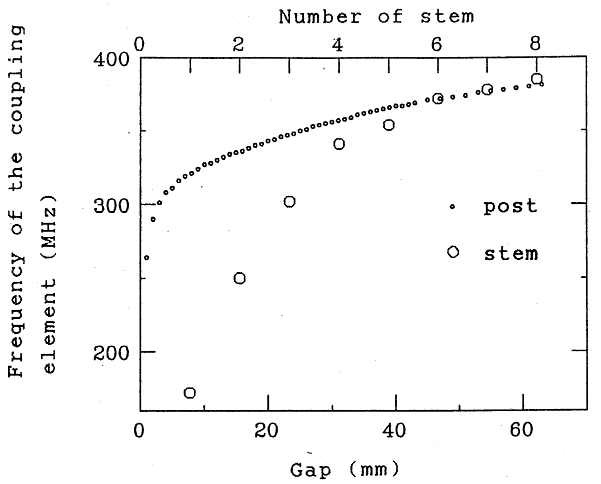

Fig. 6 Resonant frequency of the coupling elements vs. the gap between a post-coupler and the outer wall, or the number of the stem.

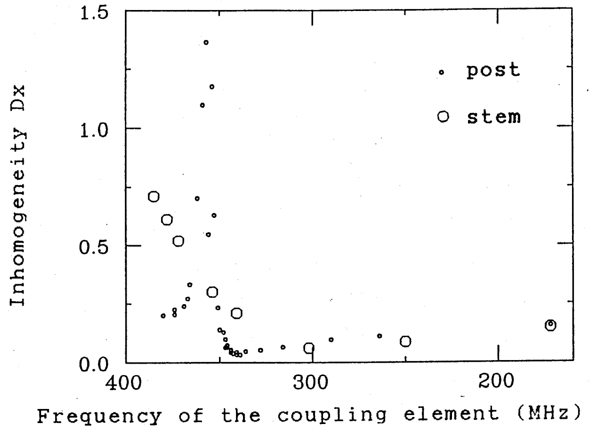

Fig. 7 The Dx dependence on the frequency of the coupling elements in this experiment.

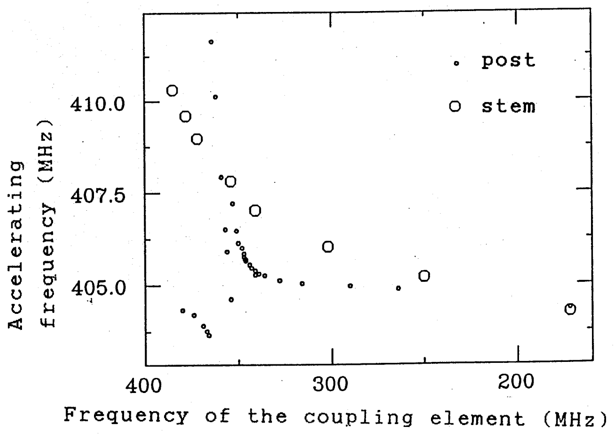

Fig. 8 Shift of the resonant frequency of the accelerating mode in both cases of the the post-coupled and the multi-stem.

Frequency of the accelerating mode

In the bead perturbation measurement, we made a self excited loop including the cavity and could know the frequency of the accelerating mode. Figure 8 shows the dependence of it on the frequency of the coupling element. As the analysis predicted, there was a frequency jump at the distortion frequency in the post-coupled structure, and no such a jump in the multi-stem.

CONCLUSION

We made the experiment to clarify the equivalent circuit analysis on the post-coupled and the multi-stem structure. The two typical differences between these structures were shown experimentally as predicted by the analysis. One of these is that the multi-stem is more insensitive to the resonant frequency of the coupling element than the post-coupled. The other is that there is no harmful frequency of the coupling element in the multi-stem at which the field is distorted definitely in the post-coupled. These result were obtained within 170 MHz to 380 MHz of the coupling elements.

ACKNOWLEDGMENTS

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