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FIELD STABILIZATION IN THE QUASI-ALVAREZ STRUCTURE

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Abstract

The Quasi-Alvarez accelerating structure, proposed for the Linac injector of the CERN heavy ion complex, has a super-period consisting of drift-tubes in $2\beta\lambda$ and $\beta\lambda$ cells supported within a cylindrical cavity of diameter 0.7λ ($f_0 = 202.5$ MHz). Between 0.25 MeV/u and 2.0 MeV/u the design accelerating field increases by 95%, ideally with stabilization by post-couplers. As this is known to be difficult both as regards β and cavity diameter, a 500 MHz scale model of the 0.25 MeV/u to 0.65 MeV/u part has been used to study a comprehensive range of post-coupler dispositions and geometries.

Introduction

The quasi-Alvarez structure is being studied at CERN as one of the injector Linac options for the heavy ion programme [1,2]. Its advantages as an accelerating structure between 0.25 MeV/u and 4.2 MeV/u have been detailed elsewhere with emphasis on the way the focusing periodicity leads to significant reductions in numbers and gradients of the focusing quadrupoles [3]. Another paper deals with the dynamics aspects of the structure showing that tight electric field tolerances are not necessary for good quality beams at 4.2 MeV/u [4].

The Need for Field Stabilization

Post couplers were initially developed a) to make the steady state accelerating field more stable against manufacturing errors and variations during operation, and b) to increase the group velocity of power flow especially under transient conditions. Note that the field errors in the unstabilised Alvarez structure scale as (cavity length/λ)^2. This was not a problem for CERN Linac 1 at low currents (maximum $L/\lambda = 8.1$). For Linac 2, with high currents (150 mA) and strict requirements on the field, post coupler stabilization was necessary on all three tanks. The novelty was to have post couplers on the first tank ($L/\lambda = 4.7$) and to set them asymmetrically relative to the drift tubes to obtain a stabilized field which increases by 21% along the cavity [5]. For the quasi-Alvarez the desirability of stabilization is more linked to field adjustment in the first cavity (where it increases by nearly 100%) than to field errors or transients ($L/\lambda = 5.2$ and low beam currents).

Previous experience with the stabilization of large diameter Alvarez cavities suggests that the stabilization with standard post couplers is very difficult or even impossible [6]. A comparison of accelerators where standard post couplers have been used (or tried) demonstrates that the limiting cavity wall to drift tube distance for stabilization being possible is about $\lambda/4$ [7]. The reason is that for a post coupled system to work two conditions must be satisfied: the couplers must be tuned to the correct frequency and they must couple to the TM01 band. For large diameter cavities, the tuned condition leads to large gaps between the post and the drift tube, but at the same time this distance determines the coupling between the two systems, which in such cases falls below the limit for effective stabilization. The particular geometry of the Quasi-Alvarez, where the critical distance is $1.23\lambda/4$, led us to expect difficulties in the stabilization.

The Quasi-Alvarez Model

The aim with the model was to try configurations of posts with different periodicities and different geometries, for $\lambda/4$ types and if necessary the $3\lambda/4$ type with a coaxial structure outside the cavity. In addition the field adjustment in the difficult region at low energy should be tested. The 0.411 scale cavity was machined from a solid cylinder of aluminium and has 41 drift-tubes supported from a removable girder (Figs 1,2). It represents the 0.25 MeV/u to 0.65 MeV/u part of a high gradient version, and parameters are given in Table 1.

Inside Length		1021	mm
Inside Diameter		423	mm
Design Freq.(no stems)		493	MHz
Gaps		2.5→4.8	mm
	"Large" DTs	"Small" DTs	
Number	13+2x(1/2)	28	
Length	26.5→40.6	11.6→18.5	mm
Diameter	61.6	32.9	mm
Aperture Dia.	5.0	5.0	mm
Stem dia.	10.0	6.0	mm

Table 1: Parameters of the Quasi-Alvarez Model

The Quasi-Alvarez model has movable end half drift-tubes to detune the end cells during field tilt measurements. In the cavity wall opposite the 13 large drift-tubes, 39 threaded holes of 30 mm diameter allow several varieties of post- coupler to be mounted with nearly regular arrangements possible for 13, 7, 6 and 4 couplers.

Measurements were made on frequency, Q, end tuner calibrations and frequency perturbation due to support stems. The TM010 frequency was 491.12 MHz but corrections for holes (+267kHz), support stems (+820 kHz) and air dielectric (+132 kHz) brings this to 492.4 MHz, close to the SUPERFISH computation (493.1 Mhz). The Q of the TM010 mode was 19300 i.e about 69% of theoretical for aluminium (and brass stems).

As a preliminary measurement to stabilization studies, dispersion curves for the lower bands of the cavity have been established (Fig. 3), identifying the different modes by exploring their field symmetry with dielectric or metallic perturbators. The band structure is that typical of an Alvarez cavity, where the TE11 band is separated by the presence of the stems into two polarities. For the one with the E-field parallel to the stems (TE11n$\|$), the frequency is heavily loaded and falls below 300 MHz. The other with E-field perpendicular to the stems (TE11n$\perp$) is only slightly affected and starts below the TM01 band. The major effect of the stems on the TM01n band is to decrease the frequency of the modes with $n \geq 1$, causing the two bands to cross.

At the TM010 mode, the "Alvarez" mode, the electric field on axis was measured by moving a 2.5 mm diameter metallic bead along the cavity and recording the corresponding phase shift on a HP8753C Network Analyzer, to get the field distribution of Fig. 4. The particular drift-tube arrangement of the quasi-Alvarez structure produces a higher field level in the gaps between two small drift tubes, and the measured ratio between the peaks in a cell agrees with the SUPERFISH computations. The tilt sensitivity of the model was then measured using the standard technique of inducing a longitudinal tilt by pushing in and out respectively the first and last half drift tubes, changing the frequency by 250 kHz (corresponding to a change in the gap of about 1 mm) and then coming back to the original value; the resulting tilted field on axis was measured, and then the measurement was repeated inverting the drift tube movements and therefore the tilt. For each of the 14 "central" gaps, the ratio of the difference between the two measured gap fields and their average value is calculated and plotted. The result is the curve of Fig. 5, whose slope represents the sensitivity of the cavity to perturbations involving components of the first longitudinal mode (TM011), and is the parameter to reduce to improve the cavity stability.

Stabilization with Stepped Post-Couplers

Special post couplers have been installed, having a step in the diameter from 28 mm to 10 mm, in order to decrease the post inductance and to have correspondingly smaller gaps between the posts and the drift tube, hoping in this way to increase the effective coupling to the Alvarez mode and make stabilization possible. Thirteen such post couplers were inserted, one in front of each large drift tube on alternate sides (Fig. 2). Fig. 6 shows the measured behaviour of the post couplers band for different gaps (S) between the post coupler and the drift tube. Comparing the curves of Fig. 3 and Fig. 6, one sees that effect of the post couplers is to capacitively load the modes of the TE11 band, characterized by a strong E-field on the plane of the posts, thus decreasing their frequency proportionally to the order of the mode. Moreover, the open TE11 band becomes the closed pass band of a periodically loaded structure. The mode at the highest frequency on this band has the same longitudinal period as the post couplers arrangement, and is therefore strongly affected by the posts. They change its field distribution drastically, as for all the modes on the top of the band, in such a way that those modes can couple with the TM01 band, making a confluence between the two bands possible.

In spite of the fact that the post coupler band crossed the confluence position, for none of the post lengths analyzed has a stabilizing effect been observed. The crossing between the two bands happens for S$\simeq$30 mm, and this distance is not short enough to assure a sufficient coupling for stabilization. Actually, the consequence of the low coupling is to reduce drastically the range of post coupler frequencies, and therefore post coupler lengths, where the confluence takes place, and where the tilt sensitivity is affected [8]. In fact, with the steps of a few mm of our measurement, nothing could be observed, but repeating the measurement with a reduced number of post couplers (7), it has been possible to find a single post coupler length where the tilt sensitivity was affected, but in a totally irregular way. This showed that a confluence was taking place, but the system in that case was so sensitive that no improvement was possible.

Stabilization with $3/4\lambda$ Post-Couplers

To increase the coupling yet keep the possibility of tuning the post to the required frequency, an arrangement of six $3/4\lambda$ post couplers (Fig. 7), has been installed, one in front of each second large drift tube. Here the post frequency is mainly determined by the external coaxial cavity, and it can be tuned by changing the length of the short-circuiting brass cylinder, thus changing the effective coaxial length. Several effective coaxial lengths have been tried, each one leading to a different distance between the post tab and the drift tube, and an optimum from the point of view of stabilization has been found for an external coaxial length of 95 mm, leading to gaps of about 22.5 mm. Shorter gaps make the system very sensitive to errors in the capacitance between the post and the drift tube, and therefore difficult to tune, while larger gaps retain the problems related to the low coupling coefficient.

With this arrangement of post couplers, stabilization was achieved relatively easily. The tilt sensitivity was first measured for different lengths of the post coupler arms (all at the same length). The sensitivities were not linear, because the increasing cell length in the model required different tuning states for the different post couplers. Therefore, all the post couplers have been adjusted to the length giving the flattest tilt sensitivity in the first half of the cavity, and then the length of the three post couplers in the second half of the cavity has been changed in order to flatten the tilt sensitivity there too. Residual small asymmetries have then been eliminated by changing slightly the length of the post coupler near to where the asymmetry was, to get finally the tilt sensitivity of Fig. 8, corresponding to an average S=22.5 mm, with 1.5 mm difference in length between the first and the last post coupler. In Fig. 8 one can observe that the first and the last gaps remain unstable, as the post couplers start only at the second drift tube. In the rest of the cavity the tilt sensitivity presents the typical saw-tooth pattern due to the fact that the post couplers stabilize the system only at each second drift tube. The overall increase in the stability for this configuration with respect to the unstabilized case (Fig. 5) is about a factor of 10.

When the tabs on the posts were rotated by $\pm 90^0$ from their central position, the induced tilt ranged from -3% to $+35\%$. However, the tilt sensitivity did not change appreciably, indicating that the cavity remained stable.

Conclusions

As expected when this model of the input part of the Quasi-Alvarez structure was proposed, the stabilization proved very difficult with traditional $\lambda/4$ post couplers but with 6 of the nominal $3\lambda/4$ (actually $1.84\lambda/4$!) couplers, it was possible to improve the tilt sensitivity by a factor 10. In addition this tilt sensitivity remained low for fields tilted by rotation of the coupler tabs, a strong reason for using post couplers on short tanks (5.2λ). Thus we conclude that for the full-sized Quasi-Alvarez structure it is worth developing post couplers with an external circuit especially as this external part is only $0.8\lambda/4$ long.

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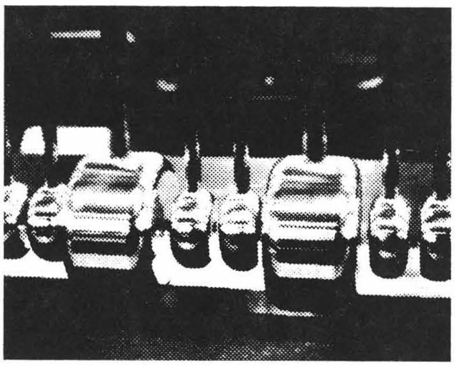

Figure 1: Drift-Tube Arrangement in the Model

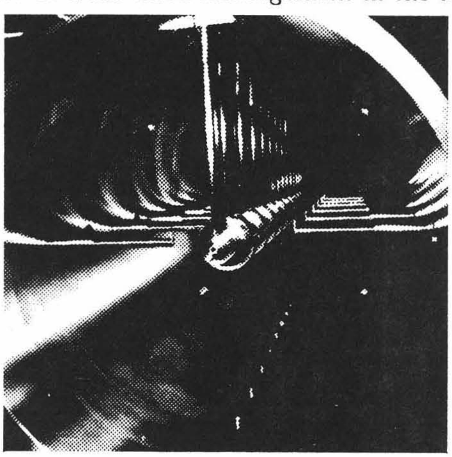

Figure 2: Quasi-Alvarez Model with Stepped Couplers

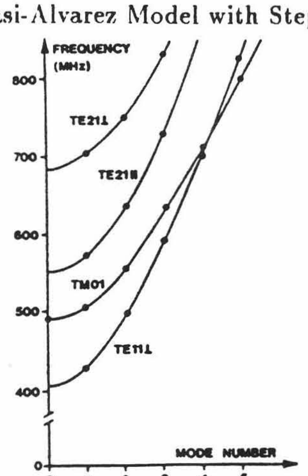

Figure 3: Dispersion Curves of the Unstabilized Model

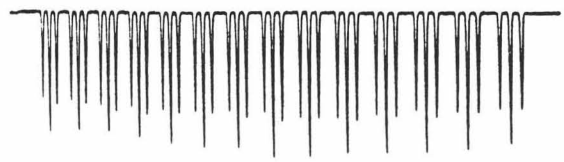

Figure 4: Bead-Pull Measurement of the Field on Axis

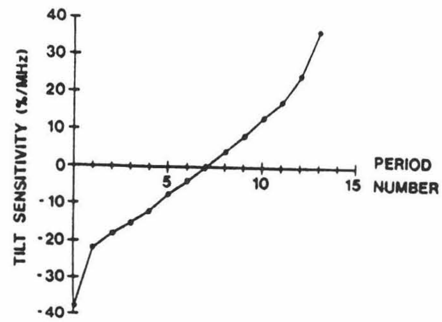

Figure 5: Tilt Sensitivity of the Unstabilized Model

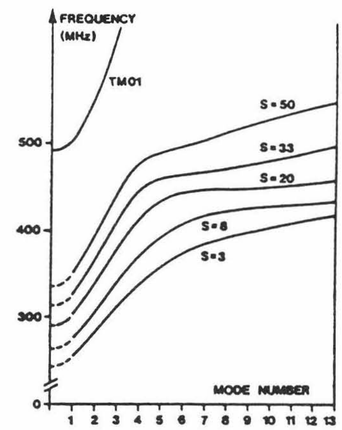

Figure 6: Dispersion Curves with Stepped Post Couplers

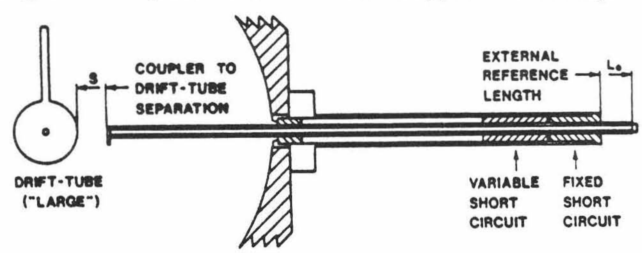

Figure 7: The $3\lambda/4$ Post Coupler

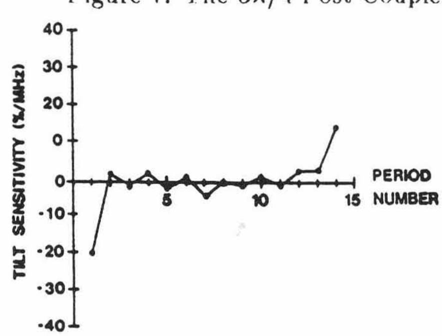

Figure 8: Tilt Sensitivity of the Model stabilized with $3\lambda/4$ Post Couplers