MESON FACTORY ACCELERATING STRUCTURE TUNING

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Abstract

The linear accelerator of H^+ and H^- ions up to the energy of 600 MeV at the average current of 0.5 mA is under completion in the INR of the Academy of Sciences of the USSR. One of the main stage of the linac development is a radiotechnical tuning of the accelerating cavities. 5 cavities with the drift tubes are used for the ion acceleration up to the energy of 100 MeV (initial part of the linac). 108 disk and washer accelerating sections jointed into 27 cavities are used in the main part of the accelerator. Up to now the tuning of 4 drift tube cavities and 15 DAW cavities have been completed. The main stages of the cavities tuning are presented below.

1. Drift tube cavity tuning

After installation and alignment of the drift tubes and preliminary vacuum tests the tuning procedure was done[1]. It includes the precise adjustment of the operating resonant frequency of 198.2 ± 0.001 MHz, the field flattening with the 1% rms deviation and the field stabilization against the various perturbations and beam loading. The adjustment of the precise frequency and the field flattening is made by using of bulk-and piston-type tuners.

The post couplers installed in the drift tube stems plane are used for field stabilization in according with the "antipode" method developed at the Kharkov Physico-Technical Institute[2]. A specific feature of the stabilization method from those before known is that a number of the posts is essentially less than a number of the drift tubes. In according with such method strong interaction between the post and cavity modes occurs. It results to the formation of a hybrid mode spectrum which differs essentially from the cavity eigenfrequencies.

The dependence of the resonant frequencies of the posts length was measured (Fig.1). The lengths of all posts were the same. It is seen that a transformation of the highest modes to the lower and post modes occurs. According to the requirement of the same frequency shifts of the two nearest modes the posts length of 298 mm was selected for the cavity No.1. As things turned out the operating mode field distribution was extremely unflattening and its destortions were localized near the posts. Moreover a weak dependence of the destortions on the post length was observed. To study the effect in detail one of the posts was installed in the minimum E_{011} mode and its influence on the accelerating field distribution was considered. A tab rotation results in a change of the field configuration of the post mode. Finally there is a position of the tab when interaction of the post and operating modes disappears. On the other hand a rotation of the tab does not couse an appreciable effect on the field distribution of $E^*_{s(-1)}$ and E^*_{011} modes*). When the post lengths are equal an influence of a single post movements on a frequency and a field distribution of the modes $E^*_{s(-1)}$ and E^*_{011} shows itself essentially in different ways.

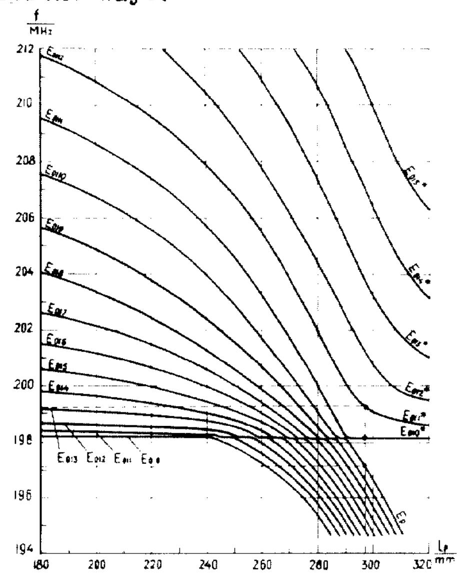

Fig.1 Frequency spectrum transformation vs. the length of posts. Number of posts is 12.

In a real accelerating structure some nonuniformities are presented because of a changing drift tube length along the cavity. Therefore the electric lengths of the posts with equal geometrical length and consequently their eigenfrequencies are different. If a resonant frequency detuning of the posts is essential the electric field distributions of the hybrid E^*_s modes in the cavity with drift tubes are quite local and the posts influence on the $E^*_{s(-1)}$, E^*_{011} modes is individual. To produce the optimum frequency shifts of the nearest modes $E^*_{s(-1)}$, E^*_{011} and to obtain a similar field distributions of those modes one should provide the same resonant frequencies of the posts. The lengths of the posts which correspond to the same value of their resonant frequencies were found.

The result of our investigation is the development of the following stabilizing posts tuning procedure:

1. Every post is introduced into the cavity individually and the post length corresponding to the same frequency is determined.
2. Inserting all posts simultaneously and

*) The sign * is appropriated to the modes formed after the interaction between the operating and post modes.

keeping their length proportions constant the frequency dependence of the resulting modes vs the post lengths is measured. In such a way the post lengths are choosen to provide an equal frequency shift of the nearest upper and lower modes against the operating one.
3. The electric field distributions of the E^*_{011} and $E^*_{S(-1)}$ modes cavity axis are measured. By the individual tuning of the posts the congruent field distributions of the above mentioned modes obtained. So the post lengths are selected finally.
4. The last stage of the tuning is the field flattening with the help of the eccentric tabs. The accelerating field distribution is measured for the various positions of the tabs. As a result a necessary field flattening is achieved.

After fulfillment the total procedure the measuring of the stabilization coefficient is carried out. It turns out that the usual determination of the stabilization coefficient (with the help of a field tilt measurement) does not give the necessary information about the field ununiformity distortion in a presence of the standart perturbation. Indeed when the perturbating bead is introduced into the edge accelerating gap of the cavity the high order spatial harmonics of the Fourie expansion of the accelerating field are excited which distort strongly the field distribution. For that reason we have determined the stabilization coefficient from the expression

$$K_{st} = \frac{\sigma_E \cdot \Delta f^*}{\sigma_E^* \cdot \Delta f} \qquad (1)$$

were σ_E, σ_E^* are rms deviation of the accelerating field of the unstabilized and stabilized cavity, $\Delta f, \Delta f^*$ are the frequency shifts during the measurement. The results of the cavity No.1 tuning are presented in the Fig.2,3.

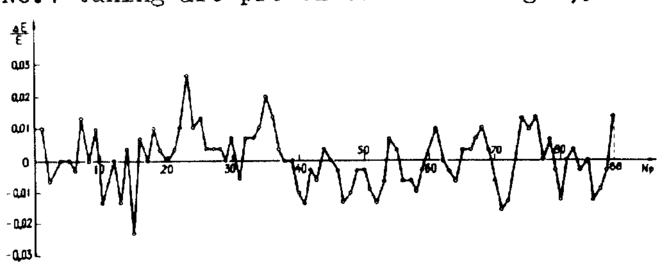

Fig.2 The accelerating field distribution in the cavity No.1 after tuning.

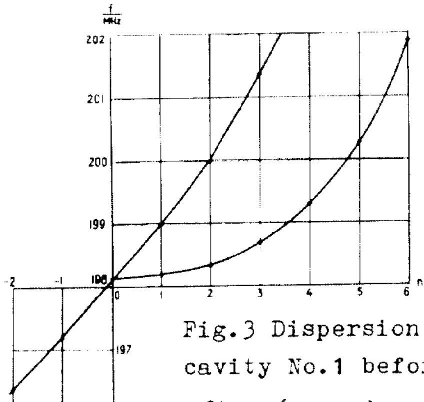

Fig.3 Dispersion curve of the cavity No.1 before(o o o) and after (• • •) stabilization.

2. Four tank module tuning

The module of the main (991 MHz) part of the linac consists of four tanks (sections) of DAW structure. The tanks are connected with the resonant rectangular waveguide bridge couplers. The methodics of DAW tank tuning are given in /3/.

The module tuning procedure includes frequency setting to the design value 991±0.03 MHz, making the tank average amplitudes agree to better than ±0.8% and stabilizing the field distribution against the tank frequency perturbations. The tuning is performed mainly by change of electrical lengths and symmetry of the bridge couplers using special bellows and plungers (Fig.4).

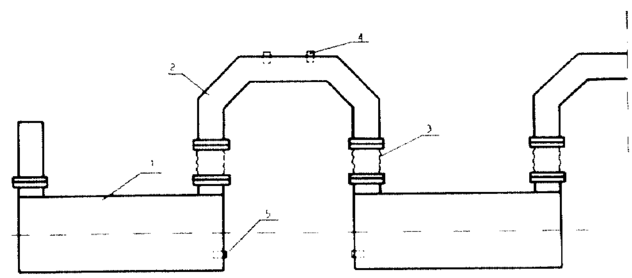

Fig.4. Four-tank module of the main part of INR linac. 1 - DAW structure tank; 2 - bridge coupler; 3 - special bellow joint; 4 - plunger; 5 - unadjustable post for $\pi/2$-mode frequency correction.

The experience shows that for a small module perturbation the tank field average $\tilde{E}_{ik}$ at k-th tank for i-th mode is expressed quite well through the parameters of unperturbed module:

$$\tilde{E}_{ik} = E_{ik} + \sum_{\substack{i\neq j\\ j=1}}^{7} \frac{\sum_{p=1}^{7} E_{ip}\,\delta_p\, E_{jp}}{f_i^2 - f_j^2} \cdot E_{jk} , \qquad (2)$$

where f_i is eigenfrequencies of the module; δ_p is frequency perturbation of p-th element (tank or bridge) of the module; the number of the operating mode is i=4.

At a first sight it looks sufficiently to set the symmetry of the two nearest modes (i=3; i=5) to get the acceptable stability of the field distribution in a module. But the experiment and the coupled oscillator model calculations showed that for a maximal field stability both the symmetry of all frequencies in spectrum and the equality of the tank field averages of the symmetrical modes ($E_{2k}=E_{6k}$; $E_{1k}=E_{7k}$; $E_{3k}=E_{5k}$) are necessary. Essentially, that the symmetry of all spectrum provides in inevitable way this equality. That is due to the theorem of unity for eigenvalue problem with three-diagonal symmetric matrics (the coupled oscillator model description of the module is such a problem)/4/.

In an ideal case the eigenfrequency spectrum of the module looks like:

$$(f_i/f_4)^2 = 1 + 2K\cos(i\pi/8) , \qquad (3)$$

where i=1,...,7; K is coupling coefficient (0.004-0.006).

The normalized tank field average E_{ik} at k-th tank for i-th mode is

$$E_{ik} = \sin(ik\pi/8)/2 \quad , \qquad (4)$$

where k=1,3,5,7 - number of the tank as a module element (the bridges have even numbers).

In a real module the spectrum assymetry is caused by the frequency errors of the bridges. So, the stabilisation of the field in a module consists in setting the propper electrical lengths of the bridge couplers.

The values of the electrical length corrections nedeed for the bridge frequency tuning are given by the relations

$$\Delta(1,1)\approx a1\cdot\ell_1;\ \Delta(1,2)\approx a2\cdot\ell_2;\ \Delta(3,3)\approx a3\cdot\ell_3 \ , \quad (5)$$

where ℓ_m is the value of the length correction for m-th bridge coupler (m=1,2,3); $a1\approx a2\approx a3$ are the empirical coefficients; $\Delta(p,n)$ - the change in the field average difference between n-th and (n+1)-th tanks determined as

$$\Delta(p,n) = (\tilde{E}_n - E_n + E_{n+1} - \tilde{E}_{n+1})\ 100\% \ , \quad (6)$$

where p is the number of tank in which a perturbation is introduced (the dielectric cord exeeding the tank length); E_n is a field average in n-th tank with respect to the module field average; $\tilde{E}_n$ is a tank average of perturbed module.

The lengths of bridge couplers are changed by use of special bellows so, that bridge frequency tuning and the equalization of the field averages are produced simultaneously. The final equalization is performed by using the plunger tuners.

Fig.5 shows the changes in the tank field averages due to perturbation before and after stabilization.

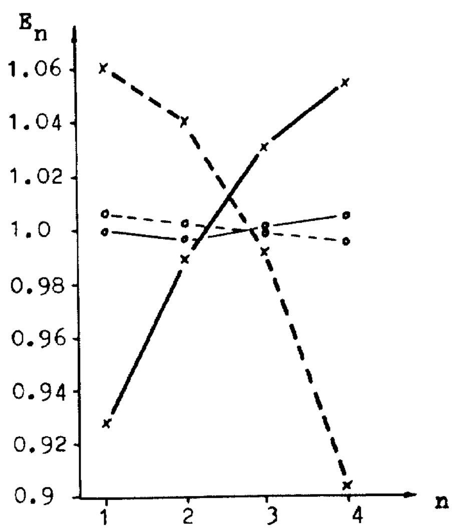

Fig.5. Tank field averages (module No3) before (x) and after (o) tuning when the perturbation is introduced in the 1-st tank (——) and 4-th tank (- - -).

The quality of stabilization is defined as

$$S = \sum_{n=1}^{3} \sum_{p=1,4} \sqrt{\Delta(p,n)^2/6} \cdot 100\% \qquad (7)$$

which is a change of the rms differences between the tank field averages when the 1-st and 4-th tanks are detuned by an amount $\approx$ 300 kHz. Usually S=8-10% before and S=0.3-0.4% after the module tuning. The tolerable value of S is determined by the beam dinamic requirements and the expecting frequency errors due to nonuniform module heating at a high power operation. It is supposed to be of 1-2%.

The unadjustable short posts in tanks are used for correction of the module operating mode frequency. They are placed in the region of the maximum of magnetic field into the end half-cells of the tank through the holes which are free of the monitor loops. In the propper tuned tanks such perturbations do not spoil the tank field distributions owing to the high stability of the DAW structure. Final frequency tuning takes into account the difference in the dielectric constant under atmosphere and under vacuum. The correction in our case is about 280-360 kHz.

Conclusion

By using the described method for the drift tube cavities the sufficiently similar field distribution of the nearest modes was successfuly achieved. The rms deflection of the stabilized field was less than 1%. The frequencies of the neighboring modes were removed from the operating mode 1% MHz area. The stabilization coefficients determined by the expression (1) were 27, 23, 17 to the 1-st, 3-d and 4-th drift tube cavities accordingly. The results of the drift tube cavity tuning have shown effective properties of the posts installed in the drift tube stem plane.

At the moment 15 of 27 modules of the main part of the linac are tuned. They have the following RF parameters: the operating mode frequency is equal to 990.8 $\pm$ 0.03 MHz at 25°C under atmosphere, the tank field averages are equal with an accuracy better than $\pm$ 0.5% within the module, the stabilization parameter S=0.15-0.5%.

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