EXPERIMENTS CONNECTED WITH TUNING OF THE DRIFT TUBE CAVITIES STABILIZED WITH POST COUPLERS

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Abstract

A linear accelerator for 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. A major stage of the linac's development is a radiotechnical tuning of the accelerating cavities. Five cavities with drift tubes (DT) are used for ion acceleration up to 100 MeV (initial part of the linac). The main part of the accelerator uses 108 disk-and-washer (DAW) accelerating sections joined into 27 cavities. At this time four DT cavities and 18 DAW cavities have been tuned. Recently the proton beam was formed and accelerated to 20.5 MeV in a first DT cavity. The main features of DT cavity tuning are presented below.

Hardware

The electric field distribution was measured by the standard bead pull perturbation technique using a driver oscillator with automatic frequency tuning to the resonant frequency of the cavity during bead pull process[1,2]. Data was recorded by an SM-4 type mini-computer. Accuracy of the frequency controller is 5×10^{-9}. The speed of the perturbating bead (1.5 m/min) was selected for sufficient quantity of data in the accelerating gap. All cavity holes were carefully sealed in order to decrease frequency drift during measurement. When the pertubating bead is placed in the center of the drift tube, the resonant frequency of the cavity is used as a reference to exclude occasional frequency drift. Relative values of the accelerating field in the middle of a gap are counted by using the least-squares method. The average electric field E_i over a cell is determined by using the coefficient K_j computed by MULTIMODE code[1]. Knowing the spatial harmonic magnitudes of the measured field and the frequency deviation made it possible to construct a system of linear equations to count the tuner positions, providing the desirable field flattening at a specified value of the resonant frequency.

A set of runs shows that random errors are less than 0.2%. Systematic errors arising from field redistribution when the bead is introduced into the accelerating gap, influence of the measuring loop, and a cavity deformation due to vacuum pumping are less than 1% in a nonstabilized structure and decrease many times when stabilization is used. The most substantial systematic error is caused by nonuniformity of the field in a gap. For this reason the measured field at the middle of a gap is smaller than a real one. Theoretical considerations show that it is necessary to take this effect into account at the first 40 gaps of the first cavity of the INR linac. A value of the effect is equal for both stabilized and nonstabilized structures. This kind of error was evaluated by using light hollow balls with various diameters. Results are shown in Fig. 1.

Drift Tube Cavity Tuning

Tuning procedure includes precise adjustment of the operating resonant frequency to 198.2+0.001 MHz, field flattening with 1% rms deviation, and field stabilization against various perturbations and beam loading. Adjustment of precise frequency and field flattening is made by using bulk- and piston-type tuners. Post couplers installed in the drift tubes plane are used for field stabilization in accordance with the "antipode" method developed at the Kharkov Physico-Technical Institute[2]. A specific difference in the stabilization method from those known before is that the number of posts is essentially fewer than the number of drift tubes (see Table 1). In accordance with such method, strong interaction between the posts and cavity modes occurs. It results in the formation of a hybrid mode spectrum which differs essentially from the cavity eigenfrequencies. The best stabilization of the accelerating field has been achieved when two conditions exist:

a) the frequency shifts of the upper and lower modes nearest the operating mode are equal;
b) the electric field distributions of the two neighboring modes along the cavity are similar.

The dependence of the resonant frequencies of the post lengths was measured (Fig. 2). The lengths of all posts were the same. It is seen that a transformation of the highest modes occurs. According to requirements a) and b), the post length was selected. Analysis of field distribution shows that distortions were localized near the posts. Moreover, a weak dependence of the distortions on the length of the posts 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 observed. It turns out that the rotation of the elliptic tab installed eccentrically on the post tip makes it possible to obtain various field distributions (Fig. 3). An interaction of the post mode with the operating mode is explained by the existence of similar components of their field distributions, possibly due to the existence of a radial component of the E_{010} mode near the post. A tab rotation results in a change of 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 cause an appreciable effect on the field distribution of $E^*_{s(-1)}$ and E^*_{011} modes.

* (Note: The symbol "*" is assigned to modes formed after the interaction between operating and post modes.)

When the post lengths are equal, an influence of a single post movement on a frequency and a field distribution of the modes $E^*_{s(-1)}$ and E^*_{011} shows itself essentially in different ways. In a real accelerating structure some nonuniformities are present because of a drift tube length changing along the cavity. Therefore the electrical lengths of the posts with equal geometrical length, and consequently their eigenfrequencies, are different. If a resonant frequency detuning of the posts is essentially different, the electrical field distributions of the hybrid E^*s modes in the cavity with drift tubes have quite local character, 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 distribution of those modes, one should provide the same resonant frequencies of the posts. Lengths were found for all posts corresponding to the same value of their resonant frequencies. Using the following procedures, each post was taken to provide practically no interaction of post and cavity mode. In this case the frequency of observable oscillation is close to the eigenfrequency of the post. In this manner the lengths of the posts have been adjusted to the given frequency.

In order to remove the nearest H-modes the perpendicular to the drift tube stems plane posts was predicted. To decrease the influence of these posts on the E_{01n} modes, the location near the cavity end was chosen at which E_{01n}, only one post appeared adequate to provide 2.25 MHz frequency shift of the nearest H-mode.

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

1. Every post is introduced into the cavity individually and the post length corresponding to the same frequency is determined.
2. By inserting all posts simultaneously and keeping their length proportions constant the frequency dependence of the resulting mode versus the post length is measured. In such a way the post lengths are chosen to provide an equal frequency shift of the nearest upper and lower modes against operating ones.
3. The electrical field distributions of the E^*_{011} and $E^*_{s(-1)}$ modes on the cavity axis are measured. By individual tuning of the posts, congruent field distributions of the above mentioned modes are obtained. Thus the post lengths are finally selected.
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 performing this 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 uniformity distortion in a presence of the standard perturbation. Indeed, when the perturbating bead is introduced into the edge accelerating gap of the cavity, the high order spatial harmonics of the Fourier expansion of the accelerating field exist strongly distort strongly the field distribution. For that reason we have determined the stabilization coefficient from the expression

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

where σ_E and σ_{E*} are r.m.s. deviations of the accelerating field of the unstabilized and stabilized cavities, and Δf, $\Delta f*$ are the frequency shifts during the measurement. The results of the tuning of cavity No. 1 are presented in Fig. 4 and Fig. 5.

Conclusion

By using the described method for the drift tube cavities, the sufficiently similar field distributions of the nearest modes were successfully achieved. The parameters of radiotechnical tuning are given in Table 1.

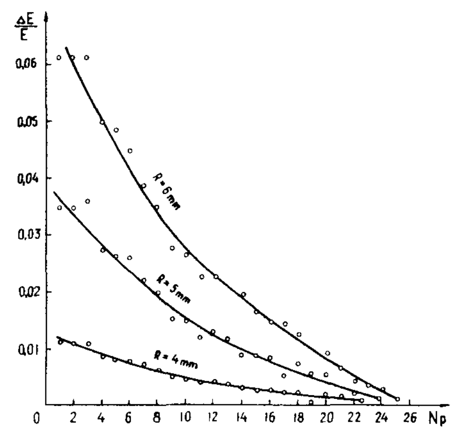

Fig. 1. Dependence of the systematic error due to a field nonuniformity in the gap at the various bead diameters.

Table 1

F_{E010} MHz	198.2	198.2	198.2	198.2
$f^*_{s(-1)}$	197.3	196.9	196.8	–
f^*_{E011}	199.0	199.4	199.5	199.3
Q	63000	52000	48000	87000
K_{st}	27	23	17	–
Number of posts	11	10	8	–
E' %	1.0	0.6	0.7	1.1

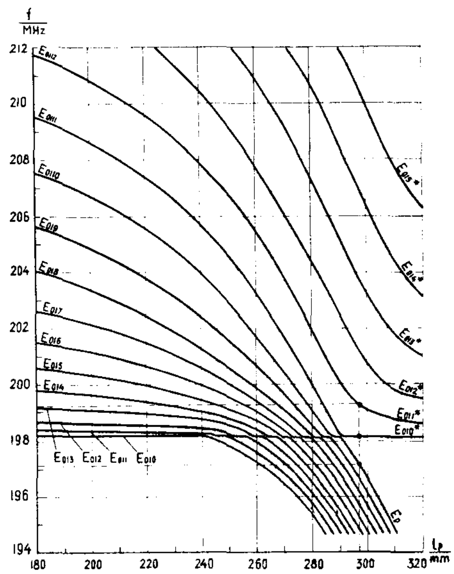

Fig. 2. Frequency spectrum transformation vs. the length of posts.

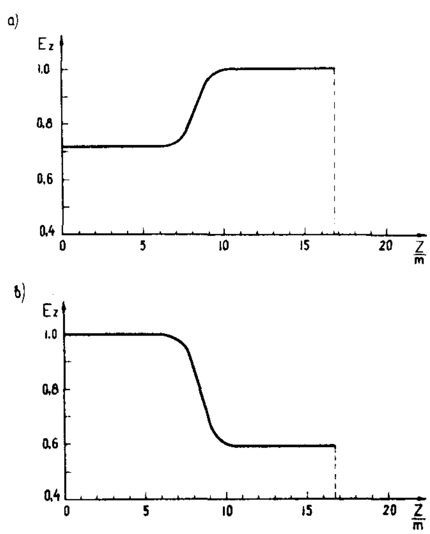

Fig. 3. The effect of tab rotation on the E_{010} field distribution:
a) the tab pointed left;
b) right.

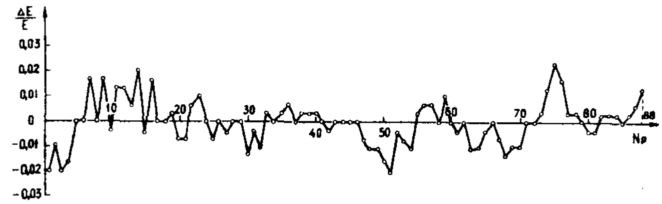

Fig. 4. The accelerating field distribution in cavity No.1 after tuning.

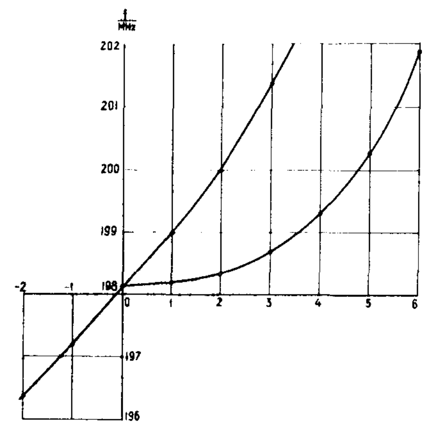

Fig. 5. Dispersion curve of cavity No.1 before (o o o) and after (• • •) stabilization.

References

1. I.V. Gonin et. al. Proceedings of the IX All-Union accelerator conference, v.1, Dubna, 1985, p. 137 (in Russian).

2. V.A. Bomko et.al. Particle Accelerators 7, No. 2 (1976), p. 97.