THE DISK AND WASHER STRUCTURE FOR MOSCOW MESON FACTORY LINAC

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Introduction

The disk and washer (DAW) accelerating structure, originated by V.G.Andreev[1], created a great deal of interest for many particle accelerators, because of a high coupling between the accelerating and coupling modes, a high efficiency to convert RF power into particle energy, a good vacuum properties etc. First DAW has been used for high energy (100 to 600 MeV, 360 m) part of the Moscow meson factory proton and H^- (I=0,5÷1 mA) Linac (LA MMF). At the moment the fabrication, tuning and installation in the tunnel of all (110) accelerating tanks are finished; tuning, geodesical surway, vacuum and high power tests of four tank modules are in progress. This paper presents some results and conclusions of tnis work.

1. The DAW tank fabrication.

The accelerating tank (Fig.1) consists of a number of cells (17 to 26), subdivided into two or three sections in which they are connected by brazing in the hydrogen furnace. The end half-cells have window for coupling

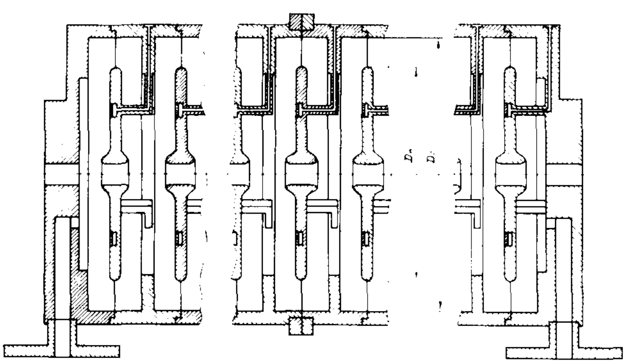

Fig.1. The disk and washer accelerating tank.

with bridge coupler, designed on the base of rectangular waveguide, operating at the H_{10n} mode. The washer in each cell is attached to the disk by three L-supports. Two of them have the bore for cooling water, which pass through the circle channel inside washer.

The principal steps of the DAW fabrication are: the die-stamping of cell blank from billet of copper, the rough-machining with a stock of 1 mm in each size, the brazing of the ring in a washer cooling channel with simultaneos annealing, the fine-mashining to tune radiotechnical parameters, the brazing of cells into sections, the assembly of sections into tanks, frequency and field measurements and vacuum tests. The technology and methods of the DAW accelerating tank fabrication are described earlier[2] and it have, in our opinion, the like labour input in comparison with on-axis coupled structure fabrication. In this paper we would like to discuss merely the questions of the machining errors influence on the RF parameters of DAW.

The DAW structure, as well as biperiodic structures with inside and outside coupling cavities, is compensated one, but it has substantial peculiarities, concerned with specific dispersion characteristic, that manifests itself in a big coupling between neighbouring and other to the next cells[3] . So the definition of coupling coefficient (for LA MMF tanks ≈40%) through pass-band width for DAW is not entirely correct[4].

We determine the criterion for option of the accuracy class of the DAW cell fine - machining as the tolerable r.m.s. deviation of the cell accelerating mode frequency, making a substantial contribution to unflatness of the accelerating field distribution. Investigations have been run in two directions: 1) estimation of the accelerating mode frequency spread at different accuracy of the cell fabrication, defined as $\sigma_f = \sqrt{\sum_i C_i^2 \sigma_i^2}$, where C_i - coefficient of the i-th size influence to the frequency, σ_i - standard deviation of size in case of the normal distribution ; 2) agreement of the accelerating field distribution at different values σ_{fa} .

The detail description of experiments and resilts is published earlier[5,6] .

One may say, for example, that the increase of the tolerance on the washer diameter (D_w = 300 mm) from 0,1 mm to 0,34 mm increases σ_{fa} approximately twice (from 200 kHz to 400 kHz in our case) resulting in additional r.m.s. accelerating field unflatness of about 1%. Practically a worsening of quality factor Q and effective shunt impedance zT^2 do not take place.

These results show the possibility of DAW cells routine fabrication by ordinarly industrial plant. This situation is a very substantial for construction of facility like LA MMF which consists of thousands of cells, because the time of manufacturing shortens and the cost of the accelerating system decreases.

2. The DAW tank tuning.

The tuning procedure of the accelerating tank includes adjustment of the accelerating mode and the coupling mode to the given operating frequency and flattening of the accelerating field. The next tolerances have been accepted for LA MMF DAW tanks: operating frequency f = 990,8 ± 0,1 MHz at the temperature 25°C, r.m.s unflatness of the accelerating field $\langle E \rangle \leqslant 2\%$, field tilt $E \leqslant 8\%$.

The tolerance on the frequency of the coupling mode (stopband) is determined from the point of view of the accelerating field distribution stability. Papers[3,6] show, that allowable deviation of the coupling mode frequency from the operating frequency is equal a few MHz in our case. At the same requirements for accelerating field distribution stability the allowable deviation of the coupling cell frequency for the side-coupled structure is by a factor of ~100 smaller (a few tens of kHz).

The tuning procedure of LA MMF DAW tanks is described in detail at[7].

The cell tuning to the accelerating mode frequency proceeds by reduction of the washer diameter Dw; the coupling mode frequency is adjusted by mashining of the cavity inner diameter Dc[8] (Fig.1). A high stability of the accelerating field distribution at DAW offers, in contrast to all coupled cavity structures, to eliminate individual cell tuning to the operating frequency, that let to increase the production speed and drops the construction price of the multy-cells fasility. The only end half-cells of the tank are to be tuned individually.

We developed the tuning procedure, wich makes possible to avoid step-by-step approach to the necessary sizes Dw and Dc and, practically, each cell is mounted on the lathe for f_a and f_c -tuning at once. For this purpose at f_a -tuning the tank is divided into 3-4 groups of about 6-7 cells in each. From experimentally determined coefficient C_{Dw} the washer diameter of first group is reduced. In the case of frequency deviation from the operating value the necessary correction of a Dw-value at the mashining of the next group of cells is introduced. Estimation of the correction performs proceeding from relation:

$$f_t = (f_e + \sum_{i=1}^{N} f_i)/(N + 1) , \quad (1)$$

where f_t - the tank frequency; f_e - frequency of the cell, formed by two end half-cells; f_i - accelerating mode frequency of the i-th cell; N - the number of the regular cells in tank. The frequency detuning between groups of cells must not go over ≈ ±300 kHz limit. In this case the accelerating field distribution has no significant distortion.

The stopband width δf is determined from frequency measurements of two or three pair of modes nearest to the operating mode according to expression[9] :

$$\delta f = (m^2 \Delta F_n - n^2 \Delta F_m)/(m^2 - n^2) , \quad (2)$$

where $\Delta F_m = f'_m + f''_m - 2f$; $\Delta F_n = f'_n + f''_n - 2f$;
m = 1,2; n = 2,3.

The necessary magnification of Dc for the coupling mode frequency is determined from the dependence δf = = a*Dc, where a - empirical coefficient. As shown above, the parameter δf for DAW has rather high tolerance, that makes possible perform the magnification Dc for all cells by the same value and in one pass.

The necessity of the field flattening is a result of the disk supports influence. In our case (L-type supports) it is necessary to eliminate the uniform field tilt. This procedure, taking into account manufacturing errors, has been performed during the brazing in the hydrogen furnace. It reduces the to longitudinal displacement of supports and is described in detail at[6,7].

Using one lathe and one frequency and beadpull equipment the tuning of each accelerating tank, consisting of ~23 cells, takes about 8 days, wich is quite a moderate time.

Results of LA MMF tanks tuning are given in[10]. R.m.s. unflatness of the tank field distribution does not exceed 2% and the average of that value for linac is 0,65%. The effective shunt impedance zT^2 = 22-40 MOm/m haz been measured, the quality factor is Q = = $(1,7-2,9)*10^4$.

3. Parasitic modes.

Presence of the parasitic modes with azimuthal field variations in the operating mode neighbourhood[11,12,13,14] is a disadvantage of the structure. Coupling of parasitic mode with operating one due to L-supports inluence leads to the worsening of Q-value and to the deviation of the operating mode frequency. The criterion of the coupling value estimation is the relation zT^2/Q for the operating mode. Parasitic modes have E_z = 0 at the axis of the structure and the coupling with operating mode leads to decreasing zT^2/Q for operating mode. Noncorrect option of number and relative position of the supports could result in a critical decrease of the zT^2/Q factor[15].

If parasitic modes removed from operating mode neighbourhood more then 15-20 MHz L-supports, used at LA MMF structure, and T-supports, proposed in[16] cause a weak coupling.

It is known[16] that four T-supports mounted in each second period displace a parasitic mode frequencies by necessary value. This configuration may be useful for serial production of the same tanks. In a multy-tanks ion linacs all tanks are different and consider preferable to use more flexible resonant methods of the parasitic modes removal. In paritcular at LA MMF tanks the combined resonant slits (three in each disk) are realized[17]. It is known that modes with azimuthal field variations cause the beam break up instability. In a single tank facility a regenerative mechanism of the instability represents the danger. Calculations show[18] and experiments confirm[19] that the threshold of the regenerative mechanism is high enough: few amperes of the beam current for electrons and few tens of amperes for protons. In a multitank linac the cumulative mechanism of the instability is more dangerous. The transversal shunt impedance $r_\perp$ and a frequency of the parasitic modes are the parameters of most importance. Characteristics of modes with one azimuthal field variation for LA MMF structure on seven branches of its dispersion curve have been calculated by MULTIMODE-code[20] and are presented in[21]. The experimental study bottom branches shows a good agreement with calculated data[22]. For example it is received for mode with one azimuthal field variation at second branch of the dispersion curve: for zero harmonic $r_{\perp o}$ = 100 kOm/m, for minus first harmonic $r_{\perp -1}$ = 36 kOm/m. The calculated data $r_\perp$ are the upper estimation for experimental data. It is shown that L-supports affect the frequency and characteristics of the parasitic modes weakly, by them a possibility of calculated data, not taking into account of supports, use is confirmed also.

Study of the beam break up instability limit in the linac taking into account the displacement of the parasitic modes frequencies by use of resonant slits and considering the change of the parasitic modes frequencies from tank to tank the pulse current limit for LA MMF of 1-2 A was found (the design value of the pulse current is 50 mA). The beam deflecting modes, in our opinion, are not a real barrier to design a multi-tank high intensity proton linac on the basis of the DAW accelerating structure.

4. Vacuum and RF testing.

The DAW tank has a high vacuum conductivity of about 100 l/s and an attainment of vacuum in it of 10^{-6} - 10^{-8} Pa is well decided engineering problem. The vacuum system for high energy part of LA MMF has three forevacuum lines (one for 36 tanks) and 140 high vacuum pumps (five 250-400 l/s titanium pumps for each four-tank module). Vacuum of $\sim 10^{-6}$ Pa had been reached without some special measures for surface treatment .A good vacuum properties of DAW are especially important for H^--ion acceleration.

Comprehensive testing results of four-tank module are presented in[23], where also results of vacuum testing, residual gas analisis and results on vacuum resources at the high power lewel are presented . The module is fed by RF power through the central bridge coupler from a 4,5 MW 991 MHz klystron. The repetition frequency is 25-100 pulse/s, the pulse duration is 130 μs. The nominal pulse power of 2,3 MW has been put into the module within 14 hours of processing. To determine the electrical strength reserve the module has been tested at the power level P = 2,8 MW (P_{av} = 28 kW). A stable operation without breakdown has been achieved. So in terms of electrical strength the DAW structure is on a par with another accelerating structuries.

In author's[24] opinion the energy gain $\sim$40 MeV/m may be achieved by design of washer without a cone nose at the axis region.

Conclusions.

The different aspects of fabrication, tuning and properties of the DAW structure are presented briefly. Experience of production of 110 DAW tanks for Moscow meson factory linac and results of the structure study allows to say that DAW accelerating structure is one of the best options for high-energy part of a proton linear accelerator.

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