Accelerating Frequency Shift Minimization.

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Abstract

A method of thermocompensation of the resonante frequency shift for accelerator structures is proposed. Using the bimetallic construction allowed us to design the accelerator structure without the resonante frequency shift under rf power. The results of computer simulation of thermal conditions for the on-axis coupled structure are presented.

I. INTRODUCTION

Room temperature continuous wave (cw) accelerator structures have been applied in developing cw racetrack microtrons (RTM) with output energies of hundreds of MeV and industrial accelerators with output beam energies up to 10 MeV and beam powers of hundreds of kilowatts as well as accelerating cavities for storage rings. Considerable progress in the development of accelerator structures for RTMs has been achieved at Mainz University (Germany) /1/ and NIST (USA) /2/, in the design of high power industrial accelerators on the basis of cw accelerator structures - at AECL (Canada) /3/.

The main problem in operating room temperature cw accelerator structures is the high levels of rf power dissipated per structure unit length (from 10 to more than 100 kW/m). Due to heating and deformations of these structures: a) there is a frequency shift in the accelerating and coupling cells, b) there are changes in a stopband frequency gap and c) distortions of accelerating field distributions take place.

A cw RTM of 175 MeV output energy and average beam current of 100 mA is presently under construction at the Institute of Nuclear Physics of Moscow University /4/. In this paper accelerator structure characteristics and the results of a numerical simulation for thermal stresses, which allows a suggestion for an accelerator structure version that is free of frequency shifts during the structure start-up are discussed.

II. ON-AXIS COUPLED ACCELERATOR STRUCTURE CALCULATIONS.

The electrodynamic characteristics were calculated and optimized using the computer code *PRUD-0* /5/, and for the thermal stresses analysis the program *HAST* /6/

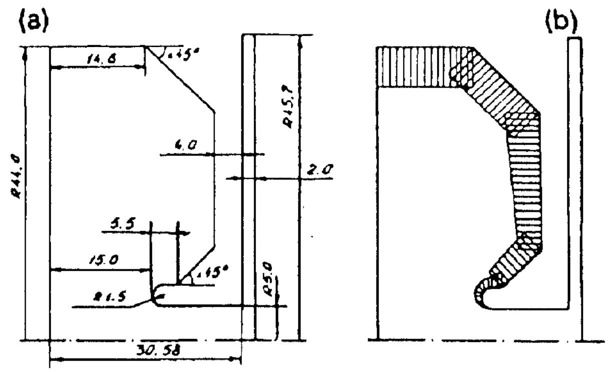


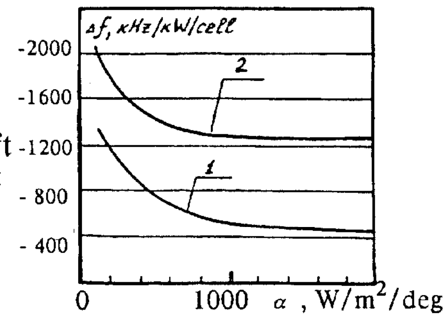
Fig. 1. a) - Parameters of the OCS,
b) - distribution of rf losses among structure element.

was applied. A common finite element mesh generator simplified the processing of the data.

Fig. 1 shows a cross-section of accelerating and coupling half-cells profiles and the basic dimensions of a β=1 cell for a rf frequency of 2450 MHz. For the β<1 accelerating sections, the cells differ only by their length and gaps between the noses. The absence of elements with spherical surfaces reduces the structure's effective shunt impedance, ZT^2, by several percent, yet, it also simplifies the cells fabrication and tuning and allows the coupling slots to be a greater distance from the structure axis in a magnetic field of higher magnitude. Thus the same coupling constant, as for the cavities with spherical surfaces, can be obtained with a smaller azimuthal angle of coupling slots, i.e. with a smaller reduction in shunt impedance. The calculated values of the quality factor and the effective shunt impedance are Q_0 = 17500, ZT^2 = 92 MW/m, respectively. This calculation doesn't take the influence of the coupling slots into account.

The density distribution of the rf losses over the surface of an accelerating cell is shown in fig. 1b. An analysis of the thermal stresses was carried out for a structure with peripheral cooling. Fig. 2 shows α-dependences of accelerating and coupling cells frequency shifts for β=1. 1 kW of rf power was dissipated in a single accelerating cell. In order to ensure the correct description of boundary conditions, the calculations of thermal deformations were carried out for a significantly long structure, and deformations of the central cell were used to estimate the cells frequency shifts. The accelerating cell frequency shift

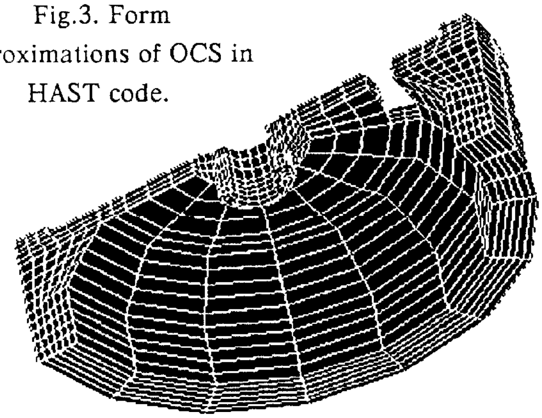
Fig. 2. Accelerating (1) and coupling (2) cells frequency shift versus a heat transfer coefficient.



for β=1, α >10000 W/m/^{0}C is Δf_a=-455kHz/kW/cell. The frequency shift of the coupling cell is Δf_c = -1300 kHz/kW/cell. So a stopband frequency gap of 845 kHz per 1 kW of dissipated rf power appears in the structure tuned at a low rf power level.

Understanding the time dependence of frequency shifts is important for the development of the start-up procedure. According to calculation the time necessary to reach thermal equilibrium is about 20 - 25 seconds. In order to estimate the coupling slot influence, 3-D calculations of temperature distributions were made using the code *HAST*. 3-D approximation of form of OCS using *HAST* is shown in fig. 3. The azimuthal temperature variation, which is affected by the presence of coupling slot, doesn't exceed 1.03 ^{0}C, thus when accounting for, the coupling slot can not essentially change the results of 2-D calculations.

Fig.3. Form approximations of OCS in HAST code.



III. ACCELERATING FREQUENCY SHIFT MINIMIZATION.

Accelerating frequency shifts during start-up considerably complicate the operation of the accelerating sections under cw conditions. That is why a design of an accelerator structure with minimal frequency shifts is of great interest. Frequency shifts can be reduced by designing more extensive cooling circuits. It was shown /6/ that web cooling in addition to circumferential cooling reduces the accelerating frequency shift by a factor of 2.5. However, the problem can not be completely solved by more elaborate cooling circuits. Though it is possible to reduce temperature gradients and to increase construction rigidity by increasing the web thickness, it would result in extreme changes of the effective shunt impedance /7/.

The accelerating frequency reduction is caused by increasing the cells volume and displacing the construction elements relative to the initial positions. However, the displacement of some construction elements, in particular, an increase of the gap between the accelerating cells noses increases the accelerating cells frequencies. Thus, by changing the picture of deformations it is possible to completely compensate frequency shifts during start-up. Two methods of the frequency shift compensation calculated using the programm *HAST* are discussed: a) by realizing more extensive cooling circuits and b) by changing the picture of deformations using bimetallic constructions made on the base of copper and molybdenum. Fig. 4 illustrates different variants of molybdenum insertions and an additional cooling channel location near the axis. In all the design possiblities, circumferential cooling is assumed. The results of calculations for these variants are listed in table 1: frequency shifts and effective shunt impedance reduction are all normalized to 1 kW per cell of the dissipated rf power; ; maximum levels of the dissipated rf power and maximum energy gains per unit length are limited by elastic limit deformations. The calculations were carried out for a single half-cell, this limitation reduced frequency shifts by 50 - 100 kHz. In the most interesting

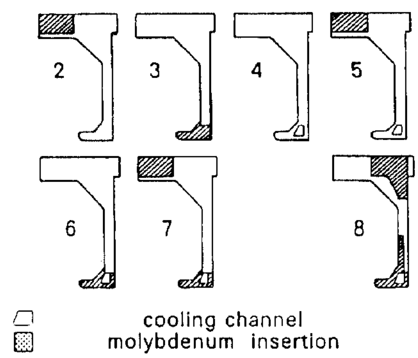


Fig. 4. Different variants of molybdenum insertions and of additional cooling channel.

cases, the results were specified by calculations made for a greater number of cells. These cases are marked by an asterisk in table 1.

From the analysis of the results given in the table 1 the following conclusions can be drawn. The minimum frequency shift without additional cooling takes place in variant 3. Compared to the initial variant, 1, the frequency shift is reduced by a factor of 4, that the energy gain limited by copper elastic limit deformations is 1.65 MeV/m. An energy gain of 2.8 MeV/m was obtained with additional nose cooling without molybdenum insertions with the frequency shift reduced by a factor of 3 comparing to variant 1 . A high energy gain and a positive frequency shift calculated for a single half-cell, were obtained in variant 7. However, the specification of boundary conditions for an increased number of cells, gives a frequency shift of -40 kHz/kW/cell. Finally, a positive frequency shift of +90 kHz/kW/cell was obtained in variant 8, calculated for several cells, which can compensate a frequency shift caused by water heating. A positive frequency shift was obtained as a result of increasing the gap between the accelerating cells noses by 22 mm, normalized to 1 kW of the rf power. A comparison of deformations for this variant with variant 1 is given in fig. 5. The large value of deformations limits the energy gain to 1.54 MeV/m. As the energy gain increases for a fixed beam power, the accelerator efficiency is reduced. This variant of the structure can be used for racetrack microtrons with typical energy gains of 1 MeV/m and for industrial linacs with beam powers up to 100 kW and energies up to 5 MeV. The absence of frequency shifts during start-up makes it possible to design multi-section accelerators with a simple rf power system. It should be noted that the discussed results were obtained for the on-axis coupled structure. The positive frequency shift was obtained to a considerable extent by reducing the coupling cells resonant frequencies. For variant 8, the coupling cell frequency shift is -7 MHz/kW/cell. This shift, however, can be compensated by preliminary coupling cells tuning at higher frequencies.

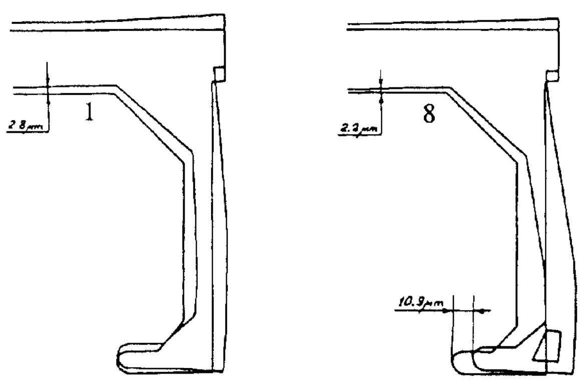


Fig. 5. Comparison of deformations for variant 8 and variant 1.

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TABLE 1 The results of calculations for different accelerator structures

variant No	P_{max} [kW/m]	$\Delta f / \Delta P$ [kHz/kW]	$\Delta ZT^2/ZT^2$ [%]	ΔW [MeV/m]
1	45.5	-345 b -455	4.2	1.68
2	39.4	-282	4.2	1.62
3	41.5	-86	4.3	1.65
4	130.8	-114	2.4	2.8
5	121.8	-69	2.4	2.72
6	139.	-46	2.5	2.85
7	128.2	+8.5 b -40	2.6	2.75
8	35.9	+90.3	5.2	1.54