PRACTICAL SOLUTION OF HIGH GRADIENT ACCELERATING STRUCTURE FOR LOW ENERGY MEDICAL LINEAR ACCELERATOR

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Abstract

In Accelerator Physics Laboratory of the Soltan Institute, a new technological solution of high gradient accelerating structure was elaborated, and the practical full-scale model was constructed, addressed to potential application in low energy medical accelerators. Motivation for this work was the requirement to achieve reduced length of the structure, enabling its location directly on axis of collimator fastened to rotating gantry with source - to isocentre distance 1000mm. The designed energy is 4 MeV at total length below 260mm (including the gun). The solution is based on the system of two independent, interlaced chains of resonators[1], fed from the same microwave power source through 3 db hybrid coupler - dividing the power in two halves and ensuring 90 degrees phase shift. Original technology was adopted for connection of accelerating and side coupling cells. In the paper, results of resonators' computation, simulation of acceleration of the electron beam, as well as results of microwave measurements are presented.

1 INTRODUCTION

In low energy medical accelerators, the accelerating structure is typically located in the radiation head, directly on the output beam axis, what allows to avoid bending of the beam and simplifies the construction. In this solution, the mechanical length of the structure must be sufficiently small, to enable rotation of radiation head around the patient, and to keep the distance from radiation source to the isocentre at desirable value. In solution of CO-LINE accelerator, produced at present by Establishment for Nuclear Equipment, at SWIERK, the length of the structure, permits for Source-Isocentre Distance (SID) of 80 cm. To match to modern therapy standards, this distance should be 100 cm. It requires in turn, shortening of accelerating structure from present 45 cm to below 30cm. Such value is practically not attainable in "classical" design of standing-wave, $\pi/2$, on –axis coupled S-band structure. Therefore it was desirable to look for a new type of structure with very high accelerating field .

The adopted solution is the configuration composed of two interlaced chains of resonators, with off-axis coupling cavities, and the shapes of accelerating cavities allowing for very high accelerating fields. The designing process included following main steps:

- numerical calculations of electromagnetic fields, microwave circuits and beam dynamics,
- mechanical design and construction of subsequent models, approaching the final technological solution
- experimental investigation of models, and measurements of principal R.F. fields' parameters.

The shapes of cells were optimised and dimensional tolerances were found using the SUPERFISH code[2]. The everage accelerating field necessary to reach the energy of 4MeV in configuration composed of 6 accelerating cells is 30MV/m and maximum field on the surface is below 46MV/m. The corresponding calculated RF power dissipated in each chain of the structure is 0.72 MW in pulse. Both chains are fed with microwave power from the same magnetron, throughout a special coupler which splits the power into two halves, with 90^0 phase-shift between them. In this way during transmission of bunched accelerated beam, in all cavities exist accelerating fields of proper phase. To avoid the RF coupling between successive accelerating cells the beam hole is only 6mm in diameter. The beam dynamics simulations (Fig.2) show the possibility of acceleration of over 300 mA electron beam bunch.

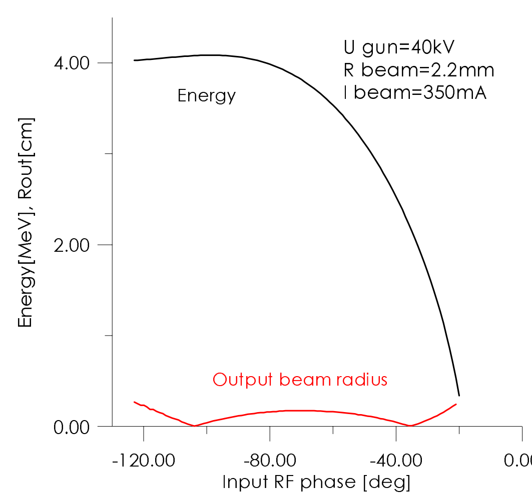

Fig.2 Output energy and output beam spot size in „supershort" structure

2 DESIGN AND TESTING PROCEDURES

The full-scale model of "supershort" accelerating structure 4 MeV was designed and built in 1998. As material for construction a technical copper was used. The principal aim of this model was verification of mechanical dimensions of accelerating and coupling cavities important for obtaining proper resonant frequency, dispersion curve, as well as over critical coupling of the structure with feeding wave guide. Results of model's measurements, and careful inspection of technological procedures, served to elaboration and construction of the prototype from OFHC copper .

The prototype structure is composed of two identical substructures A and B, each one having 3 accelerating and 2 coupling cavities. Electrical identity of both substructures is one of essential conditions for achieving the main goal of the project - acceleration at high average axial field.

The microwave measurements were carried out step by step after every stage of mechanical execution [3]. The first tuning done before soldering process, gave satisfactory identity of substructures and proper resonant frequency - according to design data.

An important component of the system is 3-db directional coupler at the input to the structure. Its aim is the splitting of RF power into two equal parts for supply of both substructures. The measurements confirmed, that only 0.3 percent of supplied power goes back to generator as reflected wave. It gives a perfect isolation of RF generator from loading by the structure. The measured data of the coupler were:

coupling coef. - C = (3 ± 0.15) db

phase shifting - $\Phi = 91^0$

attenuation - T < -0.15 db

The achieved identity of substructures' frequency with 3 dB power divider was

$$f_{\pi/2\,A} - f_{\pi/2\,B} \leq 1.5 \text{ MHz}$$

After the first soldering, frequencies of side coupling cavities were corrected, and before second soldering the tuning holes in these cavities were closed. The transitions sections to waveguides in the middle cavities were connected in following soldering.

After the second soldering, final tuning of accelerating cavities was effectuated. For tuning procedures the approximation was adopted:

$$k_2 = k_3 = 0$$

(no direct coupling between consecutive coupling or accelerating cavities)

The only important coefficient was k_1 - coupling between neighbouring accelerating and coupling cavities. The accelerating cavities were tuned for the mode $f_{\pi/2}$ for minimum of electric field in coupling cavities. For a given coupling coefficient k_1, the frequencies of modes

Fig.3 The 4 MeV “supershort” accelerating structure.

f_0 and f_π are described as:

$$f_0 = f_{\pi/2}\,(1+k_1)^{-1/2}$$
$$f_\pi = f_{\pi/2}\,(1-k_1)^{-1/2}$$

For determined experimentally frequencies of the modes f_0 and $f\pi$, the frequency of $f\pi/2$ can be calculated:

$$f_{\pi/2} = f_0 \sqrt{\frac{2}{1+(\frac{f_0}{f_\pi})^2}}$$

At this frequency, the "stop band" on the dispersion curve approaches zero.

Using this procedure, both substructures were tuned to the operating frequency

$$f\,\pi/2 = 2.999187 \text{ GHz}$$

Two identical dispersion curves give coupling k_1=2.6% with stop band - below 5 kHz.

Coupling to the waveguide was $\beta = (1.7 \pm 0.02)$.

Measurement of axial field distribution, done by perturbation method, indicated 3% deviation of uniformity, what is tolerable.

The quality factor Q_0 achieved for both substructures was: Q_0 = 10 000 to be compared with 11 500 of theoretical value.

3 CONSTRUCTION OF THE STRUCTURE

Mechanically, high-gradient accelerating structure shown in Fig.1 and Fig.3 forms an integral unit connected with electron gun and waveguide coupler.

Composed of two interdigitised chains of resonators independently fed with r.f. power is exited from the same magnetron, through power coupler-divider and transition section matching an impedance of waveguide to the resonant structure.

Feeding waveguide is connected to middle cell in both chains. The side-coupling cells are machined in common copper blocks with accelerating cells. There are seven copper slices of cylindrical form and thickness 25 mm. Every slice has on both sides the halves of accelerating and coupling cavities. Position of dividing planes at accelerating cells equators between slices ensures:

- precision machining of complicated shapes of cavities
- precise correction of cavities' frequency during tuning

Heat generated in the structure, is transmitted to cooling channels with water flow in closed circuit equipped with temperature control.

Vacuum tightness of the structure is achieved by two step soldering in vacuum furnace, with help of silver based alloys. Final tuning of the structure is realized in several steps:

- shape correction of cavities by machining before soldering
- shape correction of coupling cavities with tuning pegs done after first soldering
- local shape deformation of accelerating cavities after second soldering

Diode type electron gun is connected to the accelerating structure in a detachable way and sealed with metal sealing rings. Electron emitter is of dispenser type cathode of small dimensions, what with proper optics gives narrow electron beam of designed current intensity. The copper anode of the gun is fastened to the first structure's cell.

The waveguide coupler is done from stainless steel, and connected to the structure's flanges with gold sealings. At the input port, and the side port for water load, there are located standard ceramic waveguide windows. An additional port in the coupler is provided for connection of vacuum ion-pump. All connections on the ports are sealed with high-vacuum gold sealing rings.

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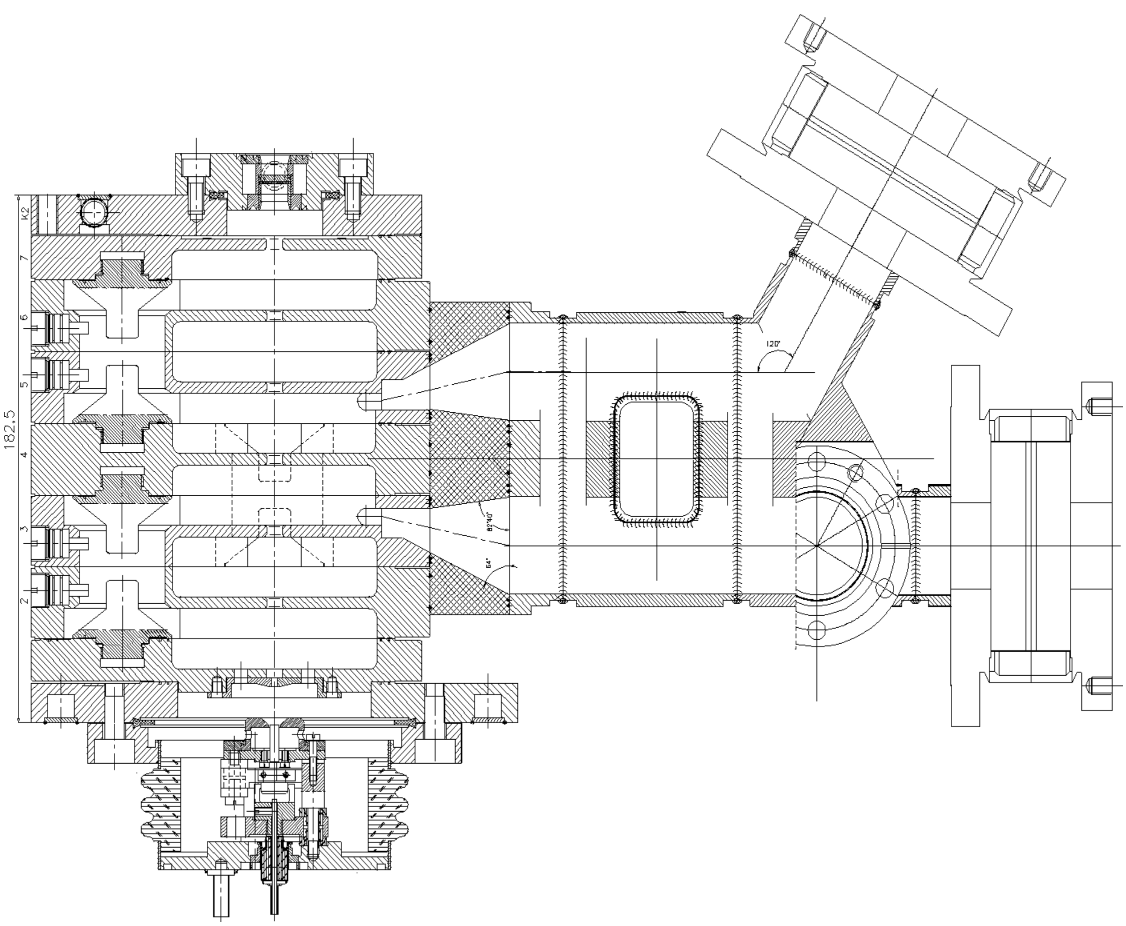

Fig. 1: Cross-section of high gradient 4 MeV structure