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THE DESIGN OF 1 MeV PROTON LINAC OPERATING IN CW

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Abstract

Experimental results and computer simulations of electrodynamic and thermodynamic characteristics are presented for an accelerating structure that is excited in the TM_{010}^{0} mode and that has the accelerating channel of URAN-1M located in the diametric plane. The idea of using this structure in the particle accelerator URAN-1M, located at the Baikov Institute of Metallurgy and Materials Science, with the goal of increasing the average beam current is explored.

INTRODUCTION

1 MeV Proton LINAC URAN-1M was developed and been in successful operation for many years at the A.A.Baikov Institute of Metallurgy and Materials Science (IMET), Russian Academy of Sciences (RAS) [1, 2]. Currently, IMET is planning to upgrade this LINAC to achieve higher average beam current. As the pulse beam current is close to the Coulomb limit, only an increase in the duty factor could allow to increase the average beam current. The high duty factor operation runs into heatsink problems. The development of a new more efficient accelerating structure could reduce the level of RF power and cool down the structure.

INVESTIGATION OF MOCKUP E-TYPE ACCELERATING STRUCTURE

The accelerating structure [3], excited in TM_{010}^{0} mode, with accelerating channel in the diametric plane, was selected as prototype for the new accelerating structure. Figure 1 shows the design of this structure. The two longitudinal bars, that hold the accelerating channel with drift tubes are placed on two cylindrical supports inside of the cylindrical cavity and are placed at its central axis. The diameter of the cavity is D=420 mm, the height of cavity is H=263 mm. The accelerating channel consists of 12 drift tubes, the tubes' length are 20 mm and gaps between them are 12 mm. The channel was designed for relative speed of protons β=0.022 ($\beta=v/c$, where v – speed of protons and c – speed of light in free space).

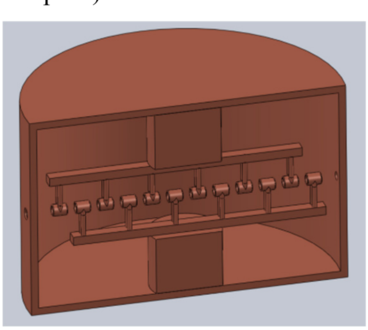

Figure 1: The model of the accelerating structure operating in TM_{010}^{0} mode.

As the result of simulating the accelerating structure in CST Microwave Studio, it was computed that $f_0 = 174.5\ MHz, Q_0 = 9457,\ R_{sh} = 260\ M\Omega/m$. Figure 2 presents the calculated field distribution.

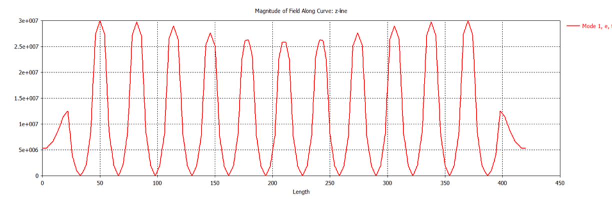

Figure 2: E_z field distribution calculated using CST Microwave Studio.

The maximum E_z field in gaps depends on distance between these gaps to the middle of the accelerating channel. For longer distances, the field in the gaps is higher, for shorter distances, the field in the gaps is lower. Growing electric potential along cylindrical supports and further along the longitudinal bars results in growing field distribution.

Wrapping of copper foil around the longitudinal bars and its insertion under their cylindrical supports has redistributed the electrical potential and made accelerating field uniform along the accelerating channel. Figure 3 shows the wrapped parts of the accelerating channel.

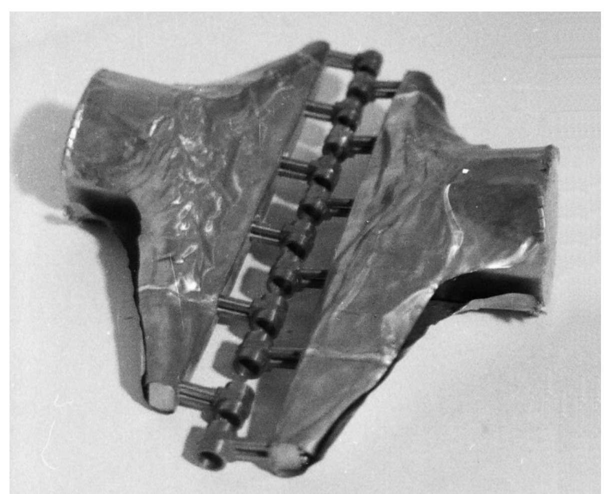

Figure 3: Acceleration channel with wrapped parts.

The cavity of this structure is composed of five machined copper cylinders with 420 mm inner diameter. To provide good electrical contacts, two flanges squeezed the cavity using twelve threaded rods of 12 mm in diameter. The 2 mm wide cylindrical contact tooth in the top of the cylinder's surface also helped provide good electrical con-tacts between cylinders and lids (Fig. 4).

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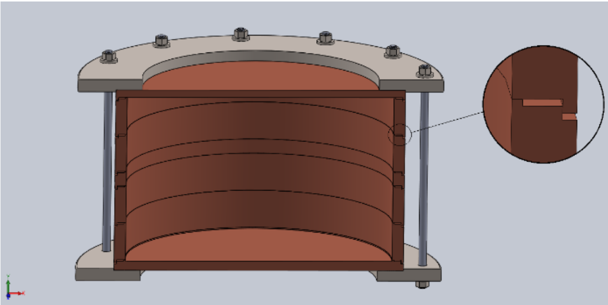

Figure 4: The design of the cavity.

The results of measurements of the mock-up structure are presented in Table 1.

Table 1: Results of Measurements

f_0, MHz	$R_{sh}, \frac{M\Omega}{m}$	Q_0
170.613	287	9171

Figure 5 shows the measured distribution of the accelerating field.

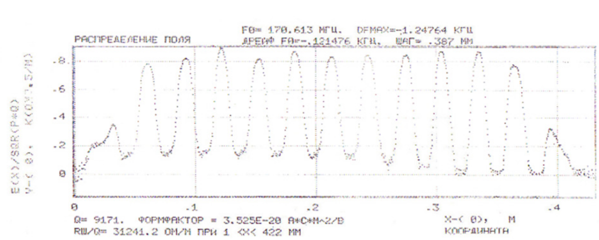

Figure 5: The tuned distribution of accelerating field measured using instrument PIRC-1.

ACCELERATING STRUCTURE OF 1 MeV PROTON LINAC

The next goal was to develop the new accelerating structure based on the above investigated structure and the accelerating field distribution of URAN-1M structure [4]. Figure 6 demonstrates the field distribution of URAN-1M structure.

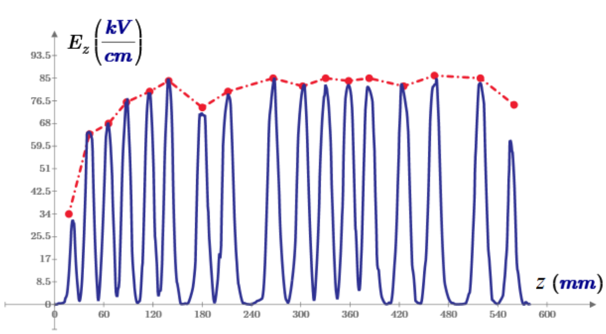

Figure 6: The distribution of the accelerating field in the accelerating structure of the accelerator URAN-1M.

This field distribution is unique in that the accelerating field in gaps is growing from the first to the sixth accelerating gap. The new design uses the change of potential along the radius of the cylindrical cavity of the resonator excited in TM_{010}^0 mode. The first six drift tubes (Fig. 7, pos. 1, 2) are connected to the bottom and top of the cavity at different radii to achieve a growing field. The rest of drift tubes are attached to the longitudinal bars that are sitting on the big cylindrical supports in the centre of resonance cavity (Fig. 7, pos. 3, 4) and on the shorting conductors (Fig. 7, pos. 5, 6). Those are used for adjustment of the field distribution.

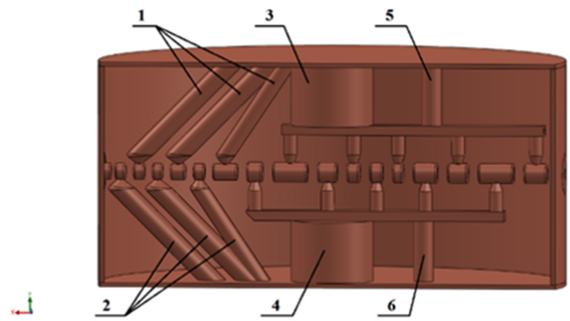

Figure 7: The new accelerating structure of URAN-1M excited in TM_{010}^0 mode.

The simulation of electromagnetic field of the proposed accelerating structure in HFSS ANSYS Electronic Desktop showed that it is possible to tune the field distribution rather close to what is required (Fig. 6).

Adjustments in positions of the supports of tubes (Fig. 6, pos. 1 and pos. 2) that attached to the lids of cavity, tune the fields in the first six accelerating gaps. Adjustments of the main cylindrical supports' position (Fig. 7, pos.3, 4) and the positions of the shorting conductors (Fig. 7, pos. 5, 6) tune the field distribution along the rest of the accelerating channel. The installation of different shims around the main cylindrical support allows for frequency tuning.

THE RF AMPLFIER

The high shunt impedance allows to use lower level of RF power to achieve the required field distribution. The calculation showed that 15 kW of power would be enough to reproduce the field distribution of the URAN-1M structure (Fig. 6). The reduction of RF power creates the condition for higher duty cycle and even for operating LINAC in CW regime. CW regime allows increasing the average beam current up to 4.0 mA.

The other benefit from using lower level RF power is that a cheaper RF amplifier could be used that has smaller dimensions. Specifically, one cabinet measuring 482 mm x 450 mm x 800 mm could contain such 15 kW solid-state amplifier.

COOLING OF ACCELERATING STRUCTURE

The simulation of thermal regime in ANSYS Workbench using steady-state thermal solver showed that the supports of the drift tubes, the longitudinal bars, the supports of the accelerating channel, shorting conductors and cylindrical surface of the main chamber all require water-cooling. Additional two spots in each lids of the cylindrical cavity

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should be water cooled down. The design of water cooling system is presented in the Fig. 8.

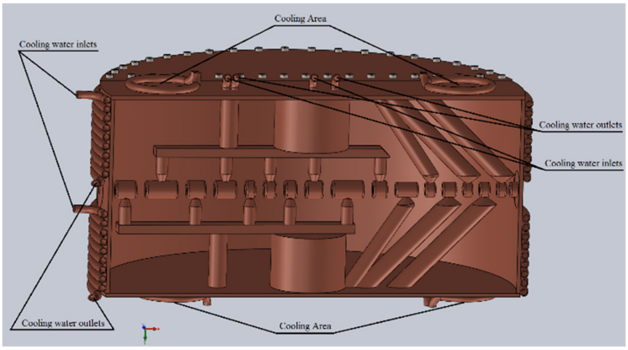

Figure 8: Water cooling system.

The steady-state thermal simulation in ANSYS Workbench showed that temperature of any part belonging to the accelerating structure will be below 78°C, if the temperature of cooling water is sustained below 35°C (Fig. 9).

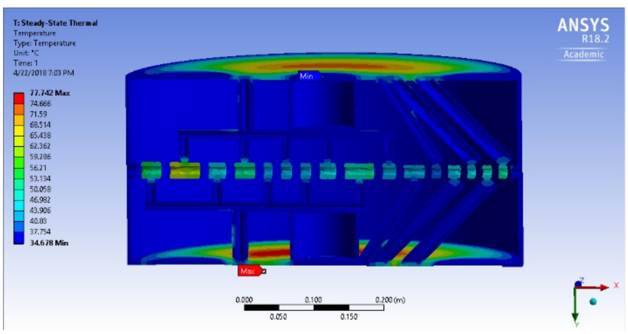

Figure 9: The steady-state thermal simulation of the accelerating structure running 15 kW CW of RF power

Water cooling cylindrical parts are arranged as coaxial pipe. The inlets are connected to the inner pipes, outlets are connected to the space between outer and inner pipes. 10 mm in diameter copper pipes are soldered to the outer cylindrical surface (Fig. 8). Longitudinal bars are water cooled. There are also four spots, optimally soldered on the top and bottom of the cylindrical cavity that are also water cooled. The cooling system requires 23 L/min of water, if the water temperature is to be supplied at 22°C.

To reduce mechanical deformation due to heat generated from the RF power, the centers of cavity lids have stainless steel fixtures to prevent deformation in the central part of the cavity. The static structural simulation in ANSYS Workbench showed maximal deformation causes 292 μm deflection in the last drift tube position (Fig. 10). The deviation of the frequency due to total deformation will be below 50 kHz, the maximum deformation takes places in the position of the first and last drift tubes.

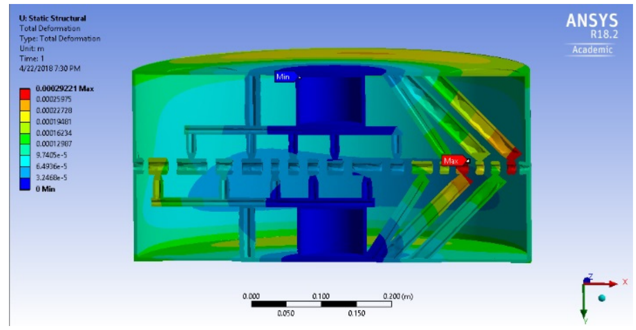

Figure 10: Static structural simulation in ANSYS Workbench of the structure.

CONCLUSION

The present design shows possibility to build 1 MeV LINAC for acceleration of light ions, operating in CW mode. The average beam current could reach at least 4 mA. This LINAC could be used for imitation of influence of transmute hydrogen. It also be used to study mechanical properties of austenitic steels, to study degradation of their mechanical properties, and to study embrittlement of vanadium alloys under exposure to a proton beam.

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