optimized for a value of 190T/m, is commercially available for 31 mm long elements.

RF power considerations led us toward a design with an aperture radius of the cells of 4 mm, which results in a non normalized acceptance of 14.7 π mm mrad. This value, which is small in respect to the injected beam, results in the immediate consideration that a lot of beam will be lost at the entrance of the first module. Transmittance has been optimized to a total value of 9%, while the useful part is 8.4%: this latter being defined as the ratio between the amount of extracted beam sufficient for the therapy (within the energy window 61-62MeV) and the injected one. Nearly 70% of the injected beam is lost within the first 2 modules. These figures have been obtained taking a synchronous phase of -18°. Eleven PMQs are positioned between the adjacent tanks and at the beginning and exit of ACLIP. The resulting total length is 3.1m.

Simulations have been performed to study the effect of electrical field modulation on beam transmittance and peak energy in the last module. Results show that the transmittance is not influenced, the energy spread is constant and the final energy may be modulated by 3 MeV by changing the electric field in a range of 5 MV/m.

MECHANICAL DESIGN

Accelerator elements

All the ACLIP modules are essentially identical, except for their progressive increase in length, due both to the increasing velocity of the protons and to the different numbers of accelerating cells. The accelerating structure of each module consists of three basic elements: the “basic cell plate”, the “bridge coupler” and the “end cells”. The basic cell plate is the elementary building block of a tank. Particular care has been devoted to the design of this item to take into account mechanical limitations arising from the low value of β (which limits the cell longitudinal size), to simplify the brazing process (limiting the number of the involved pieces) and to maximize the shunt impedance. The bridge coupler is composed of 3 basic copper elements and the end cells are simply single pieces. A waveguide brings the RF power through a slot in the bridge. A pick up loop for RF field measurements is available in each end cell and movable rods are inserted in all the elements of the module to tune the structure after the final brazing.

Materials, machining and brazing

All the module components, are made of copper OFE UNS10100 (according to ASTM B170 as chemical composition and ASTM F68 as mechanical properties and allowed defects) cold forged and lathed to the required size for the final machining (nearly 10 mm of extra material) in order to guarantee a maximum grain size of 100 μm. The stainless steel pieces are made of forged 316 LN stainless steel. All the first module pieces have been machined on numerically controlled milling machines, with dimensional and flatness tolerances of the order of 10 μm. The more stringent details required for the cell nose profile, have been verified using a 3D optical machine. A stress relieving process has been included after the rough machining of the pieces as a mandatory step in the final machining procedure.

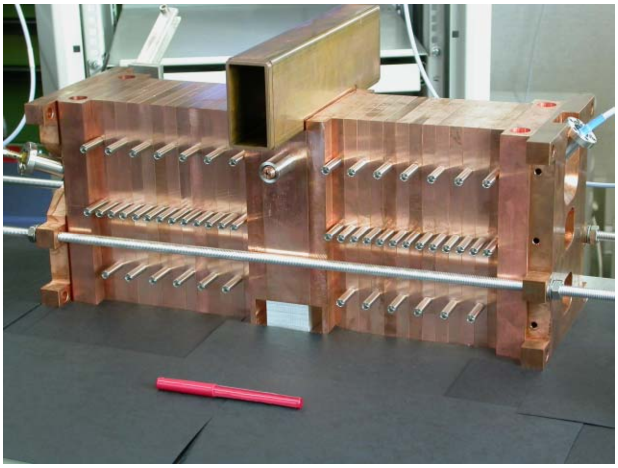

Figure 1: Assembly of the first module.

Cooling

The compact size of the module forced us to choose a cooling scheme based on external plates brazed on either side of the module. The plates provide internally machined water channels (8 x 10 mm size). Each module uses 8 plates connected in a serial-parallel scheme. An in depth investigation has been performed using Ansys finite elements code to maximize the cooling performances of these elements. This confirms that the maximum power that the structure may sustain is consistent with the maximum field available for acceleration. An autonomous Neslab chiller unit has been chosen for each module to provide a maximum of 10 l/min of water. This scheme allows 1.5 kW to be removed from the module, for a RF duty cycle of 0.05%, with a maximum temperature rise in the cooling water of 2°C and an increase in the cell nose temperature with respect to the lateral sides of 10°C.

RF ASPECTS

RF design

The RF design of ACLIP is based on the same mean accelerating field on axis in all the 10 tanks. The cavity shape has been studied by means of Superfish code at the frequency of 2998 MHz (at a working temperature of 28 °C). The design foresees a peak surface field such that the bravery factor is 1.8, with a mean axial field value of E=20MV/m. The behaviour of the coupled cavities has been studied by means of MWS Studio.

The quality indices to optimise the cavity behaviours are the shunt impedance and the thermal rise of the nose in the cavity. This analysis was conducted using Ansys and Superfish codes, as a function of the septum thickness and the nose cone angle. The coupling coefficient is of the order of 4% and the bridge coupler between the tanks is a

3-cell magnetically coupled one. The cells size has been optimized in order to allow the positioning of a PMQ within the bridge coupler.

RF tuning

The intrinsic complexity of the components of the module, along with their strict mechanical tolerances and the effects of the brazing process, may introduce unavoidable errors in the frequency and field shape. This problem has been approached from two sides. A new model has been developed and tested to understand and to correct the behaviour of SCL structures, starting from a reduced set of measurements. A new tuning system (the only one available), based on tuning rods, has been designed and incorporated in the mechanical components of the modules. It may be used to compensate errors even after the final brazing. This system is characterized by a maximum correction factor of 6.6 MHz for each accelerating cell (two tuners are available) and 8 MHz for each coupling cell (two tuners are available).

Low power RF measurements

The machining process developed during the initial tests on the basic elements of the module, along with the use of good quality copper material, has enabled the production of high quality components, also from the RF point of view. Indeed, field flatness of the order of 6.2% was obtained on single tanks before brazing without inserting any tuner rods. Preliminary insertion of the rods brought this value to 4.5%. After inserting the bridge coupler the whole module was retuned, using the additional tuner rods available in the bridge coupler to obtain final field flatness of 3 %. During these procedures the tuning mechanism proved to be extremely sensitive and repeatable.

High power tests

An agreement has been set up with e2v (Chelmsford, UK) to carry out high power testing of the first ACLIP module with a 4 MW magnetron/modulator (MPT5839) at the Chelmsford site.

The construction of a second module is already underway to attain a final energy, after the acceleration through the two modules, of 41 MeV. This will allow us to verify experimentally, for the first time, the possibility to use phase locked magnetrons for the powering of particle accelerator modules. RF power components used in multi-modules linac, are currently based on klystron amplifiers. Even if these components have experienced a high degree of technologic evolutions in the recent years, to make them more compact and less expensive, they are still the most costly part in the economic budget of a linac. Beam measurement related issues are also driving the building of this second module. The energy gain produced by the first module is quite modest and this makes it difficult to detect the beam related parameters. Beam dynamics studies have confirmed that adding a second module and thus increasing the energy gain may resolve these difficulties.

ACTIVATION STUDY

The optimization of the linac design has to take into account also the beam losses along the machine that lead to activation of the components during accelerator operation. In case of a subsystem failure, activation may pose severe limitations on maintenance schedule resulting in a limited performance of the accelerator. Since it has been shown that nearly 70% of beam losses occurs in the first 2 modules, the study of the activation process has been limited to the interaction of the primary 30 MeV beam with the copper cavities of the first module.

The study has been carried out using both an analytical model and a simulation process based on FLUKA. The results obtained, in a scheme which foreseen a continuous irradiation time of 100 hours, are that after 1 hour from the beam stop, the dose rate at contact is of the order of 18 mSv/h. This value is well within the allowed limit that the Italian Legislation imposes for professional workers involved in ionizing radiation.

PRESENT SITUATION

The components of the first ACLIP module were machined by the end of February 2007 and low power RF measurements were performed in March 2007. The components were then delivered to CERN for the brazing process. The bridge coupler and the RF waveguide were recently brazed. All the elements of the RF power experimental setup are ready to be transferred to e2v in Chelmsford for the RF power test, which is expected to take place at the end of 2007. On completion of the power test, the module will be moved to INFN-LNS in Catania to carry out beam acceleration tests using a 30 MeV proton beam from the Superconducting Cyclotron.

The design of the second ACLIP module has been accomplished and we plan to start the machining of the components by the end of 2007.

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