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COMPACT PROTON ACCELERATOR IN UHF BAND AT KAHVELab *

S. Esen †, A. Adiguzel, O. Kocer, Istanbul University, Turkey
A. Caglar, Yildiz Tech. University, Turkey
E. Celebi, S. Oz, V. E. Ozcan, Bogazici University, Turkey
A. Karatay, F. Yaman, O. H. Yilmaz, Izmir Institue of Technology, Turkey
U. Kaya, Istinye University, Turkey
A. Kilicgedik, Marmara University, Turkey
G. Turemen, Turkish Energy, Nuclear and Mineral Research Agency, Turkey
N. G. Unel, UCI, Irvine, California, USA

Abstract

Proton Test Beam at KAHVELab (Kandilli Detector, Accelerator and Instrumentation Laboratory) project aims to design and produce a radio frequency quadrupole (RFQ) operating at 800 MHz in Istanbul, Turkey using the local resources. The beamline consists of a proton source, a low energy beam transport (LEBT) line including the beam diagnostic section and the RFQ cavity itself. This RFQ is 4-vane, 1-meter-long cavity to accelerate the 20 keV beam extracted from plasma ion source to 2 MeV. Its engineering prototype is already produced and subjected to mechanical, low power RF and vacuum tests. In this study, the results of the first test production, especially the bead-pull test setup will be discussed.

GENERAL DESIGN

PTAK (Proton Testbeam At KAHVELab) RFQ design process aimed to achieve a state of the art accelerator with the local production capability. Design goals as chosen to achieve a 30% acceleration of a 1 mA proton beam to roughly 2 MeV using less than 60 kW pulsated RF power at 800 MHz. In process we iterated our initial cavity design and decided on a new intervane voltage value all to achieve a better power usage. With the intervane voltage set to 33 kV and the cavity geometry designed, we were left with a challenge of designing the vane-tip geometry out of the standard process. We decided to replace shaper and gentle buncher sections with a much shorter design. Then we set the acceleration section modulation and the synchronous phase. Also we keept both intervane voltage and the R_0 constant throughout the accelerator. In the end only two values for the replacement section needed to be determined along its length; modulation and the synchronous phase. We wrote a script that randomly tests different values of modulation and phase with PARMTEQM. Batches of these simulation results were tabulated and bounds of values adjusted. The minimum longitudinal radius of curvature for the vane tip value also important machinability of the parts and promising designs were evaluated accordingly. After few iterations of limits we found the design and manually tweaked the values a bit more to achieve the final design which is shown in Figure 1 [1,2]. The parameters are shown in Table 1.

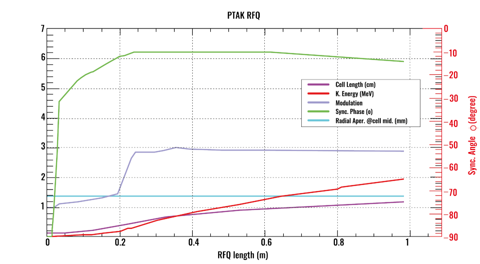

Figure 1: General design parameters of PTAK.

Table 1: Design Parameters

Parameters	PTAK-RFQ
RF Frequency	800 MHz
Length	980 mm
Input Energy	20 keV
Output Energy	2 MeV
Vane Voltage	33 kV
Minimum Aperture	0.64 mm
Maximum Aperture	3.0 mm
Vane Tip Radius ρ	1.4 mm
Transmission	30 %
Acceptance (Total Norm.)	0.16 πmmmrad
RF Peak Power	48.5 kW

PROTOTYPE PRODUCTION

The production of the trial RFQ module, whose vanes were designed using Parmteq programs, was manifactured in DORA MAKİNA company in Ankara, Turkey. Manufacturing error of the prototype is below 20 micron. Parameters of prototype in Table 2 and the picture of it can be seen in Figure 2 [3].

Table 2: The Prototype Measurement Results

Parameters	Prototype RFQ
Frequency	799.6 MHz
Max. Assembly Error	±18 um

* Work supported by TUBITAK Project No: 118E838
† yavuzzseyma@gmail.com

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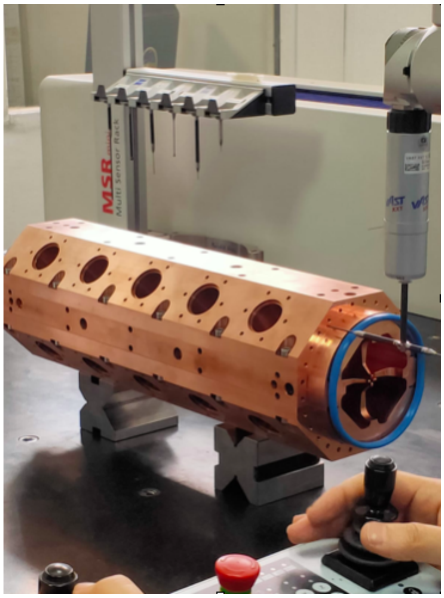

Figure 2: Picture of prototype module at CMM frame.

ELECTROMAGNETIC DESIGN

The cavity cross section of the four-vane type RFQ is optimized with SUPERFISH and designed to operate at 800 MHz with CST MWS eigenmode solver including 3D effects. The features of the tuners, vacuum ports and the cutbacks of the end sections are tuned for the operating frequency and the field flatness over the cavity. The quality factor and the RF power loss on the cavity walls was primary consideration while the design phase of whole structure to achieve low as possible RF power requirement. Designed cavity has quality factor of 6973 and power dissipation of 46.2 kW (without tuner, RF coupler and vacuum ports) according to 3D computations. The resonant frequency of the cavity is calculated as 796.05 MHz when tuners are at flush position. The Kilpatrick factor is estimated as 1.39 which is found acceptable for this structure. Electric field and magnetic field simulations of RFQ are done by CST, which can be seen in Figure 3, before the production process.

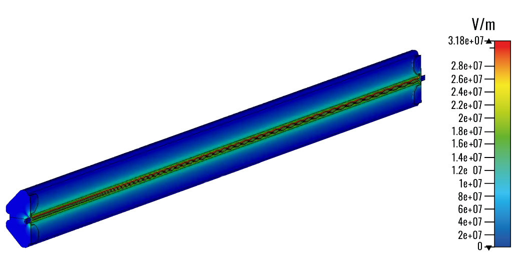

Figure 3: Electric field map of RFQ in CST.

RF POWER COUPLER DESIGN

The RF power requirement of KAHVELab's 800 MHz RFQ is calculated by DemirciPRO, Parmteq and CST Softwares as below 50 kW to obtain 2 MeV proton beam. Inclusion of 3D effects and the losses on the waveguide type transmission line, increases the operational need to about 60 kW with starting repetition rate of 1 Hz. This power is to be produced by two PSUs and delivered to the RFQ by a transmission line containing custom-built circulator and RF combiner which are already built and tested. The power supplies comprise of a solid state power amplifier up to 5 kW and TH582, TH382 tetrode tubes, with each PSU providing to about 35 kW peak power for a typical pulse duration of about 100 μs. Power coupler is designed and simulated to transfer produced power from transmission line to RFQ. The scattering parameters of the coupler has been used to determine reflection and transmission levels obtained via the CST Microwave Studio, can be seen in Figure 4. Also, alumina and peek dielectric materials used in the coupler as RF window has been examined to find out RF power levels at which the multipacting effect occurs has been examining. Alumina window simulation study can be seen in Figure 5.

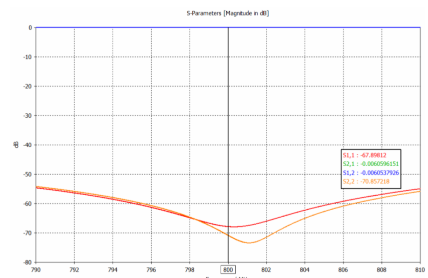

Figure 4: Simulated obtained S-Parameters for alumina window coupler.

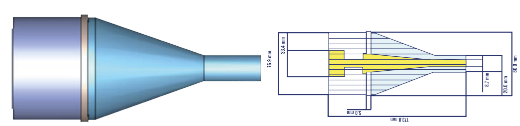

Figure 5: Alumina window coupler design and size image.

Vacuum Tests

Vacuum tests are finalized with He Leak detector for RFQ prototype in Ankara and vacuum level is 2.79×10^{-6} mbar. Sealing is provided by Viton 3D O-ring and the results are compatible. Thank you TENMAK for providing He Leak test device [4].

BEADPULL MEASUREMENT

In the beadpull experiment performed with the RFQ module, 7 mm long and 4 mm diameter aluminum beads are passed from the midpoint of each quadrant close to the vane walls of the RFQ module, and the H magnetic field is expected to be disrupted. In Figure 6 [3], experimental setup of beadpull system is schematized.

Slater perturbation theory is used during the tests:

$$\frac{\Delta f}{f} \cong \frac{\Delta U}{U} = \frac{\tan[\phi(f)]}{2Q_L} = \frac{-\pi r^3}{U}(\epsilon_0 \frac{\epsilon_r - 1}{\epsilon_r + 2} E_0^2 + \mu_0 \frac{\mu_r - 1}{\mu_r + 2} H_0^2)$$

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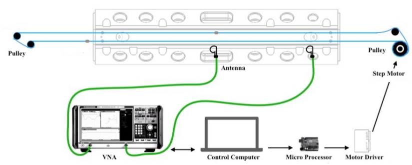

Figure 6: Scheme of the beadpull setup.

During the experiment, phase shift for each quadrupole measured by VNA can be seen in Figure 7.

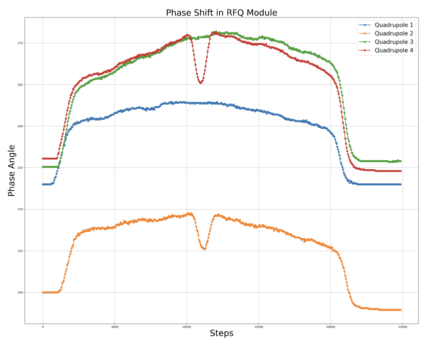

Figure 7: Phase shift caused by bead perturbation.

During the experiment, perturbated magnetic field of cavity for each quadrupole calculated by using Slater perturbation theorem can be seen in Figure 8.

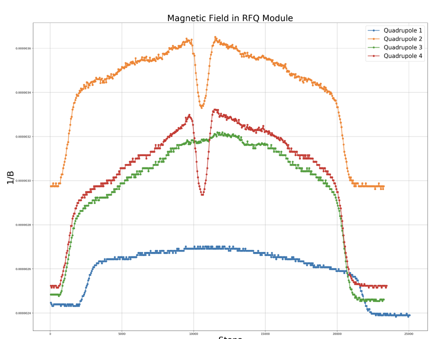

Figure 8: Magnetic field changing inside the cavity.

LabVIEW Control System

The LabVIEW control program of the bead-pull experiment prepared for the RFQ trial module is shown in Figure 9. In this program, in which many parameters of the system such as homing, direction, motor speed and step length can be controlled, VNA parameters can be manipulated, the distortion caused by the entry of the bead into the system on the magnetic field is plotted with the phase values [5].

SURFACE ROUGHNESS

To examine surface roughness effects for the fundamental RF cavity parameters such as resonant frequency and quality factor sinusoidal roughness pattern proposed on the cavity walls consists of a combination of two modules. The maximum values for the amplitudes of the roughness model were chosen as 50 micrometers. As a result of our first investigation, a relatively slight decrease

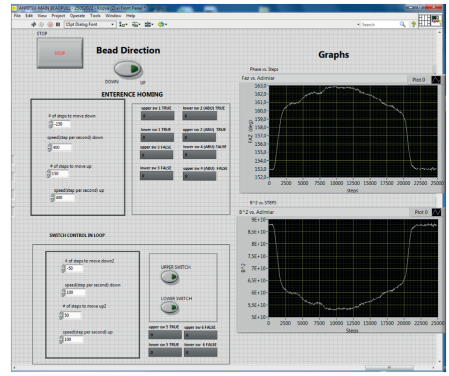

Figure 9: Control program user interface.

in the quality factors of the first four cavity modes was observed; see Figure 10, where the first two modes represent dipole modes, and the third and fourth modes represent quadrupole modes. Furthermore, for our case, surface roughness caused a frequency shift in all modes in the range of several hundred kHz; see Figure 11, which could be treated mechanically via a tuner [1].

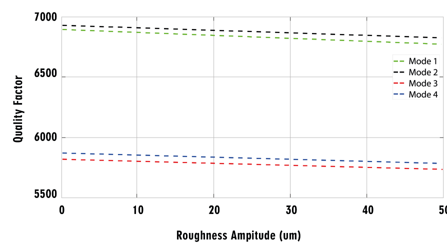

Figure 10: Effect of the surface roughness on the quality factor.

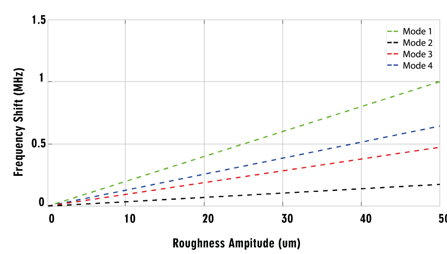

Figure 11: Effect of the surface roughness on the frequency.

CONCLUSION

Prototype RFQ module @ 800 MHz produced; mechanical, electromagnetic and vacuum measurements ongoing, electromagnetic field and related phase/frequency shift measurements made by bead-pull method, surface roughness simulations and related Q value changes are shared in the paper. The project aims to combine the 2 modules to accelerate the proton beam to 2 MeV energy by the end of 2023.

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