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DESIGN AND CACULATION OF THE RF SYSTEM OF DC140 CYCLOTRON

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Abstract
Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research carries out the works under creating of FLNR JINR Irradiation Facility based on the cyclotron DC140. The facility is intended for SEE testing of micro-chip, for production of track membranes and for solving of applied physics problems. The main systems of DC140 are based on the DC72 cyclotron ones that now are under reconstruction. The DC140 cyclotron is intended for acceleration of heavy ions with mass-to-charge ratio A/Z within interval from 5 to 5.5 up to two fixed energies 2.124 and 4.8 MeV per unit mass. The intensity of the accelerated ions will be about 1 pμA for light ions (A<86) and about 0.1 pμA for heavier ions (A>132). The designed RF-system of the DC-72 cyclotron with a half-wave cavity is not suitable due to the big vertical size. For this reason, a new quarter-wave RF-system was developed for the DC140 cyclotron project. The results of calculating the parameters of the new RF-system are given in this work.

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INTRODUCTION

The RF system of the DC140 cyclotron works as a resonator, which creates the necessary voltage in the accelerating gaps for acceleration of beam. The quarter-wavelength coaxial resonant cavity has been adopted in DC140.
According to the technical documentation of the DC140 cyclotron the main parameters of RF system are presented in the Table 1.

The RF system of DC140 cyclotron consists of:

- Dee;
- Stem;
- Cavity
- Adapter sleeve;
- Outer barrel;
- Short-circuiter;
- Coupling loop;
- Tunable shorted terminal

Table 1: The main technical parameters of the RF system of DC140 cyclotron

Parameter	**Value**	
RF frequency, MHz	8.632	
Harmonic number	2	3
Energy, MeV/u	4.8	2.124
A/Z range	5.0÷5.5	7.57÷8.25
RF voltage, kV	60	
Number of dees	2	
Resonant type	$\lambda/4$ coaxial	
Dee azimuthal extension	40°	

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CALCULATION OF THE RESONANT

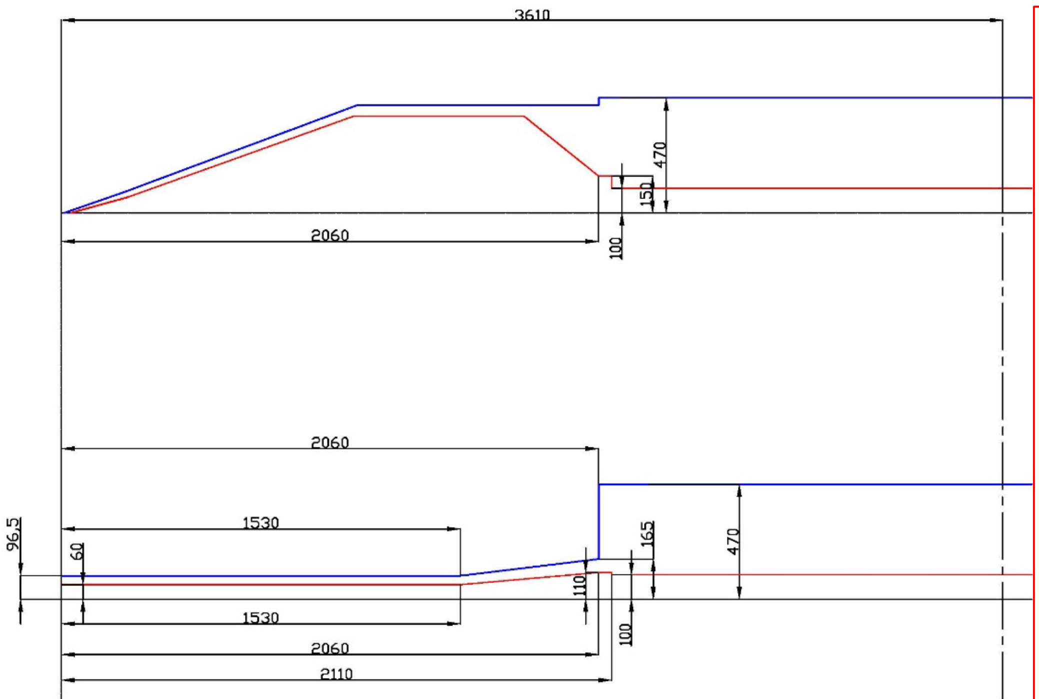

Figure 1: Sketch of the cavity system of DC140 cyclotron.

The geometry of the cavity system is limited by the layout of the cyclotron magnet and magnetic channel MC2. It is installed inside the dee. The widest part of the dee was lengthened to protect the magnetic channel from the cavity electromagnetic field.

The height of the dee gradually increases from a distance of 1530 mm from the center of the cyclotron. This ensures its structural strength and fastening to the stem.

The dee enters the coaxial part of the RF system by 50 mm to avoid electrical breakdown between the electrodes at the attaching point of the adapter sleeve with the outer barrel

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The results preliminary calculation and 3D simulation has been calculated, as shown in Table 2.

Table 2: Results Preliminary Calculation and 3D-Simulation

Parameter	Preliminary	3D-Simulation
Frequency *f*, MHz	8.632	8.632
Cavity length, mm	3610	3606
Power dissipation *P*, kW	7.57	8.12
Quality factor *Q*	8452	8054

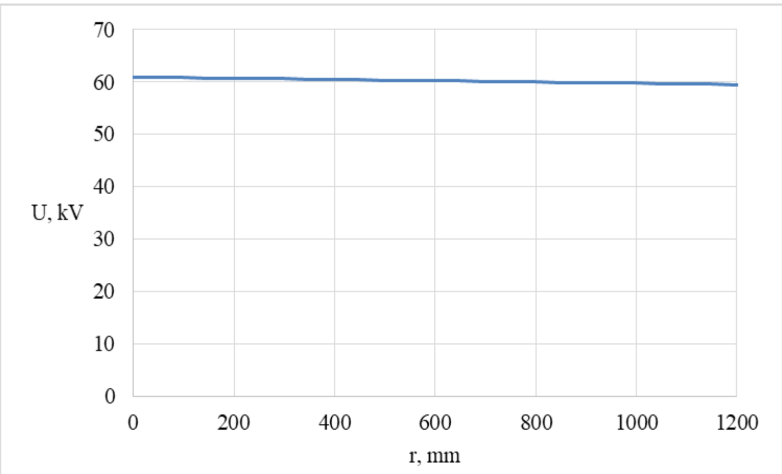

Figure 2: The voltage distribution along the radius.

The RF cavity created for to generate the high-frequency electric field in the gap between the dee and the ground. Accelerating voltage was obtained according to the integral of tangential component of the electric field in the accelerating gap on a fixed radius. The voltage distribution along the radius was shown in Fig. 2. The dee voltage practically does not change with increasing radius.

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POWER LOSS

The surface loss of the conductors can be written as:

$$P = \frac{1}{2} \cdot \sqrt{\frac{\pi \cdot \mu \cdot f}{\sigma}} \cdot \int \left| \overline{H}_{\tau} \right|^2 \cdot dS \quad (1)$$

Where μ is the copper permeability, μ = 4π×10-7 H/m, f is the working frequency, σ is conductivity of the cavity materials (commercial copper); H is the magnetic intensity vector.

The distribution of power loss of each part has been calculated, as shown in Table 3.

Table 3: The Distribution of Power Loss of Each Part

Part	Cavity length (mm)	Power loss (W)
Dee	0 – 2110	973.9
Stem	2110 – 3606	4714.4
Cavity	0 – 1530	208
Adapter sleeve	1530 – 2060	672.7
Outer barrel	2060 – 3606	1045.7
Short-circuiter	3606	508.2
ALL	-	8122.9

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COUPLING LOOP

The geometric dimensions of the coupling loop are related to the power loss according to the formula:

$$2\pi \cdot \left(r_1 - \sqrt{r_1^2 - r^2}\right) + (r - r_{cut}) \cdot \ln\left(\frac{r_1}{r_2}\right) = \frac{\sqrt{2 \cdot W \cdot P}}{\mu_0 \cdot f \cdot I_{cav}} \quad (2)$$

Where r is the radius of the circle of the coupling loop, r_1 is distance from the stem center to the center of the coupling loop, r_2 is inner radius of the outer barrel, W is feeder impedance, I_{stem} is stem current at the location of the coupling loop, r_{cut} is cutting radius of conductor.

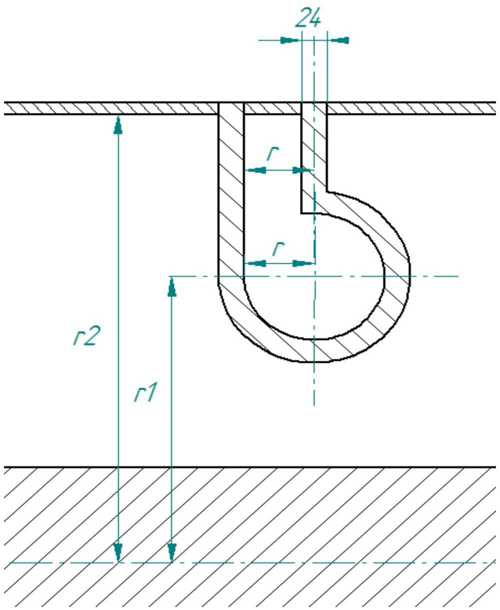

Figure 3: The conditional layout of the coupling loop.

Table 4: The Results of Calculating the Coupling Loop

r_1 (mm)	r_2 (mm)	r (mm)	M_{opt} (nH)	M (nH)	P (W)
400	470	83	7.62	10.55	65

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TUNING

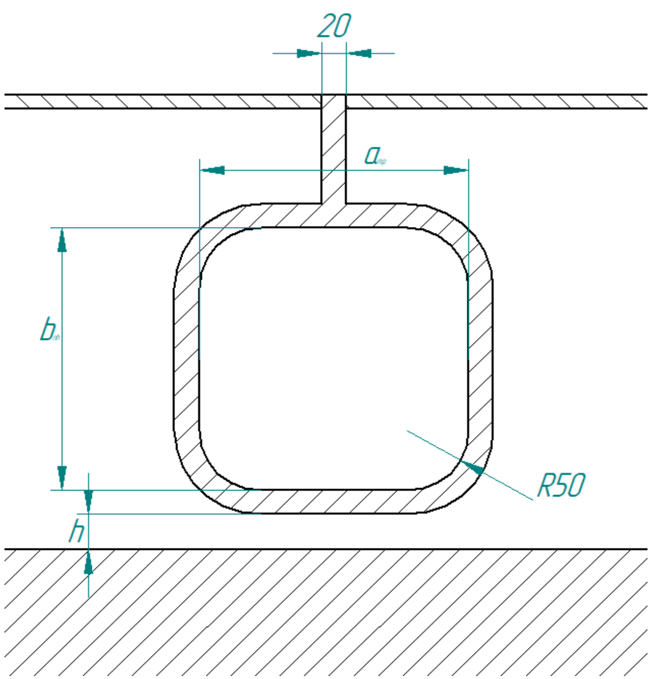

Figure 4: The conditional layout of the tunable shorted terminal.

Because of the RF power loss, increasing temperature must influence the resonance frequency of cavity. The tunable shorted terminal is used compensate for this frequency shift. The tunable shorted terminal is decided to be located on the top of the outer barrel at a distance l = 3300 mm from the center of the cyclotron, as shown in Fig. 4.

The tuning system is designed to cover the resonant frequency of the 8.632 MHz with bandwidth of ±13 kHz (~0.15 %f). The results of calculating the tuning system are shown in Table 5.

Table 5: The Result of Calculation the Tuning System

a **(mm)**	***b*** **(mm)**	***h*** **(mm)**	**Δ*f*** **(kHz)**	***P*** **(W)**
210	**210**	**20**	**29.22** (0.34 %)	**400.2**

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COOLING

The calculation results of cooling of the RF system are shown in Table 6.

Table 5: The Result of Calculation the Cooling System

Part	**$P_{+30\%}$ (W)**	**Q_V, l/min**	**d_{min} (mm)**	**δ (mm)**	**ΔL (mm)**
Half of dee	633.1	1.81	6.9	2	254
Stem	6128.8	17.53	21.6	3	86
Half of cavity	135.2	0.39	3.2	2	499
Adapter sleeve	874.5	2.5	8.1	15	151
Outer barrel	1359.4	3.9	10.2	15	201
Shorting-circuiter	660.6	1.9	7.1	5	283
Coupling loop	84.5	0.12	1.8	-	-
Tunable shorted terminal	455.9	1.5	6.3	-	-

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SUMMARY

The geometry of the resonator system of the DC140 cyclotron was chosen. This geometry provides an almost constant dee voltage with increasing radius. The characteristic parameters of RF cavity are calculated using simulation. Total power loss of the cavity is 8.59 kW. The coupling design has been completed through inductive coupling. It was decided that the design of the coupling loop will be identical to the U400M project. The tuning system is designed to the resonant frequency of 8.632 MHz with bandwidth of ±29 kHz.

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