10th Int. Particle Accelerator Conf. IPAC2019, Melbourne, Australia JACoW Publishing
ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB029

DESIGN OF THE ELLIPTICAL SUPERCONDUCTING CAVITIES FOR THE JAEA ADS*

B. Yee-Rendon†, Y. Kondo, F. Maekawa, S. Meigo, J. Tamura,
JAEA J-PARC Center, Tokai, Ibaraki 319-1195, Japan

Abstract

The superconducting CW proton linear accelerator for an Accelerator Driven Subcritical System (ADS) proposed by Japan Atomic Energy Agency (JAEA) employs elliptical cavities for the final acceleration of 180 MeV to 1.5 GeV. Since this energy region implies a changed of β from 0.55 to 1, two cavity models were developed using the geometrical betas of 0.68 and 0.89 to improve the acceleration efficiency. The study of the electromagnetic design was simulated using SUPERFISH (SF) code and python program to do variable scan, the results were benchmarked with CST Microwave Studio program (CST).

INTRODUCTION

The superconducting CW proton linac is a fundamental component of the Accelerator Driven Subcritical System (ADS) proposed by Japan Atomic Energy Agency (JAEA) [1]. The requirements of high beam power and CW operation support the use of superconducting cavity as the best candidate for this task , additional, to achieve the final energy of 1.5 GeV, the use of elliptical cavities represents the clear choice.

The selection of cavity types as well as the numbers of cells per cavity was based on similar project [2]. The number of superconducting families and their energy range operation were decided to achieve the maximum voltage gain per cavity (assuming sinusoidal electric fields and a fix synchronous phase of 30 °) and smooth transition between cavities (See Fig. 1). Table 1 shows a summary of the superconducting cavities families selected for the JAEA-ADS project.

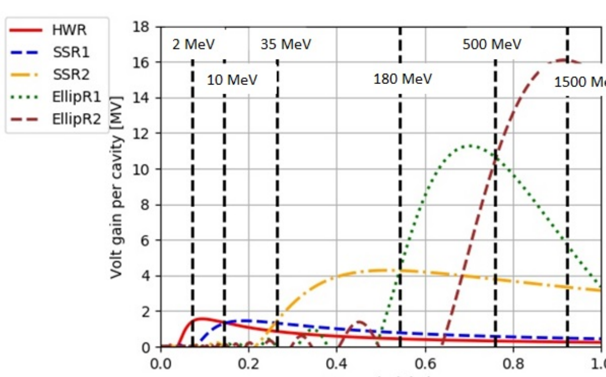

Figure 1: Voltage gain per cavity as a function of relativistic beta for the JAEA-ADS project.

Table 1: Parameters of the Superconducting Cavities

Cavity	Frequency [MHz]	β_g	Energy range [MeV]
Half Wave Resonator (HWR)	162	0.08	2-10
Single Spoke 1 (SSR1)	324	0.16	10-35
Single Spoke 2 (SSR2)	324	0.43	35-180
5-cell Elliptical 1 (EllipR1)	648	0.68	180-500
5-cell Elliptical 2 (EllipR2)	648	0.89	500-1500

SIMULATIONS

The 5-cell multicell elliptical cavity geometry was developed by using the programs SUPERFISH (SF) [3] and python [4] for the two-dimensional (2D) models and CST Microwave Studio (CST) [5] for the three-dimensional (3D) ones. The parametrization of the half elliptical cell is described in Fig. 2.

Using the common method for designing multicell elliptical cavities, the inside cell (the cell that is surrounded by other cells) and the end cell were designed with different geometries [6–10]. The reason is the change in the boundaries symmetries in the end cell due to connection with the beam pipes. This affects the flatness of the electric fields between cells, thus, the end cell geometry is adjusted to compensate that effect and keep the cavity frequency.

The criteria to choose the parameter values is described next:

- inside cell:
  - The cell length is defined as

$$L = \frac{\beta_g c}{4f}, \tag{1}$$

    where β_g is geometrical beta, c is the speed of light and f the frequency.

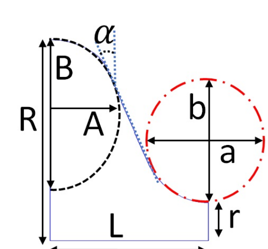

Figure 2: Parametrization of the half cell geometry. R is the cavity radius, L half of the cell length, r is beam pipe radius, A and B are the semi-axis of the ellipse dome, a and b are the semi axis of the ellipse iris and α is the wall angle.

---
* Work supported by Subvention for ADS development.
† byee@post.j-parc.jp

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB029

- The frequency tune is done by adjusting R or A/B or α, etc (only one variable at the time).
- A,B, a, b and α were changed to obtain the values of the figures merit required (if the parameter was chosen to tune the frequency, it was not used to improve the figures of merit).

• end cell:
  - Using the inside cell as baseline, only L and α were modified to preserve the same frequency and achieve a high value of the electric field flatness.

Most part of the geometry optimization was done in 2D by using a python interface with SF to make a variable scan, the design goals were:

- High gradient (lower enhancement factors: ratio of the magnetic peak with respect to the accelerating gradient (Hpk/Eacc) < 4.6 mT/MV/m and the ratio of the electric peak with respect to the accelerating gradient (Epk/Eacc) < 2.6 (standard values).
- Lower power dissipation which implies large R/Q and Geometrical factor (G).

After the cavity designs achieved the primary goal performances, the 3D models were created using CST. To achieve that a CST program was written to create automatic the cavity geometry. The models were simulated using tetrahedral mesh , which can fix better to complex geometries, and the number of mesh cells of the order of 10^5.

RESULTS

Figure 3 shows the values of the Epk/Eacc and Hpk/Eacc for different values of the iris ratio by adjusting the ellipse dome ratio and α to tune the frequency. After the comparison of the different variable to do the frequency tuning, It was founded that R was most effective for adjusting the frequency than the others. Therefore, R was used to tune the frequency for these studies.

Double variable scanning simulations were implemented, these scans generated surface plots for the figures of merits

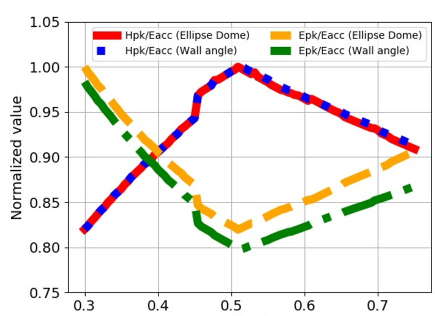

Figure 3: The electromagnetic peaks as a function of the iris ratio by adjusting the ellipse dome ratio (solid red line and dashed orange line) and adjusting α (dotted blue line and dashed-dotted green line) to tune the frequency . The values were normalized to maximum value of electromagnetic peaks.

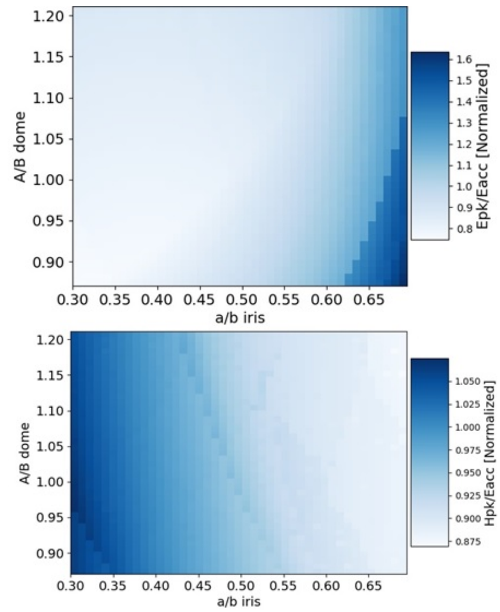

Figure 4: The surface plot by changing the iris and the dome ratio to select the parameters to minimize the Epk/Eacc (top) and Hpk/Eacc (bottom).

which were fundamental for the election of the parameters. As example of this, Fig. 4 presents the values of Epk/Eacc and Hpk/Eacc normalized to 2.6 and 4.6 mT/MV/m (the upper limits), respectively. It can be seen that region of a/b around 0.55 and A/B equals 1.05 represent the best trade off to achieve lower values for both electromagnetic peaks.

After the scanned of all the variables, the final parameters were selected, Table 2 presents the geometry values for the inside cell and end cell of the two elliptical models, the descriptions of the parameters are given in Fig. 2 and the units are in mm for length and degree for the angle, the next notation were used: inside cell (ic) and end cell (ec).

The comparison between the 2D and 3D models are discussed next. A good agreement of the electric field profile between the SF model and CST model was achieved, the comparison of the absolute value of the longitudinal electric field of EllipR1 model is presented in Fig. 5.

Table 2: Geometry Parameters for EllipR1/EllipR2 Cavities

Parameters	**EllipR1**		**EllipR2**	
	ic	**ec**	**ic**	**ecl**
r	40		47	
R	196.6		199.4	
L	78.6	79.5	102.9	104.6
A	61.5		82.6	
B	68.9		79.4	
a	14.8		16.1	
b	26.5		31.9	
α	2	2.75	5	6.7

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB029

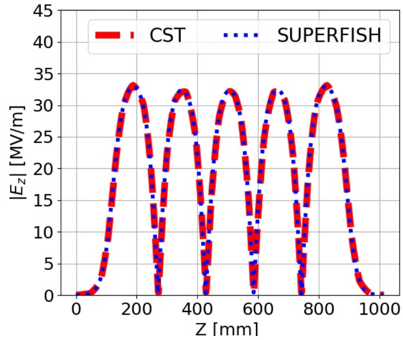

Figure 5: The comparison of the absolute value of the longitudinal electric field between SF and CST for the EllipR1 models.

Finally, Tables 3 and 4 show a summary of the values of the figures of merit of EllipR1 and EllipR2 models; in addition, a comparison with advance models of Project-X [10] is included. The figures of merits of the JAEA-ADS models were calculated for a temperature of 2 K.

CONCLUSION

The python interface with SUPERFISH played a fundamental role in the geometry optimization studies. The double scans allowed to investigate thousands configurations. Consequently, the two 5-cell elliptical cavity models achieved an Epk/Eacc and Hpk/Eacc values lower than 2.6 and 4.6 mT/MV/m and higher values of R/Q and G which were the primary goal.

Moreover, the JAEA-ADS models presented similar values of the figures of merits (Epk/Eacc, Hpk/Eacc, R/Q, etc.) as the advance designs such as the PROJECT-X (PIP-II) elliptical cavities [10]. Additionally, a field flatness over 0.96 was obtained.

Other interesting results was the preservation of the same geometry for the dome and iris between the inside and the end cells for both models. Thus, one would expect that this help to simplify their manufacturing.

The CST 3D models presented good agreement with the 2D SUPERFISH ones, the difference of the values of the figures of merit between the two codes were lower than 4.5% for the EllipR1 and 10% in the case of EllipR2. The reasons were associated with the difference of mesh method between 2D and 3D models and a slightly change in cavity geometry between the two model codes of 0.3% and 0.5% for EllipR1 and EllipR2, respectively.

Table 3: Figures of Merits of the PROJECT-X Elliptical Cavity and the EllipR1 Cavities (SF and CST)

Parameters	PIP-II	EllipR1	
		SF	CST
β_g	0.61	0.68	
Frequency [MHz]	650	648	
Eacc [MV/m]	15.9	15.9	
Epk/Eacc	2.26	2.15	2.17
Hpk/Eacc [mT/MV/m]	4.21	4.04	4.22
R/Q [Ω]	378	442.78	443.22
G [Ω]	191	208.80	208.82
Field Flatness	–	0.98	0.96

Table 4: Figures of Merits of the PROJECT-X Elliptical Cavity and the EllipR2 Cavities (SF and CST)

Parameters	PIP-II	EllipR1	
		SF	CST
β_g	0.9	0.89	
Frequency [MHz]	650	648	
Eacc [MV/m]	17.8	17.8	
Epk/Eacc	2.19	1.99	2.11
Hpk/Eacc [mT/MV/m]	3.75	3.70	4.07
R/Q [Ω]	638	619.86	619.73
G [Ω]	255	256.11	256.17
Field Flatness	–	0.98	0.98

ACKNOWLEDGEMENTS

The authors would like to thank to the members of the JAEA-ADS, J-PARC linac, KEK SRF and Riken SRF group for their comments and suggestions.

REFERENCES

[1] K. Tsujimoto, T. Sasa, K. Nishihara, H. Oigama and H. Takano, "Neutronics design for lead-bismuth cooled accelerator-driven system for transmutation of minor actinide", *JNST*, vol. 41, p. 21, Jan. 2004 doi:10.1080/18811248.2004.9715454

[2] V. Lebdev *et al.*, "The PIP-II reference design report V1.00", Fermilab Batavia, U.S.A, doi:10.2172/1365571

[3] K. Halbach and R. F. Holsinger, "Superfish – A computer program for evaluation of RF cavities with cylindrical symmetry", Part. Accel. **7**, 1976., pp. 213, 222.

[4] Python, http://www.python.org

[5] Computer Simulation Technology, https://www.cst.com/

[6] H. Padamsee, J. Knobloch, and T. Hays, *RF Superconductivity for Accelerators*. New York,NY, USA: Wiley-VCH Verlag GmbH and Co.KGaA, Weiheim, 2008.

[7] V. Shemelin, "Optimal choice of cell geometry for a multicell superconducting cavity", *Phys. Rev. STAB*, vol. 12, p. 114701, Nov. 2009. doi:10.1103/PhysRevSTAB.12.114701

[8] A. R.. Jana, V. Kumar, A. Kumar, R. Gaur, "Electromagnetic desig of β_g= 0.9 650 MHz superconducting-radio-frequency cavity", *IEE Trans. Appl. Supercond.*, vol. 23, p. 3500816, Aug. 2013. doi:10.1109/TASC.2013.2256356

[9] S. Belomestnykh and V. Shemelin, "High-ß cavity design – A tutorial", in *Proc. 12th Int. Conf. RF Superconductivity (SRF'05)*, Ithaca, NY, USA, Jul. 2005, paper SUA02, pp. 2–19.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB029

[10] V. P. Yakovlev *et al.*, "Concept EM design of the 650 MHz cavities for the Project X", in *Proc. 24th Particle Accelerator Conf. (PAC'11)*, New York, NY, USA, Mar.-Apr. 2011, paper TUP089, pp. 994–996.