# ELECTROSTATIC ANALYSIS OF 750 keV DC ACCELERATOR

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*Abstract*

The indigenously developed 750 keV DC accelerator working at RRCAT for the last 5 years uses $SF_6$ at 6 bar pressure as the insulating gas. The green house potential of this gas is about 22,000 times more than that of $CO_2$ gas. An electrostatic analysis of this accelerator was performed in order to probe the necessity of using this gas with a very elaborate gas handling system. The DC accelerator is approximated by a 2-D axisymmetric model in ANSYS and voltages were defined at the individual stages of the accelerating tube. The result of the study shows that the present design needs $SF_6$ gas and the pressure vessel dimensions need to be modified to operate the DC accelerator with environmentally friendly $N_2$–$CO_2$ mixture. This paper presents the methodology of the analysis, discusses the DC accelerator finite element model and presents the results of the analysis. The paper also proposes changes in the DC accelerator design to run the accelerator with $N_2$–$CO_2$ mixture.

## INTRODUCTION

Raja Ramanna Centre for Advanced Technology, Indore has built a 750 keV, 10 mA DC Accelerator. The accelerator is being used for conducting research using low energy electron beam. It can be used for disinfestations such as medical sterilisation, herbal irradiation, spice irradiation apart from some industrial usage involving cross linking of polymers. The electrons are emitted by thermionic emission from a triode type electron gun. These electrons are passed though a successively increasing voltage decks in the accelerating tube to impart them the required energy. The entire accelerating tube is kept in high vacuum condition ($10^{-7}$ mbar) to avoid loss of electrons due to interaction with gaseous molecules on the path. The outer geometry of the accelerator consists of a pressure vessel which contains insulating gas $SF_6$ at a pressure of 6 bar to sustain the high electric field. *Fig.1* gives a schematic of this particle accelerator.

## DESCRIPTION OF THE PROBLEM

Operating voltage range for the accelerator is 300 to 750 kV with a maximum beam power of 20 kW. The outer body of the accelerator is grounded. Inside, from top to bottom, the high voltage dome assembly (fig. 1B) is floated at a voltage of 750 kV, the electron gun is floated on the same potential followed by the accelerating column. The accelerating column consists of a number of ring shaped ceramic insulators. Metallic plates are sandwiched in between the ceramic rings (fig. 1C). This provides ultra high vacuum path as well as stage wise potential gradient for acceleration of the electrons. The high voltage is generated by balanced Cockroft-Walton voltage multiplier circuit that uses a chain of diodes and capacitors. The topmost stage is at -750 kV and the voltage decreases in steps to zero at the bottom of the column i.e. lowermost stage is at zero potential and is attached to the outer dome. The high voltage assembly is immersed inside the $SF_6$ environment as described above. This gaseous medium is important from HV insulation point of view because of its excellent dielectric as well superior arc quenching properties to prevent the HV breakdown [1]. Because of its higher dielectric constant, electric field decays rapidly in between the HV inner assembly and the outer body.

Figure 1. The DC accelerator (left), HV assembly (right top), gun & acceleration column (right bottom).

Since, the rate of decay depends on the dielectric strength of the insulation medium; one must ensure before changing the same that the dielectric strength is sufficient to prevent the chances of HV breakdown. Therefore, we have examined the possibility of using $N_2$ as dielectric gas with the help of FEM simulation.

## FINITE ELEMENT MODEL

The DC accelerator can be simulated very closely in 2D axisymmetric finite element model. For this purpose,

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small ceramic spacers between the high voltage generator stages were ignored in the analysis and they were modelled with insulating gas dielectric strength only. This keeps the analysis conservative and simplifies the modelling by a great deal. We chose ANSYS™ to perform the analysis due to its programming interface and availability of 2D electrostatic analysis. This helped in application of numerous boundary conditions by employing a couple of 'do loops'. We used PLANE 121 finite element formulation. This is a 2-D, 8-node, charge-based electric element [2]. The element has one degree of freedom, voltage, at each node. The element has compatible voltage shapes and is well suited to model curved boundaries. This element is based on the electric scalar potential formulation.

The boundary conditions are specified in terms of static potential at the metallic surfaces. So, the 2D Laplace equation will be solved for the entire domain to get the solutions in terms of scalar potential (V):

$$\frac{1}{r}\frac{\partial}{\partial r}\left( r\frac{\partial}{\partial r}V(r,z)\right) + \frac{\partial^2}{\partial z^2}V(r,z) = 0. \qquad (1)$$

This can be seen here that, we get values of potential at all nodes in the domain and then we need to perform the differentiation of these potentials to get the electric field distribution. This further justifies the use of second order element.

In our FE model, we have imposed the HV boundary conditions as realistically as possible and have changed the dielectric constant of the insulation medium and observed whether the HV criteria exceeded the limit or not.

We have two other candidates for the insulating gas – $N_2$ and $N_2$-$CO_2$ mixture [2]. However, the breakdown strength of $N_2$-$CO_2$ mixture is more or less similar to that of $N_2$. The main purpose of using $CO_2$ in the mixture is to prevent the HV arcing. Hence, for the purpose of this analysis, we need to model only one dielectric gas for comparison with $SF_6$ gas which has been identified as a greenhouse gas with a long atmospheric lifetime. The relative DC uniform breakdown strength of $SF_6$ vs. $N_2$ is approximately 10:3 [3].

## RESULTS & DISCUSSION

The maximum electric field appears on the uppermost surface of corona guard ring. The magnitude of this field is 6.57 MV/m (Fig-2).

If we increase the separation between the two uppermost corona guard rings by 10 mm and increase the vessel inner radius by 200 mm then this field reduces to 5 MV/m (Fig-3). This will require modification in the pressure vessel.

## CONCLUSION

The maximum electric field of 6.57 MV/m is a very safe value for SF6 from the high voltage insulation point of view. This value also indicates that the accelerator may also be operated with $N_2$-$CO_2$ mixture at the same pressure. However, if we wish to operate the accelerator with maximum field of 5 MV/m with $N_2$-$CO_2$ mixture for increasing the safety margin, then the pressure vessel as well as the spacing between the uppermost corona guard rings needs to be modified in the previous article.

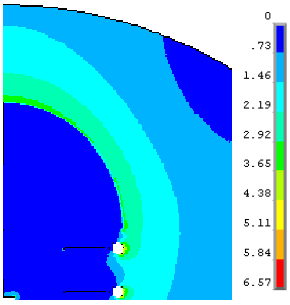


Figure-2: Electric field distribution in original configuration.

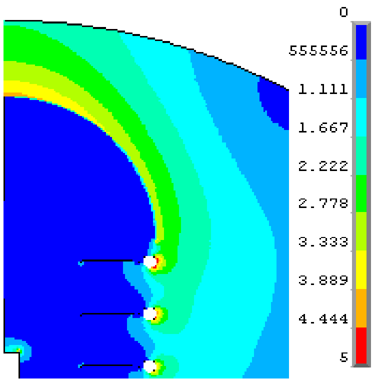


Figure-3: Electric field distribution in modified configuration.

The normal convention of adoption of $SF_6$ for HV insulation has brought advantages in performance, size, weight, cost and reliability. However, due to the greenhouse potential of $SF_6$ gas, use of environment friendly and naturally occurring insulating gas is worth considering. $N_2$-$CO_2$ mixture is an attractive alternative and has been used in such conditions. This work seeds a comparative study on replacement of $SF_6$ as insulating gas. This should be noted that use of $SF_6$ also requires a very elaborate and expensive gas handling system.

## ACKNOWLEDGEMENT

We thank Mr. Pramod Radheshyam for the technical discussions held during the work.

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