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Review on Design of main Post Insulator of DNB Beam Source for INTF vacuum vessel

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Abstract — *The Diagnostic neutral beam (DNB) is used as a beam for active charge exchange recombination spectroscopy to measure the helium ash density in the core plasma region. The DNB injects H^0 beam to the plasma. The Indian Test Facility (INTF) is a facility being constructed at Institute for Plasma Research (IPR), to characterize ITER (International Thermonuclear Experimental Reactor) -DNB beam with full specification. INTF is a vacuum vessel of 180 m3 volume and capable of providing Ultra High Vacuum Environment for the beam operation. The DNB beam source produces and accelerates negative ions. It is supported on the vessel mechanically and, for its functionality, is feed with high electrical potential of -100kV. For electrical isolation between Beam Source and Vacuum vessel, Post Insulators have to be provided to meet the electrical and mechanical requirements. The Post Insulators are mainly composed of ceramic attached with the metallic flanges and then coupled to beam source support structure to provide them mechanical support and electrical isolation.*

Keywords- *Post insulator; DNB; Beam source; INTF; vacuum vessel*

I. INTRODUCTION

The DNB system injects H^0 beam at 100 keV radial to the ITER plasma as a beam for active charge exchange recombination spectroscopy. The diagnostic neutral beam (DNB) line shall be used to diagnose the He ash content in the plasma of the ITER machine using the charge exchange recombination spectroscopy (CXRS) but there were several challenges related to the production, neutralization and transport of the neutral beam over path lengths of 20.665 m, to be overcome. Indian Test Facility (INTF) is a serious effort from INDIA to test DNB and to explore in the R&D, one of the most important challenges in ITER. This INTF vessel consist of internal components named DNB beam source and beamline components. The beam source of INTF is an assembly of ion source and accelerator. The negative ions are produced in ion source and are accelerated up to 100KeV in the accelerator. Thus for functional requirements beam source is provided with -100 kV high potential. To mount this -100kV beam source into grounded vessel, insulators are required. The insulators are subjected to electrical as well as mechanical load due to beam source. [14]

II. HISTORY OF INTF AND DNB BEAM SOURCE

M.J. Singh, [1] et al. developed concept of INTF (Indian Test Facility) to test DNB for ITER. The facility comprises of a main vacuum vessel coupled to a smaller vacuum vessel through a duct. The main vacuum vessel comprise of DNB beam source and other beamline components like neutralizer, RID, calorimeter etc. The main vacuum vessel shall rest on pillars raised from the ground level in order to enable serviceability. The exit of the duct shall be coupled to a vacuum chamber housing a second calorimeter. The facility contains other systems such as high voltage bushing, diagnostic system, magnetic shielding, pumping system, power supply etc.

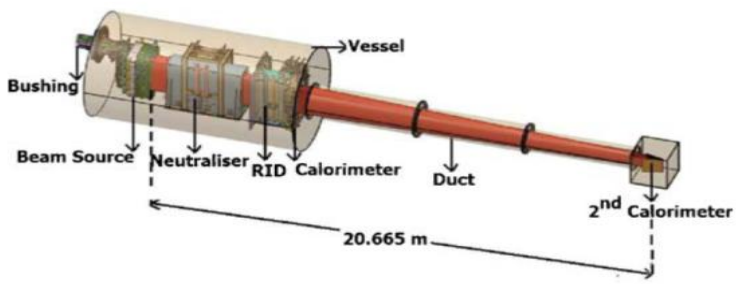

Figure (a) INTF beamline with 20.665m transport length

Jaydeep Joshi, [2] et al. presented design of vacuum vessel for INTF for 100KeV neutral beam. Vacuum vessel is designed in cylindrical shape having length of ∼9 m with diameter of ∼4.5 m and has a detachable top-lid for mounting as well as removal of internal components during installation and maintenance phases. Vessel duct is composed of three segments with length ranges from 3 m to 5 m with diameter of ∼1.5 m and one vessel at the end to house the second calorimeter. Design was prepared as per ASME-BPVC SectionVIII-Div.1 and subsequently Finite Element Analysis (FEM) method has been adopted to verify the design.

A. Chakraborty, [3] et al. had given a status update for Indian Test Facility in IEEE conference publication 2015. Several prototype activities had been initiated to realize full scale component development and their performance. Some design changes have been made in INTF comparing to DNB for simplification such as cylindrical vessel in place of rectangular, beam source integration. According to that the INTF can be operated as a global R&D facility by late 2017.

M. Bandyopadhyay, [4] et al. designed movement mechanism for DNB source used in DNB ITER. Due to long transport length of 20.667m, a small misalignment of the ion source will cause significant transmission loss of the beam and produce asymmetric heat load on the beamline components and on the duct assembly therefore ion source positional adjustment is needed during DNB operation. This can be addressed by making provisions for the desired vertical and horizontal movements in the ion source support structure. Two independent translations for horizontal angular and linear misalignment adjustment are achieved by means of master–slave configuration. Due to isolation of −100 kV beam source with respect to the grounded DNB vessel ceramic isolators should be provided at support.

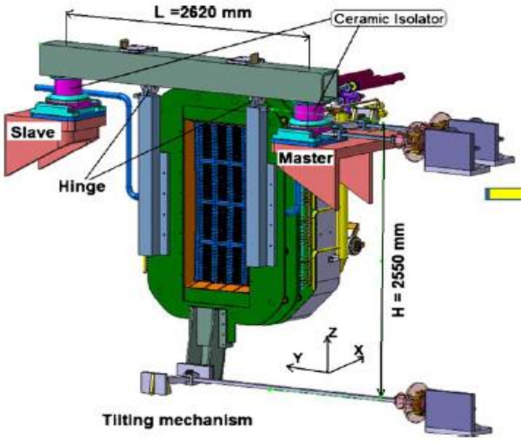

Figure (b) Support structure of beam source in ITER

III. MATERIALS FOR INSULATORS

A. E. Schwalm [5] had provided definition that, “An insulator is a device intended to give flexible or rigid support to electric conductors or equipment and to insulate these conductors or equipment from ground or from other conductors or equipment.” According to material used insulators are mainly of two type ceramic insulator and non-ceramic insulator (NCI). Again ceramic insulator can be of two type glass and porcelain. Ceramic materials are strong and rigid, and under appropriate, controlled loading conditions they are mechanically strong while predominantly used NCIs are not mechanically strong – in fact they are quite weak. On other side new materials offers some advantages over the ceramic insulators such as lighter weight to higher tensile strength, easier handling, and toughness.

Erhard Huttel, [6] presented report on materials that can be used in vacuum for accelerators. According to that ceramics (mostly aluminum oxide which can be produced without porosity) are used as insulators and for vacuum chambers in rapidly changing magnetic fields where conducting material cause unacceptably high eddy currents. Compared to glass, ceramic has the advantage of better mechanical strength. In addition the compressive strength is higher by a factor of ten compared to the tensile strength. Sintered alumina is the best suitable material for ultra-high vacuum and high voltage applications. In many application of high voltage insulation Porcelain material is also used.

Xu Rutian, [7] presented composition and properties of electric porcelain in China. The paper describes five types of electrical porcelain by variation percentage of composition(c-111, c-110, c-112, c-120 and c-130) which is conformable to IEC-60672-3. These materials have been using in manufacturing various insulators up to 500kV. According to paper high strength aluminous porcelain can be used for high strength and high voltage insulation so C-130 (IEC 60672-3) can be used for this purpose.

N. Riahi Noori, [8] et al. presented effect of materials design on properties of porcelain insulators. In this study six composition of porcelain is selected. Group 1 had the common composition of electrical insulator bodies. In groups 2–6, silica content decreased gradually and alumina content increased gradually. In group 6, silica was totally replaced by alumina. The maximum firing temperatures selected in this study were 1250, 1300, and 1350°C for preparing porcelain. After test it is concluded if silica content in porcelain was replaced by alumina then its strength and density increased and no significant effect on dielectric properties.

Lijian Ding, [9] et al. studied effect of sintering temperature of ceramic on flashover performance of insulator in vacuum. Flash over is a condition in which, the insulator may be over heated which may ultimately results into shuttering of it. Four kinds of alumina insulator were studied, which were prepared using the same formula with different sintering conditions. The sample was subjected to an impulse voltage and experiment was carried out. Based on the experimental results, the characteristics of preflashover and flashover vary with different kinds of test samples. It was found that the insulators with a higher sintering temperature had a lower flashover voltage, and more active preflashover. It is concluded that the influence of sintering temperature can be attributed to the change of microstructure of alumina so sintering at a lower temperature could have better performance.

IV. HISTORY OF POST INSULATOR DESIGNS

A Post Insulator is an electrical insulator whose internal electric charges do not flow freely, and therefore make it nearly impossible to conduct an electric current under the influence of an electric field. This contrasts with other materials; semiconductors and conductors, which conduct electric current more easily. The property that distinguishes an insulator is its resistivity. Insulators have higher resistivity than semiconductors or conductors. Insulators are used in electrical equipment to support and separate electrical conductors without allowing current through themselves. The term insulator is also used more specifically to refer to insulating supports used to attach electric power distribution or transmission lines to utility poles and transmission towers.

R. A. Bernstorf [10] had given the parameters used in selecting an appropriate insulator. An insulator is a mechanical support and used to separate power line from ground. Thus design of insulator includes two aspects named Mechanical aspect and Electrical aspect. For mechanical aspects maximum loading can then be compared to the ratings applied to the insulator. Porcelain and Non Ceramic Insulator line posts are mechanically rated in terms of their cantilever strengths. After the mechanical aspects of a design have been finalized, electrical characteristics are added. An insulator selection begins with the impulse withstand and switching surge over-voltage requirements. By that all characteristics are finalized that needed for insulator design.

Joze Hrastnik, [11] et al. developed new design of composite post insulator and analyzed it by using 3-D Electric-Field Analysis. The designing of new a composite post insulator was presented with the upper fitting made of insulating material which is conventionally made up of metallic material. The composite post insulator is made entirely in one piece and has a relatively plain structure. The main elements are supportive core, upper, and lower fitting and protective layer. Generally upper fitting and lower fitting both is made up of metal but here Polyamide PA6 with the addition of 30% fiberglass had been selected as a material for upper fitting. The electric-field strength analysis was carried out for both conventional and new design. The results for electric-field strength computation confirmed that electric-field strength inside and around the insulator with an upper fitting made of insulation material is lower in comparison with the insulator with a metal upper fitting.

Siamak Epackachi, [12] et-al presented mechanical behavior of electrical hollow composite post insulators used in electrical substations subjected to any horizontal excitation due to the earthquake, or any extreme event in its service condition. Test series comprise of pull and cyclic quasi-static tests in addition to impact hammer tests was described, to assess the mechanical behavior of the insulators subjected to the lateral forces at different stages of damage. The specimen consisted of a 6-mm thick tube of fiber glass reinforced polymer and metal caps at both ends of the tube. The tube was connected to the metal caps using a bonding material between the tube and metal caps. Pull test was successfully completed but at the end of cyclic test presented, there was damage to the post insulator concentrated near the base of the tube within the zone of the connection between the composite tube and metal cap. Damage to the post insulator was initiated by a bond failure at tube-flange connection and followed by buckling and crushing of the tube inside of the flange. On the basis of the test results, an analytical model was developed to simulate the mechanical behavior of the post insulator before and after damage.

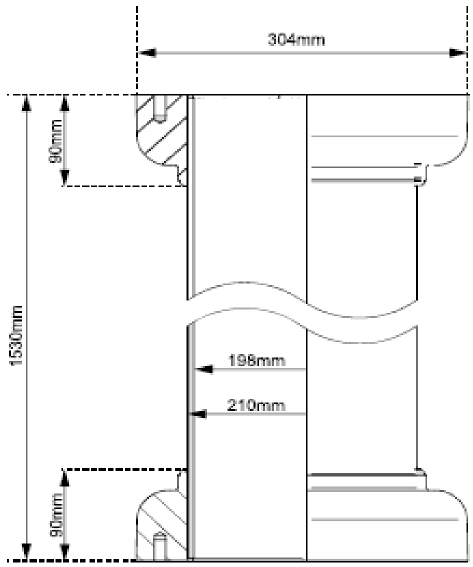

Fig (c) Post insulator with upper and lower metallic flanges

N. Pilan, [13] et-al performed the R&D activities for alumina insulators used in 1 MV accelerator of NB injector. This accelerator is composed of five stages of grids and polarized at potentials ranging from −1 MV to ground (0 V) with five main stages of 200 kV each. Five sets of alumina cylindrical insulators are located between the accelerator grids; the insulators are therefore subjected to 200 kV dc and to structural loads. The ion source and the multi-stage accelerator constitute a cantilevered structure sustained from the grounded stage. The insulator is a cylinder made of high purity alumina C799 according with the ITER requirements; the cylinder had a diameter of 130 mm and a length of 280 mm. Each ceramic insulator is connected to the structure by means of a couple of stainless steel (SS) flanges which are directly bolted on the frames sustaining the accelerating grids. After preparing design the manufacturing and testing of the full prototype, for a thorough mechanical and electrical validation of the design, with reference to the numerical verification is described. The insulator design had been analyzed considering both mechanical and electrical aspects. Experimental validation had been started, with positive results in both involved fields.

V. CONCLUSION

After analyzing above papers it is concluded that DNB beam source for ITER is subjected to -100kV for its functional requirement so there is a need of Post Insulators to mount DNB beam source into grounded vessel. From mechanical point of view these Post Insulators are subjected to dead weight of beam source and bending moment due to translational and rotational movement of beam source. From electrical point of view they are subjected to -100kV volts at one end and grounded on other end. Porcelain and alumina both can be used as material for main Post Insulator. For finalizing dimensions of Post Insulator design calculations are required according to loading conditions. After that prepared design should be verified with FEA software and validated by experimental testing.

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