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Prototype high voltage bushing: Configuration to its operational demonstration

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ABSTRACT

High Voltage Bushing (HVB) is the key component of Diagnostic Neutral Beam (DNB) system of ITER as it provides access to high voltage electrical, hydraulic, gas and diagnostic feedlines to the beam source with isolation from grounded vessel. HVB also provides primary vacuum confinement for the DNB system. Being Safety Important Class (SIC) component of ITER, it involves several configurational, technological and operational challenges. To ensure its operational performance & reliability, particularly electrostatic behavior, half scale down Prototype High Voltage Bushing (PHVB) is designed considering same design criteria of DNB HVB. Design optimization has been carried out followed by finite element (FE) analysis to obtain DNB HVB equivalent electric stress on different parts of PHVB, taking into account all design, manufacturing & space constraints. PHVB was tested up to 60 kV without breakdown, which validates its design for the envisaged operation of 50 kV DC. This paper presents the design of PHVB, FEA validation, manufacturing constraints, experimental layout with interfacing auxiliary systems and operational results related to functional performance.

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1. Introduction

To diagnose helium (He) ash during deuterium-tritium (D-T) phase of ITER [1], Diagnostic Neutral Beam (DNB) Injector [2] will provide a probe beam of 100 keV neutral hydrogen atom (H^o) with equivalent beam current of 60 A. Inductively coupled Radio frequency (RF) source [3] is used in ITER DNB, followed by an accelerator system, made of 3 grids [4] to produce desired hydrogen beam. To operate this ion source and the beam accelerator system, electric busbars, hydraulic lines, gas feed line, Cesium (Cs) delivery tube are connected to the beam source, which are lifted at −100 kV voltage with respect to the ground. High voltage bushing (HVB) is an isolation feedthrough to carry all these high voltage feedlines to the beam source through the grounded body of the vessel. Being an extension of the vacuum boundary of the tokamak (as it is connected to the DNB Vessel), it forms a part of the primary vacuum boundary of ITER. As a result, HVB is classified as safety important class (SIC) component of ITER from tritium confinement perspective. Due to its SIC classification [5], it involves several configurational and therefore technological and operational challenges. Several literatures are available on different HVB configurations and their electrical and mechanical analysis [6–9]. Based on these available database, single stage HV Bushing with two concentric insulators is designed for 100 kV isolation for DNB [10] as shown in Fig. 1 and validated analytically by FEA [11].

HV bushing is combination of several materials (metal and non-metal) with different dielectric strength. However, there are no specific safety codes and standards available for non-metallic material. Hence, the design validation by performance assessment becomes very important aspect of this experiment. Further, it is difficult to define acceptable electrostatic stress (kV/mm) in different areas without experiment. To assess electric stresses, one has to rely on simulation results as it is not possible to measure it in-situ during experiment. Even then the assumptions are correct only if, the fabricated part is exactly same as considered for simulation. However, during manufacturing, some non-conformance cannot be avoided and hence, its operational validation becomes very important to ensure its performance in desired experimental environment.

To ensure operational performance of DNB HV bushing, half scale down configuration is designed and named Prototype High Voltage Bushing (PHVB) with the mandate to operate for 50 kV. Reason for choosing half scale is to replicate electrostatic stresses with similar configuration of stress shields of the DNB HV bushing,

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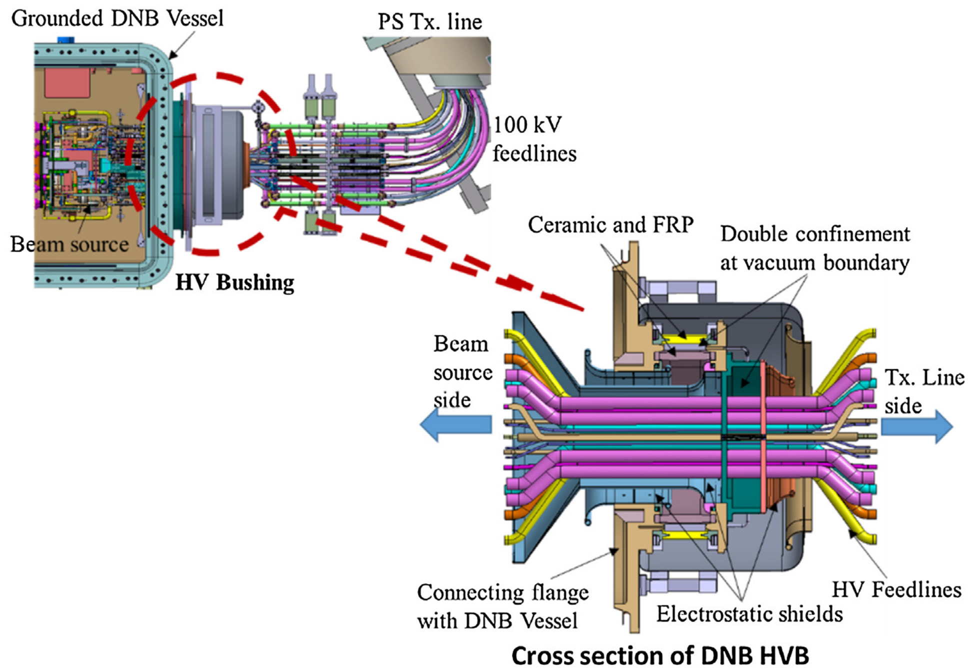

Fig. 1. DNB HV Bushing with its interfacing systems.

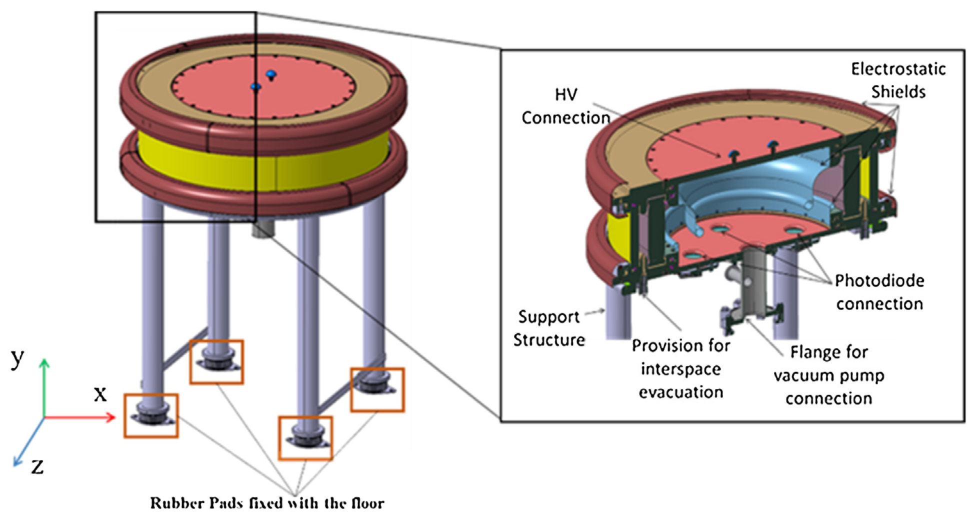

Fig. 2. Schematic of PHVB with its support structure.

considering cost effective solution. The design is validated by FEA to evaluate electric and structural stresses prior to the experiment. Final configuration of PHVB is an outcome of several iterations that have been carried out to optimize electric stresses same as DNB HV busing in order to ensure its operation for ITER. This experiment also aid in understanding of manufacturing and operating aspects of some of the non-standard parts like (i) Ceramic-Kovar braze joint and spilling phenomenon, (ii) FRP-metal glued configuration, (iii) Vacuum sealing configuration, (iv) Electrostatic stress shields, etc. This paper describes prototype design configuration, FE analysis, manufacturing challenges and experimental results.

2. Design of PHVB

Schematic 3D cross sectional view of prototype HV Bushing is shown in Fig. 2. Overall diameter of the system is ~802 mm and its height is ~278 mm which is almost half of DNB HVB [10]. Approximate weight of the complete system is ~375 kg. The setup is placed on a metallic support structure which is mounted on vibrational isolators on the ground to protect the system from any unforeseen vibrations or any seismic event. Vacuum compatible materials are selected for all vacuum boundaries. Assembly aspects are folded in the design consideration.

For 50 kV insulation, the PHVB consists of two co-axial cylindrical insulators viz Al_2O_3 ceramic and Fiber reinforced polymer (FRP) rings with metallic transition to ensure its leak tight connection with corresponding metallic flange as shown in Fig. 3. Two insulators are considered for DNB in order to form double confinement as per SIC guidelines of ITER and same configuration is considered for PHVB. Interspace between the two insulators will be maintained ~0.8 bar for DNB HVB. However, for present phase of experiments of PHVB, interspace is kept at 1 bar. Ceramic ring is forming the vacuum boundary. PHVB is designed in such a way that no mechanical load other than the self-weight is transferred on the ceramic ring in

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