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ABSTRACT

A new ITER-like ICRH antenna is being developed to deliver over 7MW at high power density ($8MW/m^2$) to the JET plasmas. The paper discusses the RF, mechanical and hydraulic design aspects of the option for Internal Vacuum Transmission Lines based upon in-vessel motor actuators.

1. INTRODUCTION

Four Internal Vacuum Transmission Lines (VTL) are to be installed inside the antenna support box to feed Radio Frequency (RF) power to the antenna straps through in-vessel matching capacitors mounted on the end of the internal-VTLs (Fig.1). It is foreseen that a series of RF capacitive probes will be installed along the VTL in order to measure the Voltage Standing Wave Ratio (VSWR).

Key functional elements of the system are located inside the body of the Internal VTL conductor:

- The actuators must provide adequate force to overcome the spring constant of the bellows mounted in the variable capacitors and give linear travel with positional feedback instrumentation.
- The cooling system is designed to limit the temperature excursion of the capacitors. It must provide turbulent flow within the capacitor bellows convolutions to prevent air pockets forming, without exceeding the design pressure of the capacitor (3 bar absolute).

The various RF requirements, such as actuator accuracy (especially at high frequency) together with vacuum/tritium boundary issues, effects of disruption loading, and assembly considerations, make the Internal VTL design a challenging piece of work.

2. RF REQUIREMENTS AND SIMULATIONS:

2.1 TOLERANCES ON THE RF PART OF THE INNER VTL

Four issues have been evaluated using Matlab[1] and Microwave-Studio[2] (MWS) simulations:

a) How significant is the tolerance on the gap between the inner VTL and the outer VTL?

The first step is to quantify the dependence of the 9.5W characteristic impedance of the VTL on changing gap width. The thermal expansion of INCONEL 718[3] is very small, and so variations in gap width will most likely arise from machining and assembly inaccuracies. An increase of the gap by 2mm, for instance, results in a 1W change in characteristic impedance. This will change the VSWR at the RF-generators with respect to the reference, but this will be compensated by Stub and Trombone[4] adjustments. Simulations have shown that a gap variation of up to 3mm can be tolerated, whilst still achieving matching at all frequencies.

b) How much influence have changes of the length of the VTL on the matching?

The tolerance on VTL length is determined by the need to maintain the length of RF gap (Fig.2) at the rear of the VTL close to the optimum value of 23mm. Modeling using MWS has shown that a tolerance of ± 3mm is acceptable before excessive reflection will occur.

c) Effects of higher RF modes.

MWS simulations show that non-TEM effects on the VTL are only appreciable in the neighbourhood of the junctions, manifesting themselves as a top-bottom asymmetry in the current density distribution (Fig.3). To avoid perturbations, the RF voltage measurements[5] should be taken at least 50cm from the ends of the VTL.

d) How important is Silver coating of Inner and Outer VTL?

Silver coating of the inner and outer conductor of the VTL (for the nominal matching case of 3W) produces only a maximum gain in efficiency of 0.9%. Temperature increases and associated different thermal expansions appear to remain quite modest for the VTL conductor, as these conductors will be partially(outer VTL)/fully (Inner VTL) cooled, and so damage to the coating during thermal ratcheting is not considered to be an issue. Also manufacturing will be simpler without a coating. The only position where coating will be carried out is where the capacitors fit into the VTL, due to the high current density at this position.

2.2. ROLE OF ACTUATORS IN THE CONJUGATE-T MATCHING SCHEME.

The "conjugate-T " [6] circuit provides internal matching of the launcher over its operating frequency range (30 to 55MHz) by feeding pairs of radiating straps in parallel through adjustable capacitors [7].

Simulations show that the accuracy requirement of the actuators increases with frequency. To avoid any trip of the generators, the VSWR (Fig.4) needs to be kept below 1.5. Depending on the capacitor range, the worst case requirement is a positioning accuracy of ± **0.2mm** (for the VSWR to remain below **1.2**). Therefore the control system of the positioning of the actuators will be extremely important [8]. DC-Motor simulations show that the dimensions, forces, velocity are realistic for the design.

Actuator Specifications:

- Force: 1000N
- Linear movement 55mm/sec
- Accuracy 0.1mm
- Magnetic field 0.35T
- Dimensions: - Max-diameter: 120mm
  - Max-length: 200mm

2.3 HOW CAN WE AVOID OUT-GASSING DURING OPERATIONS?

Just before the plasma shot, the Torus and hence the VTL's are filled with gas, normally deuterium. The VTL is perforated with a series of small holes (Four rows of 15 circular holes Δ 10mm), located in the corners of the VTL. Advantages of corner locations are: the lowest electric field amplitude, the lowest current density amplitude, the lowest perturbation of the VTL characteristic impedance and the shortest particle removal length, during vacuum pumping.

During a plasma shot the Torus will act as the main vacuum pump. The vacuum around the VTL will be better than 10^{-5} mbar, a safe level as far RF voltage standoff is concerned. To avoid any out-gassing of the actuator drive system, a private vacuum-can will enclose the drive system. This vacuum can also makes the choice of the lubrication easier. The use of a GETTER-pump inside the VTL has been rejected, due to the difficult conditioning of those pumps after exposure to air.

3. MECHANICAL, HYDRAULIC, BLACK BODY RADIATION AND MAGNETIC FIELD SIMULATIONS

3.1. BLACKBODY RADIATION AND COOLING REQUIREMENTS

The Stepper-motors are located inside the VTL inner conductor, which itself is inside the VTL outer conductor. The port around the VTL outer conductor radiates at 200°C. It is not assumed that the VTL outer conductor is actively cooled in the regions of the motors and it is not assumed that the inner conductor is cooled in that region. Therefore the temperature of the VTL inner conductor is assumed to be 200°C. These assumptions are conservative. For a 2mm copper jacket and two cooling tubes the temperature becomes 108°C.

The water cooling for the capacitors will be provided at a rate of **20 l /min** by de-ionised water and should not be higher than **3bar absolute** pressure at the input for each capacitor. The temperature of the cooling water is around 30°C. The pressure drop after going through the two capacitors is **1.2Bar** absolute. Those extreme conditions make the water flow very turbulent (Reynolds Numbers are around **$3.5\text{x}10^4$**). Pressure drop calculations (**2.2bar**) confirm that the best solution is to go first around the 2 actuators, then through each capacitor with a straight return to the exit located at the Service Stub[4] (approximately a distance of 8m).

The diameter can increase outside the service stub. Stainless Steel double skin bellows must be placed between the exit of the APTL (Antenna Pressurised Transmission Line [1]) and the pumping system. This is important when a disruption will take place. Vacuum baking will be at 200°C without any water-cooling applied for a period of several hours. During this period, the **15mm** cooling pipes must be filled with pressurised Nitrogen.

3.2 MAGNETIC FIELD INSULATION FOR THE ELECTRICAL MOTORS

Due to the proximity of Torus magnetic coils, the electrical motors will be subjected to a magnetic field of up to **0.35Tesla**. A simple solution is to shield each motor in a **19mm** soft iron tubular screen. For a radial and vertical field variation of **40T/s** during a worst case disruption, a total torque of **280Nm** is generated about the toroidal direction. In addition, each screen is subject to a force up to **1100N** due to the local magnetic field gradients. The perturbation produced by this relatively large amount of ferromagnetic material on the plasma is being assessed.

CONCLUSIONS.

The VTL has been designed so that the required RF performance can be achieved and arcing is avoided. Silver coating will be used on the front of the VTL. RF voltage measurements should be taken at least 50cm from the ends of the VTL. The accuracy requirement for the actuators is demanding and increases at high operating frequencies (0.2mm at 55MHz). Due to the low allowable pressure in the capacitor bellows, a closed loop cooling circuit has been designed. Magnetic field effects on the motors have been assessed.

ACKNOWLEDGEMENTS

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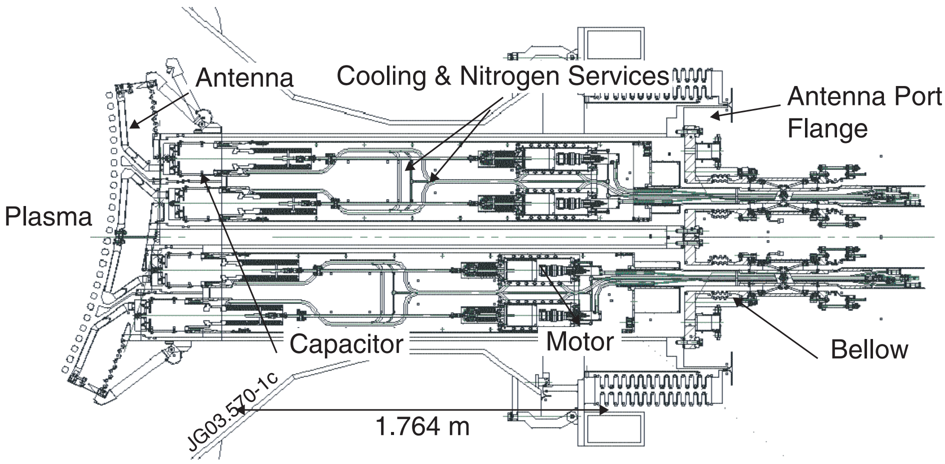

Figure 1: ITER-like ICRH antenna; Internal VTL with In-vessel Motor System.

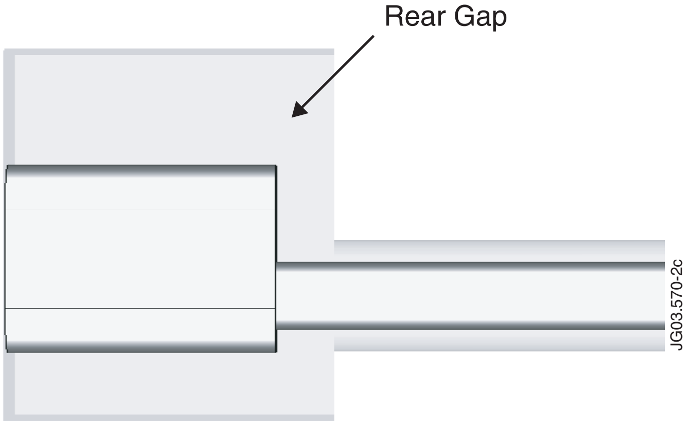

Figure 2: Rear gap of VTL

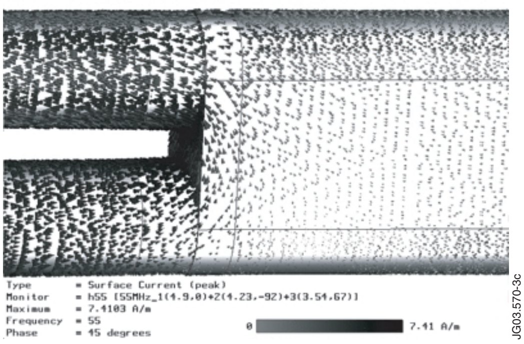

Figure 3: Current density of junction and front part of Inner-VTL at 55 MHz. In this study, the 2 capacitors are replaced by metal cylinders, but the 3 ports of the system are stimulated to reproduce operating conditions.

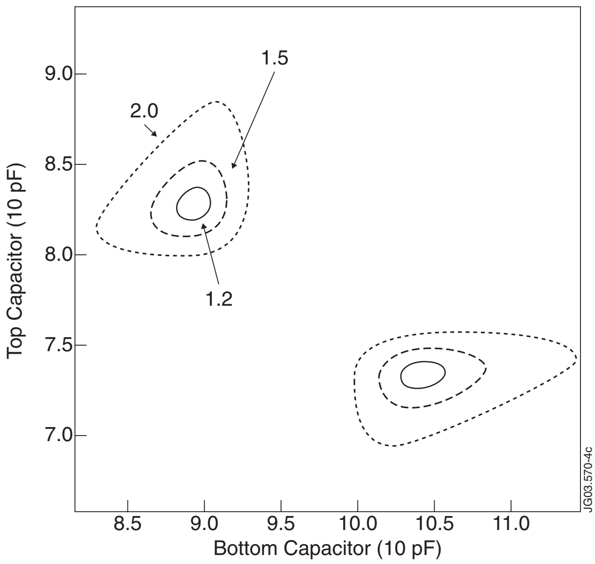

Figure 4: Constant VSWR curves (levels 1.2, 1.5, 2) versus bottom and top capacitor, these show us that the accuracy is important.