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RF tests of the electrical insulations for the toroidal structures of RFX

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Abstract

Modified conducting structures of the RFX machine have been designed to intentionally reduce electrical discontinuities, thus error fields due to eddy currents have been substantially reduced also. For this reason, for example, the stabilizing shell features a single poloidal and a single equatorial gap. Electrical insulations of those gaps shall be verified before and during the assembly phase of the various components. On the other hand, an applied voltage test can not be carried out in the quasi-static regime, so a radio frequency (RF) method has been used.

This paper deals with description of the test bed, set up to verify the feasibility of the RF test and to set up the necessary equipments. Moreover, all the tests carried out are described in details together with the actions taken to overcome some of the problems which arise with radiated electromagnetic power.

Keywords: Radio frequency (RF); Toroidal structures; Electrical insulations

1. Introduction

The new load assembly of RFX, almost completed and restored, is characterized by an Inconel® vacuum vessel, a copper shell and a stainless steel toroidal supporting structure [1]. The copper shell is composed of two halves joined on the outer equatorial plane by copper plates which short-circuit the gap on the outer side, whereas the inner remains open. In the region of the single poloidal gap, two copper layers overlap each other for about 23 toroidal degrees and the electrical insulation between them is guaranteed by a 2 mm PTFE layer (see Fig. 1). This particular arrangement for the poloidal gap of the shell has been found to be effective for the reduction of the error fields [2].

The maximum toroidal loop voltage attainable with the magnetizing winding of RFX is 700 V, whereas in the case of fast plasma current termination the observed peak reaches roughly the same value (duration <1 ms), at least for plasma current up to 1.1 MA. The maximum poloidal loop voltage is instead about one order of magnitude lower than the toroidal one.

All the insulating gaps need to be tested during the assembly phases, to verify the good conditions of the electrical insulation. In particular, the poloidal gap on

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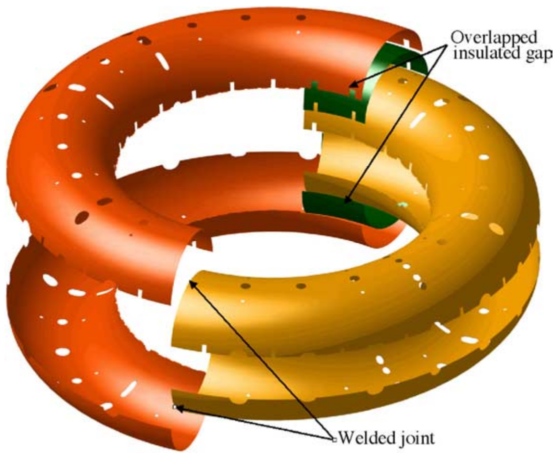

Fig. 1. Exploded CAD view of the new RFX shell.

the shell shall be tested at least at 1 kV, which cannot be applied using a conventional scheme.

Simulations of a first method based on a capacitor bank discharge, have been carried out, but the duration of the voltage applied at the gap was very short (fractions of milliseconds) and, moreover, the circuit design to reach such high voltages was rather complex.

A different approach was then studied: the principle of this second method is to exploit the overvoltage on a capacitance, the shell poloidal gap in our system, at the resonant frequency of the circuit on which it is connected. Since the calculated resonant frequency of the new RFX shell was in the range of radio frequency (RF), also the electromagnetic radiated power had to be taken into account.

Considering that the new copper shell was under construction, it was necessary to develop in advance a reliable system to perform the electrical tests on the vertical insulated gap. For this reason, some preliminary tests have been carried out. In particular, the RF system was previously set up on the old RFX shell, to select the best matching equipment for the RF amplifier and to verify both the maximum attainable voltage and the ground effect. Then the RF system was efficiently used to apply 1 kV to each halves of the shell as acceptance test.

2. Equivalent circuit of the shell

The equivalent electric circuit of the shell, in terms of lumped parameters, consists in an RLC series circuit (see Fig. 2). Calculations of their values in steady state yield $L_s = 3.6\,\mu H$, $C_s = 22\,nF$ and $R_s = 2.5\,\mu\Omega$. Unavoidable mechanical tolerances on the two halves of the shell, which generate two air gaps between the PTFE insulation layer and the copper sheets, suggest to consider for C_s roughly half of the theoretical value. On the other hand, the value of R_s shall account for the penetration thickness according to the formula:

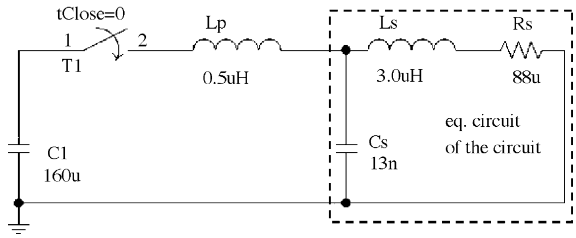

Fig. 2. Priciple scheme for the capacitor bank discharge test.

$$R_s \cong R_s^0 \frac{s}{\delta}$$

where R_s^0 is the steady state value, s the shell thickness and λ is the penetration thickness.

With the above mentioned values, the natural frequency of the shell results 735 kHz.

3. First method

A principle scheme for a capacitor bank discharge test is reported in Fig. 2, where C_1 is the capacitor bank, whose value has been chosen equal to that of an available equipment, L_p is the sum of the connections inductance and capacitor bank inductance, T_1 is a solid state switch (e.g. a thyristor) which includes also the 10 mΩ connections resistance.

For $t > 0$, C_1 will charge C_s with a fast time constant then the capacitor equivalent to the parallel of C_1 and C_s will run down oscillating with a frequency of about 7 kHz. If C_1 is charged with 1 V the resulting potential on C_s is reported in Fig. 3, whereas the current in C_1 is reported in Fig. 4. Fig. 3 shows that the applied voltage to C_s is halved in 0.5 ms and is practically extinguished after 2 ms.

This type of test to verify the electrical insulation of the vertical joint of the shell, involves substantially different types of drawbacks: