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Effects of Resonance Phenomenon caused by Power Supply on JT-60SA CS

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ABSTRACT

☑ Each CS module in the JT-60SA is composed of six octa-pancake coils and a quad-pancake coil.
☑ The maximum voltage between the CS module terminals is designed to be 10 kV, the voltage between the layers under ideal conditions is then about 0.38 kV because the CS module has 52 layers.
☑ But, in operating condition, there is a possibility that the voltage between the layers is higher than 0.38 kV due to the voltage fluctuations of the power supply and the inhomogeneous voltage distribution in the CS module induced by the resonance phenomenon.

In the present study, which is based on the results of previous studies, we created a circuit simulation model for the JT-60SA CS (four CS modules), including the structures (ground resistance, CS structure, TFC cases, and EFC covers), and used it to estimate the voltage distribution produced by the resonance phenomenon.

---As a result of analysis---

we conclude that the resonance phenomenon caused by power supply frequency components does not impact the insulation between the CS conductors.

Ⅰ. INTRODUCTION

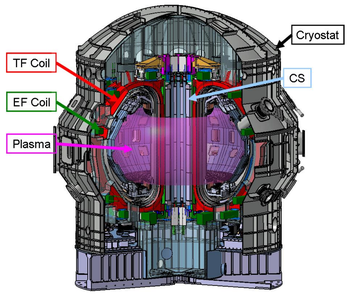

Fig. 1. JT-60SA

The magnet system of JT-60SA
- 18 toroidal field (TF) coils
- 6 equilibrium field (EF) coils
- A central solenoid (CS) with 4 modules

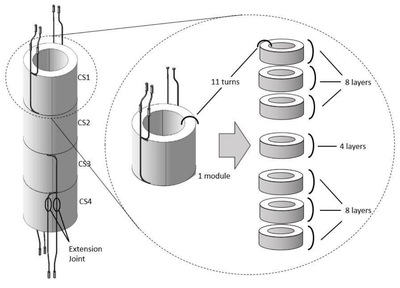

Fig. 2. Schematic of JT-60SA CS modules.

1 module
- 6 octa-pancake coils
- 1 quad-pancake coil

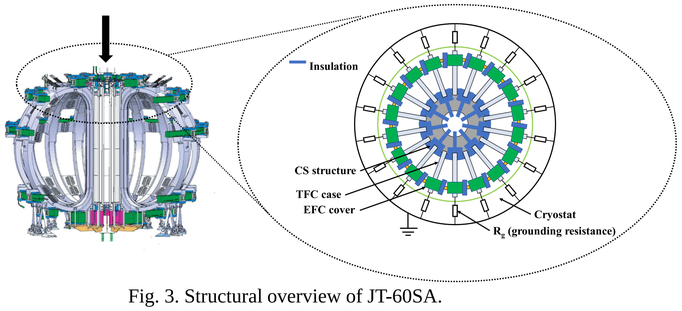

Fig. 3. Structural overview of JT-60SA.

CS structure, TFC case and EFC case are grounded via a grounding resistance outside the cryostat.

The grounding resistances are 18 resistances of 0.1 Ω each.

The CS consists of four independent modules covered by structures supporting TFCs.

Table 1. Specification of CS module.

Outer diameter (mm)	1986
Inside diameter (mm)	1310
Height (mm)	1599
Number of layers	52
Number of turn	11
Type of stand	Nb_3Sn
Maximum voltage	10 kV

Number of layers:52
Maximum Voltage:10 kV
↓
The voltage between the layers under ideal conditions:**0.38 kV**

◆ JT-60SA CS
- Four electrically independent modules. (Each module has 52 layers.)
- The current flows to the ground resistance through the construction (CS structure, TFC case, EFC case).

◆ The power supply for the JT-60U
(similar to the power supply for the JT-60SA.)

The voltage contains multiple frequency components.

↓

The voltage between the conductors can become larger than 0.38 kV, because the frequency component cause resonance phenomenon.

Ⅱ. CIRCUIT SIMULATION MODEL FOR JT-60SA CS MODULE WITH STRUCTURES

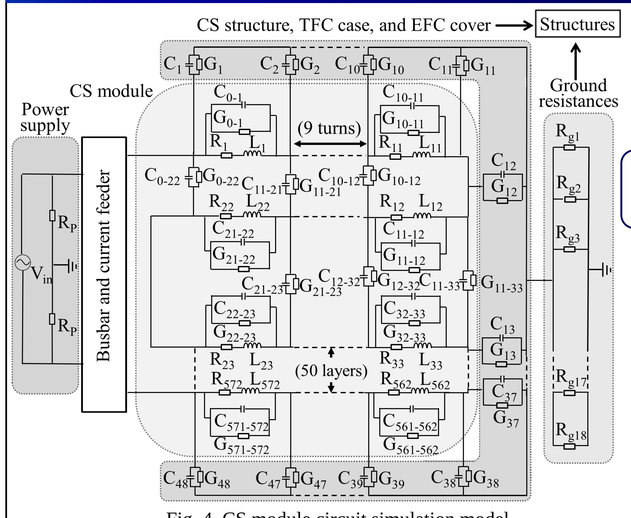

Fig. 4. CS module circuit simulation model

The previous model
Including the CS module, busbar, and feeder

↓

The present model
Adds structures to the previous model

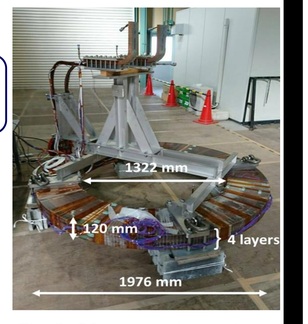

Fig. 5. CS model coil used in previous works.

◆ CS module

R : Longitudinal resistance
L : Inductance (self and mutual)
➡ Shape and materials of the conductors

◆ CS structure, TFC case, and EFC cover

C : Capacitance
G : Equivalent conductance
➡ Shape and materials of the structure

C : Capacitance
G : Equivalent conductance
➡ Fitting parameter (ε_r = 3.3, σ = 2.3× 10^{-5}) from previous works

◆ Ground resistances

R_g : ground resistance
➡ R_g are 18 resistances of 0.1 Ω each.

The voltage between the layers under ideal conditions is then approximately 0.38 kV.

The design value become approximately 0.077 when the voltage is normalized by 5 kV.

Ⅲ. EFFECTS OF STRUCTURES ON JT-60SA CS MODULE

◆EFFECTS OF STRUCTURES ON JT-60SA CS MODULE

➢ The frequency dependence of the maximum voltages between the conductors normalized by the power supply voltage. (The ground resistance is 0.1 Ω.)

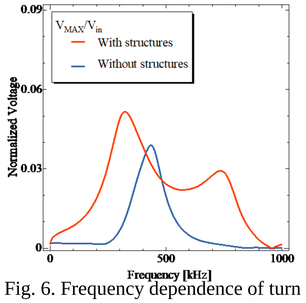

Fig. 6. Frequency dependence of turn voltage.

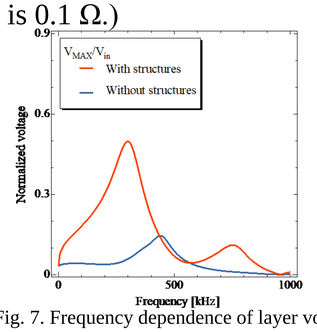

Fig. 7. Frequency dependence of layer voltage.

The resonance frequencies of the turn and layer voltages were 757 and 295 kHz, respectively.

When the structures was connected to the CS module,

the resonance frequency decreased & the maximum voltage increased

➢ The capacitance between conductor and structures and the ground resistance dependence of the maximum voltages between the conductors

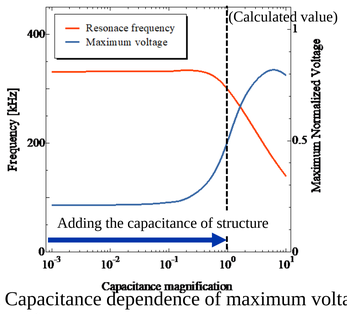

Fig. 8. Capacitance dependence of maximum voltage and resonance frequency.

When the magnification is less than 10^{-1},

the resonance frequency & maximum voltage are constant.

When the magnification is higher than 10^{-1},

the resonance frequency decreases

the maximum voltage increase

Adding the capacitance of structure influences the maximum voltages between the conductors.

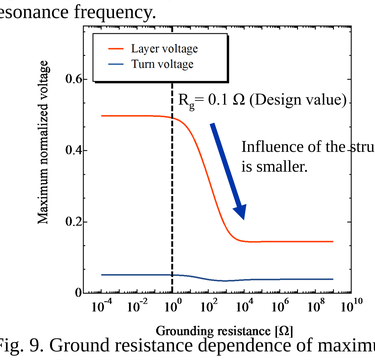

Fig. 9. Ground resistance dependence of maximum turn and layer voltages at resonance frequency.

When the ground resistance is 10^{-4} to 10^{0} Ω,

The maximum layer voltage is 0.49.

When the ground resistance is 10^{3} to 10^{9} Ω,

the voltage is 0.14.

This is because the current does not flow to the structures when the ground resistance is large.

When the CS module is operated with alternating current (AC) voltage,

the effect of the structures on the maximum voltage between conductors should not be ignored.

Ⅳ. ANALYSIS OF JT-60SA CS

◆Analysis of Power Supply Frequency Spectrum

➢ The power supply of JT-60U has the same characteristics as the power supply of JT-60SA.

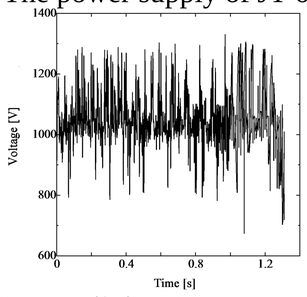

Fig. 10. Time profile for JT-60U power supply voltage.

FFT analysis

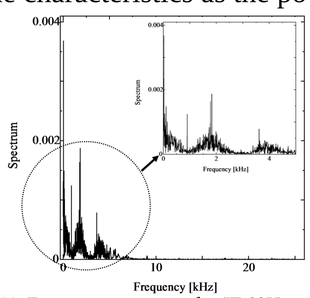

Fig. 11. Frequency spectrum for JT-60U power supply.

The main frequency component is less than 5 kHz.

◆ANALYSIS OF JT-60SA CS SINGLE-MODULE

➢ The turn and layer voltage distributions of the one module at frequency spectrum of the JT-60U power supply (and 5 kHz).

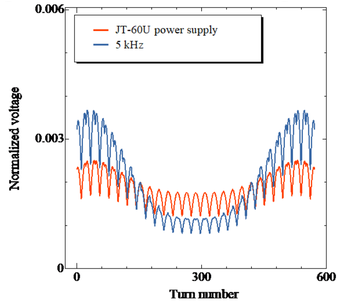

Fig. 12. Turn voltage distribution for JT-60U power supply.

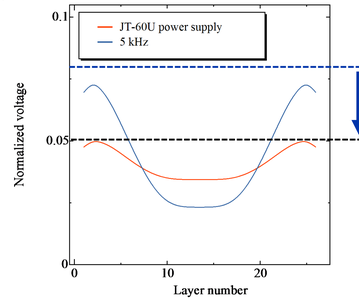

Fig. 13. Layer voltage distribution for JT-60U power supply.

Design voltage 0.077

Maximum layer voltage of 0.049 (at the JT-60U power supply)

The maximum voltage is less than the design voltage.

The voltage is highest at the edges of the module.

◆ANALYSIS OF JT-60SA CS

➢ The turn and layer voltage by increasing the number of modules.

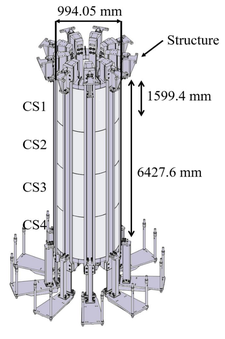

Fig. 14. JT-60SA CS, including structure.

Analytical Model

Each module is electrically independent.

It is necessary to consider the mutual inductances between the modules.

The mutual inductances between the modules was calculated using Neumann's formula.

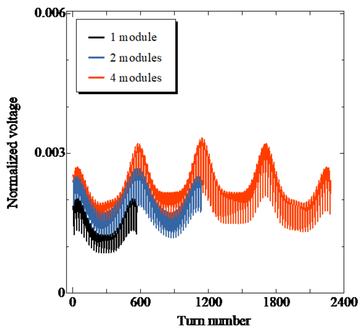

Fig. 15. Turn voltage distribution with multiple modules.

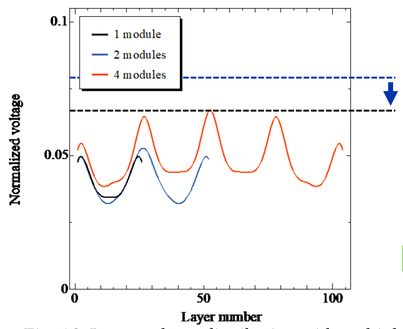

Fig. 16. Layer voltage distribution with multiple modules.

Design voltage 0.077

Maximum layer voltage of 0.066 (of four modules)

The maximum voltage is less than the design voltage.

The CS module has a sufficient margin for safe operation of the JT-60SA CS.

Ⅴ. CONCLUSION

☑ Due to the presence of the structures, the total capacitance increased the resonance frequency decreased, and the maximum voltage increased.

☑ For ground resistances of 10^{-4} to 10^{9} Ω, the maximum voltage between conductors was found to change significantly.

☑ For JT-60SA CS (four modules), the normalized maximum layer voltage do not exceed the design value.

We conclude that resonance phenomenon caused by power supply frequency components does not impact the CS conductors, and hence the CS is electrically stable under normal operating conditions.