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

The magnet system of JT-60SA

- 18 toroidal field (TF) coils
- 6 equilibrium field (EF) coils
- A central solenoid (CS) with 4 modules

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

The grounding resistances are 18 resistances of 0.1 Ω each.

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

| 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 | Nb3Sn |
| Maximum voltage | 10 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 voltage contains multiple frequency components.

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

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.](image)

![Fig. 7. Frequency dependence of layer voltage.](image)

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 and the maximum voltage increased.

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

When the magnification is less than $10^{-1}$, the resonance frequency and maximum voltage are constant.

When the magnification is higher than $10^{-1}$, the resonance frequency decreases and the maximum voltage increases.

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

When the ground resistance is $10^4$ to $10^9$ 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.

![Fig. 8. Capacitance dependence of maximum voltage and resonance frequency.](image)

![Fig. 9. Ground resistance dependence of maximum turn and layer voltages at resonance frequency.](image)

![Fig. 10. Time profile for JT-60U power supply voltage.](image)

![Fig. 11. Frequency spectrum for JT-60U power supply.](image)

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.

![FFT analysis](image)

The main frequency component is less than 5 kHz.

![Fig. 12. Turn voltage distribution for JT-60U power supply.](image)

![Fig. 13. Layer voltage distribution for JT-60U power supply.](image)

The voltage is highest at the edges of the module.

![Fig. 14. JT-60SA CS, including structure.](image)

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.

![Fig. 15. Turn voltage distribution with multiple modules.](image)

![Fig. 16. Layer voltage distribution with multiple modules.](image)

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

![Analytical Model](image)

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. 17. Mutual inductance between modules.](image)

![Fig. 18. Design voltage comparison.](image)

Design voltage 0.077

Maximum layer voltage of 0.066 (of four modules)

The maximum voltage is less than the design voltage.

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.