Thermal Quench Behaviors of 2G HTS Coil with Polyimide Film and MIT Insulation Materials (MT25-Wed-Af-Po3.11-01)

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I. INTRODUCTION

A metal–insulator transition (MIT) materials such as vanadium III oxide (V_2O_3) have a resistivity variability on temperature, i.e., resistivity of MIT material is decreased with temperature increased. Since the smart insulation (SI) coil with MIT materials may be insulation coil which is completely isolated by polyimide film between turn-to-turn of coil and no-insulation (NI) coil which is directly contacted between turn-to-turn of coil in thermally stable and unstable condition, respectively due to resistivity transfer characteristics of MIT materials, As a turn-to-turn insulation material on second generation high-temperature superconducting (2G HTS) coils, SI winding technique may enhance not only current control performance but also the thermal stability of 2G HTS coils. Thus, it is expected to redeem NI winding technique which has a delay of target magnetic field by transformation to single turn of coil due to bypassed current and hence is hard to be apply for field coils of rotating machine.

This paper presents thermal quench behaviors of 2G HTS coils insulated respectively with Kapton polyimide film and V_2O_3. An over-current experiment with pulse current was performed to investigate thermal behaviors in quench state of both HTS coils and to verify the standout thermal performance of MIT material as a turn-to-turn insulation. Finally, the applicability of SI coil with MIT material on rotor field winding of HTS rotating machine was discussed on the basis of above experimental results.

II. SAMPLE PREPARATION & FABRICATION OF TEST COILS

A. Specification of conductor and test coils

1) Specifications of a 2G HTS wire

Parameters	Data
Company	SuNAM
Model name	SCN04200
With [mm]	4.1±0.1
Substrate thickness [μm]	150±15
Coefficient of variation	0.7
Bare Substrate Magnetic Properties	Non-magnetic
Maximum Critical current [A]	261
Minimum Critical current [A]	243

2) Specifications of HTS coils

Parameter	KPI	SI
Total tape length [m]	1.52	1.52
Conductor width [mm]	4	4
Conductor thickness [mm]	0.18	0.18
Number of turns	6	6
Inner diameter [mm]	80	80
Outer diameter [mm]	81.47	81.26
Insulation materials	Kapton Polyimide film	V_2O_3
I_c at 77 K [A]	135	142
B_z at center [mT]	9.1	9.6

3) Overview of insulation materials

(1) Polyimide Film Insulation (PFI) Coil

1) The Kapton polyimide film with 4 mm width and 0.03 mm thickness was co-wound between turn-to-turn of coil.

(2) Smart Insulation (SI) Coil

1) Vanadium III oxide (V_2O_3) was used for turn-turn insulation by drying at 120° C for 12 hours after pasted between turn-to turn of the coil.

2) V_2O_3 is one of the MIT (Metal Insulator Transition) materials that has changing resistivity property in specific temperature condition.

3)The resistivity value of V_2O_3 changes rapidly to approximately 1/600,000 times of its normal value when the temperature stays between 150 and 160 K.

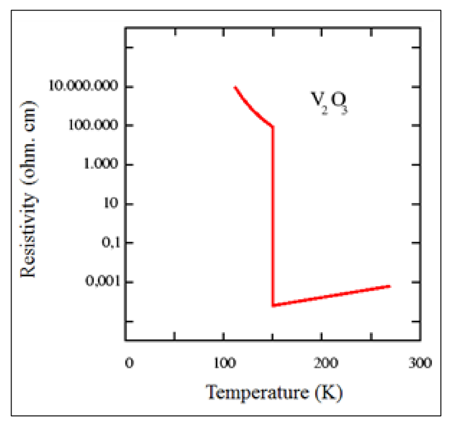


Fig.1. Changes in resistivity of V_2O_3 according to temperature

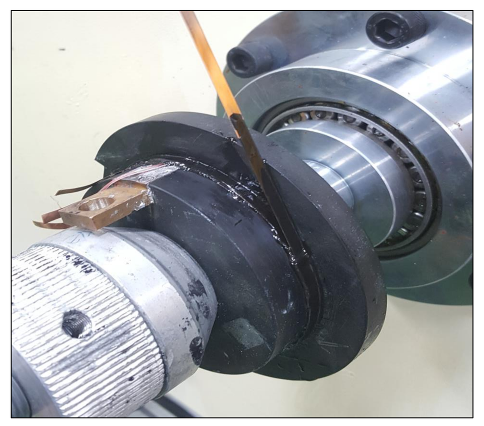


Fig.2. Photograph of pasting work of V_2O_3 during coil winding

B. Structure and assembly of Test coil

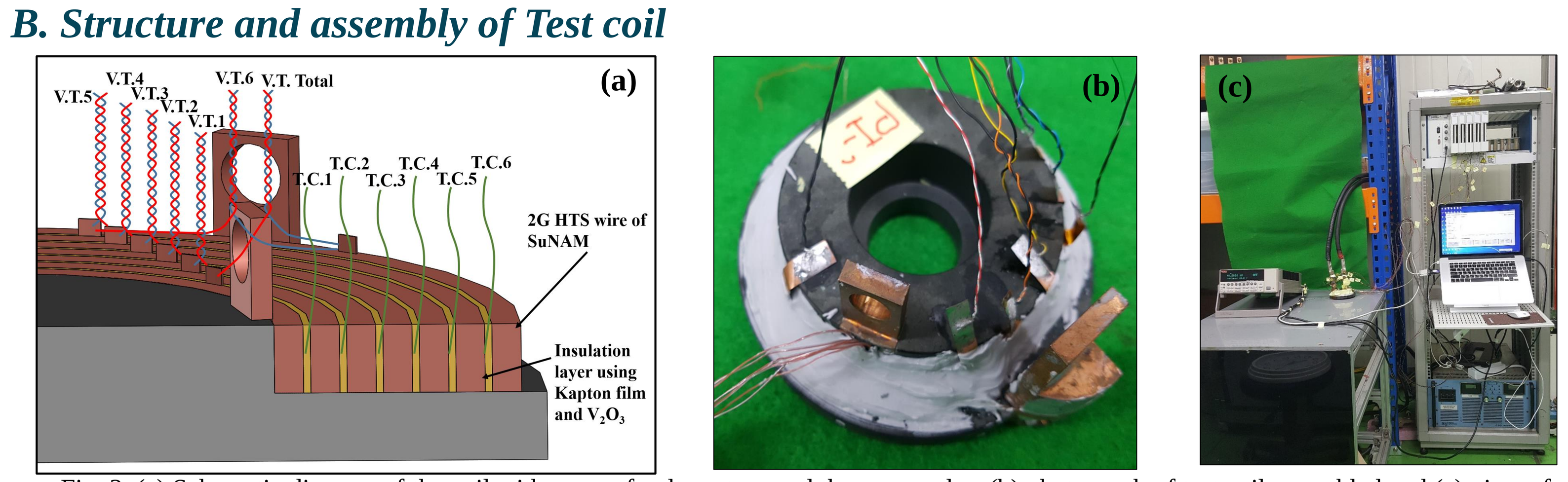


Fig. 3. (a) Schematic diagram of the coil with array of voltage taps and thermocouples, (b) photograph of test coil assembled and (c) view of experiment set-up

III. QUENCH TEST & RESULTS

A. I_c measurement

1) Critical Current measurement

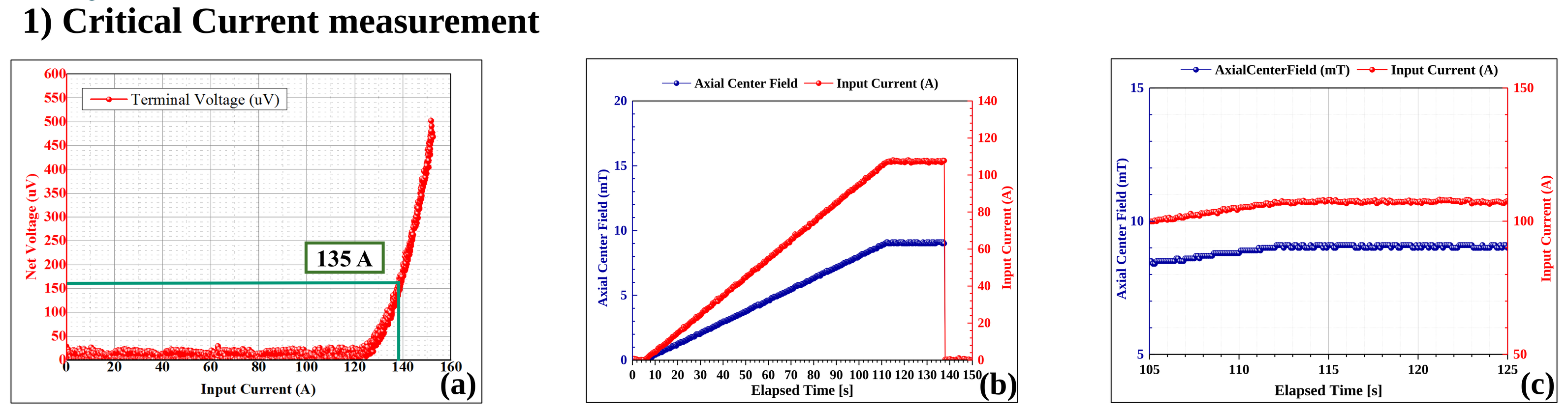


Fig. 4. (a) I-V and (b), (c) charging & discharging curves of KPI coil

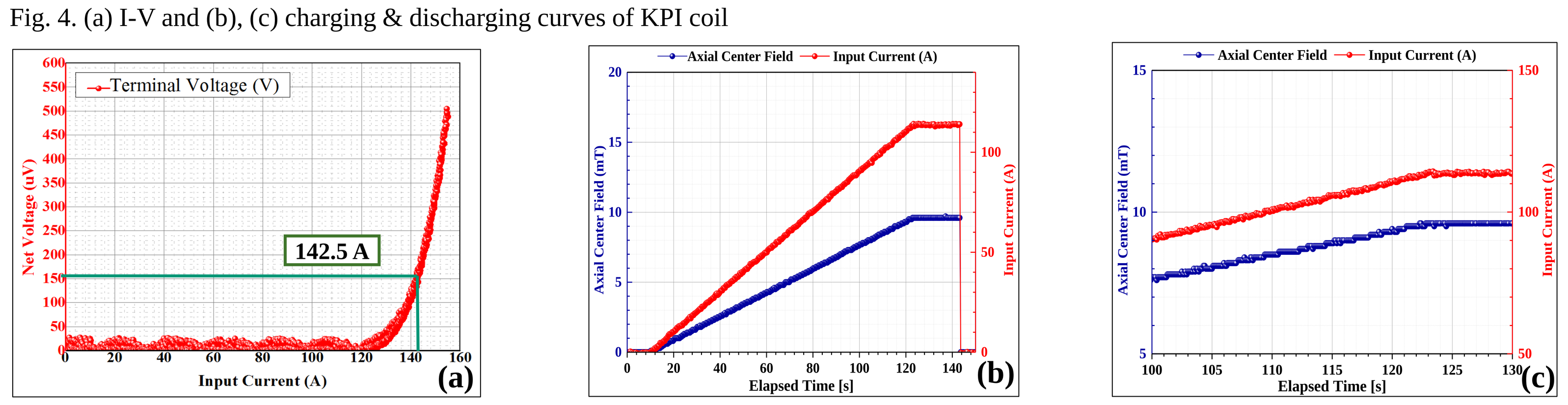


Fig. 5. (a) I-V and (b), (c) charging & discharging curves of SI coil

B. Quench testing

1) Set-up of over pulse current

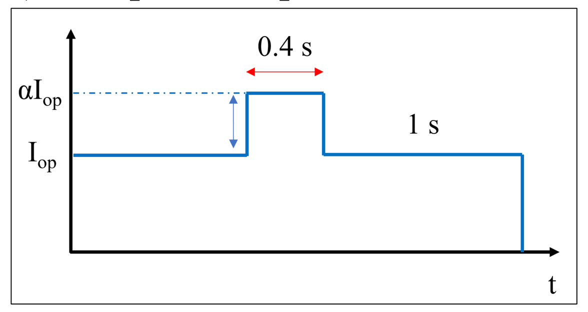


Fig. 6. over pulse current profile

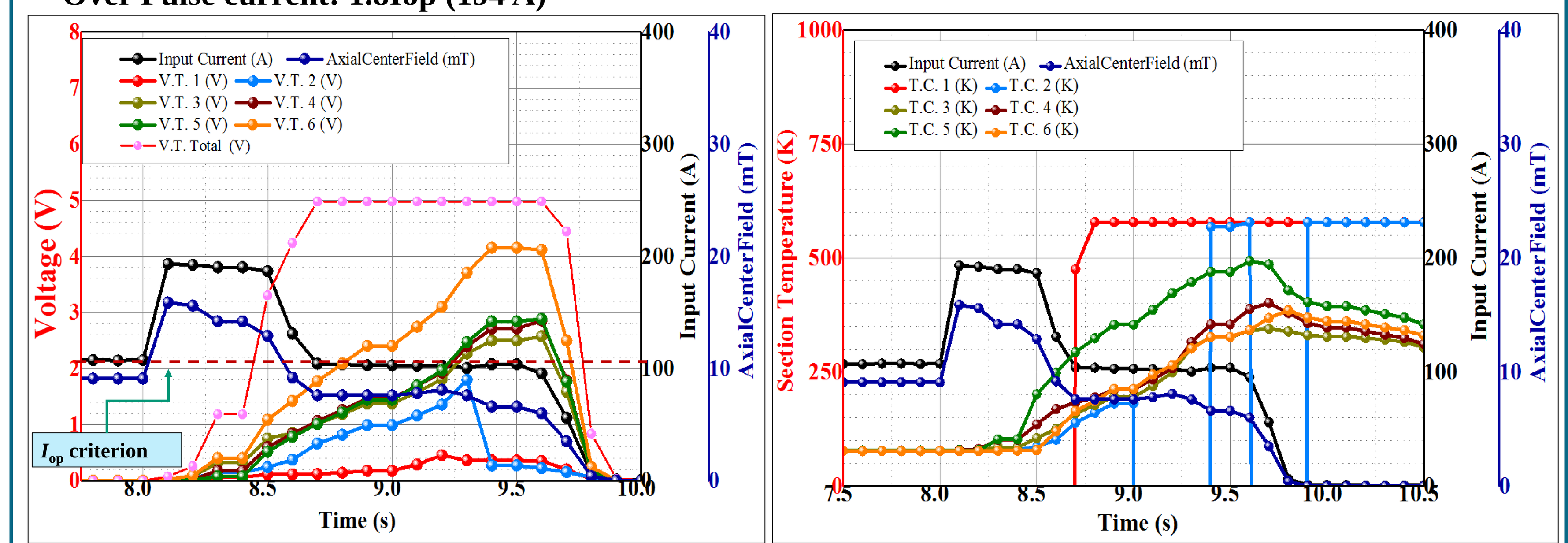
<Limits of measurement: over 5 V and 600 K>

Parameters	PI		SI			SI
Critical current (I_c) [A]	135		142			165
Operating current ($0.8I_c$) [A]	108		114			132
Duration after over pulse current [s]	1		1			2
Multiples of I_{OP}	1.8	1.9	1.7	1.8	1.9	1.7
(αI_{OP}) [A]	194	205	193	204	216	224
Pulse duration [s]	0.4					

2)Test result

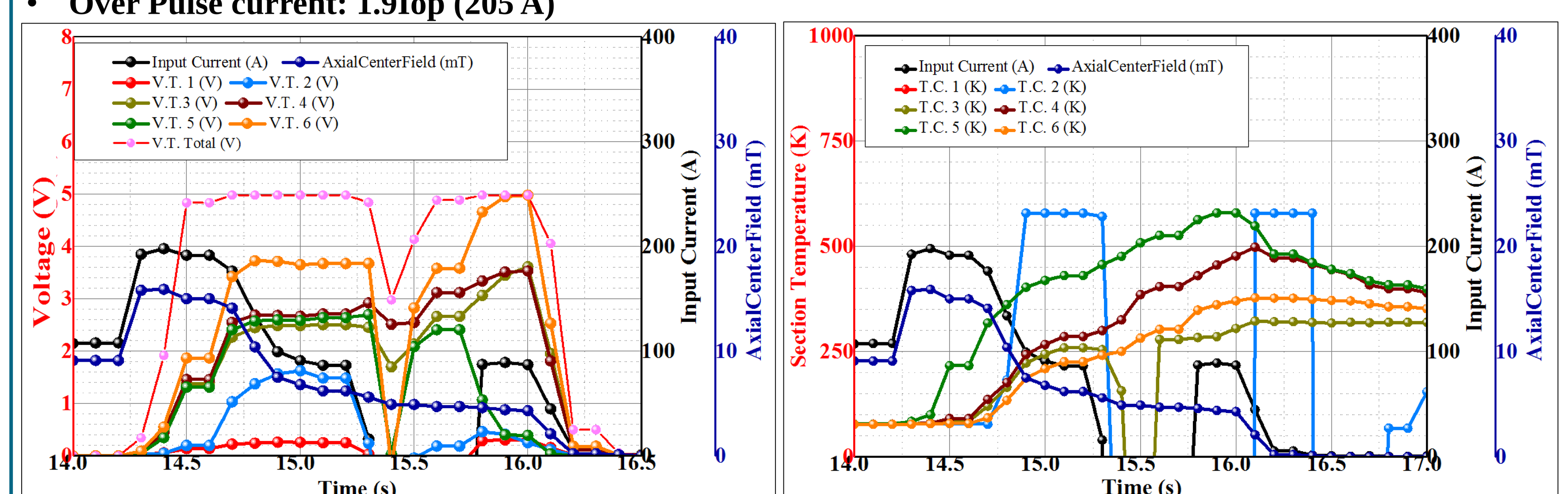
① Kapton Polyimide Insulation Coil with transport current duration of 1 s after launching over pulse current

- **Over Pulse current: 1.8Iop (194 A)**



- Terminal and section voltages of the PI coil have started to increase at the starting point of over pulse current, viz, about 8.0 s and especially, the terminal voltage was over a 5 V, which is limit of DAQ system, at the end point of over pulse current, viz, 8.5 s. Thus, for 1 s after over pulse current shooting, targeted I_{op} and axial center field can't be maintained by the limit of power supply due to quench voltage of beyond 5 V.
- Temperature between turns also was increased with over pulse current shooting and especially, temperatures at T.C. 2 were over 600 K. All temperatures were simultaneously recovered with shutdown of I_{op}.

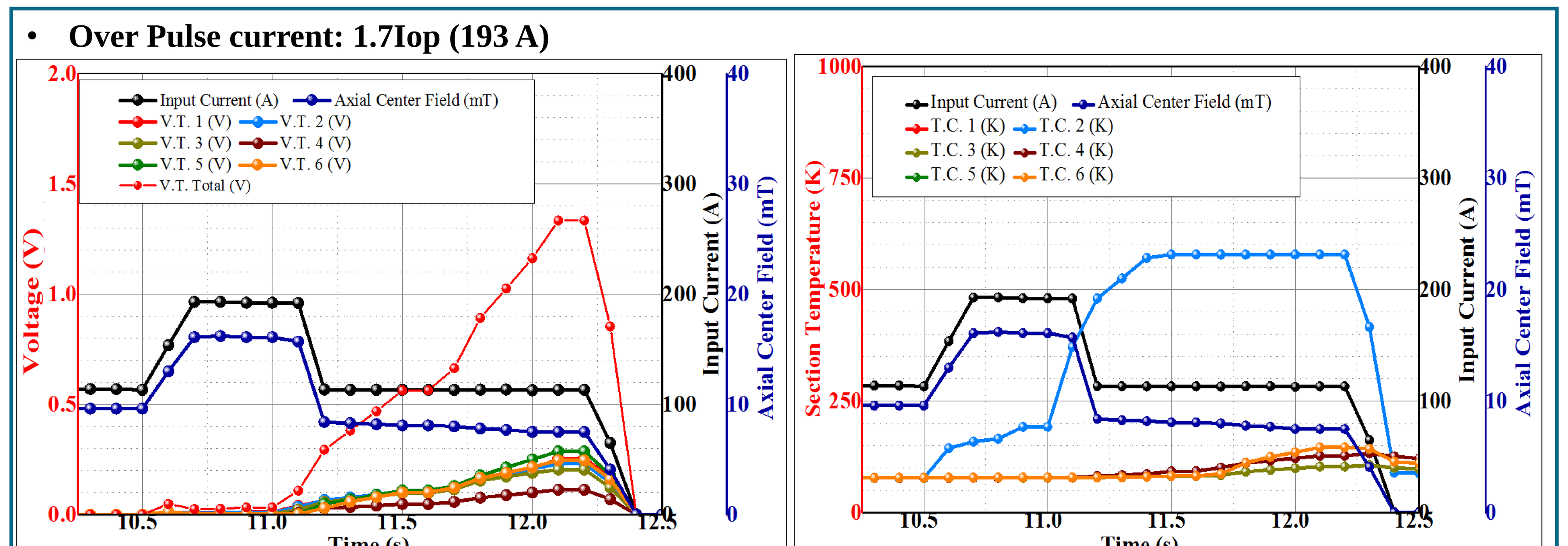
- **Over Pulse current: 1.9Iop (205 A)**



- The phenomenon that I_{op} from power supply can not be maintained becomes more clear, as getting stronger over pulse current intensity because not only terminal voltage but also section voltages were more higher than that of cases of $1.8I_{op}$ pulse shooting.
- Terminal voltage and section voltages were more higher and reacted more faster to increased over pulse current. The voltages were rapidly increased even before the end of over current pulse.
- Temperature profiles also have the same tendency of voltages.

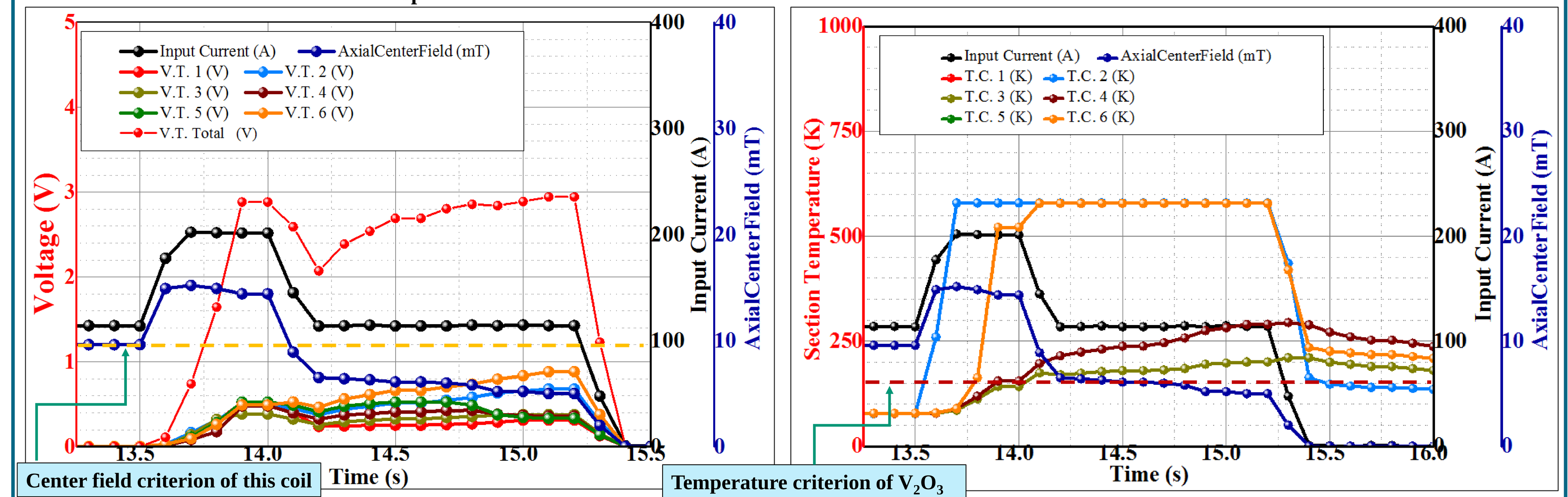
② Smart Insulation Coil with transport current duration of 1 s after launching over pulse current

- **Over Pulse current: 1.7Iop (193 A)**



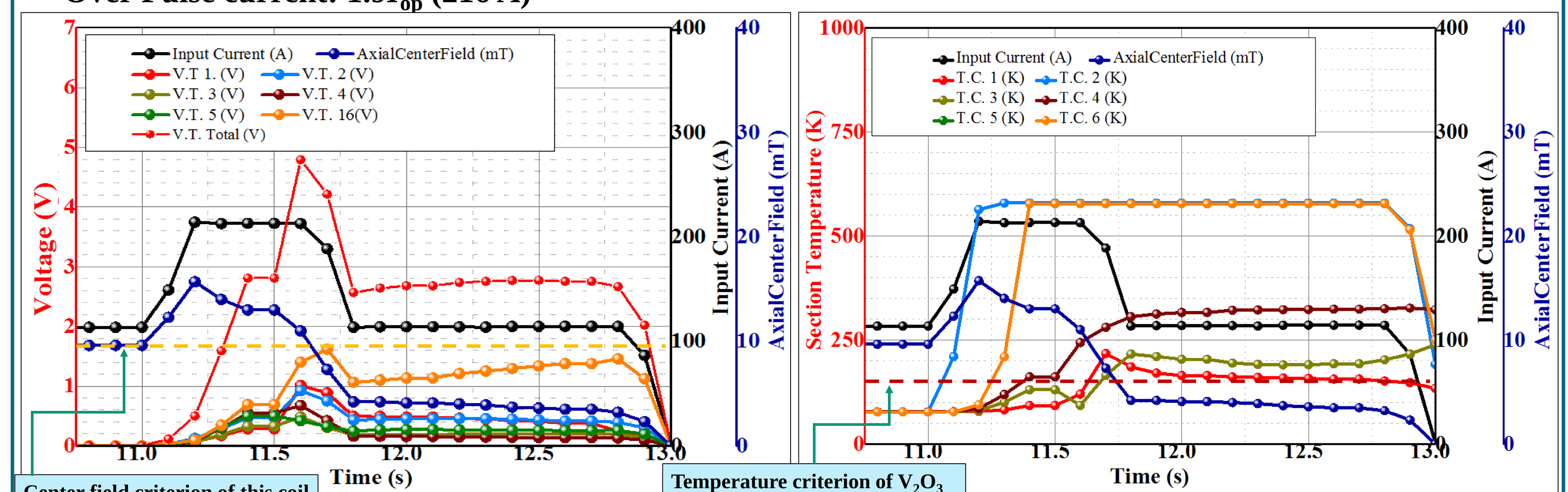
- Voltage and temperatures were gradually increased after end of over pulse shooting. Terminal voltage and temperature at T.C.2 were reached to about 1.3 V and over 600 K, respectively.
- When I_{op} of 114 A was constantly kept for 1 s after end of over pulse shooting, we can observe the phenomenon that center field is gradually decreased due to bypassed transport current between two turns. We can confirm that this phenomenon was because contact resistance between 2nd and 3rd turns was decreased due to resistivity transfer characteristic of V_2O_3 when temperature between 2nd and 3rd turns (T.C. 2) was rapidly going beyond 150 K after end of over pulse shooting.

- **Over Pulse current: $1.8I_{op}$ (204 A)**



- The phenomenon that center field is decreased due to bypassed transport current between two turns becomes more clear than that of over pulse current case of $1.7I_{op}$.
- This is because transport current was starting to bypass between other turns due to increased temperature over 150 K between two turns although over pulse current was not ended.
- The voltages of SI coil were generally smaller than that of KPI coil with same multiples of over pulse current, viz, $1.8I_{op}$. Thus, we conclude that this was also because of the current bypassing phenomenon of SI coil.

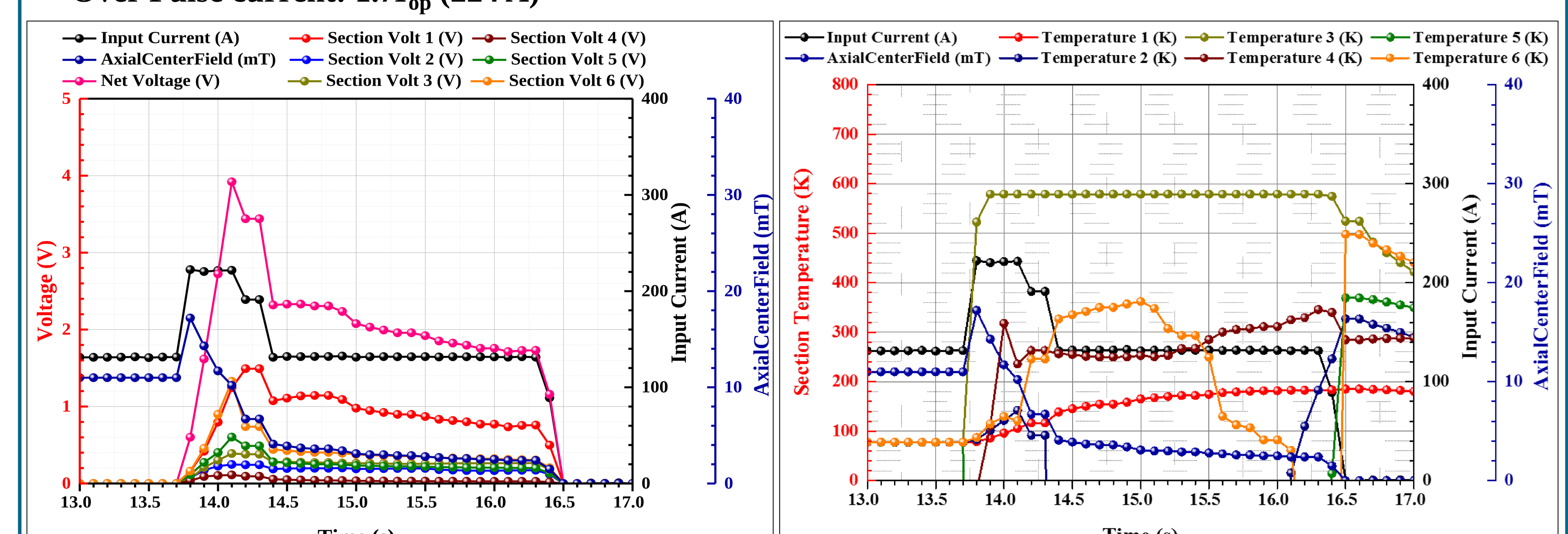
- **Over Pulse current: $1.9I_{op}$ (216 A)**



- When over current pulse of 216 A was launched to SI coil, center field was starting to decrease together starting point of pulse current, viz, about 11 s. We can conclude that it can be expected to generate current bypassing area across the SI coil.
- The terminal voltage of SI coil was reached to near 5 V that is acquisition limit of DAQ device.

③ Smart Insulation Coil with transport current duration of 2 s after launching over pulse current

- **Over Pulse current: $1.7I_{op}$ (224 A)**



- I_c and I_{op} ($0.8I_c$) were 165 and 132 A, respectively for this SI coil.
- Although transport current of 132 A was maintained for 2 s after the end of over pulse current, current bypassing phenomenon was observed and the voltages were decreased with starting to reduced center magnetic field.

CONCLUSION

In this study, quench test of KPI and SI coil with over pulse current shooting and their behaviors were presented. Especially, the case of SI coil is the world's first quench tests with shooting over pulse current. The technical key points of over pulse current test are as follows:

- **The voltages and temperatures in both HTS coils were more higher and more faster reacted to over pulse current as stronger over pulse current intensity.**
- **The voltages of SI coil were generally smaller than that of KPI coil with same multiples of over pulse current because of the current bypassing phenomenon of SI coil.**
- **In case of SI coils, the phenomenon which center field is decreased due to bypassing transport current after over pulse current launching, so-called, the magnetic field loss will be used to detect the quench and hence HTS coil can be protected during a certain period of time when the magnetic field is reduced.**

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