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Development and Performance of 65 T Fast-cooling User Magnet with Long Service Life

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Introduction

Peak fields up to 90 ~ 100 T have been achieved in several laboratories worldwide. Due to the ultra-high magnetic force, these magnets have relatively short service life. Additionally, these magnets have huge volume. The cooling time between two pulses ranges from two to several hours, which reduces substantially the experiment efficiency. Therefore, the pulsed magnets designed for 60 ~ 70 T, service life more than 500 pulses and cooling time less than one hour are the workhorse magnets in the laboratories.

Five 65 T fast-cooling magnets with long service have been developed at the WHMFC. The magnets are energized by a 2 or 3 MJ capacitor bank for 40 ~ 70 ms pulse duration for electrical transport measurement. For magnetization measurement, shorter pulse duration of 11 ms for field waveform with almost symmetrical rising and falling edges can also be produced with a 1.25 MJ capacitor bank. The cooling time between two 60 T pulses ranges from 30 to 50 minutes. Up to now, three of these magnets failed after 916, 668 and 947 pulses with the magnetic field above 60 T. The other two have delivered 706 and 56 pulses above 60 T and are still in operation.

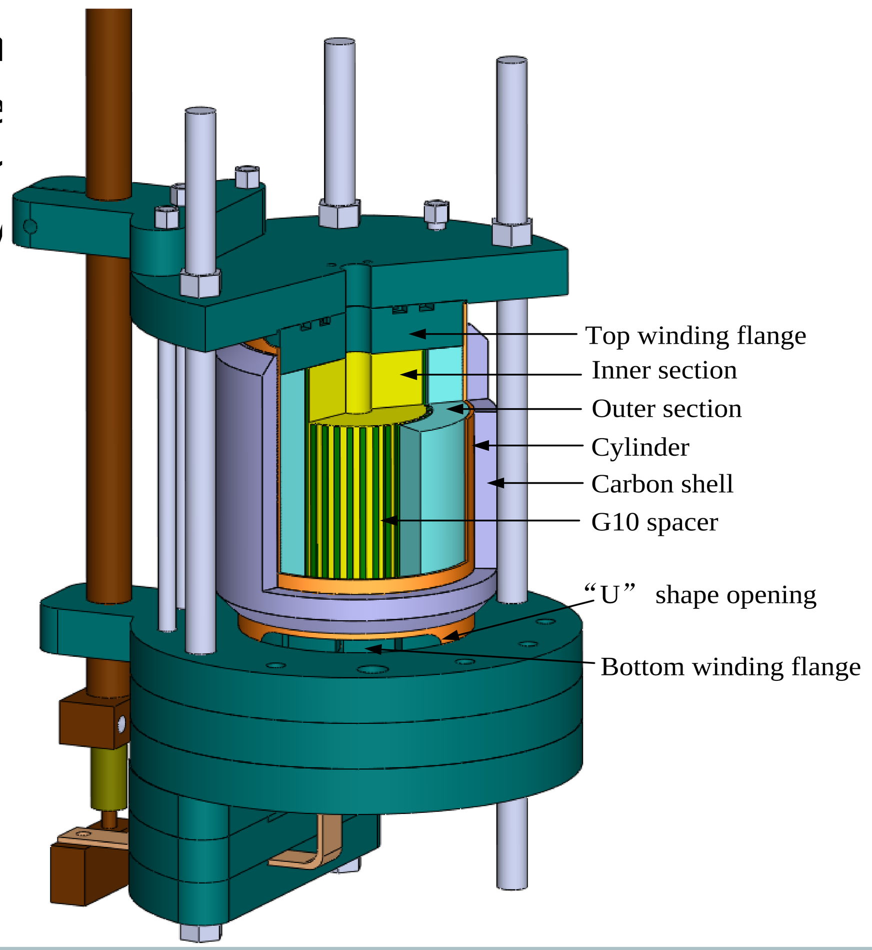
Magnet Parameters

In order to reduce the cooling time, all the five pulsed magnets are designed with 5 mm gaps in the radial direction to allow the flow of liquid nitrogen in the coil windings. The conductor wire is the CuNb micro-composite produced by the China Northwest Institute for Non-ferrous Metal Research. Each conductor layer is reinforced with Zylon/epoxy composites.

	P031	P034	P036	P038	P039
Bore (mm)	21	21	23	21	21
Energy (MJ)	2	3	3	3	1.25
Capacitance (mF)	6.4	9.6	9.6	9.6	4
Cooling time (min)	35	50	50	50	35
Coil Height (mm)	160	160	180	180	180
Pulse duration (ms)	40	60	70	70	11
Conductor layers	10	12	12	12	10
Internal Reinforcement	Zylon/epoxy composite				
Conductor	2.8 mm×4.3 mm CuNb wire				

CuNb wire

- **cross-section:** 2.8 mm × 4.3 mm
- **UTS @ room temperature:** ~ 830 MPa
- **Conductivity @ room temperature:** ~ 71% IACS



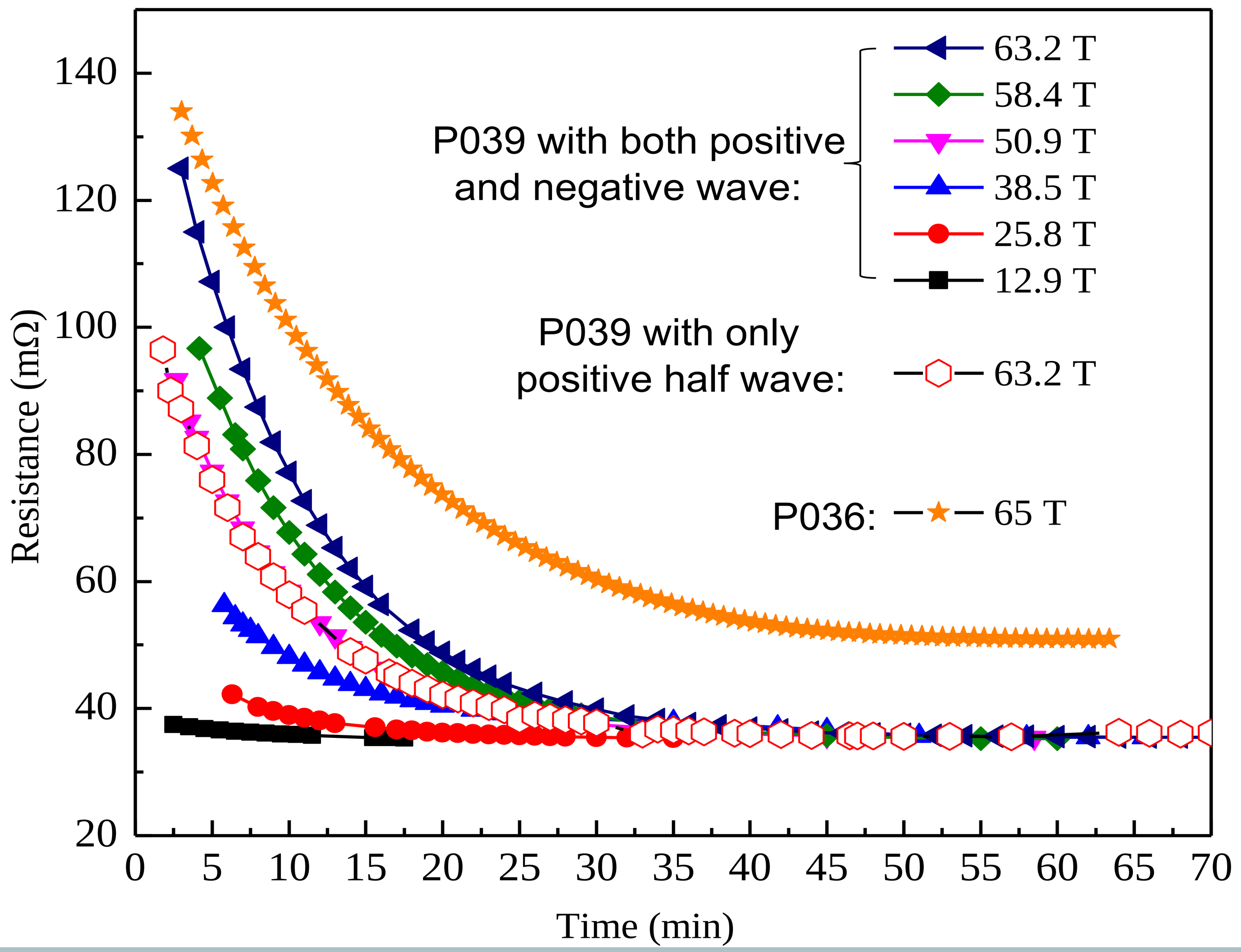
Experimental Results

Cooling time

The cooling curve of P039 and P036 are displayed for comparison. For magnet P039, the cooling time after a 63.2 T pulse with both positive and negative waves is 30 minutes. For pulse with only positive wave, the resistance just after the pulse is 96.5 mΩ. In comparison, the resistance after the pulse with both positive and negative waves is 135 mΩ, however, there is almost no difference between the cooling time due to the same thermal time constant.

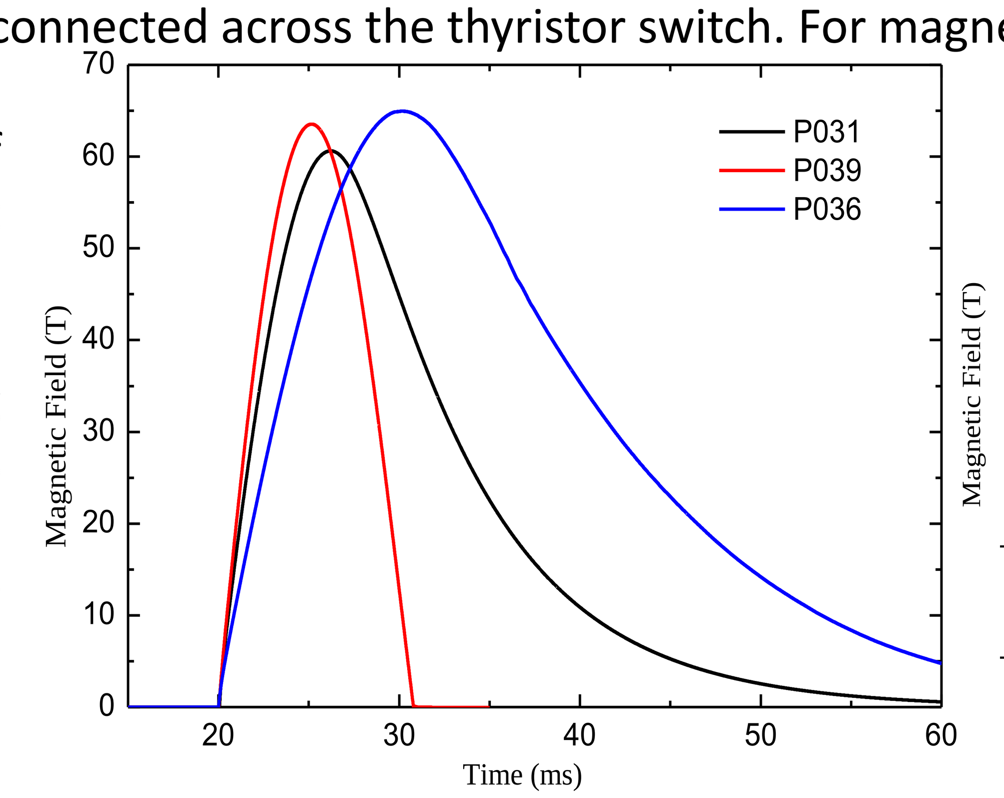
Service Life

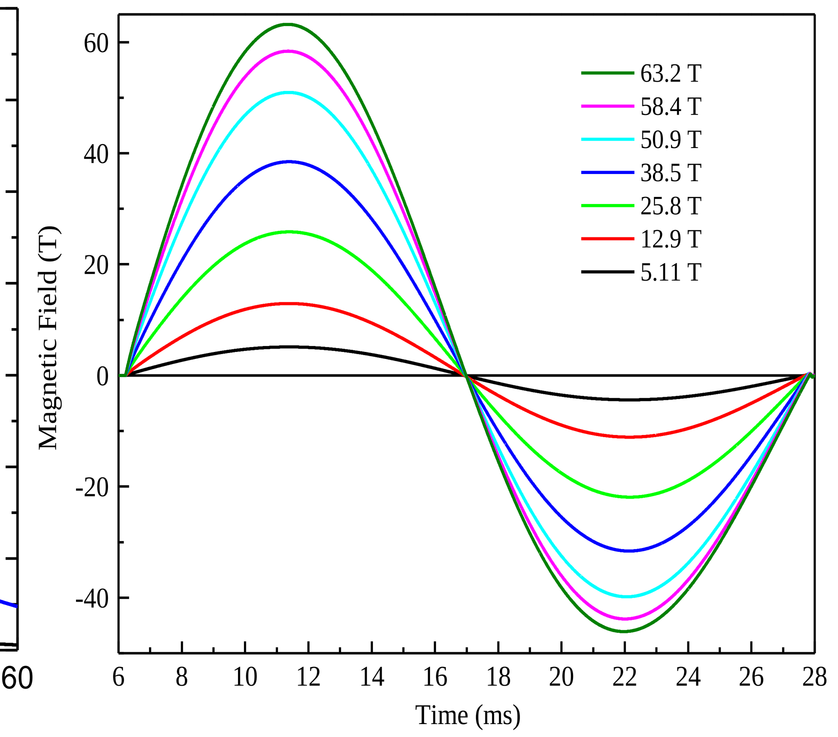
Each of the pulsed magnet P031, P036 and P038 have delivered 2000 ~ 4000 pulses, in which 916, 668 and 947 pulses are in the range from 60 to 65 T before the magnet failure. The pulsed magnet P034 and P039 have already delivered 706 and 56 pulses above 60 T and are still in operation.



Field Waveforms

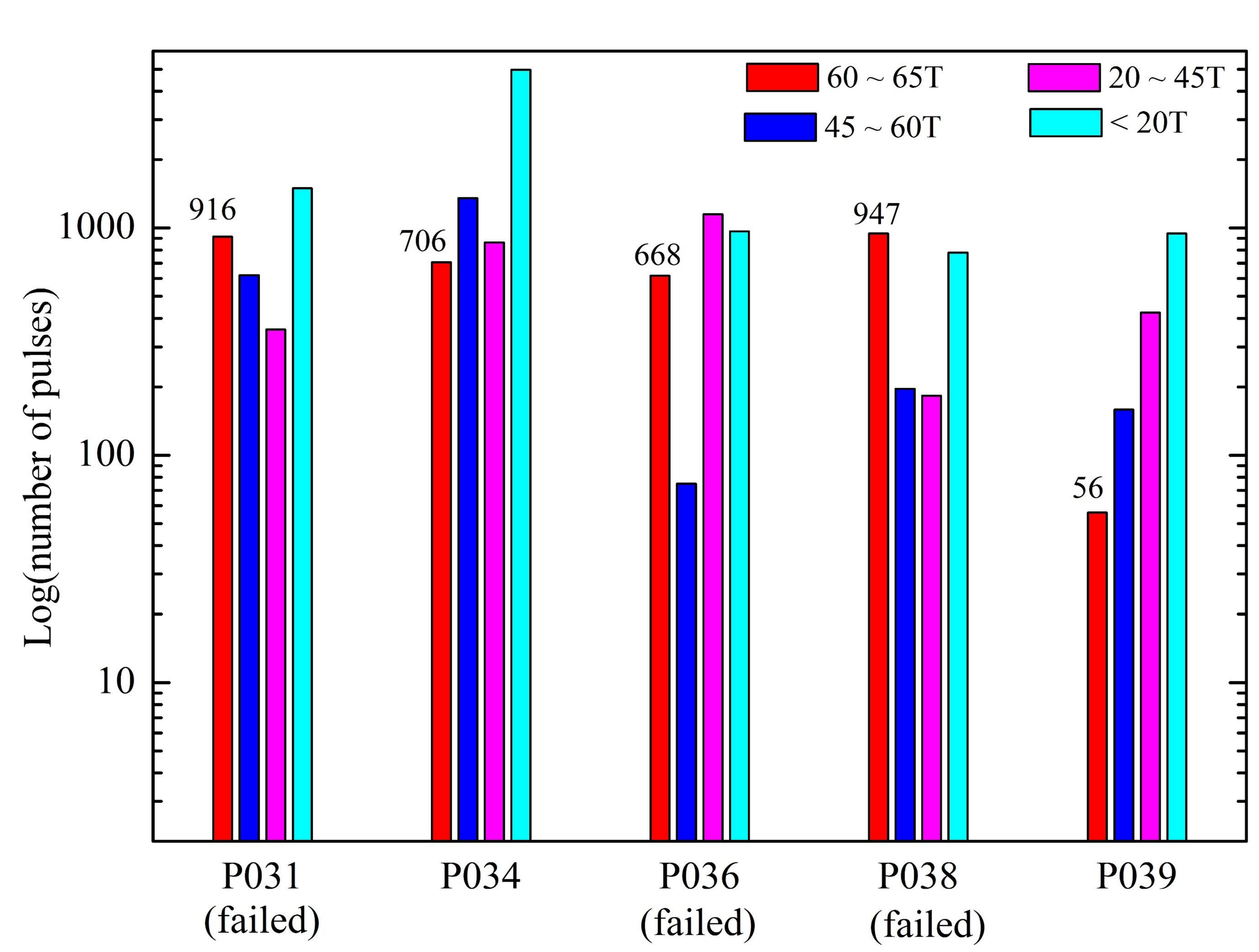
The measured field waveform of P036 is displayed below, as well as the field waveforms of P031 and P039. The magnet P039 has less layers and driven by a capacitor bank with smaller capacitance. The capacitor bank can be configured with and without a diode connected across the thyristor switch. For magnetization measurement, the diode is normally disconnected, thus the thyristor switch is turned off automatically when the magnet current decays to zero. Thus, the field with only positive half wave and almost symmetrical rising and falling edges is obtained. If the diode is connected, the current continues and reverse field with negative half wave is achieved.

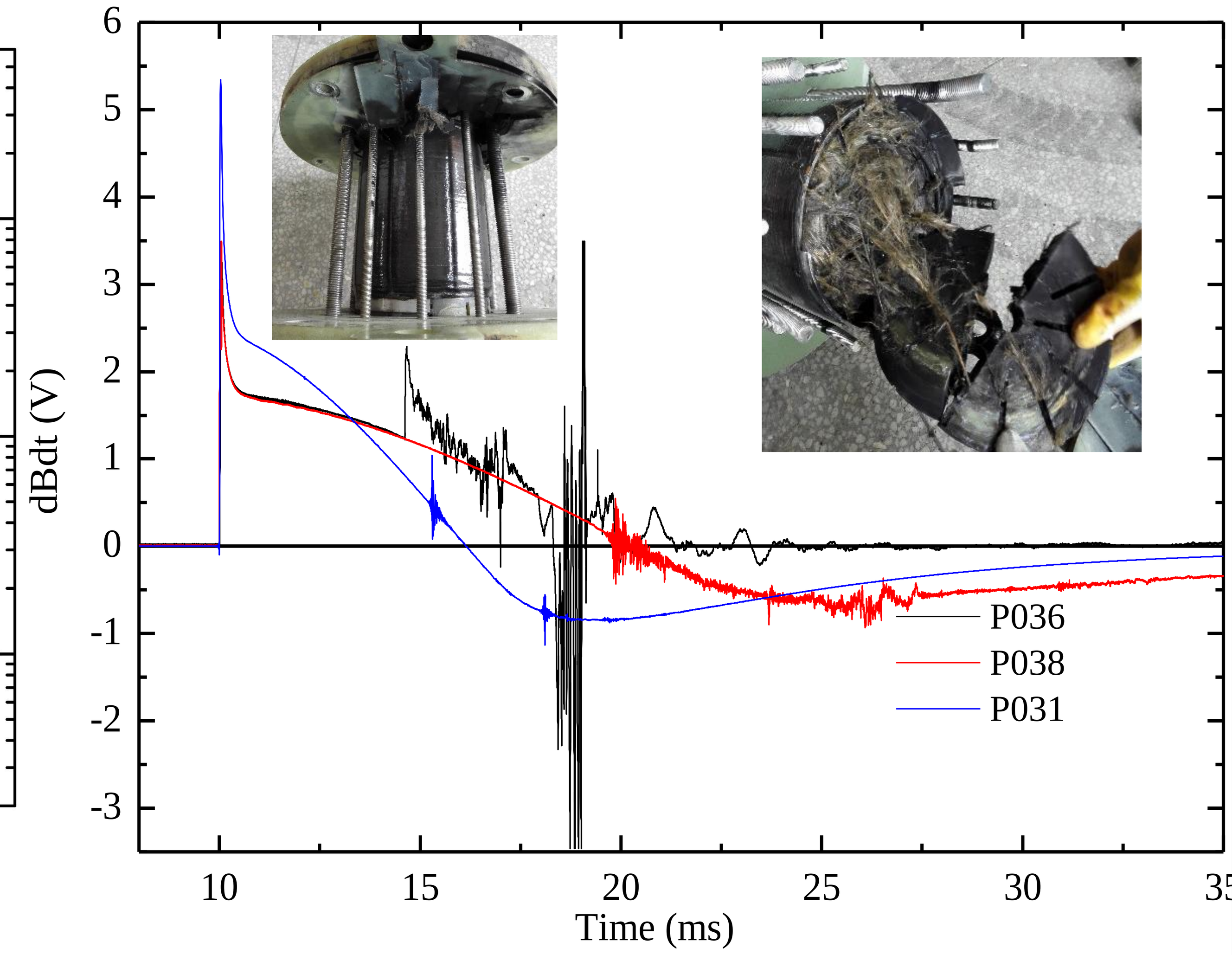




Failure Analysis

The measured dB/dt curves show that failure happened in the rise edge of the magnetic field at which moment the voltage was not the highest. These three pulsed magnets have been disassembled. The outer most layer of reinforcement was not damaged. The G10 flange at the side of the contacts and the wires at the end of the winding burned. The black dust indicates that the electrical arc happened. It is quite possible that the failure was caused by the magnetic force induced insulation failure after more than hundreds of pulses.





Conclusions

- ❖ Five user magnets have been developed and have delivered more than 3000 pulses in the range of 60 to 65 T.
- ❖ Three of these magnets failed. The average service life is 800 pulses and maximum service life 947 pulses.
- ❖ Fabrication of the layer transition of the wire will be improved by inserting more insulation. The improved 65 T class magnets are desired to have service life more than 1500 pulses.
- ❖ For higher field requirements, 75 T class magnet will be designed to have a service life of 500~ 800 pulses.