Quench Tests Analyses of the First JT-60SA Toroidal Field Coils

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CEA Saclay

Context (JT-60SA)

Fusion energy:

Fusion reactions:

$Deuterium + Tritium$

$\rightarrow He4\ (3.56MeV) + neutron\ (14.03MeV)$

$Deuterium + Deuterium$

$\rightarrow He3\ (0.82MeV) + neutron\ (2.45\ MeV)$

(plasma state: high temperature ~ 10^8 K)

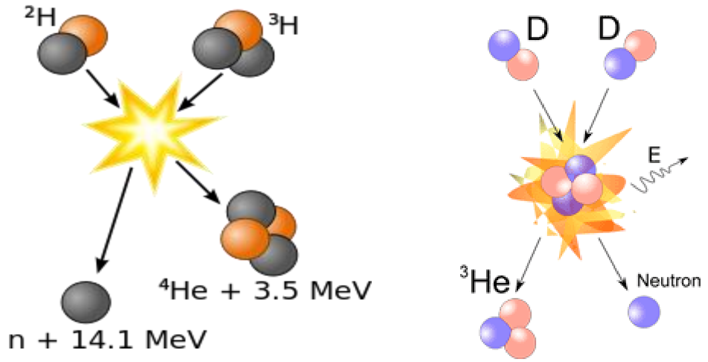
Fusion approaches:

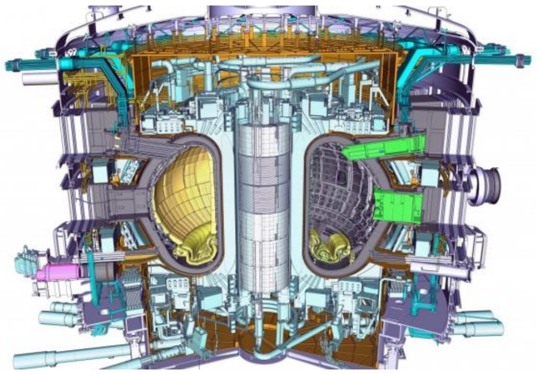
Magnetic confinement

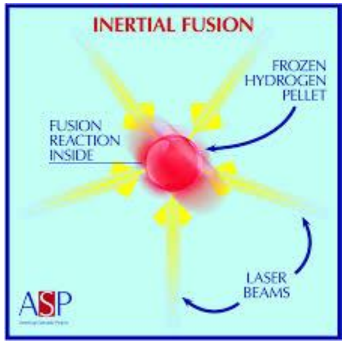
- **tokamak (donut shaped chamber)**
- spherical tokamak
- stellarator, etc

Inertial confinement (lasers' high energy)

- direct drive
- indirect drive, etc







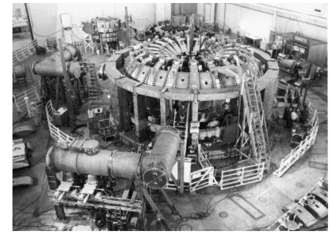
Context (JT-60SA)

International fusion project prospects[1] :

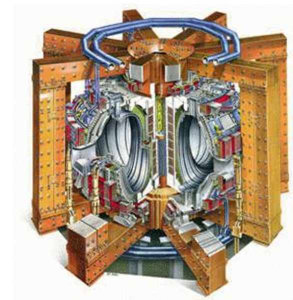
<u>First step:</u> scientifically feasible (1970s ~ 2000)
e.g. TFTR, JET, JT-60U

<u>Second step:</u> technically feasible
e.g. **ITER[2]**, 2005~2025 construction;

<u>Third step:</u> commercially feasible
e.g. DEMO, design & concept.



<u>TFTR</u>



<u>JET</u>

<u>JT-60U</u>

(1) « Fusion – The energy of the universe », Garry McCracken & Peter Stott
(2) International Thermonuclear Experimental Reactor

Context (JT-60SA)

Fusion experiment: JT-60SA

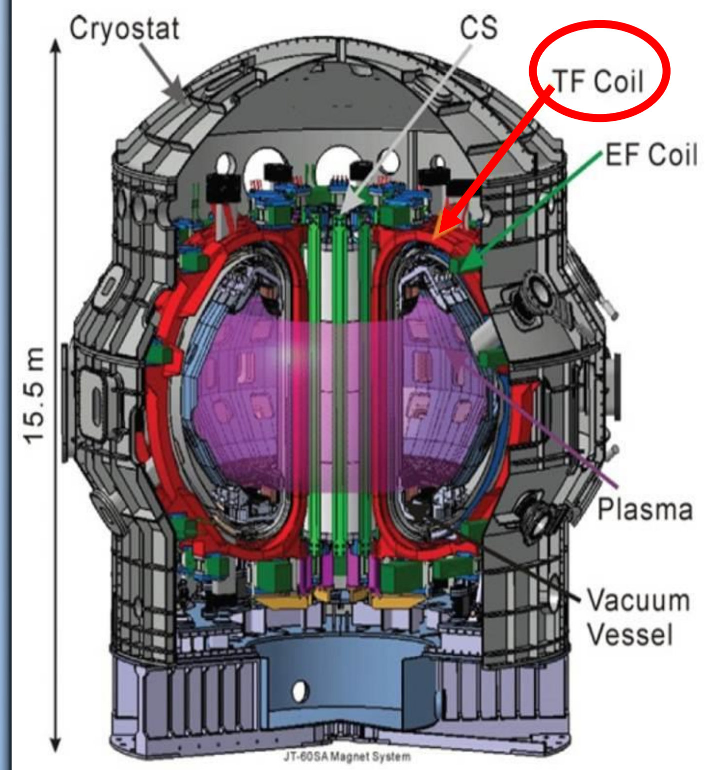
Background: JT-60U (copper coils)

Participants: Europe (18 Toroidal Field coils: fabrication and tests)
Japan (existing infrastructure JT-60U + other components)

Role: Support to the operation of ITER
Addressing key physics issues for ITER & DEMO

My topic:
Quench test analyses of the first **JT-60SA** Toroidal Field **(TF) Coils**

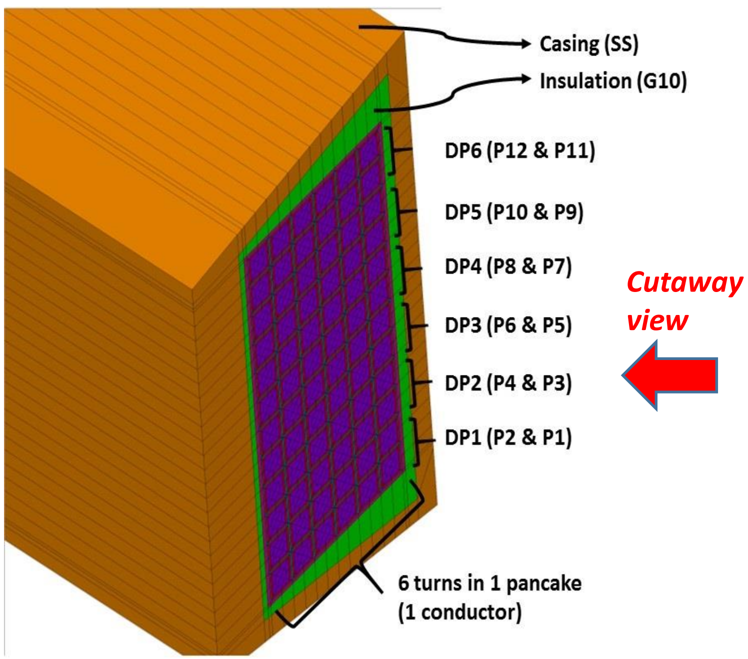
Quench: electrical conductor’s sudden transition from superconducting state to normal resistive state

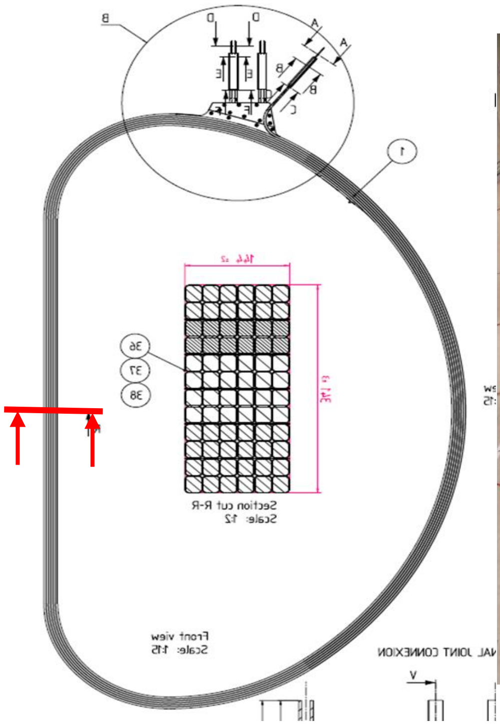


Instrumentation

Configuration of TF coils:

- 4.5 x 7.5 m;
- ~ 16 t;
- 12 pancakes stacked;
- 113 m long / pancake





Instrumentation

Cold Test Facility (CEA Saclay): cryostat, valve box, helium refrigerator, power supply, rapid acquisition system, etc

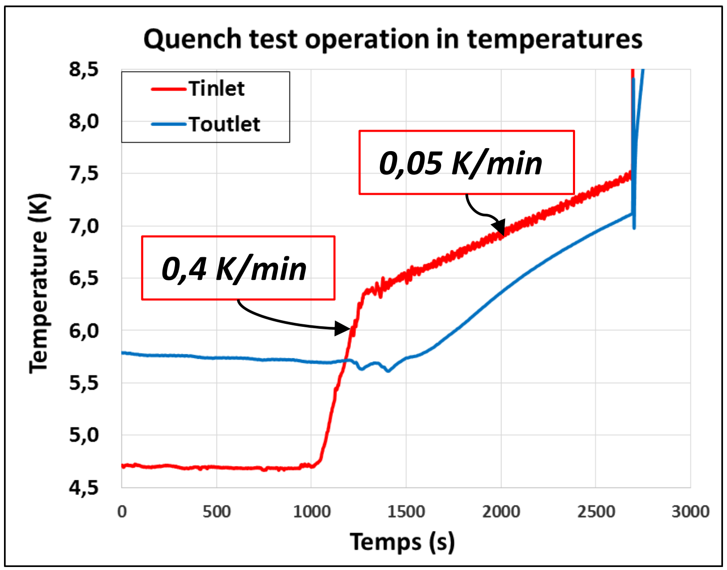
N° TF coil	Manufacturer	Test date	N° DP quench
10	France	19/02/2016	DP6
10 (bis)	France	25/02/2016	DP1
11	France	11/04/2016	DP6
12	France	11/07/2016	DP1
13	France	04/10/2016	DP4
14	France	03/11/2016	DP3
15	France	09/02/2017	DP2

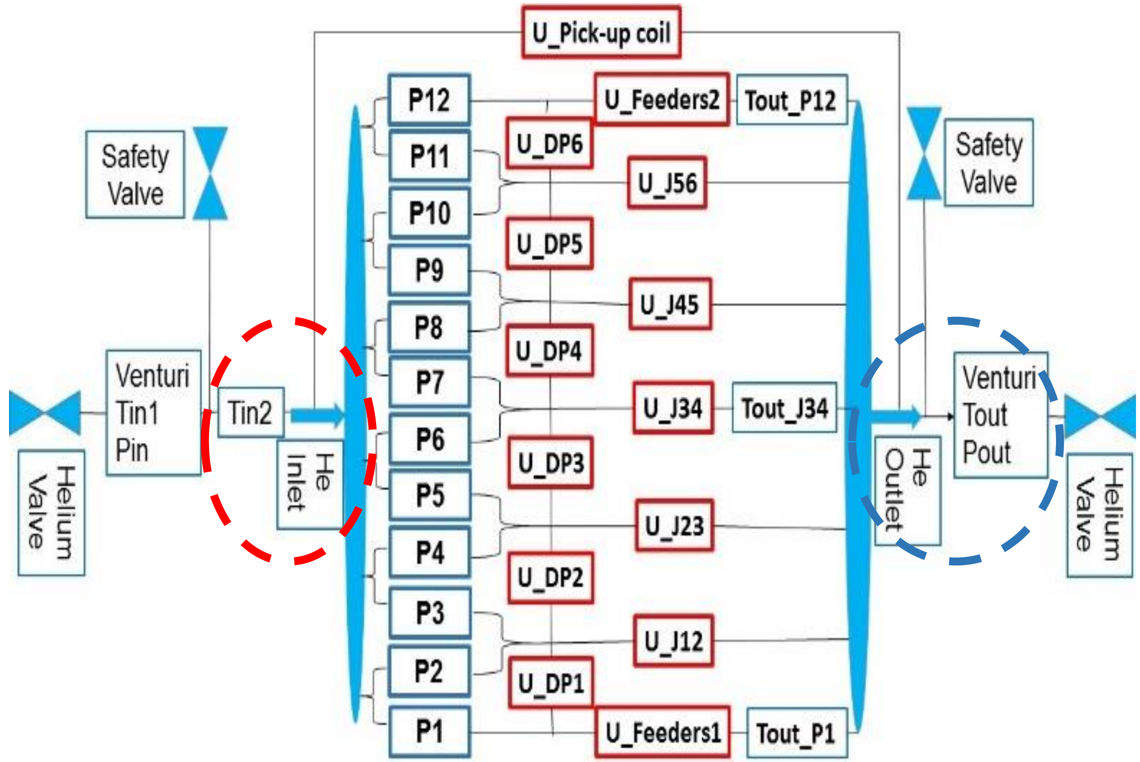
N° TF coil	Manufacturer	Test date	N° DP quench
01	Italy	07/06/2016	DP5
03	Italy	31/08/2016	DP6
04	Italy	28/11/2016	DP6
05	Italy	12/01/2017	DP6
06	Italy	13/03/2017	DP3

Instrumentation

Operating conditions ***CTF:***

- Tinlet 4.7 K => 7.5 K
- Pressure ~10 bar
- Nominal current 25.7 kA
- Peak field ~ 3 T

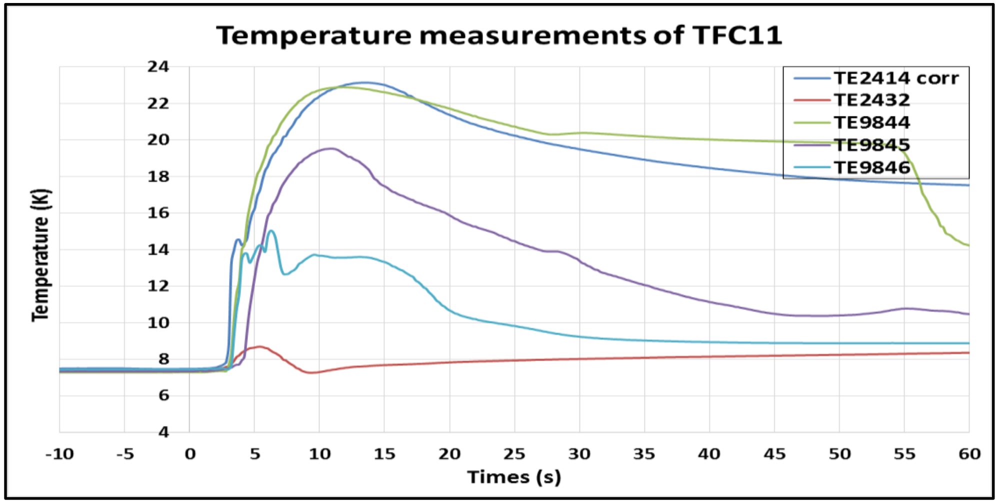


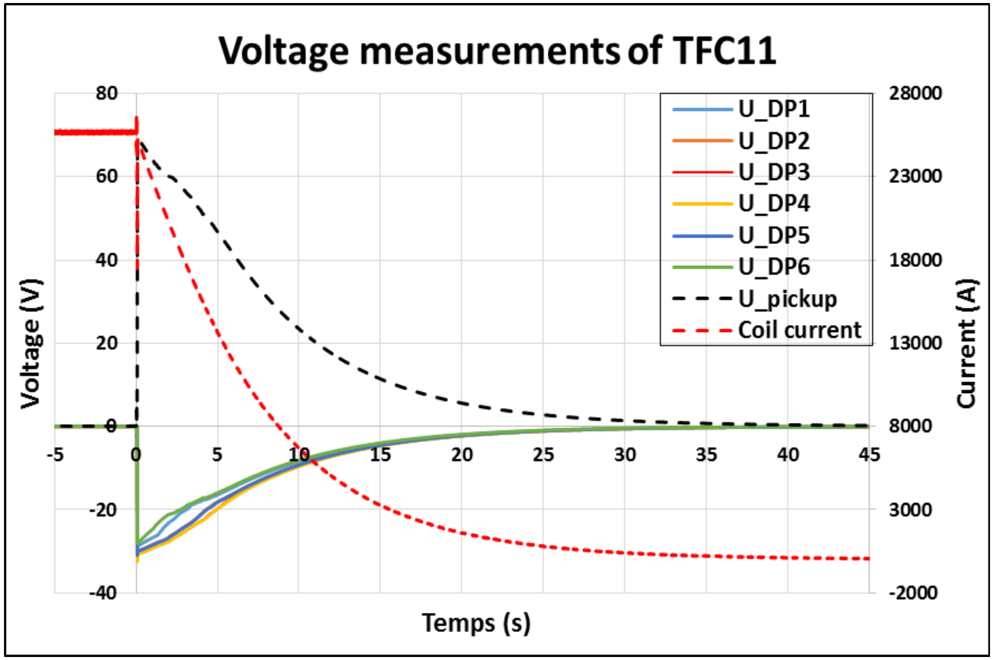


Data

Instrumentation of CTF	
Cryogenic system	Measurement
TE2414	WP inlet temperature
TE2432	WP outlet temperature
TE9844	DP6 outlet temperature
TE9845	DP1 outlet temperature
TE9846	Joint DP3-4 outlet temperature
PT2416	WP inlet pressure
PT2424	WP outlet pressure
P_Capa_C	Helium container pressure

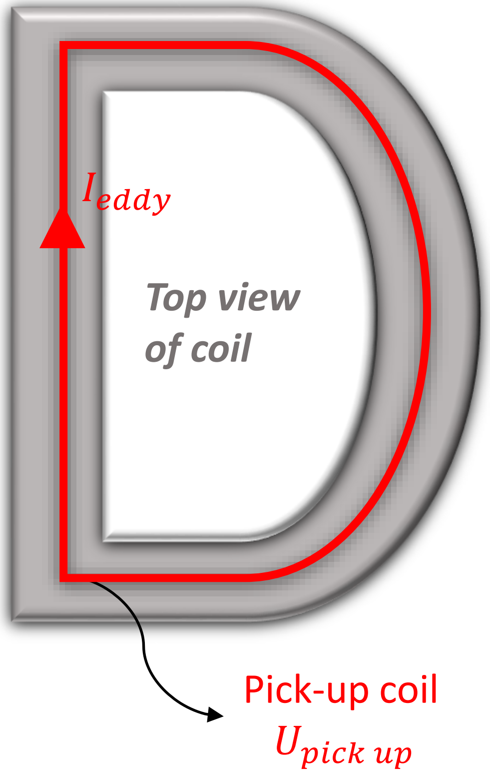
Instrumentation of CTF	
Electrical system	Measurement
Vb1	DP1 voltage
Vb2	DP2 voltage
Vb3	DP3 voltage
Vb4	DP4 voltage
Vb5	DP5 voltage
Vb6	DP6 voltage
U_Jb1-2	Joint DP1-2 voltage
U_Jb2-3	Joint DP2-3 voltage
U_Jb3-4	Joint DP3-4 voltage
U_Jb4-5	Joint DP4-5 voltage
U_Jb5-6	Joint DP5-6 voltage
U_SL1	Feeders DP1-valve box voltage
U_SL2	Feeders DP6-valve box voltage
Vpick	Pick-up coil voltage





Data exploitation

Transit resistance for double-pancakes: method by **pick-up coil compensation**
Faraday's law of induction => **eddy currents** induced by changing magnetic field
=> create another magnetic field to oppose the original one

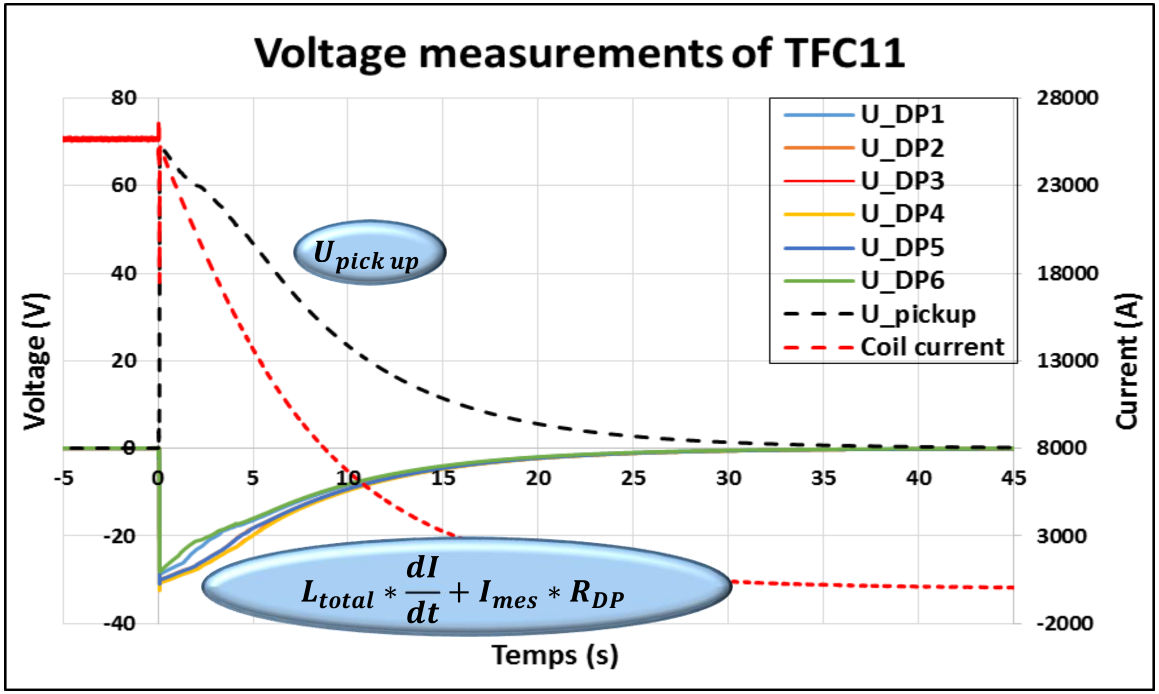


Calculation of transit resistance R_{DP} with the pick-up coil compensation:

$$U_{DP\ mes} = U_{DP\ inductive} + I_{mes} * R_{DP}$$

With $U_{DP\ inductive} = L_{total} * \frac{dI}{dt} \propto U_{pick\ up}$ (γ)

Notes: with the test Fast Discharge (Coil 10), the ratio γ can be determined



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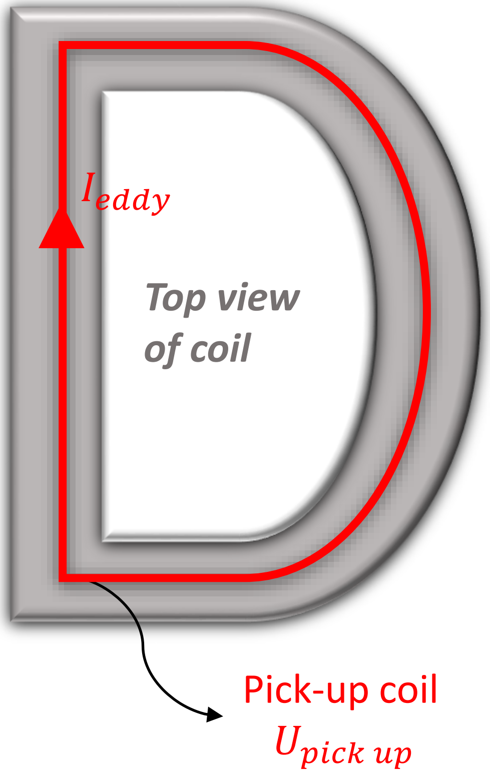
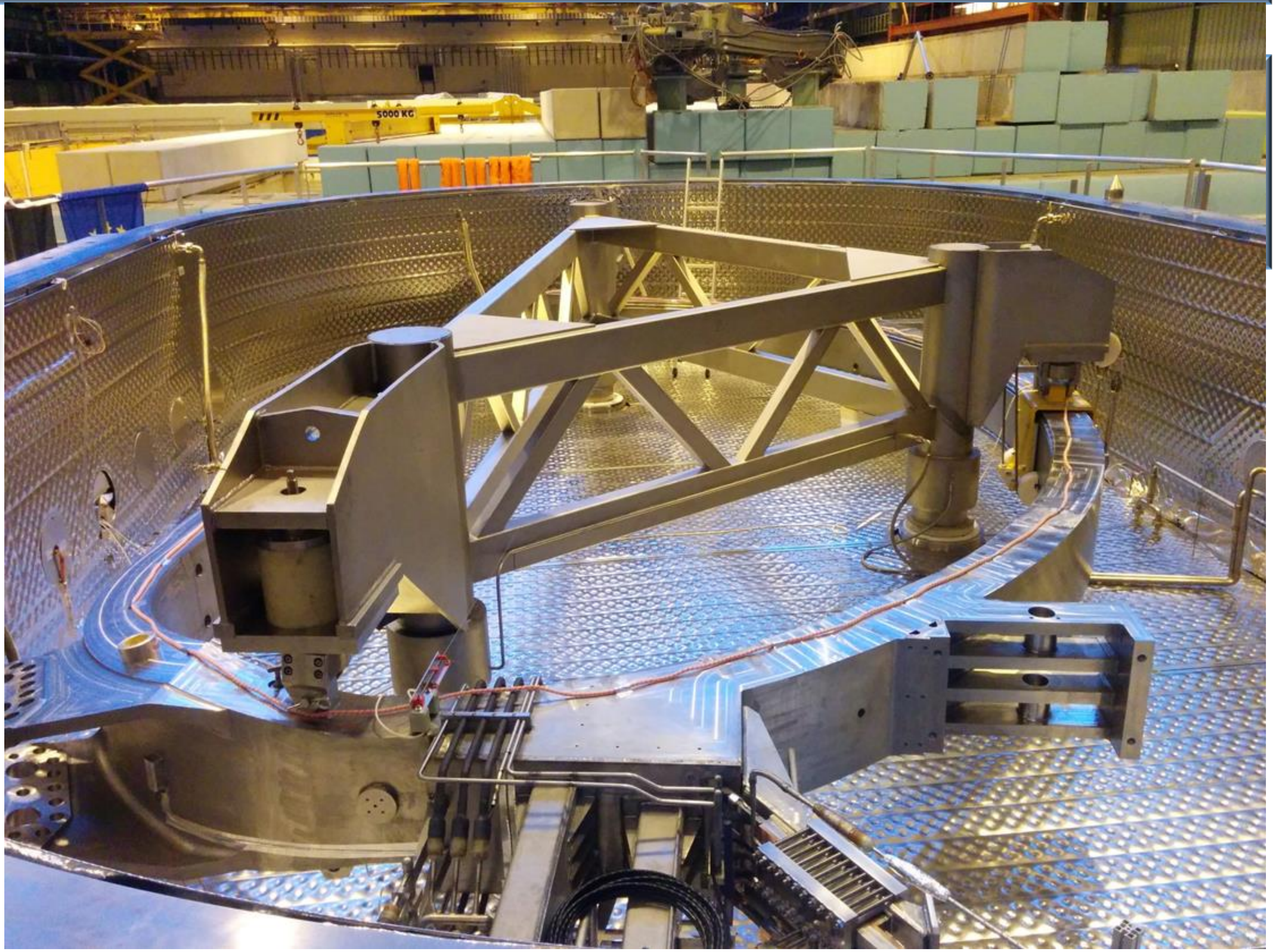
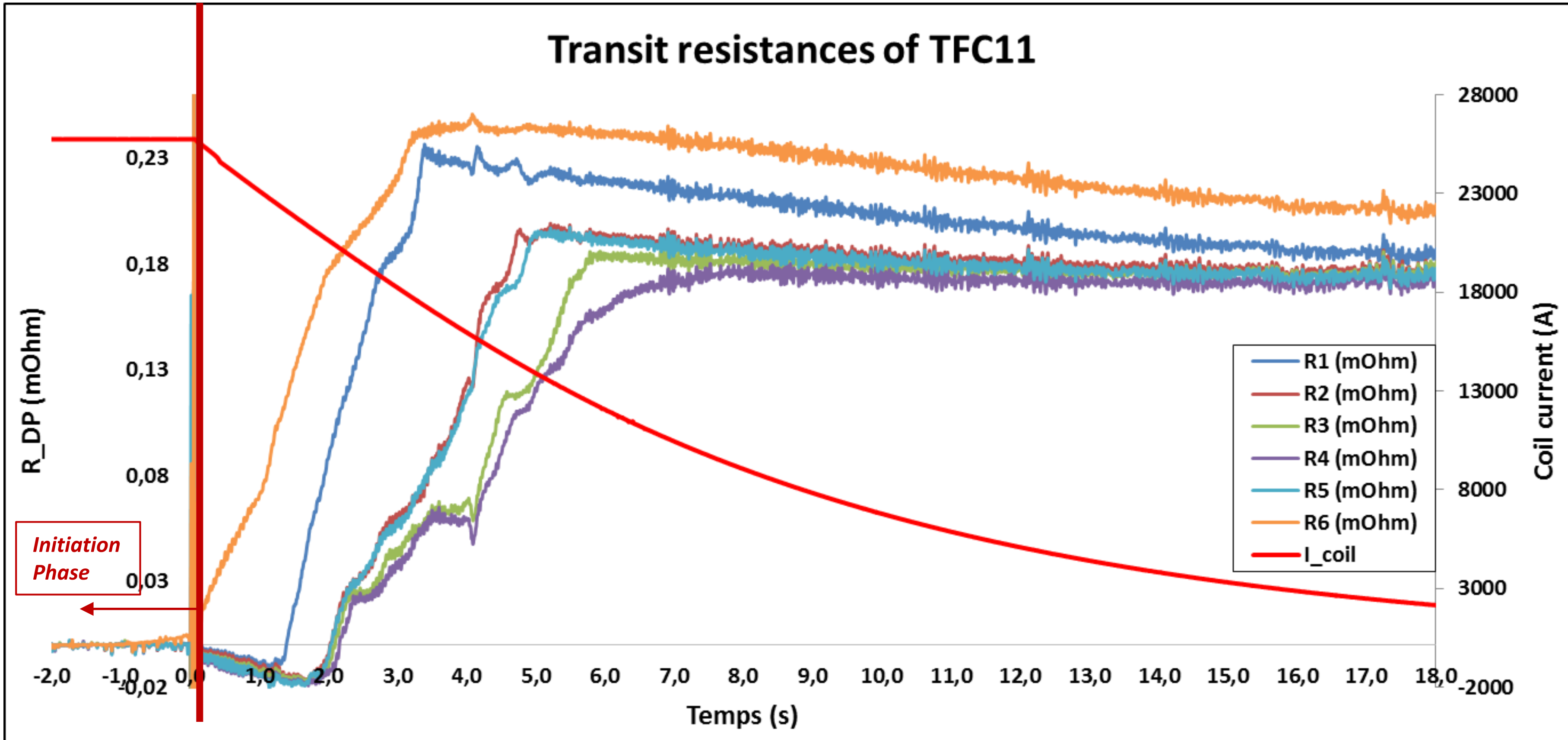




Quench dynamics (TFC11)

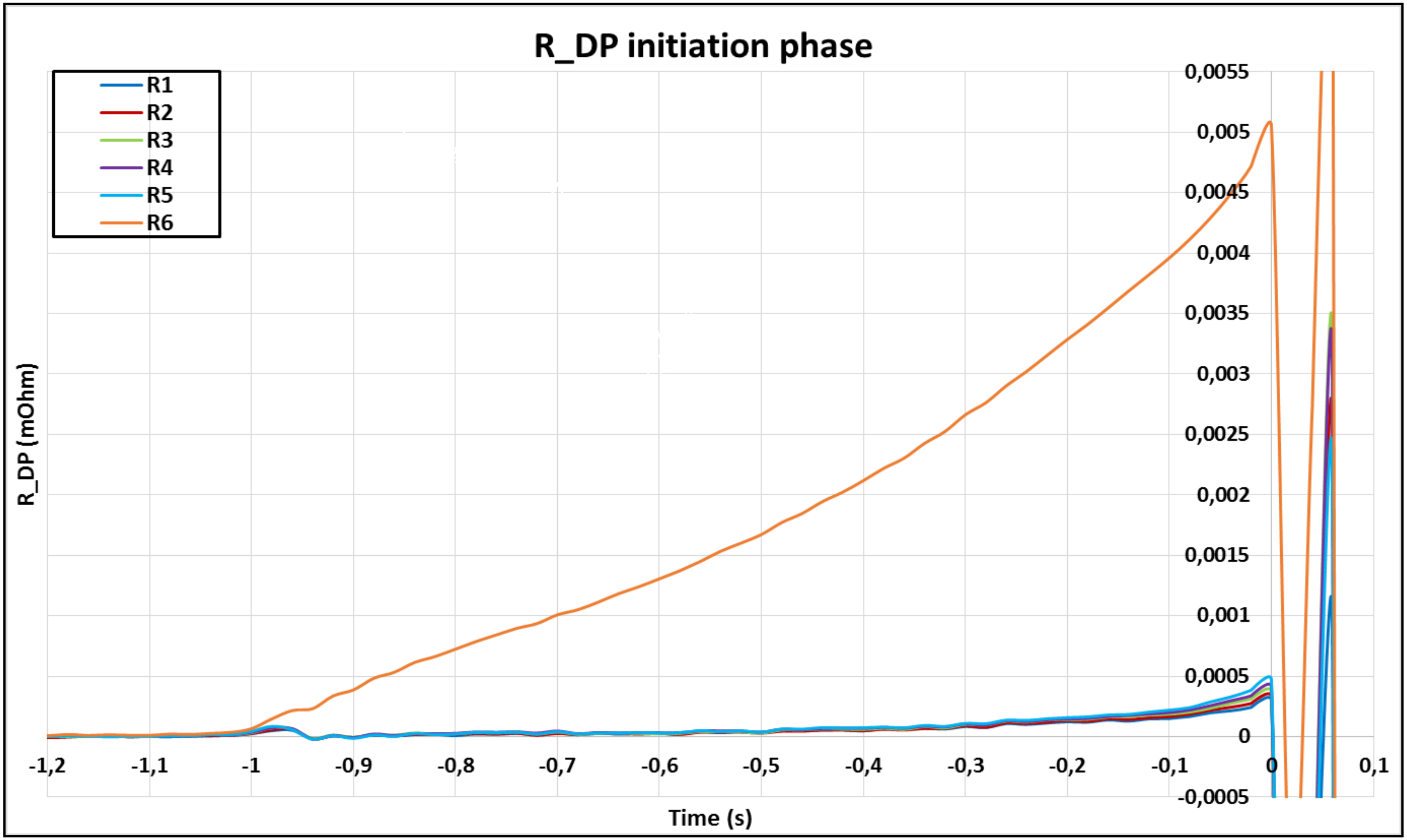


4 quench dynamic phases:
- Quench **initiation** phase

Source: TFC11 quench test, 11 avril 2016

Quench dynamics (TFC11)

First phase: quench initiation phase



Quench dynamics (TFC11)

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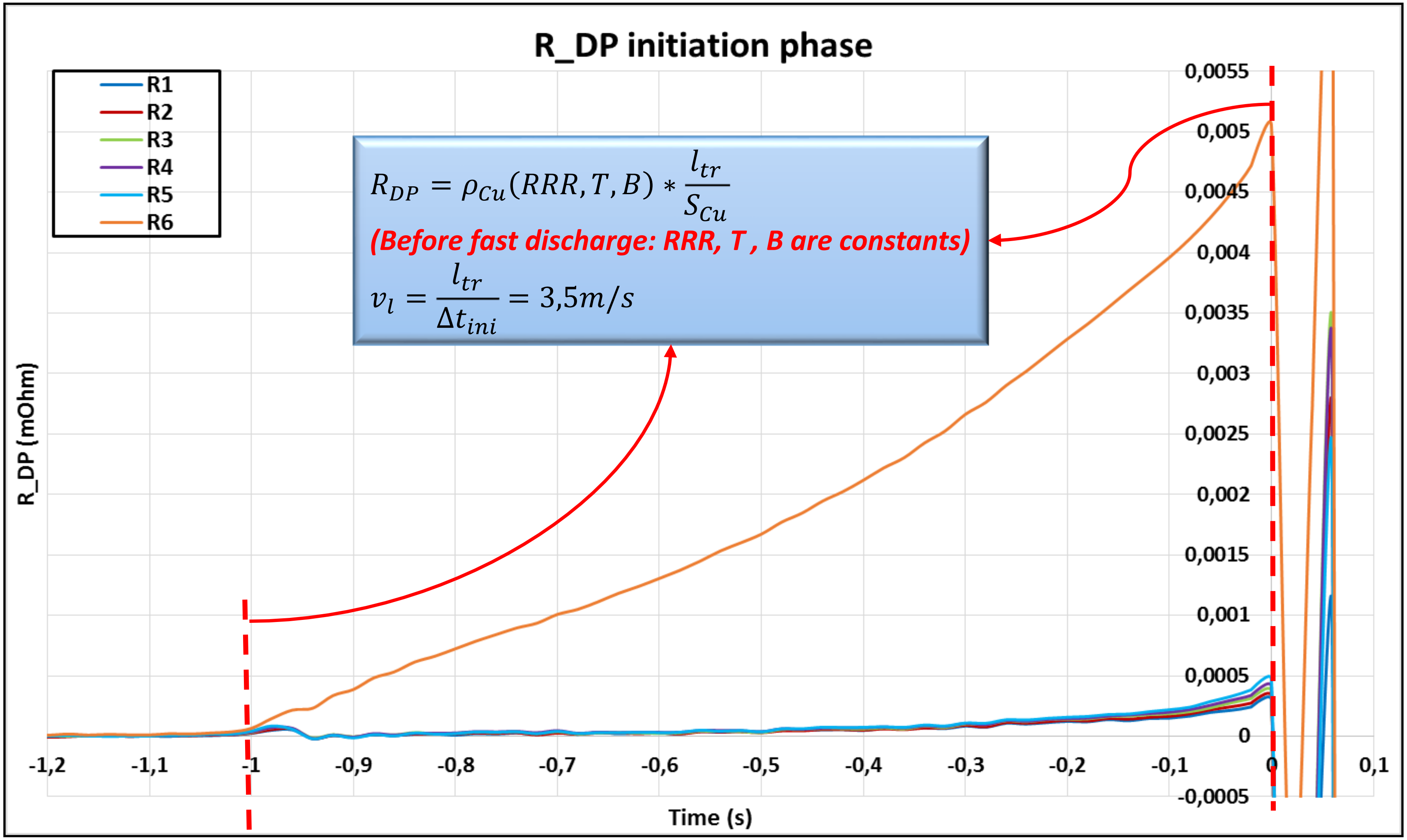

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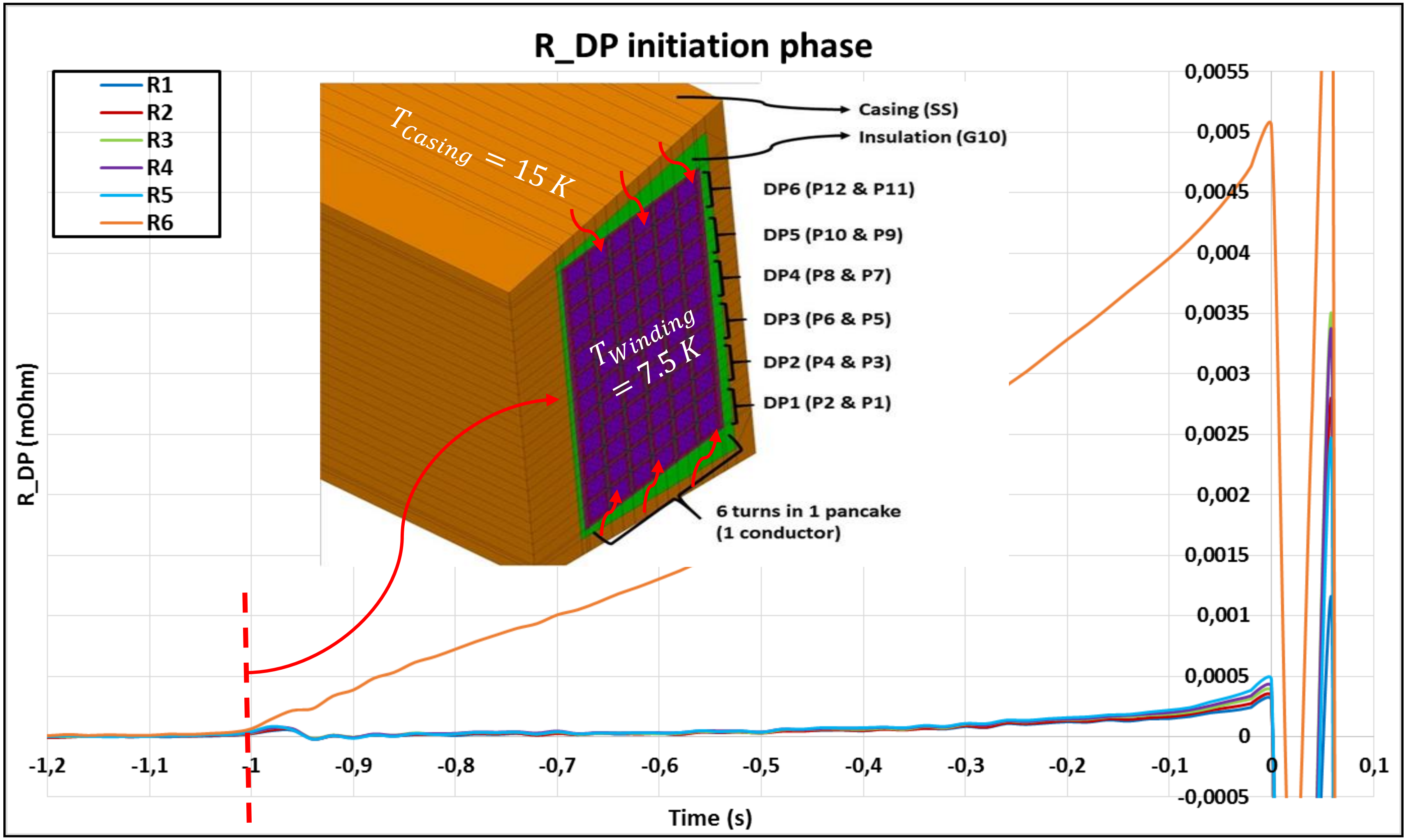

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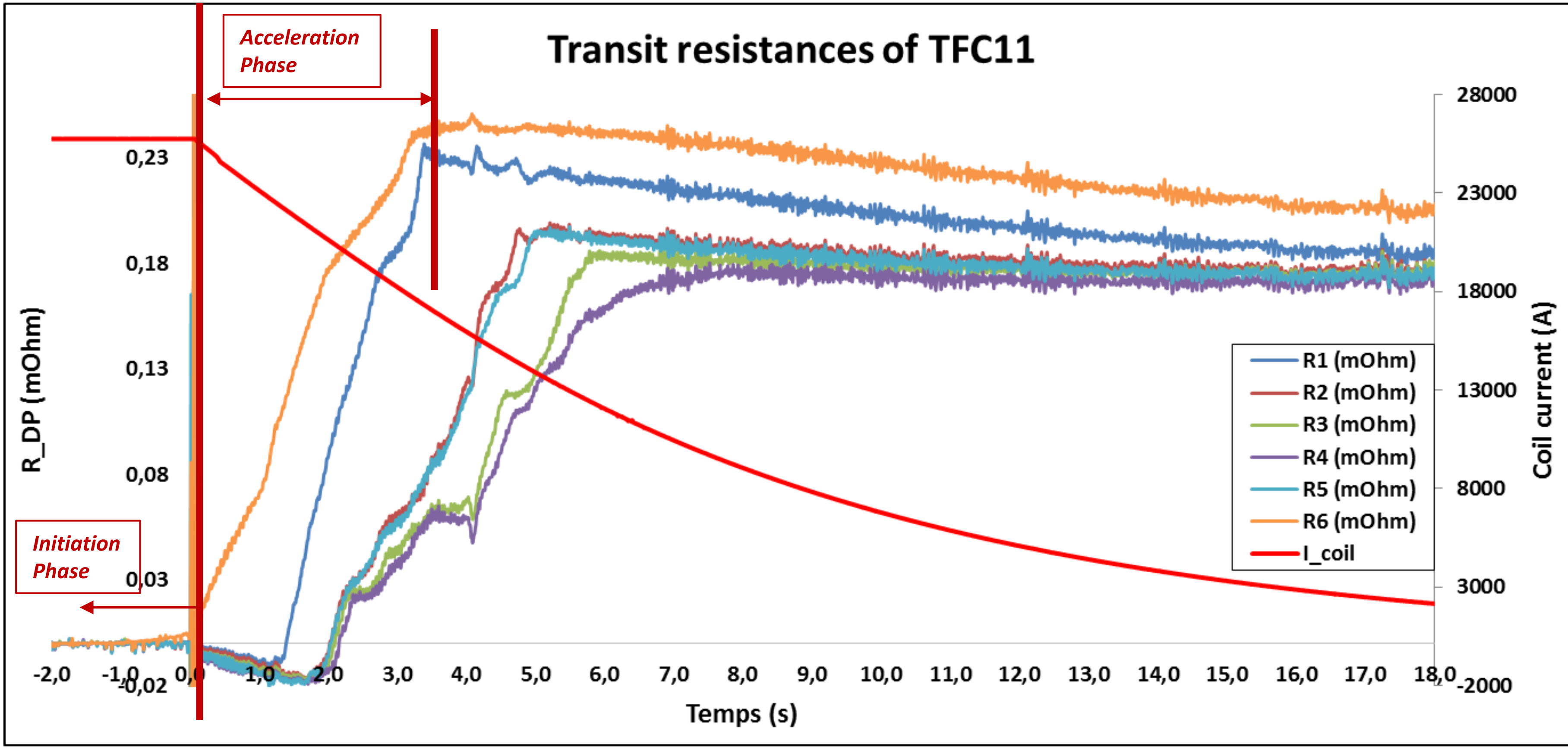
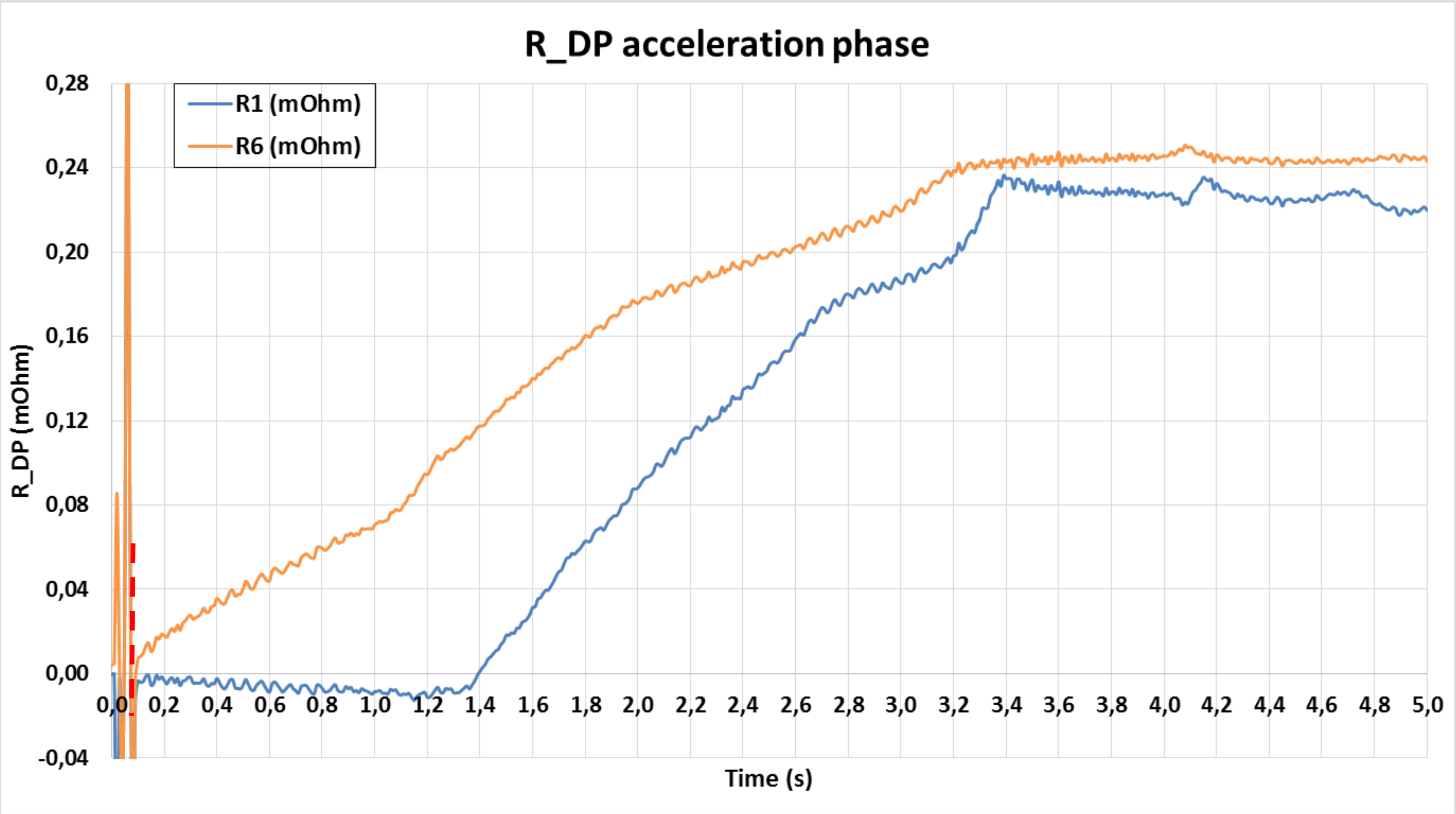


4 quench dynamic phases:
- Quench **initiation** phase
- Quench **acceleration** phase

Source: TFC11 quench test, 11 avril 2016

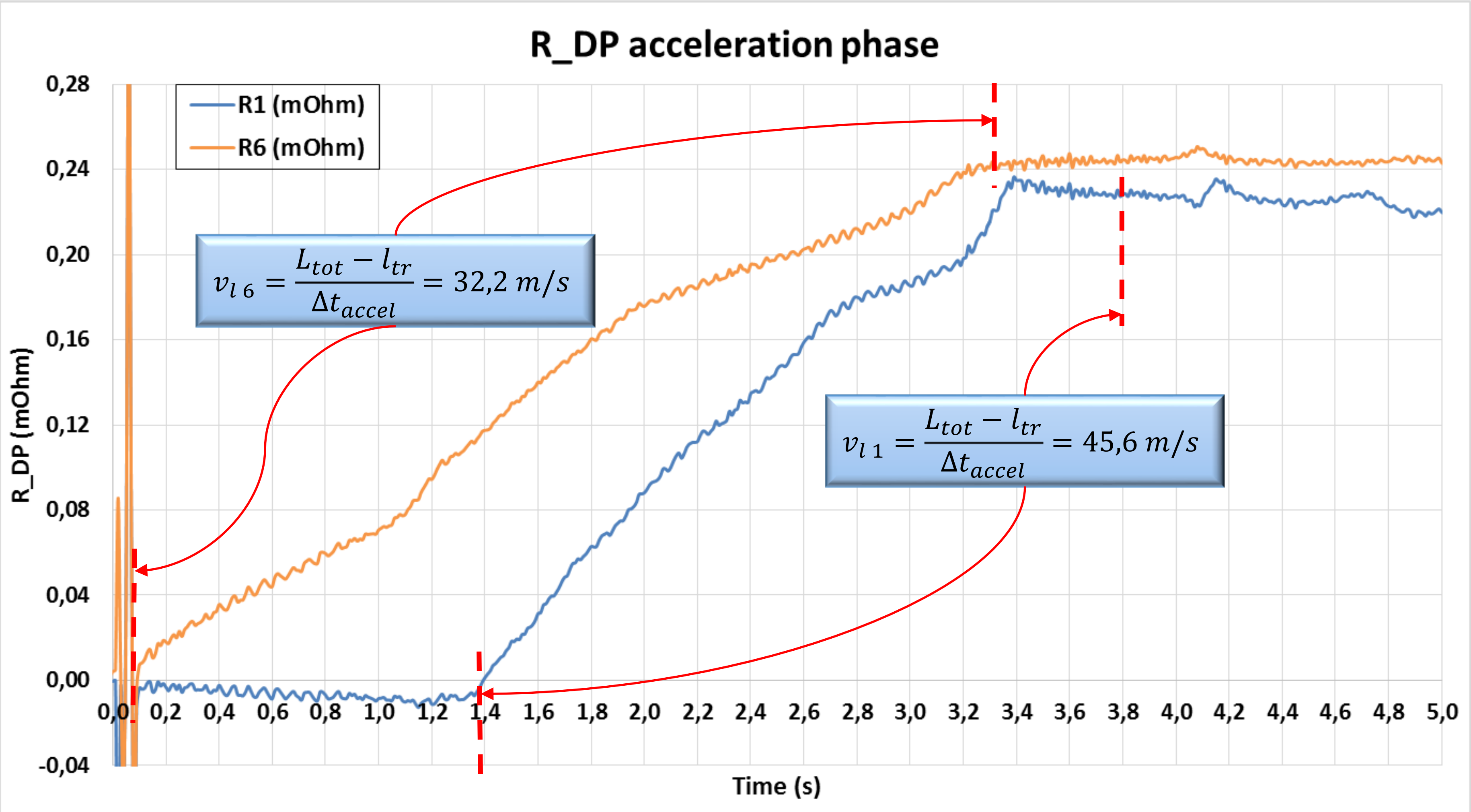
Quench dynamics (TFC11)

Second phase: quench acceleration phase



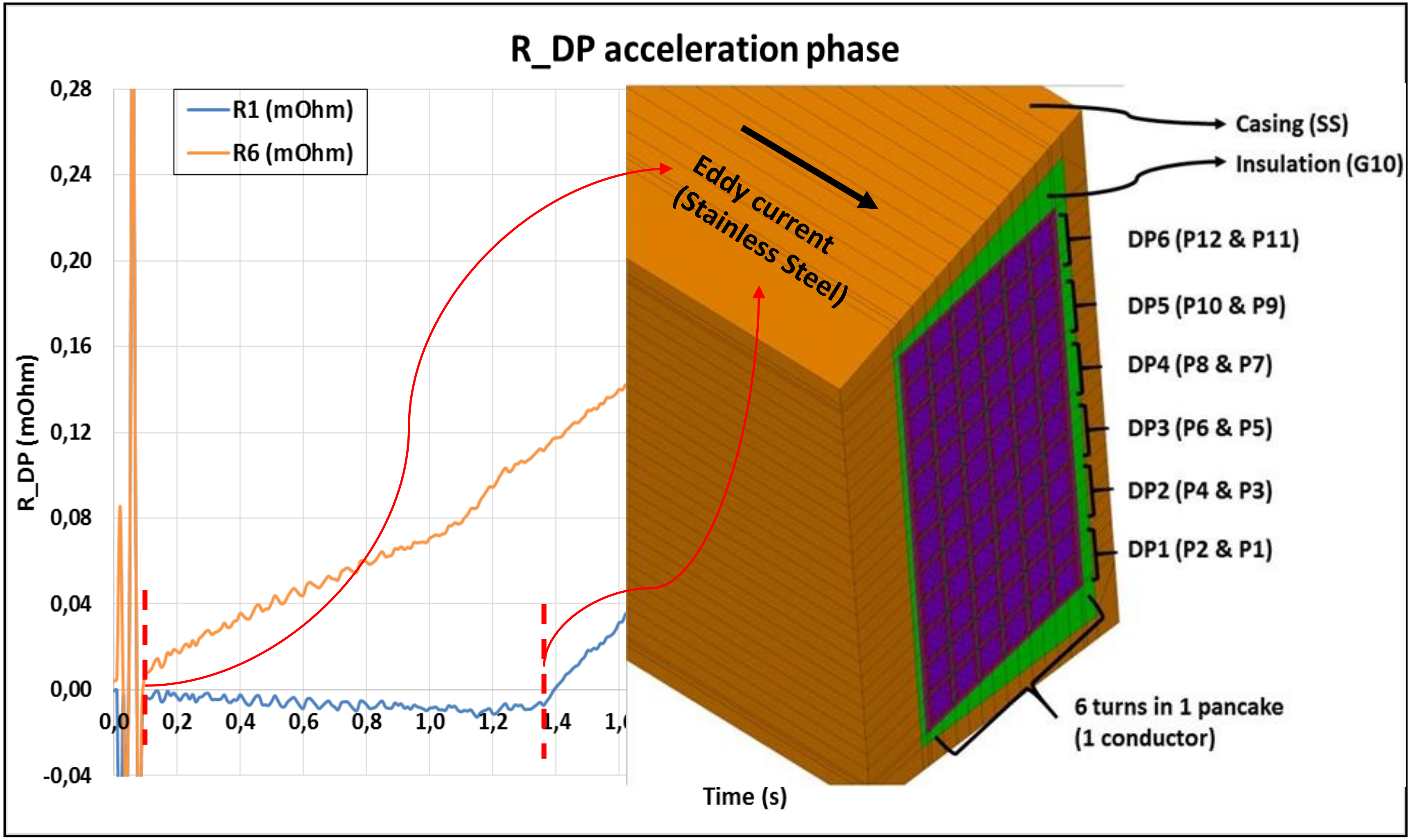
Quench dynamics (TFC11)

Second phase: quench acceleration phase

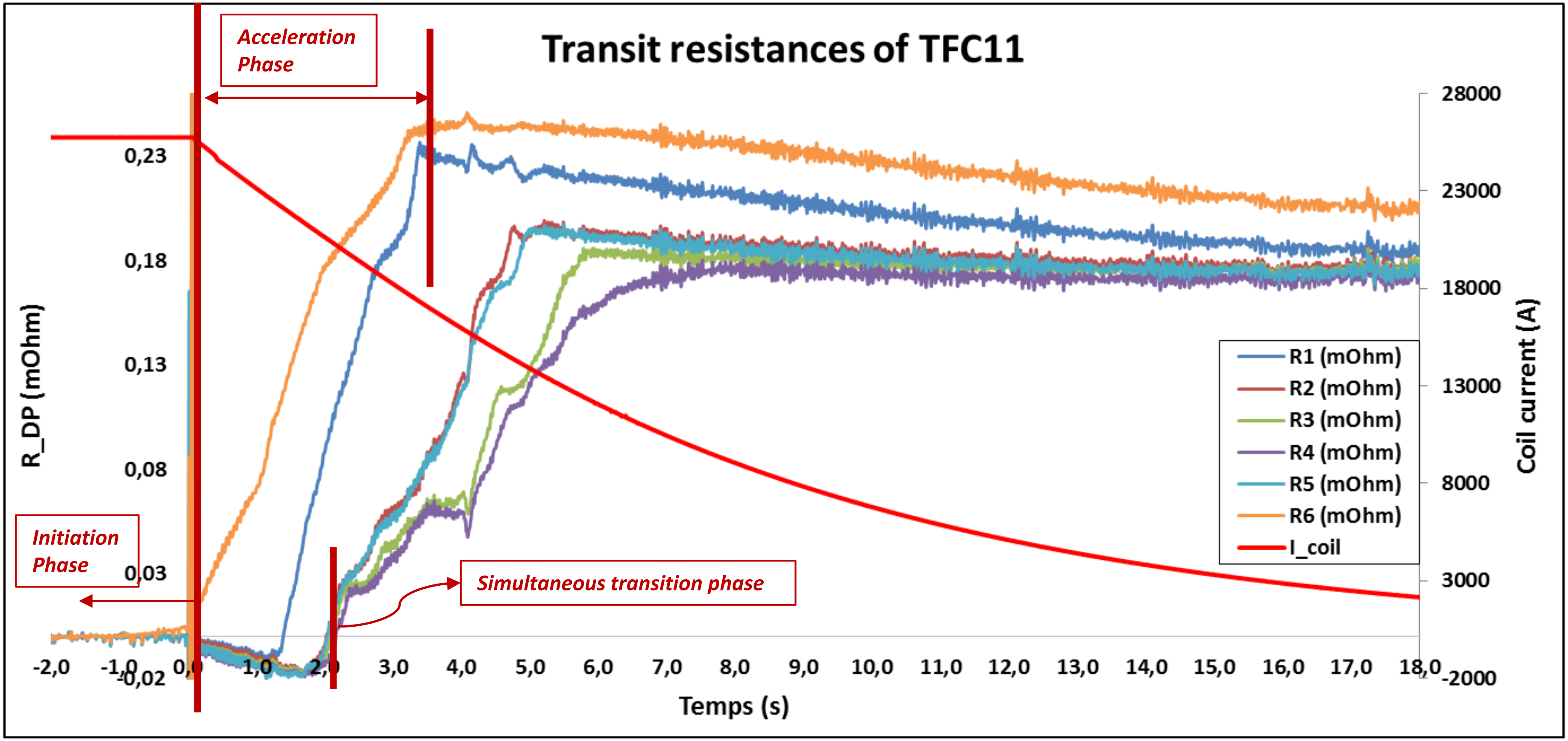


Quench dynamics (TFC11)

Second phase: quench acceleration phase



Quench dynamics (TFC11)



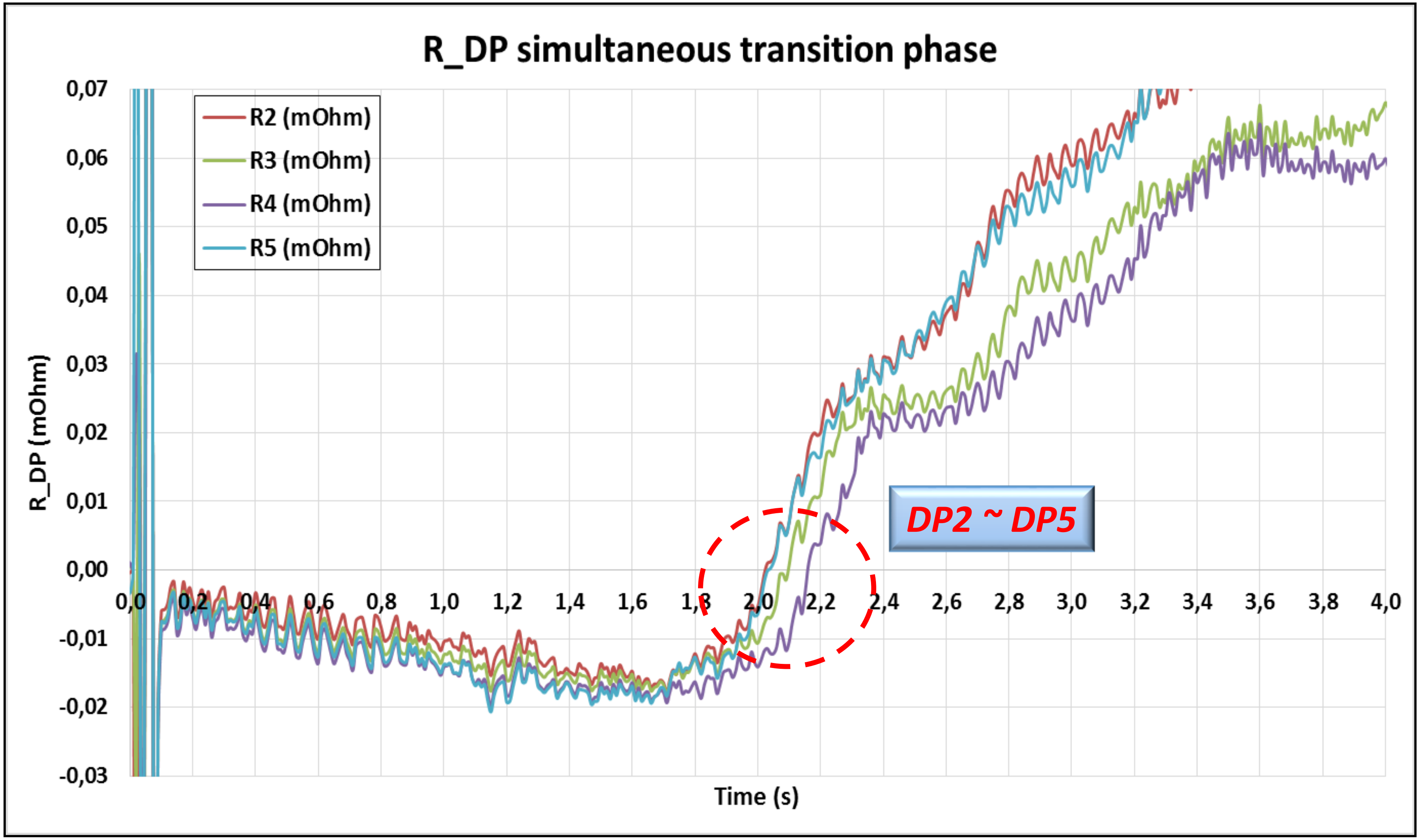
4 quench dynamic phases:

- Quench **initiation** phase
- Quench **acceleration** phase
- **Simultaneous transition** phase for latter quenched pancakes

Source: TFC11 quench test, 11 avril 2016

Quench dynamics (TFC11)

Third phase: simultaneous transition phase for latter quenched pancakes

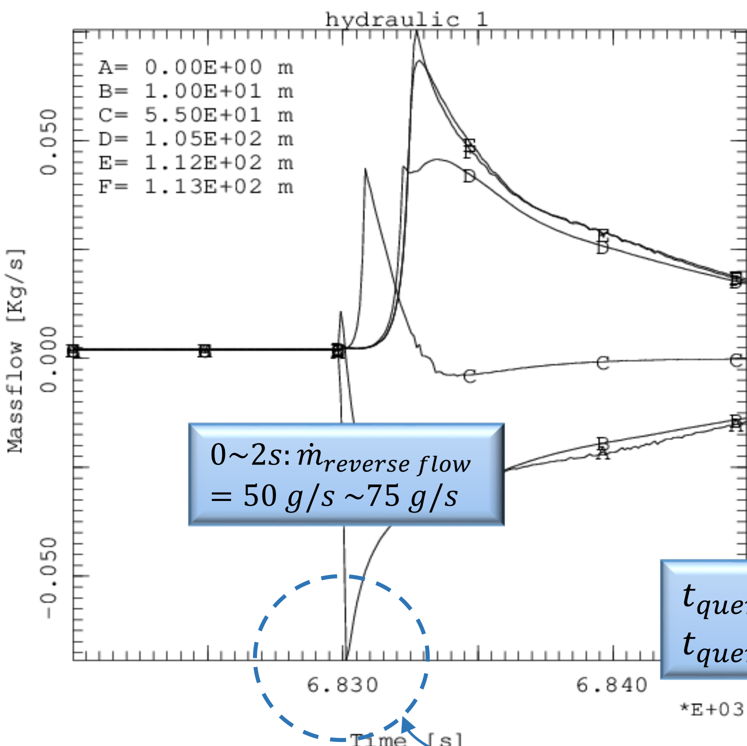


Quench dynamics (TFC11)

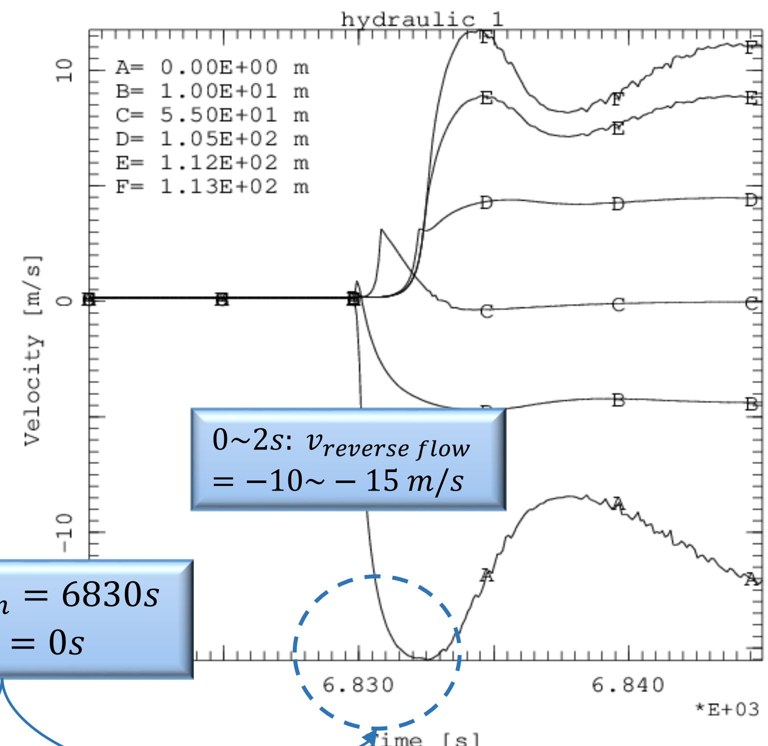
Third phase: simultaneous transition phase for latter quenched pancakes

THEA 2.1 13/04/2017 16:44:42 -- JT60SA_DP1a_v2 --

Reverse flow effect



$0\sim2s$: $\dot{m}_{reverse\ flow} = 50\ g/s \sim 75\ g/s$

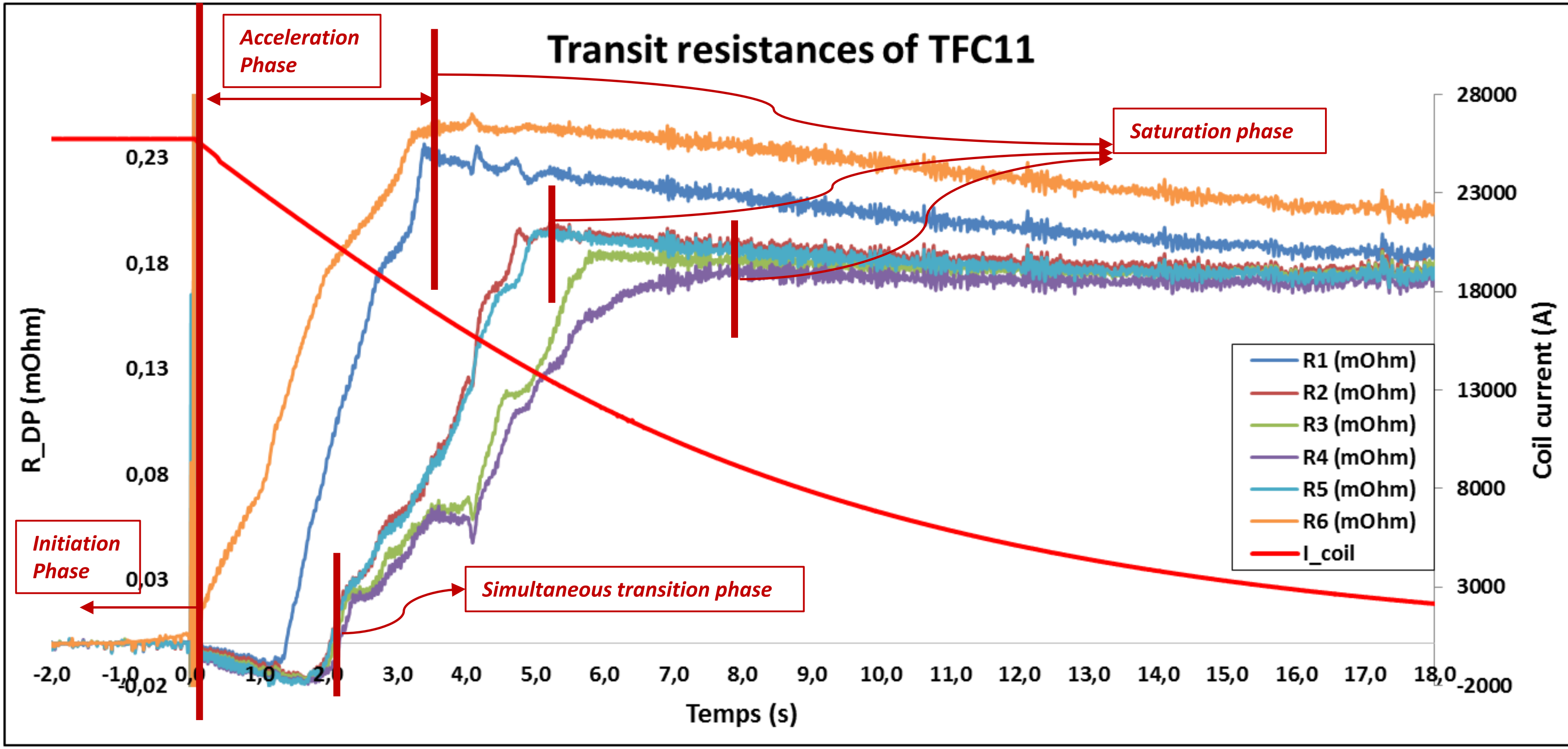


$0\sim2s$: $v_{reverse\ flow} = -10 \sim -15\ m/s$

$t_{quench\ num} = 6830s$

$t_{quench\ exp} = 0s$

Quench dynamics (TFC11)



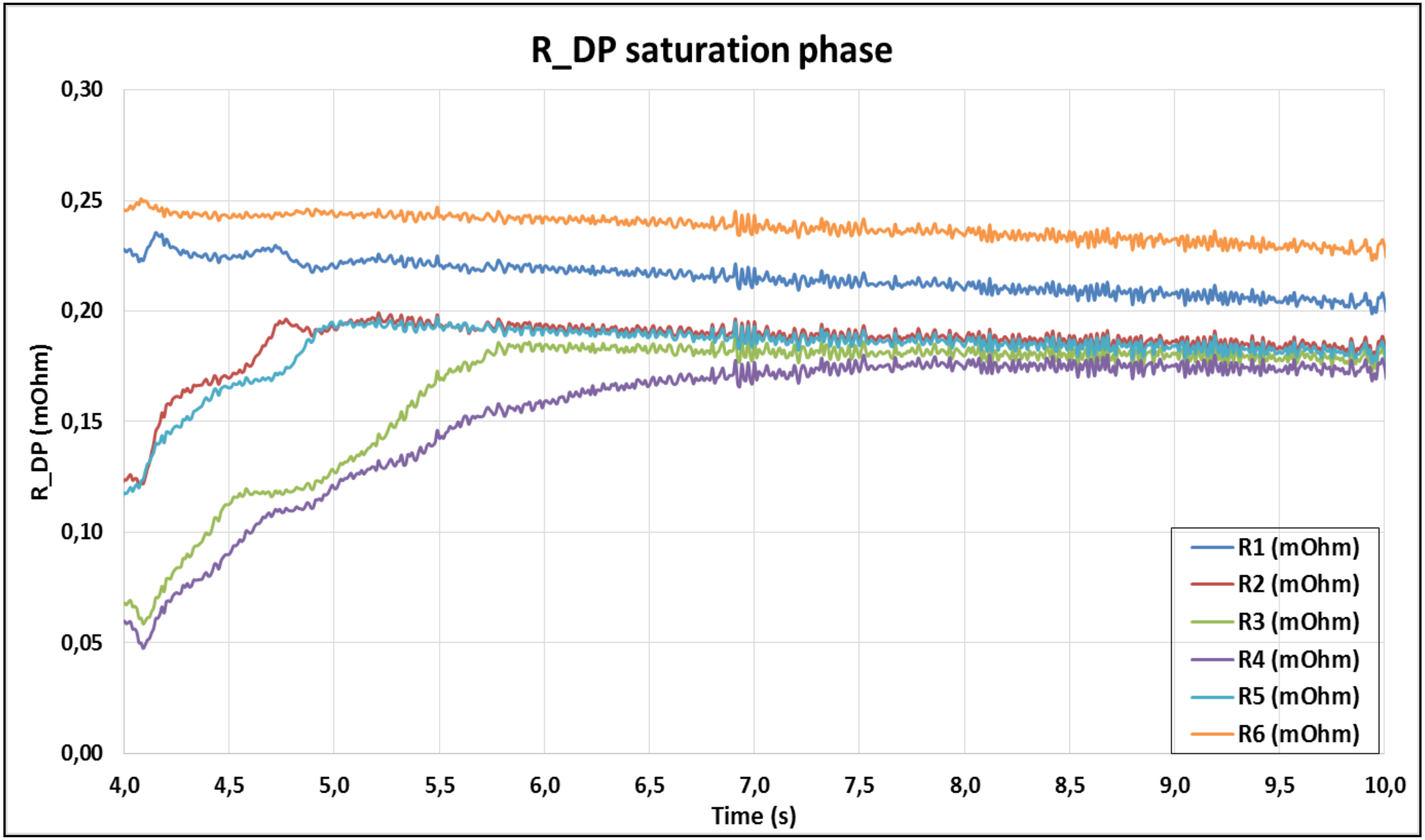
4 quench dynamic phases:

- Quench **initiation** phase
- Quench **acceleration** phase
- **Simultaneous transition** phase for latter quenched pancakes
- Quench **saturation** phase

Source: TFC11 quench test, 11 avril 2016

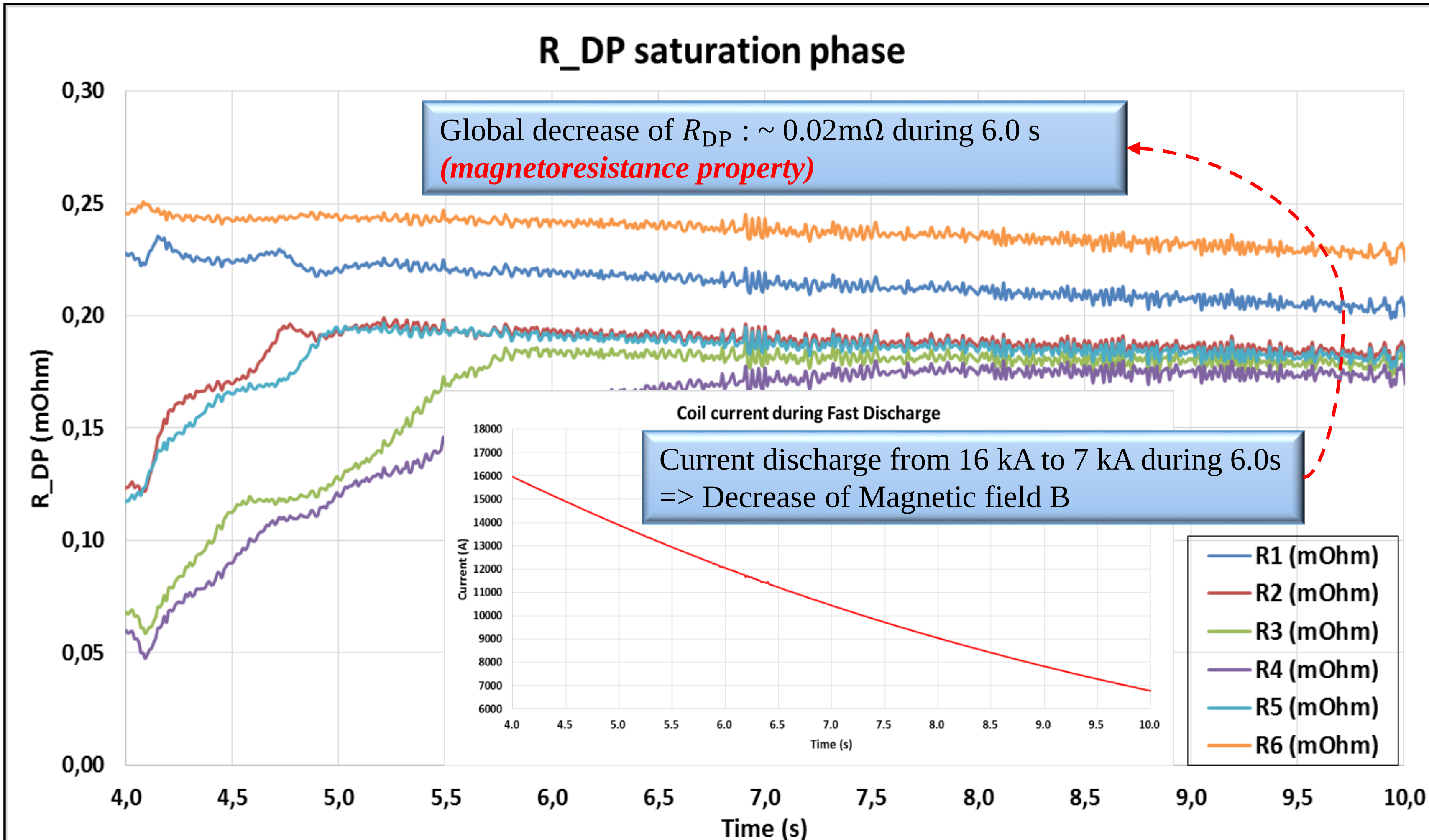
Quench dynamics (TFC11)

Last phase: quench saturation phase



Quench dynamics (TFC11)

Last phase: quench saturation phase



Conclusions

- ***Successful quench tests for 12 JT-60SA TF coils (update today)***
- ***A quasi-complete database and a correct way for data exploitation***
- ***Experimental analyses for all possible quench dynamics***
- ***Already some verifications with modeling results***

- ***Prospects for next step*** (Quasi-3D computation codes for modeling quench behavior):
  - **THEA** (Thermal Hydraulic and Electric Analysis of superconducting cables) for 1D thermo-hydraulic modelling along the CIC (Cable-In-Conduit) conductor
  - **Cast3M** for 2D transverse thermal diffusion in a limited number of coil cross-sections

Thank you for your attention !