Bruker HTS

HTS Power devices with low cryo-consumption for current conditioning, switching and limiting

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Background

HTS current conditioning devices look very simple, nevertheless by practical realization some important problems should be solved as:

- High cryo consumption that requires cryo-coolers with respective maintenance
- Problems at high voltages: irreparable breakdowns
- Heavy (3-20t) iron in inductive SFCL
- Long recovery time (from seconds to minutes)

Low cryo-consumption represents one of the most important requirements in large-scale field.

Objectives

Development of principles and concepts for electrical devices with low cryo-consumption.

Comparative analysis of resistive, inductive and hybrid current conditioning devices regarding performance / consumption ratio.

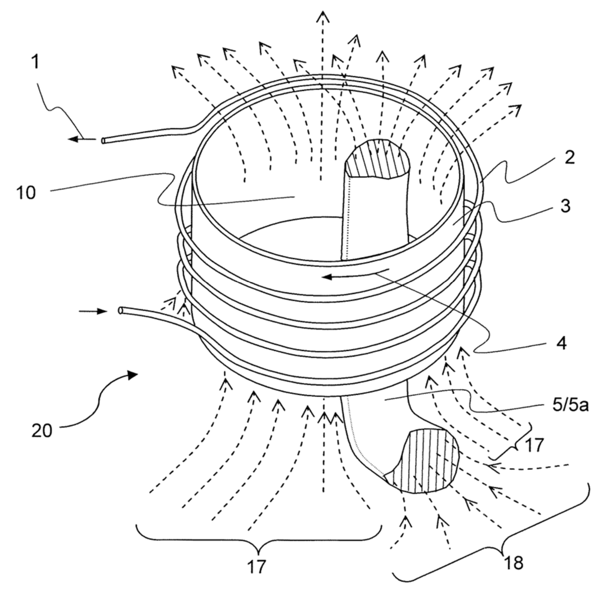
Executive Summary

- We demonstrate opportunity to confine quenching time of single HTS element to its physical limit of 0.01-0.05 ms. This limit is determined by intrinsic inductance, heat capacity and aspect ratio of the HTS element.
- Shortage of elementary quench event by a factor of 20-100 results in substantial suppression of heat losses caused by transient process when internal resistance of the entire device is nearing an equivalent ohmic resistance of the external circuit.
- In some cases very quick performance stays in confrontation with system requirements where current spikes should be suppressed. It is shown that depending on the art of flux sharing a sequential quench or a parallel quench or their combination may be activated.

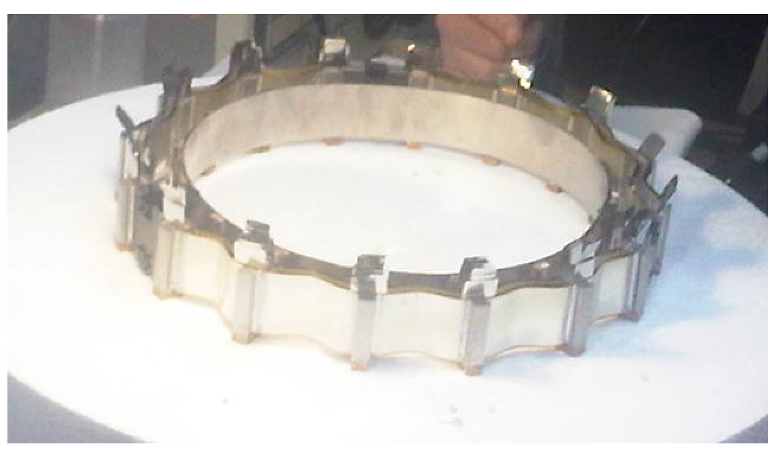
Development of Concepts

Basic principle

- Air core reactor (1, 2) with inserted HTS cylinder (3) are sufficient for impedance modulation via quench transition
- Moderate amount of iron (5) inserted into cylinder gains the amplitude of "modulation" providing minor influence to the nominal (not quenched) modus
- Ultra short quench with transient time of ~10 µs enables several new concepts for current conditioning devices:

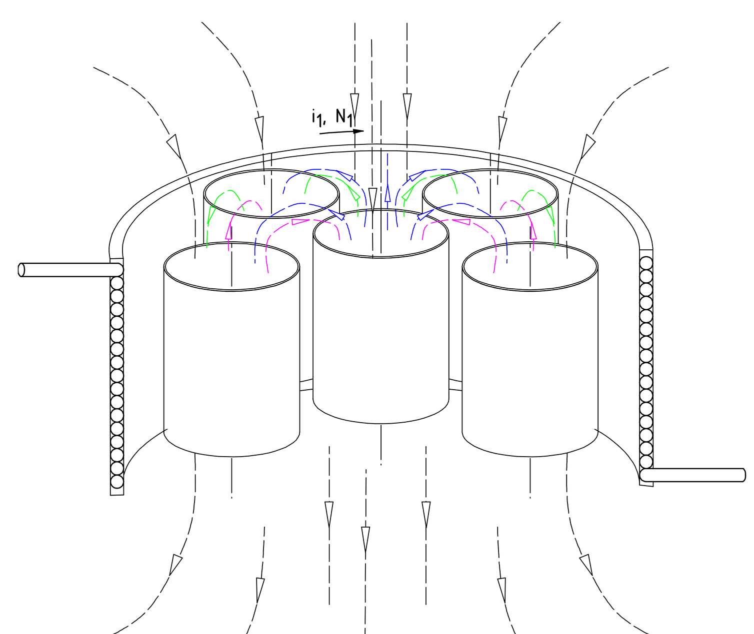


Concept of iSFCL: Standard, multi-concentric rings with common shunt:



- Very low Joule losses at non-quenched state *(S. Pamidi, CAPS, FSU)*
- Joule heat in shunt confines quench time to 1 s
- Recovery after quench may take 1 min

Concept of SFPS based on non-concentric rings: interaction of rings:



- Each ring creates additional field that should be compensated by adjacent rings. Thus they stay in "competition" one to other.
- If one ring quenches, currents in other rings are reduced. Entire inductance will grow by a step.
- Such behavior is similar to a "sequential" quench

Ultra short quench

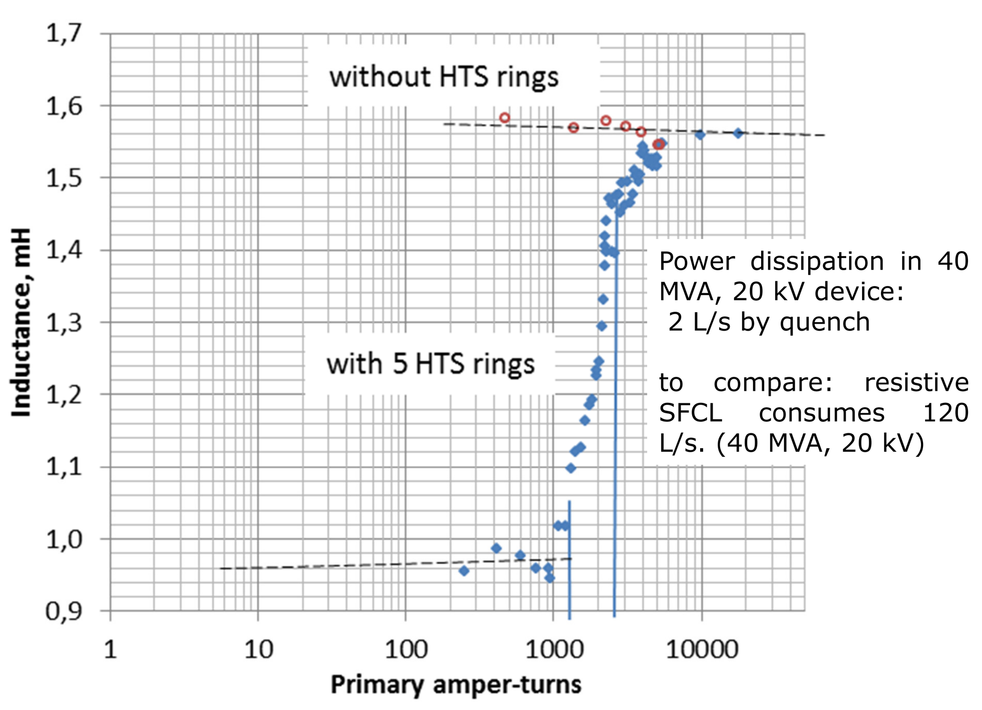
- Very quick quench propagation estimated to be 1 km/s.
- Small energy (of only 5-10 W) stored in magnetic field of single ring may cause a switch-like quench because of "floating" impedance which is changed from 10^{-9} to 1 Ω. This means, the power dissipation is increasing during quench.
- Such "dynamic" quench serves for self-protection of the superconducting element. Nevertheless because of non-linearity it may be theoretically damaged because of reduction of time constant resulting in an increase of locally dissipating power by several orders of magnitude.

Entire cryogenic losses: example of SFCL 40 MVA, 2 kA, 20 kV

Design:	conventional	low-loss
HTS splices (by R_s=10^{-8} Ohms*cm^2)	1 L/hour	0.4 L /hour
Current feedthroughs:	7 L / hour	0 L/h
Cryostat :	1 L/hour	0.2 L/hour
Total (without ac losses)	9 L/hour	0.6 L/hour
Quench modus:		
Losses by quench	120 L/s	2 L/s
Maximal quench duration	0.08 s	unlimited*)

*) quench durations from 2 to 300 s were tested without HTS tape damage; in general, duration is limited only by amount of available LN2 (1s corresponds to about 1L in low loss case)

Test results confirmed: duration of quench may exceed 60 min.



Prospective current is suppressed to 25 kA instead of 77 kA by Z=0.26 Ohms

Condensed Conclusion

- Ultra-short quench duration of < 20 µs was demonstrated
- This art of quenching allows to reduce cryo-consumption because of reduction of heat energy generated in the transient process
- New concepts based on such phenomena are analyzed
- Combination of short-duration quenching with variety of critical currents within different superconducting elements enables a wide flexibility of transition kinetics. This allows to design conditioning devices that can meet very different system requirements.

Innovation with Integrity