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Experimental investigation of the switching behavior of high-temperature superconductors with an alternating magnetic field

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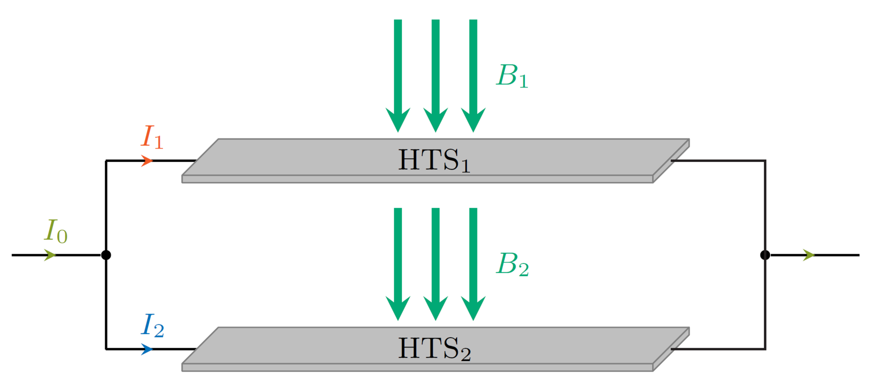
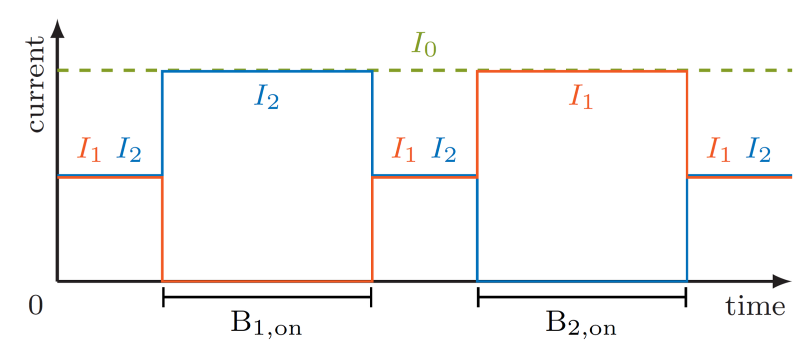
Introduction

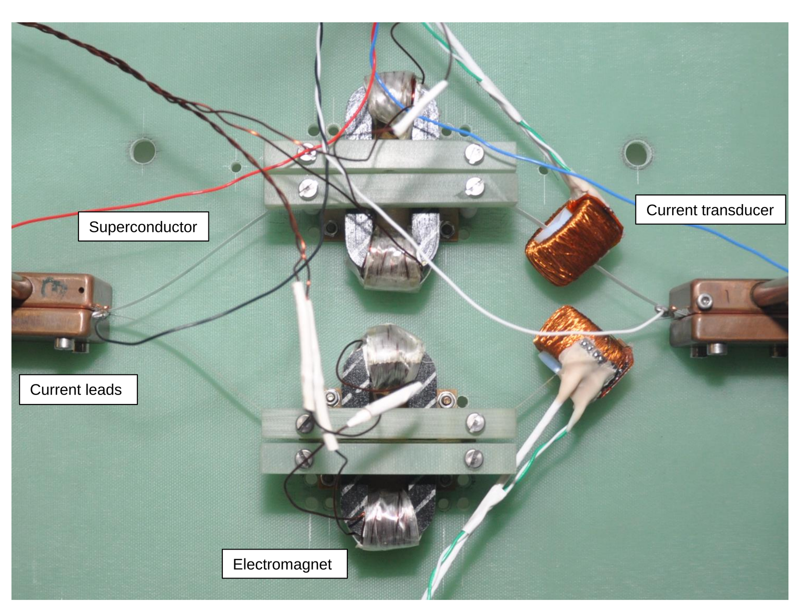
A high-temperature superconductor subjected to an alternating magnetic field creates a resistance which is called dynamic resistance. The resistance that is achieved is highly dependent on the amplitude. angle and frequency of the magnetic field. This unique characteristic can be used to build a fast superconducting switching unit and is further investigated in this work.



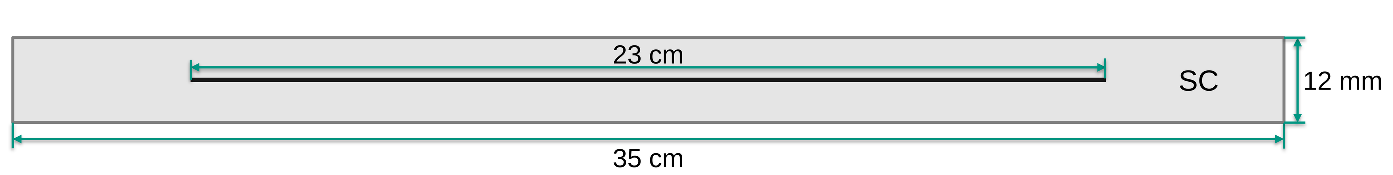


Experimental setup

- Two parallel superconductors contacted through copper current leads
- Each is equipped with an iron core electromagnet with an effective length of 2 cm
- Closed loop hall effect current transducers to measure direct and alternating current
- Voltage taps to measure built-up dynamic resistance
- Experiments in liquid nitrogen at 77 K

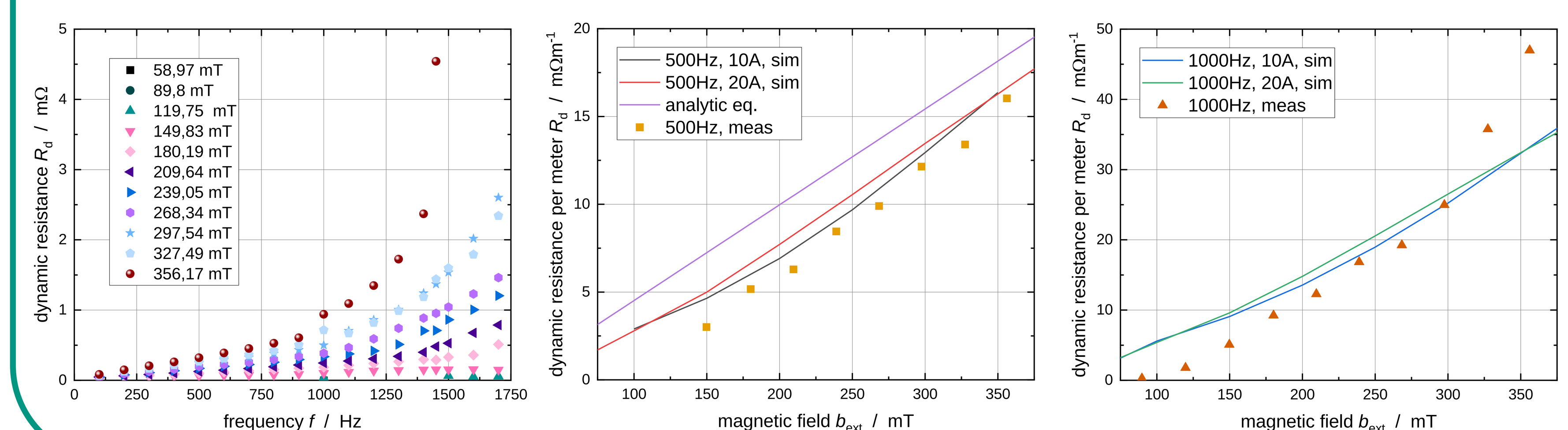


Superconductor	
Manufacturer	Superpower
Model	SF12100
Self-field critical current at 77 K	380 A
Thickness of Ag stabilizer layer	2 µm
Thickness of superconductor layer	1 µm
Thickness of substrate	100 µm
Resistance per length at RT	3.175 mΩ·cm^{-1}
Resistance per length at 77 K*	0.729 mΩ·cm^{-1}
Critical temperature	92 K



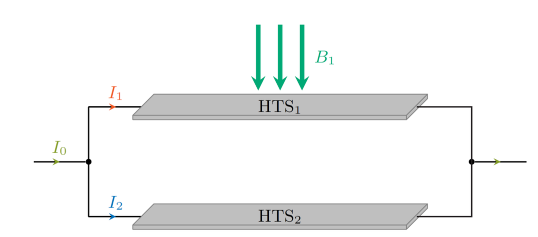
Measurement of dynamic resistance

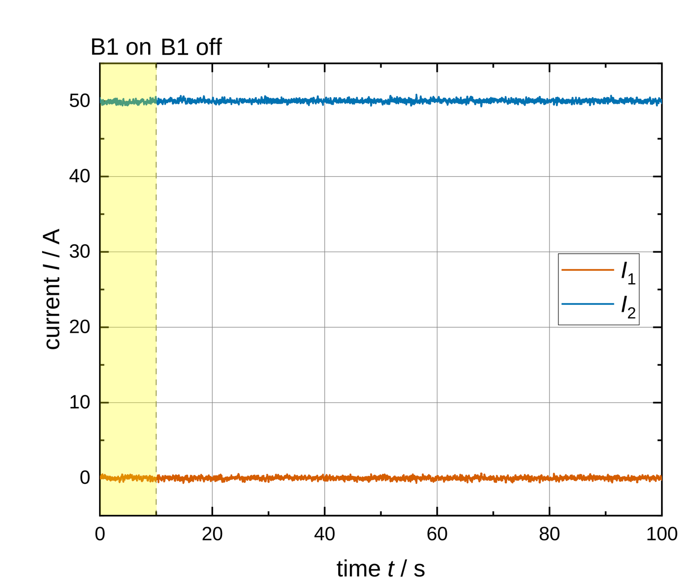
- Experimental setup with one superconductor and a parallel normal conducting current path
- Variation of amplitude b_{ext} and frequency f of the applied sinusoidal magnetic field applied on the superconductor (b_{ext} : 0 – 350 mT, f: 100 – 1700 Hz)
- Electromagnetic finite element model in Comsol with H-formulation for validation of experimental data
- Angle-dependent critical current values by Robinson database (SuperPower M3)
- Very good agreement of theoretical and measured values for small amplitudes and frequencies
- Temperature-dependency was not considered



Single-sided triggering

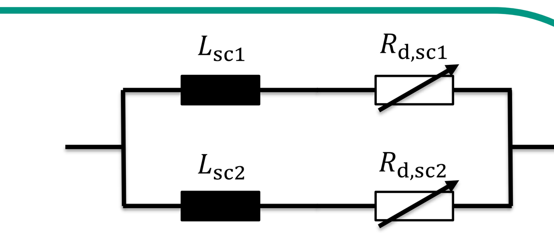
- Experimental setup with two parallel superconductors
- Only one superconductor is triggered by the magnet
- Equal current distribution between the two paths at the beginning
- Triggering one superconductor leads complete redistribution to the other superconductor
- After deactivating the magnet current distribution stays the same
- Zero contact resistance between both superconducting paths





Double-sided triggering

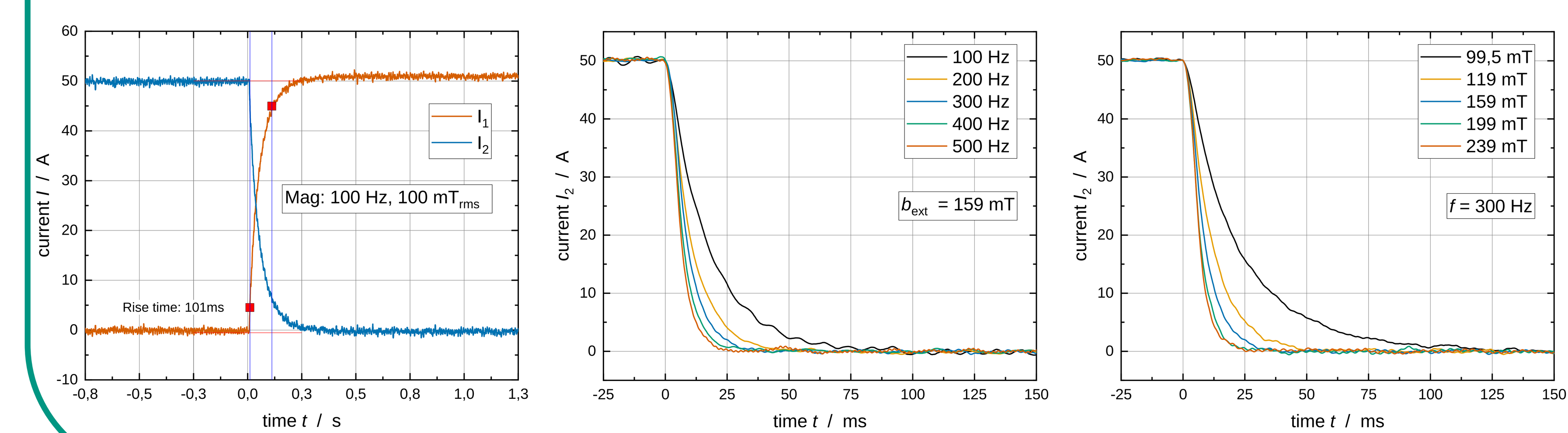
- Experimental setup with two parallel superconductors each with a magnet
- Equal current distribution between the two paths at the beginning
- Magnets are triggered in an alternating pattern, therefore, switching current paths
- Current redistribution is recorded and analyzed
- Rise and fall time t_r is calculated and converted in time constant τ
- Time constants as low as 2.5 ms could be achieve
- Estimation with dynamic resistance and inductance of a straight conductor agrees with the measured values



$$\tau = \frac{L}{R_d}$$

$$t_r = (\ln 0.9 - \ln 0.1) \cdot \tau$$

τ in ms		frequency f in Hz								
		100	150	200	250	300	350	400	450	500
b_{ext} in mT	59.7	170.1	158.4	149.5	145.6	133.6	123.2	124.2	93.9	91.5
	79.6	50.5	37.4	30.7	24.7	23.1	19.4	17.2	15.4	13.6
	99.5	33.8	23.3	18.9	16.2	13.2	11.5	10.6	9.1	8.6
	119.4	24.5	17.5	13.7	11.8	9.4	9.0	7.6	6.6	6.5
	139.3	20.6	13.8	11.7	9.4	8.0	7.2	6.4	5.5	4.9
	159.2	15.7	11.9	8.8	7.8	6.5	5.4	5.1	4.5	4.0
	179.1	13.6	9.1	6.9	6.1	5.7	4.7	4.3	4.0	3.8
	199.0	11.1	8.0	6.0	5.7	4.7	4.1	3.6	3.3	3.1
	218.9	10.3	6.5	5.7	4.5	3.9	3.5	3.2	2.9	2.9
	238.8	8.0	6.2	4.3	4.0	4.2	3.3	3.2	2.5	2.5



Conclusion and Outlook

- The dynamic resistance of an HTS superconductor was measured and validated by a numerical model
- Transient current redistribution was investigated and dependencies were analyzed
- Fast switching of HTS tapes with magnetic fields may enable new use cases

Basic principle → Single unit → Dynamic interaction → Circuit