Manufacturing and AC losses measurements in wire and cable samples

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The instrumentation for AC losses measurement in short samples of superconducting wires and cables (without transport current) was designed and constructed at Laboratory of High Energies JINR. The scheme of instrumentation is shown in Fig. 1. The sample of superconductor (5) is placed inside a vertical cryostat. The dipole magnet (2) is used for generation of a pulsed magnetic field. The pulses had triangular shape. The amplitude of the field as well as the field ramp rate can be changed from 0 to 2 T, and from 0.05 to 6 T/s respectively. The magnetic field was directed perpendicular to the longitudinal axis of the samples. The measurements were carried out at 4.2 K using calorimetric method. AC losses are calculated from the energy balance.

The calorimeter consists of two coaxial tubes. The inner tube inside of which liquid helium, sample of superconductor (5), electric heater (6), and level indicators (A, B, and C) are placed has a diameter of 18 mm and thickness of 0.15 mm. The pressure regulator (12) and gas flow meter are used to determine vaporization heat of helium in the calorimeter at constant pressure. The range of measuring of AC losses is from 10 to 600 mW. It is possible to change sample position in space by rotation of the calorimeter around its axis. Basic parameters of the setup are presented in Table I.

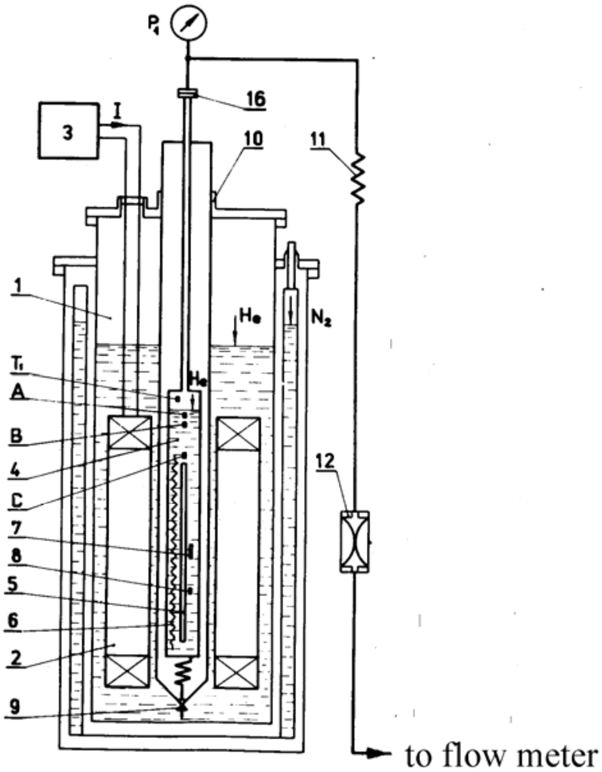

Fig. 1. Setup for AC losses measuring in short samples of superconductors: 1 – cryostat for liquid helium; 2 – superconducting dipole magnet; 3 – power supply; 4 – calorimeter; 5 – sample of superconductor; 6 – electric heater, 7 – Hall transducer, 8 and T_2 - temperature sensor; 9 – liquid helium input valve, 11 - heat exchanger for helium from calorimeter; 12 – pressure regulator; A, B, and C - liquid helium level indication points; P_1 - pressure gauge.

Table I. Basic parameters of the setup for AC losses measuring

Peak magnetic field	T	2.0
Maximum ramp rate	T/s	5.0
Minimum ramp rate	T/s	0.05
Maximum rate of heat release	mW	600
Minimum rate of heat release	mW	10
Heat inflow	mW	≤ 15
Internal diameter of the calorimeter	mm	18
Maximum length of the samples	mm	330
Accuracy of the measurement	%	10

Two types of samples were used:

- a cluster of wires (sample W 1 - a cluster of 43 wires in the sample, sample W 2 - a cluster of 42 wires in the sample);
- Nuclotron - type hollow cable with SC wire wrapped around the cooper-nickel tube (sample C1 - 2 cable pieces with 31 wires in each piece, sample C2 - 2 cable pieces with 23 wires in each piece, and sample C3 - 2 cable pieces with 21 wires in each piece).

Three model cables have been made by means of Nuclotron cable machine after its adaptation to the sizes of a cable for SIS100 magnets. Main characteristics of the wire and cable samples are presented in Table II.

Table II. Main characteristics of the wire and cable samples

Sample	Wire diameter (mm)	Wire design	Filling factor of NbTi	Filament diameter (μm)	Filament twist pitch (mm)	Cu-Ni tube diameter (mm)	AC losses versus dB/dt @ B_m = 1.05 T ($mJ \cdot cycle^{-1} \cdot cm^{-3}$ of NbTi)
W 1	0.825	FAIR 2 3132*5 = 15660	0.4185	4.2	11.7	_	Q=12.06+38.85*dB/dt
W 2	0.825	FAIR 1 379*84 = 31836	0.4128	3.0	11.0	_	Q=23.78+20.82*dB/dt
C 1	0.5	379*27 = 10233	0.397	3.1	8.0	5.0	Q=1.02+18.79*dB/dt
C2	0.79	FAIR 2 3132x5 = 15660	0.400	4.0	8.0	5.7	Q=29.41+15.85*dB/dt
C3	0.825	FAIR 2 3132*5 = 15660	0.4185	4.2	11.7	5.7	Q=34.03+25.79*dB/dt

The experimental dependences of the AC losses on the magnetic field ramp rate dB/dt for two different samples of superconducting wires W 1 and W 2 are presented in Fig. 2 and Fig. 3, respectively. The error at measurement of losses in the sample W 1 was more than usual value because of low level of liquid helium in the calorimeter. The AC losses as function of the magnetic field ramp rate dB/dt for cable samples C 1, C 2, and C 3 are given in Fig. 4, Fig. 5 and Fig. 6, respectively. The measurements of losses in all samples are performed at amplitude of an external magnetic field of 1.05 T. This value corresponds to average value of a magnetic field in the coil of SIS 100 magnet at the maximum field in the aperture of magnet approximately 2.1 T.

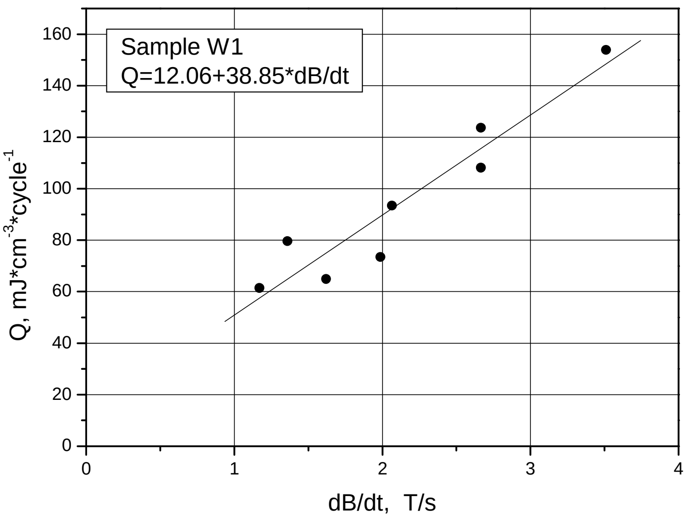

Fig. 2. AC losses in wire sample W 1 as a function of the magnetic field ramp rate at B_m = 1.05 T.

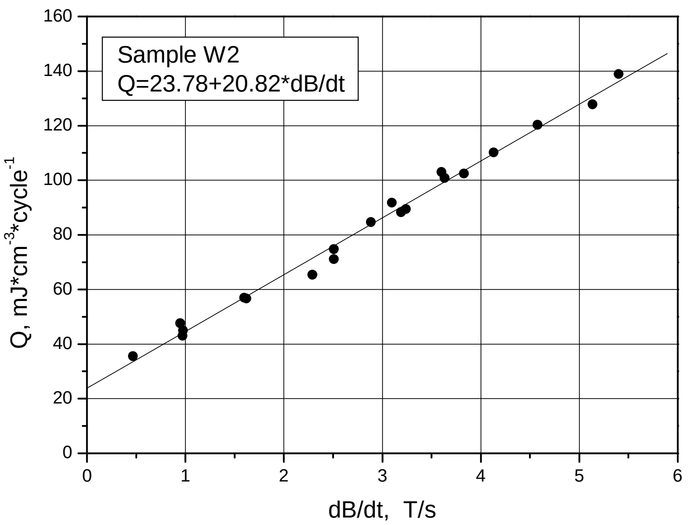

Fig. 3. AC losses in wire sample W 2 as a function of the magnetic field ramp rate at B_m = 1.05 T.

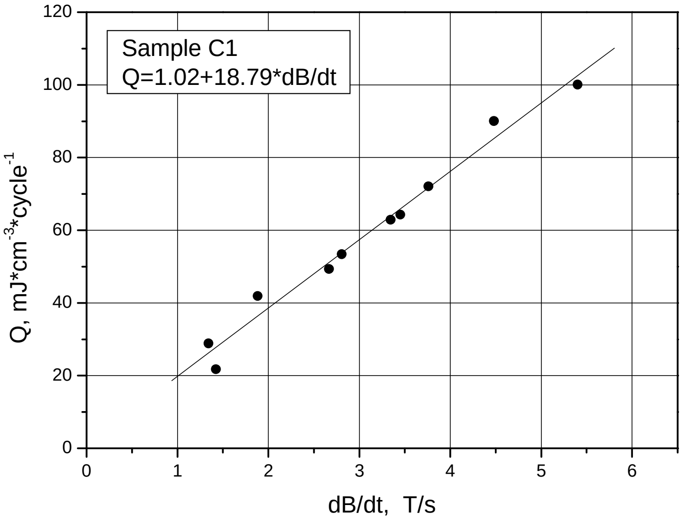

Fig. 4. AC losses in cable sample C 1 as a function of the magnetic field ramp rate at B_m = 1.05 T.

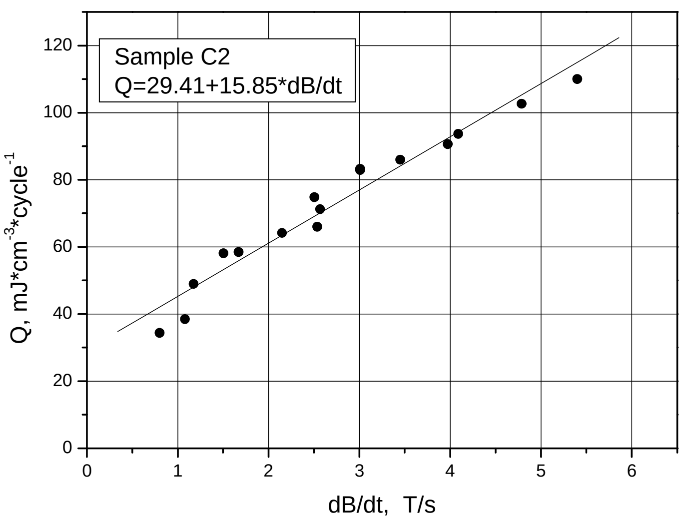

Fig. 5. AC losses in cable sample C 2 as a function of the magnetic field ramp rate at B_m = 1.05 T.

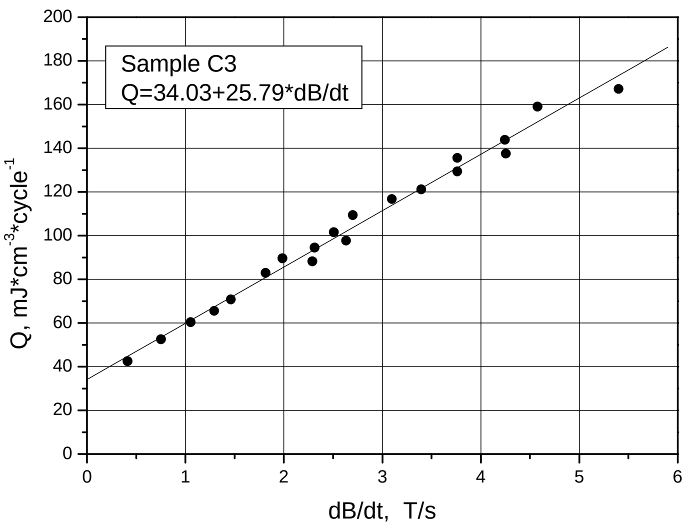

Fig. 6. AC losses in cable sample C 3 as a function of the magnetic field ramp rate at B_m = 1.05 T.

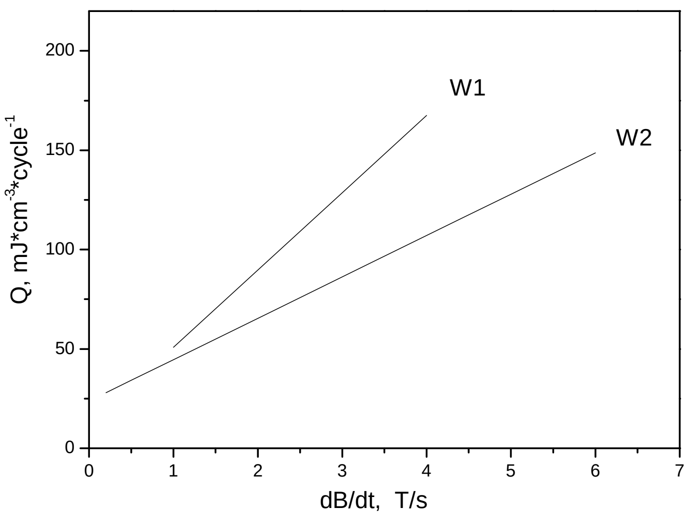

Fig. 7. Comparison between the AC losses in wire samples as a function of magnetic field ramp rate.

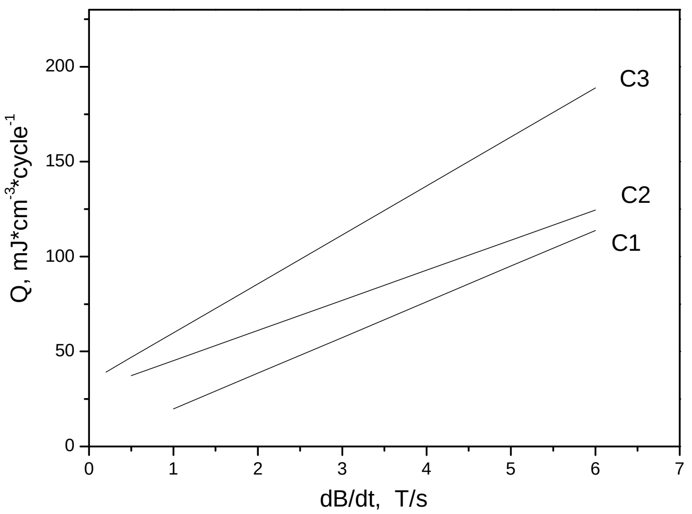

Fig. 8. Comparison between the AC losses in cable samples as a function of magnetic field ramp rate.

The AC losses comparisons in wire and cable samples are given in Fig. 7 and Fig. 8, respectively.

Conclusion

- The AC losses in a wire of the design FAIR 1 are less than losses in a wire of the design FAIR 2.
- The lowest AC losses have the cable sample C1 from a wire of 0.5 mm with the size of filaments about 3.1 microns.
- The AC losses in the samples 2 and 3 differ because of a different twist pitch of the filaments.
- The further reduction of the AC losses in wires and cables can be reached by means of the filaments twist pitch reduction.