Investigation of 0.5 MJ superconducting energy storage system by acoustic emission method.

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Abstract

The rapid development of small-scale (1-10 MJ) Superconducting Magnetic Energy Storage Systems (SMES) can be explained by real perspective of practical implementation of these devices in electro-power nets. However the serious problem of all high mechanically stressed superconducting coils - problem of training and degradation (decreasing) of operating current still exists. Moreover for SMES systems this problem is more dangerous because of pulsed origin of mechanical stresses - one of the major sources of local heat disturbances in superconducting coils. We investigated acoustic emission (AE) phenomenon on model and 0.5 MJ SMES coils taking into account close correlation of AE and local heat disturbances.

Two - coils 0.5 MJ SMES system was developed, manufactured and tested at Russian Research Center «Kurchatov Institute» in the frames of cooperation with Korean Electrical Engineering Company (KEPCO) [1]. The two-coil SMES operates with the stored energy transmitted between coils in the course of a single cycle with 2 seconds energy transfer time. Maximum operating current 1.55 kA corresponds to 0.5 MJ in each coil. The Nb-Ti-based conductor was designed and used for SMES manufacturing. It represents transposed cable made of Nb-Ti strands in copper matrix, several cooper strands and several stainless steel strands. The coils are wound onto fiberglass cylindrical bobbins.

To make AE event information more useful a real time instrumentation system was used. Two main measured and computer processed AE parameters were considered: the energy of AE events (E) and the accumulated energy of AE events (E_Σ). Influence of current value in 0.5 MJ coils on E and E_Σ was studied. The sensors were installed onto the bobbin and the external surface of magnets. Three levels of initial current were examined: 600 A, 1000 A, 1450 A. An extraordinary strong dependence of the current level on E and E_Σ was observed.

The specific features of AE from model coils, operated in sinusoidal vibration current changing mode were investigated. Three current frequency modes were examined: 0.012 H_z, 0.03 H_z and 0.12 H_z. In all modes maximum amplitude 1200 A was realized.

Maximum E corresponds to the maximum current and practically no unload/reload Kaiser effect was observed.

On model SMES the correlation of E and E_Σ with vibration current frequency was discovered.

Introduction

Many investigations have been carried out on AE in superconducting magnets for different applications. Meanwhile there is a shortage of experimental data collection and interpretations of bursts anatomy in SMES. Different metallic and plastic materials form the structure of 0.5 MJ SMES coil: Nb-Ti-based, copper and stainless steel strands, fiberglass, epoxy and mylar insulators. As a very complicated composite material this structure predispositions to be very acoustically active when subjected to pulse loading. Transient heat disturbances of different origin internal and external to the conductor may present during charging-discharging of SMES: dislocation motion, twinning and phase transformation, epoxy cracking, glass-fiber delamination and matrix unbonding. In addition to high level of AC losses discrete bursts act as a principal factor of instability in SMES.

1. Acoustic emission data processing.

The simplified diagram of acoustic emission test system is shown in Fig. 1.

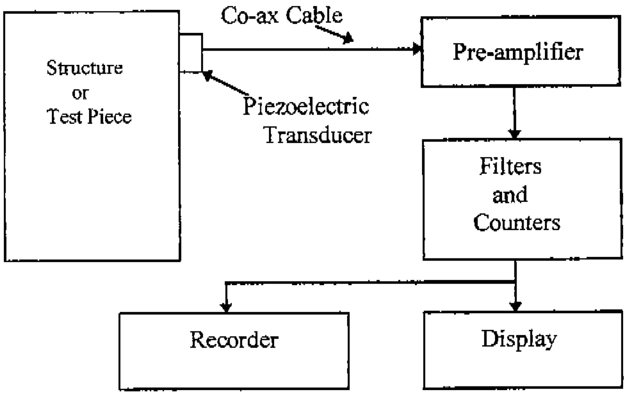


Fig.1. Diagram of AE test system.

Signals from Piezoelectric Transducer (PZT) were transmitted over Co-ax Cable to preamplifier, located near testing cryostat. The preamplified signals were then carried to filters, main amplifier and analyzing-recording circuit. The schematic output of AE signal is shown in Fig. 2.

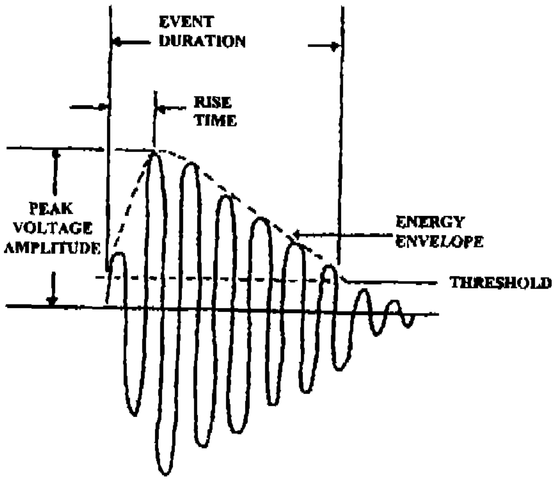


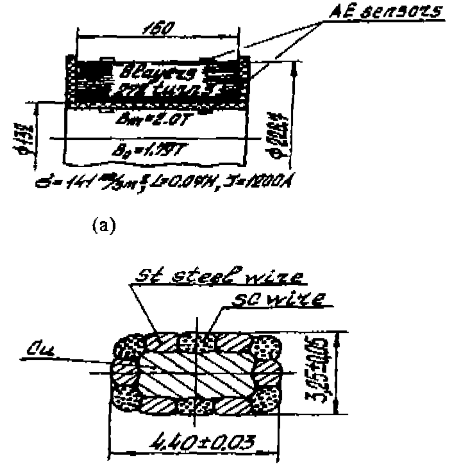
Fig.2. The schematic output of AE signal.

The energy of AE event (dash line envelope, Fig. 2) was computer-processed in real-time observation. The monitoring system provided the exact arrival time for every AE signal with an accuracy of 0.25 microseconds. Transducers were attached to the external surface of the magnet and bobbin. The resonant frequency of transducers was 500 kHz. All experiments were performed by setting high-pass filter at 400 kHz and a low pass filter at 600 kHz. In order to separate AE signal from noise 45 dB level threshold was set. Both 8 channel preamplifier and main-amplifier provided a total gain 60 dB.

2.Monitoring of model coil.

2.1 Sinusoidal current changing mode.

Main parameters and dimensions of model coil and transposed cable are illustrated in Fig. 3 (a) and (b).



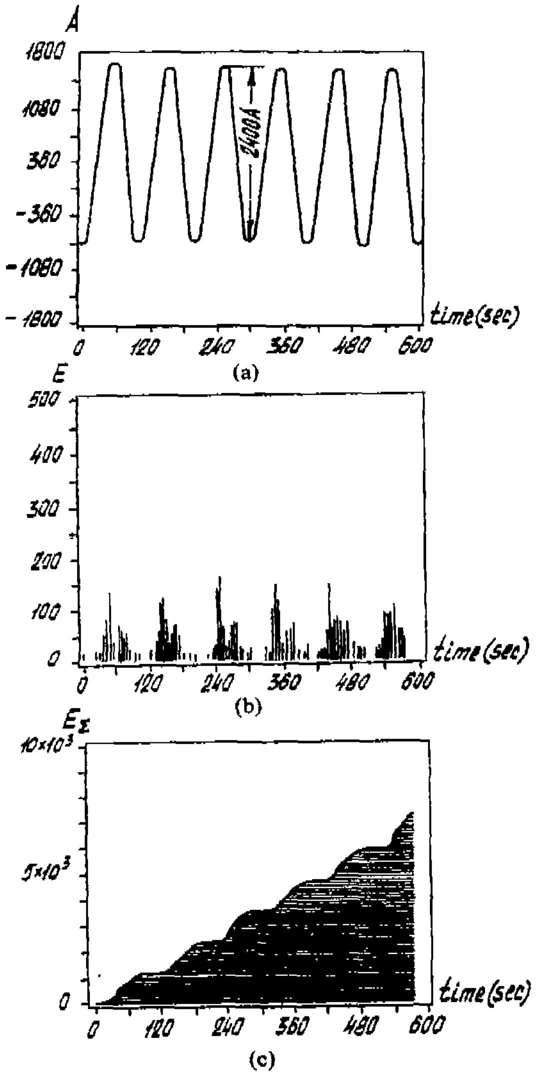
(a)

(b)

Fig.3. Parameters and dimensions of model coil and transposed cable.

The model coil was operated in sinusoidal current changing mode and the specific features of AE were investigated. Three current frequencies modes were examined: 0.012 Hz, 0.03 Hz and 0.12 Hz. In all modes max. Amplitude 1200 A was realized.

The wave form of the 0.012 Hz current mode, measured and computer processed E and E_Σ are shown in Fig. 4 (a), (b), (c).



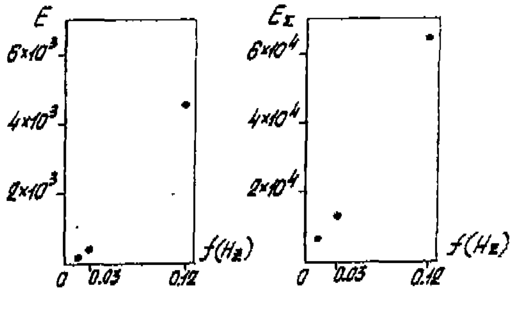
(a)

(b)

(c)

Fig.4. Wave form of the 0.012 Hz current mode, computer processed E and E_Σ.

Maximum E corresponds to the maximum of current and practically no unload/reload Kaiser effect was observed. The mechanism of frictional motion caused by Lorentz forces, mainly motion between neighboring conductors (or/and conductor and supporting structure), can explain the observed results. The energy of AE events (E) and the accumulated energy of AE events (E_Σ) as a function of current frequency are indicated in Fig. 5 (a) and (b) respectively. The energy of AE events (E), an indicator of bursts (puls heat)activity,increased considerably (≈ 1 x 10^2) when frequency changed in the range 0.012 ÷ 0.12Hz.



(a) (b)

Fig.5. E and E_Σ as a function of current frequency.

2.2. Linear current changing mode.

E as a function of current in real time measurement is shown in Fig. 6.

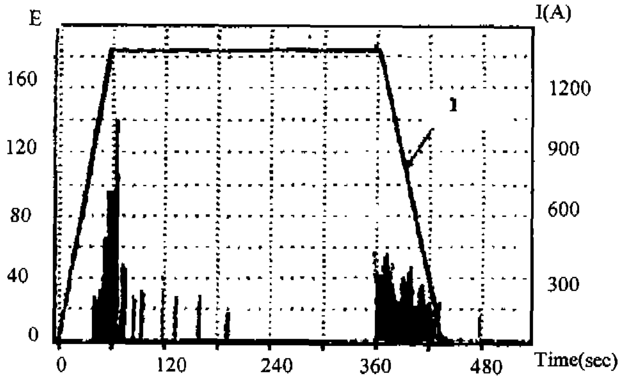


Fig.6. E as a function of current.

Current amplitude and charging-discharging rates are similar to the 0.012 Hz mode. E has a sharp peak in the high current region in charging interval. In the discharging interval E has a broader peak at lower current value. Practically negligible signal activity was observed in the interval dI/dt = 0. The relationship between E and current can be explained in the frames off mass-spring pattern [2]. In charging interval the coil is pressed mainly under the influence of axial Lorentz forces. Axial friction deformations cause high rate AE activity No deformations of coil structure and relative AE activity can be obtained in the interval dI/dt = 0. In the discharging mode the reversal frictional movement of coil forms main AE bursts activity.

3.Monitoring of 0.5 MJ coils.

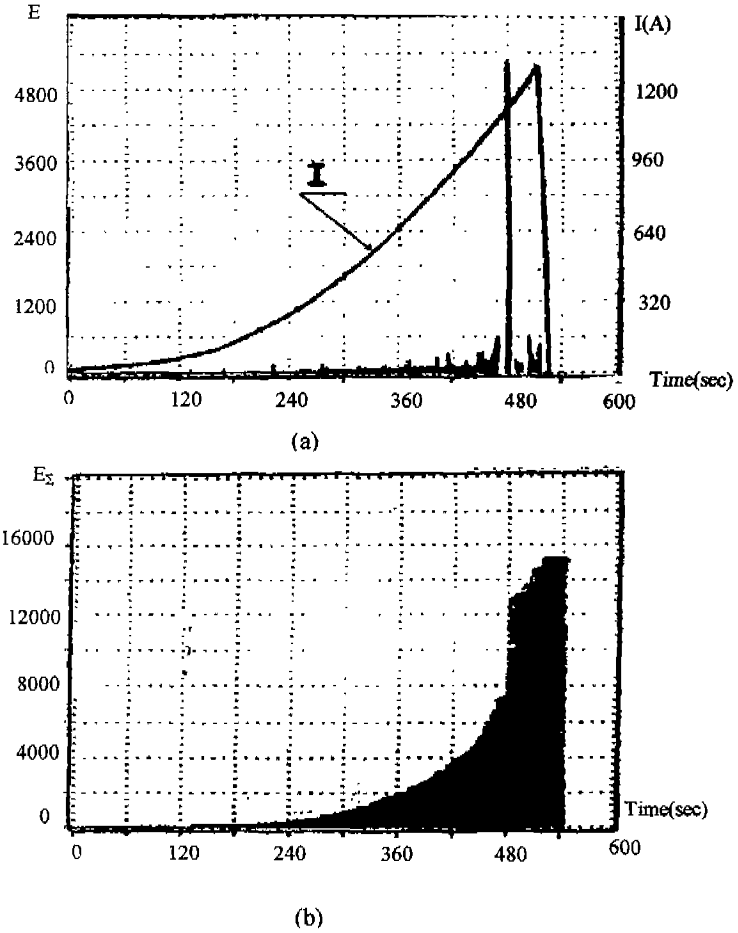
Both coils and full scale model are practically identical from the point of view of output parameters. Main characteristics of coils are given in Table 1.Coils are wound onto fiberglass cylindrical bobbins. The thickness of layer-to-layer spacers is 0.5 ÷ 0.7 mm. The spacers are made of half-potted glass fiber cloth [3].

Table 1. Main parameters of SMES coils.

	SMES 1	SMES 2
Magnet type	Solenoid	Solenoid
Central field (T) at 1550 A	3.39	3.47
Maximum field(T) at 1550 A	3.66	3.72
Inductance, H	0.42	0.432
Number of turns	1310	1326
Inner Diameter, mm	400	400
Outer Diameter, mm	552	514
Axial Length, mm	580	580
Overall Current density at 1550 A, A/mm^2	46.1	62.2

3.1. Low charging rate.

On full scale 0.5 MJ model we investigated AE correlation with quench current. As it can be seen in Fig.7, E(a) and related E_Σ (b) increased monotonously in sweep-up mode, before a sharp peak signal was monitored just a few seconds before quench. Similar high intensity AE behavior has a statistical relationship with quench currents in other training excitations.



(a)

(b)

Fig.7. Full scale model , low charging rate.

It must be pointed out that frictional dissipation can be generated not only by single wire motion (sharp peak) but also cumulative slips can initiate quenches taking into account extremely low heat capacities of materials at 4.2 K.

3.2. Energy transfer rate.

After the initial low rate charging of the coil 1 to a preset current level, the current is stabilized during 10 sec. interval and then the magnetic-energy transfer from the coil 1 to the coil 2 and vice versa begins. The diagram of current changing in two SMES coils simultaneously is shown in Fig. 8.

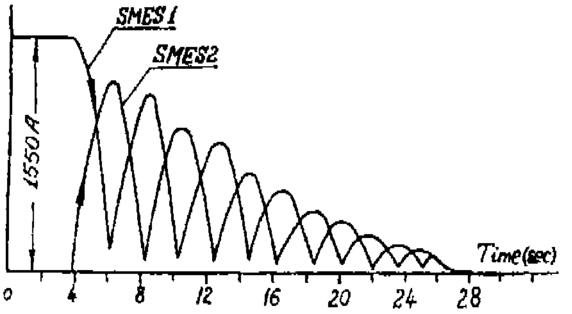


Fig.8. The diagram of current changing in two SMES coils.

The preset current level is 1550 A. The observed specific of AE burst activity during energy transfer rate (E and E_Σ) with preset current level 1000 A are indicated in Fig. 9 (a) and (b).

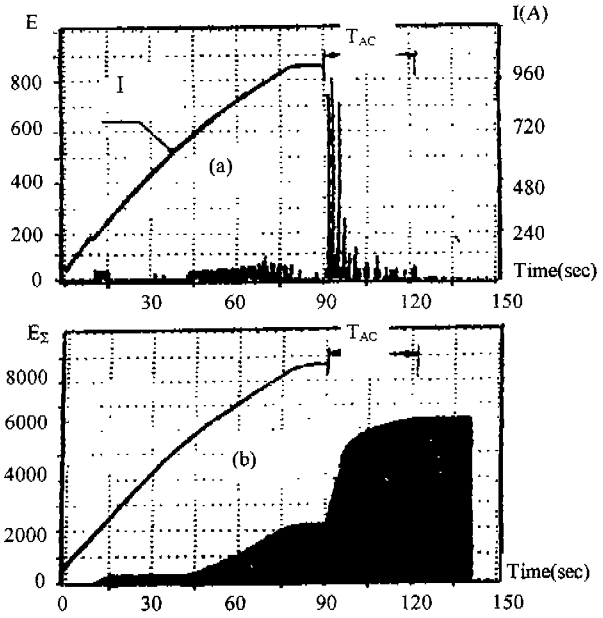


Fig.9. E and E_Σ in energy transfer rate with preset current 1000 A.

A few high intensity peaks (E, Fig a) were monitored in the beginning of the energy transfer interval (T_{AC}). This behavior did not change with excitation number at different current levels. Added with other forms of power dissipation in T_{AC} interval, mainly AC losses, high intensity burst disturbances accumulate an increased damage of quenches in SMES coils. We have also studied the correlation of preset current level (current density) with E and E_Σ. The form of energy transfer was similar to the form, shown in Fig. 8 with three levels of preset current: 600 A, 1000 A, 1450 A. The subsequent analysis of monitored results with the assistance of computer data reduction is indicated in Fig. 10 (a) and (b).

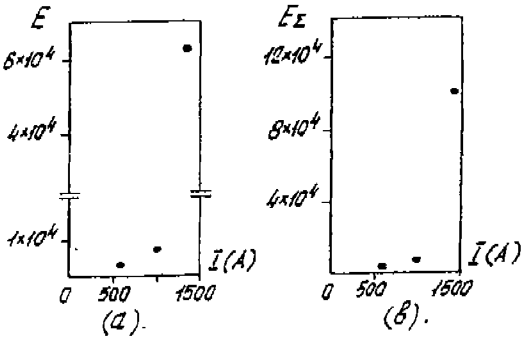


Fig.10. Correlation of preset current level with E and E_Σ in energy transfer rates.

As it can be seen there is an extraordinary high dependence of current level (current density) on bursts activity (E and E_Σ) in energy transfer mode.

4. Localization of bursts.

An attempt of linear localization of bursts was performed. Two sensors were attached to the inner surface of SMES 1 bobbin, Fig. 11 (a).

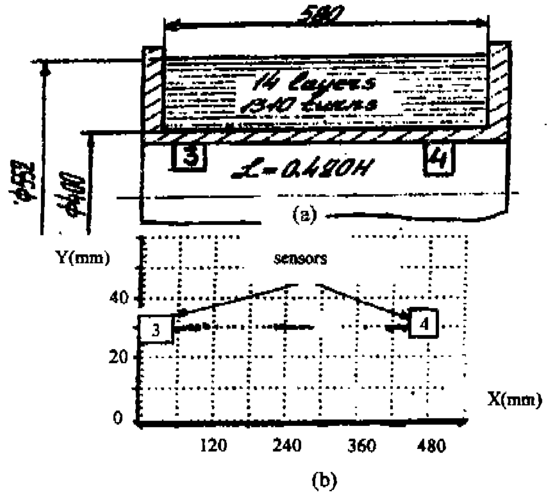


Fig.11. Disposition of sensors (a). Axial localization of bursts activity (b).

The difference in arrival time of AE signal to sensors was the basic principle in localizing instrumentation. The monitored, computer processed and displayed results of axial localization are given in Fig. 11 (b). One dot can be associated with single high amplitude event (hit) or a group of simultaneous low amplitude bursts.

Three zones of AE events activity were detected: both borders of the coil near flanges and the middle part. The adequate interpretations of test results can have close correlation of bursts activity with axial and radial deformations of SMES coil: maximum axial frictional deformations near flanges and radial - in the middle part.

Conclusions.

1. Modern AE instrumentation system was successfully adapted for measuring burst disturbances in 0.5 MJ SMES coils.
2. An extremely strong dependence of current density and vibration current frequency on bursts activity (E and E_Σ) was observed.
3. In linear localization three zones of high level acoustic emitting were detected.
4. Using AE instrumentation system combined with information from other test methods the performance of pulse (SMES) coils can be predicted with more accuracy.

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References

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