Bi-2223 and Bi-2212 tubes for small fault current limiters

T. Janowski, H.D. Stryczewska, S. Kozak, P. Surdacki, B. Kondratowicz-Kucewicz, G. Wojtasiewicz, J. Kozak, H. Malinowski

***Abstract*— The superconducting fault current limiters (SFCL) can be used to limit the short-circuit current level in electrical transmission and distribution networks. These fault current limiters, unlike reactors or high-impedance transformers, will limit fault current without adding impedance to the circuit during normal operation. In one concept of SFCL - serial resistive limiter, the superconductor is inserted in the circuit directly. During a fault, the fault current pushes the superconductor into a resistive state and resistance, which limits the fault current, appears in the circuit. Another concept - inductive limiter works like transformer with shorted superconducting secondary winding. The impedance of this limiter under standard operation conditions is nearly zero, since the zero impedance of the secondary superconducting winding is reflected to the primary. In the event of a fault, the resistance in the secondary winding is reflected into the circuit and limits the fault current. The small inductive type SFCLs with Bi-2223 tubes with critical current =112 A, 625 A, and 1210 A (at 77 K and self-magnetic field) are presented with their limitation coefficients. The resistive type SFCL based on Bi-2212 tube with critical current = 125 A (at 77 K and self-magnetic field) is presented too.**

***Index Terms*— Bi2223 tube, Bi2212 tube, fault current limiter, inductive SFCL, resistive SFCL.**

I. Introduction

THE special feature of superconductors – resistance jumping growth of superconducting element beyond the critical current can be used to build the superconducting fault current limiters for power systems [1], [2].

Superconducting fault current limiter (SFCL) is one of the most promising devices for transmission and distribution of electrical energy due to low nominal losses, rapid reaction times to fault currents and an automatic response without external trigger mechanisms. Operating characteristics of superconducting fault current limiter are shown in Fig. 1.

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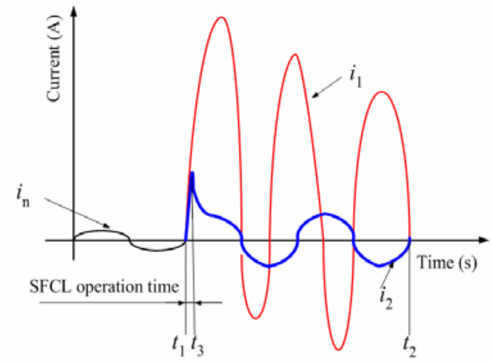

Fig.1. Operating and currents characteristics of SFCL: i_1 - expected fault current without limiter, i_2 - current limited by SFCL, i_n - nominal current, t_1 – fault, t_3 - SFCL operation , t_2 - the operation of conventional switch.

Depending on their fault limitation, superconducting limiters could be divided into resistive, inductive and hybrid ones. YBCO thin films are used in resistive type superconducting fault current limiters. Bi-2223, Bi-2212 as well as YBCO superconductors constructed in the form of rings and cylinders, have been used in inductive type superconducting fault current limiters. Superconducting materials for fault current limiter shall fulfill three basic requirements: low AC losses, high mechanical durability and good thermal stability. This paper describes the physical models of inductive and resistive type of limiters that have been performed and investigated in the Cryoelectromagnets Laboratory and Lublin University of Technology [3]. The aim of the work has been to carry out static characteristics test of several types of inductive and resistive type of superconducting fault current limiters models.

II. Experimental Models And Measurements Of Inductive Type SFCL

The inductive type of superconducting fault current limiter is characterized with low impedance under normal operation conditions, high impedance under fault conditions and rapid return to low impedance after removal of the fault.

The operation of inductive SFCL is based on the fast quench, i.e. transition from the superconducting to the resistive state. The transition is triggered when magnetically induced screening currents exceed the critical current of the superconductor. This type of SFCL has been designed as the transformer with a shorted secondary winding. The secondary winding is usually a HTS cylinder whose function under normal condition is to shield the flux generated by the primary winding from entering the iron core of the limiter. The primary winding made usually by copper is connected directly to an electric circuit. If the secondary winding is driven beyond the critical current of the superconductor it reverts to a resistive state, thereby destroying the ampere-turns balance of the transformer and flux from the primary winding enters the iron core. The inductance and impedance of the primary winding rapidly increase limiting the fault current of the circuit.

The small models of inductive type of SFCL based on three Bi-2223 superconducting tubes, Fig.2, with critical current, I_c, 112 A, 625 A and 1210 A (at 77 K and self-magnetic field), were made, with both open and close iron core [4].

Fig. 2 Superconducting elements for inductive fault current limiters: ***A*** – Bi-2223 tube 625 A (77 K), ***B*** – Bi-2223 tube 112 A (77 K); ***C*** – Bi-2223 CSL-18/160.2 tube (current lead) (all elements made by Can Superconductors)

The static V–I characteristics of the limiters were evaluated and discussed below.

A. SFCL with 625 A (77 K) HTS tube

The constructed model consists of closed iron core, normal conducting copper winding and a shorted secondary winding of superconducting tube Bi-2223, the parameters of which are presented in Table I.

TABLE I
PARAMETERS OF 625 A, BI-2223 SUPERCONDUCTING TUBE

Critical temperature	108 K
Inner diameter	59 mm
Height	50 mm
Wall thickness (approx.)	2.5 mm
I_c in tangential direction (77 K)	625 A

The SFCL model is presented in Fig. 3. The parameters of the model are shown in Table II.

Fig. 3. Model of 625 A superconducting fault current limiter.

TABLE II
PARAMETERS OF 625 A SFCL

Primary copper winding		
Diameter of conductor		0.7 mm
Number of turns		236
Height of winding		49 mm
Inner diameter of winding		73 mm
Limiting current		2.65 A
Magnetic cores		
Cross - section	20 mm x 20 mm	20 mm x 30 mm
Height of core limb	103 mm	103 mm
Width of core window	36 mm	36 mm

The measurements were carried out for the model with different magnetic cores. *V–I* characteristics of this model are shown in Fig. 4

The chart presented below shows that inductive SFCL with larger cross-section of magnetic core is more efficient than the limiter with smaller cross-section of the core.

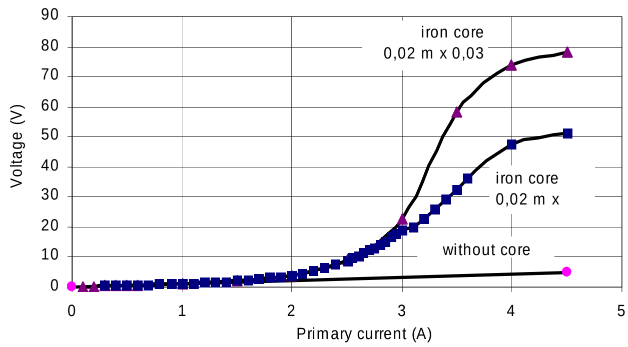

Fig.4. *V-I* characteristics of SFCL with different magnetic cores.

B. SFCL with 112 A (77 K) HTS tube

The constructed model consists of closed iron core, normal conducting copper winding and a shorted secondary winding of superconducting tube Bi-2223, the parameters of which are presented in Table III.

TABLE III
PARAMETERS OF 112 A, BI-2223 SUPERCONDUCTING TUBE

Critical temperature	108 K
Inner diameter	15 mm
Height	15 mm
Wall thickness (approx.)	1.5 mm
I_c in tangential direction (77 K)	112 A

The SFCL model is presented in Fig. 5. The parameters of the model are shown in Table IV.

Fig. 5. Model of 112 A superconducting fault current limiter.

TABLE IV
PARAMETERS OF 112 A SFCL

	Primary copper winding	
1	Diameter of conductor	0.7 mm
	Number of turns	112
	Height of winding	14 mm
	Inner diameter of winding	26 mm
	Limiting current	1 A
2	Diameter of conductor	0.7 mm
	Number of turns	448
	Height of winding	14 mm
	Inner diameter of winding	26 mm
	Limiting current	0.25 A
	Magnetic core	
Cross-section		10 mm x10 mm
Height of core limb		49 mm
Width of core window		11 mm

The measurements were carried out for models with various numbers of primary winding turns. *V–I* characteristics of this model are shown in Fig. 6 and Fig. 7.

The charts presented below show that the limiting factor of inductive SFCL depends on numbers of primary winding turns but is independent of the type of magnetic core.

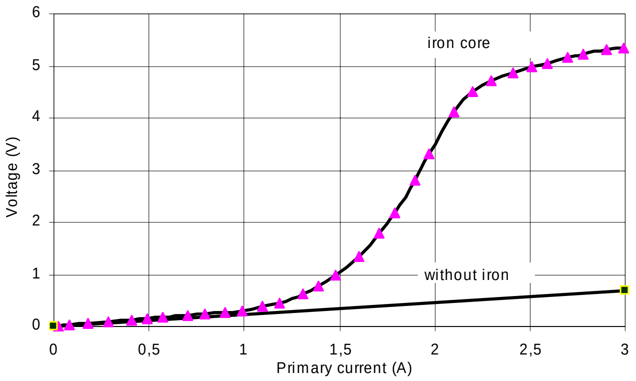

Fig. 6. *V–I* Characteristic of SFCL model with 112 turns of primary winding.

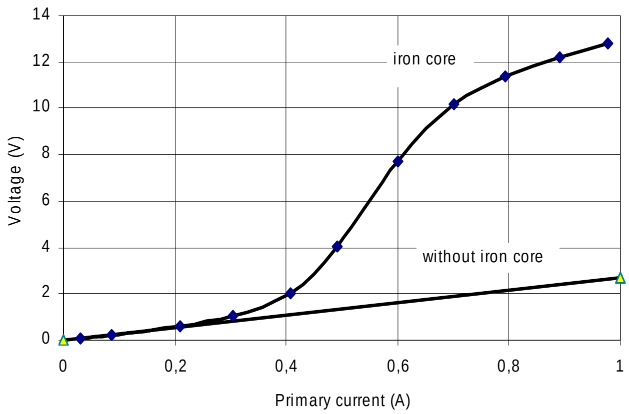

Fig. 7. *V–I* Characteristic of SFCL model with 448 turns of primary winding.

C. SFCL with CSL-18/160.2 tube (1210 A at 77 K)

This SFCL with CSL-18/160.2 tube (current lead), has open magnetic core. The operation principle of the SFCL with open core is the same as SFCL with closed core. The design of the limiter has plenty of advantages: simple structure, light weight, easily removed superconducting tube. Magnetic field generated in large space outside the limiter seems to be one of the disadvantages which lead to the decrease of the quenching time and it can disturb the operation of nearby devices [5].

The superconducting tube parameters of this SFCL are presented in Table V

TABLE V
PARAMETERS OF 1210 A, BI-2223 CSL-18/160.2 SUPERCONDUCTING TUBE

Critical temperature	108 K
Inner diameter	18 mm
height	160 mm
Wall thickness (approx.)	2 mm
I_c in tangential direction (77 K)	1210 A

The SFCL model is presented in Fig. 8. The parameters of the model are shown in Table VI.

Fig. 8. Model of 1210 A superconducting fault current limiter with open magnetic core.

TABLE VI
PARAMETERS OF 1210 A SFCL WITH CSL-18/160.2 TUBE

Primary copper winding	
Diameter of conductor	0.45 mm
Number of turns	1200
Height of winding	170 mm
Inner diameter of winding	20 mm
Limiting current	1 A
Magnetic core (silicon steel plate)	
Cross - section	110 mm^2
Length of core	170 mm

The results of the measurements are shown in Fig. 9

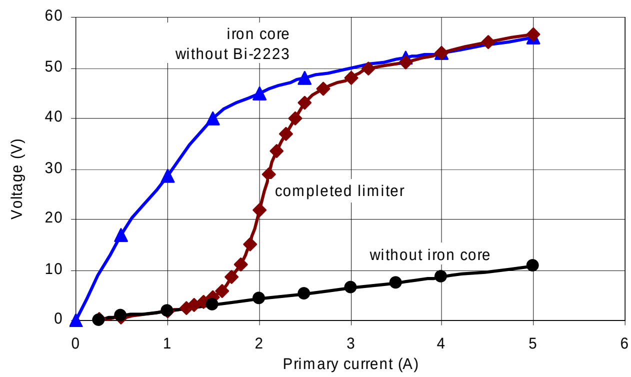

Fig. 9. *V–I* characteristics of SFCL model with CSL-18/160.2 HTS tube.

The application of long HTS and long open magnetic core significantly influences the efficiency of the limiter. The increase of the number of primary winding turns leads to higher slope of voltage-current characteristics and therefore the limiter operates more rapidly.

III. Experimental Model And Measurements Of Resistive Type Of SFCL

The resistive type of superconducting fault current limiter consists of series resistive elements, exploits the nonlinear resistance of superconductors in a direct way. The superconductor is inserted directly in the circuit. During fault, the fault current pushes the superconductor into a resistive state and resistance appears in the circuit, limiting the fault current of the circuit.

A physical model of resistive type of SFCL was made. The model based on superconducting Bi-2212 bifilar coil with critical current 125 A (77 K), Fig. 10, the parameters of which are presented in Table VII.

Fig. 10. Bi-2212 bifilar coil (C02-034 bifilar coil made by Nexans)

TABLE VII
PARAMETERS OF BI-2212 BIFILAR COIL

Critical temperature	108 K
Inner diameter	45 mm
Outer diameter	52 mm
Length of superconductor	5400 mm
$Area_{SC}$	7.5 mm^2
I_c (77 K)	125 A

Fig. 11 shows the experimental system used in the investigation of resistive-type SFCL. The parameters of the limiter are shown in Table VII.

Fig. 11. Experimental system (resistive-type SFCL shown without cryostat).

V–I characteristics of this model are shown in Fig. 12

The operation of resistive SFCL with bifilar coil and the resolution of its *V-I* characteristics depend on the superconducting material and the performance of the coil and its geometry. The required parameters of the coil, with long conductor length can be obtained by cutting superconducting tubes to bifilar coil.

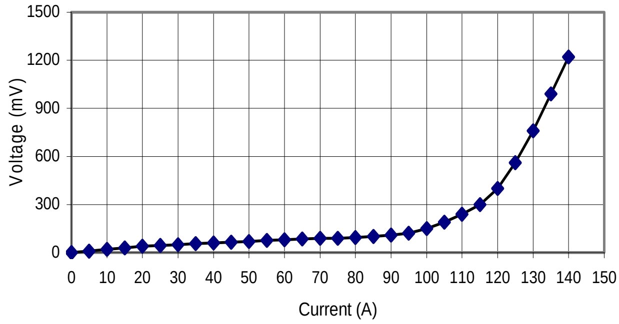

Fig. 12. *V–I* characteristic of resistive-type SFCL model.

The operation of resistive SFCL with bifilar coil and the resolution of its *V-I* characteristics depend on the superconducting material and the performance of the coil and its geometry. The required parameters of the coil, with long conductor length can be obtained by cutting superconducting tubes to bifilar coil.

IV. Conclusion

The operation parameters of the inductive SFCL depend on performance of the superconducting tube, primary Cu winding and iron magnetic core:

– the increase of number of the primary winding turns causes the growth of the inductive limiter's impedance,
– the more slender construction of the inductive limiter, the more significant the current limitation effect,
– the dimension and the type of iron core determine inclination of static characteristic to a great extent and the efficiency of inductive SFCL,
– the cross-section of the iron core highly influences the inductive limiter's limiting current.

The operating parameters of resistive SFCL based on 2212 bifilar coil depend on performance of the superconducting elements especially on cutting superconducting tube to bifilar coil.

References

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