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Iron –based superconductors – development prospects

Streszczenie. *W artykule omówione zostały właściwości nadprzewodników żelazowych, porównano je z właściwościami nadprzewodników innych rodzajów oraz opisano najnowsze badania naukowe, mające niebagatelny wpływ na przyszły rozwój technologii związanych z nadprzewodnictwem na bazie żelaza.*

Abstract*. The article discusses the properties of iron superconductors. These properties has been compared to the properties of other superconductors. The latest scientific research that has a significant impact on the development of iron-based superconducting technologies in the future has been described.* ***(Nadprzewodniki na bazie żelaza - perspektywy rozwoju)***

Keywords: superconductivity, iron-based superconductor, critical current density, critical temperature, superconducting tape.
Słowa kluczowe: nadprzewodnictwo, nadprzewodnik żelazowy, gęstość prądu krytycznego, taśma nadprzewodnikowa.

Introduction

The history of superconductivity reaches over 100 years back, when in 1911, Dutch physicist Heike Kamerlingh Onnes discovered loss of electrical resistance in mercury at near absolute zero temperature. Over time, superconductivity was discovered with the participation of further elements. In 1933 there was another breakthrough – the phenomenon of ideal diamagnetism in superconductors was discovered. It is directly responsible for commonly known magnetic levitation phenomenon.

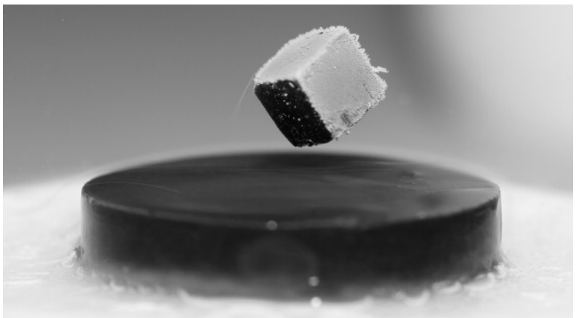

Fig. 1. Meissner-Ochsenfeld effect (magnetic levitation) [1]

The progress of research led to the creation of the theory of superconductivity in both microscopic and macroscopic scale. Quantum phenomena, occurring in superconductors were discovered. In the eighties of the twentieth century, the so-called high temperature superconductors were discovered. Thanks to scientists hard work, critical temperature of superconductors was systematically raised. 2008 year brought the discovery of the iron-based superconductors in $LaFeAsO_{1-x}F_x$ compound.

The importance of iron-based superconductors discovery is that they have several unique properties, which are not present in other types of superconductors. It also turned out that there are many varieties of iron superconductors. Each of them has specific electromagnetic properties. [3]

Iron-based superconductors retain it's superconducting properties in strong magnetic fields, while the density of currents flowing through this type of superconductors is relatively small. Research is currently underway to improve this parameter, but this is achieved at the cost of lowering the critical temperature of the superconductor [4].

The properties of iron-based superconductors are making it an object of various applications – electric vehicles, wind turbines and medical equipment are just some of the potential applications of iron superconductors.

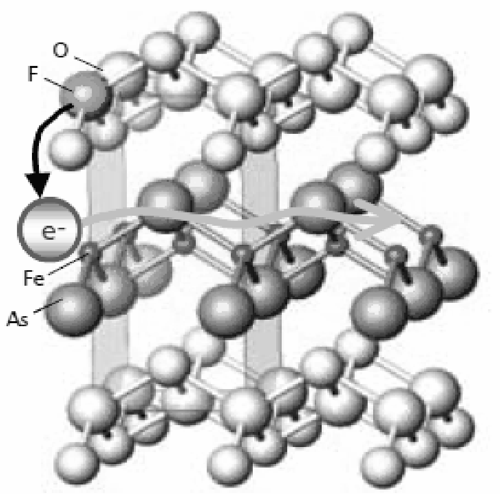

Fig. 2 Crystalline structure and the role of $LaFeAsO_{1-x}F_x$ compound doping [2]

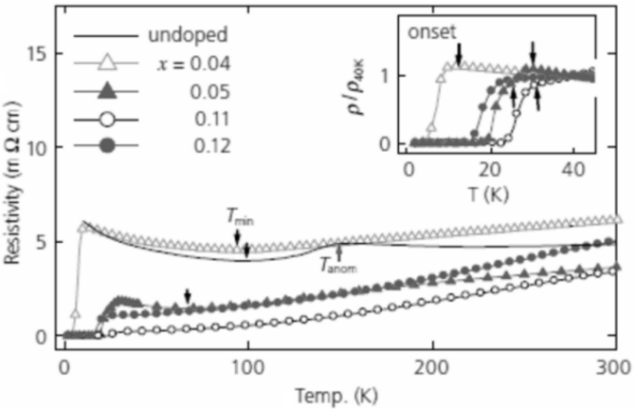

Fig. 3 Resistivity to temperature dependence for $LaFeAsO_{1-x}F_x$ compound [2]

Increasing the critical current density in iron-based superconductors

The value of critical temperature and the critical current density in superconductors are the biggest obstacles to the intensive dissemination of superconductivity. In practice it is very hard to improve these two parameters at the same time. It turns out, that the bombardment by low-energy protons, brings extremely desirable effect of increasing both critical temperature and the critical current density. [4].

Superconducting properties of $Sr_{0.6}K_{0.4}Fe_2As_2$ tape and coils made of it

Iron-based superconductors are divided into two groups - pnictides and chalcogenides. Each of them are intensively studied. The research over the methods of it's production for specific applications are in progress. Research teams from China and Japan are developing innovative method of producing $Sr_{0.6}K_{0.4}Fe_2As_2$ tapes and fabrication of superconducting coils [5].

Superconducting transformers

Improving the technology associated with iron superconductivity makes it obvious to use it in superconducting transformers. The first superconducting transformer designs were created in the 1960s. This kind of devices are distinguished by number of parameters, which are extremely important in suppressing phenomena occurring during such transition states as short-circuits or connecting the transformer to the network. The most important property of superconductors, considered from the point of view of use in transformer windings, is the high currents conductivity at negligible losses [6]. Replacing conventional transformers with superconducting transformers in power grids would reduce transmission losses by more than 60%.

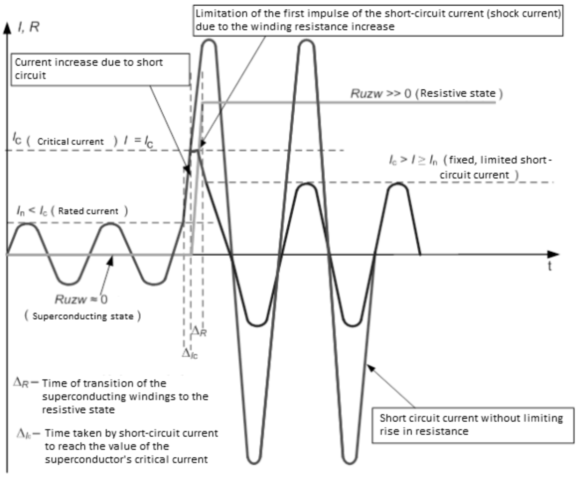

Fig. 4. The effect of self-limiting short circuit current in the superconducting transformer's windings [7]

The winding resistance rises after exceeding the critical current density and the critical temperature value of the superconductor to a value that limits the short-circuit currents. Superconducting transformers generate less losses and beat classical transformers in cathegories of mass and dimensions - they are lighter and more compact [8].

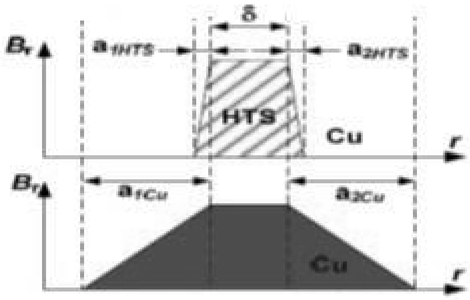

Fig.5 The dependence of thickness of the transformer's windings on the short circuits percentage voltage [6]

The transformers short-circuit resistance is limiting voltage fluctuations in the network during load changes and reducing the value of the short circuit's percentage voltage. At present, the disadvantage of superconducting transformers is the cost of its production, which several times exceeds the cost of production of conventional transformers.

The primary property of superconductors is their rapid decrease in resistance when the critical temperature Tc is reached [9] [10]. The simplified characterization of the superconducting transition is shown in Figure 6.

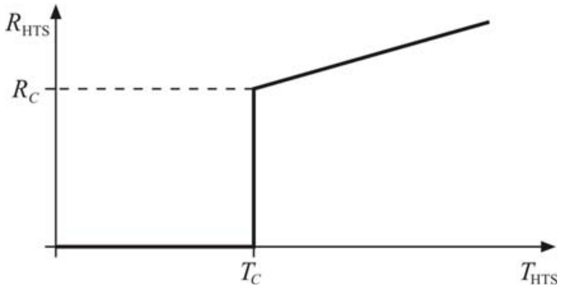

Fig. 6. Simplified characteristics of material transition into superconducting state [9] [10]

The members of the Institute of Electrical Engineering and Electrotechnologies in Lublin have experimentally tested a single-phase transformer with windings made of second-generation superconducting tape. The parameters of the superconductor transformer with the parameters of its windings are shown in Table 1.

Table 1. Transformer's nominal data [11].

Power:	13.8 kVA
Frequency:	50 Hz
HV/LV winding voltage:	230 V/60 V
HV/LV winding current:	60 A/230 A
Magnetic induction:	1.6 T
No-load current:	0.7 A
Short-circuit voltage:	3.2%
Material:	(Re)BCO SCS4050-AP/SCS12050-AP
Dimensions:	0,1x4 mm / 0,1x12 mm
Length:	46,6 m / 9,7 m
Resistance in 293K:	2,9Ω / 0,57Ω
Resistance in 77K:	$0{,}0466\cdot10^{-18}\Omega$/ $0.0097\times10^{-18}\Omega$
Windings in resistive state:	23 µΩ/5 µΩ
Windings inductance	290 µH/18 µH

Superconducting tapes parameters are presented in Table 2.

Table 2. Structure of the applied superconducting tapes [11]

Layer no.	Thickness	Material	Resistivity 20°C	Temperature coefficient of resistance
1	20 µm	Copper	1.72×10^{-8} Ω×m	3.9×10^{-3} K^{-1}
2	2 µm	Silver	1.59×10^{-8} Ω×m	4.1×10^{-3} K^{-1}
3	1 µm	(Re)BCO	-	-
4	1 µm	Buffer zone	-	-
5	50 µm	Hastelloy C-276	1.26×10^{-6} Ω×m	1.3×10^{-4} K^{-1}
6	1.8 µm	Silver	1.59×10^{-8} Ω×m	4.1×10^{-3} K^{-1}
7	20 µm	Copper	1.72×10^{-8} Ω×m	3.9×10^{-3} K^{-1}

The next picture (fig. 7) shows the prototype of superconducting transformer made under the direction of PhD. Grzegorz Komarzyniec at the Faculty of Electrical Engineering and Computer Science at the University of Technology in Lublin.

The measurements were made in the no-load and short-circuit state of transformer. The following drawings (fig. 8 and fig. 9) shows the characteristics obtained from the measurements.

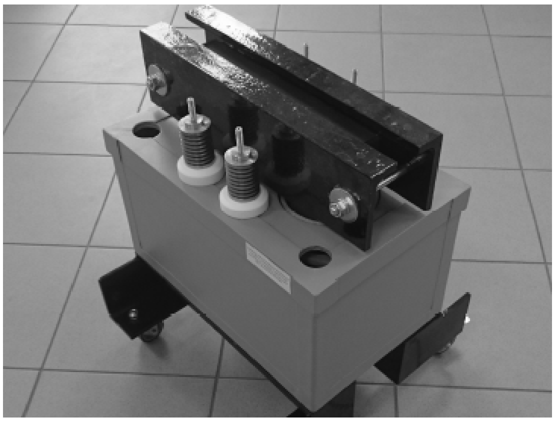

Fig. 7. 15 kVA superconducting transformer [11]

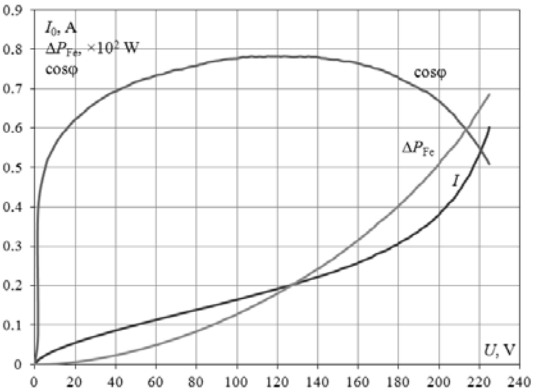

Fig. 8. 13,8 kVA no-load transformer characteristics [11]

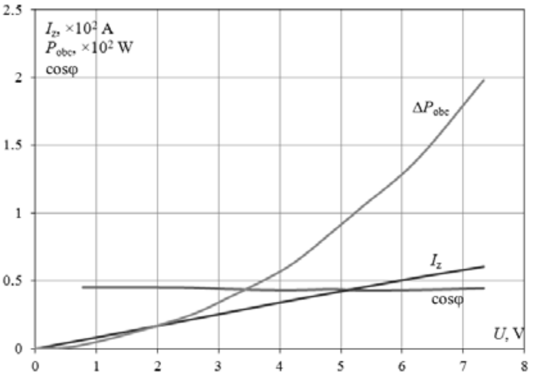

Fig. 9. 13,8 kVA transformer characteristics in short-circuit state [11]

The knowledge of the critical current density Jc, the critical temperature Tc and the critical magnetic field intensity Hc, allows to determine the limit conditions at which superconductivity will persist. The sum of the above parameters, expressed in absolute terms, determines the critical area of the superconductor (Fig. 10).

Current limiters, motors, generators and electromagnets based on iron superconductors.

There are a whole range of applications potentially ready to implement an iron-based superconducting solutions.

Superconducting current limiters are capable to switch to high impedance state, just milliseconds after the occurrence of a short circuit. The result is a significant reduction of the short-circuit current [13].

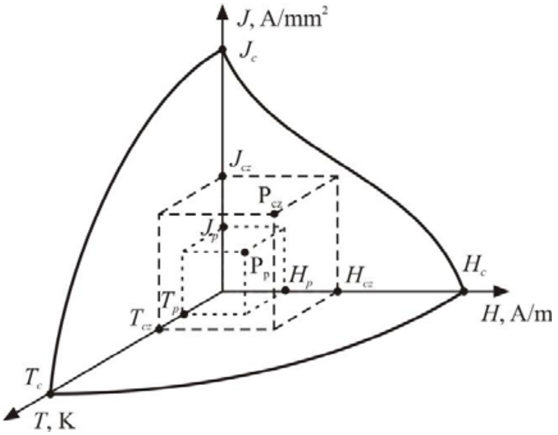

Fig. 10. Superconductor’s critical area [9] [10]

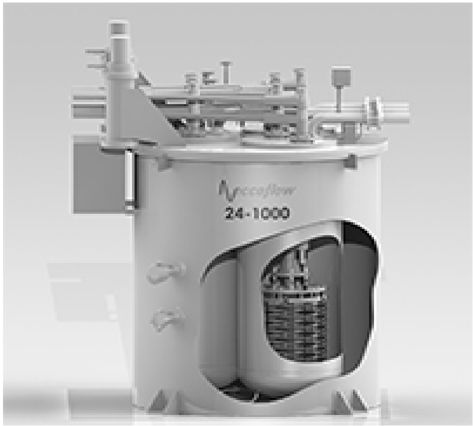

Fig. 6. Nexans superconducting current limiter [12].

A new class of large generators and motors that offer reduced operating costs and significantly improved performance, would not appear without the superconducting technology. High power motors have very large dimensions and consume big amounts of energy. Even a little extent of efficiency improvement, significantly affects energy savings. Another aspect that will change will be the classic drive of any class of means of transport. Thanks to extensive work, the internal combustion engines should be partially eliminated from the market by a very efficient, reliable and eco-friendly electric motors.

The research connected with superconducting electromagnet technology has made a positive contribution to improving the concept of generating electricity using wind turbines. The use of superconductors as a stator winding increases the turbine output and reduces its size. In view of the occurrence of extremely high currents in the stator, new turbine impeller configurations are being developed. Research shows that, thanks to the use of new solutions, the efficiency of wind turbines may increase by 8% [14].

Conclusions

The current intensity of research focused on superconductivity in iron-based materials shows, that the dynamic development of discussed technology should be maintained. Naturally, the deeper understanding of the phenomena occurring in iron-based superconductors will give us wider scope of its practical applications. It is obvious, that it’s properties significantly outrank conventional conductive materials. The forthcoming future should revise the assumptions underlying the predictions of the rapid spread of superconductors. Superconducting technology is still relatively expensive, but in a few years the situation will change. Iron superconductors have an unquestionable chance to have an important role in improving today's technology.

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