

Magnetization of YBCO bulks with permanent magnets and hybrid magnetizer

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We have designed, built and tested three magnetizers that enable fast and inexpensive magnetization of YBCO bulks with the FC method. The first device consists of a permanent magnetic circuit with moveable magnetic poles. The other one is a hybrid magnetizer where we applied permanent magnets and properly designed coils with dc current excitation. The third version is a magnetizer just with an excitation coil without cooling. In this case we have measured 2 Tesla at 2650 W electrical power in 18.4 mm air gap. These solutions are of low cost.

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1. Introduction

The investigation of magnetization is part of material testing of YBCO bulks [1]. Magnetization is possible with FC and ZFC methods. We have designed, built and tested three magnetizers that enable fast and inexpensive magnetization of YBCO bulks with the FC method.

The first device consists of a permanent magnetic circuit with moveable magnetic poles.

With this equipment we could magnetize an YBCO bulk of 27 mm diameter and 15 mm height up to 0.72 Tesla.

The other one is a hybrid magnetizer where we applied permanent magnets and properly designed coils with dc current excitation. With this equipment it is possible to generate flux density of maximum 1 Tesla in a 20 mm air gap in the axis of the symmetry. Both magnetizers are suitable for pre-testing and fast testing of HTS bulks. The following experiments have been carried out to develop a method that is non-traditional and cheap to create about 1 T induction in a work space of 15 – 25 mm height.

The third version is a magnetizer just with an excitation coil without cooling. For example, in this case we have measured 2 Tesla at 2650 W electrical power in a 18.4 mm air gap in the axis of the symmetry and this version is able to generate 1 Tesla in a 50 mm air gap in the centre of the air gap.

Its application can be significant for magnetic levitation, separators, fly wheel energy storing, current limiter and bearings with superconductors. [4], [9], [10]. The equipment can of course be used for machining materials and magnetic material testing. [5], [6], [7], [8]. The modified form of the hyperbolic model introduced by Meszaros [11] efficiently can be used for testing and designing magnetic circuits.

2. Design and construction of the magnetizers

2.1 Magnetization with permanent magnetic circuit.

We have put magnets on the surface of the movable iron poles. The size of the surface of the movable iron poles is 60×60 mm.

The distance between the poles can be adjusted. The application of this magnetizer is preferable instead of using some more expensive equipment. With this method we can see the trapped flux in an YBCO superconductor bulk in Fig. 6. The moveable magnetic poles contain 5 pieces of $50 \times 50 \times 25$ mm magnets each.

Both poles contain 1 piece of magnet of $\varnothing 40$ mm and 5 mm height each to focus and shape the magnetic field.

The magnetizer and the characteristics of the applied magnets are as follows: Fig. 1, 2 and 3.

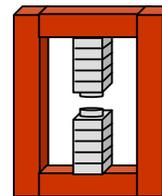


Fig. 1. The scheme of the magnetizer.

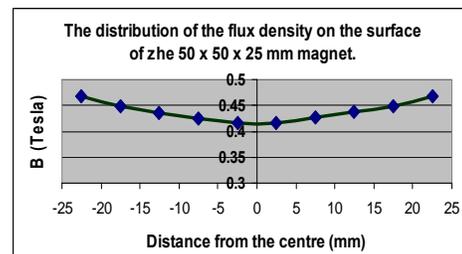


Fig. 2. The distribution of the flux density on the surface of the $50 \times 50 \times 25$ mm magnet.

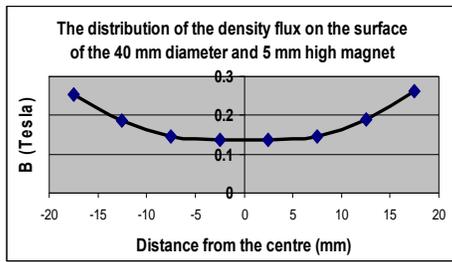


Fig. 3. The distribution of the flux density on the surface of the 40 mm diameter and 5 mm high magnet.

The measured value on the surface of the poles of a 20 mm air gap was 0.937 Tesla, while in the center of the air gap it was 0.862 Tesla.

The diameter of the poles was 40 mm.
Measured results:

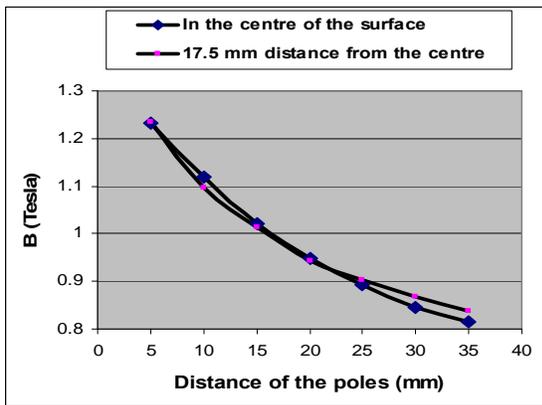


Fig. 4. Surface flux density depending on the distance of the poles.

We can see that in Fig. 4 the field is practically homogeneous.

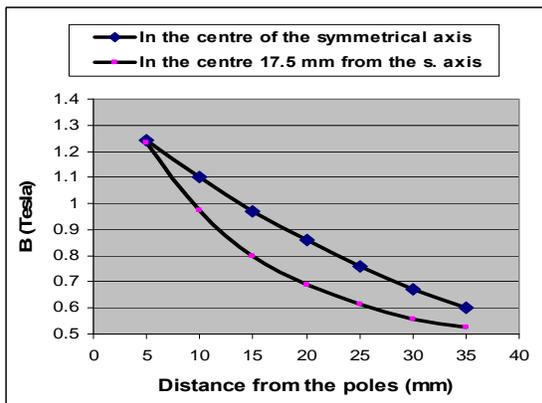


Fig. 5. Flux density depending on the distance of the poles in the centre of the air gap.

We can see that flux density in the centre of a \varnothing 20 mm air gap varies between 0.7 – 0.87 Tesla depending on the

space. The magnetic field is the least homogenous around 20 mm.

The magnetization of the YBCO bulk was carried out with the equipment containing only permanent magnets. The results can be seen in Fig. 6.

This YBCO superconductor bulk was produced in IPHT, in Jena, Germany. Its size: \varnothing 27 mm, height: 15 mm.

The original YBCO bulk was \varnothing 50 mm and 15 mm high. We have produced a ring and a bulk from this sample. Earlier we have developed a new technology at the Budapest University of Technology and Economics, Hungary [2], [3]. We are able to drill the YBCO bulk fast. This technology is of low cost. We have introduced this technology at 4th Japanese Mediterranean Workshop, in 2005, in Cairo.

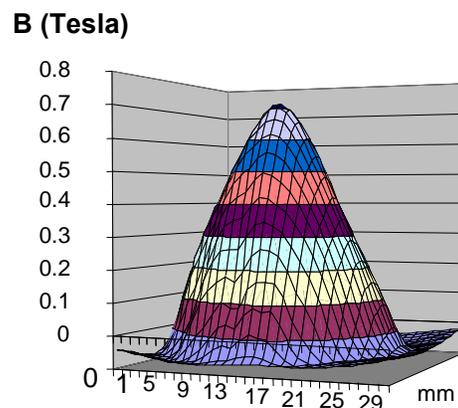


Fig. 6. The result of magnetization.

An YBCO bulk (40x40x8mm) was also magnetized with a permanent magnetizer for curiosity's sake as shown in Fig. 7. ($B_{max} = 0.334$ Tesla, $B_{min} = -0.229$ Tesla).

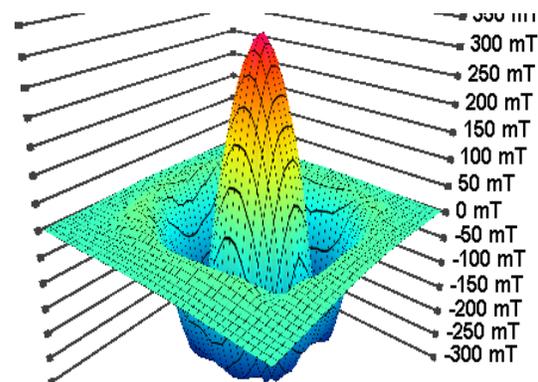


Fig. 7. The result of the magnetization with permanent magnetizer.

Fig. 7 shows the overlap of two different magnetizations, it is two opposite concentric groups of flux lines.

2.2 Hybrid magnetizer

This solution contains permanent magnets and coils with dc excitation. The maximum mmf was 68 000 A turns. The scheme is shown in Fig. 8. As this solution contains fewer permanent magnets than the previous solution, flux density is lower between the poles when no excitation current is applied.

Without excitation in a 20 mm air gap the measured flux densities were as follows:

- On the surface of the magnetic pole: 0,893 Tesla.
- In the center of the air gap: 0,798 Tesla.

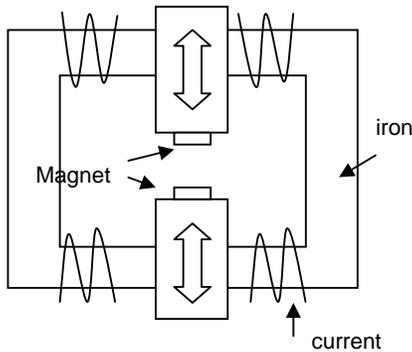


Fig. 8. Hybrid magnetizer.

The major characteristics of the equipment: 4×1000 coil turns, current: 4×17 Amper, power unit: 3-phase Graetz transfer.

Details of the measured results:

First we examined the magnetizer without the magnetic poles. The results are shown in Fig. 9.

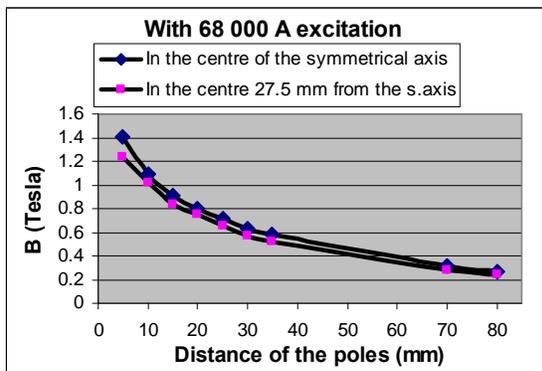


Fig. 9. The distribution of flux density in the centre of the air gap without magnets.

The field was relatively homogeneous in this case.

In the case of hybrid magnetizer we applied permanent magnets ($50 \times 50 \times 25$ mm + 40 mm diameter and 5 mm high magnets) and excitation at the same time.

The results are shown in Fig. 10.

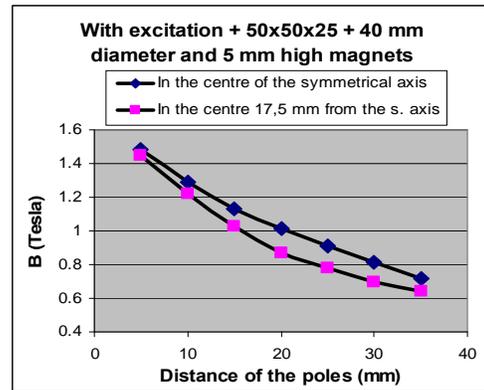


Fig. 10. Flux density in the centre 17.5 mm from the axis of the symmetry.

If distance of the poles is 20 mm:

$$B_{\min} / B_{\max} \text{ in the centre of the air gap} = 0.859.$$

We can see that flux density is relatively high in the case of 15 – 25 mm air gap.

The result of magnetization with hybrid magnetizer (40×40 mm, height: 8 mm YBCO bulk), the results of the flux density are shown in Fig. 11.

$$B_{\max} = 0.912 \text{ Tesla.}$$

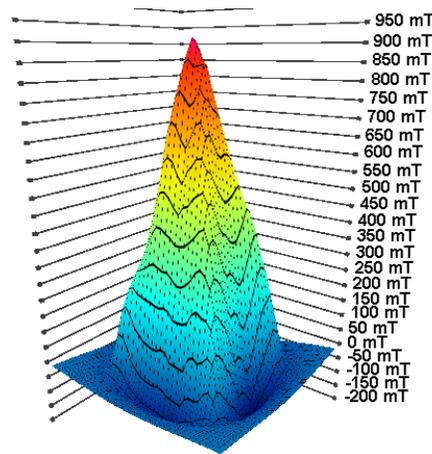


Fig. 11. The result of magnetization with hybrid magnetizer.

2.3 Magnetizer just with excitation coil without cooling

The measured results we can see in the following 1, 2 Tables.

Table 1. Measured results at 2650 W.

In the centre of the air gap mm	[B] Tesla	[P] W
18.4	2	2650
20	1.93	2650
25	1.7	2650
50	1	2650

Table 2. Measured results at 1325 W.

In the centre of the air gap mm	[B] Tesla	[P] W
20	1.7	1325
25	1.5	1325
40	1	1325

The solution: coned iron core with electrical excitation. In Fig. 10 we can see the shape of the coned coil.



Fig. 11. The shape of the coned copper coil.

We analysed two cases.

Version one

How does flux density change depending on core angle if electric excitation is constant?

$$B(\varphi) = ?, \quad \text{if } \Theta = \text{constant}$$

Version two:

How does flux density change depending on core angle if the current density of electrical excitation is constant?

$$B(\varphi) = ?, \quad \text{if } J = \text{constant}$$

This means that electric power loss related to one unit of the volume of the copper coil is kept constant.

In both cases the external diameter of the coil is not changed. We can see the scheme of the equipment in Fig. 12.

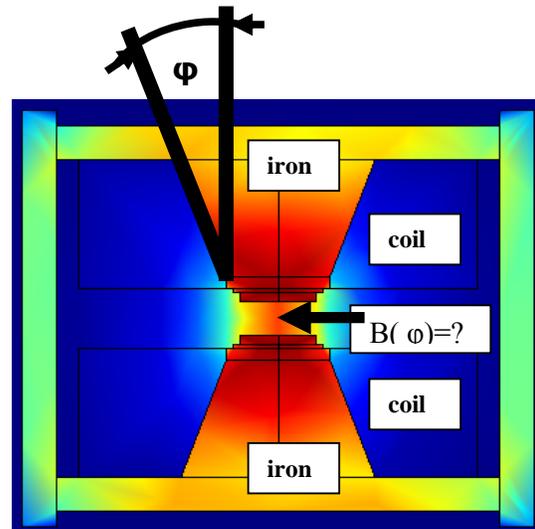


Fig. 12. The scheme of the equipment.

The simulation of the examined flux density in the air gap was carried out with Comsol software.

The result is shown in Table 3. If the angle of the cone increases flux density also increases in the air gap, if $\Theta = \text{constant}$.

For example, if electrical excitation is $\Theta = 37800 \text{ A}$, the results are as follows:

Table 3. The results if $\Theta = 37800 \text{ A}$.

degree	B Tesla in 25 mm air gap
0^0	1.169
10^0	1.487
20^0	1.604
30^0	1.649
40^0	1.66
48^0	1.688

But there occurs a problem, we need higher current. Consequently, there is unnecessarily higher loss of electrical energy.

Version two

Simulation result in the second version if current density (J) is constant is shown in the two graphs of Fig. 13.

In this case, the electric power loss related to one unit is constant. The equipment was designed and built with a 20 degree cone angle. In this case $J = 2.366884 \text{ A/m}^2$, maximum flux density is 1.6 T at $\varphi = 20^0$, the air gap is 25 mm. The diameter of poles is 52 mm.

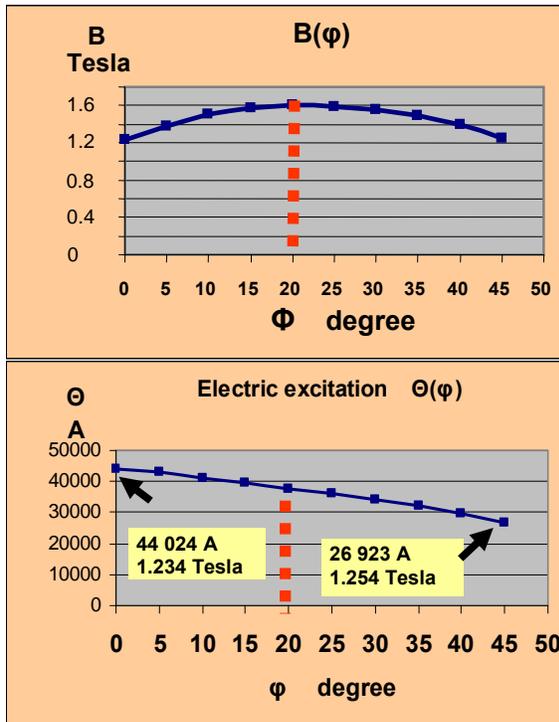


Fig. 13. Simulation results.

We can also see that 1.2 Tesla can be achieved at 0° and 45° as well. As excitation is lower at 45° , it is more economical than at 0° . Maximum flux density can be measured at 20° . Results are shown in Fig. 13.

We can see the evaluation of simulation results in Fig. 14.

If we increase the current density then the optimum is at a higher cone angle.

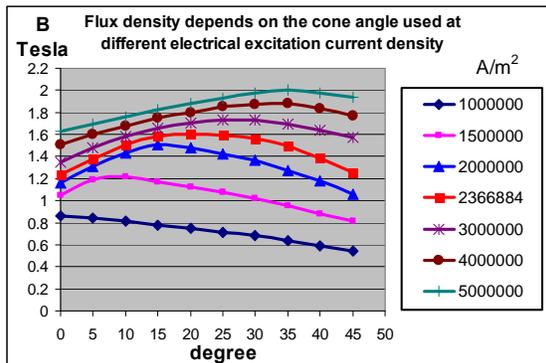


Fig. 14. Evaluation of simulation results.

We can see measured results in Fig. 15, 16:

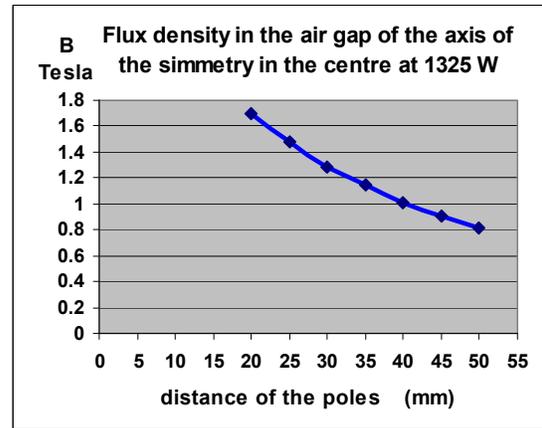


Fig. 15. Flux density in the air gap in the centre at 1350 W.

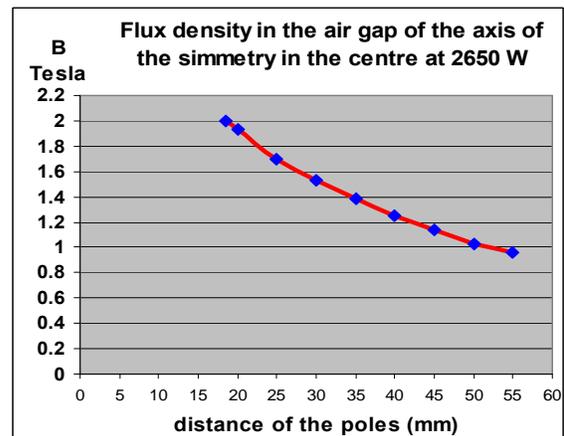


Fig. 15. Flux density in the air gap in the centre at 2650 W.

3. Conclusion

- Permanent magnetizer can be perfectly used for the magnetization of an YBCO bulk of 20 mm Ø and 8 mm height. It is not necessary to use electrical excitation.
- A hybrid magnetizer is suitable the magnetization of an YBCO bulk of $40 \times 40 \times 8$ mm.
- In the centre of 18.4 mm air gap we can produce 2 Tesla without refrigeration at 2650 W with an optimal cone angle. In this case the maximum of the period is 150 seconds.
- Refrigeration is not necessary and we have 2 Tesla and magnetization is of low cost.

Acknowledgment

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