Application Note NAS02-i

Field homogeneity in Helmholtz coils

What is the shape of a magnetic field generated by a pair of Helmholtz coils? How its homogeneity is defined? Questions like these arise to many of us who work with these devices. In the following we will try to clear up this topic.

Definition

The homogeneity of the generated field is usually defined in according to the next formula, definition that we apply at *Serviciencia*:

$$\boxed{Homogeneity\ [per\,cent] = \frac{(B_0 - B_i)}{B_i} \cdot 100}$$

Formula 1

Where B_0 is the magnetic field intensity at the coils centre and B_i is the field intensity at any other point into the volume in which the homogeneity is defined. The homogeneity is shown as a per cent (%) difference in relation to the central field.

Visual representation of the field

As an example let's look at the volume into a Helmholtz pair in which the homogeneity is of ±1% in according to the Formula 1.

A relatively simple way to do that is to perform a computer simulation of the generated field. In this case we have used the *FEMM 4.2* program created by *David Meeker*, which calculates the field value by Finite Elements in 2D, to graphically simulate the field generated by the *X*-axis coils of a *Ferronato BH1300-2B-A* coil-set. These coils have a nominal diameter of 1300 mm.

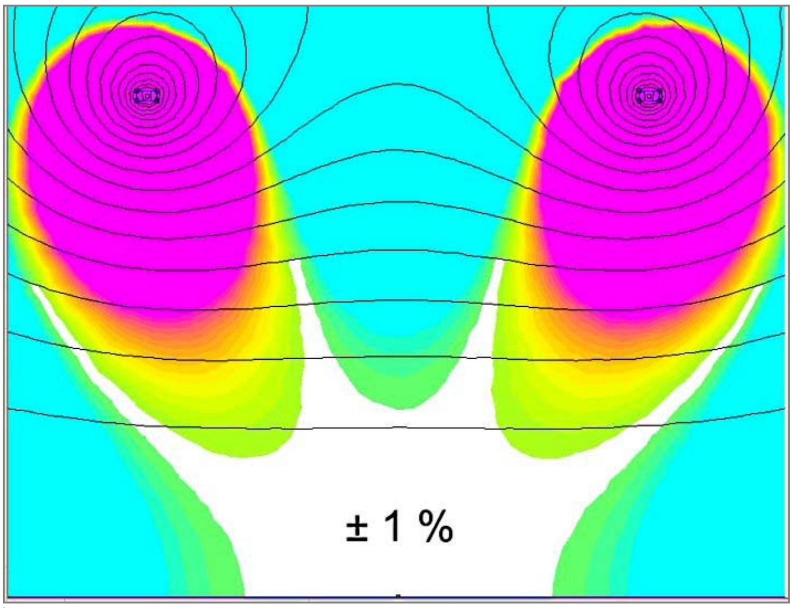

Fig. 1: 2D field simulation with *FEMM 4.2*. The White area indicates homogeneity of ±1%.

The Fig. 1 represents half the plane, whereas the other half is symmetrical to this. The main area with ±1% homogeneity in according to Formula 1 is White highlighted. The finer ends of the area were cut in order to simplify it.

By a revolving transformation of the White area, by means of some graphical manipulations, we can get an image of the volume with a ±1% homogeneity, as it is shown in the Fig. 2.

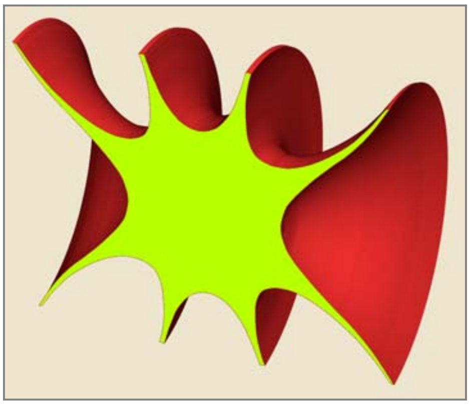

Fig 2: Volume with ±1% homogeneity, cut in half (cut in Green).

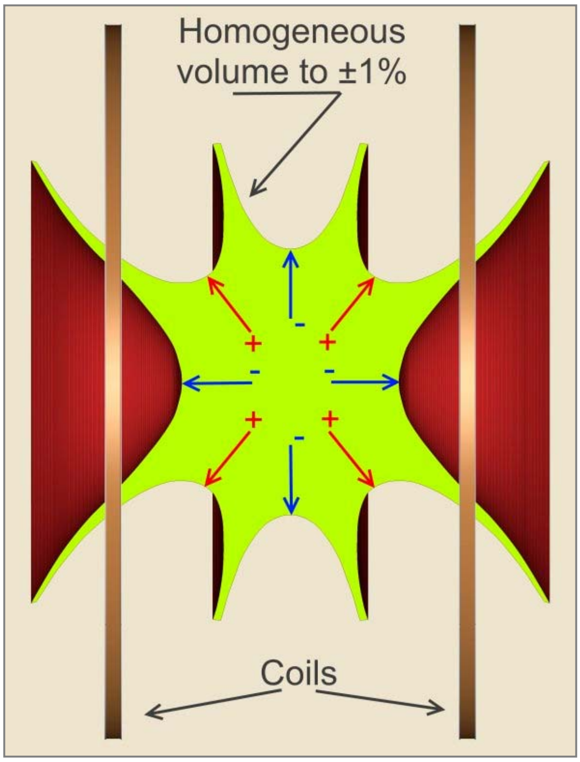

Fig. 3: Volume to ±1% with the coils that generate it. The arrows indicate the field variation.

The Blue arrows in Fig. 3 indicate the directions on which the field decreases from the centre, whereas the Red ones indicate the directions towards the field increases, on the cut plane.

The volume for a ± 5% homogeneity, for example, will be logically larger than for a ±1% one, however its general shape will be similar to the shown in here.

Field checking by measurements

To confirm that the volume obtained by *FEMM 4.2* simulation does fit the true field we have performed a series of measurements of the magnetic field generated by same pair of coils. A steady current of 2.00 A DC was used to generate a static field of 400 µT (4 Gauss). The measurements were done with a *Bartington Mag-03MC-1000* probe (fluxgate, triaxial) and a *Pico ADC24* high-resolution A/D converter connected to a computer. The resolution of the measurement system is lower than 1 nT.

The measurements were done on a grid in the space (3D), every 50 mm, and some extra points were inserted on the limits of the volume with ±1% homogeneity as indicated by *FEMM 4.2*. The coils were positioned to minimise the terrestrial field component on the *X*-axis.

Fig. 4: General view of the measurement system.

Fig. 5: Probe support with XYZ rules.

The measurements confirmed the accuracy of the *FEMM 4.2* representation, with an uncertainty of some few millimetres for the boundaries of the ±1% homogeneity volume.

Homogeneity specification in practise

However, to specify the volume in which the field from some Helmholtz coils has certain degree of homogeneity, the volume shown in Fig. 1 and 2 has a too much complicated shape. In practise volumes of cylindrical or spherical shape are considered in order to specify the field homogeneity, for what it is necessary to know the cylinder, or sphere, of the larger possible size which could be inscribed in the volume of the specified homogeneity.

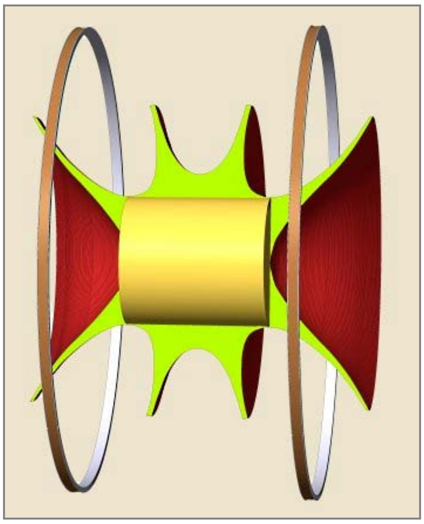

Fig. 6: Maximum cylinder inscribed.

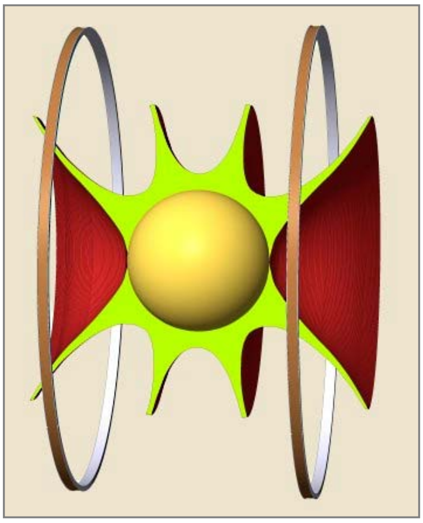

Fig. 7: Maximum sphere inscribed.

In Fig. 6 and 7 it is shown the cylinder and the sphere with the maximum size that could be inscribed in the volume to ±1%. It can be noted that in both cases, on the central plane parallel to the coils and around it, the volume with the indicated homogeneity is substantially larger than the inscribed simple volume.

For a certain coils pair the cylinder has a volume approximately 8.5% larger than the sphere, due to what the cylinder would seem more suitable than the sphere to specify the field homogeneity. However the sphere is attractive due to its symmetry in regarding to any axis, although some volume is wasted at field specification. In practise both volumes can be used.

In the case of a coil-set of two or three pairs of coils orthogonal among them, the cylinder is not longer useful and the best is to employ a spherical volume for the specification of the homogeneity, which is valid for all the axes. The sphere for that would be the larger one that could be inscribed in the zone of a certain homogeneity corresponding to the coil pair with the smaller diameter in the coil-set.

The homogeneity values most often specified are the ones of ±1% and ±5%, which are enough for most the cases. However, sometimes those of ±0.1%, ±0.5% or ±10% (or others) can be specified, especially when it is specifically demanded by some application.

According to the above, the homogeneity specification for a standard coil-set manufactured and supplied by *Serviciencia* would be something similar to the following:

Differences lower than ±1%, in relation to the centre, in a spherical volume of 280 mm in diameter centred in the coils. Differences lower than ±5%, in relation to the centre, in a spherical volume of 540 mm in diameter. These volumes to ±1% and ±5% are larger along some directions.

Final words

Our wish is that this work be of some help for Helmholtz coils users. Your comments or enquiries at this regarding are welcome.

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