A Colloidal Solution of Fe_3O_4 Crystallites to Optically Locate the Magnetic Center of Multipole Magnets

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Abstract

A colloidal solution of Fe_3O_4 crystallites has been made. A recipe for the colloid and its performance in locating the magnetic center of quadrupole magnets are presented.

Introduction

In the alignment of accelerator components or beam transport components along the beam line, it is important to know the magnetic center of multipole magnets, which does not necessarily coincide with the mechanical center.

There are several methods to locate the magnetic center of multipole magnets such as rotating loop coils, floating wires and a colloidal solution of Fe_3O_4 crystallites. The resolution for the position of the magnetic center of magnets is the order of 100μm in the former two methods, rotating loop coils and floating wires. On the other hand it is as good as the order of 10μm in the method of the colloidal solution of Fe_3O_4[1]. This is because the magnetic center can be observed directly by eyes and neither elaborate equipments nor the accurate alignment of the colloidal solution are necessary in the method using the colloid.

The colloidal solution of Fe_3O_4 crystallites had been used to study the domain configuration of ferromagnetic materials. Several recipes for the colloid were reported such as Elmore's[2], Bozorth's[3] and Craik-Griffiths's[4]. The colloid was proposed and used to locate the magnetic center of quadrupole magnets by R.M. Johnson[5]. Scattering patterns of plane-polarized light emerging through the colloid placed in the magnetic field was formulated by J.K. Cobb and J.J. Muray[1].

A setup for the magnetic center location in a multipole magnetic field is shown schematically in Fig.1. White plane-polarized light is directed through the colloidal solution of Fe_3O_4 crystallites placed in a multipole magnetic field. At the exit of the colloid is placed another polarizer such that its direction of the polarization is perpendicular to that of the first polarizer. If there is no magnetic field applied, no pattern is observed but it is just dark. With the multipole magnetic field applied, Fe_3O_4 crystallites are align along the direction of the magnetic field, and they rotate the direction of the polarization of the incident plane-polarized light by the scattering. The scattering pattern emerges on the second polarizer. The magnetic center can be located by the cross point of dark lines as shown in Fig.1. Taking the X- and Y-axes as the direction of the polarization of the second and the first polarizers respectively, θ the angle between the direction of one of the north poles of the magnet and the X-axis, and ϕ the angle between the center of one of the dark lines in the scattering pattern and the X-axis, as shown in Fig.2, angles θ and ϕ have the relation $\phi=2\theta$ for the quadrupole magnetic field. In case of $\theta=0$ (the north pole is along the X-axis), the dark lines emerge on the X- and Y-axes. And when θ becomes 45°, again the dark lines emerge on the X- and Y-axes.

The colloidal solution of Fe_3O_4 crystallites was sold commercially, but it is not these days. So we have tried to make the colloid for ourselves according to the recipe of Craik and Griffiths[4].

In the following are presented our recipe for the colloid and its performance.

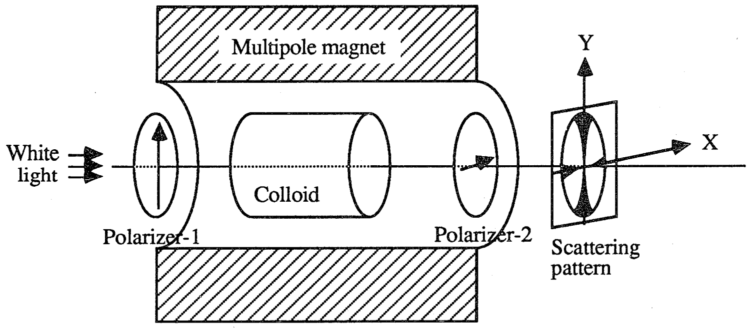

Fig.1. Setup for magnetic center location

Recipe for the colloid of Fe_3O_4

(1) Prepare (a) an NaOH solution by dissolving 2.5g of NaOH in 25cc. of water, and (b) 100cc. solution of 0.1N HCl.

(2) Dissolve 1g $FeCl_2 \cdot 4H_2O$ and 2.7g $FeCl_3 \cdot 6H_2O$ in 150cc. of water at 70°C. The solution has dense tan color.

(3) Add (1-a) NaOH solution with constant stirring. A heavy black precipitate of magnetite slurry is formed. This process can be done without waiting until the solution (2) is cooled down.

(4) Filter and wash this precipitate with distilled water until a top water shows pH of 7. In the filtering a usual filtering paper can be used as the size of magnetite slurry is big enough. The magnetite slurry is heavy and is accumulated at the bottom. So the time of filtering can be saved by removing transparent top water by a pipette.

(5) Dip the filter paper, with the magnetite slurry sticking, into the (1-b) HCl solution, and dissolve the magnetite in the HCl solution. It is said that the processes (4) and (5) should be done in several hours.

(6) Leave this solution for about a day. Then magnetites are peptized and a colloidal solution of Fe_3O_4 crystallites is formed. The particle size is as small as 0.1-0.5μm.

(7) Prepare two cups of solution of cellulose and glycerin by dissolving 1g cellulose powder (Polydextrose made by Pfizer Ltd.) and 10g glycerin in 100cc. of distilled water. Add NaOH solution until pH of 7 as the solution of polydextrose has low pH.

(8) Add the cellulose solution (7) to the Fe_3O_4 colloidal solution (6). Stir gently for a few minutes. The particle size becomes 0.5-1.0μm. It is thought that the size of Fe_3O_4 particles becomes bigger because they are coated by cellulose molecules.

(9) Filter the colloidal solution with membrane filters. Nitro-cellulose membrane filters were used. A filtering equipment with

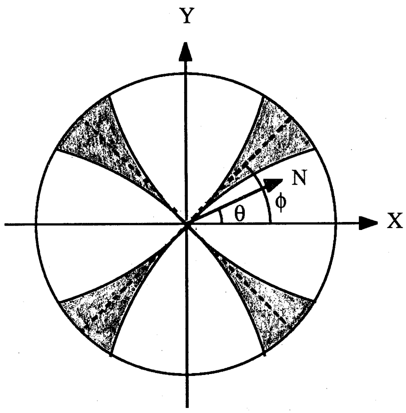

Fig.2. A scattering pattern for a quadrupole magnet. The vector N is the direction of the north pole of the magnet.

vacuum suction is necessary. Filter the colloidal solution with the pore size of 1μm and remove dusts. Then filter with the pore size of 0.5μm and wash the Fe_3O_4 crystallites with distilled water. In filtering the membrane filter is clogged soon. Then remove the top solution and wash crystallites sticking to the filter several times with distilled water. Then dip this filter in 100cc. of cellulose solution (7). Repeat this procedure and accumulate 6 filters with Fe_3O_4 crystallites sticking in the cellulose solution.

(10) Stir the above solution and remove Fe_3O_4 crystallites from the filters into the cellulose solution. Then take out the filters.

(11) In locating the magnetic center, use this colloidal solution of Fe_3O_4 by diluting with glycerin at the rate of 10cc. of the colloidal solution to 50cc. of glycerin .

We failed in making the colloidal solution at the beginning because it was not described that the peptization took so much time in the paper [4]. We looked for a substitute to the Celacol, a soluble derivative of cellulose made by British company [4], and found polydextrose. The dilution with pure glycerin works well as described in the next chapter.

Performance

The colloidal solution of Fe_3O_4 crystallites is tested with a permanent quadrupole magnet. The picture of the test setup is shown in Fig.3. The bottom black tube is the light source of plane-polarized white light. Atop the light source is mounted a quadrupole magnet made of 16 pieces of permanent magnet. The inner diameter of the quadrupole magnet is 14mm and the field gradient is 180 T/m. The colloidal solution of Fe_3O_4 is contained in the acrylic tube, and placed in the inner hole of the quadrupole magnet. As the top plate of the acrylic container is made of a polarizer, the scattering pattern of the plane-polarized light emerges on this top plate. A picture of the scattering pattern is shown in Fig.4. This picture was taken one hour later since the colloidal solution was placed in the magnetic field. The pattern still can be seen clearly after two days. With the colloidal solution manufactured by J/D Scientific, however, the pattern becomes indistinct in about 40 minutes. The pattern life is thought to depend on the density of Fe_3O_4 crystallites and the viscosity of the colloidal suspension. Our colloidal solution has much higher density of Fe_3O_4 crystallites and higher viscosity than that commercially sold. Fig.5 shows the picture of our colloidal solution left for two days in the quadrupole magnetic field. Dense stripes of Fe_3O_4 crystallites attracted by the quadrupole magnetic field can be seen on the container wall. In case of the colloidal solution commercially sold, this striped pattern is scarcely seen. If the cellulose is not used, the particle size of Fe_3O_4 crystallites in the colloid is smaller as described in the previous chapter and the life of the scattering pattern is about an hour. Polydextrose looks playing an important role in improving the pattern life. It was tried to align the hair-cross of an alignment telescope onto the cross point in the scattering pattern repeatedly. The telescope was placed 2m far from the colloidal solution. The reproducibility of the alignment was less than 20μm.

Conclusion

A colloidal solution of Fe_3O_4 crystallites have been made according to the recipe of Craik and Grifiths. The life time of the scattering pattern formed by the scattering of plane-polarized light in our colloidal solution is longer than two days, which is much better than the pattern life of about 40 minutes for the colloidal solution commercially sold. The reproducibility of the alignment of the hair cross of the telescope onto the cross point of the pattern is less than 20μm. Polydextrose, a soluble derivative of cellulose, looks playing an important role in improving the pattern life.

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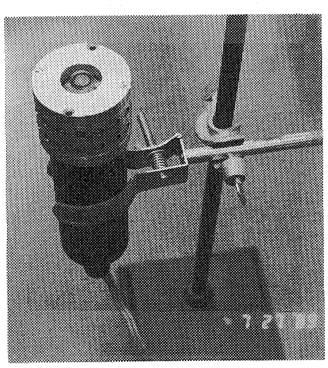

Fig.3. Test setup for magnetic center location.

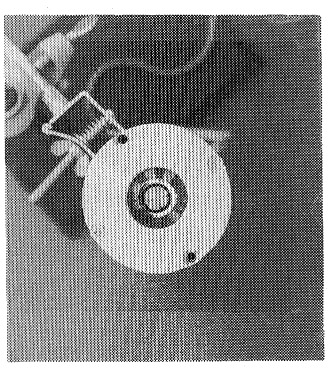

Fig.4 Scattering pattern of plane-polarized white light by the colloidal solution of Fe_3O_4 crystallites.

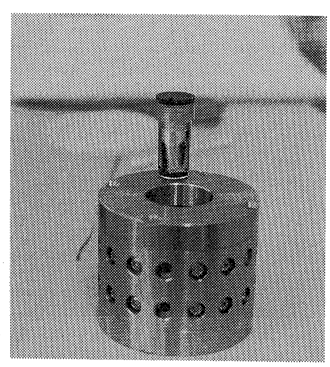

Fig.5 Colloidal solution left in a quadrupole magnetic field of 180 T/m for two days.