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A ROTATING SAMPLE MAGNETOMETER

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ABSTRACT

A rotating sample magnetometer, optimized to measure magnetic anisotropy, is described. The design offers definite advantages in simplicity, ease of operation and accuracy. The driving motor, the shaft-position encoder and a long, interchangeable rod with the sample are arranged coaxially for easy and reproducible sample-changing. A special pick-up coil system with high discrimination against electrical noises is used. The sensitivity of this system is highly uniform, rendering the inaccuracy due to slight displacement of the sample negligible. Lock-in technique is adopted to extract the desired information. Typical data are presented.

РЕЗЮМЕ

Описан магнитометр в вращающимся образцом, оптимизованный для измерения магнитной анизотропии. Его преимуществами являются простота, легкость в обращении и точность. В целях легкой и воспроизводимой замены образца, двигатель, кодирующее устройство угловых позиций и длинный заменяемый держатель образца размещены коаксиально. Во избежение электрических шумов мы применили систему сильно дискриминирующих специальных приёмных катушек с однородной чувствительностью. Вследствие ошибками, возникающими из-за малых смещений образца, можно пренебречь. Для получения информации мы применили электронную схему с фазочувствительным детектором. Сообщаем типичные результаты.

KIVONAT

Mágneses anizotrópia mérésére optimalizált forgómintás magnetométert ismertetünk. A készülék előnye egyszerüsége, könnyü kezelhetősége és pontossága. A könnyü és gyors mintacsere érdekében a forgató motor a szögpozició-kódoló és a hosszu, cserélhető mintatartó koaxiálisan helyezkedik el. A mágneses térre és a forgástengelyre merőleges mágnesezettségkomponenst különleges tekercsrendszer érzékeli, amely nagy térfogatban homogén érzékenységet biztosit és egyszersmind csökkenti a szórt mágneses terekből adódó zavarokat. A kivánt információ kinyeréséhez fázisérzékeny detektálási módszert alkalmazunk.

In conventional anisometry the perpendicular component of magnetization is detected by measuring the torque exerted on the sample by an external magnetic field. The same quantity can also be detected by measuring the flux in a suitable coil system. This latter method is adopted in the rotating sample magnetometer /RSM/. The torque method is especially suitable for highly accurate measurements at fixed temperatures, while the RSM is more appropriate when a large number of samples must be investigated with moderate accuracy in quickly changing environment.

In the instrument described the sample rotates with constant angular velocity around a vertical axis in a horizontal magnetic field and the time derivative of the magnetization perpendicular to both the axis and the field is detected by measuring the voltage induced in a pickup coil. This voltage is proportional to the angular derivative of the conventional torque curve and it is inversely proportional to the external magnetic field. The amplitudes and phases of its Fourier components /harmonics/ can be used to determine the anisotropy constants as described in a review paper by Flanders [1]. Discussions here are confined to problems specific to RSM, namely the mechanical construction and the coil design.

Mechanical design

In the mechanics /Fig. 1/ special care has been devoted to the quick and easy change of the sample fastened to the lower end of a vertical shaft of about 85 cm in length, called sample rod. This rod, together with the sample, can be extracted and replaced in less than one minute through a vertical bore in the shaft of the drive system.

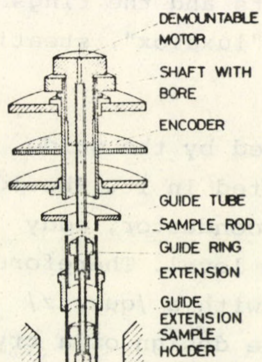

Fig.1 Diagram of the mechanics

The sample rod, the angular position encoder and the driving motor /omitted from the diagram in Fig. 1 for clarity/ are arranged coaxially. To minimize the stray magnetic field of the drive system, a motor originally designed for studio-quality tape recorders was selected. This is of external rotor type with synchronous speeds of 500 and 1000 revolutions/minute when driven from 50 Hz.

The correlation of the signal detected with the angular position of the sample is made possible by the encoder. Its main part is a silver-coated glass disc with windows evenly spaced along coaxial circles. The disc is mounted on a tubular shaft. An opto-electrical system similar to that of a punched-tape reader is used to obtain electrical impulses at angular positions dictated by the Fourier component to be measured. Since both the amplitude and the phase must be known, in-phase as well as quadrature references are needed at each of the harmonics. This is accomplished by the division by four of a pulse train of four times the frequency required and resetting the divider to either zero or one at the beginning of each revolution. To obtain the harmonics from the 1^{st} up to and including the 9^{th}, as well as the 12^{th} and 16^{th}, six different circles were necessary.

The most delicate part of the mechanism is the sample rod. For this a stainless steel tube is used having a diameter of 4 mm and a 0.2 mm wall for the upper part, extended by a 3 mm dia. x 0.5 mm quartz tube of about 15 cm in length. The joint is threaded for easy replacement of the fragile quartz tube. The sample itself is cemented to a 2,5 cm long disposable holder which is then screwed on to a threaded part of the lower end of the quartz extension.

Guide rings of about 8 mm in diameter are fastened to the sample rod. These fit with a clearence of about 0.1 mm inside of a fixed guide tube to restrict the whipping. A minimum number of these rings should be used in order to prevent the excitation of transversal vibration modes of the sample rod and/or the guide tube. We use two rings, one for the sample and another at the joint of the extension and the stainless steel tube as indicated.

Teflon is the best material for the threaded parts and the rings below about 450 K. At higher temperatures boron nitride, "luxalox", steatite or /possibly/ graphite may be used.

In operation the guide tube is continuously tapped by the guide rings and acoustic vibrations of small amplitude are excited in it. Should the part exposed to the magnetic field be made of a good conductor, eddy currents would be generated causing a high magnetic noise level. Therefore the guide tube /brass in our case/ must also be provided with a /quartz/ extension. This must be kept in mind especially during the design of a cryostat or furnace, of which the guide tube must be an integral part.

The mechanism described is completed with the means of moving it in three mutually perpendicular directions so that the sample can be placed exactly in the centre of symmetry of the coil system. Rubber pads are also provided to isolate the mechanical vibrations from the electromagnet and, especially, from the pick-up coils.

Signal detection

The pick-up coils must be sensitive to the time-varying perpendicular component of the magnetization while at the same time they must discriminate strongly against unwanted signals. Sources of such signals can be the lateral motion of the sample during rotation due to unavoidable imperfections of the mechanism as well as the more or less homogeneous stray magnetic fields present in the laboratory.

Using a reciprocity theorem of electrodynamics [2] it can be shown that the coil system would be insensitive to this lateral motion if, when energized, it produced a homogeneous magnetic field at the sample. The good old Helmholtz arrangement is not suitable for pick-up coils, however, because of its senstivity to homogeneous stray fields.

The /second/ degree of inhomogenity compensation of the Helmholtz system can be also achieved by using two pairs of identical coils in series opposition [3]. This system is not only insensitive to homogeneous external fields but it has the additional advantage of having larger radial access than that of the Helmholtz arrangement for the same external diameter. The price paid for this is some 30 % reduction in sensitivity. The coil system we use is shown in Fig. 2.

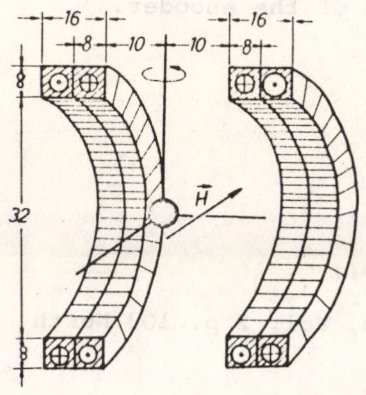

Fig. 2 Pick-up coil system. The coils in each half are in series opposition. The sample is located at the centre of symmetry. Dimensions are given in mm.

The coils should be exactly coaxial and thier axis must be exactly perpendicular to the field of the electromagnet otherwise hum pick-up from the energizing current of the magnet will be received. It must also be kept in mind that coils in some 10 kOe are fairly effective dynamic microphones unless they are bolted strongly to the faces of the magnet. The space between the coils and their holder was filled with Araldite to form a monolithic block in order to obtain extreme rigidity.

The signal level is in the hundred microvolt range with ferro- or ferrimagnetic samples of a few hundred milligrams. To improve the signal-to-noise ratio and to measure selectively each of the harmonics, phase sensitive detection is used. Alternatively time-domain averaging with a boxcar integrator can be also accomplished if higher accuracy is required. Minor imperfections in the mechanics prevented our obtaining a precision higher than a few percent therefore the lock-in technique suffices.

The signal is plotted against the magnetic field by an X-Y recorder. A plot similar to the one shown in Fig. 3 for Gd-doped YIG can be obtained in a few minutes. To further illustrate the versatility of the instrument, a first order phase transformation of MnAs is displayed in Fig. 4.

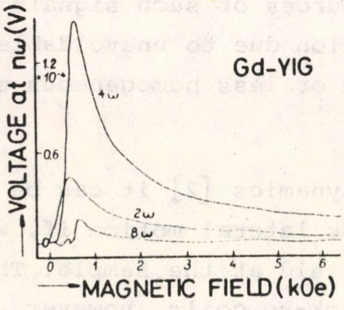

Fig. 3 *Plot of induced voltage at different harmonics for Gd-doped YIG, as a function of the magnetic field*

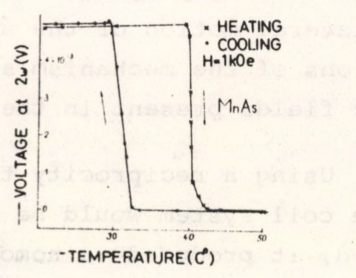

Fig. 4 *Magnetic phase transformation in MnAs, detected by the induced voltage at 2 ω*

The anisotropy constants may be determined e.g. by the curve-fitting method described in [1]. The instrument must be calibrated with a sample of known anisotropy energy.

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