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Hidetoshi Shibuya and Tetsuya Michikawa

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Calculation of Superconducting Rock Magnetometer response to long core

Hidetoshi Shibuya* · **and Tetsuya Michikawa****

Abstract.

A fortran program calculating SRM (Superconducting Rock Magnetometer) response for pass-through measurements of core samples was developed, so as to make better deconvolution of the magnetic measurements. Calculation agrees with measurements for both point and half circle samples. The results shows that the position of the sample must be carefully set for the pass through measurements with deconvolution.

Key words : Paleomagnetism of sediment cores, Superconducting rock magnetometer, Deconvolution

Introduction

The recent development of the pass-through SRM makes the remanence measurements of sediment cores so easy that it is now commonly used. The problem with such measurement is that the result is a convolution of the magnetization and the response of the SRM. There are two approachs to get more detailed magnetization. One is providing SRM with narrower response [Nagy and Valet, 1993; Weeks *et al.*, 1993], and the other is performing deconvolution [Dodson *et al.*, 1974; Constable and Parker, 1991; Oda and Shibuya, 1994]. One may want to apply deconvolution with the higher resolution SRM to get even more detailed variation in magnetization. The deconvolution operation is unfortunately very unstable being essintially a high pass filter, and is very sensitive to noise. We, therefore, have to introduce smoothing in some way to the result, assuming that the magnetization does not change fast.

We recently developed a new method of the deconvolution based upon the Bayesian statistical model. This method is totally objective, in other words, has no parameter to be adjusted arbitrary, within the model implemented. The assumptions of the model are as follows:

(1) Magnetization is constant within a horizon in both intensity and direction.
(2) The smoothness of changing magnetization does not vary throughout a single pass-through measurement.
(3) The error of the measurement follows a single normal distribution throughout a core.
(4) Proper response function is given.

Although this paper is concerned with the 4th point, we will also briefly discuss other points.

The first one is unavoidable so far as the measurement is one dimensional. The second one is related with the prior distribution of the Bayesian model. In the Bayesian model, other knowledges than the data themselves are expressed in the prior distribution, and it is rather easy to take other situation into account as shown in Oda and Shibuya [1997]. The third one is related only to the statistical feature of the measurement error. The fourth one is easiest one to be controlled and is treated in this paper.

Determining precise response is particularly important for the small bore SRMs. The distance of the sample from the pickup coils tends to be small so that the response function has an important high frequency content. The response of X, Y and Z axes could be quite different, making large swing in inclination or declination.

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* Department of Earth sciences, Faculty of Science, Kumamoto University, 2-39-1, Kurokami, Kumamoto 860-8555, Japan

** Japan System Design Co.Ltd., Chiyodaku, Tokyo, Japan

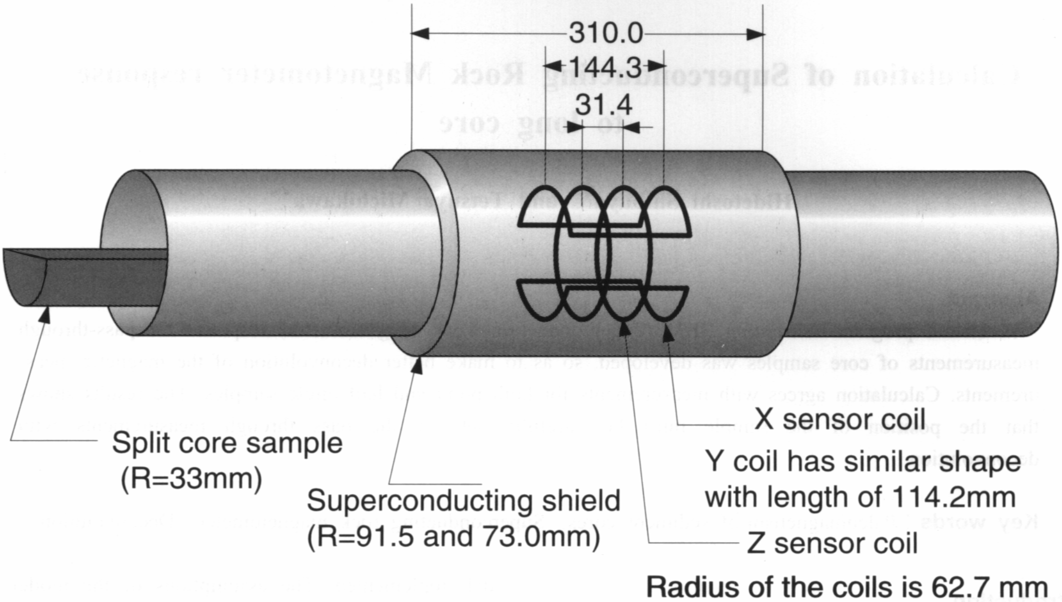

Figure 1. Schematic diagram showing the shape and size of the pickup coils and super-conducting shield.

Calculation of the response function

The 2-G SRM has three sets of pickup coils corresponding to X, Y, and Z axes (Z is parallel to the axis of the magnetometer). The pickup coil system is situated in the cylindrical superconducting shield bulging in the middle. The Z-pickup coil consists of a Helmholts pair so that the Z-coil and the shield system has cylindrical symmetry. The X- and Y-coils have a saddle shape and are essentially the same (Fig. 1).

The SRM response as a function of the position is defined by the current in the pickup coil (P), when an magnetic dipole of unit strength aligned in X, Y, or Z axis approached from infinite distance. The dipole can be replaced by an infinitesimal coil (S), and put the current on instead of moving it from the infinite distance. Since we are assuming the coil P is superconducting, the current on the coil P (I_P) is propor-

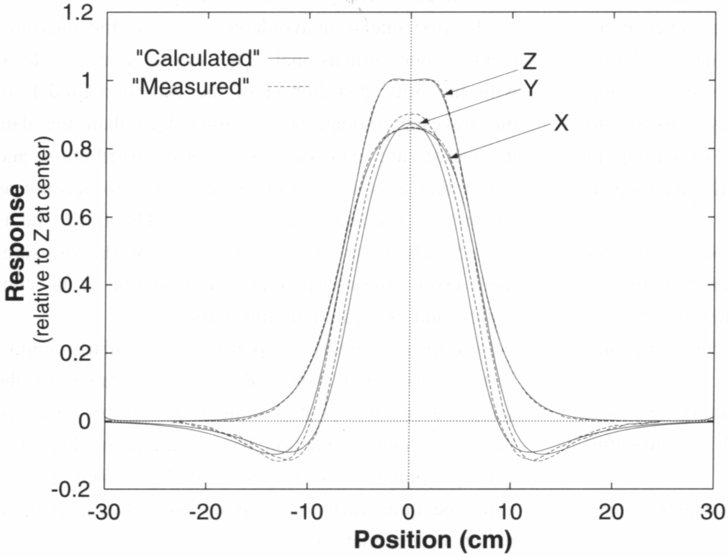

Figure 2. The response calculated and measured for point magnitic dipole on the magnetometer axis.

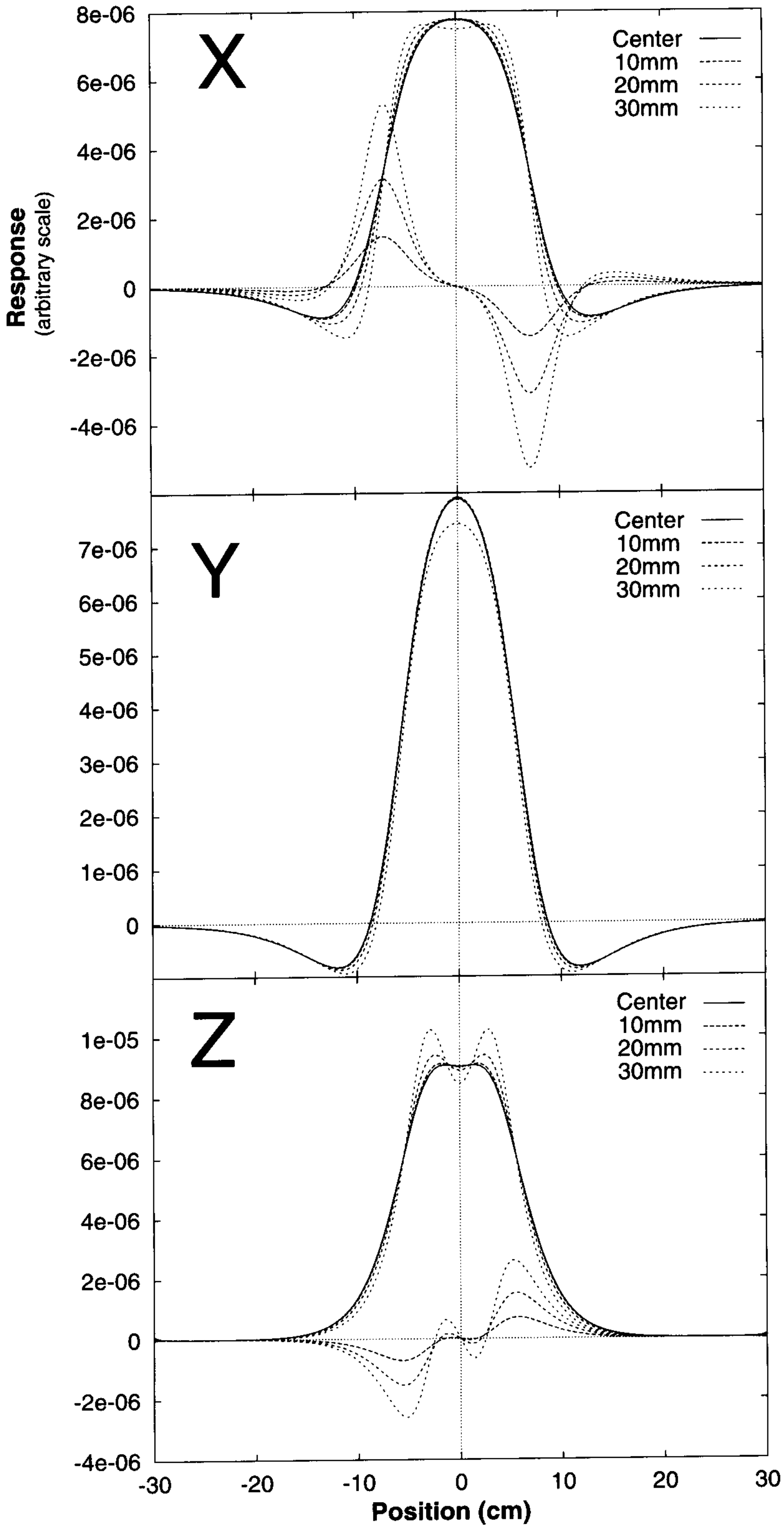

Figure 3. The response calculated on the line off the axis to X direction. Cross term between X and Z sensors, and Z and X magnetization, respectively, appears if the sample is not on the axis of the SRM.

tional to the current on the coil S (I_{P0}) as

$$I_P = MI_{S0}$$

where M is mutual inductance. As the mutual inductance is reciprocal, the current on the coil S (I_S), which is induced by the current on the coil P (I_{P0}) is

$$I_S = MI_{P0}$$

Since I_S is proportional to the field at the coil S, the response of the SRM to a unit dipole at a point is proportional to the magnetic field by the unit current on the pickup coil.

If there is no superconducting shield, The field of a coil is an easy problem. However, as the magnetic field is strongly distorted by the shield, it is more complicated. Flux is excluded from superconducting material (the Meissner effect). It gives the boundary condition that the field perpendicular to the shield is zero. And within the sample space surrounded by the superconducting shield, the magnetic field by the shield is divergent and rotation free. We can, therefore, calculate the field within the shield by putting virtual magnetic sources on or outside the position of the shield so as to cancel the magnetic field by the pickup coil in the component perpendicular to the shield in order to calculate the effect of the shield.

For ease of calculation, we put the magnetic charges on the surface of the shield for saddle shaped pickup coil which is used for the non axial (X and Y) components in SRM, and adjusted the intensity of the charges so as to cancel the vertical component of the coil field at each point of the charge. The field created by the charge at the test point is treated as distributed in a density $\rho = q/a$, where a is the area of the grid, thus the field is $\rho/2$. For the axial component, a series of axial (Z) coils put on the shield was used instead. As the field perpendicular to the shield at a coil by itself is zero and the calculation is one dimensional, it is much easier in the Z coil than others.

The dimension of the superconducting shield and pickup coils, which we used for calculation, is shown in Figure 1. These values are for SRM on the JOIDES Resolution and were given by Goree (1994).

Results and discussion

The resulting magnetic field, which is the same as the response curves, normalized by the center of Z-component, along with the measurements are illustrated for each components (Fig. 2). The calculation reproduces the measurements astonishingly well in z component. The reproducibility is worse in X and Y component due to the complexity of the pickup coils. The placement of the coils would not be technically easy and actual coil parameters would not be exactly the same as the designated value. A great improvement in fitting with Y component is obtained using slightly longer and wider coil in calculation. The relative sensitivity between X, Y and Z axis was also well reproduced.

Figure 3 shows the responses off the magnetometer axis. They are more complex in shape, approaching to the pickup coil. Integrating them in a half circle, we

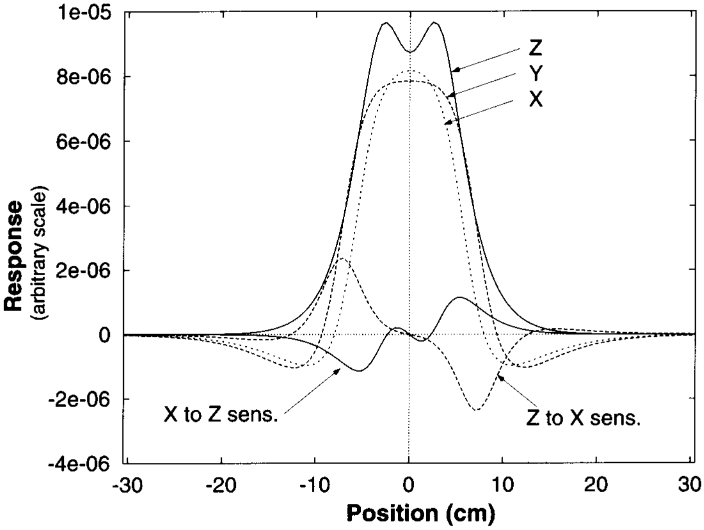

Figure 4. The response calculated for the split core, which is routinely measured in the ODP cruises.

can obtain the response for the split core samples usually used in the ODP routine measurements (Fig. 4). The split core response was measured in Leg 139 [Oda and Shibuya, 1996]. The relative sensitivity between the components was not known in the measurements, since the standard samples for X, Y, and Z axes could not be the same. For the center response the relative sensitivity can be obtained realign the same single small sample to each of three axes. However, it is not easy to prepare the sample of the shape of the section of the split core with known magnetization. The measurements fits fairly well for all axis and cross term between X and Z. The fitting is greatly improved (especially for X component) assuming the center of the core did not precisely aligned with the center of the sensor but situated a few millimeters above. Since the magnetic field near the sensor coil varies strongly, the response curve will be more ragged if a portion of the sample comes close to the coil. It is, moreover, varies by small change in the position of the core. Careful positioning will be required if the sample is large enough to reach close to the sensor coil.

The passthrough measurements are getting more and more popular, and the cross section of the sample varies case by case. Moreover, the isochronal section is not always perpendicular to the axis of the core. The response varies as well. It is difficult to prepare the standard sample uniformly magnetized within a large area. The calculation would give a convenient way to prepare the response.

Advancing the passthrough measurements, it would be required to designing the pickup coil and the superconducting shield to get desired response optimized for the passthrough measurement. As shown in the course of calculation, the response is not easily estimated from the configuration. This program would help the design.

Conclusions

(1) A fortran program calculating the sensor response of SRM's was developed. It restored the measured response well for both the point source at the center, and the split core shaped magnetization source.

(2) The cross term between X and Z axis is strong enough to affect to the calculation in the deconvolution. It is very sensitive to the position of the core, *i.e.*, the sample volume which is very close to the sensor coil. Therefore, those who want to get detailed change in magnetization by means of deconvolution must place the sample carefully not to vary the position of the sample.

(3) The program will also be useful to assess the response of the magnetometer in the stage of design, and to make the optimum design for the magnetometer for both the uniform response for single sample, and steep response for high resolution pass-through measurements.

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コア通過型超伝導岩石磁力計の感度曲線

渋谷秀敏・路川徹也

要　旨

堆積物コア試料の古地磁気測定には通過型超伝導岩石磁力計（SRM）が近年よく使われる。SRMの出力はコアの磁化と磁力計の感度曲線とのコンボリューション積分であり，コアの磁化を得るためには逆演算のデコンボリューションが必要である。デコンボリューション演算は一般に安定性は良くないが，感度曲線が実際のものと違っていると真実から離れた結果を導く可能性がある。感度曲線の実測にはいくつか難点があるので，センサーと超伝導シールドの形から感度曲線を計算するプログラムを作成した。計算結果は，実測された感度曲線をかなり良く再現した。また，計算で感度曲線が試料の形状や位置かなり左右されることが分かった。SRMの測定には個々の場合の感度曲線が重要であるので，測定に際しては試料の形状や位置を正確に測定する必要がある。