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Separating Permanent and Induced Magnetic Signature: A Simple Approach

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***Abstract*—**Magnetic signature detection provides sensitive detection of metal objects, especially in the natural environment. Our group is developing a tabletop setup for magnetic signatures of various small and model objects. A particular issue is the separation of permanent and induced magnetization. While the latter depends only on the composition and shape of the object, the former also depends on the magnetization history. With common deperming techniques, a significant permanent signature may still remain, which confuses measurements of the induced component. We investigate a basic technique of separating the two. Measurements were done by moving the object along an aluminum rail while the three field components are recorded by a detector attached near the center. This is done first with the rail parallel to the Earth magnetic field and then with anti-parallel orientation. The reversal changes the sign of the induced- but not the permanent magnetization so that the two can be separated. Our preliminary results on a small iron block show excellent reproducibility. A considerable permanent magnetization was indeed present, resulting in a complex asymmetric signature. After separation, a much more symmetric induced signature was obtained that can be studied in detail and compared with theoretical calculations.

***Keywords*—**Magnetic signature, data analysis, magnetization, deperming techniques.

I. Introduction

MAGNETIC techniques of detecting various objects form a significant field of interest [1]-[4] as well as, especially in the military context, techniques to avoid detection [5], [6]. Well, known are magnetic mines, which were developed when it was found that a compass needle was affected by nearby metal objects such as ships. However, it is also more, in general, a technique that is suitable for detecting activities of human origin [7]. Although magnetic signals can be very small, sensitive detection is often possible because clutter from the natural environment is extremely small. Magnetic signatures typically originate from electric currents and movement of metal-containing objects, both of which are indeed related to human activities. Magnetic sensors are also used for other purposes such as navigation [8], traffic management [9], [10] and even non-traditional applications such as using the smartphone for through-wall pipe detection [11].

In the military context, we are interested both in ways to detect various objects and in ways to avoid detection. Simulation and model measurement are used to study or predict the magnetic signature properties of various vessels and other objects of interest, especially in the design phase. Our group is developing a tabletop setup for detecting magnetic signatures of various small and model objects. This setup can be used for research, training, and other education purposes. The object is moved in a straight line past a magnetic detector, and changes of the magnetic field are recorded. These changes are due to the magnetic field of the object, which is composed of a permanent field and a field induced the Earth magnetic field. Thus, the recorded signature depends on the orientation and magnitude of the Earth magnetic field with respect to the setup.

Separation of permanent and induced fields is a particular issue. While the latter depends only on the composition and shape of the object, the former also depends on the magnetization history. The permanent field can be removed by exposing the object to a strong oscillating field and slowly reducing the amplitude, a procedure that is called deperming. Therefore, in principle, we are interested mainly in the fields that are induced in the objects at various orientations. In our test situations, we experience that is not always possible to remove the permanent field to the desired extent, even with repeated deperming. Thus, there is a need to separate the two fields so that they can be analyzed separately.

To distinguish permanent and induced field we utilize the property that the latter is (linearly) dependent on the inducing field of the environment while the former is constant, at least on the time scale of the typical experiment. One may study how the overall signature of the object is affected by changes of the inducing field. The permanent signature is then obtained by extrapolating the inducing field to zero. The inducing field can be changed by applying a field with the help of electric coils. However, this is not a trivial task since the field needs to be homogeneous across the track of the object. A more basic approach is to change the orientation of the entire setup with respect to the Earth magnetic field. The magnitude of this field cannot be changed, but the altered orientation also induces changes in the induced signature and may help to distinguish permanent and induced.

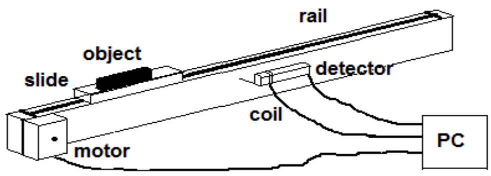

Fig. 1 Schematic representation of the setup. The PC controls the stepper motor and the synchronization coil and records measurements from the detector

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In a previous publication, we characterized induced signatures by rotating the setup in the horizontal plane [1] however it was not possible to fully characterize the permanent contribution because the vertical component of the inducing field could not be affected. Here we present a basic approach aimed specifically at determining the permanent and induced contributions if only to determine whether the permanent contribution has been sufficiently reduced by a determining procedure. The basis of the present approach is to reverse completely the orientation of the inducing field. This is done by first recording the signature with the setup parallel to the Earth magnetic field and then rotating the setup by 180° so that it becomes antiparallel. Observing from the setup, it implies that the Earth magnetic field is rotated by 180° so that its sign is changed and thus also the sign of the induced signature changes. By taking the average of the two measurements, only the permanent signature remains.

Our separation approach is basic in theory but not trivial in practice because the inducing field needs to be sufficiently homogeneous, which can be especially difficult to realize in an indoor environment, but also because of the inclination of the Earth magnetic field, which implies that the setup has to be reproducibly aligned in 3D. Our preliminary results do however indicate that this simple approach provides a high degree of separation.

II. Experiment

The basics setup is illustrated in Fig. 1. Measurements were done by moving the object (attached to a slide) over a distance of 1.5 m along an aluminum rail. The slide moves through a slot and is attached to a rubber-timing belt that is pulled by a stepper motor attached at one end of the rail. A typical measurement takes 30 s (so the slide moves at 5 cm/s). The three components of the magnetic field are recorded 10 times per second by a magnetic detector (Sensys FGM3D/500) that is attached to the center of the rail, typically at a distance of some 10 cm. The stepper motor is controlled by a computer, which also records the field measurements. A small coil (4 windings) is wound around the detector and controlled by the computer. It produces a small magnetic field pulse for synchronization purposes with a duration of 1 s immediately before the and after the measurement.

To check that the setup itself, and in particular the slide, does not produce a magnetic signal the experiment is first carried out with an empty slide. This produces a negligible signal on the scale of our experiments. The drift of the positioning of the slide is monitored by marking a fixed point on the rail where the slide returns automatically after each measurement. Accuracy and reproducibility were measured by repeating a measurement several times and checking for shifts of the signal. The positioning accuracy is of the order of 1 mm or better which is a considerable improvement over our previous setup, which used a small servo, controlled motor.

For our present experiment, the rail is first oriented parallel to the Earth magnetic field. This is done with the help of the detector. One end of the rail is placed at a fixed and marked position on the floor. The other end rests against a construction and is moved until the perpendicular components of the measured fields are components are less than 40 nT (< 0.1% of the longitudinal component). One or several recording runs are performed after, and then the rail is rotated 180° and re-aligned anti-parallel for the second set of recording runs. The rotation is done such that the rails rest on the floor at the same marked position as in the parallel orientation and the perpendicular fields are again less than 40 nT. When required the homogeneity of the inducing field along the rail can be checked by attaching the detector to the slide and moving it along the rail similarly to the other recordings.

Our first results using a small iron T-bar (200 gr. 13 cm x 3 cm x 3 cm, thickness: 3-4 mm) were quite surprising (not shown). The recorded fields with the anti-parallel orientation (slide moving upwards) were irregular and smaller than the fields recorded with the parallel orientation. The induced and permanent fields obtained from the analysis were quite similar. This could be coincidence or caused by the fact that we used a relatively long sample. To make sure that the results were not due to a measurement error we repeated the measurements with the different sample (iron block. 1000 gr. 6.5 x 4.5 x 4.5 cm). The results for this sample, showing each of the three recorded field components, are shown in Fig. 2.

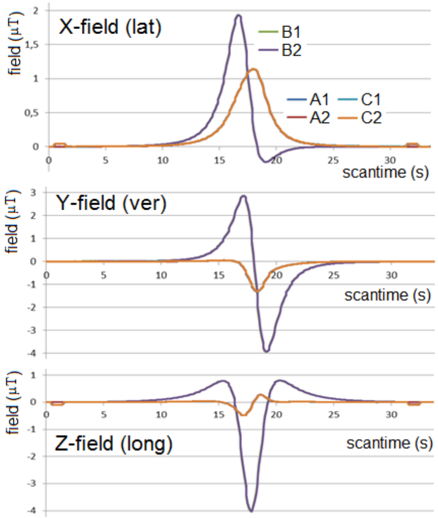

Fig. 2 Signature measurement. The horizontal axis shows time into the scan (see text). Vertical axes show the measured field in all three directions. The first measurement time point is shifted to zero since only the variations are significant. All measurements were performed twice. First with the slide moving down (A1/2), then with the slide moving up (B1/2) and finally with the slide moving down again to check reproducibility (C1/2)

The results show excellent reproducibility each recording run was done twice (A1/2 and B1/2) and the setup was rotated back to the parallel position after the anti-parallel runs to check the original results were reproduced (C1/2). The corresponding traces cannot be distinguished in Fig. 2. This could only be done by zooming into the original data traces. So, only two traces are visible for each field component, one for each orientation. At the beginning and end of the traces, the 1 s synchronization pulses can be distinguished. The traces were shifted by hand (by deleting points at the start of each trace) to overlay these pulses. The offset field (approximately 50 μT for the longitudinal component) a t = 0 was arbitrarily subtracted. It can be seen that the recorded signatures converge to zero at the beginning and end of each trace so that the entire signature of the object is recorded.

As in the first tests, the recordings were again somewhat surprising in the sense that the measurements in one orientation were much smaller than in the other, especially for the vertical and longitudinal field, indicating a strong cancellation of the induced and permanent field for that orientation. The shapes of the traces are typical for a dipole parallel to the inducing field: the sign of the lateral components switches once and that of the longitudinal component twice. However, the fields are not quite symmetrical. Even for the seemingly symmetric Y-component, the negative peak is some 30% larger than the positive component. At present, we have no explanation why the permanent and induced fields are so similar. The samples had been kept in one location for many months, but not in a particular orientation with respect to the Earth magnetic field. However, in view of the reproducibility of the measurements and the fact that we observed this twice, we presume it is an actual result and not a measurement error.

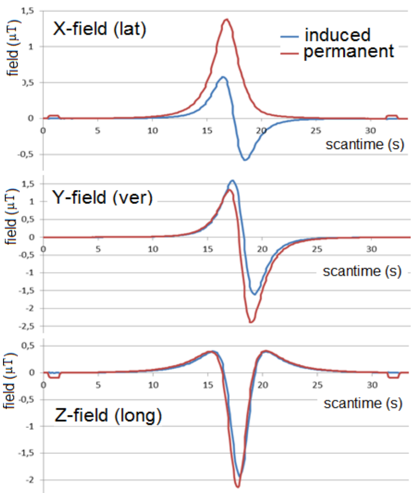

Fig. 3 Separation of permanent and induced signature. The horizontal axis shows time into the scan. Vertical axes show the field in all three directions

Using the results in Fig. 2, we can now separate the permanent and induced components of the field. As explained above the sign of the inducing field is reversed between the two orientations and therefore also the sign of the induced component of the signature. Thus by taking the average of the two traces the permanent signature is obtained, i.e. the part of the signature that is due to the permanent field of the object. By taking the difference (and dividing by two) of the raw measurements the induced signature is obtained.

The results are shown in Fig. 3. The measured signals in Fig. 2 are a linear combination of these two. For the downward case, the experimental signal is retrieved by adding the induced to the permanent signal. For the upward case, one subtracts the induced signal. We find a good agreement with our expectation that the induced signal is more symmetric and reminiscent of a dipole oriented parallel to the inducing field. In particular, it can be seen that the positive and negative peaks of the lateral signals are almost of the same magnitude.

As expected from the measurements in Fig. 2 the permanent signature is indeed of a similar magnitude as the induced signature. The permanent signature is not symmetric, but this is also to be expected since the permanent magnetization can have any shape depending on the magnetization history. Most likely, it will also be similar to a dipole, but not necessarily related to the orientation of the inducing field. The fact that the lateral signal does not change sign indicates a dipole that has a lateral component of some strength although the other two signals also indicate a strong longitudinal component. The angle could be some 45° with the symmetry axis of the metal bar and may be calculated accurately using simulations.

III. Discussion

In the results above we describe the further development of our prototype of a table top magnetic signature detector and in particular tested a basic approach to separate, by reversing the orientation of the setup, the permanent and induced magnetic signature of the object that is being studied. Signatures are a present several μT, recorded at a distance of approximately 10 cm from the track followed by the object. The setup is largely made of aluminum, and although it cannot be excluded it may have some small magnetizable components, the signature of the setup itself is negligible on the scale of the present signal. The positioning using a slot, timing-belt, and the stepper motor is accurate up to 1 mm or better.

Using this setup, we were able to obtain reproducible signals even after reversing the orientation several times. And our results indicate that we successfully separated the permanent and induced component of the recorded signal. At least the induced component is quite symmetric and reminiscent of an induced dipole parallel to the inducing field as may be expected because we used a symmetric block of iron. As a further test, we could change compare the measurements to calculated fields for the object. Alternatively, we could affect the permanent field by subjecting the object to a strong field or reduce it by means of determining and investigate how this affects both the recorded permanent and induced field. The latter should of course not be affected by such procedures.

A present the procedure is still tedious in practice since the entire setup needs to be exactly reversed while preferably remaining in the same position. The cables and attachments (for example the detector) should be carefully manipulated to avoid any changes to the setup. Also, the measurements were carried out indoors and where we experienced that the Earth magnetic field was not completely homogeneous. Better measurements may be done outdoors, and reproducible, easy rotation may be realized by attaching the entire setup to a rotating frame. At present we will continue our testing and vary the permanent field so that the separation technique can be more rigorously tested.

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