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Abstract

Measurements of the magnetic moments of motor vehicles indicate moments in the range 6×10^4 e.m.u. to 13×10^4 e.m.u. for small to medium sized vehicles. These moments are substantially stronger than for solid bodies of similar masses. To avoid disturbance to a magnetometer of sensitivity 0.5 gamma, vehicles must not be allowed to come closer than 40 metres. This rule should be observed particularly in the selection of sites for magnetometers used to look for local seismomagnetic effects.

1. Introduction

The search for the seismomagnetic effect requires the operation of sensitive magnetometers in arrays designed to observe with high sensitivity magnetic effects of local origin. Experiments in progress in U.S.A. (Breiner 1964), Japan (Rikitake et al 1966) and in Australia and New Zealand by the authors, are based on the comparison of data from magnetometers sited several kilometres apart, which may be differentially connected to produce difference readings directly or else take precisely timed readings for subsequent comparison. Local changes in field of order 10 gammas are expected to result from seismic stresses, by virtue of the piezomagnetic effect in igneous rocks (Stacey 1964). From an array of carefully spaced magnetometers in East Anglia, Stacey and Westcott (1965) concluded that effects of this magnitude would be distinguishable from background disturbances, but in a geologically more complicated area Rikitake (1966) found much larger background disturbances, presumably due to irregularities in the earth currents induced by extra-terrestrial magnetic fluctuations. It is evident that successful observations of seismomagnetic effects will require not merely great care but favourable local conditions. In particular man-made disturbances must be completely avoided.

It was partly with this in mind that Stacey (1967) devised a simple rule for estimating the stray magnetic fields of ferrous bodies, such as motor vehicles, which could disturb a sensitive magnetometer. He concluded that a vehicle of weight 1000 kg. must come within about 26 metres to cause a change of 1 gamma. During trials of differentially connected proton magnetometers we have made a check of this estimate, using several different vehicles, and found that Stacey significantly under-estimated the magnetic moments. We have therefore measured the moments of the vehicles, in various orientations in the Earth's field, to establish a new specification for the closest tolerable approach of a motor vehicle to a magnetometer. Our measurements show a general agreement with the observations of Kuboki (1966) although we differ in some details. We have also calculated the magnetic moments induced in hollow shells of high magnetic susceptibility and find satisfactory agreement with the new observations. The moments of hollow iron bodies, and long rods, etc., are stronger than the moments of solid equidimensional bodies of similar masses, to which the earlier theory of Stacey (1967) is applicable.

2. Measured Magnetic Moments of Motor Vehicles

Vehicles with a range of sizes from a small car to a medium-weight truck were used and we also compare the data with observations by Bullard and Mason (1961) on the magnetic fields of ships. Each of the vehicles was driven past one detector of a pair of proton magnetometers, with the second detector more than 100 metres away. Difference readings were taken with the vehicles at measured intervals along North-South and East-West lines with the vehicles facing north, south, east and west in turn. No two of the numerous curves of field vs. distance were alike and some were quite complicated; two examples are shown in Fig. 1. It is apparent that the distributions of magnetization were very variable and in one case the observations indicated opposite polarities in different parts of the same vehicle. In view of the variability, detailed results are of limited interest. However at distances exceeding 15 to 20 metres the inverse cube law was found to hold in all cases, showing that at this range the dipole field is observed and the higher order multipoles are ineffective.

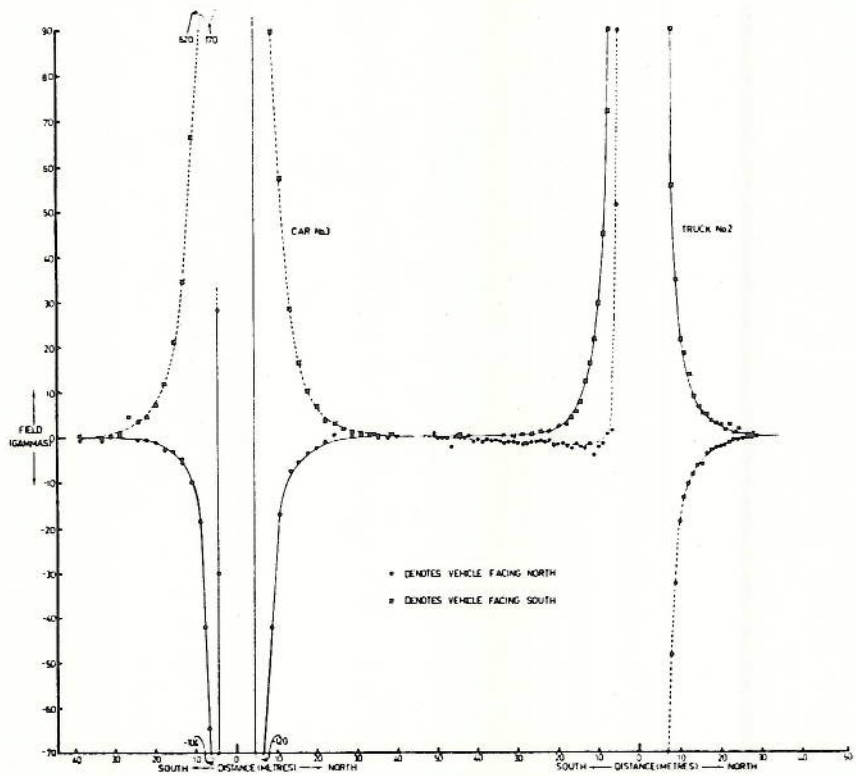

Fig. 1. Disturbance to total field as recorded by a proton precession magnetometer, as a function of distance, for two motor vehicles.

The disturbance fields were invariably slightly stronger when the vehicles were directed north-south, from which we conclude that the components of magnetization along the lengths of the vehicles were somewhat greater than either vertical or transverse moments. Allowing for the local magnetic dip angle of 55°, we calculated the apparent moments of the vehicles, the range of values being 6×10^4 e.m.u. to 13×10^4 e.m.u.. Correlation with the masses of the vehicles was poor, so that values of moment per unit mass are evidently not significant within the limited range of masses which we used. The experimentally observed magnetic moments are significantly larger than the values found from Stacey's (1967) "rule" and necessitate a revision of the rule. This arises because hollow bodies, such as motor vehicles have stronger magnetic moments, both induced and remanent, than solid bodies of similar masses. This theoretical problem is considered in the following section and a revised rule is presented in section 5.

3. Theory of the Magnetization of a Hollow Body and of Other Shapes Having Extreme Dimension Ratios

A hollow rectangular box of iron or steel whose walls are thin compared with its other dimensions, behaves essentially as a set of independent sheets of magnetic material. If the demagnetizing factor of a sheet in the direction of a field H is N and the intrinsic susceptibility is χ_i, the magnetization I of the sheet is given by

$$\frac{I}{H}=\frac{\chi_i}{1+N\chi_i}=\text{Apparent susceptibility, } \chi_a$$

Normal to the sheet $N\longrightarrow 4$ and $I\longrightarrow H/4$ e.m.u., but parallel to the sheet N becomes very small, approaching zero as the area/thickness ratio of the sheet becomes very large. Values of N for ellipsoids with a wide range of dimension ratios are tabulated by Stoner (1945). For a sheet of dimension ratio of order 1000 : 1, which is typical of motor vehicle panels within a factor of 2 or so, $N\approx0.01$. Taking $\chi_i=40$ e.m.u. as representative of cold-rolled steel, we thus obtain for apparent susceptibility:

$$\text{In plane of sheet, } \chi_{op}\approx 30 \text{ e.m.u.,}$$
$$\text{Normal to sheet, } \chi_{on}\approx 0.08 \text{ e.m.u.}$$

The value of χ_{op} is insensitive to the actual dimension ratio because $N\chi_i<1$. We can therefore take the above value of χ_{op} to be a satisfactory estimate for steel sheets with a wide range of dimension ratios.

It is evident that magnetization normal to the sheet is very small compared with the magnetization in the plane of the sheet and can be neglected in the present problem, so that the magnetic moment in a field H at an angle θ to the plane of a sheet of volume v, lies in the plane of the sheet and has a magnitude

$$m=v\chi_{op}H\cos\theta$$

Taking a vector sum of the moments due to six faces of a box (an idealised motor vehicle) we obtain the total moment:

$$M=\frac{2}{3}V\chi_{op}H,$$

where V is the total volume of steel in the shell of the vehicle. A rough estimate of M is obtained by taking $10^4\,cm^3$ as an approximate value for V. Then if the Earth's field, H, is 0.5 oersted, the magnetic moment is calculated to be 10^5 e.m.u., in satisfactory agreement with the observations reported in section 2.

The variability of the magnetic moments of the vehicles used in our experiments was too great to allow us to demonstrate the general correlation of magnetic moment and volume or mass over the limited range of sizes. Kuboki (1966) made measurements on vehicles with a greater range of masses from a bicycle to a bus and confirmed the expected correlation, but with individual variations of a factor of 4 from the average moment/mass relationship. However, Kuboki referred his measurements to a distance of 10 metres and it should be emphasised that our measurements showed that the dipole law of force breaks down at 15 to 20 metres and dipole moments cannot be estimated inside this distance.

Hollow boxes are not the only shapes whose magnetic moments can be represented by the above theory. The susceptibilities χ_{op} and χ_{oa} apply to any shape of extreme dimension ratios, such as a long thin rod, or tube, whose axial susceptibility is χ_{op}. However, we have not been able to confirm the conclusion of Kuboki (1966), which has been pointed out to us by Dr. T. Yanagihara, that the transmission shafts of vehicles make important contributions to their magnetic moments. Transmission shafts were magnetically insignificant in the vehicles which we examined and of the two cars with no transmission shaft at all, one had the largest moment but the smallest total mass.

Data on the magnetic moments of two ships, given by Bullard and Mason (1961), can also be compared with these results. Fitting the dipole field law to their data we estimate the magnetic centre of 'Discovery II' to be 40 metres forward of the stern and the magnetic moment to be 3×10^8 e.m.u.. According to our calculations for motor vehicles, this moment could be due to a magnetic shell of mass 2.5×10^8 gm or 250 tons. This is 10% of the weight of the ship, and since the steel sheeting of the hull presumably exceeds 10% of the total weight, the ship is evidently somewhat less magnetic than our equations indicate.

4. Contribution of Internal Components to Magnetic Moments of Vehicles

Intuitively one might expect that the field of an independent magnetic moment enclosed within a car, would be magnetically screened and that its field would therefore appear diminished in measurements made outside the car. This is not so. The effect of the magnetic screen is to transfer the moment to the body as a whole, but not to diminish it. We have verified this by making measurements with a current-carrying coil of moment 10^5 e.m.u.. When the current was switched on, the field increment seen by a magnetometer at a fixed distance was the same independently of whether the coil was inside a car or not. A detector inside the car is screened from a field produced outside but not vice-versa. Therefore we must consider the contribution of internal parts to the moment of a vehicle.

The most obvious internal magnetic component is the engine block, which has a dimension ratio no more than about 4 : 1 and is substantially solid so that it is reasonably described by Stacey's (1967) theory, according to which the moment M of volume V, induced by a field H, is:

$$M=\frac{H}{N}V,$$

where N is the demagnetizing factor in the direction of M. To the accuracy required here, the demagnetizing factor in the a direction of a body with dimensions a, b, b is

$$N_a \approx 4\frac{b}{a}$$

provided the dimension ratio a/b does not exceed about 5 or so. These relationships may be used to relate magnetic moment to volume or mass directly. For a solid iron or steel mass of m gms, with dimension ratio a/b,

$$M \approx \frac{m}{64}\frac{a}{b} \text{ e.m.u.},$$

which is smaller by a factor of order 10 than the moment of a hollow box with the same mass. It was neglect of this difference which invalidated Stacey's (1967) calculations. We must therefore expect that, except in unusual circumstances, the magnetic moment of a motor vehicle is dominated by the metal shell.

5. Recommendation for the Closest Tolerable Approach of a Motor Vehicle to a Magnetometer

If the maximum acceptable disturbance to the field observed by a magnetometer is ΔH, then a disturbing body of magnetic moment M must be kept more remote than a distance d where

$$\Delta H=\frac{2M}{d^3}$$

or

$$d=\left(\frac{2M}{\Delta H}\right)^{1/3}$$

Taking the upper limit of $M (15\times 10^4$ e.m.u.) from our observations and assuming $\Delta H=0.5$ gamma, we obtain

$$d=40 \text{ metres.}$$

If ΔH is as low as 10^{-7} oersted (10^{-2} gamma), as in the rubidium magnetometer measurements of Breiner (1965), then

$$d=140 \text{ metres.}$$

Larger vehicles must, of course, be kept even further away. A really gross disturbance of 100 gammas, such as Moore (1964) observed before the March 1964 Alaskan earthquake, would require the approach of a motor vehicle to within about 10 metres, at which distance non-dipole components of the disturbance field become important and may greatly increase the field.

Kuboki (1966) suggested 50 metres as the minimum distance of a car for a tolerance of 0.5γ. The discrepancy with our conclusion is not wholly insignificant as it implies a factor 2 difference in the estimated maximum magnetic moment, which is suprising, in spite of the considerable variability apparent in both Kuboki's data and in ours. The difference may arise from the method of making measurements. Kuboki measured separately the vertical and horizontal field intensities, whereas we used a total field instrument and made a vector calculation of magnetic moments from measurements made with vehicles approaching from opposite direction and also reversed in orientation. Another possible explanation is that Kuboki's estimate was made partly from measurements at distances of about 10 metres, at which contributions from higher multipole moments of vehicles can enhance the disturbance fields.

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References

Breiner, S. The piezomagnetic effect at the time of local earthquakes. *Nature*, 202, 790, (1964).

Bullard, E.C. and Mason, R.G. The magnetic field astern of a ship. *Deep Sea Research*, 8, 20 (1961).

Kuboki, T. The artificial disturbances due to various cars, bicycles etc. (in Japanese with English abstract). *Memoirs of Kakioka Magnetic Observatory* 12 (No. 2), 263 (1966).

Moore, G.W. Magnetic disturbances preceding the 1964 Alaska Earthquake. *Nature*, 203, 508 (1964).

Rikitake, T. Elimination of non-local changes from total intensity values of the geomagnetic field. *Bull. Earthq. Res. Inst.* 44, 1041 (1966).

Rikitake, T. et al. Geomagnetic and Geoelectric studies of the Matsushiro Earthquake swarm (1)-(4). *Bull. Earthq. Res. Inst.*, 44, 363, 409, 1335 and 1735 (1966).

Stacey, F.D. The seismomagnetic effect. *Pure and App. Geophysics*, 58, 5 (1964).

Stacey, F.D. Simple order of magnitude rule for estimating stray fields of ferrous components in laboratory apparatus, in '*Methods in Paleomagnetism*'. Editors D.W. Collinson et al (Amsterdam: Elesvier 1967).

Stacey, F.D. and Westcott, P. The seismomagnetic effect-limit of observability imposed by local variations in geomagnetic disturbances. *Nature*, 206, 1209 (1965).