Def Sci J, Vol 37, No 3, July 1987, pp 319-325.

Underwater Magnetic Survey

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ABSTRACT

Describes the various types of magnetometers for marine survey. Various practical considerations and search procedures to facilitate planning and conduct of survey and magnetic survey conducted off Bombay are described.

1. INTRODUCTION

Objects which are submerged, buried or otherwise hidden from view can be detected or mapped from aircraft, surface vessels or submersibles, using a variety of techniques and instrumentation. Among these remote sensing instruments the more popular ones are sub-bottom seismic profilers, side scan sonars, electromagnetic detectors and magnetometers. This paper presents the state-of-art and application of magnetometer systems used in marine magnetic surveys,[1] such as (a) exploration of hydrocarbons and magnetic ore deposits, (b) the location of buried pipelines, buried wreck and (c) determining magnetic anomalies in the sea. Some points to be borne in mind during surveys as well as brief account of typical magnetic survey off Bombay are presented.

2. MAGNETOMETERS

The common types of remote sensing instruments for magnetic survey are fluxgate, proton precession and optically pumped magnetometers.

2.1 Theory of Operation

The theory of operation, accuracies and other details of these magnetometers are as follows :

Received 01 March 1985, revised 27 February 1987

2.1.1 Fluxgate Magnetometer

This instrument determines changes in the intensity of the earth's magnetic field components parallel to the axis of the sensor. The magnetometer consists of a core of highly permeable material wound with primary and secondary coils excited at a particular frequency. The secondary output is proportional to the ambient field in which the core is placed. The magnetometer can be used for continuous measurement but it is liable drift and therefore requires calibration periodically. Fluxgate magnetometer are of two types. (a) Peak height fluxgate[2] (PHF) and (b) Second harmonic fluxgate magnetometer. PHF magnetometers have sensitivity of one milligauss.

Sensor Orientation: The axis of the sensor has to be aligned in the direction of the earth's magnetic field. This is achieved by mounting the mutually perpendicular fluxgate elements on a servo controlled platform which is automatically oriented until the output from two elements is zero, the third element is then oriented along the direction of the field to be measured.

2.1.2 Proton Precession Magnetometer

The proton precession magnetometer utilises the frequency of precesion of spinning protons or nuclei of the hydrogen atoms in a sample of water or hydrocarbon fluid to measure the total magnetic field intensity. The spinning protons in a sample of kerosene or alcohol are temporarly aligned or polarised by the application of a uniform magnetic field generated by a current carried by a coil wound over the sensor. When the current is switched off, the spin of the protons causes them to precess about the direction of the ambient magnetic field, generating a small signal in the small coil which has been used to polarise them. The frequency of this signal is proportional to the total magnetic field intensity. The precession frequency typically 2KHz is measured by digital counters which are calibrated to give the absolute value of the total magnetic intensity. Proton precession magnetometers[3] are of two types. (a) Direct reading and (b) Reciprocal type proton precession magnetometers. It has an accuracy of 0.1 to 1 gamma.

Sensor Orientation: The measured precession frequency is independent of the orientation of the sensor, but the amplitude of the signal decreases as $\sin^2 a$, where a is the angle between the ambient field and the sensor axis. It is thus an advantage to have the coil axis perpendicular to the ambient field.

2.1.3 Optically Pumped Magnetometer

This magnetometer is based on an effect in which the atomic levels in a gas (caesium, rubidium and metastable helium) are split into sublevels whose seperation depends on the ambient magnetic field. In the sensor, the atoms are raised to the excited state by absorbing energy from an external light source. The precession frequency is detected as the atoms precess back to the ground state in the presence of the ambient magnetic field and is directly proportional to the magnetic field intensity. Its accuracy is 0.005 gamma.

Sensor Orientation: The sensor is not completely omnidirectional and exhibits dead zones and heading errors. These drawbacks limit its use in mobile applications unless multicell or servo systems are employed.

2.2 Operational Considerations

Although the magnetometers have no moving parts and are unaffected by accelerations of the platform on which they are mounted, certain operational requirements such as (a) magnetic effect of ships, (b) towing system, (c) location of sensors and (d) sensor orientation, have to be met during recording at sea.[4]

(a) Magnetic effect of ships : The sensors should be towed at a distance not less than twice the ship's length behind the ship to minimise the effect of the ship's magnetic field. The magnetic effects of the ship as a function of length of the tow system are given in Table[5] 1.

Table 1. Approximate magnetic effects of ships measured by a magnetometer tow system

Ship size	Length of tow system			
	30m	100m	150m	250m
25m 200 tons	200 gammas	6 gammas	1.6 gammas	
50m 700 tons	700 gammas	20 gammas	6 gammas	
70m 1700 tons	1700 gammas	50 gammas	13 gammas	
90m 3300 tons	3300 gammas	80 gammas	25 gammas	

(b) Towing system : The towing cable and fish containing the magnetometer sensor should be designed to withstand the hydrodynamic forces and should not produce microphonic or other interfering noise.

(c) Location of sensor : The limiting factor in geophysical mapping is frequently the accuracy of the positioning system of the fish relative to the survey ship and the area being surveyed.

(d) Sensor orientation : The sensor orientation details of these three types of magnetometers are given in section 2.1.

It is clear from the above discussion that the proton magnetometer is the most widely used by the offshore industry.

3. IMPORTANT CONSIDERATIONS FOR MAGNETIC SURVEYS

When planning a magnetic survey, the estimation of the amplitude of the expected magnetic anomaly and its probable signature is important. This knowledge is desirable in order to determine the minimum seperation between survey lines to ensure detection of the target.

(a) Anomaly amplitude and detectability : An important factor affecting detectability is the distance between the magnetometer and the object, for most anomalies in a survey vary inversely as the cube of the distance.

The expected anomalies for a variety of objects of search is given in Table 2. Geomatrics of California have prepared a monogram for estimating magnetic

Table 2. Magnetic anomalies of common objects

Object	Typical maximum anomaly	
	Near distance	Far distance
Ship (1,000 tons)	30m	300m
	300 to 2000 gammas	0.3 to 2.0 gammas
Anchor (20 tons)	15m	30m
	200 to 650 gammas	25 to 80 gammas
Light aircraft	6m	15m
	10 to 30 gammas	0.5 to 2 gammas
Pipeline–30 cm dia	8m	15m
	50 to 200 gammas	12 to 50 gammas
Pipeline–15 cm dia	3m	15m
	100 to 400 gammas	4 to 16 gammas
DC Electric Train	150m	300m
	5 to 200 gammas	1 to 50 gammas
Magnet (5cm dia 25cm)	6m	30m
	60 to 200 gammas	0.5 to 1.5 gammas
Well casing and Wellhead	15m	150m
	200 to 500 gammas	2 to 5 gammas
Automobile (1 ton)	10m	30m
	40 gammas	1 gamma

anomalies (Breiner).[6] An important consideration is the amount of ferromagnetic material associated with object in contrast with the surrounding material.

Another significant criterion for detectability of the object is the expected background magnetic noise arising from sources such as geology or man-made material and electric power. In general, most sedimentary rocks and their metamorphic equivalents, salt or fresh water or air do not alter the magnetic anomaly. The distance between the sensors and object is the sole criterion when the object is buried in such material.

(b) Anomaly signature and width : The actual shape of the magnetic anomaly is important in order to estimate its depth. The anomaly for object will appear broader proportionately as the object is deeper or more distant. This width/depth characteristics of magnetic anomaly behaviour serves as a means for determining the depth to the source. An example of anomaly depth and amplitude behaviour is shown in Fig. 1.

Figure 1. Depth/amplitude behaviour of magnetic anomalies from a finite-sized iron object.

3.1 Search Procedures

The first consideration in conducting a search is to estimate the magnetic mass. It is then possible to determine the maximum probable anomaly at various distances. Knowledge of this maximum anomaly is important in determining the grid spacings and sensor positioning. Ideally, the area under survey should be covered by regular grids such that the anomaly is detectable on any two adjacent traverses, particularly if the water depth is great and control of sensor position minimal. In general the direction of the principal traverses should be made in North-South direction in any latitude because there will be a greater peak-to-peak magnetic anomaly in this direction. Another point in the survey is the mapping of the area already surveyed by suitable radio navigation systems. If the water depth varies greatly and the object is relatively small and difficult to detect, it is advantageous to utilise a multiple transverse sensor array. The sensor should be held always near the ground for small objects buried at shallow depths.

3.2 Detailed Mapping for Pin Point Location

After locating a given anomaly on a traverse, its location on the traverse should be noted. It is likely that the object may not be precisely under the original traverse, but rather on one side. Therefore, the next traverse should be perpendicular to the original traverse at a point on the latter where the maximum horizontal rate-of-change (gradient) is observed. On this second or perpendicular traverse, the anomaly is usually of much greater amplitude and larger rate of change with distance indicating that it is closer to the object of search. A third traverse perpendicular to this second traverse and parallel to the original is required for the exact location of the object. Typical profiles[6] from a sequence of such traverses are shown in Fig. 2.

4. TYPICAL MAGNETIC SURVEY OFF BOMBAY

A magnetic survey was carried out off Bombay using a proton precession magnetometer. The magnetometer measures the total field in gammas and its stability is better than two gammas. The magnetic measurements were carried out to a total

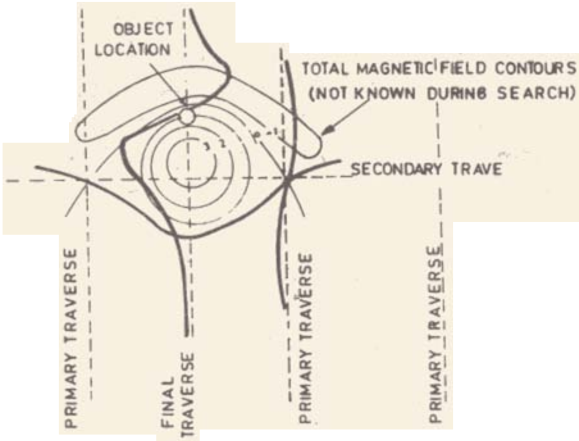

Figure 2. Typical sequence of traverses during search procedures.

length of 150 meters along the jetty at intervals of 10m at depths of 4m and 6m below the water surface. The measurements were also taken parallel to jetty at distances 10, 20 and 30 m. The results of magnetic survey at each grid point at the two different depths (4m & 6m) at the three distances (10, 20 & 30m) away from the jetty are plotted in Fig. 3 (a & b).

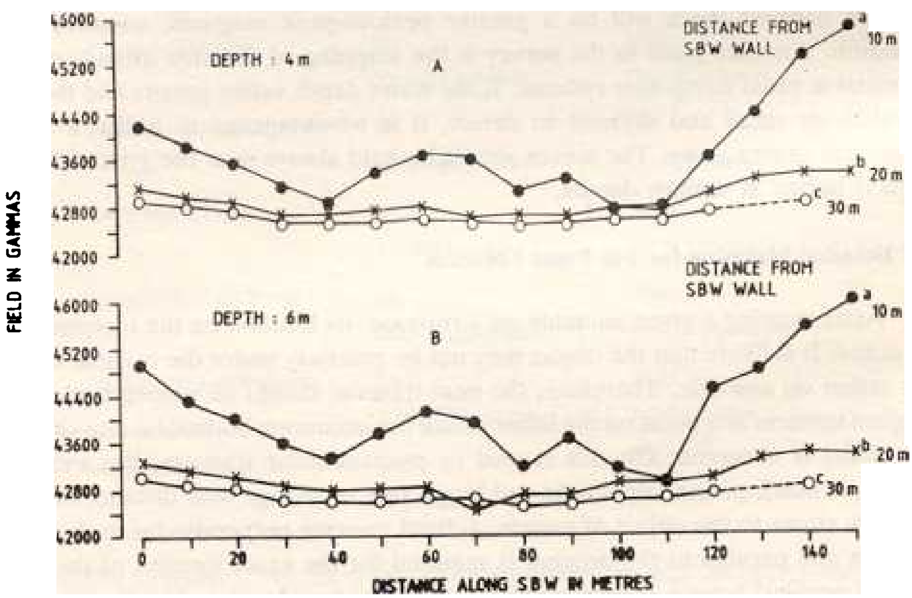

Figure 3(a&b). Variation of the magnetic field in SBW area.

It could be seen from Fig.3 (a & b) that the pattern of magnetic field is similar at depths 4m and 6m. The variation of field at a depth of 6m is marginally more than that at 4m. The effect of crane positioned on the jetty is seen to increase in the field between stations 11 and 15 (grid points) at 10m distance from the jetty wall. Similarly the increase in the field between stations 0 and 4 (grid points) may be due to effect of ships in the vicinity. The large variation in magnetic field between stations 4 and 10 with a maximum at stations 6 and 9 at a depth of 6m at 10m distance from the wall is ascribed due to the gradients produced by the ferrous materials in the piles and bollards of jetty. Neglecting the decrease in field at a station 7 and effect of ships and mobile crane, at a distance of 20m from the wall the total field variation is less than 2 milligauss. The field is almost uniform at a distance of 30m from the wall of jetty from stations 3 to 11.

These results can be summarised as follows

(a) Magnetic field pattern at 4m and 6m depths are similar.

(b) The magnetic anomalies at a distance 10m from the wall may be due to ferrous material used in construction of the jetty and also the effects of mobile crane and ships in the vicinity.

(c) Anomalies in magnetic field decreased with distance away from the jetty.

It is therefore seen that the magnetometer is a useful instrument for magnetic surveys and for underwater experiments.

ACKNOWLEDGEMENT

The author is thankful to Dr. H.N. Swamy for his guidance in preparation of this paper.

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