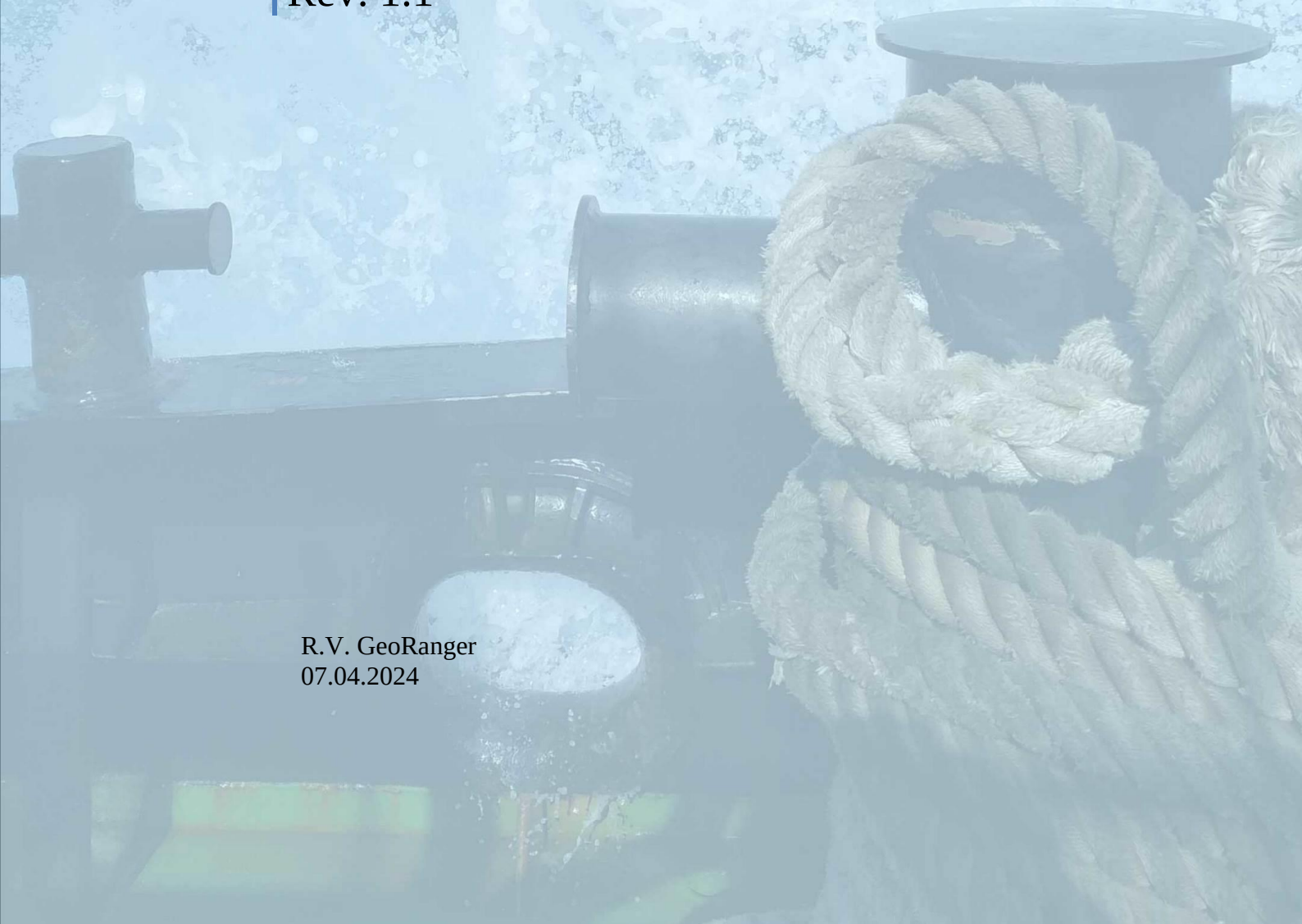
Noise from Scan Fish fasteners

Effect of metal located near magnetic sensors on magnetic field recordings

Rev. 1.1



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07.04.2024

SEA

Contents

History of changes

Version	Date	Description of changes
1.0	2024-03-26	The document was created by Ivan D.
1.1	2024-04-07	A section was added on the effects of aluminium by Ivan D.

List of Figures

Introduction

One could summarize the entire text of the paper in a simple thesis – **no metal near magnetic sensors**. However, metal is a convenient and cheap material which serves as a basis for producing almost all fasteners (bolts, angles, rods). Thus, over and over again, metal fastener elements are placed next to magnetic sensors on the grounds that “they are not magnetic”.

The paper considers two cases:

-- the brass bolts’ effect,

-- the aluminium plate effect.

Examples of magnetometer recordings with anomalous effects produced by metal fasteners are presented.

The document presentation is organized as follows: description of the confusing effect, search for its cause, assumed cause of the effect and results of its elimination. For the reader, whose plans do not include mentally going through all the stages of experiments and successively finding the causes of the effects that are revealed in the data, the best solution would be to start reading the document with the Conclusion and then read the main part of the text taking it as a substantiation of the conclusions we already know.

1 Brass bolts effect

1.1 Magnetic anomalies due to rolling and pitching

When analyzing the magnetic field recordings made with Scan Fish, a specific feature was found on a portion of the recordings:

(1) The vertical gradient of the total magnetic induction vector (hereinafter referred to as VG) calculated over all pairs of magnetometers varies in a regular and in-phase manner for the anomalies caused by magnetic masses (***Figure 1.1***),

(2) For some pairs of magnetometers there are VG anomalies recorded "in counter-phase" to the other pairs of magnetometers (***Figure 1.2***, – pairs of magnetometers Mag3-Mag4 and Mag5-Mag6). The VG anomalies recorded "in counter-phase" are associated with a strong change in the Scan Fish pitch or roll.

In ***Figure 1.2***, the magnetic field gradient anomaly with an amplitude of 2.3 nT corresponds to a change in the pitch angle with a spread of 28 degrees (the graph of which is shown in the lower part of the figure). Analysis of the magnetic field recordings shows the "counter-phase" effect for VG anomaly to be always related to the change in the Scan Fish roll-pitch angles. It is also manifested at small changes of angles, but the VG anomalies in this case have a very small amplitude. Below anomalies on VG recordings that are visually correlated with roll and pitch will be called VG_prh-anomalies (from Pitch-Roll-Heading).

80% of the magnetometer pairs installed on Scan Fish have VG_prh-anomalies recorded in-phase and are visually indistinguishable from anomalies produced by magnetic masses. This means that, when viewing the VG recordings, in-phase VG_prh anomalies will not be highlighted as "something unusual in magnetic field measurements" in most cases.

1.2 Method for detecting a "noisy" magnetometer

When analyzing strong VG_prh anomalies, it is nearly always possible to identify one "noisy" magnetometer from the pair whose vertical gradient is calculated. The measurements of this magnetometer will respond more strongly to Scan Fish tilt angles and contribute more to the amplitude of the VG_prh anomaly. To identify a "noisy" magnetometer, one should perform the following steps:

1) Find a section of the recording containing no magnetic mass anomaly on the one hand and including strong VG_prh-anomalies on the other;
2) Identify "noisy" magnetometer pairs which contain VG_prh anomalies (for ***Figure 1.2*** these pairs are Tmag3-Tmag4, Mag5-Mag6, and Tmag7-Tmag8);
3) Find "stable" pairs of magnetometers with minimal VG_prh anomalies (for ***Figure 1.2*** such pairs are Tmag1-Tmag2 and Mag9-Mag10);
4) When calculating VG, replace the measurements of one magnetometer from the "noisy" pair with those of the neighboring magnetometer from the "stable" pair, and then do the same for the second magnetometer. Highly likely, when replacing the measurements of one of the magnetometers, the VG_prh anomaly will be preserved, while replacing the measurements of the other magnetometer, the

VG_prh anomaly will be significantly weakened. This lets us assume that the second magnetometer (whose replacement brings about the VG_prh anomaly weakening) is the cause of its emergence.

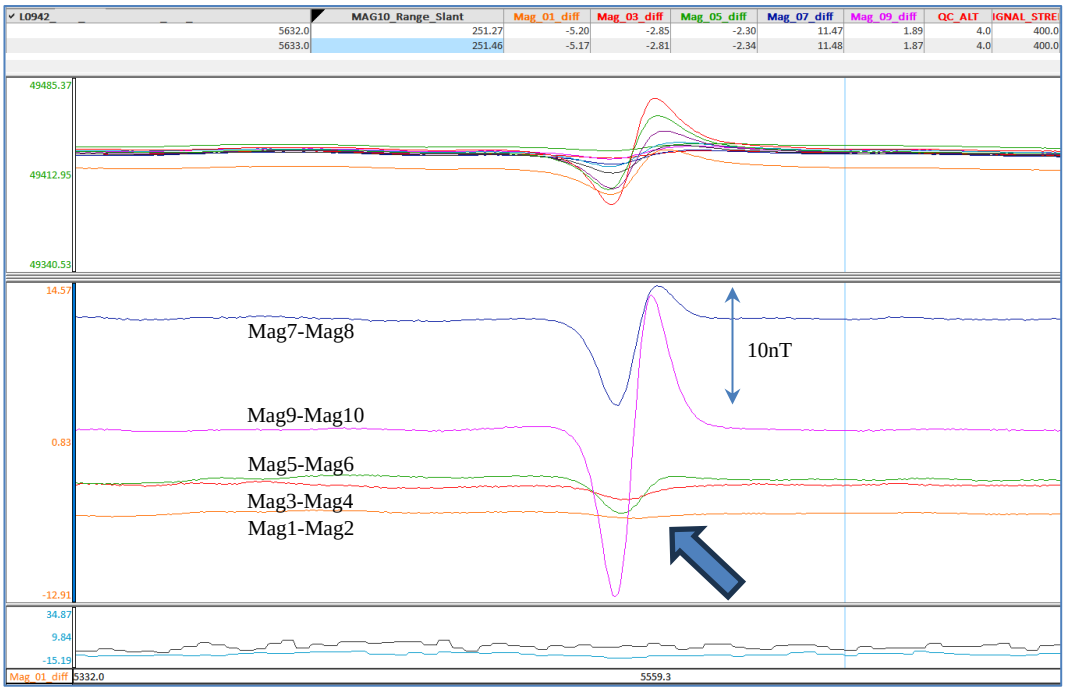


Figure 1.1 An anomaly from the magnetic mass

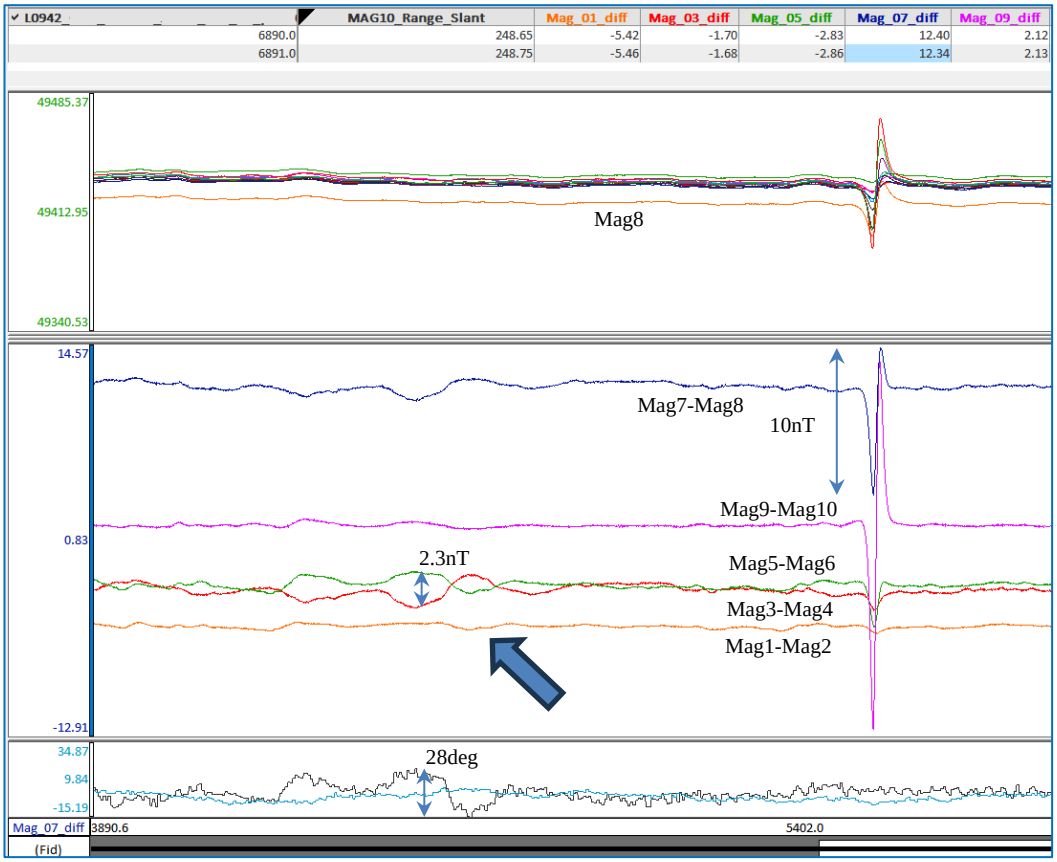


Figure 1.2 VG_prh-anomaly related to pitch (left) and magnetic mass anomaly (right)

An indirect sign of a “noisy” magnetometer is also a shift of the magnetic field value graph along the nT axis (versus the magnetic field graphs of other magnetometers installed on Scan Fish). For ***Figure 1.2*** such a magnetometer is Mag8 (the orange graph at the top of the figure). Based on this magnetometer measurements, Mag7-Mag8 pair has its VG calculated, with VG_prh-anomalies present (the blue graph in the central part of ***Figure 1.2***). It is Mag8 that turns out to be the “noisy” magnetometer in the Mag7-Mag8 pair. As a rule, the indirect sign (the graph shift) described is sufficient for determining the “noisy” magnetometer but not necessary (the graphs for the magnetometers from the other two “noisy” pairs in ***Figure 1.2*** are not subject to shift).

1.3 The Cause of VG_prh-anomalies emergence

In search of the VG_prh-anomalies cause, we have successively made three assumptions followed by a number of experiments performed.

Assumption 1. Since a large Scan Fish pitch angle is nearly always associated with a passage over heterogeneities in the seabed topography, the VG_prh anomaly was assumed to be produced by the magnetic field of the topography inhomogeneity.

The assumption is disproved by two patterns:

-- The magnetic field recordings over sand waves on an opposite tack demonstrate VG_prh anomaly in the crest area of the sand wave only when ascending a steep slope (due to the change in the Scan Fish pitch angle). When passing Scan Fish from the side of a gentle slope, VG_prh-anomalies are absent in the crest area of the wave (i.e., the sand wave material does not produce a magnetic anomaly);

-- The VG recordings contain VG_prh-anomalies recorded “in counter-phase”. This effect, according to the laws of physics, cannot be produced by the influence of the magnetic masses of the geological section.

Assumption 2: VG_prh-anomalies were assumed to be generated by moving the magnetometer sensitivity zone vs. the full vector of the Earth's magnetic field during the Scan Fish roll-pitch.

The assumption seems reasonable; the effect of moving the sensitivity zone is surely present, which is confirmed by lower Signal strength for large pitch angles (***Figure 1.5***). However, “VG_prh-anomalies in counter-phase” (***Figure 1.2***), require to assume that the magnetic field sensor registering them is characterized by features of the sensitivity zone, the latter being very different from the sensors of other magnetometers. This assumption challenges the identity of the sensors declared by the manufacturer (i.e., i.e., it is tantamount to assuming that the sensor registering VG_prh-anomalies in counter-phase is defective).

Two experiments were done to test the assumption:

-- The sensor of the magnetometer with “noise-in-counterphase” was rotated by 180 degrees. After the rotation, the character of VG_prh-anomalies did not change, – they remained in counter-phase to the anomalies of the other sensors.

-- The “noisy” magnetometer was swapped with the neighboring “stable” one. After they changed places, the “stable” magnetometer became noisy, and the “noisy” magnetometer stopped registering strong VG_prh-anomalies.

The second experiment shows that VG_prh-anomalies are related not to the peculiarities of the magnetic sensor but to the “magnetometer location”.

Assumption 3: The source of the VG_prh-anomalies (from now on we consider it as noise) is located in the “environment” of the magnetic sensor. To find the noise source, we tested the following assumptions:

-- Leaks in the cable connecting the magnetometer and Electronic Bottle on the Scan Fish. Replacing the cable did not work at all;

-- Poor electrical characteristics (current, supply voltage, leakage) of the circuitry in the Electronic Bottle to which the magnetometer is connected. The “noisy” magnetometer was attached to the connector on the Electronic Bottle where the “stable” magnetometer was previously hooked. This also failed to produce any results;

-- The influence of Scan Fish frame elements. To test this assumption, the frame element mounting bolts were moved from one magnetometer to the other. The noise then “moved” to the other magnetometer along with the set of bolts.

Thus, ***the appearance of VG_prh-anomalies was found to be caused by sets of mounting bolts located in close proximity to the magnetic sensor*** (*Figure 1.3*).

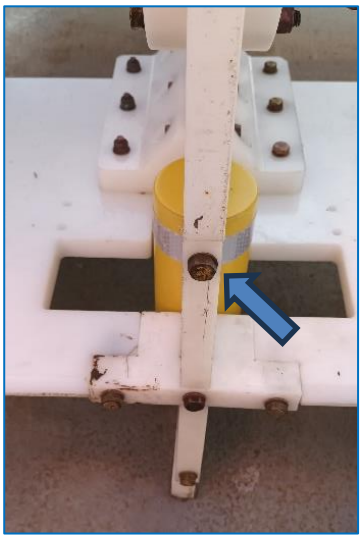


Figure 1.3 Positioning the Scan Fish mounting bolts close to the magnetic sensor

1.4 Mechanism of bolts influence on the measured magnetic field

"With a wry grin, ship cook Negoro's great-great-grandson drew five metal bolts on the blueprint, closer to the magnetic sensors." (Dick Sand, A Captain at Fifteen. The Nowadays)

The mounting bolts are made of brass, so they should be non-magnetic; however, several experiments on rearranging the bolts confirm their effect on the magnetic field recordings, which means that they are a source of VG_prh anomalies.

It is possible that the brass used for bolts fails to be fully non-magnetic. This is confirmed by the composition of brass grades shown in ***Figure 1.4*** [*1*]. Besides, the magnetic properties of some brass grades are well known to those practically involved in the activities of "treasure hunters" and scrap metal collectors [*2*]:

"Brass. Zink- and copper-containing alloys are not magnetized, though brasses of the Cu+Al+Fe and Cu+Al+Ni grades behave quite differently. Iron and nickel contained in them provides magnetic attraction. The magnetic force is not as strong as when it comes to carbon steel; therefore, you would need a neodymium magnet to feel the attraction".

Alloy 260	Alloy 280	Alloy 360	Alloy 385	Alloy 464	
Composition (wt %)	Cu: 68.5 - 71.5 Zn: 28.5 - 31.5 Fe <= 0.05 Pb <= 0.070	Cu: 59 - 63 Zn: 40 Fe <= 0.070 Pb <= 0.3	Cu: 60-63 Zn: 35.5 Fe <= 0.35 Pb <= 2.5-3.7	Cu: 55 - 59 Zn: 36.65-41.65 Fe <= 0.35 Pb <= 2.5-3.5	Cu: 55 - 59 Zn: 36.65 - 41.65 Zn Fe <= 0.35 Pb <= 2.5-3.5

Figure 1.4 Composition of yellow brass types (Fe persantage)

"Noisy sets" could be found for both the bolts that have already been in service for some time, and brand-new ones (bolts complete with a new Scan Fish).

Several rearrangements for the same Scan Fish have been done to identify the "peculiarities" of the bolts' effect. ***Figure 1.5*** shows the recordings of the same magnetometers as shown in ***Figure 1.2*** performed after two sets of mounting bolts had been swapped.

Bolts of Mag4, which was defined as "noisy" (based on the calculation methodology above), were swapped with Mag10; Mag5 bolts were rearranged with Mag9. Comparing ***Figure 1.5*** and ***Figure 1.2***, one could see the following patterns:

-- VG_prh anomaly patterns observed for Mag1-Mag2 and Mag7-Mag8 (bolt sets were not rearranged) remained the same as in ***Figure 1.2***; i.e., the counter-phase for VG plots, the relatively large magnitude of VG_prh-anomalies for Mag7-Mag8 and "stability" of measurements for Mag1-Mag2 didn't change;

-- The previously "noisy" Mag3-Mag4 magnetometer pair has become "stable" due to removing the "noisy" bolts' set. After rearrangement, the "noise" amplitude does not exceed that of the "stable" Mag1-Mag2 pair;

-- Replacing the bolts had little effect on the Mag5-Mag6 pair;

-- A previously “stable” pair of Mag9-Mag10 magnetometers, after installing “noisy” bolt sets, began to “make noise”. Moreover, due to the influence of “noisy bolt sets” on both magnetic sensors, the noise is neither in-phase nor counter-phase with respect to the other sensors and the Pitch graph; the noise forms the complex pattern of its own.

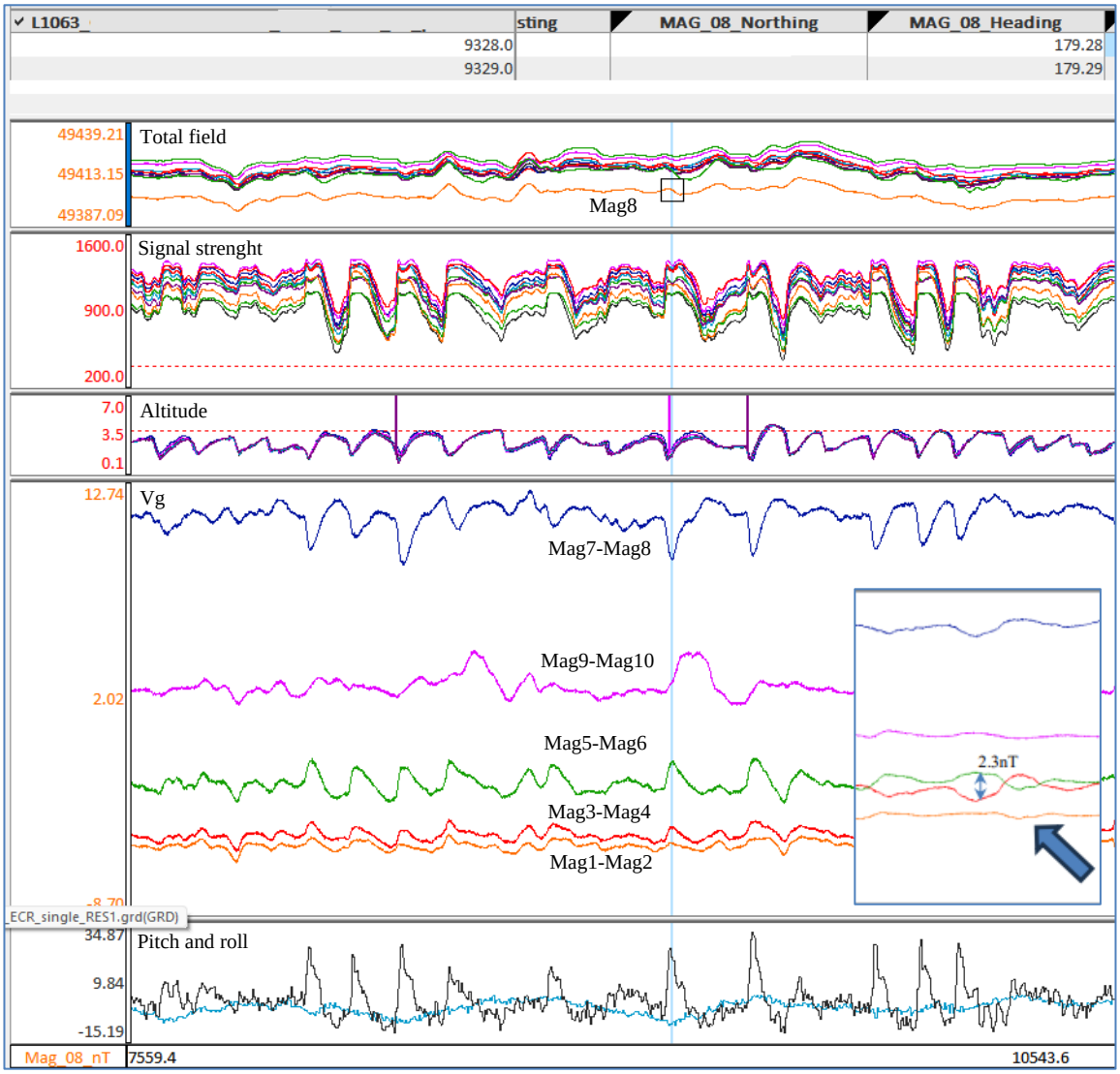


Figure 1.5 Pitch-related VG_prh-anomalies after the bolts were swapped

With our knowledge that the cause of VG_prh anomalies is related to the influence of the bolts, we can explain the above-mentioned indirect sign of a “noisy” magnetometer as a shift of the graph of magnetic field values versus the graphs of the other magnetometers (***Figure 1.5***, the upper part of the figure, Mag8). The “substandard” bolt probably has its own weak residual magnetic field, which is the cause of the shift described.

According to the documentation, the accuracy of the absolute value of the magnetic field for the G-882 is less than 2 nT. Thus, we can interpret a shift of more than 2-4 nTL as “the influence of magnetic mass in the vicinity of the sensor”. In ***Figure 1.5***, the shift for Mag8 is shown to be just over 10 nT.

The other sets of bolts for the magnetometers shown in ***Figure 1.5*** and ***Figure 1.2***, are likely to have much lower residual magnetization. Their VG_prh anomalies are probably related to the occurrence of induction magnetization under the influence of the Earth's magnetic field. While moving in the magnetic field, the magnitude of the induction magnetization is likely to change, resulting in VG_prh anomalies. It is difficult to explain why these anomalies are inverted, since the magnetic field sensor is influenced by 5 bolts at a time (***Figure 1.3***).

If VG_prh-anomalies are associated with induction magnetization, their amplitude should depend on the direction of the magnetic survey profiles.

1.5 Example of VG_prh-anomalies with high amplitude

Figure 1.6 shows an example of VG_prh-anomalies with a significant amplitude. For a pitch spread between 45-50 degrees, it constitutes 12-14 nT; for small pitch changes of 3-4 degrees, it reaches 2-3 nT. When processing the magnetic field for UXO purposes, the long-period portion of the magnetic field can be removed; however, even the remaining “short-period component” of the VG recording for Mag3-Mag4, can introduce false anomalies to the vertical magnetic field gradient map.

The shift of the magnetic field graph for Mag3 is approximately 13 nT compared to the other magnetometers (the reason being probably the residual bolt set magnetizing). The shift of the VG graph for Mag3-Mag4 is caused by Mag3 values and is also about 13 nT. The amplitude of the magnetic field variation for Mag3 reaches 14 nT, with a pitch spread between 45-50 degrees.

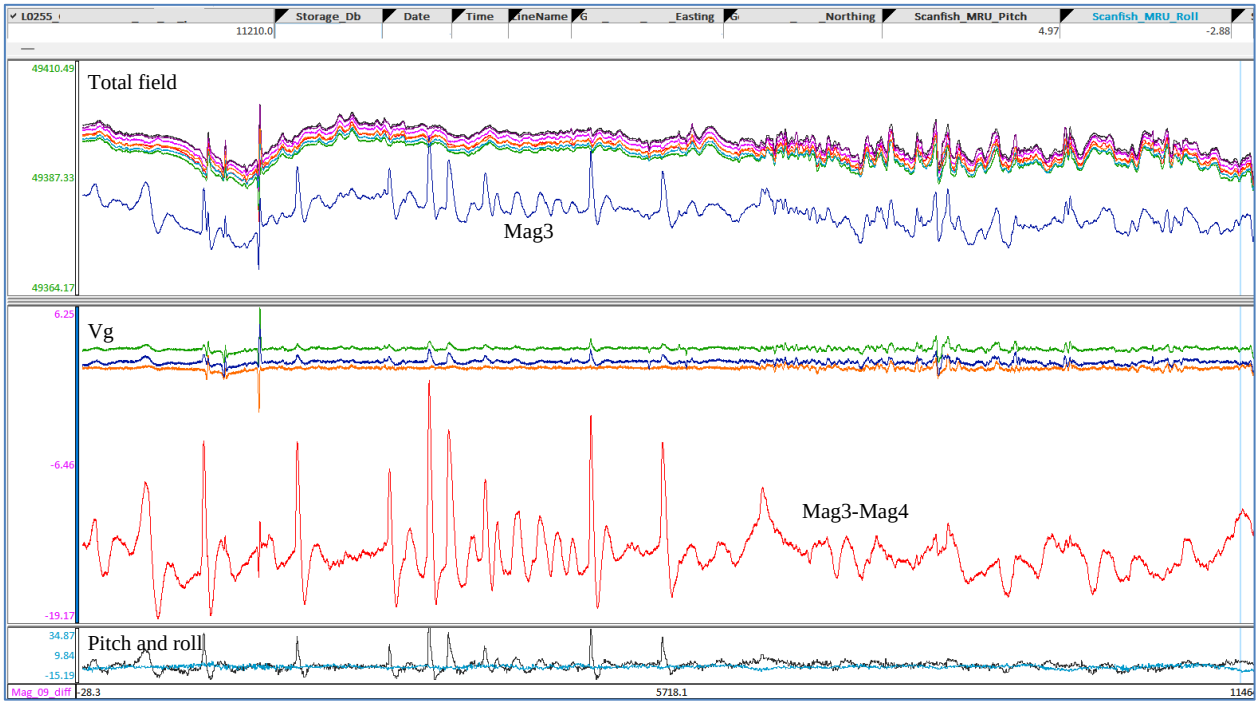


Figure 1.6 VG_prh-anomalies with high amplitude

To confirm that the VG_prh-anomalies are produced by the bolt sets, the latter have been repositioned between Mag3 and Mag5. ***Figure 1.7***. demonstrates the Scan Fish magnetometer recordings after the rearrangement: the VG_prh anomalies moved to the VGs for the Mag5-Mag6 sensors, with Mag5 becoming the “noisy magnetometer”.

The recording in ***Figure 1.7*** corresponds to the dependence of the Mag5 plot offset on the direction of magnetic survey. This offset changes sign on the opposite directions of survey lines.

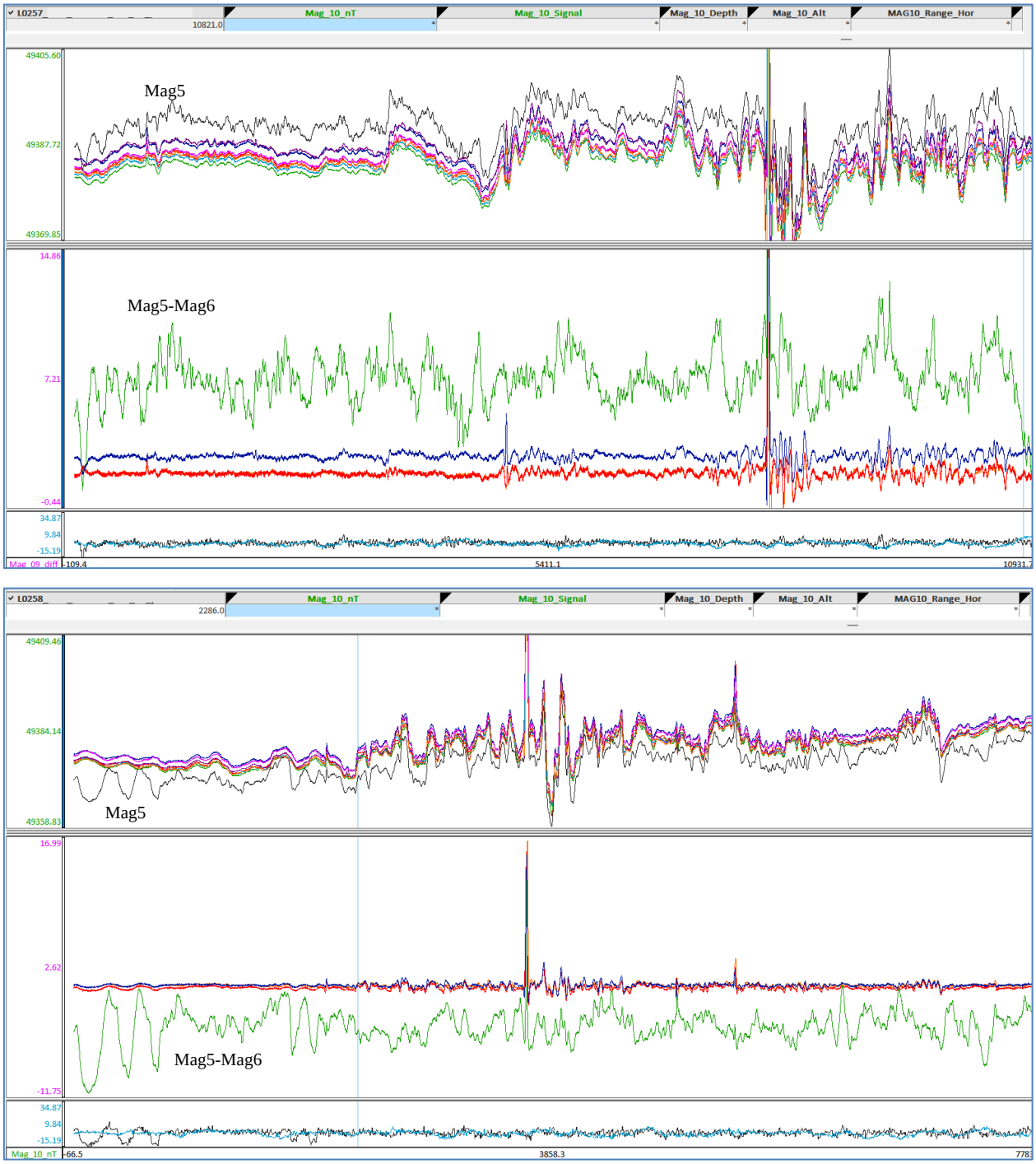


Figure 1.7 VG_prh-anomalies with high amplitude, on opposite directions of survey lines

1.6 Methods for identifying “the noisy” bolt sets

There are two possible methods to test the bolts for “magnetic properties”:

-- Use a strong neodymium magnet, when looking for “attracting” bolts. However, this method does not exclude the fact that the initially weakly magnetized bolts will become charged in a strong magnetic field of a neodymium magnet, though it is quite possible to try the method of demagnetizing with a high-frequency current to “fix” the bolts;

-- Test the bolts by moving them close to the magnetic sensor, while positioning the magnetometer away from the magnetic masses and sources of electromagnetic noise.

In addition to the bolts which can be tested and replaced quite easily, we should like to note that inside the plastic parts of the frame there are nuts, which are also located in close proximity to the magnetic sensors. It will be a “must” for some Scan Fish, whenever a “magnetic nut” is detected, to ream out the plastic part of the frame and replace the magnetic nut.

The most radical method of dealing with VG_prh-anomalies particularly noise from metal near the magnetic field sensors, is to change the frame design by removing the metal fasteners from the magnetic sensors or replacing those fasteners with the plastic ones.

2 The effect of aluminium

"Gorgon Medusa? Plainly speaking, the mirror reflects electromagnetic waves across a fairly wide spectrum. The uniqueness of Perseus' mirror implied that the reflecting surface was made of aluminium, which was quite unusual for those times. Its spectral composition of reflected waves is much wider than that of silver or gold. Clearly, all of Medusa's feedback loops went haywire... well, and then it was just a little bit of luck." (Dialog from a fairy tale for physics kids)

When installed in close proximity to the magnetic sensor aluminium structural elements, such as reinforcing plates, fasteners, frame elements, high-frequency noise appears on the magnetic field recordings. ***Figure 2.1*** shows a photo of the magnetometer frame reinforced with an aluminium plate. The plate itself is located in close proximity to the magnetic sensor.

Figure 2.1 Positioning of the aluminium element next to the magnetic field sensor

Figure 2.2 shows an example of magnetic field recordings before and after installation of aluminium amplifying elements. The vertical axis is measured in nanotesla (nT) with the constant component subtracted from the magnetometer measurements to better visualize the magnetic field recordings. The horizontal axis is the magnetometer measurement number when the measurement frequency is 10 Hz. Graphs in blue show the magnetic field recordings for the bottom row of magnetometers installed on Scan Fish before installing the aluminium amplifying elements. Graphs in red demonstrate the magnetic field recordings for the bottom row of magnetometers when the aluminium amplifying elements are installed. And graphs in green represent magnetic field recordings for the top row of magnetometers after installation of the aluminium amplifying elements. ***Figure 2.2*** clearly indicates the appearance of high-frequency noise associated with the presence of aluminium parts in close proximity to the magnetic field sensor.

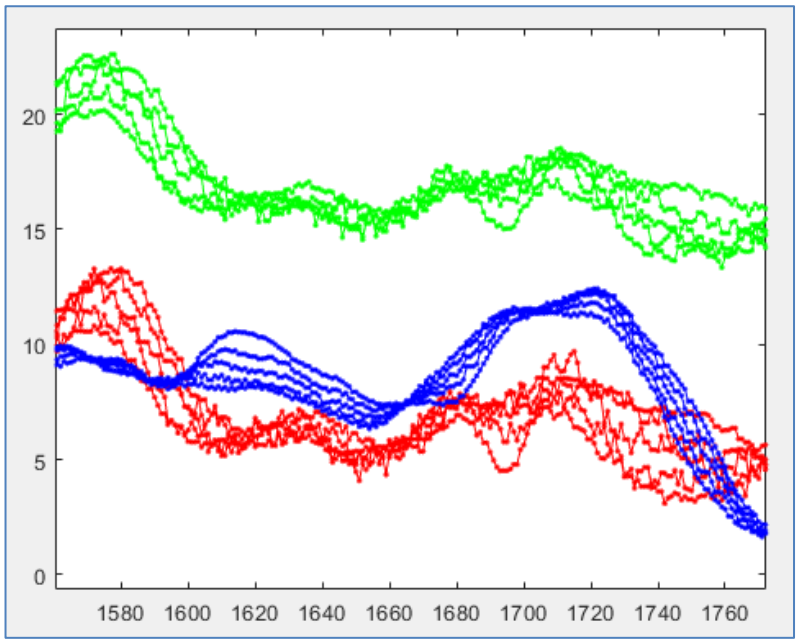


Figure 2.2 Magnetic field recordings before and after installation of aluminium amplifying elements

Aluminium is a completely non-magnetic metal; however, it is electrically conductive. Therefore, the cause of the high-frequency noise is probably related to the interaction between the electromagnetic field generated by the radio-frequency electromagnetic oscillations in the *feedback coil* included in the design of the Caesium sensor [*4*] (***Figure 2.3***, ***Figure 2.4***) and the aluminium plate. The principle of a Caesium magnetometer operation is summarized below as a reference, explaining the presence and function of a coil with radio-frequency electromagnetic oscillations.

Citation [*3*]:

A variety of optically pumped alkali vapor scalar magnetometers have been used in space. Caesium 133, Rubidium 85 and Rubidium 87 has been employed in sensors [Ness, 1970]. The alkali vapor magnetometers utilize transitions between the Zeeman sublevels in the ground state of the atom. The energy separation for the Zeeman splitting in proportional to the magnetic field. In the Rubidium self-oscillating magnetometer, a light from a Rubidium lamp is passed through a filter that only passes the 7948 Angstrom Rubidium light. The light passes through a circular polarizer and then through a cell with Rubidium vapor. The light is collected with a photoelectric cell. It is then amplified, phase shifted and then applied to a feedback coil around the Rubidium vapor cell (see ***Figure 2.3***). The circuit will oscillate at the Larmor frequency. The frequency for Rb 87 is approximately 6.99 Hz nT-1 which for a field of 50,000 nT would be ~350 KHz. The oscillation depends upon the presence of a magnetic field and ceases when the field vector is within "12o of parallel or "7o of normal to the optical axis of the sensor. There are offsets in the frequency as the field vector is reversed. This is because the circuit oscillates with a broad unsymmetrical resonance that shifts with field direction [Ruddock, 1961]. A design that minimizes this problem is one that has a single Rubidium lamp illuminating twin absorption cells…

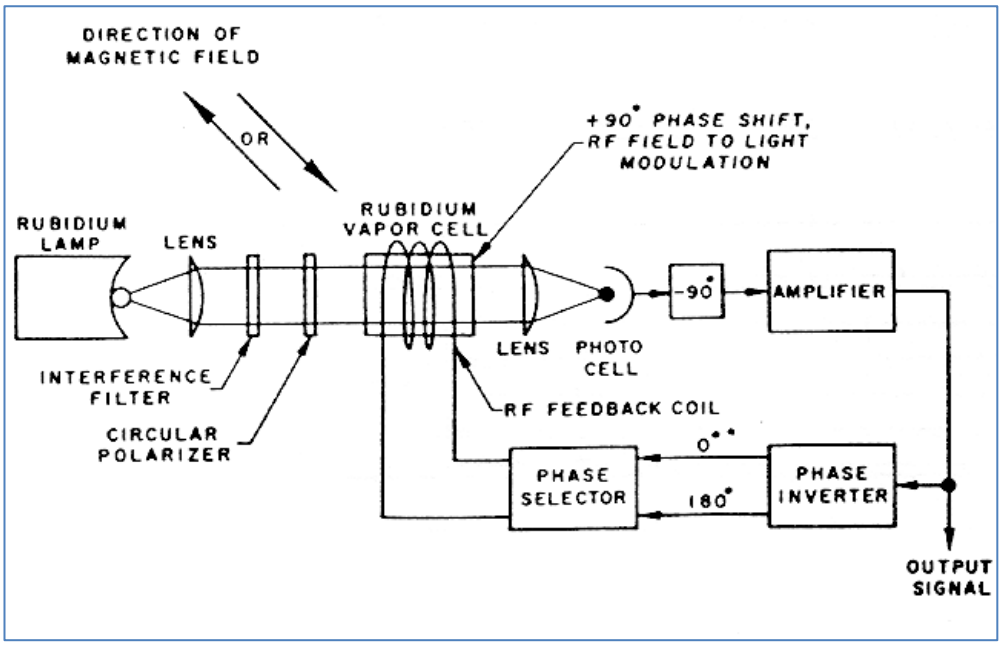
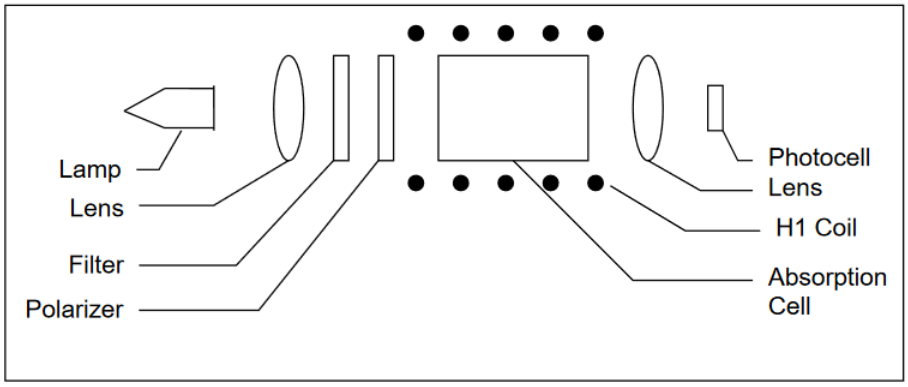


Figure 2.3 Block diagram of self-oscillating single cell rubidium vapor magnetometer [Ruddock 1961]



G−882 CESIUM SENSOR

Figure 2.4 Caesium sensor chart from G-882 operation manual

Aluminium has the ability to reflect electromagnetic waves in a wide range of high frequencies. *Figure 2.5* shows the graphs of the aluminium metal mirrors reflectivity at a normal incidence of an electromagnetic wave. As can be seen from the graphs below, depending on the condition of the reflecting surface, the reflection is close to 80-100% with the wavelengths in the range of 0.1-40 μm (frequencies 3000-7.5 THz). In this case, the waves emitted by electrons oscillating under the electromagnetic field effect dampen (shield) the incident electromagnetic wave inside the metal. The same wave as the original one is generated from the outside but propagates in a different direction. In fact, the electromagnetic waves are re-emitted by the metal.

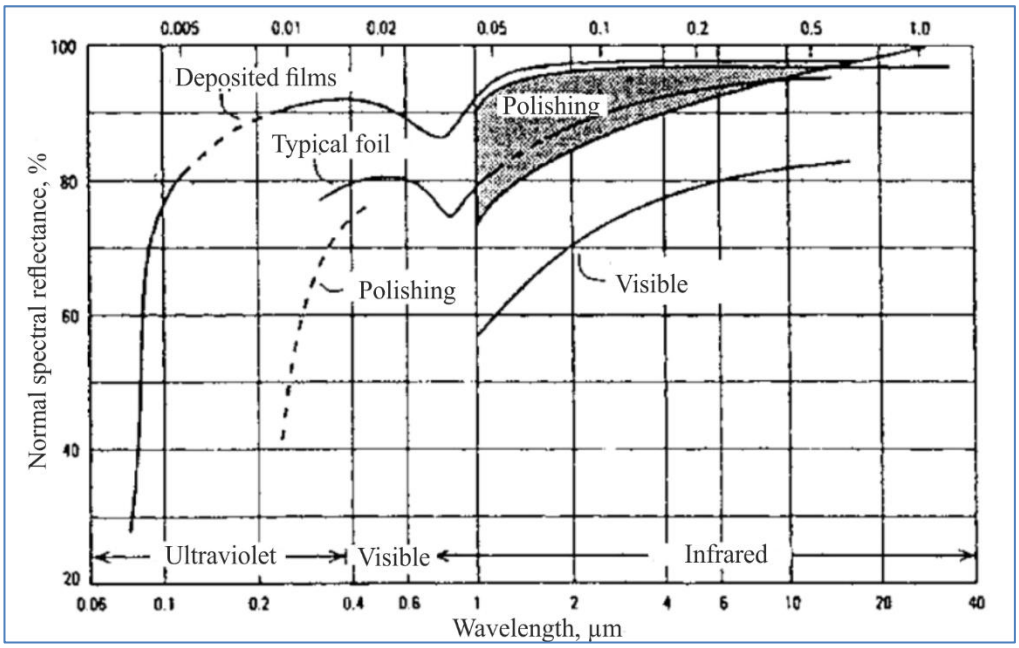


Figure 2.5 Reflectance for aluminium mirrors for different surface qualities

Figure 2.6 shows the experimental plots of the reflectance of electromagnetic wave energy in the anodized aluminium coating for frequencies 0.7-17 GHz [*5*]. The reflectance of -1Db corresponds to 90%, -5Db to 30%, and -15Db to 3%.

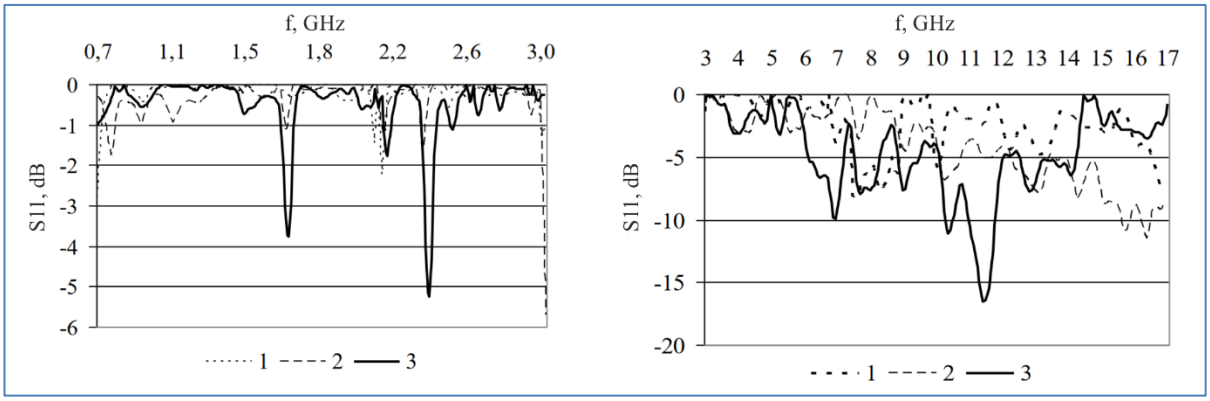


Figure 2.6 Frequency dependences of electromagnetic wave energy reflectance in the frequency range of 0.7-3.0 GHz and 3-17 GHz for samples coated with anodized aluminium: 1 – layer thickness 10 microns; 2 – layer thickness 15 microns; 3 – layer thickness 25 microns

Since we consider the Scan Fish, it has the aluminium plate positioned in the “proximity zone” to the source of electromagnetic waves (frequencies below 300MHz). Therefore, the process would be no longer correctly described as “electromagnetic waves reflection” but “Foucault currents induction” in a solid aluminium plate. In this case, the magnetic field of the Foucault currents is directed opposite the magnetic field inducing them, i.e., that of the feedback coil.

One way or another, the aluminium plate positioned in the action zone of the feedback coil alternating electromagnetic field (with a frequency of nearly 350 kHz) produces a secondary electromagnetic field. The latter is probably enough to mismatch the oscillations in the feedback coil, resulting in high-frequency noise on the G-882 magnetometer recordings.

Conclusion

As can be seen from the above, bolts installed in close proximity to the magnetic sensors (***Figure 1.3***) are considered as the Scan Fish design flaw, which leads to the appearance of VG_prh-anomalies (anomalies due to roll-pitch of Scan Fish) on the magnetic field gradient recordings. Actually, VG_prh-anomalies are noise generated by metal parts near the magnetic field sensor. The noise will be most severe in areas with relatively rugged terrain (e.g., sand wave zones), which will be enveloped by Scan Fish.

VG_prh-anomalies' amplitude presented on the full magnetic field vector recordings and that of the VG ranges from 2-3 nT (roll spread between 2-3 degrees) to 10-12 nT (roll spread between 45-50 degrees). When strong bolts effect, the magnetic field recordings appear to be completely noisy (***Figure 1.6***, ***Figure 1.7***). These recordings may cause the appearance of many "false low-amplitude anomalies" and mask the real ones caused by magnetic masses.

Reducing noise caused by metal parts near the magnetic field sensor is possible by selecting bolts which "weakly influence the magnetic field measurements", i.e., testing bolts by moving them near the magnetic sensor, while installing the magnetometer away from magnetic masses and sources of electromagnetic noise. One must also test and select the nuts that are screwed together with bolts (some Scan Fish designs have the nuts located inside the plastic parts of the frame).

Aluminium is not magnetic but highly electrically conductive. The solid plates of electrically conductive metal near the magnetic sensor are likely to produce electromagnetic interference in the feedback coil of the G-882 magnetometer (***Figure 2.3***, ***Figure 2.4***) and result in high frequency noise on magnetic field recordings (***Figure 2.2***). Thus, it is strongly discouraged to install fasteners even made of non-magnetic but electrically conductive materials near the sensor.

To reduce noise caused by a metal located near the magnetic field sensors radically, one should change the frame design by removing metal fasteners from the magnetic sensors for additional 15-20 centimeters or replacing metal fasteners with plastic ones.

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