Comparison of Rotational-Run vs Hybrid-Measurement by Modelling of a Large Test Object/Satellite

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***Abstract*— Within the AIT-process the verification of magnetic cleanliness requirements is an essential pre-requisite to ensure mission success, especially for satellites with dedicated magnetic mission requirements e.g. SOLAR ORBITER. Magnetic cleanliness verification usually comprises a combination of analytical and experimental methods. During the "magnetic system test" the object to be tested is characterized by a magnetic model which is built up of several dipoles. By measurements of projects within the last years, it became obvious that the size and weight of scientific satellites is increasing dramatically. Therefore it is necessary to adapt proven measurement/analysis methods to the new situation. This paper takes a closer look on the two special test set-ups (Rotational-Run, Hybrid-Measurement) by setting up a synthetic magnetic body, simulating a measurement in both set-ups, modeling a best fit dipole model based on the simulated measurements for each test set-up. In the end the magnetic field generated by the calculated magnetic multi dipole models is compared with the one generated by the synthetic magnetic body. This comparison takes place in an "observation area"; a region of special magnetic interest.**

Keywords—magnetic cleanliness; Rotationa-Run; Hybrid-Measurement;

I. INTRODUCTION

The magnetic remanent characteristic of any test object is often described by scanning its magnetic field signature. The readings taken during this scanning are used in a further step to build up a magnetic model of the test object based on several magnetic dipoles. This multi dipole model is able to predict the magnetic far field of the test object by calculation.

In the past the set-up of the "Rotational-Run" was used very successfully [1-4]. Due to the increasing geometrical size of the test objects it is necessary to think about different test set-ups like the "Hybrid-Measurement" set-up described in [5]. This article takes a closer look on both methods from a theoretical point of view and compares simulated results of these two test set-ups. It is known from theory that calculated models based on equally distributed measuring locations are more stable than those with non-equally distributed measurement locations. Therefore, all locations where measurements are taken shall be equally distributed on the surface of a sphere around a test object. From a practical point of view this is not always feasible due to geometrical and/or other limitations. For example it is typically not feasible to mount equipment below the floor of a facility. On the other hand it is often not possible to turn the object in all directions needed to generate equally distributed measurement locations. Therefore it is always a compromise where to put the measurement sensors and how to move or turn the test object during the testing.

II. MEASUREMENT BY "ROTATIONAL-RUN"

A. Set-Up

The test object to be characterized is placed on a table which can be rotated around its centered vertical axis by 360°. At a certain distance from the rotational axis one or more magnetometers are placed taking readings while the turn table with the test object on it is rotated in steps of typically 10°.

B. Distribution of measuing points

Fig. 1 gives an optical impression of the distribution of the measurement locations. The test object is shown as a box of glass. The test set-up itself consists of

- 6 tri-axial probes (18 probes)
- Rotation in 36 steps around the Z-axis at the center
- 648 measurement locations around the test object

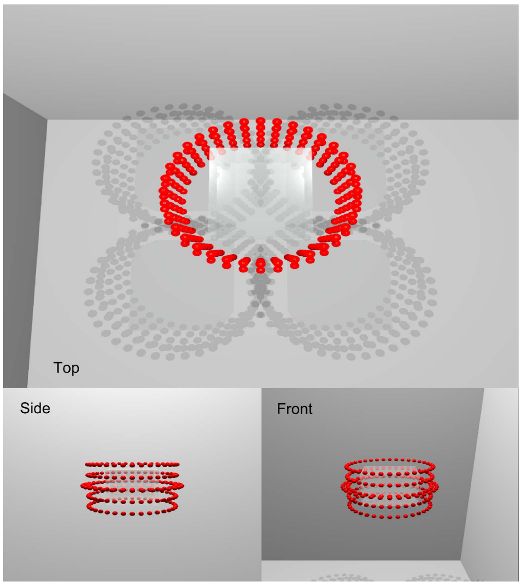

Fig. 1. View on all measurement locations where readings are taken during a "Rottional Runt". All Measurement locations are marked in red.

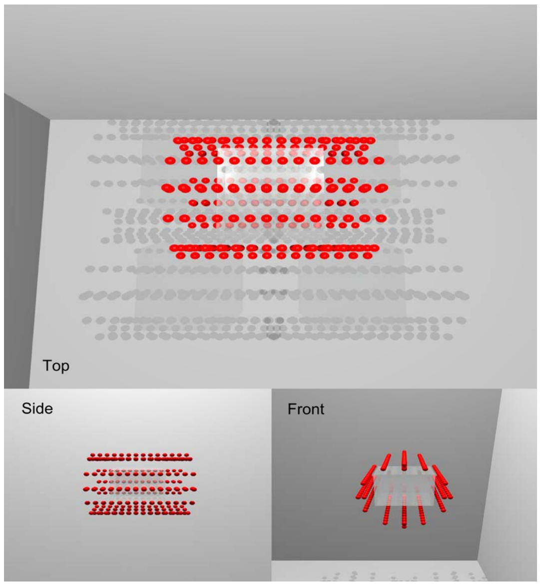

Fig. 2. View on all measurement locations where readings are taken during the "Hybrid-Measurement". All measurement locations are marked in red.

III. MEASUREMENT BY "HYBID MEASUREMENT"

A. Set-Up

The test object to be characterized is passing through a gate with a set of magnetometer mounted/grouped around it. The magnetometers are grouped such that the test object can pass the magnetometer very close by in a transversal movement.

B. Distribution of measuing points

Fig. 2 gives an optical impression of the distribution of the measuring locations. The set-up consists of

- 16 tri-axial magnetometer probes (48 single probes)
- All measurement positions are located along the X-axis
- 672 measurement locations along the test object

IV. DEFINITION OF OBSERVATION AREA

The observation area defines an area where the knowledge of the magnetic field strength and direction is of special interest e.g. the location of the onboard magnetometer. For comparison of the two set-ups Rotational-Run and Hybrid-Measurement this area is defined as a sphere with a diameter of 0.5 m at the location at (0m, 0m,-4.75m). On the surface of this sphere 126 positions are taken to calculate the magnetic field. From potential theory it is known that the minima and maxima of the fields are seen on this surface as long as there are no magnetic sources inside of this area. Therefore these extreme values are used for the further comparison of the different models. Fig. 3 shows the geometry of the observation area used in this article.

V. RULES OF MODELLING

The following rules are used during the modeling:

- All calculations are performed in one and the same right handed Cartesian co-ordinate system.
- The same synthetic model is used to simulate the measurements of the different set-ups.
- Based on these synthetic readings taken at the measurement locations a model of the magnetic signature of the test object is calculated using the following formula:

$$\vec{B}_S = \frac{\mu_0}{4\pi}\sum_{i=1}^{N}\left(3\frac{\vec{r}_i\left[\vec{M}_i\vec{r}_i\right]}{\left\|\vec{r}_i\right\|^5} - \frac{\vec{M}_i}{\left\|\vec{r}_i\right\|^3}\right). \qquad (1)$$

It is assumed that the field readings are numerically represented by fields generated by a set of N dipoles with their moments M_i located at r_i positions within

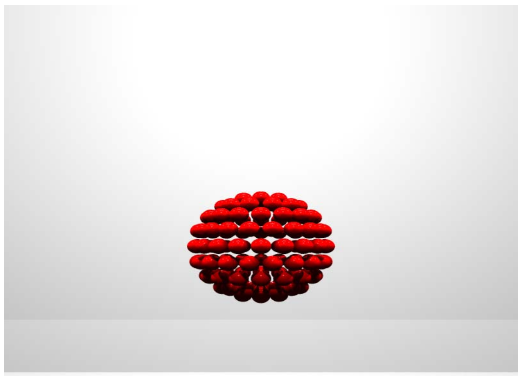

Fig. 3. View on the observation locations of the obsrervation area. All positions are marked by red spheres.

the test object. The optimal model parameters r_i and M_i (Eq. 1) are determined by use of a NLP solver (i.e. Levenberg-Marquard) through the minimization of the sum of the squares of all differences between the calculated and the measured fields (least square fit).

- The search for the best fit dipole model is performed in several steps starting with the representation of one dipole.
- At each step the model of x dipoles is calculated at least thirty times. Each calculation starts with randomly distributed set of dipoles. In the end the dipole model with the best global fit of all measurement locations is taken for that step.
- The number of dipoles is limited to 11. This takes into account that the relation between fitting parameter and measurement locations shall be greater than 10 to avoid any local fitting instead of global fitting.
- The difference between the magnetic field generated by the magnetic reference model and the magnetic multi dipole models calculated later on is compared at the positions of the observation area.
- The set-up of the magnetometer is assumed as ideal.
- No additional noise is taken into account.

VI. SYNTHETIC MODEL OF 1000 DIPOLES

All further calculations are based on a synthetic dipole model of an object with the size of 2.8m x 3.3m x 2.5m. It is not easy to setup any kind of model without information about the test object from other sources. Therefore the following assumptions are taken:

- Magnetic material is possibly everywhere within the object.
- The amount of magnetic moment taken for the object should be in the order of 10 Am².
- It should not be possible to get a perfect magnetic model of the object during the modeling process later on.

In the end the calculated synthetic model (further reference model) is build up of 1000 randomly distributed dipoles. Each dipole has a magnetic moment in each axis in between +-10 mAm² randomly distributed. The magnetic moment inserted into this model is in the order of 10 Am². Summing up the moments of all 1000 dipoles and not taking the position into account leads to a magnetic moment of approx. 0.5 Am². Therefore only 5% of the magnetic moment will be seen from outside in the far field of the reference model.

At the position of the observation area the reference model generates a magnetic field of about 0.688 nT in total. Fig. 4 shows the geometrical set-up of the synthetic model and the observation area defined above.

VII. SYNTHETIC MEASUREMENTS

Based on this synthetic reference dipole model synthetic measurements are calculated referencing a Rotational-Run measurement and a Hybrid-Measurement. Table I (Rotational-Run) and Table II (Hybrid-Measurement) show the extreme values calculated for Probe 1 – Probe 9. The readings calculated for the Hybrid-Measurement are up to a factor two higher. This is to be expected due to the closer distance between probes and test object during the Hybrid-Measurement.

TABLE I. ROTATIONAL MEASUREMENT READINGS OF FIRST 9 PROBES

Probe	Rotational Measurement					
	Min X in nT	*Max X in nT*	*Min Y in nT*	*Max Y in nT*	*Min Z in nT*	*Max Z in nT*
1-3	-10.6	2.2	-4.8	4.0	-6.1	4.5
4-6	-17.3	7.6	-13.4	6.4	-5.2	9.8
7-9	-10.7	16.9	-9.6	5.7	-7.9	5.5

TABLE II. HYBRID MEASUREMENT READINGS OF FIRST 9 PROBES

Probe	Hybrid Measurement					
	Min X in nT	*Max X in nT*	*Min Y in nT*	*Max Y in nT*	*Min Z in nT*	*Max Z in nT*
1-3	-35.1	20.7	-27.4	26.6	-17.0	23.5
4-6	-8.3	11.6	-14.8	25.1	-4.2	14.5
7-9	-20.6	35.4	-35.9	42.1	-6.0	27.0

VIII. COMPARISON OF MODELLING RESULTS

The synthetic measurements of "Rotational-Run" and "Hybrid-Measurement" are modeled separately automatically without exchanging any information. This process is defined by the following steps:

- Define the number of dipoles to be taken.
- Calculate a best fit model (least square fit).
- Repeat this 30 times with random start parameters.
- Take the model with the smallest residuals.
- Calculate the magnetic field generated by this model

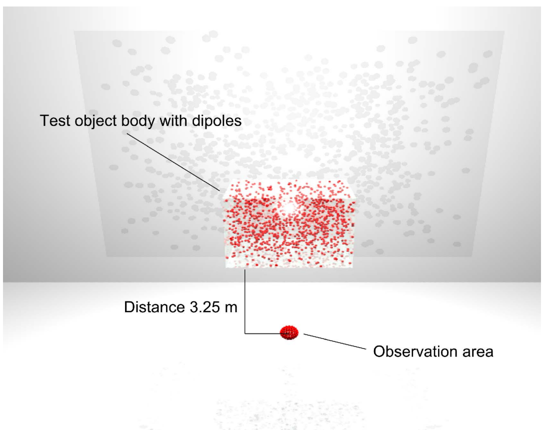

Fig. 4. View on test object with its dipoles inside. In addition the observation area is marked.

TABLE III. RESULT OF DIPOLE FITTING

No. of Dipole	Rotational			Hybrid		
	Mean in nT	*Min in nT*	*Max in nT*	*Mean in nT*	*Min in nT*	*Max in nT*
1	0.479	-0.378	-0.157	0.718	-0.767	0.197
2	0.324	-0.313	-0.058	0.735	-0.770	0.214
3	0.436	-0.388	-0.167	0.182	-0.137	0.170
4	0.253	-0.281	0.196	0.346	-0.358	0.185
5	0.426	-0.323	0.474	0.221	-0.256	0.045
6	0.279	-0.296	-0.039	0.188	-0.095	0.192
7	0.256	-0.274	0.210	0.346	-0.360	0.140
8	0.263	-0.228	-0.071	0.049	0.018	0.035
9	0.296	-0.284	-0.066	0.144	-0.127	0.105
10	0.205	-0.228	-0.006	0.098	0.031	0.088
11	0.292	-0.274	-0.043	0.011	-0.002	0.024

at the positions of the observation area.

- Compare these readings with the magnetic field readings generated by the reference model directly.
- Repeat this for each set-up and each dipole number from 1 to 11.

TABLE III summarizes the results of this approach. The column "Mean in nT" describes the total value of the mean value of all differences between reference model and fitted dipole model. The column "Min in nT" and "Max in nT" are related to the greatest differences in the magnetic field in all components. The parameter describing the residuals of fitting is decreasing with the number of dipoles used. On the other hand this is not necessarily a guarantee for a better fitting in the observation area. During typical measurements in a real world a direct access to the observation area is often not possible or at least the environment is magnetically too noisy to allow measurements with the required precision or resolution.

The Hybrid-Measurement leads to better results than the Rotational Run. This is related to the closer distance of the magnetometers with respect to the test object. Comparing the differences in the magnetic field generated in the observation area it is found that the residual field not explained by the model is much higher when performing a Rotational-Run.

On the other hand the Hybrid-Measurement in this special set-up requires a lot of more resources namely 16 tri-axial magnetometer instead of 6. The time of running a test in Hybrid-Measurement configuration is shorter (14 steps) than the one in Rotational-Run configuration (36 steps).

IX. CONCLUSION

The comparison of the test set-up of a Rotational-Run and a Hybrid-Measurement shows that both test set-ups are suitable to generate enough magnetic readings to characterize a large test object like a satellite. The usage of the Hybrid-Measurement set-up in principle allows a better modeling of the measured data. In addition the handling of the test object is simplified as the linear movement in one direction is easier to perform than the rotation of a large test object.

REFERENCES

[1] K. Mehlem, Multiple magnetic dipole modelling and field prediction of satellites.. IEE Transactions on Magnetics Sept. 1978.

[2] G. Musmann, Magnetic measurements on spacecrafts, Dt.hydrogr.Z. 41,1988

[3] F. Kuhnke, et al, The OPTIMISM/MAG Mars-96 experiment: magnetic measurements onboard landers and related magnetic cleanliness program. Planet. Space Sci.,Vol. 46, No.6/7,pp. 749-767, 1998.

[4] H. Kuegler, Lessons learned during the magnetic cleanliness programs of the cluster projects. Fourth International Symposium Environmental Testing for Space Programmes. Meeting held June 12-14, 2001, at the Palais de Congrès, Liège, Belgium. Edited by Brigitte Schürmann. European Space Agency, ESA SP-467, 2001.ISBN: 92-9092-7097, p.69

[5] H. Kuegler, "Qualification of the magnetic field simulation facility MFSA for satellites with large dimensions," Aerospace EMC, 2012, Proceedings ESA Workshop on