

Signal-to-Noise-Ratio Optimized Design of Rotating-Coil Magnetometers

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Summary:

The electronic acquisition chain of a rotating-coil magnetometer is analyzed to identify electromagnetic noise sources and the effective noise floor of the acquisition. This allows to optimize the system, and the layout and the support of the induction coils for the intended application. The influence of a built-in motor drive unit on the results is studied, in order to establish the minimum distance between the motor and the induction coils to avoid detrimental effects on the measurement accuracy. Two electronically commutated (EC) motors of different power ratings are studied.

Keywords: magnetometers, electromagnetic signal to noise ratio, electric motors

Introduction

Accelerator projects necessitate development of new measurement systems to keep up with the increasing accuracy and functional requirements on their accelerator magnets. An example of this is the Large Hadron Collider High Luminosity project (HL-LHC). The new magnets to be produced and installed in the framework of this project must be measured at ambient temperature with an accuracy that not only challenges the rotating-coil transducers, but approaches the limits of the acquisition electronics, such as the purpose-built digital integrator [1]. This is due to the low excitation-current levels that result in generated signals of tens of millivolts.

Moreover, the functionality of the magnetic measurement systems can be enhanced by adding a built-in motor unit that allows a longitudinal scan along the magnets. In this case it is important to ensure the absence of distortions in the magnetic measurements.

The test setup

The system used for the tests is the rotating-coil scanner [2] currently being developed for the HL-LHC magnets, together with its electronics rack. The main system components under study are integrators, induction coils, a patch panel, cables, slip rings and an encoder. In order to estimate the contribution of each system component to the overall noise of the acquisition chain, we characterized the background noise of various system configurations – starting with an integrator connected directly to an impedance equivalent

to a coil, through a bare coil, to the fully assembled system. The signals were acquired using the integrator at a sampling frequency of 2048 Hz. The integrator outputs the voltage integrated between two triggers, which is a measure for the flux linkage through the surface traced during this time interval, expressed in Vs.

The tests of the motor influence were conducted in an aperture of a powered magnet. Two motors were positioned at varying distances in front of the probe along its longitudinal axis, to test for the presence of distortions in the results of an ongoing magnetic field measurement. The first motor has an inner-rotor construction with a power rating of 80 W. Its dimensions are 32 mm in diameter and 130 mm length. The other, smaller motor has an outer-rotor construction, with 15 W power rating. It is 60 mm long with the same diameter of 32 mm. Both are equipped with a planetary gearbox.

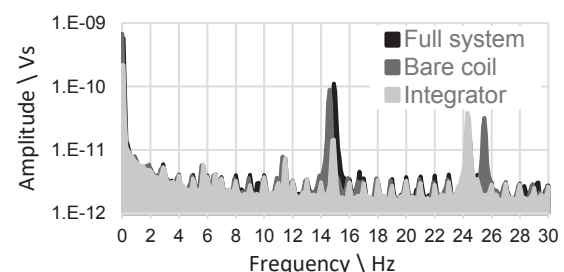


Fig. 1. Comparison of the spectra between a fully assembled system (non-rotating) and a bare coil with the integrator as a reference. The spectra were calculated from signals of 20480 samples and averaged over 50 acquisitions.

Noise evaluation results

The plot in Fig. 1 shows the noise spectra of three configurations. The cables, patch panel and slip rings add only minimal noise to the signal, which is obvious from comparing the coil connected directly to the integrator (bare coil) with the coil mounted in the transducer assembly. The bare coil is sensitive to the ambient electromagnetic interference, which represents the effective noise floor of the transducer itself. The system noise is at approximately 10 nVs RMS (root mean square) amplitude, where the integrator noise is at 1 nVs RMS amplitude.

Application example

This result can be used to design a cost-efficient transducer that provides the required signal-to-noise-ratio. The strength of the signal directly depends on the spanned surface of the coil. In a limited space, such as the bore of an accelerator magnet, the spanned surface can be enlarged only by increasing the number of coil turns, which results in additional (costly) layers when the coil is made in printed-circuit technology.

The test system has been designed for flux-density distributions with a peak of 4 mT. The precision requirements demand a SNR of at least 80 dB relative to the expected main signal. The surface necessary to generate a sufficient signal is approximately 2 m². With a safety margin, the coils were designed for 2.34 m².

The measurements with the test system indicate that the final precision is still limited by mechanical imperfections and vibrations. However, for the extracted field multipole coefficients [3], the system's precision approaches the precision of the integrator, thanks to the compensation (bucking) of the main component. This implies that for measurements that are less dependent on mechanical stability, such as fluxmeters, the acquisition electronics and signal transmission may become a limiting factor.

Influence of the motor drive

The long motor was first positioned 693 mm from the coil edge and moved by steps of 50 mm to a minimum of 93 mm, limited by the assembly. The measurements were taken in a 4.5 mT field. The only measured quantities that are noticeably affected by the motor are the multipole coefficients that are sensitive to 1 ppm levels. The effect of the motor on the measurement results is shown in Fig. 2. The distance at which first distortions above 1 ppm appear is approximately 300 mm.

The smaller motor was displaced in a similar range and in this case, the effects of the motor are only slightly discernible in the closest position, at 87 mm away from the coil edge. This means that a small motor can be placed as close

as 100 mm from an induction coil, without disturbing the measurement results. There was no significant difference in results between non-rotating and rotating motors.

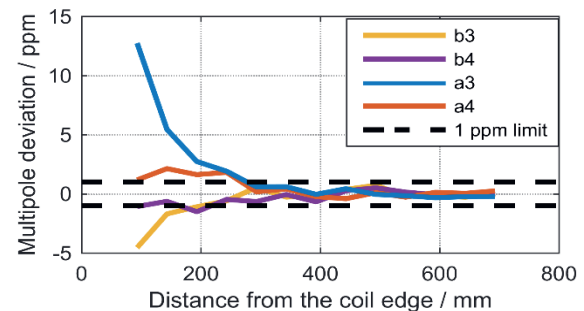


Fig. 2. Deviation of the multipoles measured in the presence of the motor from the reference measurement (without a motor). Only the affected multipoles are plotted.

Conclusions

A characterization of the noise in a rotating-coil acquisition system has been performed in order to establish the acquisition noise floor. It has been demonstrated that properly connected, screened and twisted signal cables do not add any significant noise to the acquisition chain. The limit that cannot be easily overcome is given by the background electromagnetic fields picked up by the coil. In any case, the known noise floor can be used to design a system to provide a required signal-to-noise-ratio in expected measurement conditions. It can also be used as a benchmark to evaluate the correctness of the system's assembly.

The study of the influence of the motor on the measurement results provided an estimation of a safe distance for using onboard motor units in precise rotating-coil magnetometers. The results show that it is possible to use EC motors for rotating-coil measurements inside low magnetic fields (<50 mT), if a minimal distance (depending on the motor size and power rating) is kept between the motor and the induction coil.

References

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