1 Ambient Magnetic-field Compensation (TH) (Rev:)

1.1 Overview

The location of the nEDM spectrometer in an accelerator facility necessitates a system to reduce influences of environmental magnetic fields to the experiment. As mentioned in an earlier section [ref, MSR], there is a strong background field of $\approx 350\,\mu$T in the TUCAN area in the TRIUMF Meson Hall. The FEA simulations revealed that such a strong field could saturate the mu-metal layers of MSR, and worsen its shielding performance [ref, 9.4.1]. In addition, there are also occasional field perturbations on the order of $\sim 10\,\mu$T, which may require demagnetization procedures of MSR.

The Ambient Magnetic-field Compensation (AMC) subsystem will consist of a set of coils and magnetometers to provide static and dynamic magnetic field compensation in the exterior of MSR to ensure the shielding performance of MSR and increase possible up time of the EDM measurements. This section specifies the key requirements of this subsystem and some developmental works performed in this context.

1.2 Purposes

The PSI nEDM experiment also employed a system of surrounding field compensation [Afach2014]. To compare the situations of the PSI nEDM and the TUCAN area in the TRIUMF Meson Hall, and to clarify the requirements in our case, typical numbers to characterize the magnetic environments are listed in Table 1.

One significant difference between the two is the order-of-magnitude stronger static background field in the TUCAN area which is due to the stray field of the TRIUMF cyclotron. As long as this issue is well treated and the function of MSR secured, TUCAN MSR is expected to provide sufficient suppression of the background fluctuations to the order of $\sim 10\,$pT in the averaging time of $\sim 100\,$s. Therefore, unlike the case of the PSI experiment where the active magnetic field compensation was used during the EDM measurement sequence to achieve required magnetic field stability, the active control field is not necessary during the EDM measurement sequence.

In both cases, occasional strong magnetic field variations exist. In case of the PSI experiment, neighboring superconducting magnet test facilities were operated in daily bases, producing magnetic field variations up to $30\,\mu$T. According to [Afach2014], field variations of this order required a degaussing (or idealization) procedure of the passive shielding. The needs of this procedure, which typically took about 30 min to an hour, were reduced by the active compensation suppressing them by a factor of ~ 10[Afach2014]. In case of TUCAN, the overhead bridge crane was found to produce magnetic field variations on a comparable order. Therefore we should anticipate that such field variations will make degaussing procedures required. Active magnetic field compensation can possibly reduce the needs of degaussing procedures, if it can suppress some of the field variations to the order of $1\,\mu$T or below, it can even make the EDM measurement possible under such field variations.

Based on the above discussions, the purposes of the AMC are

- to provide static magnetic field compensation in order to prevent the background field of $\approx 350\,\mu$T from saturating MSR
- to provide compensation of dynamic magnetic field. Its main target is the strong field variations on the order of $\sim 10\,\mu$T. This will increase potential up time of the EDM measurements.

1.3 Requirements

The key requirement specifications on the performance of AMC are stated below:

	PSI	TUCAN
Static background field	$\approx 62\,\mu$T	$\approx 350\,\mu$T
Background field fluctuations $\sigma_{\lvert\mathbf{B}\rvert}(100\,\mathrm{s})$	$\approx 1\,$nT (night), $\approx 80\,$nT (day)	$\lesssim 80\,$nT
Occasional variations	$\lesssim 30\,\mu$T	$\lesssim 100\,\mu$T
MSR shielding factor	$\sim 10^4$	$\sim 10^5$ (planned)

Table 1: List of typical numbers characterizing the magnetic field environment of the PSI nEDM experiment and the TUCAN are in TRIUMF Meson Hall. Typical values of the magnetic of the static background field, the magnetic field fluctuations evaluated by the Allan deviation with the averaging time of 100 s, Typical amplitudes of occasional magnetic field variations, the quasi-static shielding factor of MSR. The numbers for the PSI experiment are based on [Afach2014, Franke2013]. Those of TUCAN are based on [Sarte2013] and recent measurements discussed in [ref].

RS 1 The AMC static magnetic field compensation should reduce the field surrounding MSR such that $|\mathbf{B}| < 0.1\,$T in the outermost layer of MSR.

Rationale: The saturation magnetic induction of mu-metal is about 0.7 T. We require $|\mathbf{B}| < 0.1\,$T in order to have a large enough safety margin.

Test: In defining the geometries of the coils, FEA simulations are essential which include a realistic background field, MSR, and the compensation coils to confirm that the requirement is satisfied.

RS 2 The aimed compensation of the dynamic compensation is a factor of 10 for field variations on the order of $\sim 10\,\mu$T.

Rationale: (The threshold of where we need degaussing is not well known, but a factor significant reduction will help, this is also a realistic number)

RS 3 The target of the static and dynamic compensation should be a volume which contains the parts moved by opening or closing of the door of MSR [ref, figure in MSR section]

Rationale: So that the parts of MSR moved by opening/closing do not become saturated. This will be necessary for operation as well as construction of MSR.

We are still on the way of the concept design, the hardware requirements are not clarified on this stage. To list some which are known at this point:

RS 4 The structure of AMC should not interfere with other apparatus in the area, according to the latest layout of the assembly of the EDM apparatusv (December 2019), this volume would be **m x **m x**m

RS 5

Some other hardware requirements should include, response time of the system which would constrain the inductance of the coils and switching time of the power supplies, an adequate rate and accuracy for the readout of the magnetometers, etc.. They will be clarified as the concept design proceeds.

1.3.1 Status of the concept design

Feasibility of the static compensation

(FEA simulation of a simple homogeneous background and Helmholtz coil pair compensating it, say that the realistic field map is required for design of the actual system)

Recent magnetic field measurements in Meson Hall

(explain the motivations, show the map and coordinate definition)

Characterization of the static background field

(show the plots, above ~1 m from the floor, the z component is almost constant)

Characterization of the field variations caused by the overhead crane

(Crane variations characterized by sensors fixed at multiple locations

- Field variations created by bridge is homogeneous (<1muT/m) and not so large < 10muT
- Field near the hook even goes up to 100 μT for the nearest sensor (**m?)

As the variations of the crane is one of the main target of the dynamic compensation, these characterizations will be considered in designing the coils for dynamic compensation.)

1.4 Timeline

(aiming to complete concept design by March 2020)

————————————[Old draft]————————————

RS 3.-34

The AMC shall reduce the external magnetic field to a level comparable to Earth magnetic field, less than 50 muT
Rationale: We do not expect the outer layer of the MSR to saturate (refer to A Sher's calulations to be inserted into this document), however, the manufacturer of the MSR will not certify it's performance for any external field value larger than Earth field
Rationale: The 50 muT requirement is Earth's field, but a smaller target field may be desirable

RS 3.-35

The AMC shall be constructed in such a way that it does not prevent access to the MSR. A 'door' as well as a roof lid might be required in the AMC coil cage.
Rationale: It will certainly be necessary to enter the MSR throughout the experimental run, so the AMC cannot render this impossible.

RS 3.-36

The ambient field of the experimental area shall be mapped and monitored to a precision acceptable to specify the construction of the AMC;
Rationale: It is important to understand the ambient magnetic conditions due to other magnetic equipment prior to running the experiment. ie the maximum DC values and amplitude of AC changes need to be known such that the right power and bandwith/speed of power supplies as well as inductance of coils can be chosen/determined.

RS 3.-37

The ambient magnetic field control system shall be developed such that its cost falls within the CFI budget allocation.
Rationale: This is necessary for completion of the experiment.

RS 3.-38

Development of the ambient magnetic field control systems shall be completed in the timeframe given by the Level 1 schedule shown in Document-154393. Critically this specifies installation of all hardware by 2021.
Rationale: This timeline is necessary to begin data taking in 2021 in order for the TUCAN EDM experiment to remain competitive.

Requirement:

buck the cyclotron field to a level that fulfills IMEDCO operations conditions for the MSR (below Earth field) and ensure the outermost layer will not saturate;

Requirement:

maybe stabilize the external field in subHz region if that can improve the MSR performance

1.4.1 Other stuff

Open question:

Final conclusion of necessity of dynamic part depends on manufacturer specs, and might only be accessible once the MSR is installed at TRIUMF and tested

Baseline design:

A coil cage of three orthogonal 'merrit coils' should do the job, but it should be checked that sufficient orders of magnetic field can be covered by this kind and number of degrees of freedom

Design Status:

Simulation and design note needed, maybe tad bit more R&D

Interfaces:

Relation to thermal enclosure, inside or outside? Does their mechanical structure interfere?