EFFECTIVE SHIELDING TO MEASURE BEAM CURRENT FROM AN ION SOURCE

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Abstract

To avoid saturation, beam current transformers must be shielded from solenoid, quad and RFQ high stray fields. Good understanding of field distribution, shielding materials and techniques is required. Space availability imposes compact shields along the beam pipe.

This paper describes compact effective concatenated magnetic shields for IFMIF-EVEDA LIPAc LEBT and MEBT and for FAIR Proton Linac injector. They protect the ACCT Current Transformers beyond 37mT external fields. Measurements made on the FAIR injector are presented.

REASONS FOR SHIELDING

In a general way, current transformers bandwidth is limited at low frequencies by the magnetic core geometry: section A and circumference l, the winding turns number N, the core material permeability μ_r and the load resistance R_L.

$$fclow=RL2\pi\mu0\mu rAN2l$$

Without shielding, a DC transverse magnetic field causes the partial saturation of the transformer core, which can be viewed as a decrease of its magnetic section. The direct effect of this partial saturation is a lower winding inductance and thus a higher low cutoff frequency. The field density at which the core saturates depends mainly on the nature of its material and is defined by its saturation flux density Bs.

In the particular case of ACCT where the active electronics compensates the transformer droop to achieve low frequency measurements [1], the effect of a DC transverse magnetic field is slightly different: as long as the electronics gain can compensate the loss of inductance, the field effect is compensated. When the electronics cannot compensate anymore the saturating field effect – basically when the core is almost saturated – the low cutoff frequency increases drastically.

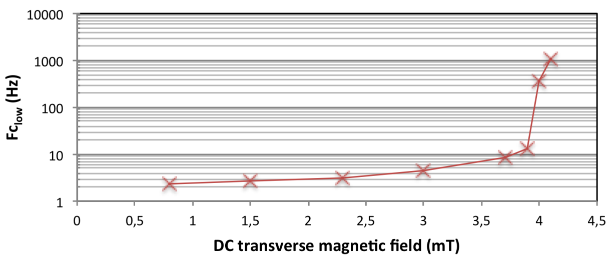

Figure 1: Influence of DC transverse H field on unshielded ACCT

Current transformer cores are at least one order of magnitude less sensitive to axial fields than radial fields. Therefore, simulations and measurements considered radial fields only.

In LEBT and MEBT sections where available space is always restricted, diagnostics might be located close to solenoids and magnets where strong stray magnetic fields are present. It becomes then essential to adopt a compact well-designed magnetic shield.

In the LIPAc LEBT section, an ACCT is installed next to a solenoid where a surrounding field up to 8mT is present. Then on the MEBT section, another ACCT coupled to a FCT had also to be located just next to a solenoid due to beam line compactness where a radial field of about 15mT is expected [2].

For the FAIR injector, an ACCT placed near a solenoid will be used to monitor the beam. It is expected to be under the influence of a 30mT radial field.

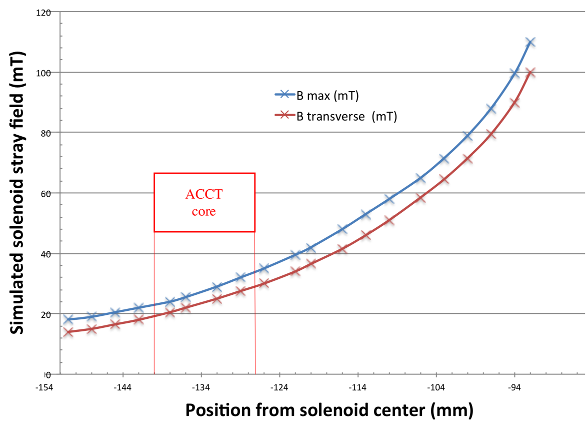

Figure 2: IFMIF MEBT field map at ACCT location [3]

Another reason to shield sensitive diagnostics from magnetic field could be the presence in their vicinity of 50Hz fields from devices such as vacuum pumps. Contrary to DC fields that show an effect on the ACCT response only when the core is saturated, AC fields caught by the transformer are directly visible in the electronics output since their spectrum is present in the instrument's output bandwidth. Figure 3 shows the influence of an AC field on the ACCT output. Without shielding, ACCT is sensitive to AC fields as low as a few mGauss.

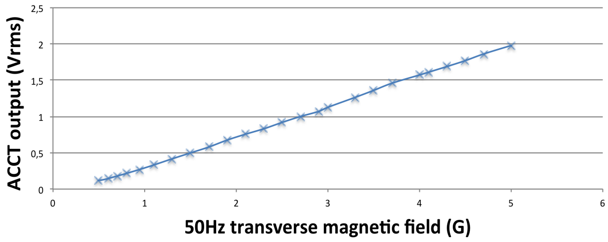

Figure 3: Influence of AC transverse H field on unshielded ACCT

Because their effect is directly detectable, AC external fields, e.g. 50Hz, can also be used to measure the shield effectiveness. To control precisely the field excitation and make accurate measurements on shields, devices such as Helmholtz coils whose field map is well known can be used.

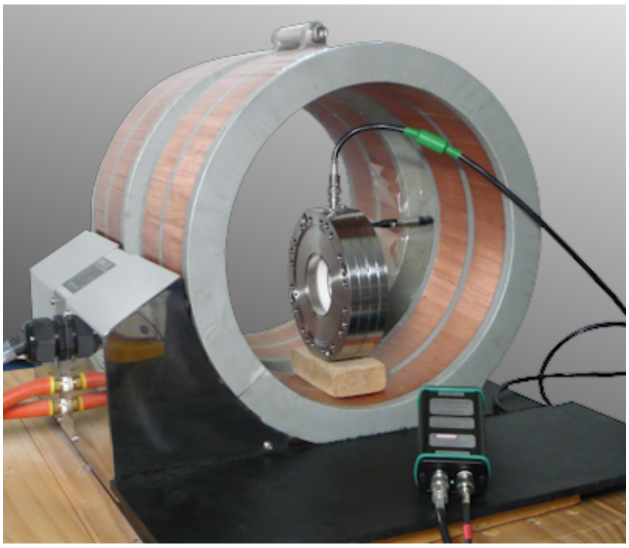
Figure 4: Shield effectiveness measurement using Helmholtz coils [4]

SHIELDING TECHNIQUES

In general, the total loss through a shield is the sum of losses by absorption and losses by reflection [5]. At DC and low frequency, the shielding effectiveness of magnetic shields is very low. Thus, rather than attenuating the field, at low frequency, the magnetic shield's aim is to deviate the field lines off their original path. The optimum shielding efficiency is obtained by a multilayer shield made of a combination of adequate materials. The assembly order of these materials is of primary importance and depends on their saturation flux density. Stray magnetic field has to be diverted step by step and none of the shielding layers must saturate at anytime. Indeed, at field density above saturation, the permeability falls off rapidly and the shield looses its efficiency. To avoid layer saturation, materials showing a high permeability at low fields – typically low-Bs materials – must be placed on the inner shield layers. High-Bs materials are used for external layers. As it happens, high-Bs materials also have a higher permeability at high fields. Typically, low-carbon steel is used on the shield outer layers to deviate high fields. Several layers might be used to reduce sufficiently the stray field magnitude. Layers of Supra [6] material and Mumetal exhibiting a lower Bs than low-carbon steel achieve a finer shielding. To deviate the weakest field lines, layers of low-Bs material such as Vitrovac or Ultraperm [7] can be used. Nanocrystalline alloys are typically too fragile to be used as shielding foils.

Magnetic materials maximum permeability occurs at field strength mid-level. At both higher and lower field strengths the permeability, and hence their shielding efficiency, is lower [5]. High-Bs materials are then least efficient for low stray fields. The best shielding efficiency is obtained by a combination of materials.

	Bs	μ_r
Vitrovac 6025 [2]	0,58 T	70000-100000
Mumetal	0,76 T	350000-500000
Supra 36 [3]	1,3 T	30000
Low-carbon steel	2,15 T	1500

Table 1: Magnetic material specifications

The shield geometry is an important factor to take into account. Best shields are made of continuous, smooth and closed geometry. Any edge in the shield surface causes breaks in the field lines propagation resulting in a loss of shielding efficiency. To shield the ACCT, a concatenation of several cylindrical boxes has been used as shown in Figure 5. Two boxes of Supra 36 material were used on the outside part of the shield, two Mumetal boxes on the inner side. Vitrovac tape was rolled around the transformer core as ultimate shield layer.

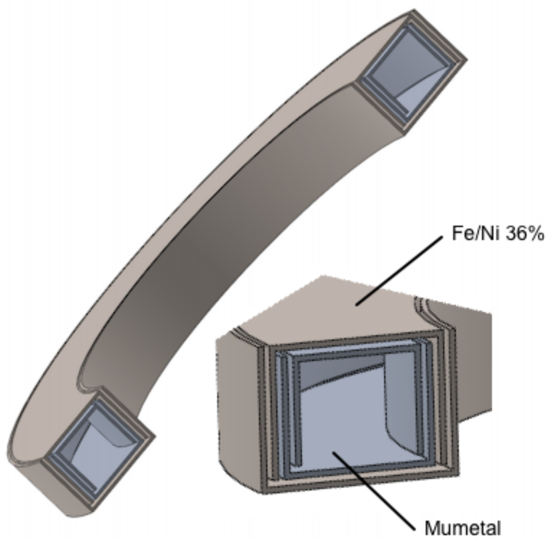

Figure 5: ACCT concatenated shield

Vigilance is required to keep an electrical isolation between each shielding box to avoid shortcutting the transformer. Drilling holes through the shield to pass the transformer's output wires must also be avoided. Any aperture in the shield layers causes drastic loss of its efficiency. It was thus decided that the output wire follows the path shown in Figure 6.

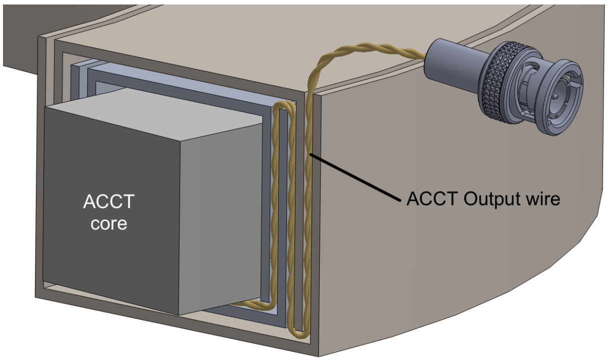

Figure 6: ACCT Output wire through shield layers

The permeability of magnetic materials is constant at low frequency and starts to decrease above 100kHz approximately. This leads to the loss of their shielding properties. At high frequency, magnetic fields create eddy currents in conductive materials. Their strength increases with the material conductivity. In short, magnetic materials are efficient to shield DC and low frequency fields, whereas high conductivity materials such as aluminum or copper must be used to shield higher frequency fields.

MEASUREMENTS ON FAIR INJECTOR

To assess the FAIR proton linac LEBT solenoid stray field magnitude at the ACCT location, a simulation showing the radial magnetic field was made with Opera. The field map was established without the solenoid shield to observe the ACCT behavior under a maximum field, as shown in Figure 7.

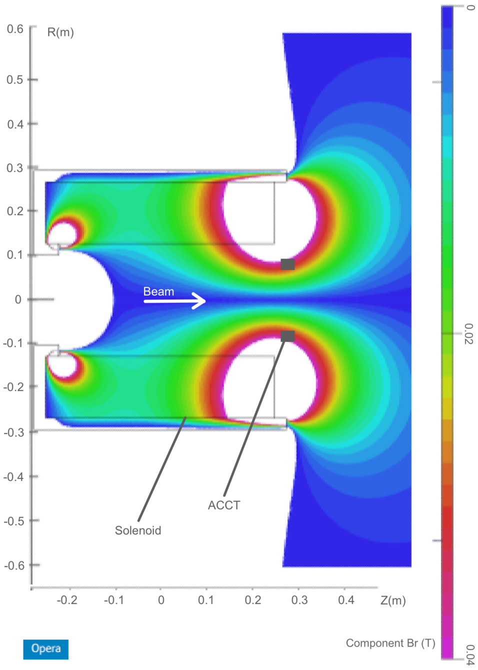

Figure 7: Br field simulation of unshielded solenoid

To test the ACCT with beam and check its shield efficiency to the solenoid stray field, the instrument was installed on the SILHI ion source at CEA/Saclay [8]. It was purposely placed closer to the solenoid than it will be in the final injector configuration to maximize the field effect. The ACCT response to a 100ms long pulse was measured while increasing the current in the solenoid to observe a potential raise in the transformer's droop.

Solenoid current	**Br simulated** at ACCT location	**Br measured** at ACCT location
100 A	20 mT	21 mT
130 A	26.5 mT	27 mT
200 A	41 mT	37 mT

Table 2: Comparison of measurements with simulation

The highest Br field value achievable with the solenoid at the ACCT location was measured at 37mT. At this value the ACCT output signal was not affected, guaranteeing the good efficiency of the ACCT shield for this field strength.

CONCLUSION

In low-energy beam lines, space charge effects limit considerably the axial length available to beam diagnostics. This leads to placing field-sensitive instruments close to magnets, RFQs and solenoids exhibiting high stray fields. Efficient and compact magnetic shields are required to protect the diagnostics. Such a compact shield was designed and tested on FAIR Proton Linac injector. It effectively protects the ACCT from radial fields up to 37mT. Similar shields have been made for other beam lines, e.g., IFMIF-EVEDA LIPAc LEBT and MEBT.

REFERENCES

[1] R. Webber, "Charged Particle Beam Current Monitoring Tutorial", FERMILAB-Conf-94/333
[2] J. Marroncle, "IFMIF-LIPAc diagnostics and its challenges", in proceeding of IBIC2012, Tsukuba, Japan.
[3] C. Olivier, CIEMAT Madrid
[4] GMW Magnet Systems, Model 5451 Electromagnet
[5] Noise Reduction Techniques in Electronic Systems, Henry W. Ott
[6] Aperam Alloys Imphy
[7] Soft Magnetic Materials, Vacuumschmeltze GmbH, Hanau
[8] C. Simon, "Tests to qualify ACCT installed on the FAIR Proton Linac injector", FPL-INJ-Note-20130304