EMC tests at the location of the DCCT and ADC calibration laboratory at FAIR project

MT25
25th International Conference on Magnet Technology
27 Aug. – 1 Sep. 2017, RAI - Amsterdam

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BACKGROUND

The requested beam precision of the Facility for Antiproton and Ion Research (FAIR) requires the regular calibration of Zero-Flux Direct Current-Current Transducers (DCCT) and ADC converters at a level of ≤ 1 ppm, which corresponds to less than 10 μV at a 10 V measurement range. A level of 0.1 ppm (1 μV) is required for the references sources. Low frequency and high frequency electromagnetic interference (EMI) from nearby interference sources such as power converters and electrical distribution systems are a potential threat which can impair the required calibration accuracy. Electromagnetic compatibility (EMC) tests were conducted to select suitable laboratory locations.

OBJECTIVES

The objective of the EMC investigation is to determine the local electromagnetic levels in terms of conducted and radiated emissions and frequency range by measurement and to determine any required EMC mitigation measures such as shielding of the laboratory location. The final objective is to ensure undisturbed operation of the calibration and test equipment within the required resolution.

METHODS

EMC SITE SURVEY

Assessment of potential EMI sources in the vicinity of the calibration laboratory (Figure 1):

- Low frequency magnetic fields from the power distribution system, including stray fields from distribution transformers, distribution panels, bus bars and power cables
- Low frequency and high frequency stray interference from magnet power converters, e.g. the input transformer, internal chokes, the IGBT inverter and Internal cabling
- Power quality and conducted emissions from equipment on the shared power supply
- HF interference from nearby equipment such as RF transmitters, HVAC[1)] and lighting equipment. [1)] HVAC = Heating Ventilation & Air Conditioning

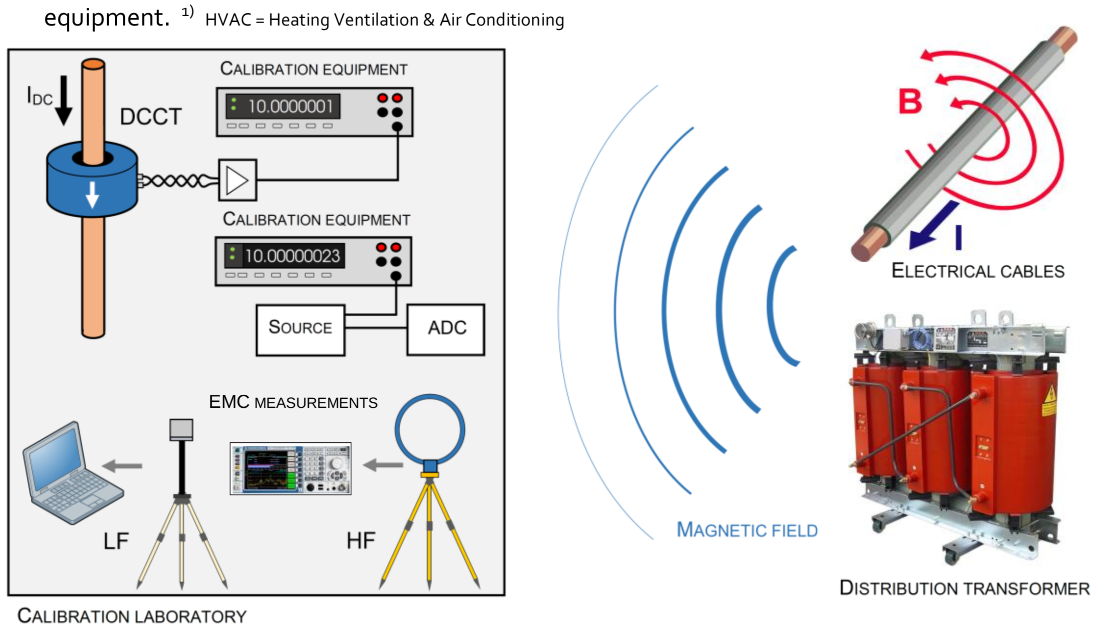

Figure 1 Arrangement of DCCT/ADC calibration laboratory with external EMI sources

MEASUREMENTS

The electromagnetic environment of the calibration laboratory was assessed by conducting the following measurements:

- Low frequency magnetic field measurements in the frequency range of 5 Hz – 100 kHz
- Power quality and conductive emission measurements of power supply to the laboratory (frequency range 50-2500 Hz and 150kHz – 30 MHz)
- High frequency electromagnetic field measurements in the frequency range 30 MHz – 6 GHz.

Measurements were conducted under realistic operational conditions of power converters.

RESULTS

1. Low frequency magnetic fields are the dominant potential sources of interference:
   - Direct fields from converter input transformers at a distance < 10 m.
   - LF magnetic field from leakage currents from TN-C(S) distribution system ($H=\Sigma I/2\pi r$).
   - Background fields from distribution transformers, distribution panels and HVAC units.

   Overall magnetic flux density values were in the range of 100nT to the low μT range under full load conditions.

   Figure 2 shows typical magnetic flux density values for various electrical sources as a function from distance.

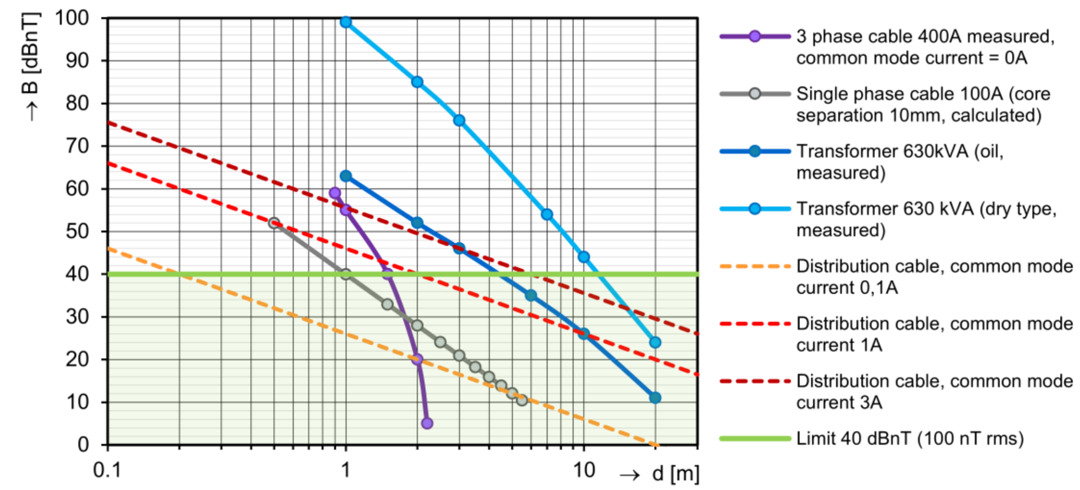

Figure 2 Magnetic flux density of various sources as a function of distance

2. High frequency electromagnetic interference from magnet power converters is generally acceptable when basic filter measures are implemented (out-of-band interference).
3. Power quality and conducted emissions of the accelerator hall were typically in line with industrial levels, which can be easily filtered by installing a mains stabilizer/filter for the power supply to the calibration laboratory.
4. EMI values show significant fluctuations over time, hence definition of test conditions to represent all accelerator conditions is important. Figure 3 shows an example of the flux density from a co-located power converter as a function of output setting.

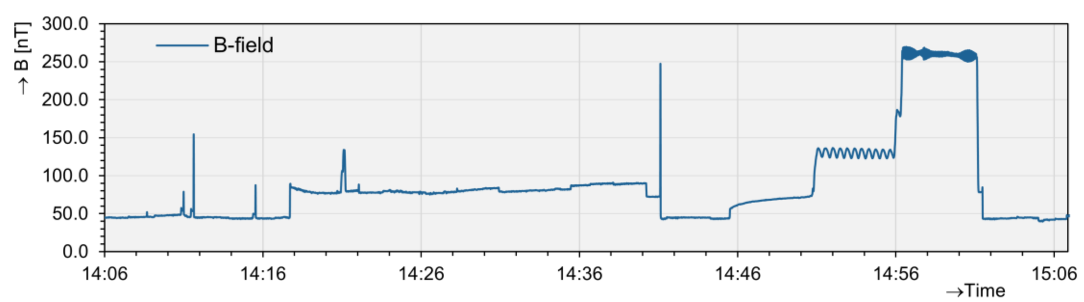

Figure 3 Trend of magnetic flux density (RMS, summation 3 axis, bandwidth 5Hz – 2kHz) at 4 meter distance from a power converter at various output settings of between 500A and 3 kA output current.

5. Low frequency magnetic fields induce interference voltage in DCCT and ADC wiring:

   $V_i = -A.dB/dt$, $B = B_p.\sin(\omega.t)$, $|V_i| = A.2\pi.f.B$,

   V_i = induced voltage [V], A = loop wire area [m²], B = magnetic flux density [T], f = frequency [Hz]

   Typical induced voltage are ≥ 1 μV for A = 0.03 m², f = 50 Hz and B > 100nT.

   The effective coupling path is to be reduced by twisting of cable wiring and considering end effects of cable terminations. Induced voltages are proportional with frequency, hence harmonics of stray currents are also to be considered.

DOMINANT EMC ASPECTS

1. Magnetic fields at the calibration equipment setup are to be kept low by retaining adequate distance to EMI sources, as found during the assessment and measurements.
2. The dominant effect turned out to be the TN-C part of the electrical distribution system, which induces neutral currents in the earthing system, Figure 4. Leakage current are additionally caused by unbalance of small single phase loads with rectifiers on a 3 phase supply system as 3rd order harmonics currents add in phase on the neutral conductor and flow through the shared earthing.
3. A pure TN-S distribution system is required with a single neutral earth connection (either transformer side or main distribution board side).

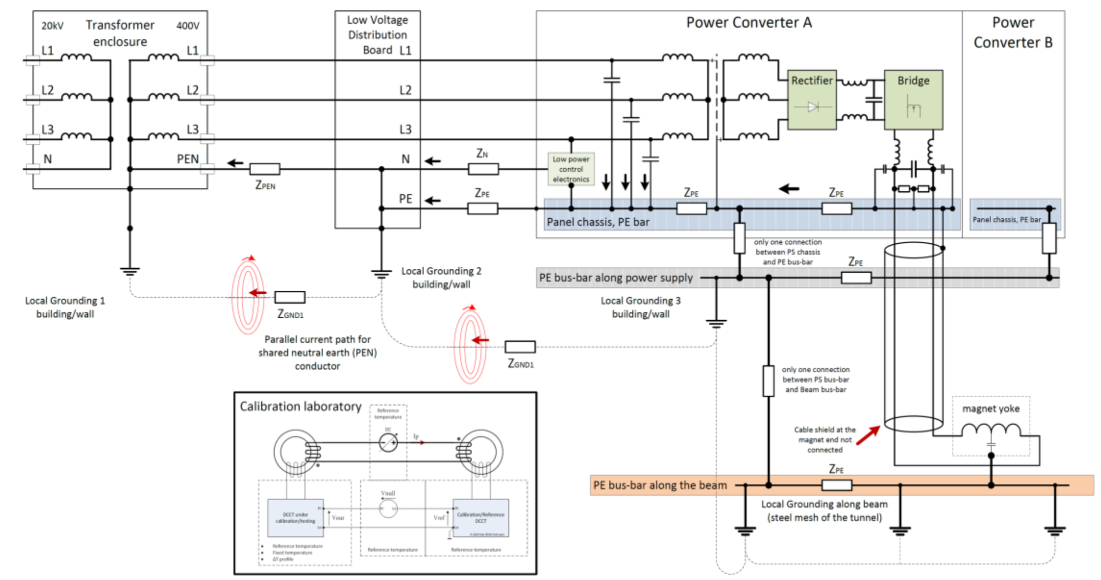

Figure 4 Schematic diagram of power supply to converters and leakage current paths causing magnetic fields at the calibration laboratory location

CONCLUSIONS

1. To ensure a calibration accuracy of < 1 ppm, the electromagnetic environment of the laboratory is to be assessed and adequately low EM levels to be confirmed by measurements. Low frequency flux density values not higher than 30 nT_{RMS} are recommended.
2. Adequate distance is to be retained to known EMI sources (as per Figure 2).
3. A coaxial arrangement is to be used for the high current primary DCCT circuit (to minimize effect of ripple current).
4. Only a TN-S power distribution system with a single neutral-earth connection (transformer or main distribution panel) is suitable for a calibration laboratory environment as per IEC 60364-4-44 (LV installations, Protection against voltage disturbances and electromagnetic disturbances).
5. All cable connections between DCCT, ADC and calibration equipment require twisted wire pairs to minimize differential mode loops and magnetic field coupling area.
6. For flux density values of > 100nT, a shielded room is to be used with μ-metal shielding or multiple mm's of steel (container). Approaching a full Faraday cage structure with minimum apertures, mains input filter and fibre optic signal connections will also reduce electrical and high frequency EM field penetration.

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