DEMAGNETIZATION OF AN ENTIRE ACCELERATOR VAULT*

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Abstract

The ARIEL electron linac produced its first high-energy beam on 31 September 2014. Despite over 40 years of experience with ion beams, transporting electrons constituted a new challenge for TRIUMF. With good reason: the difference in rest mass makes electrons orders of magnitude more sensitive than ions to magnetic fields (for the same kinetic energy). In this paper we show how beam steering could have been seriously compromised by the remament field from the structural steel of the building, and how this issue was addressed using a technique developed to demagnetize steel-hull ships: we degaussed the entire accelerator vault.

INTRODUCTION

Compensation of the ambient magnetic field in the accelerator vault has been considered since the early stage of the design of the ARIEL electron linac [1]. Two sources of ambient field had been identified: (1) the stray field from the 500 MeV cyclotron installed in the adjacent vault (see Fig. 4), and (2) the earth's magnetic field, which is mostly vertical in Vancouver [2]. Due to the nature of these two sources, the ambient field was assumed to be quasi-homogeneous, and dominantly in the vertical direction. Based on these assumptions it was established that an active compensation of the vertical component would be sufficient to bring the field below 0.2 Gauss. The electron beamline and its steering correctors were designed accordingly [3–6].

UNEXPECTED FLUCTUATIONS

A first series of magnetic measurements taken along the path of the electron beam, before the installation of the beamline, revealed unexpected fluctuations and a significantly large horizontal component of the ambient field [7]. After this first series of measurements a 3-axis Hall probe was purchased. Reproducibility better than 0.02 G was achieved with a simple setup: the probe mounted on a non-magnetic tripod, a spirit level and a plumb laser were used for alignment, and zero-field chamber was used to periodically re-zero the gaussmeter.

The measurement was repeated with the cyclotron main magnet on and off [8], see Fig. 2. The contribution from the cyclotron was smooth and almost purely vertical, following

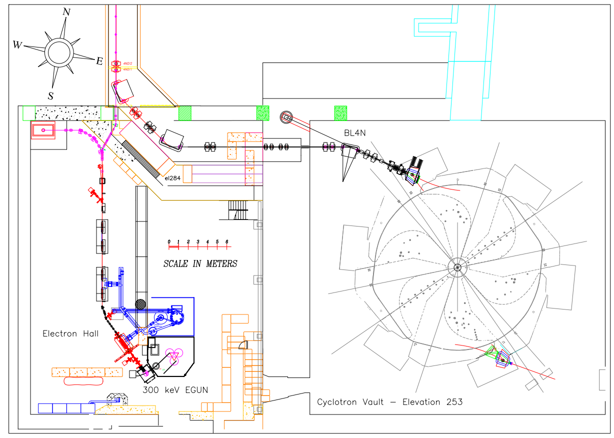

Figure 1: Schematic view showing the location of the electron linac (left) w.r.t. the 500 MeV cyclotron (right). The electron beam plane is ~61 cm (24 inches) below the cyclotron mid-plane in the electron hall.

a dipole-like drop-off [9]:

$$\begin{aligned} B_y &= \frac{-12.7\ [\mathrm{T.m}^3]}{r^3}\left(3\sin^2\lambda - 1\right), \\ B_r &= \frac{-12.7\ [\mathrm{T.m}^3]}{r^3}\left(3\sin\lambda\cos\lambda\right), \end{aligned} \tag{1}$$

where r and y are cylindrical coordinates with the cyclotron centre as origin, and with y pointing up; $\lambda = \arctan(y/r)$. It was a suprise that the fluctuations did not depend upon the cyclotron field, since it had been anticipated that the structural steel of the reinforcement bars (rebars) in the floor was magnetically soft. We concluded therefore that the rebars were magnetically (see Fig. 3). It was determined experimentally that the magnetic shield protecting superconducting cavities could handle this level of ambient field [10]. However, the designed steerers would be insufficient to keep steering errors smaller than the beam size [11].

DEMAGNETIZATION OF THE VAULT

To smooth out those fluctuations, because we thought that the cyclotron field was magnetizing the rebars, it was first considered to pave the floor below and around the beamline with steel plates [8]. As it was found that the rebar was permanently magnetized, we set about to demagnetize them using low frequency AC field with (slowly) vanishing amplitude, like steel hulled war ships are demagnetized in degaussing ranges [12].

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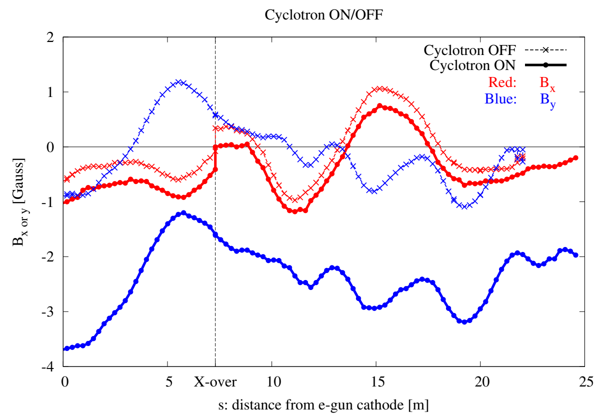

Figure 2: Transverse magnetic field components along the electron beam path (B_x: horizontal, B_y: vertical). Data is plotted as is (no smoothing). The discontinuity in B_x at s=7.3 m corresponds to the point where the coordinate system rotates to follow the beam path. Note: the fluctuations in B_y observed around $s = 22$ m have been caused by motion of the overhead cyclotron crane.

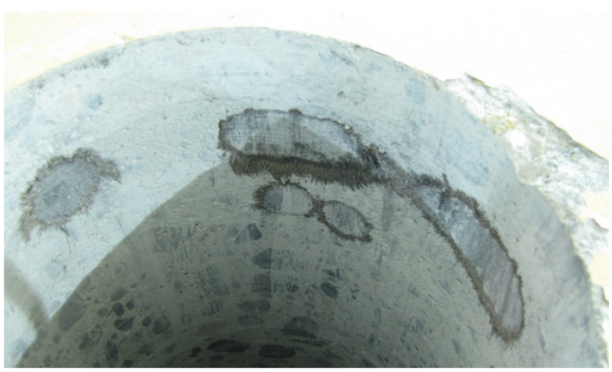

Figure 3: A coring close to the beam path showing steel re-enforcement bars with iron filings adhering to the rebar edges due to remanent magnetization.

An old ~60 cm diameter coil was put on wheels; a steel plate was installed on top to contain magnetic flux; the coil was connected to a programmable 40 A power supply, see Fig. 4. This setup produced an AC magnetic field of arbitrary low frequency and fixed amplitude (~400 G at the floor level). It was moved slowly (compared to the AC frequency) across the vault so that each point of the floor would see an oscillating magnetic field of slowly vanishing amplitude.

The frequency had to be chosen so that the skin-depth would be greater than the thickness of structural steel. Since the properties of the steel and the dimension of the bars was poorly known, we repeated the entire process several times, using decreasing frequencies, from 4 Hz down to $\frac{1}{4}$ Hz. Degaussing proved the more effective the lower the frequency [8]; but moving a ~60 cm diameter coil slowly compared to $\frac{1}{4}$ Hz means moving by only a few meters per minute, which explains why no lower frequency was attempted. As a result, the amplitude of the oscillation on the

Figure 4: Degaussing coil, on wheels, with a steel plate and a 40 A AC power supply on top. The blue line on the floor indicates the location where the beamline/linac is now installed.

ambient field has been reduced by almost a factor of four, down to ~ ±0.3 Gauss, see Fig. 5.

The origin of the permanent magnetization of the structural steel is unknown. But what is known is that the stray field from the cyclotron has not caused it: the measurement has been repeated two years later (in April 2016) on a section of the beamline still accessible for measurements (where a long drift space has been left for the instalation of a future third cryo-module). The main magnet of the cyclotron has been turned on and off several times over these two years, and the ambient field is still practically identical to what it was after the last series of degaussing (completed in February 2014), see Fig. 5.

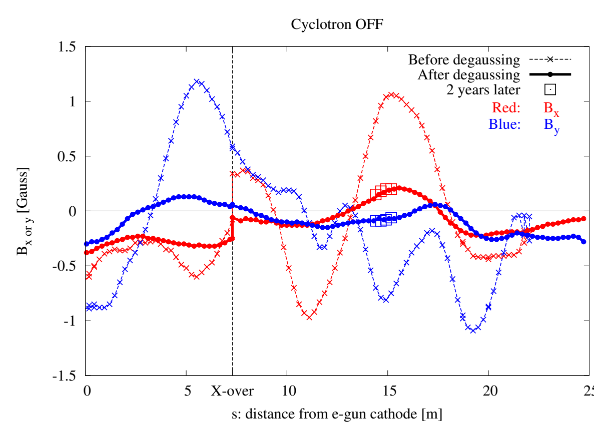

Figure 5: Ambient field measured before (same data as in Fig. 2) and after degaussing the electron hall. A third series of measurements, carried out ~two years later on a small section of the beamline shows that the permanent magnetization did not come back.

SHIELDING FROM BEAMLINE MAGNETS

So far in this study we have neglected the effect of the beamline component on the ambient field. A finite element model (OPERA-3D) of the low energy beam line showed that a significant fraction of the ambient field present before the installation of the beamline magnets is "screened" by them, see Fig. 6.

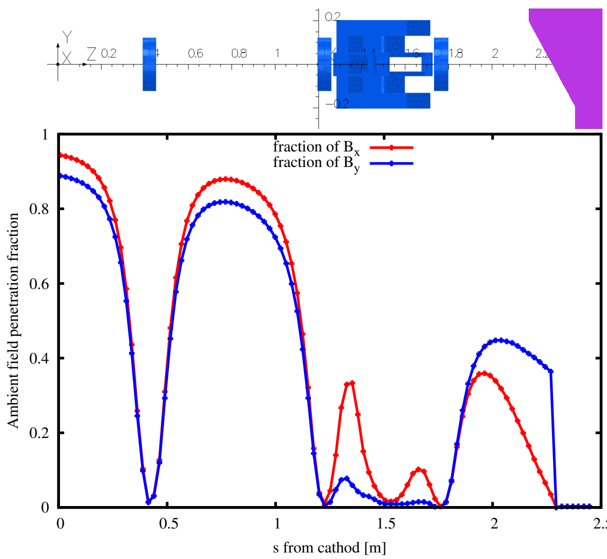

Figure 6: Top: side view of the OPERA model of the low energy transport line, that include 3 solenoids, one dipole (for momentum analysis) and the magnetic shield of the first accelerator cryomodule (magenta).

SEGMENTED HELMHOLTZ COILS

To compensate the slowly varying field from the cyclotron (Eq. 1) Helmholtz coils are placed all along the beam line, see Fig. 7; each section is powered by a separate supply. The linac will be able to run whether the cyclotron magnet is on or off; Helmholtz coils will have to be turned on or off accordingly.

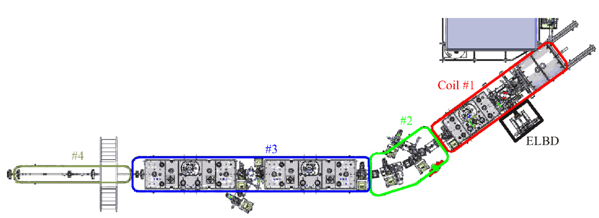

Figure 7: First four segments of the verctical ambient field compensation coils.

CONCLUSION

Demagnetization of the floor was successful. Helmholtz coils are used to actively compensate the field contribution from our 500 MeV cyclotron. The remaining ambient field seen by the beam is well within the range of our steering correctors. The electron beam lines and the two first accelerating cryomodules have been successfully commissioned; steering errors could be kept small enough that steering and focusing could be tuned independently.

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