Signal Distortion of the SIS18 DC Transformer GS01DT_ML after relocation from section 7 to section 1

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1 Introduction

The New Parametric Current Transformer (N-PCT) by Bergoz has been moved from section 7 to section 1 of the SIS18 synchrotron to make space for cavities. The PCT is now called GS01DT_ML. We briefly report on the influence of the dipole stray field on the PCT output signal in the new installation position. A simple software correction scheme is suggested which is similar to the one established at the HIT synchrotron.

2 Available Data

2.1 Xenon Data

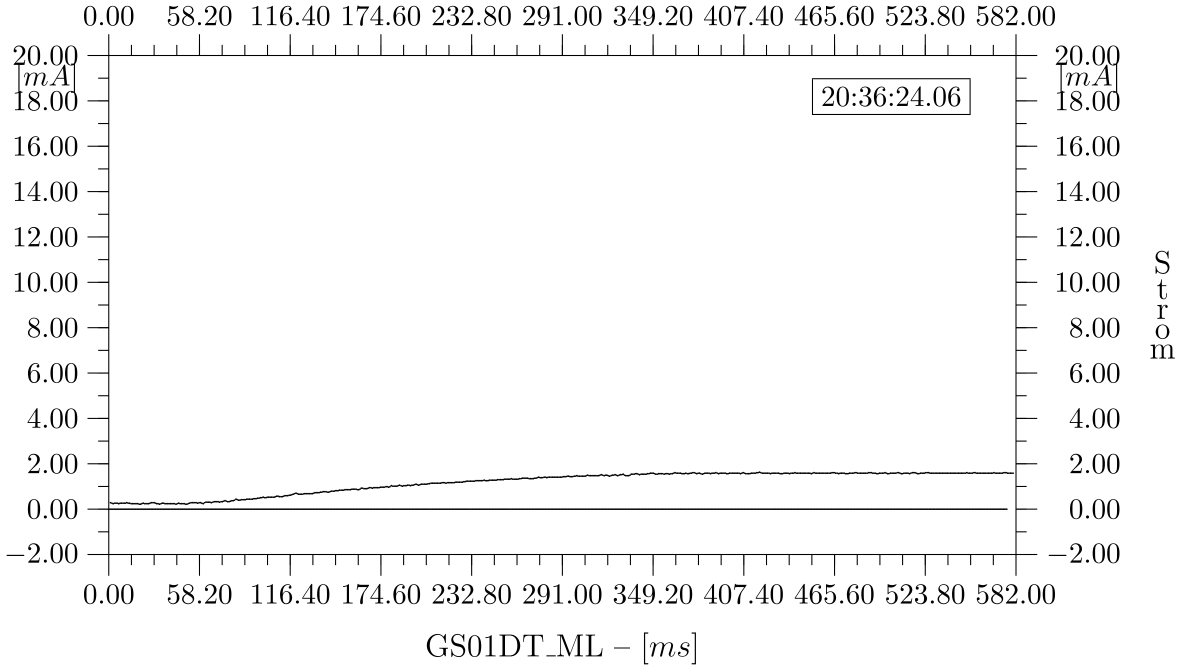
Two "empty" SIS18 cycles when no beam was in SIS18 were recorded in the control system as protocols at different magnetic rigidities $B\rho$ and different days during the Xenon beam time. These protocols lack the information of the dipole, but serve for normalisation of the ABLAXX data that are recorded in arbitrary units. The latter data include the SIS18 dipole data, but were taken with a beam of $\sim 85\mu A$. Nevertheless, the data quality was sufficient to estimate the signal distortion.

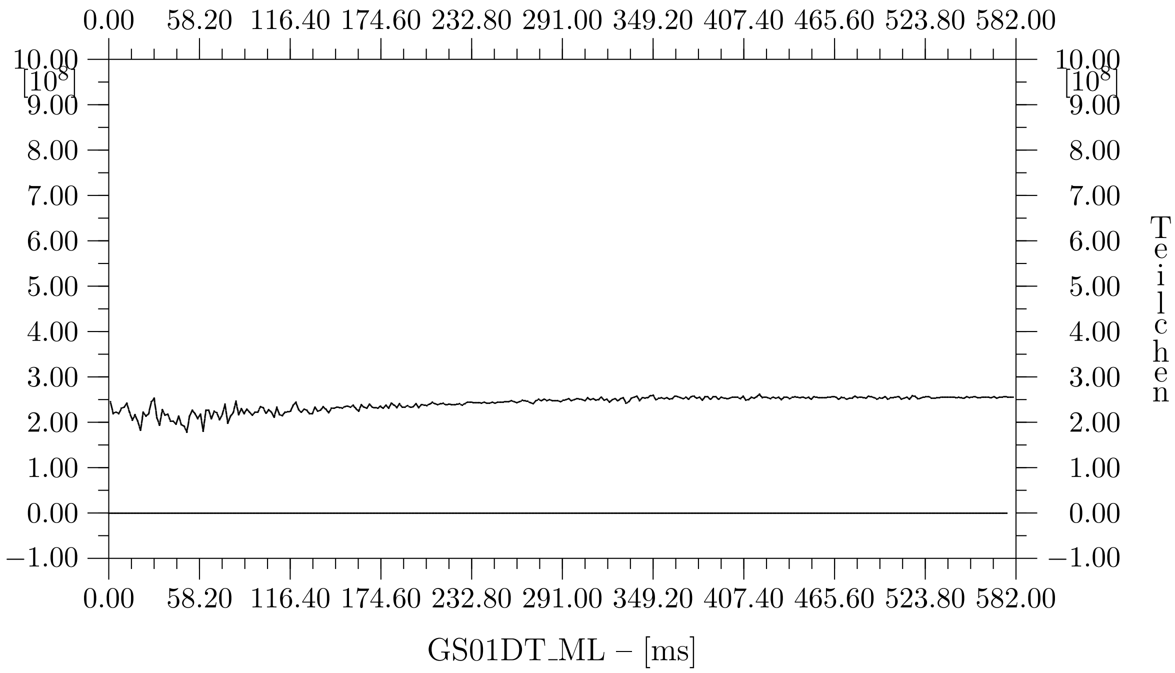
- HTP — S10 — $^{124}XE^{43+}$ — 300.000 MeV/u, 19.Jun 16 20:36:03, $B\rho = 7.74$ Tm
- HFS — S08 — $^{124}XE^{43+}$ — 600.000 MeV/u, 14.Jun 16 13:13:20, $B\rho = 11.7$ Tm

2.2 Carbon Data

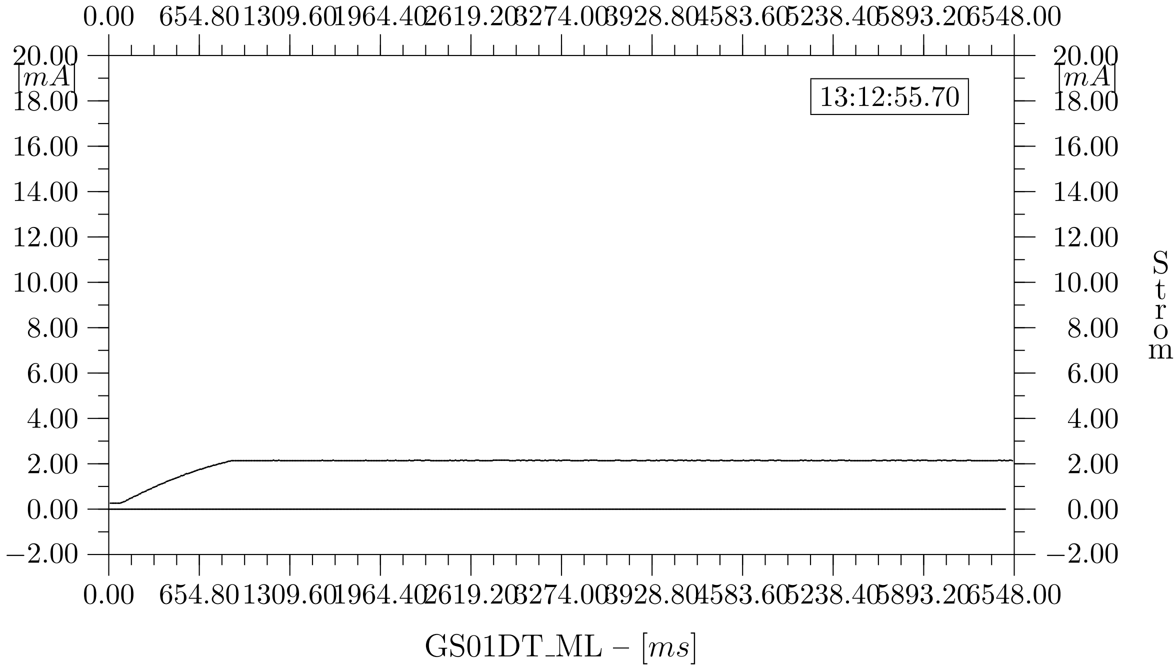
Further "empty" SIS18 cycles were recorded in ABLAXX during the Carbon beam time. Data of the main dipole and of both transformers GS01DT_ML and GS09DT_ML were recorded without beam and provide a "clean" data set for the investigation of the signal distortion of the transformer by magnetic stray fields.

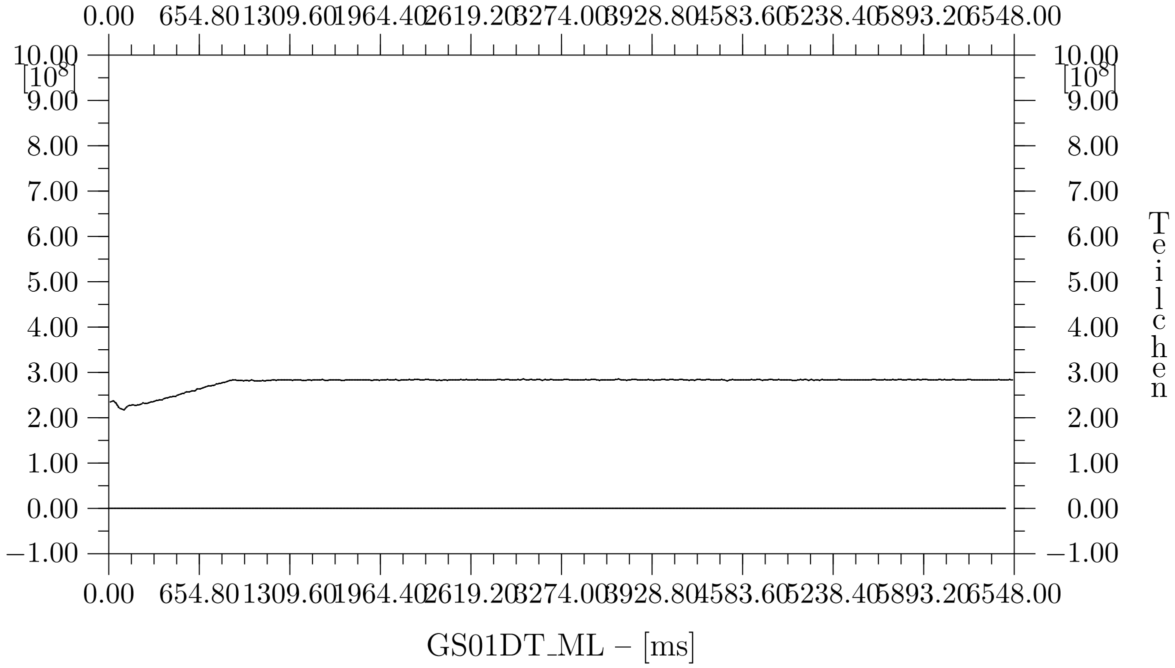
- S09 — $^{124}C^{6+}$ — 300.000 MeV/u, 02.Jul 16, $B\rho = 5.37$ Tm
- Dipole current = 979.2 A, Dipole field ~ 0.54 T





Gain	4		
Delay	2.00ms	Average	1
StromWert	1.58mA		529.8ms nach Start
TeilchenZahl	$2.54 \cdot 10^8$		





Gain	4		
Delay	2.00ms	Average	16
StromWert	2.15mA		6035.7ms nach Start
TeilchenZahl	$2.84 \cdot 10^8$		

3 Xenon data

3.1 Approximation of Dipole Distortion

Three cycles of GS01DT_ML and dipole current were recorded in ABLAXX in relative units during a Xenon (Xe 43+, 300 MeV/u) beam time for HTP detector tests at a sampling rate of 1 kHz. The beam intensity was reduced to 5x10^6 particles in the SIS18 or 83 μA at flat top. The measurement of the transformer was set to 20 mA. We disregard this DC current, 5 % with respect to flat top current, in this simple analysis.
The data of Figure 1 have been treated in the following way:

- Both signal traces were offset corrected using the final part of the data (3650-3700 ms) where no beam is left in the SIS18 and the dipole has ramped down.
- The transformer signal was normalised to 1.6 mA using the "empty cycle" data of the measurement protocol of 19th June.
- The dipole signal was normalised to the transformer signal using the flat top region (2000-2100 ms).
- The data of three SIS18 cycles were averaged.

3.2 Discussion

Figure 1 shows the two normalised signals of the 7.74 Tm synchrotron cycle together with the difference signal which was multiplied by a factor of 5 for better illustration. The dipole signal shape matches that of the transformer signal quite well. In the previous installation position the signal of a different Bergoz transformer of the same type has been influenced also by other magnets (this transformer was damaged during bake-out after relocation to S01 and replaced by the present transformer).
A small discrepancy of 40 μA (not scaled by x5!) is detectable at the injection flat top. It is due to the non-subtracted DC beam current which biases the correction coefficient. This artefact is eliminated in "empty cycle" data sets, i.e. when the SIS18 was cycled without beam, as shown in section 4.
During the ramping times systematic deviations in the range of 0.15/0.1 mA (not scaled!) at the start/end of the cycle occur. Similar observations have been reported in [1] for the HIT current transformer which however suffers from bigger stray field distortions from dipole and sextupole magnets.

Scaling the value of 1.6 mA to the 600 MeV/u data yields an estimated current distortion of 2.4 mA which is in reasonable agreement with the measured value of 2.15 mA (see data of 14th June in section 2). For the maximum rigidity of 18 Tm, the distortion would be about 3.3 mA or 16% full scale in the 20 mA range. The estimated field correction factor is about 1800 $\mu A/T$ (=3.3 mA/1.8 T). In comparison the GSI-type transformer GS09DT_ML has a field correction factor of 5.5 $\mu A/T$ which yields a maximum distortion of 10 μA (B_{max}=1.8 T).

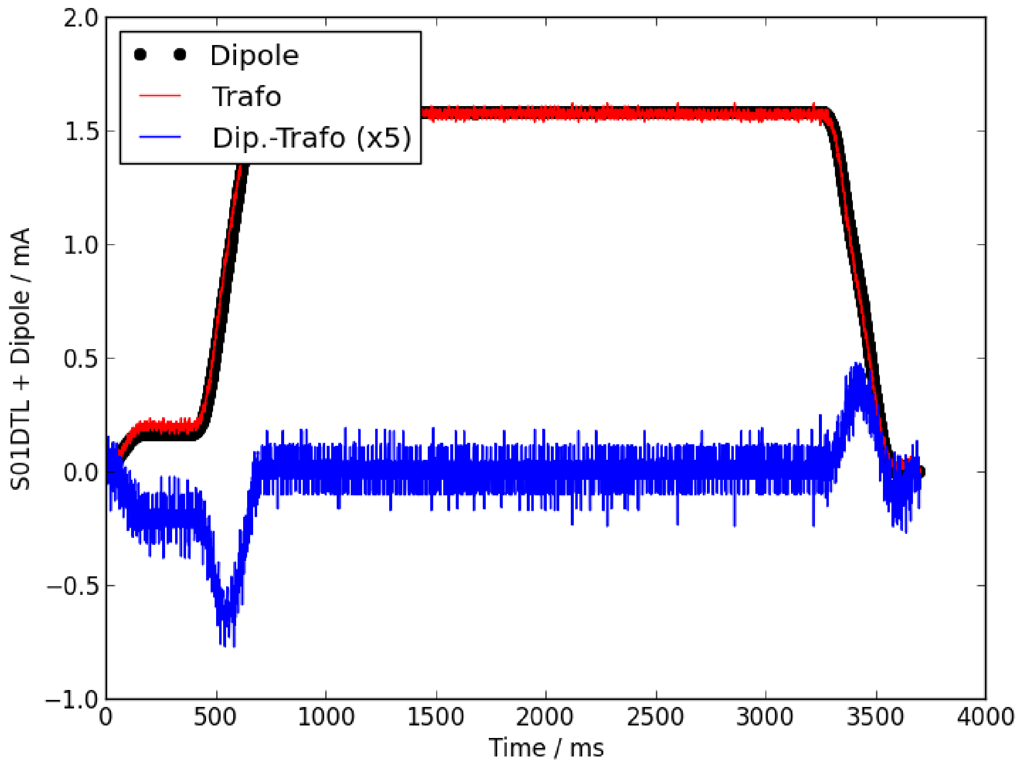


Figure 1: Signal distortion of GS01DT_ML output signal by dipole current for a magnetic rigidity of 7.74 Tm. The dipole curve (black dots) has been normalised to the transformer reading (red trace) at flat top. The difference signal (blue trace) has been multiplied by a factor 5 to enhance the remaining discrepancy along the dipole ramps.

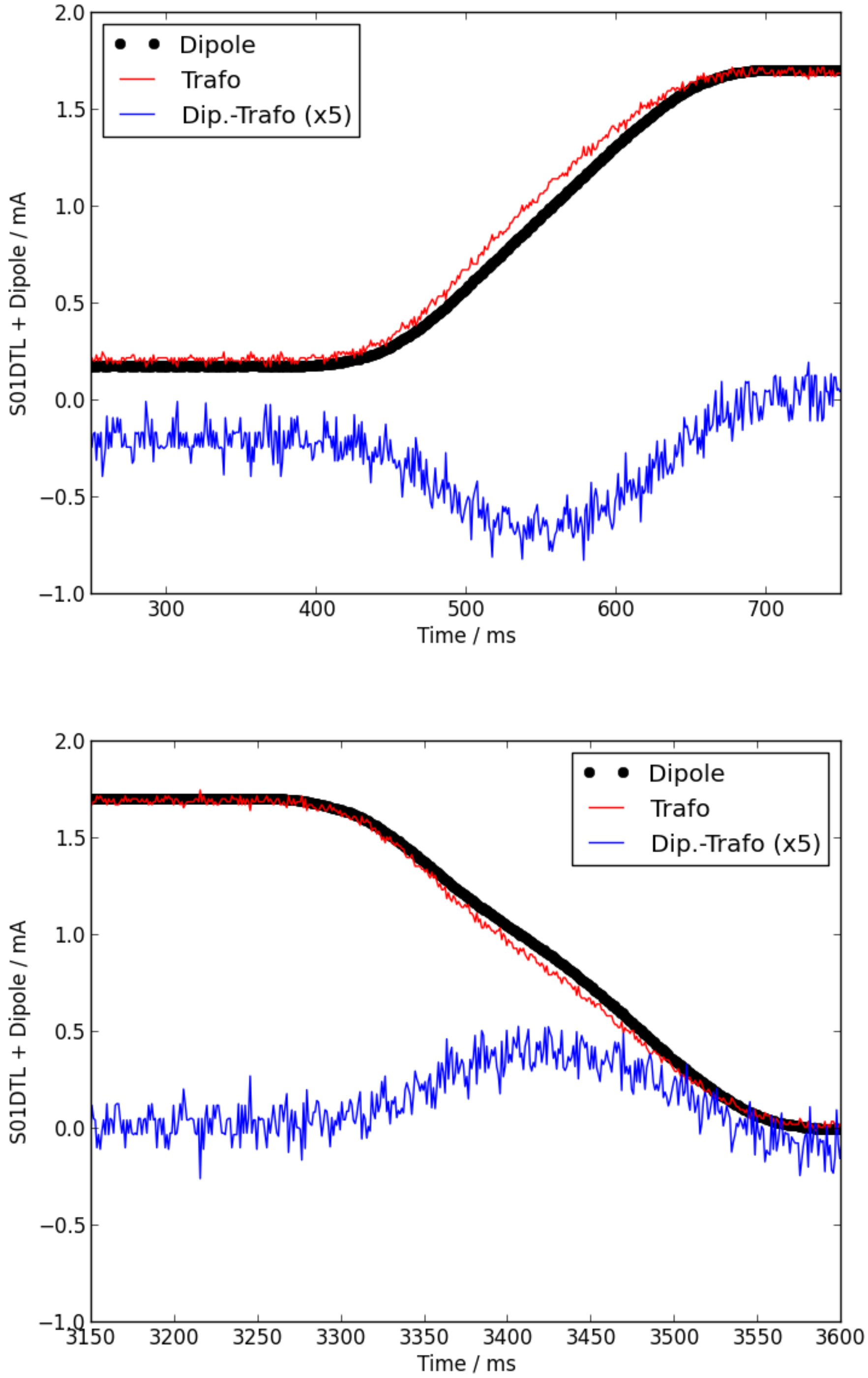


Figure 2: Data of Figure 1 for the acceleration period at the cycle start (top) and dipole ramp down period at the cycle end (bottom).

4 Carbon Data

4.1 Approximation of Dipole Distortion

Offsets in transformer and dipole signals were subtracted using the first 50 data samples. Then, the dipole data were matched to the transformer data by a least-square fit of a straight-line, yielding one offset parameter$(-12.6 \pm 0.5)\mu A$ and one dipole distortion coefficient $(1866.6 \pm 1.3)\mu A/T$. The covariance was -0.57 $\mu A^2/T$. A constant measurement uncertainty of 1% full scale was assumed for the transformer. The results are shown in Figure 3.

4.2 Discussion

The value of the distortion coefficient is in good agreement with the estimate of 1800 $\mu A/T$ (relative error< 4%). Compared to the Xenon data the constant offset at the injection plateau (200-1000 ms) has been removed in the difference signal at the expense of a small offset at the cycle start. The deviations along the two ramps are now reduced in amplitude to below 40 μA and are now bipolar in the present example.

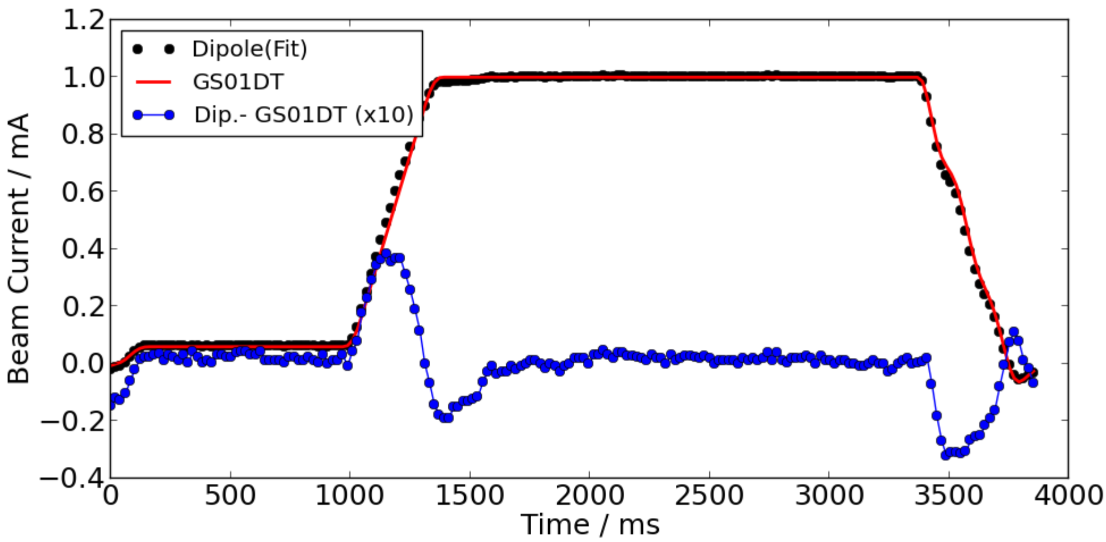


Figure 3: Signal distortion of GS01DT_ML (red trace) for a 5.37 Tm dipole ramp (black dots). The dipole ramp was scaled in order to match the transformer data using a least-square approach. The blue dots represent the enhanced difference signal which was multiplied by a factor of 10.

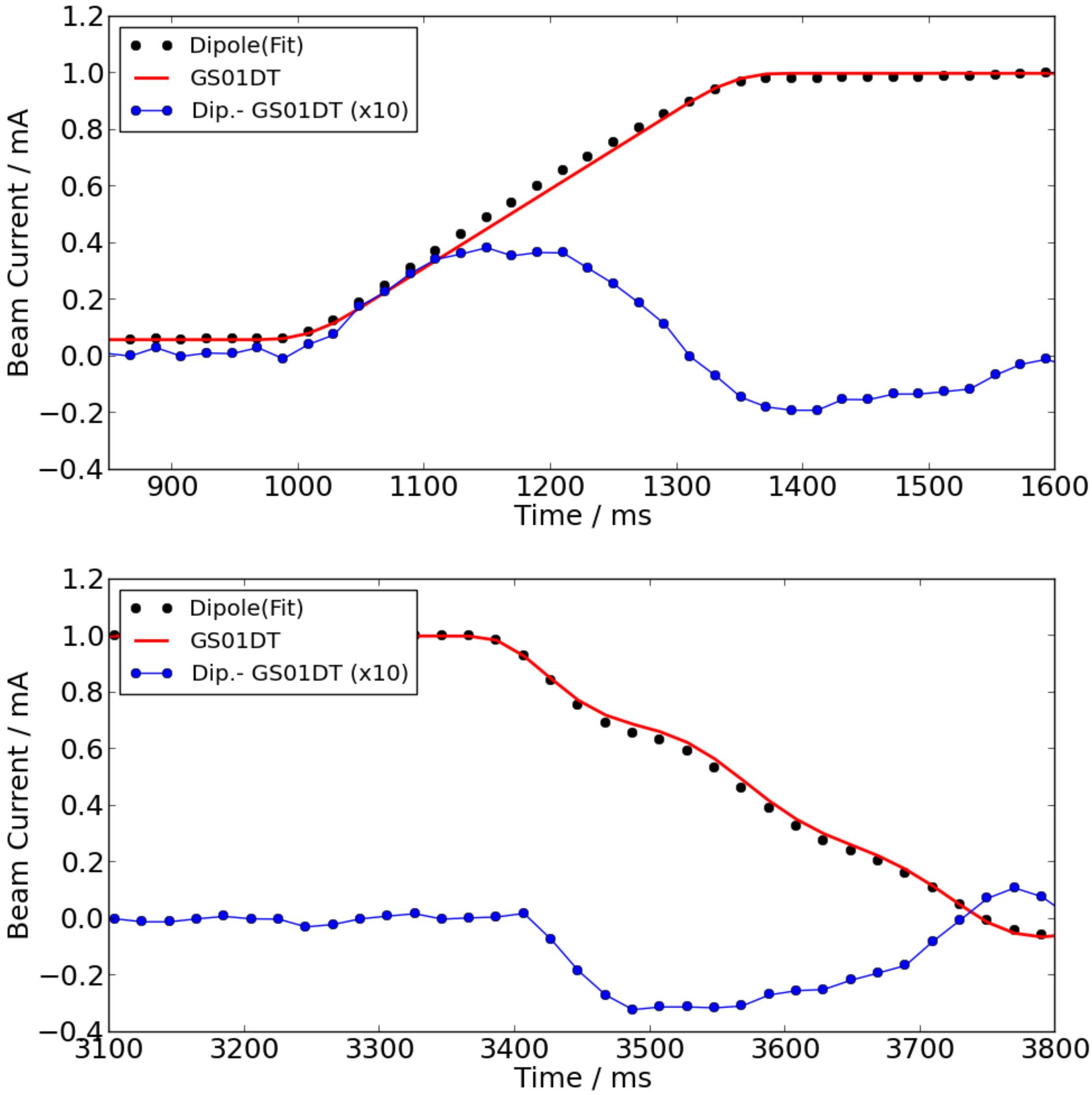


Figure 4: Data as for Figure 3 for the initial part and the ramp-down phase of the cycle.

4.3 Comparison of GS01DT_ML and GS09DT_ML

Figure 5 compares the signal distortions for both transformers GS01DT_ML (red) and GS09DT_ML (black) for cycles with beam (solid lines) and without beam (dashed lines). The blue data set represents the corrected GS01DT_ML current after subtraction of the dipole component. The difference between both transformers is shown as green trace, again multiplied by a factor of 10. At the end of the extraction the deviation is below

80 μA at 3100 ms. The discrepancy during the dipole ramp-down is of similar size, but meaningless in practical terms. Figure 6 shows that same data for different time periods of the cycle.
The "50%" spike in the GS09DT_ML data at 3250 ms is due to the automatic test procedure executed at the end of the cycle. Hereby, a test current of 50% full scale is applied to the transformer core. It is evident that the signal distortion of GS01DT_ML is not negligible for typical beam operation. In the present case about 4x10^9 C^{6+} particles are stored in SIS18 at flat top according to GS09DT_ML, while this number is 20% higher for GS01DT_ML.

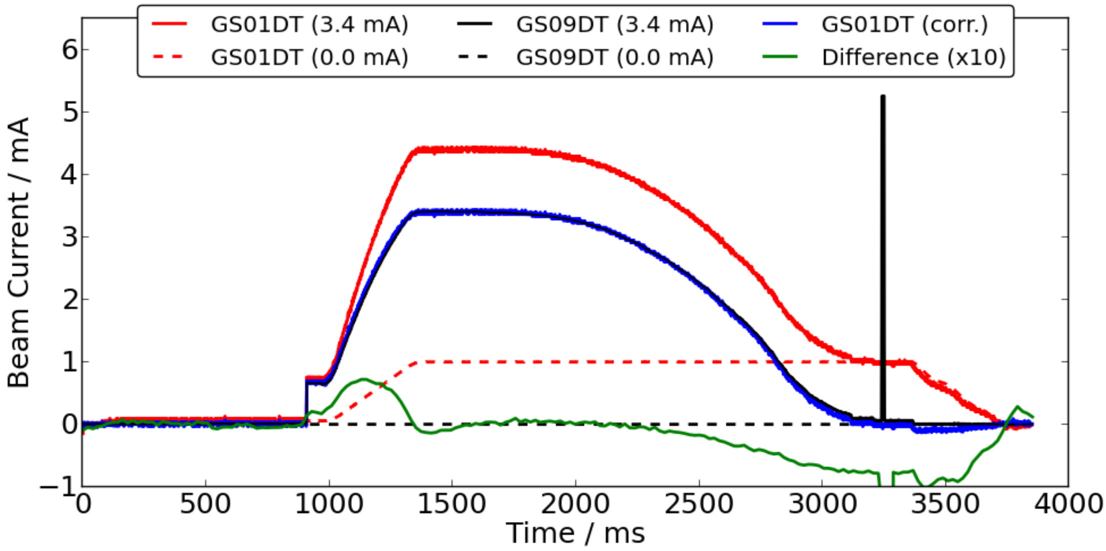


Figure 5: Comparison of transformer signal GS01DT_ML (red) and GS09DT_ML (black) for cycles with beam (solid lines) and without beam (dashed lines). The blue data set represents the corrected GS01DT_ML current after subtraction of the dipole component. The difference between both transformers is shown as green trace, again multiplied by a factor of 10.

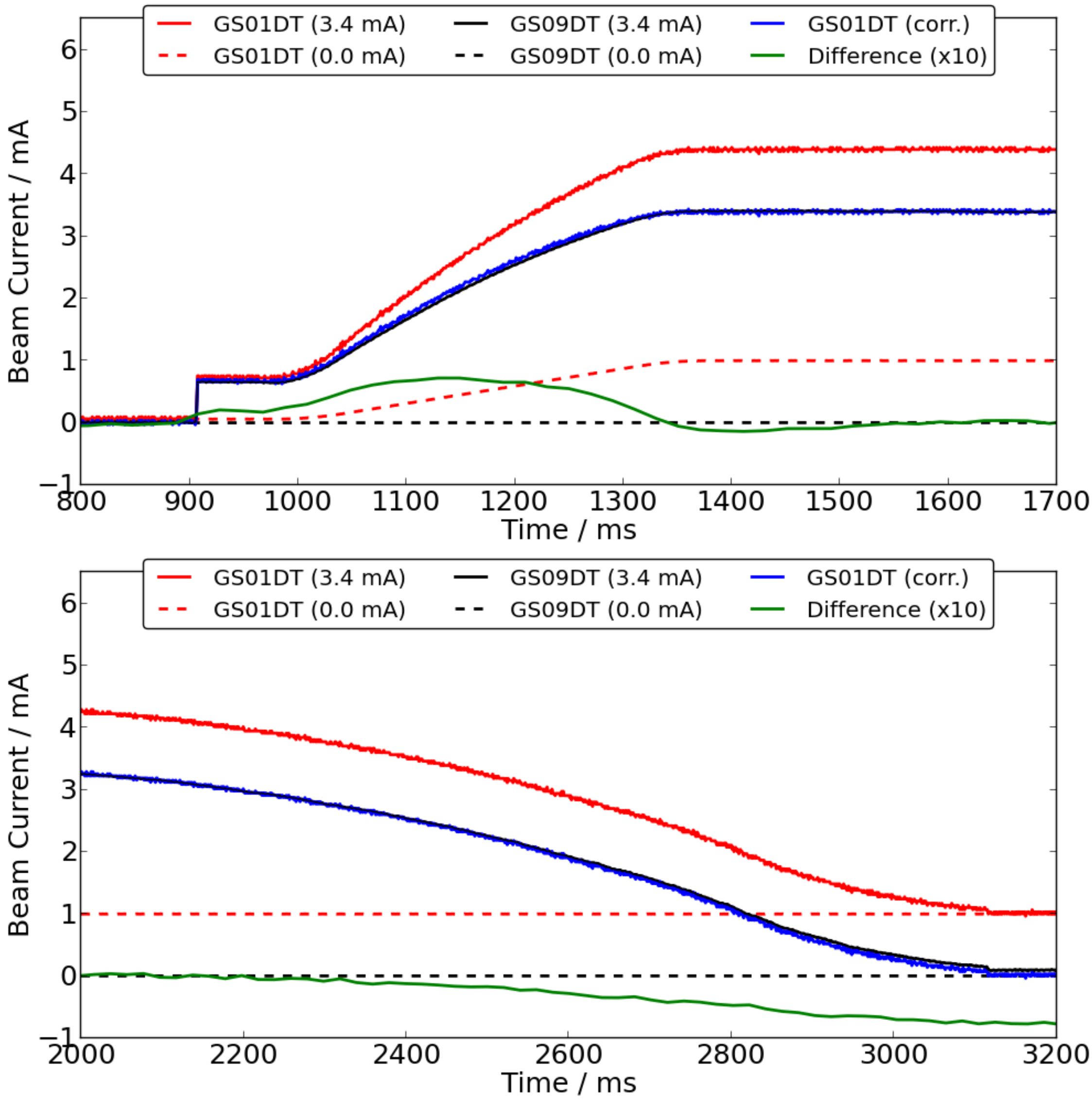


Figure 6: Data as for Figure 5 for the initial part and the ramp-down phase of the cycle.

5 Conclusion

- The distortion of the Bergoz transformer GS01DT_ML in the SIS18 synchrotron has increased by a factor 5-10 in the new installation location. A maximum distortion of 3.3 mA or 16.5% full scale of 20 mA range has been estimated for the maximum rigidity of 18 Tm.

- The magnetic field correction factor is now about 1870 $\mu A/T$ and, hence, a factor 340 larger compared to the value of 5.5 $\mu A/T$ for the transformer GS09DT_ML.

- The signal distortion can be approximated with two parameters, if the dipole ramp is known. The approximation is sufficiently accurate for operational purposes where current values are recored along the injection plateau and after the flat top has been reached. For "standard" purposes the remaining discrepancy during the ramping process after "dipole correction" seems fully acceptable.

- A software correction is suggested - at least for the 20 mA range - to compensate for the dipole distortion. The two required parameter values can be derived easily from "empty" cycle data recorded at different magnetic rigidities. The dipole ramp merely needs to be made available to the front-end acquisition system prior to the cycle via the LSA data supply.

- For typical DC beam currents of SIS18 operation and, in the future, for the beam modes "pilot beam" and "intensity ramp-up" of the new control system (and for beam delivery to the target hall limited by radiation protection shielding) the Bergoz transformer GS01DT_ML is expected to be regularly operated in the 20 mA range where the signal distortion is not negligible. For the analysed Carbon cycle the particle number was out by 20%.

- A complete investigation requires a set of data which covers the full range of magnetic rigidities. One shift of beam time is estimated to be sufficient.

- Because the PCT is being baked-out, any improvement of the magntic shielding is mechanically complex and costly. Therefore, this measure is not recommended.

References

[1] A. Reiter, *Untersuchung der Störeinflüsse auf das Signal des Transformators S5DTL im Synchrotron der HIT-Beschleunigeranlage*, Internal Report GSI, Oktober 2008