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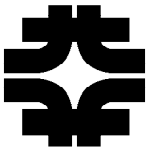

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Analysis of the Magnetic Field Specifications of the Transport Solenoid of the Mu2e experiment

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1 Introduction

This technical note summarizes the magnetic analysis of the Transport Solenoid (TS) and how it complies with the field specifications [1]. The field specifications are summarized in Figure 1.

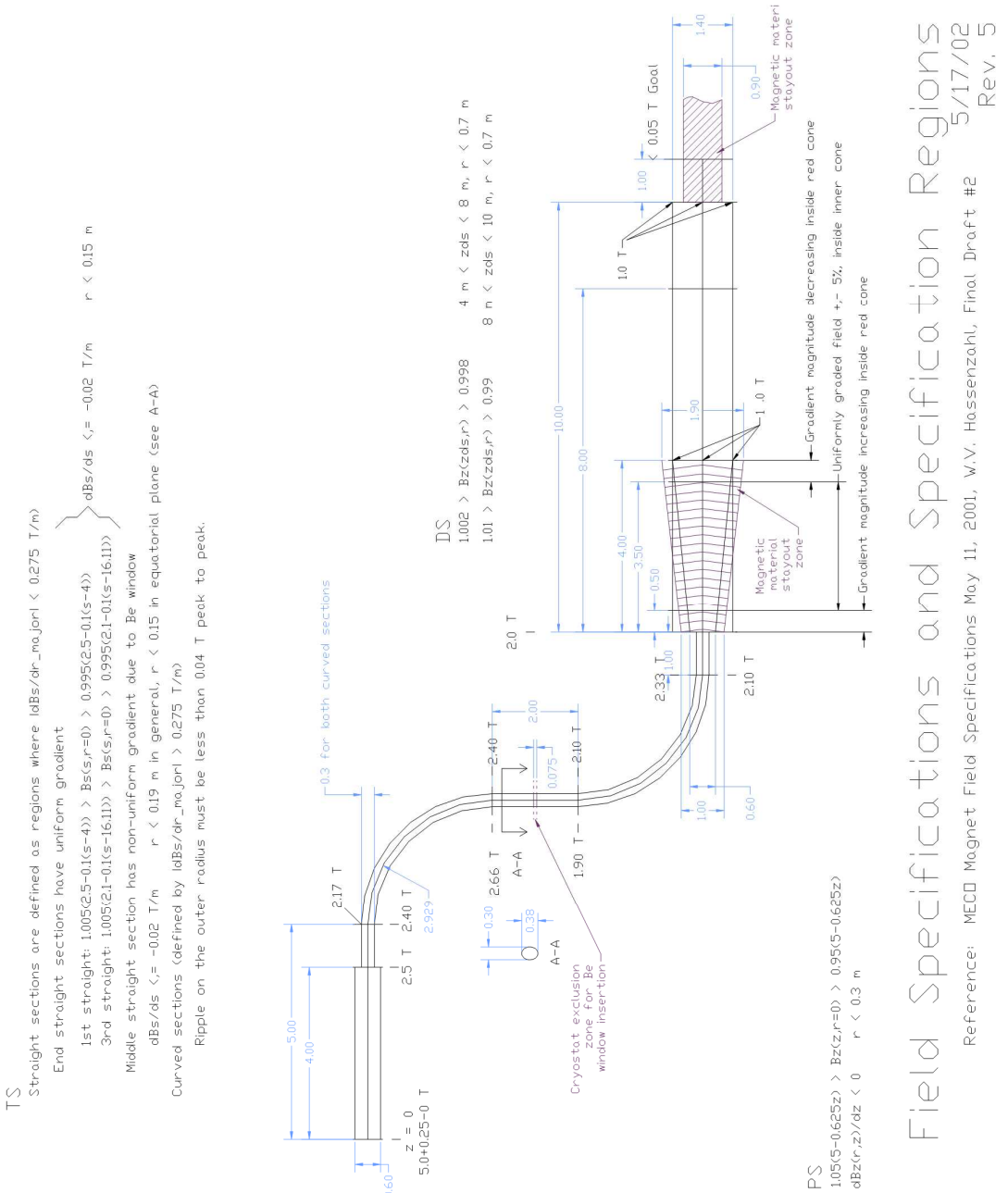

Figure 1 – Mu2e field specifications

General Atomic has provided FNAL with a 3D model (for Opera-3D) of the Mu2e magnet system as part of the CDR update. The model was originally by MIT Plasma Science and Fusion Center jointly with UC Irvine. It includes all the 62 coils of TS and the Production Solenoid (PS)

and Detector Solenoid (DS) coils with their surrounding iron. In this TD-Note we discuss the relevance of the iron yoke in order to fulfill the field requirements. The tolerances studies on the positioning of the TS coils were done by removing the iron.

2 Analysis

The analysis will be divided in three parts. First part will focus on performance of the TS versus the field requirements. Second part will deal with the influence of the iron yoke on the field distribution. Third part will approach the positioning tolerances of the TS coils on the field performance.

2.1 Model with iron and coils at nominal position

Figure 2 shows the field components distribution along the axial (s) coordinate. This analysis was done by OPERA 3D using the coil integration method. It takes around 30 hours to calculate all the points seen in Figure 2. Figure 3 Axial field component (*Bs*) along *s* for 3 different radii located in the equatorial plane The vertical black lines represent the interface between the TS segments (straight and curved sections).

Figure 4 shows *Bs* along *s* at the first and thirds sections. In the same figure one can see two black lines which represent the limits of the field distribution in those segments according to the requirements seen in Figure 1. As can be seen, the field distributions fail to meet these criteria in these segments in the regions close to the curved sections. However, a second criteria for these segments (together with the second straight section), establishes that the longitudinal gradient (dBs/ds) has to be smaller than -0.04 T/m (Figure 5). As can be seen, according to this criterion, however, these segments fulfill the criteria.

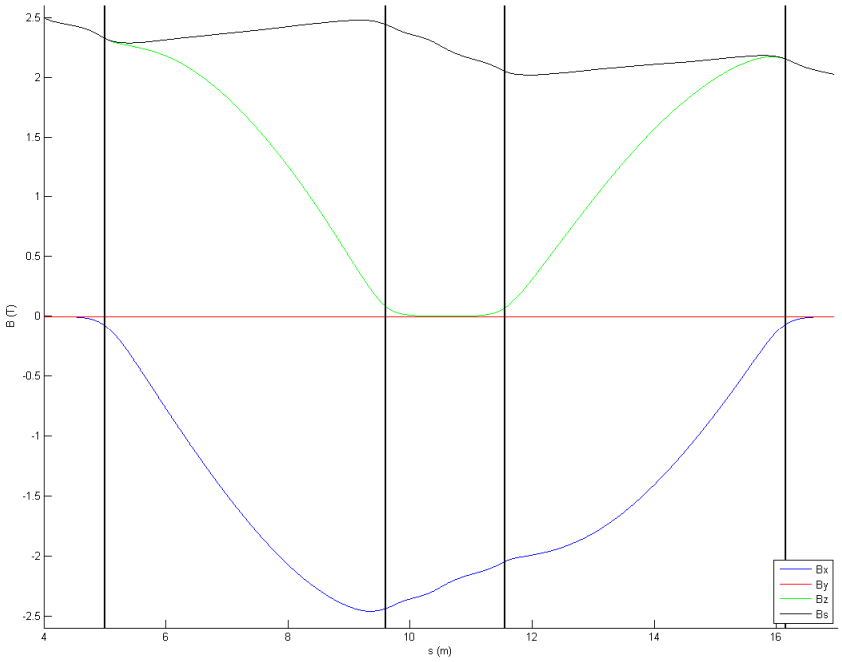

Figure 2 - Field components distribution along the axial (*s*) coordinate. The vertical black lines represent the interface between the TS segments (straight and curved sections).

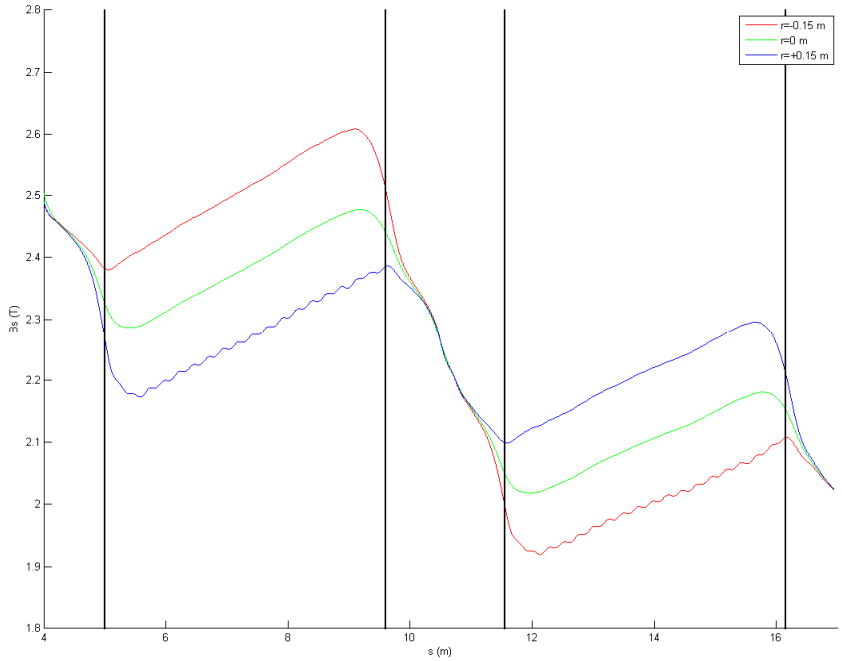

Figure 3 - Axial field component (*Bs*) along *s* for 3 different radii located in the equatorial plane The vertical black lines represent the interface between the TS segments (straight and curved sections).

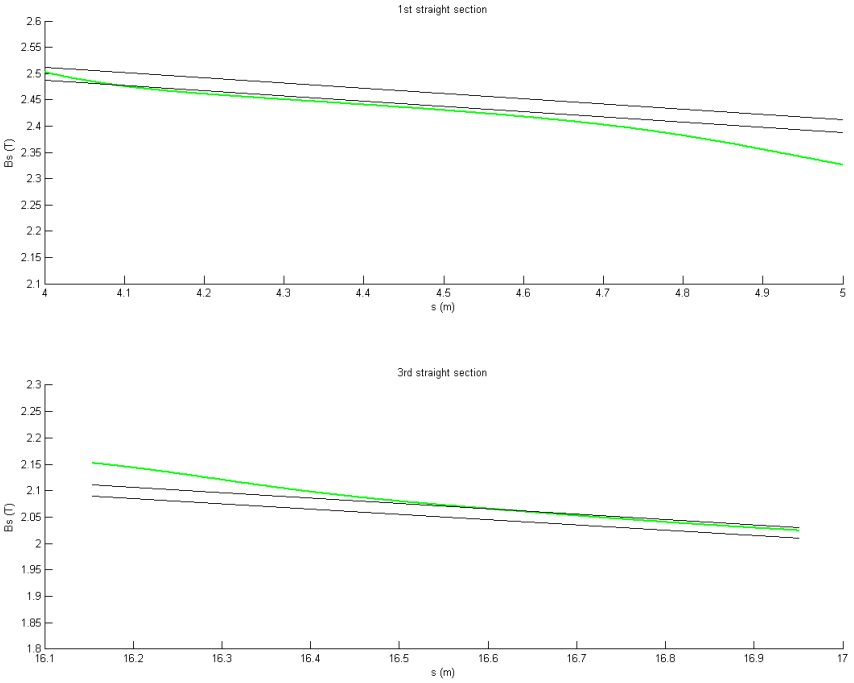

Figure 4 - *Bs* along *s* at *r* = 0 m for the first and third straight sections. The black lines represent the superior and inferior limits of the *Bs* for those sections according to the specifications.

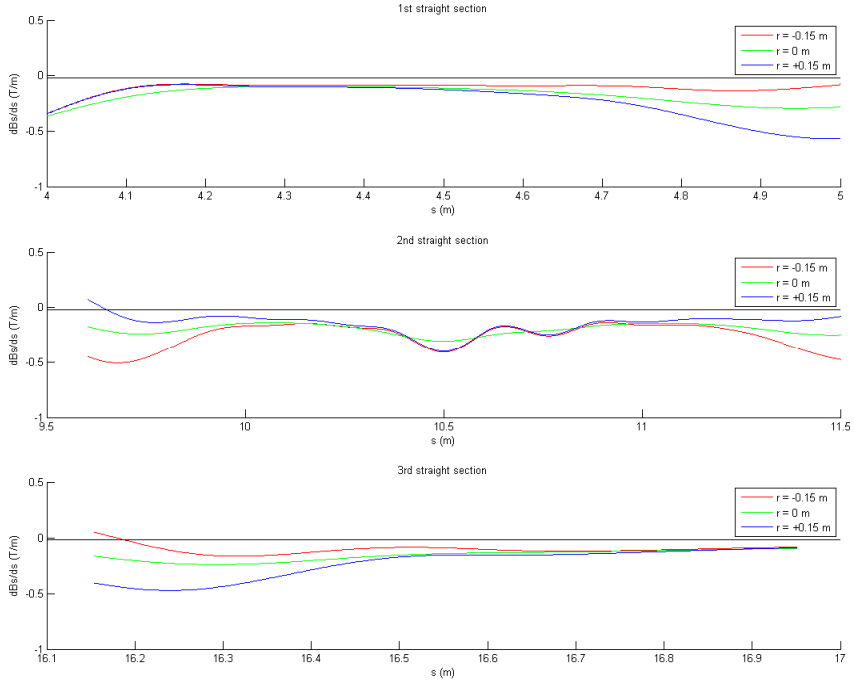

Figure 5 – *dBs/ds* distribution along *s* for the first, second and third straight sections. The black lines represent the superior limit of the *dBs/ds* for those sections according to the specifications.

Figures 6 and 7 show the analysis for the two curved sections. First shows the radial gradient (dBs/dr) along the axis. In the same figure the black line represents the inferior limit for this gradient. The second figure shows the ripple at r = ± 0.15 m. The ripple should be lower than 0.04 T pick to pick (as represented by two black lines in this figure). As can be seen, both curved sections fulfill the requirement of radial gradient or ripple.

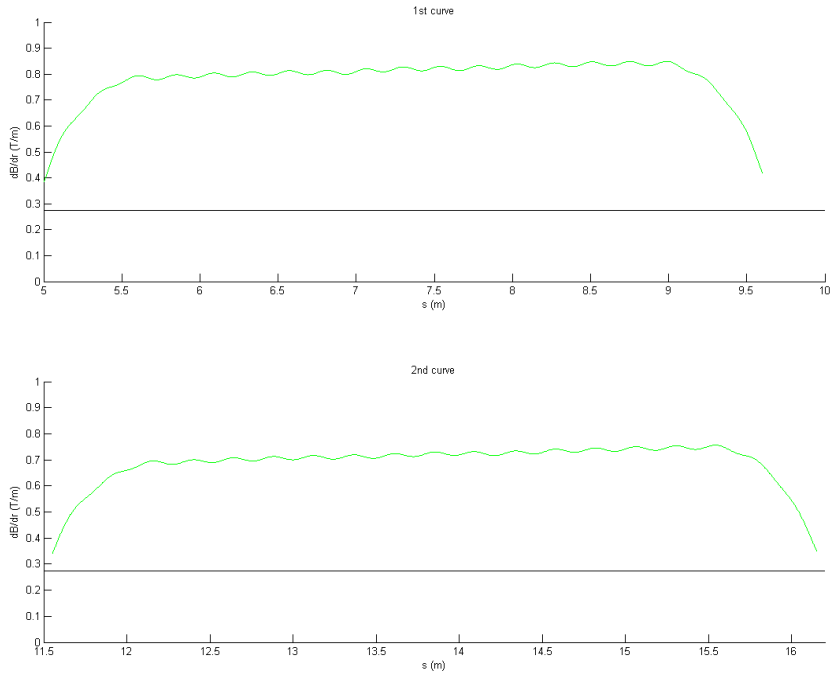

Figure 6 – *dBs/dr* distribution along *s* for the first and second curve sections. The black lines represent the inferior limit of the *dBs/dr* for those sections according to the specifications.

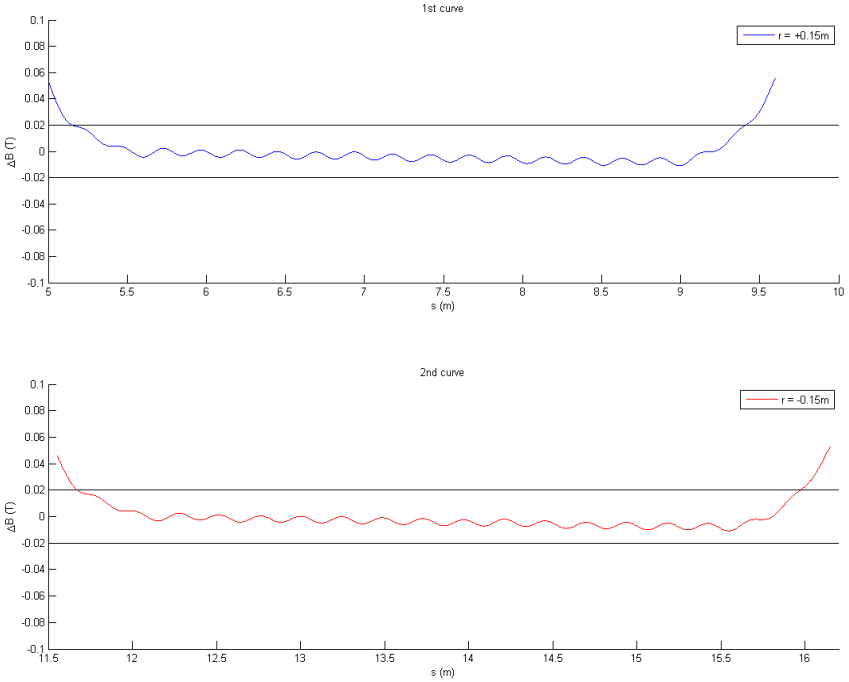

Figure 7 – Ripple distribution along *s* for the first and second curve sections. The black lines represent the inferior and superior limits of the ripple for those sections according to the specifications.

2.2 Model without iron and coils at nominal position

Since it would take 30 hours to do every case with iron we are really only interested in the relative changes in field we proceed with the analysis without the iron. Figures 8-13 show the same analysis performed in the previous item.

As it was expected, the iron yoke of the PS and DS will only impact the performance of the first and third straight sections.

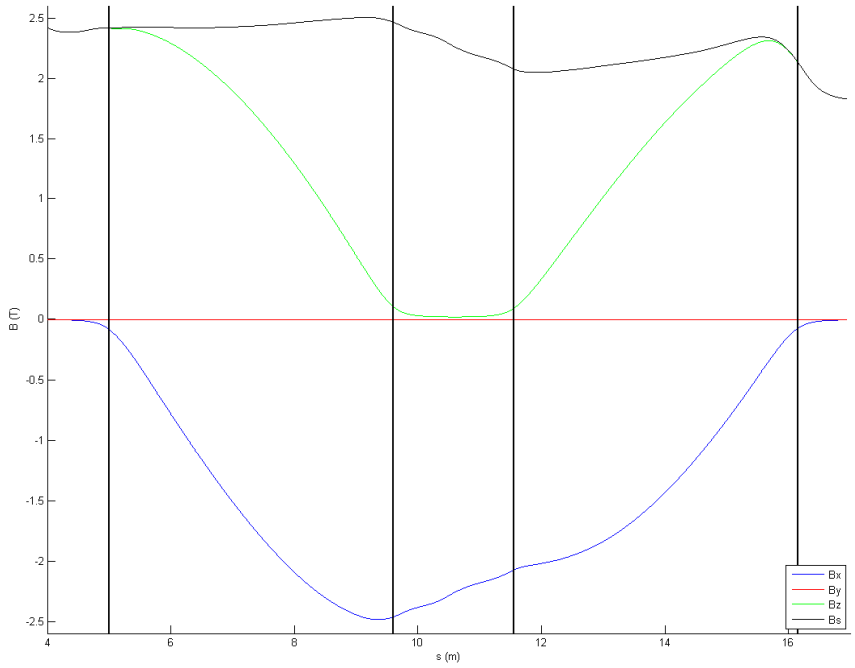

Figure 8 - Field components distribution along *s*. The vertical black lines represent the interface between the TS segments (straight and curved sections). No iron yoke at the PS and DS.

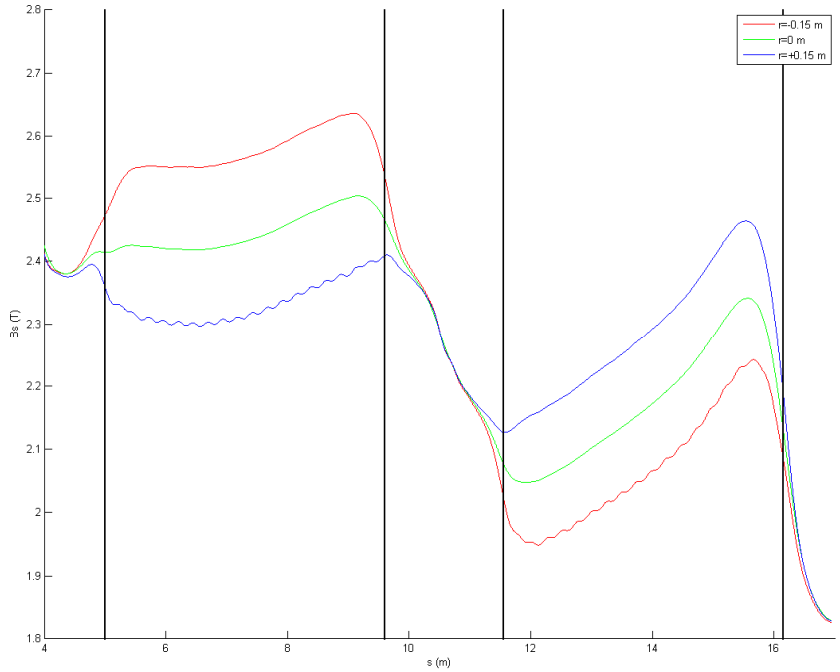

Figure 9 - *Bs* along *s* for 3 different radii located in the equatorial plane The vertical black lines represent the interface between the TS segments (straight and curved sections). No iron yoke at the PS and DS.

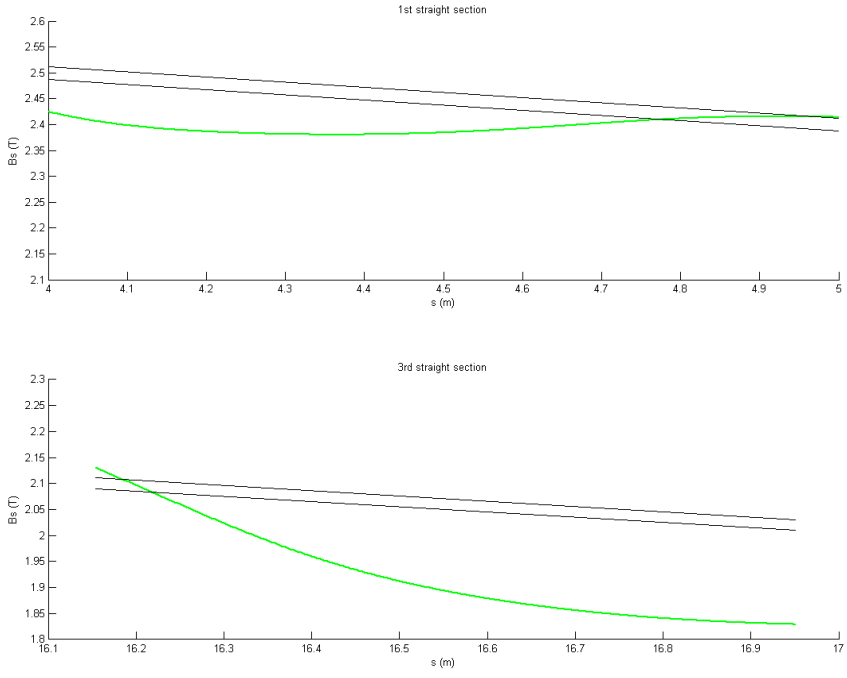

Figure 10 - *Bs* along *s* at *r* = 0 m for the first and third straight sections. The black lines represent the superior and inferior limits of the *Bs* for those sections according to the specifications. No iron yoke at the PS and DS.

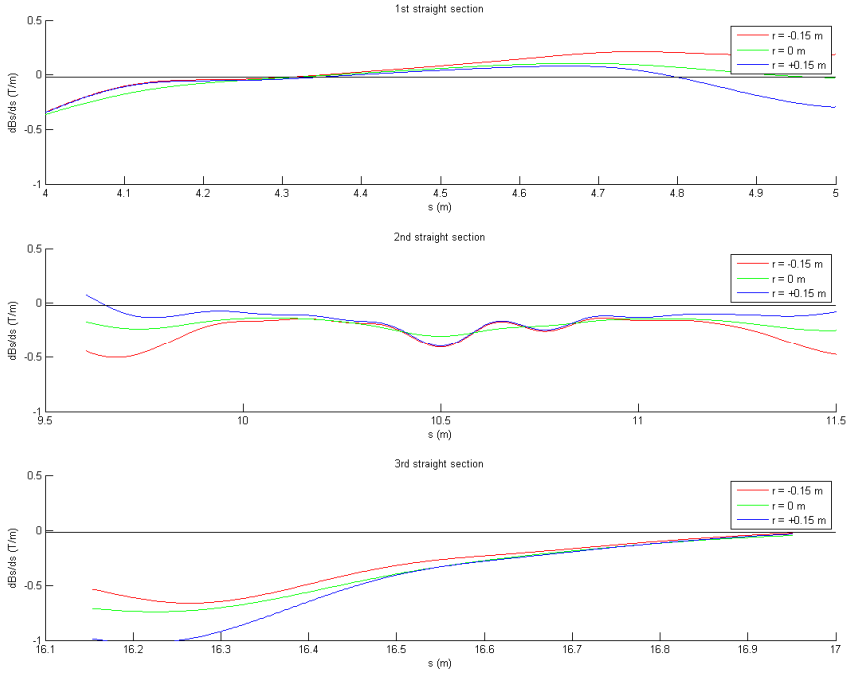

Figure 11 – *dBs/ds* distribution along *s* for the first, second and third straight sections. The black lines represent the superior limit of the *dBs/ds* for those sections according to the specifications. No iron yoke at the PS and DS.

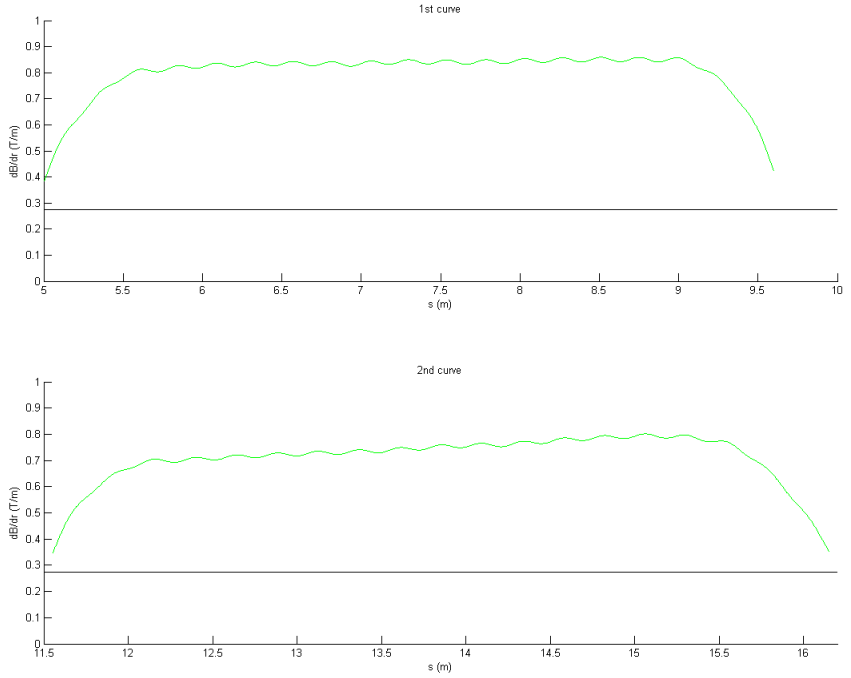

Figure 12 – *dBs/dr* distribution along *s* for the first and second curve sections. The black lines represent the inferior limit of the *dBs/dr* for those sections according to the specifications. No iron yoke at the PS and DS.

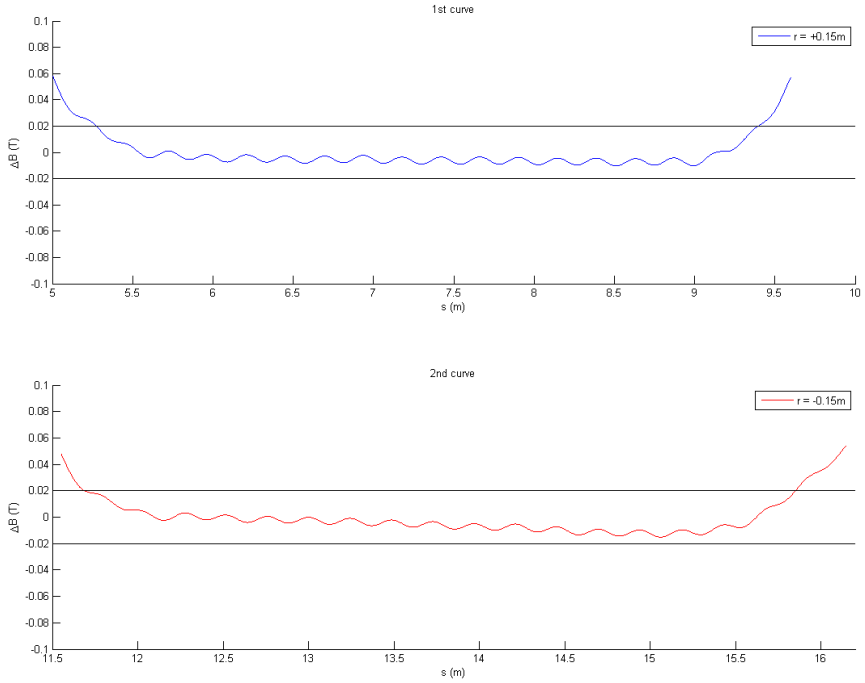

Figure 13 – Ripple distribution along *s* for the first and second curve sections. The black lines represent the inferior and superior limits of the ripple for those sections according to the specifications. No iron yoke at the PS and DS.

2.3 Model without iron and coils randomly displaced within 10 mm

In order to minimize the calculation time and to create statistics the iron from PS and DS was removed and the coils were randomly displaced within 10 mm. The average and the standard deviation were calculated over 100 randomly displaced coils. The results are shown in Figures14-18

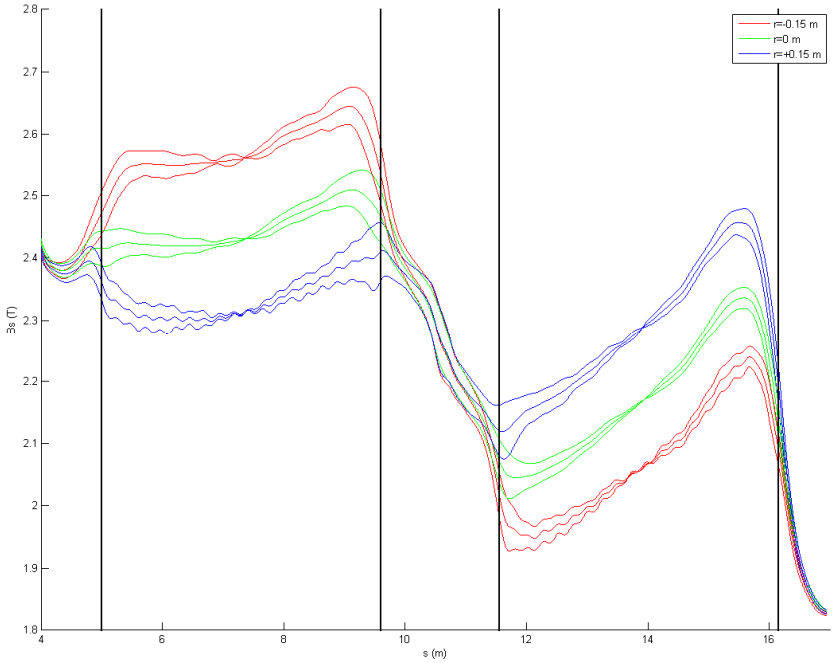

Figure 14 - *Bs* along *s* for 3 different radii located in the equatorial plane The vertical black lines represent the interface between the TS segments (straight and curved sections). No iron yoke at the PS and DS. The central line of each color represents the average (that coincides with the unperturbed model)

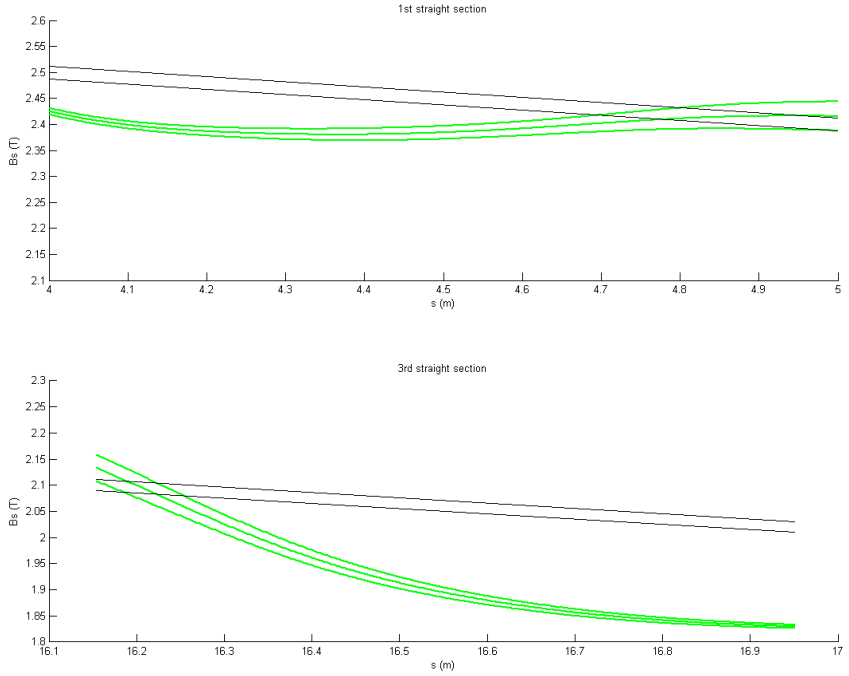

Figure 15 - *Bs* along *s* at *r* = 0 m for the first and third straight sections. The black lines represent the superior and inferior limits of *Bs* for those sections according to the specifications. No iron yoke at the PS and DS. The central represents the average (that coincides with the unperturbed model)

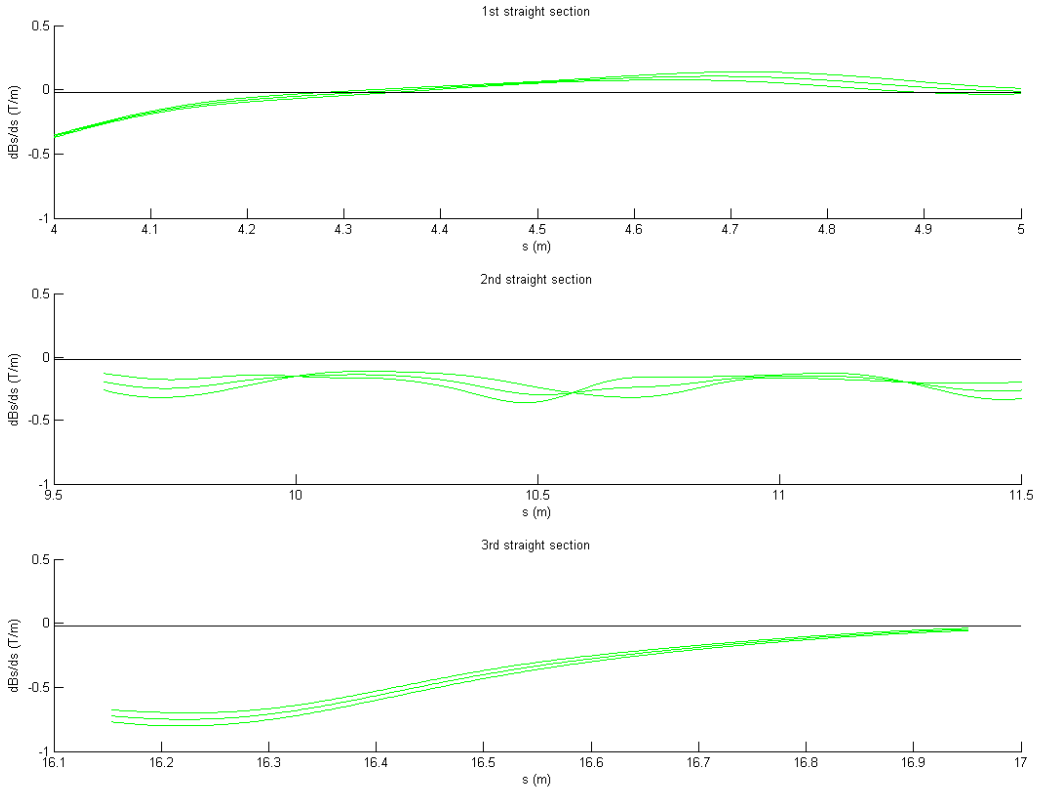

Figure 16 – *dBs/ds* distribution along *s* for the first, second and third straight sections. The black lines represent the superior limit of the *dBs/ds* for those sections according to the specifications. No iron yoke at the PS and DS. The central represents the average (that coincides with the unperturbed model)

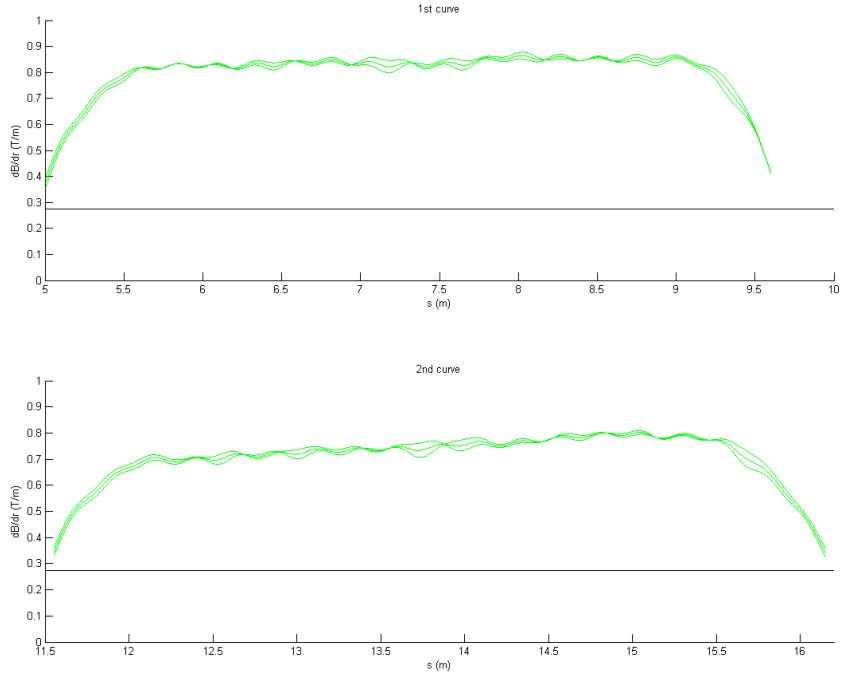

Figure 17 – *dBs/dr* distribution along *s* for the first and second curve sections. The black lines represent the inferior limit of the *dBs/dr* for those sections according to the specifications. No iron yoke at the PS and DS.

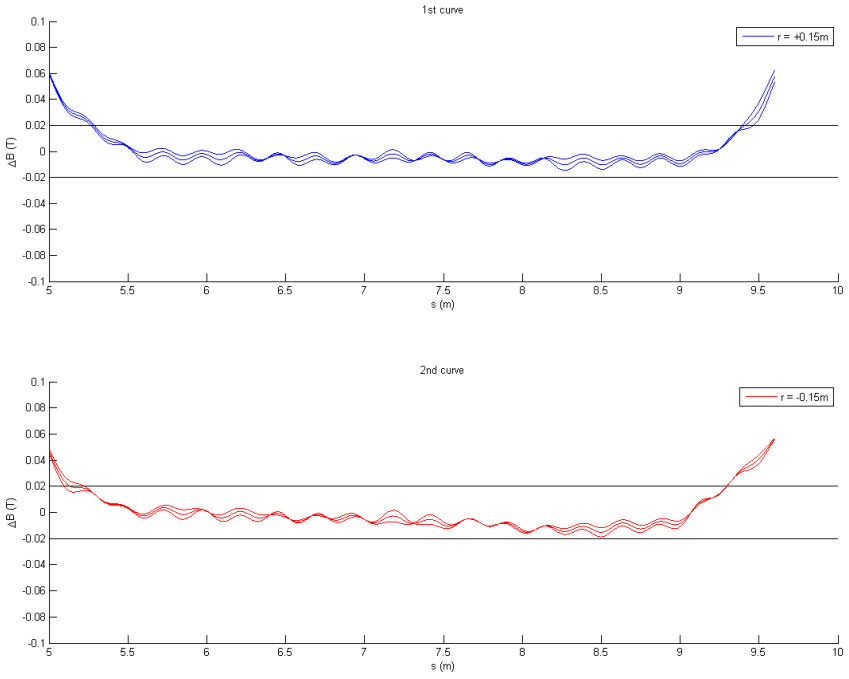

Figure 18 – Ripple distribution along *s* for the first and second curve sections. The black lines represent the inferior and superior limits of the ripple for those sections according to the specifications. No iron yoke at the PS and DS.

3 Conclusions

In this TD note we discussed the magnetic performance of the TS. The model provided by General Atomics fulfils the requirements, although the first and third straight sections do not completely fulfill the criteria for field distribution in that segment.

The magnetic performance without the iron in the PD and DS was evaluated and it is used for comparison with the coils random displaced.

Coils displacements of 10 mm do not present any significant change in the performance. Therefore, for the level of tolerances that coils are manufactured, the performance of the TS, according to the magnetic requirements, will not be affected.

References

[1] “MECO Superconducting Solenoid System Conceptual Design Report” Massachusetts Institute of Technology Plasma Science and Fusion Center, 2002