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ELENA Electron Cooler

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MAGNET DIVISION

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Magnetic Measurement Report

Revisions

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Contents

1 INTRODUCTION

To ensure that the ELENA Electron Cooler is optimised for cooling the antiproton beam, it was requested that the field produced by the Electron Cooler meets the specification that $B_{perpendicular}/B_{parallel} \leq 5x10^{-4}$ over the central 650mm at the positions shown in Figure 1. This requires that a measurement accuracy of the field components perpendicular to the axis of better than 0.05 gauss is achieved, while in the presence of a 100 gauss axial field. It was eventually agreed that the method that Tesla would employ to attempt this would be that used to measure the LEAR Electron Cooler [1].

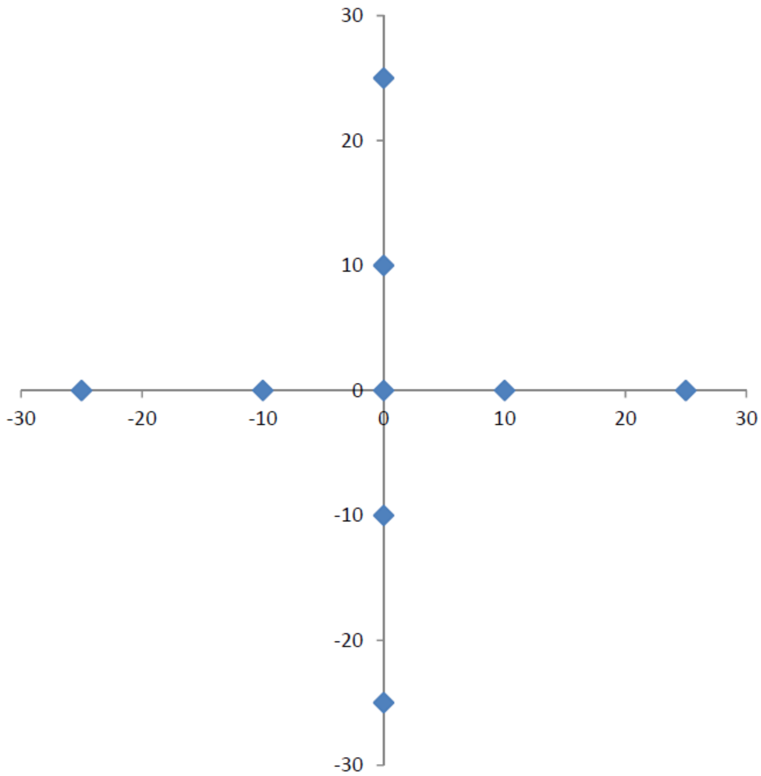


Figure 1 X-Y grid positions for the magnetic measurements along the axis

2 RESULTS OF THE MAGNETIC MEASUREMENTS

In order to allow the magnetic field of the ELENA Electron Cooler to be optimised, the magnetic field of each of the shimming coils were measured individually. The graphs showing the results of these measurements are shown in appendix A.

Initially, measurements for some of these shim coils produced results that were significantly different to the field predicted by the Opera model. To determine whether this was caused by measurement errors or build errors the magnetic measurements were repeated on these coils. Both sets of results are displayed on the graphs.

As both the Bx and By components are measured at the same time, the repeat measurements where errors were only seen in the results of one field component provide a useful tool for measuring the repeatability of the measurements in the absence of a 100 gauss axial field. An example of this can be seen in the measurements of Fine Corrector 2 with the probe in the 180 degree, r=0 position shown in Figure 2. Here, the difference in the 2 sets of measurements for Bx is ~0.005 gauss. For all the measurements where this comparison can be made, the repeatability is better than 0.02 gauss.

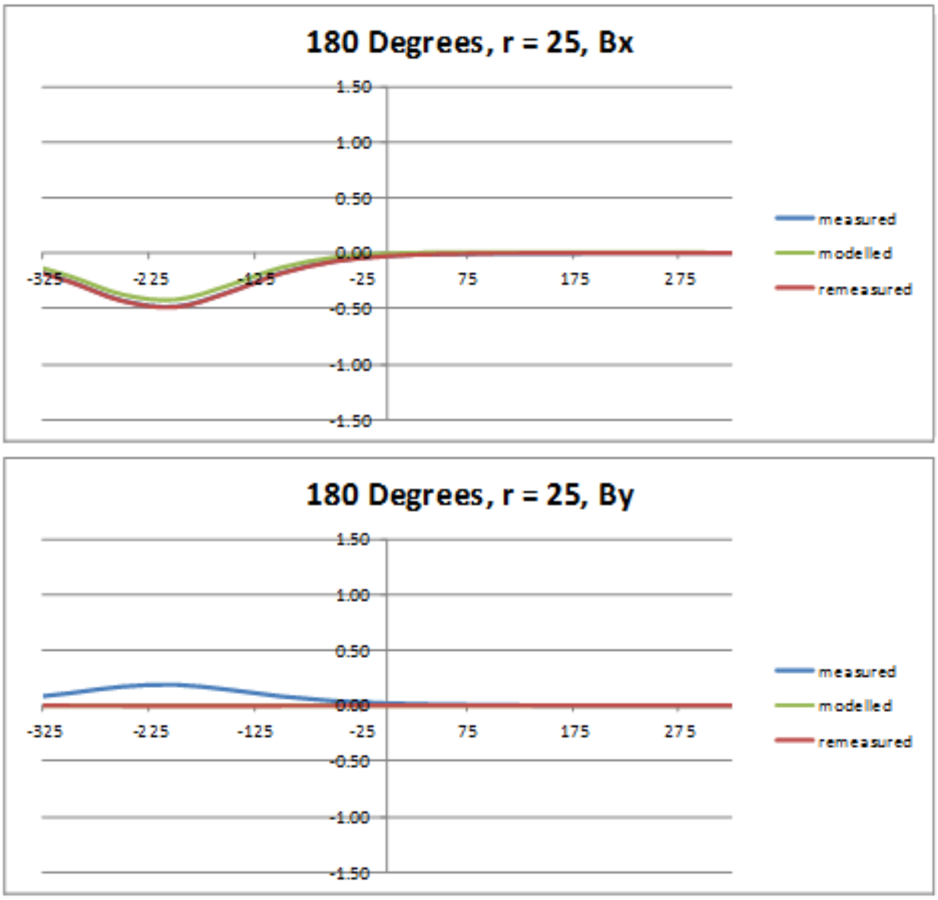


Figure 2 Field measurements for Fine Corrector 2 at 180 degrees, r=0

Following the magnetic measurements of each shim coil, the current required in each coil to produce the smallest perpendicular field in the VOI was calculated. These currents were applied to the coils and the magnetic measurements of the full assembly were performed. The results of these measurements as well as the theoretical field calculated using the measurements of the individual coils are shown in Figure 3.

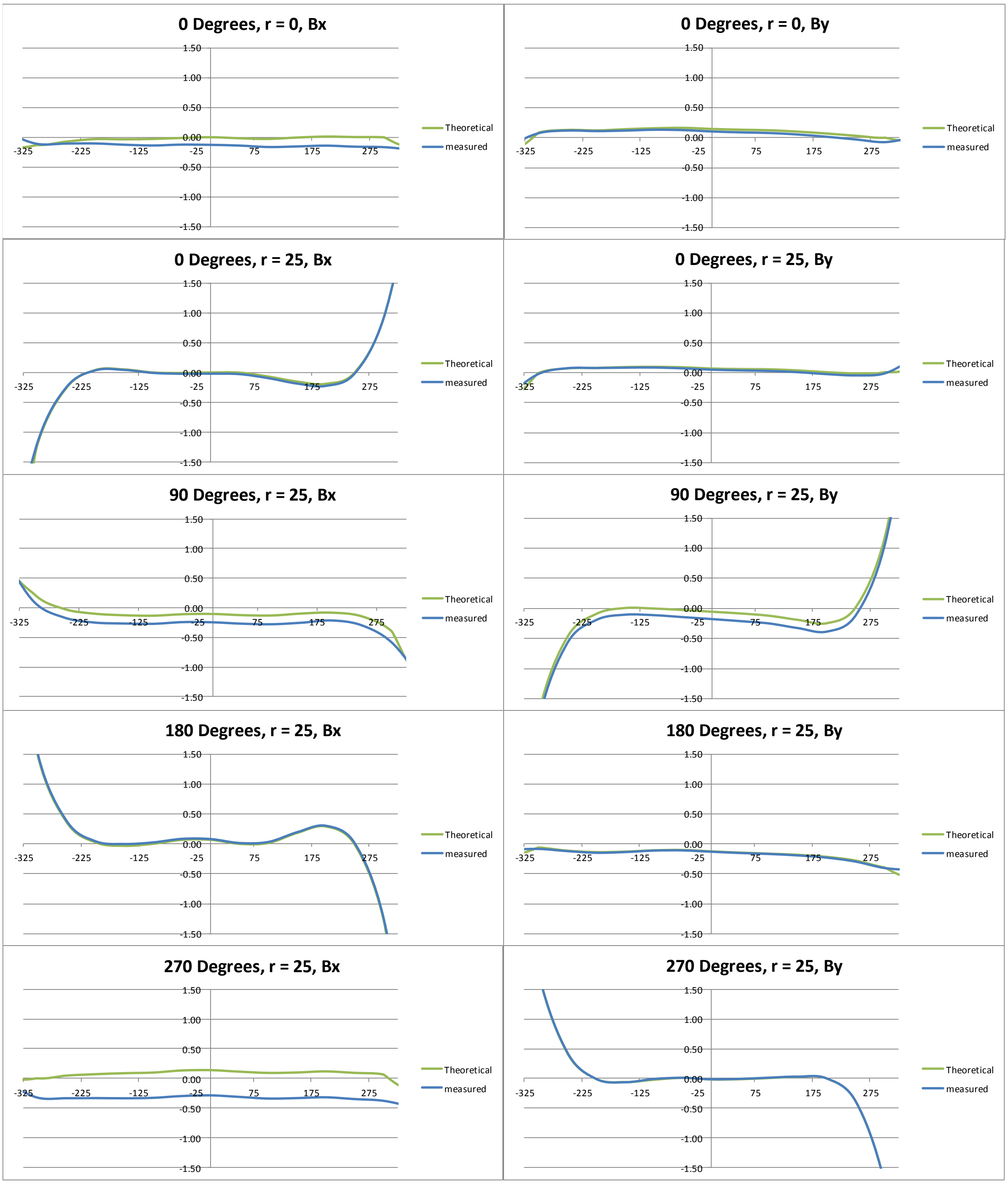


Figure 3 Measured and predicted fields for the ELENA Electron Cooler full assembly

While the field profile for all of the sets of measurements is in very good agreement with the theoretically calculated results, for a number of the graphs there is an offset between the theoretical and measured results. In order to check that the offset was not caused by improper measurement technique, the measurements in the 270 degree, r=25 position were repeated by a different operator. The results for these repeated measurements are shown in Figure 4.

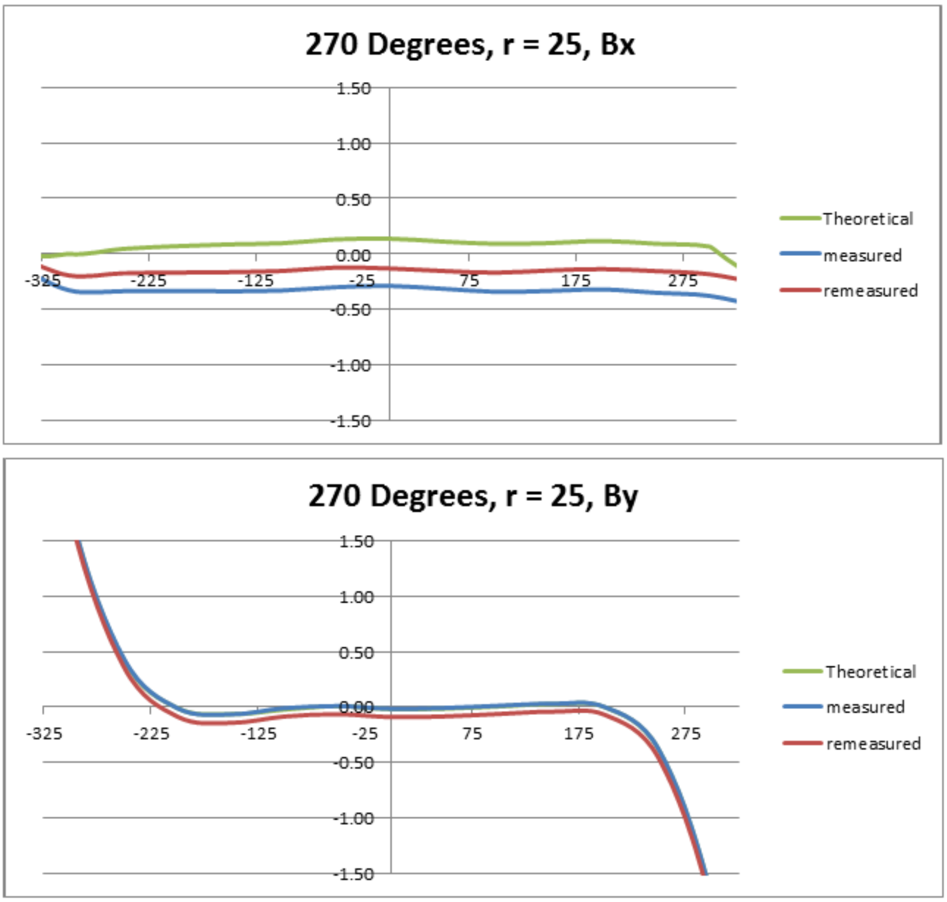


Figure 4 Repeated measurements for ELENA Electron Cooler at 270 degrees, r=25

Again, the field profile measured is in good agreement with the theoretical and previous measured results, however there is now a different offset for the Bx results and an offset has been introduced in the By results.

3 SOURCE OF THE OFFSET ERROR

As the offset in the measured results is only present in the measurements performed in the presence of a 100 gauss axial field, the possible source(s) of the error can be narrowed down considerably. The possible sources of the error that were discussed and whether/how they can be ruled out are listed below:

I. Change in temperature of the assembly – each line of measurements takes about 2 hours to complete, and the change-over time between lines is about 20 minutes. If the error was caused by varying temperature then the offset would vary along each measurement line. It is very unlikely that the temperature change only occurs during the change-over time. **Not considered the source of the offset.**

II. Change in the background field – although the method used for the magnetic measurements cancels out any static background fields, it cannot cancel out changes in the background field that occur between the measurements of the system with positive and negative current. Each line of measurements is performed first with the forward current (1 hour), then with the reverse current (1 hour). The time taken to change the field polarity is about 10 minutes. If the error was caused by varying background field then the offset would vary along each measurement line. It is very unlikely that the background field change only occurs during the change-over time. **Not considered the source of the offset.**

III. Inconsistent current output of power supplies – the calculated current difference that is required to produce the 0.2 gauss offset between the 2 sets of magnetic measurement in Figure 4 is 0.06A. The output current of the power supplies was found to be consistent within 0.01A. **Not considered the source of the offset.**

IV. Hysteresis of the shim coils – the hysteresis of the shim coils was measured to be more than 10 times too small to be the source of the offset seen in Figure 4. **Not considered the source of the offset.**

V. Hysteresis of the drift solenoid – the hysteresis produced by the drift solenoid in Bx and By was measured to be 100 times too small to be the source of the offset. **Not considered the source of the offset.**

VI. Mathematical correction for probe angle applied incorrectly – the mathematical corrections for the probe angle to the solenoid axis were applied to theoretical field values and the results were as expected. **Not considered the source of the offset.**

VII. The Hall probe's response as angle to the field is varied is not well described by the equations given by A. Wolf, L. Hutten and H. Poth [1] – if these equations do not accurately describe the response of the particular probe used, then the mathematical corrections performed on the raw data could introduce an offset in the results that varies as the probe angle is changed, as seen in the results. **This is the only remaining theory that has not been ruled out.**

Although we have only one remaining theory for the source of the offset in the results, it is possible that there is another unidentified cause. With the offset still remaining, it is currently not possible to identify the field errors that are to be shimmed with the fine tune coils.

4 POSSIBLE SOLUTIONS

Tesla has so far identified a number of possible solutions to this issue, they are described below:

I. Characterise the response of the probe as the angle to the solenoid axis is varied. This would not only require a considerable amount of time and expense, but would also need a solenoid whose magnetic axis is well known.

II. Perform the magnetic measurements on the ELENA Electron Cooler with the compass method used by BINP [2] that has been proven to have the required accuracy.

III. Do not perform magnetic measurements in order to optimise the beam cooling. Instead, with the Electron Cooler installed in the ring and with a circulating beam, adjust the fine tune coils so that beam cooling is gradually optimised.

5 SUGGESTED SOLUTION

Tesla believes that the safest option for both parties would be option 3: to install the Electron Cooler and to optimise the field by adjusting the fine tune coil currents and measuring their impact on beam cooling. Although time consuming, it avoids the costs associated with option 2 and the technical challenge associated with options 1 and 2.

6 REFERENCES

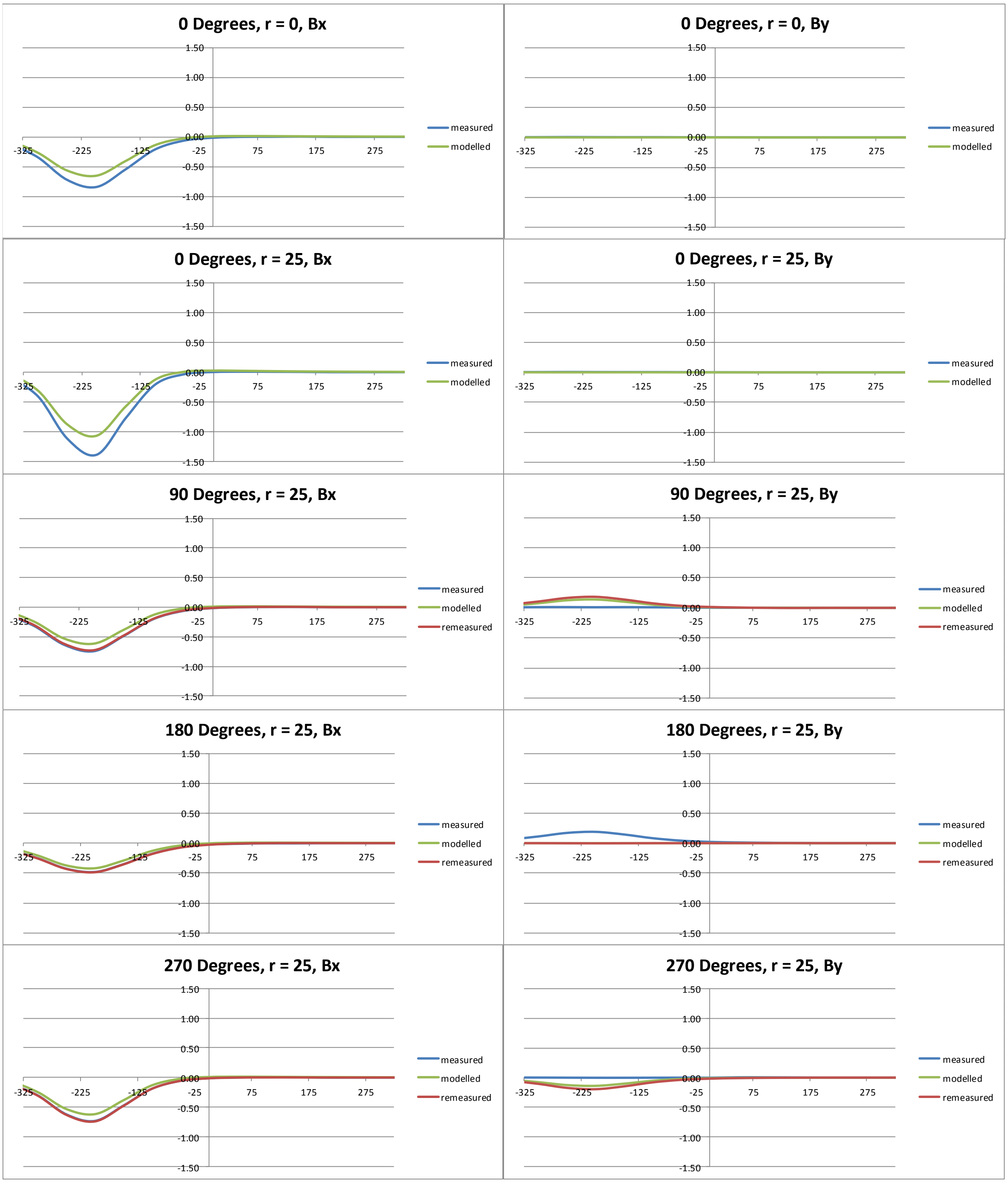
[1] A. Wolf, L. Hutten and H. Poth, “Magnetic Field Measurements In The Electron Cooling Device For LEAR”, CERN-EP-INT 84-01, 1984.

[2] V. N. Bocharov et al., “Sensor For A Precise Measurement Of The Magnetic Field Direction”, XVIIth workshop on particle accelerators.

Appendix A

Fine Corrector 1

Fine Corrector 2



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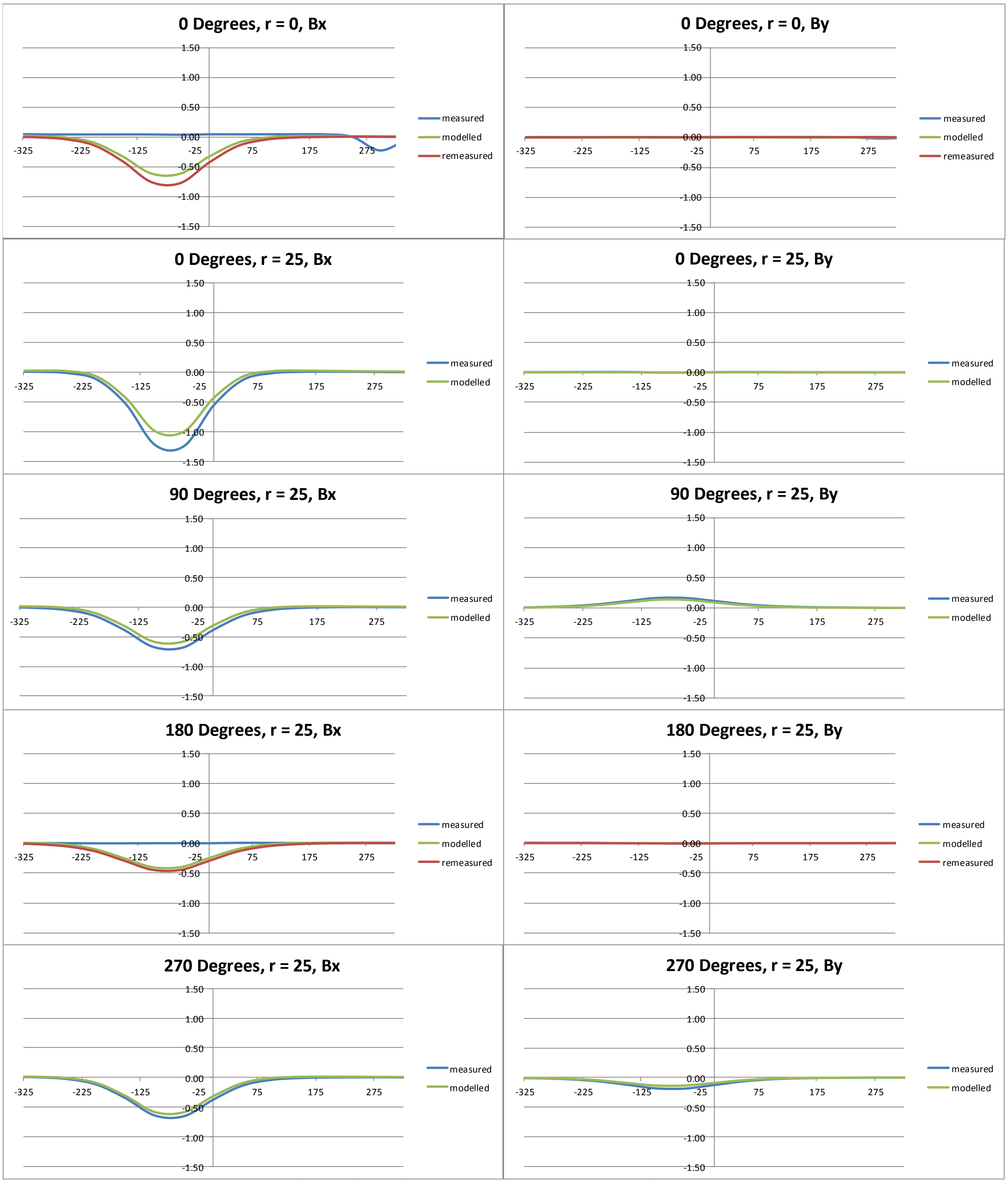

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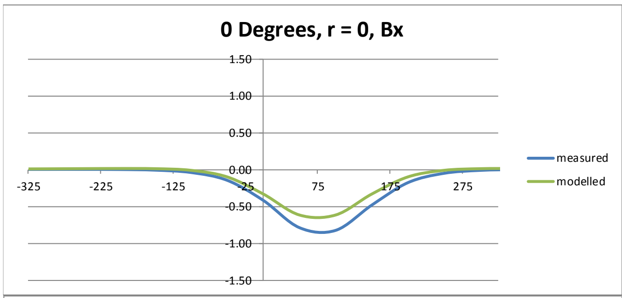

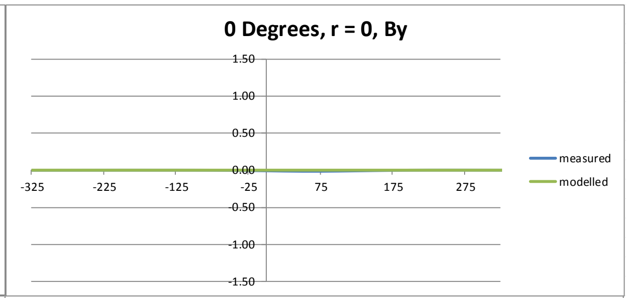

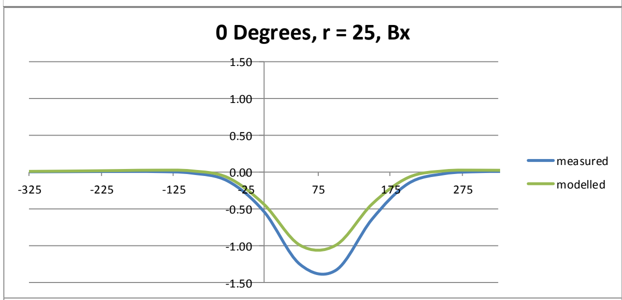

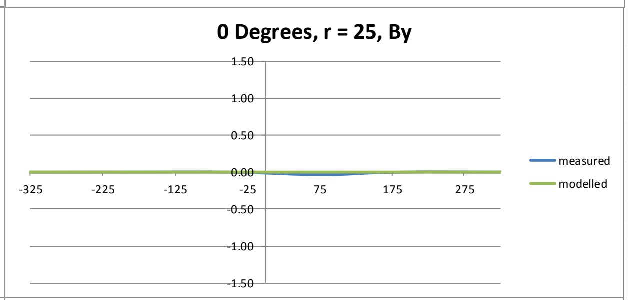

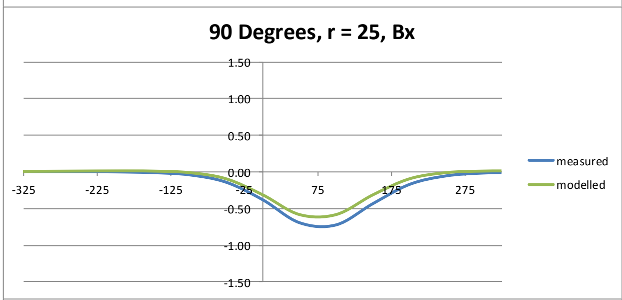

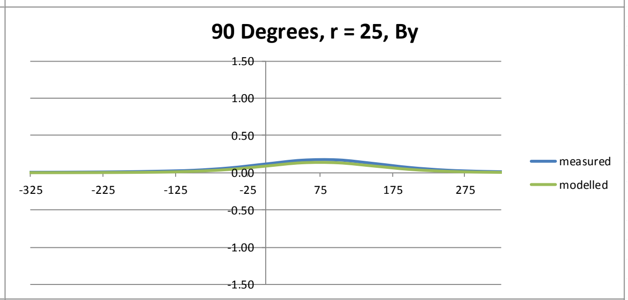

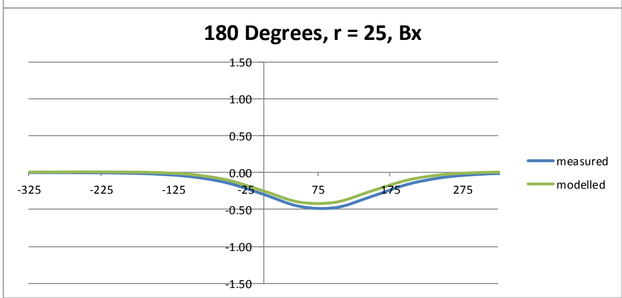

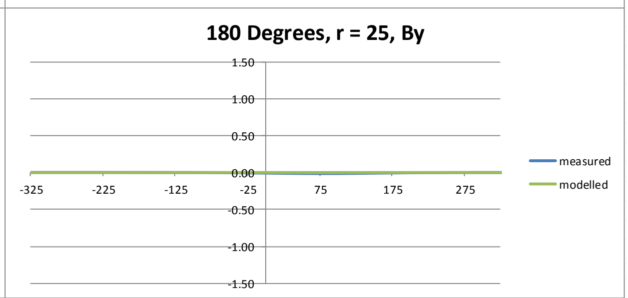

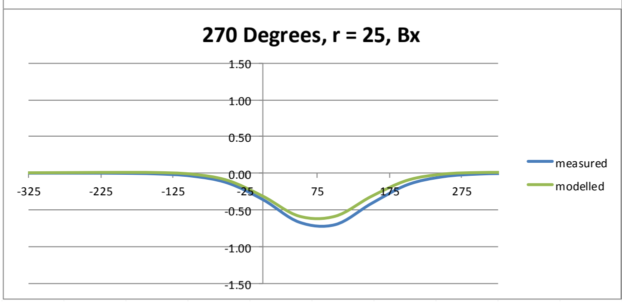

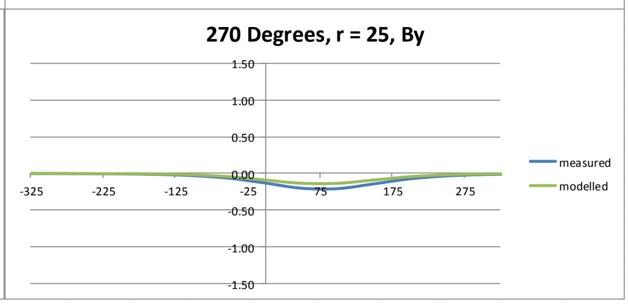

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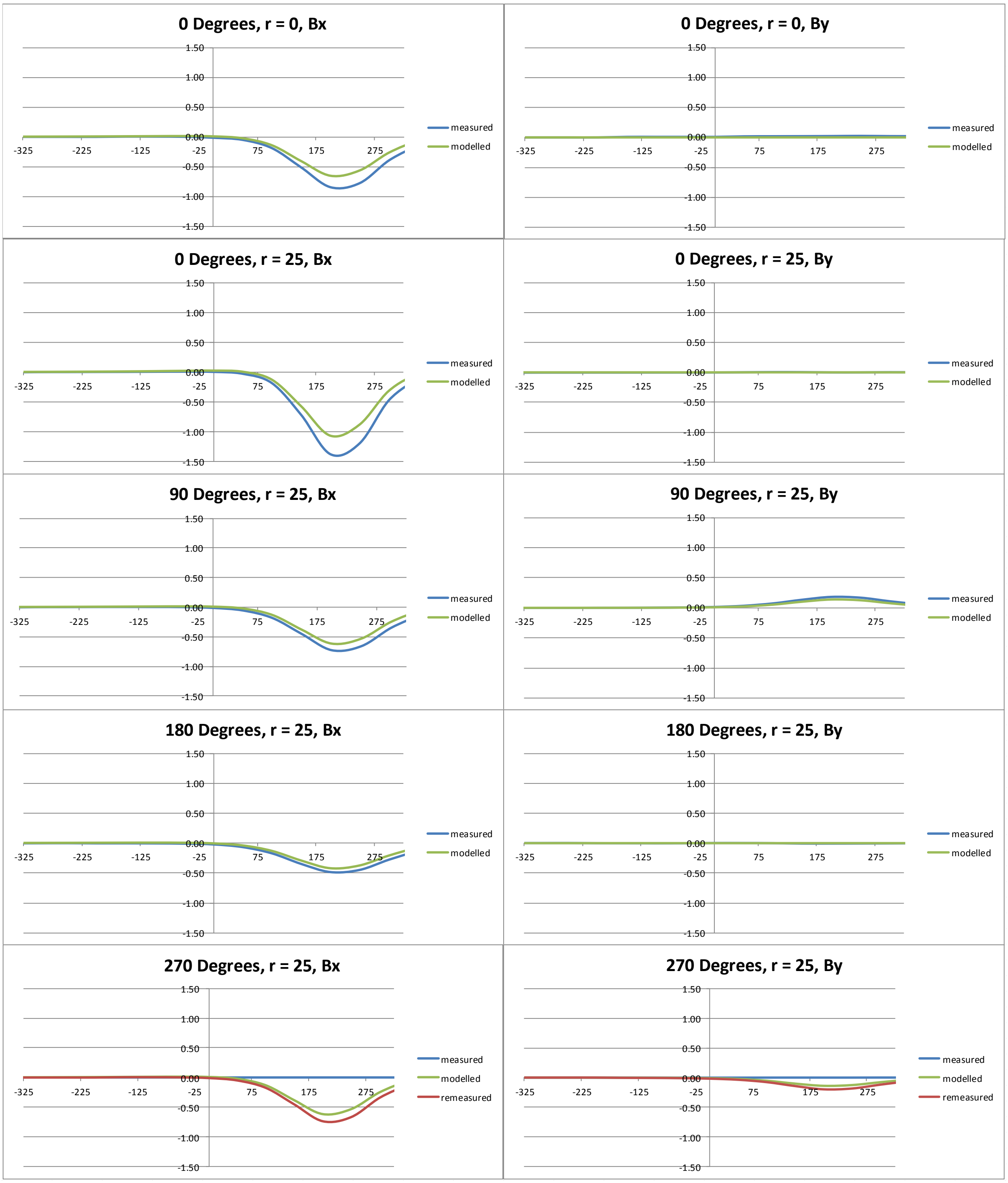

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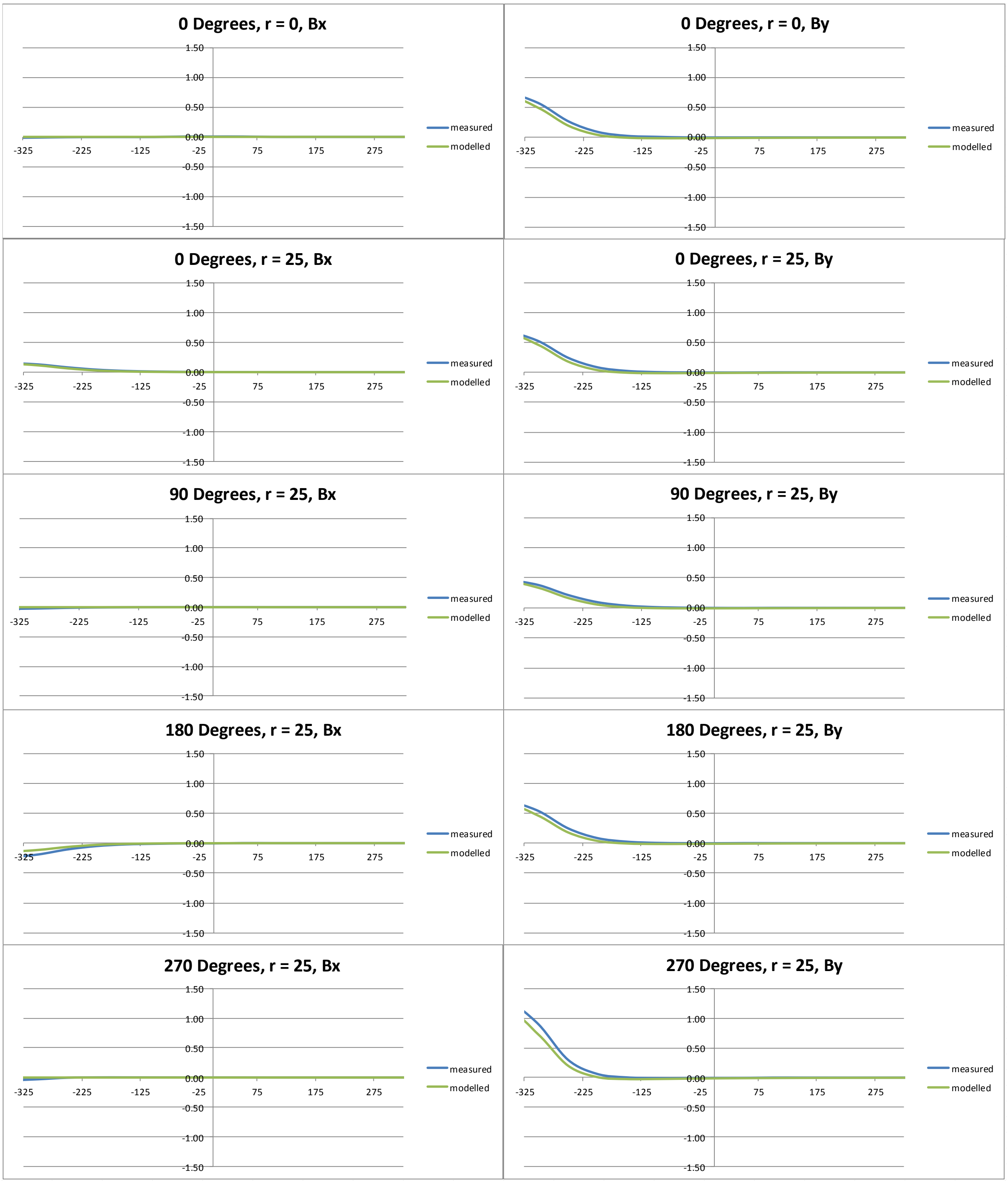

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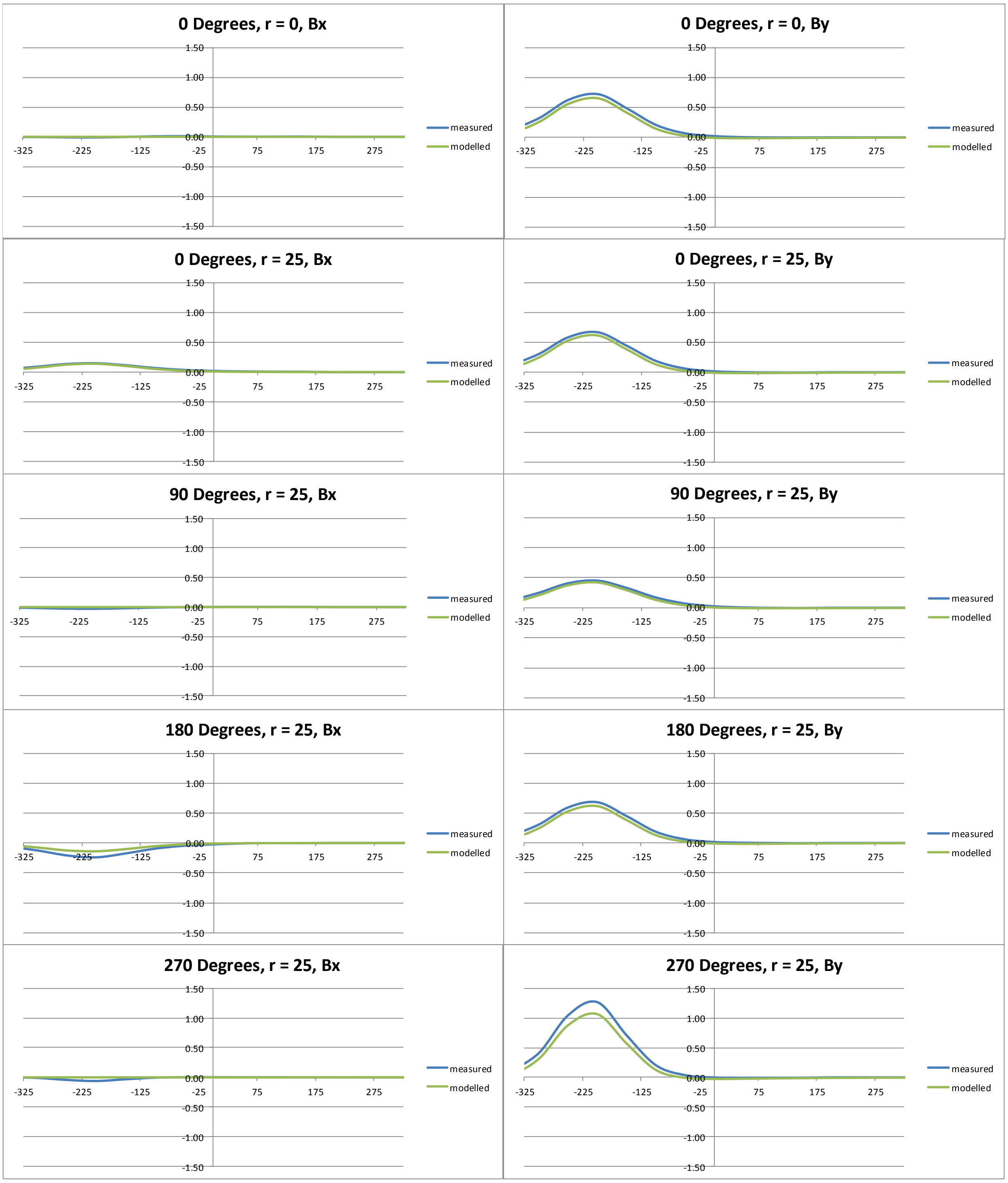

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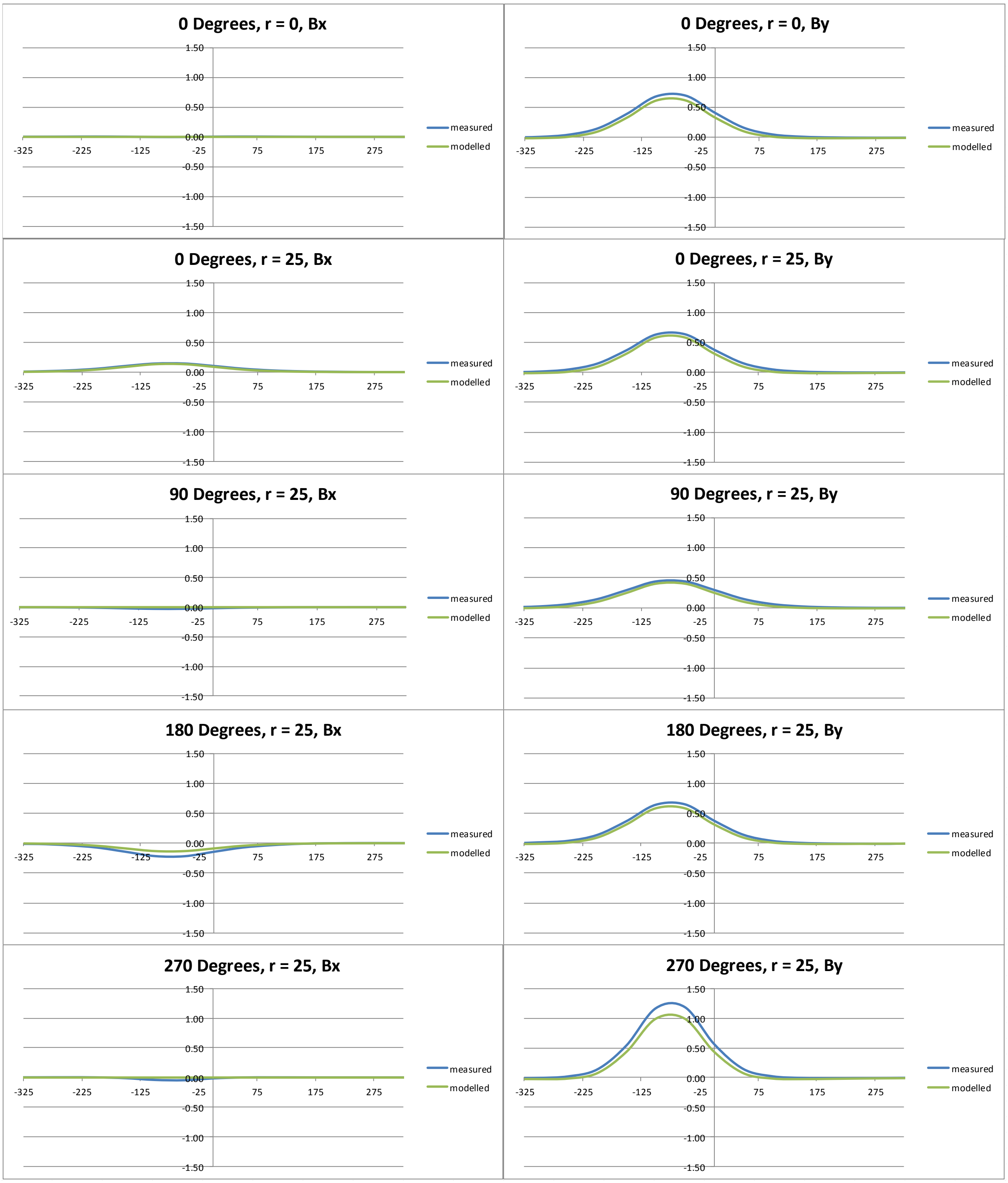

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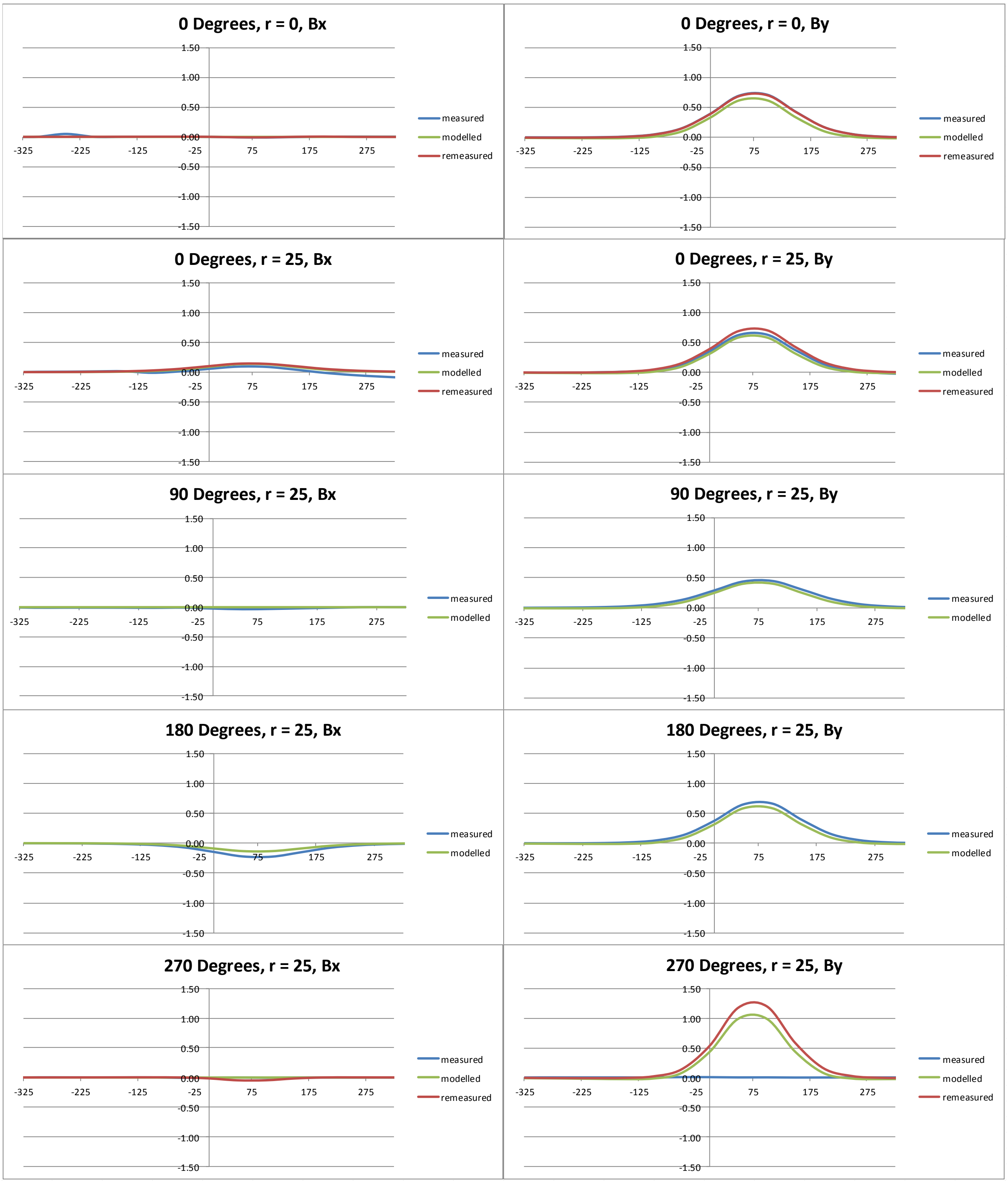

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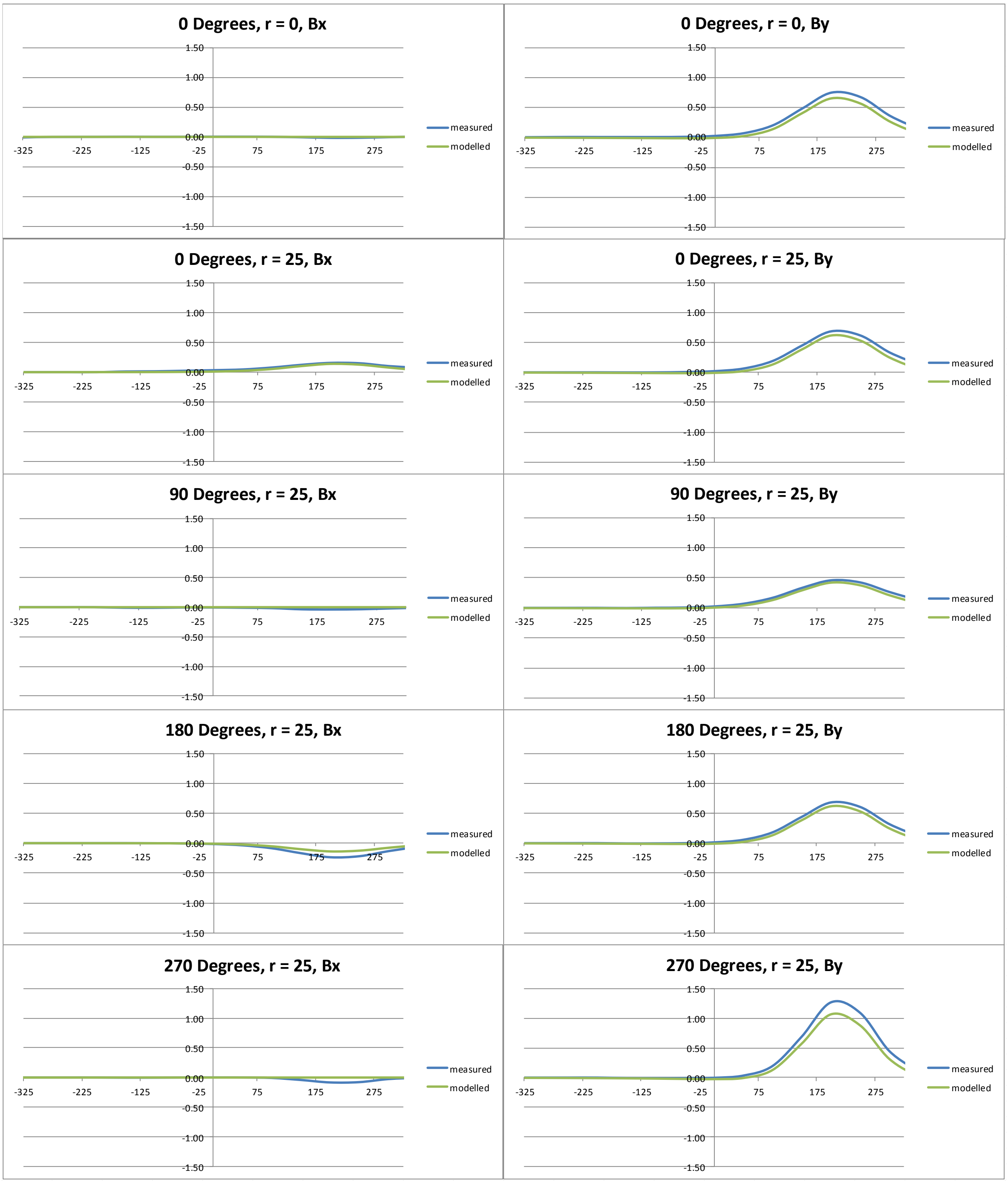

Fine Corrector 12

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Fine Corrector 14

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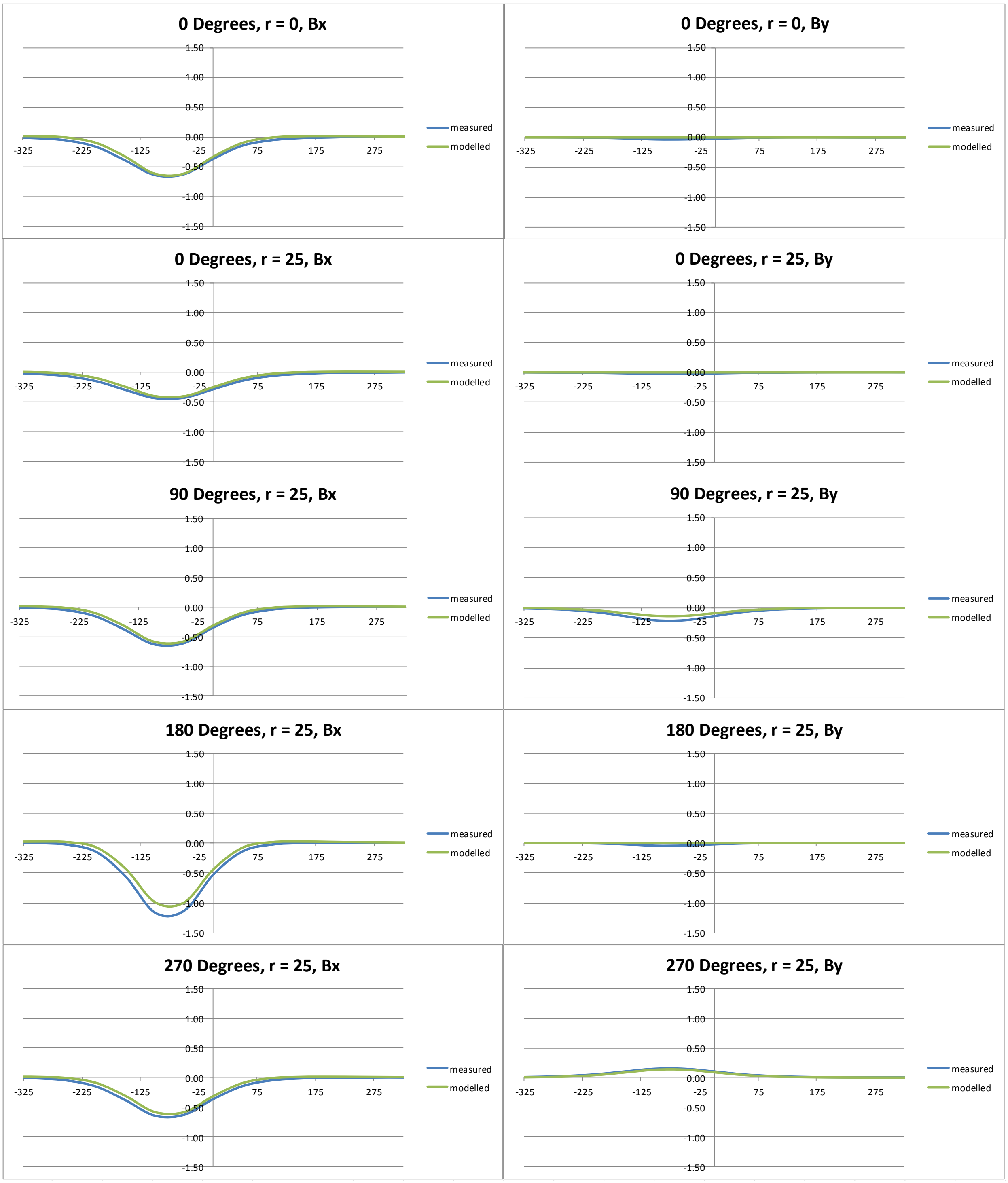

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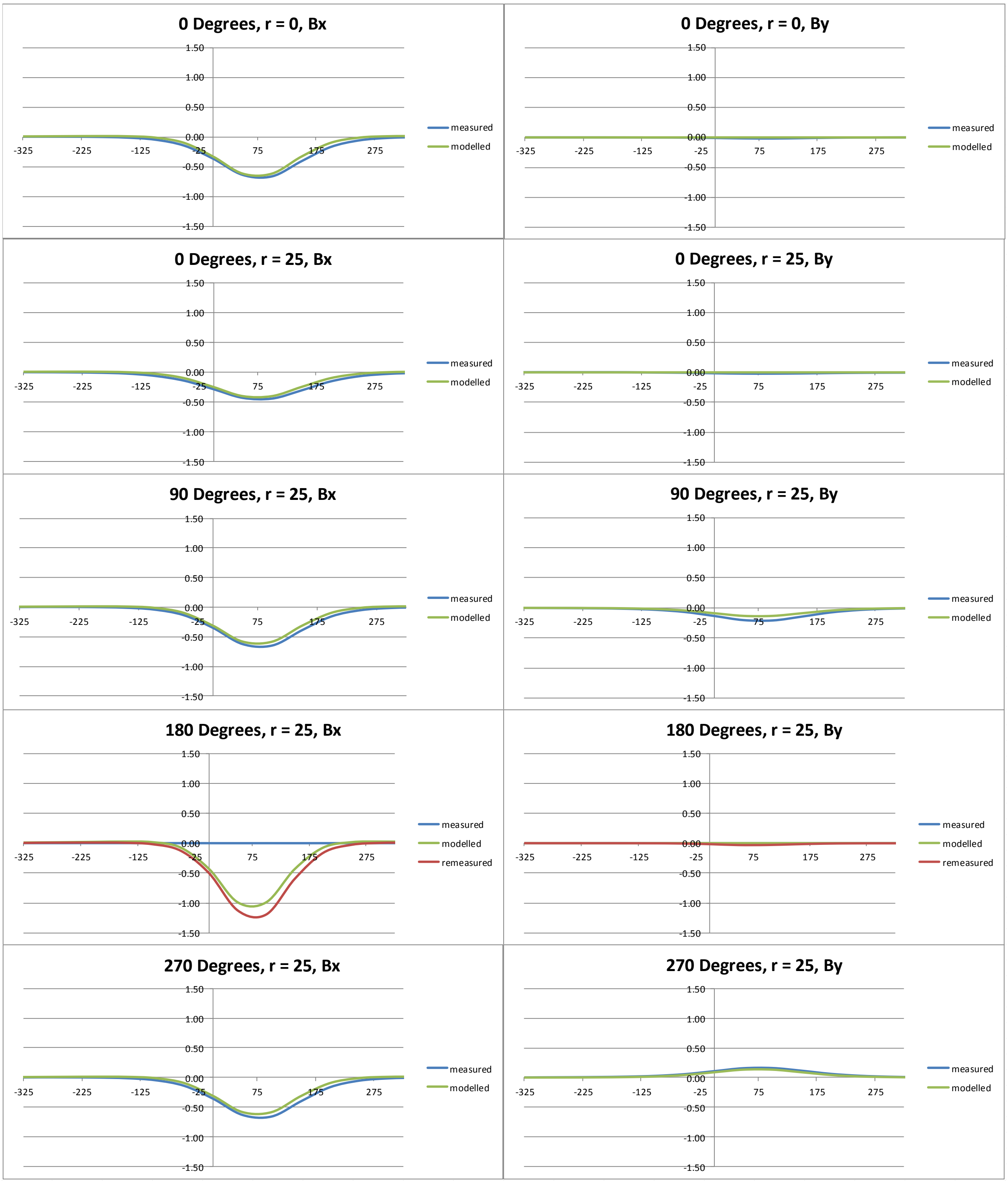

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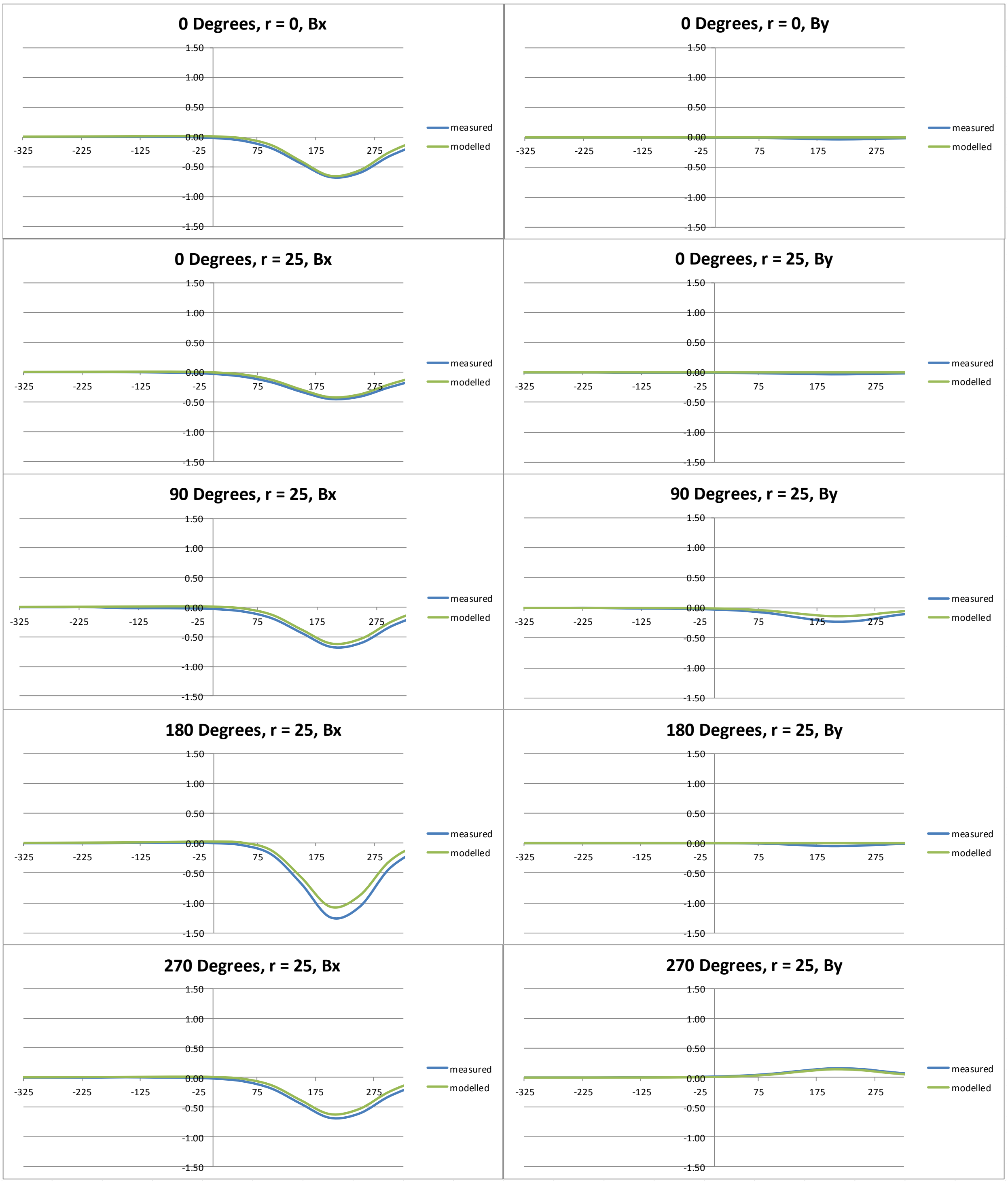

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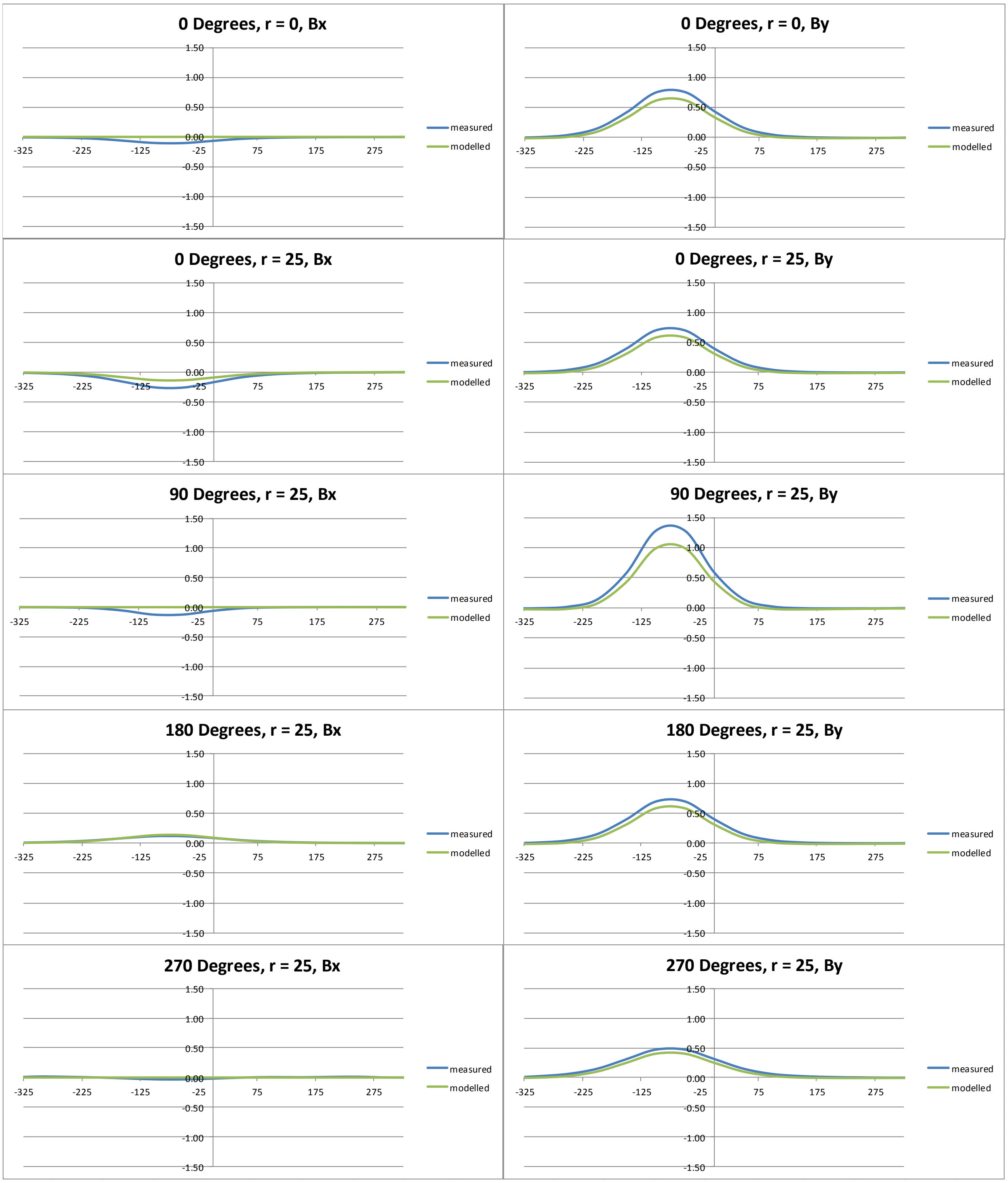
Fine Corrector 19

Fine Corrector 20

Fine Corrector 21



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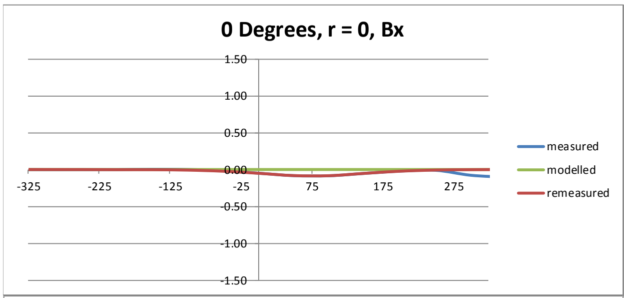
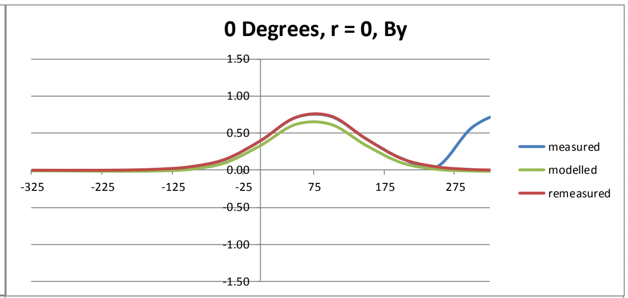
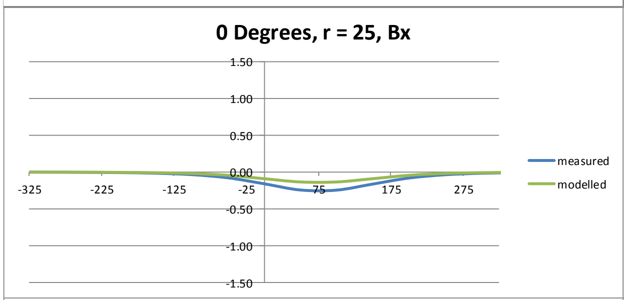
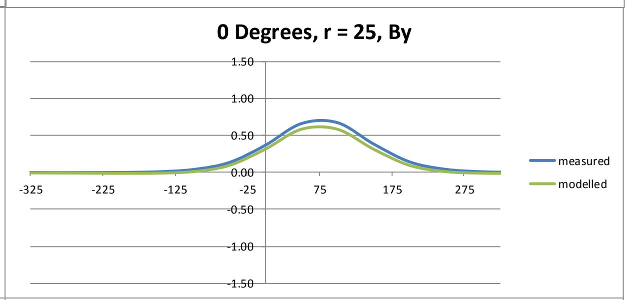
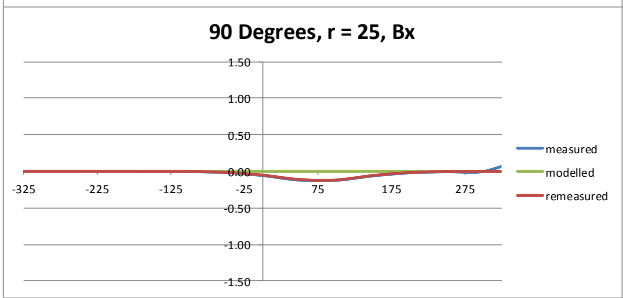
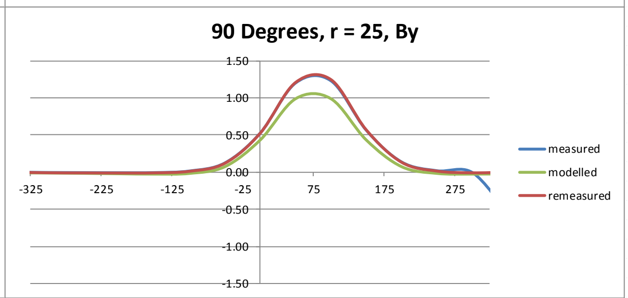


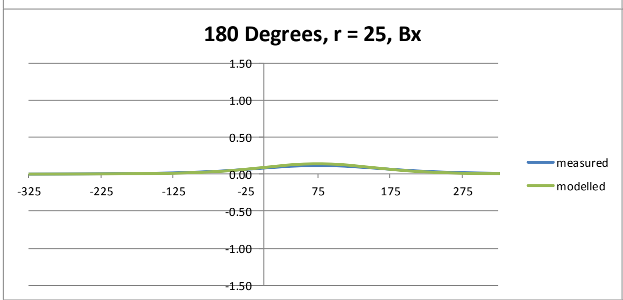


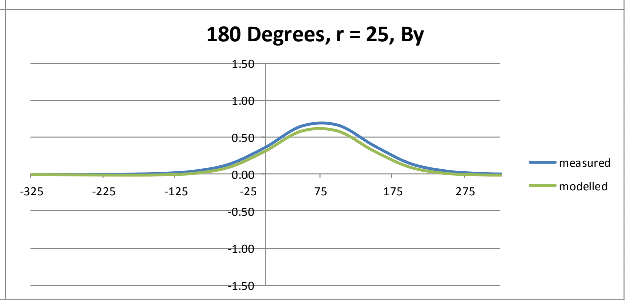


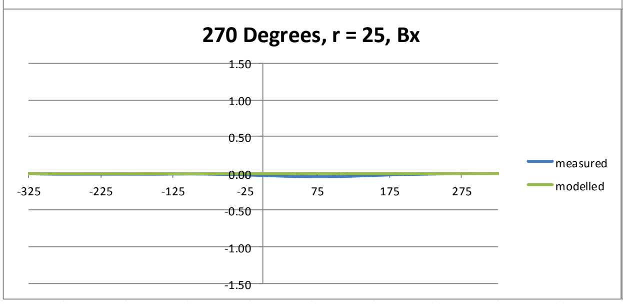


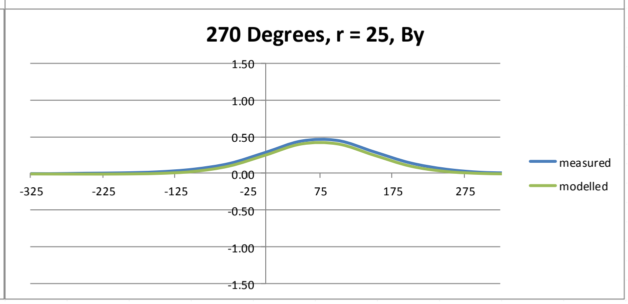




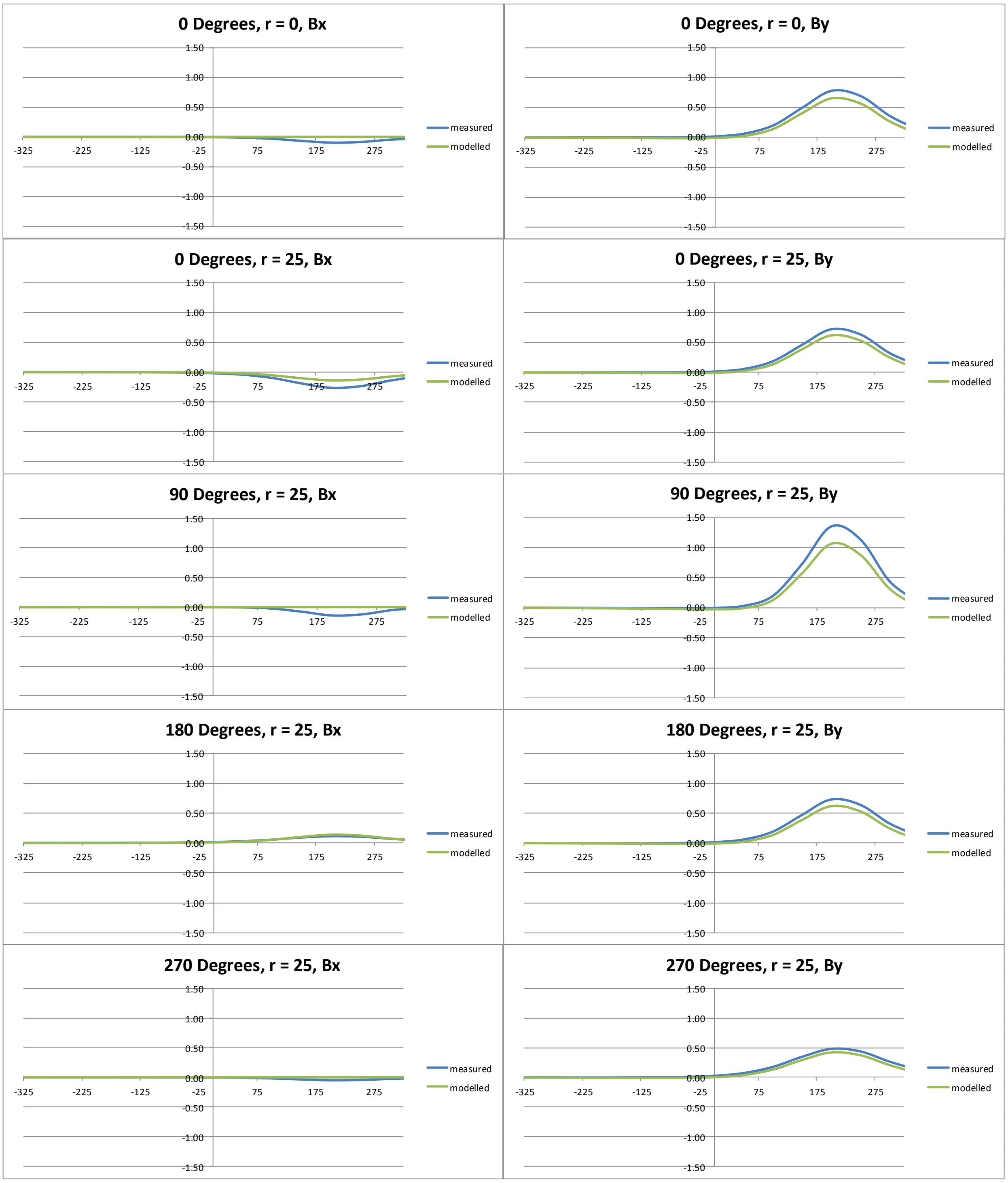








Fine corrector 23



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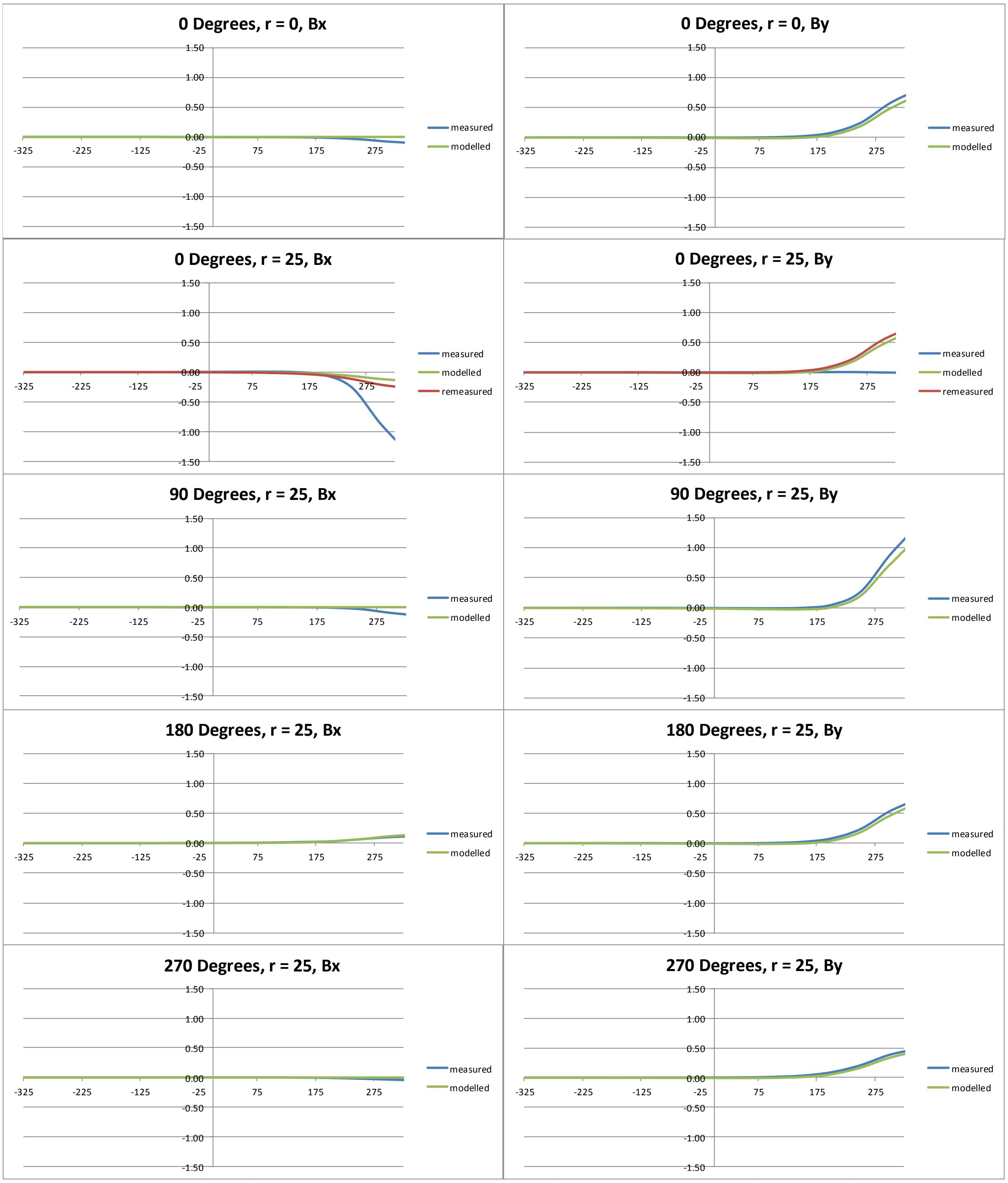

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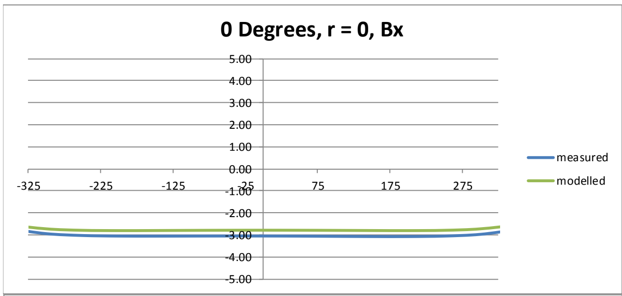
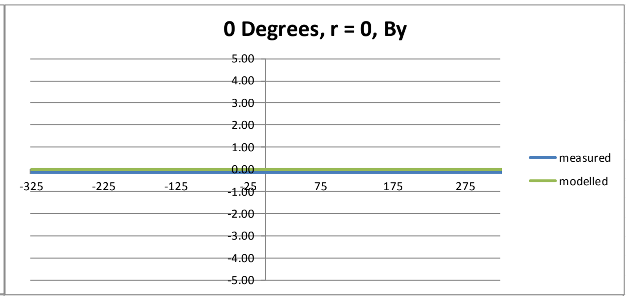
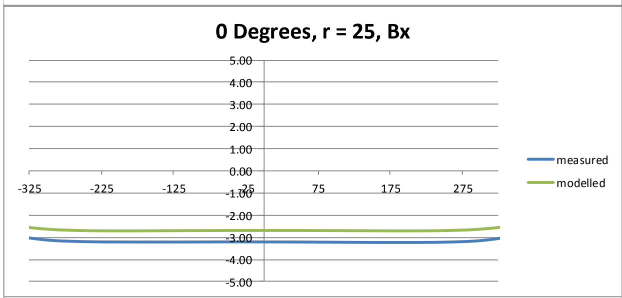
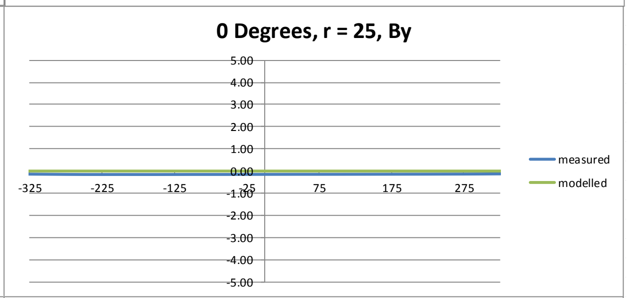
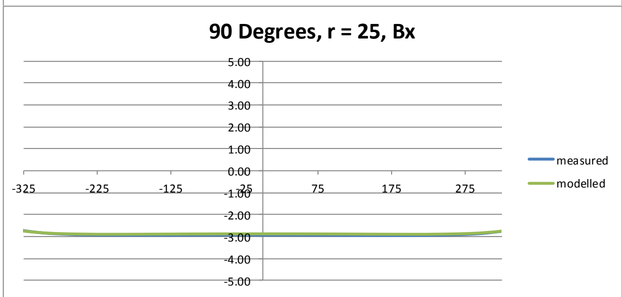
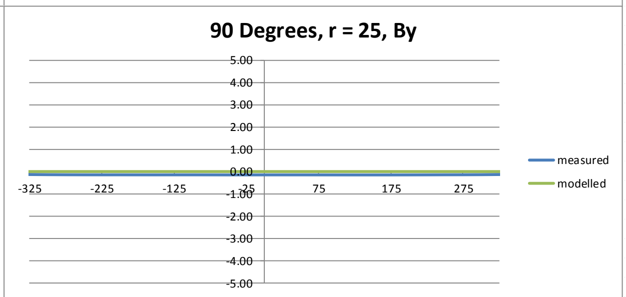


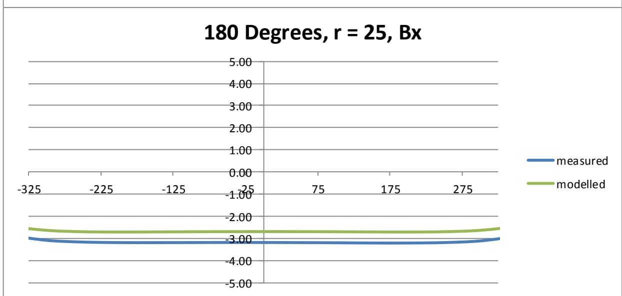


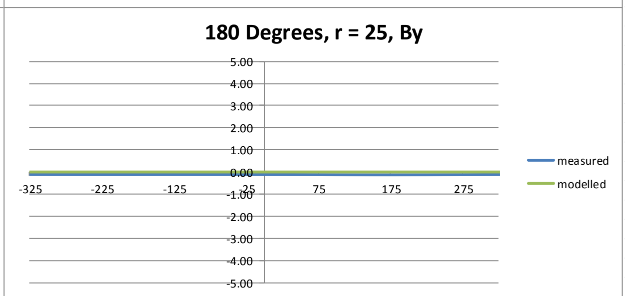


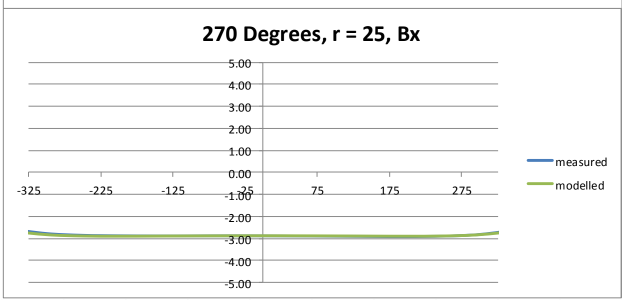


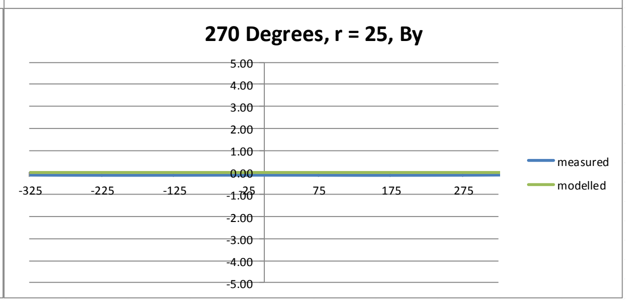








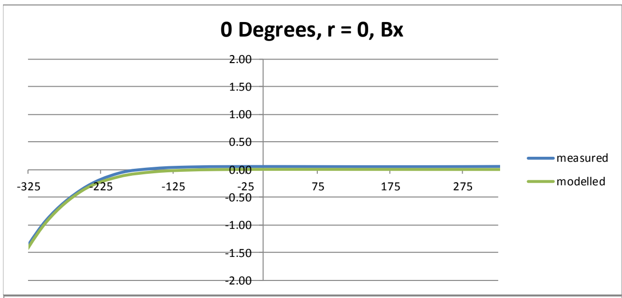


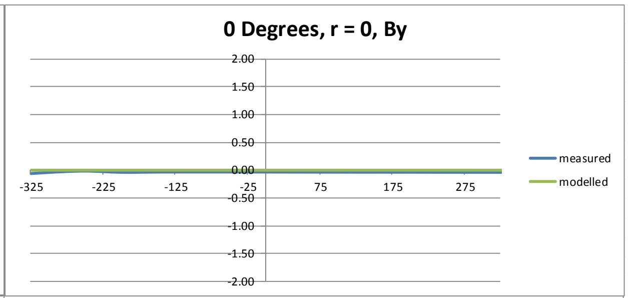


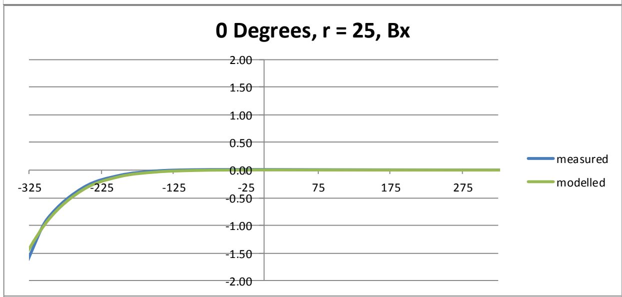
Helmholtz pair 2

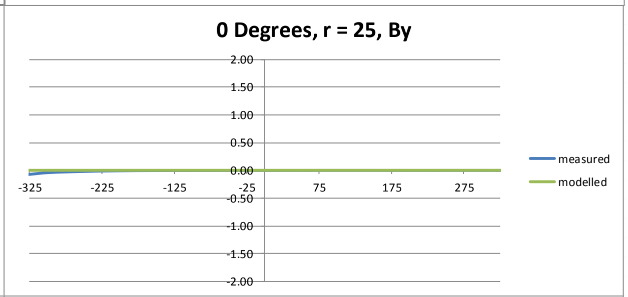
Saddle pair 1

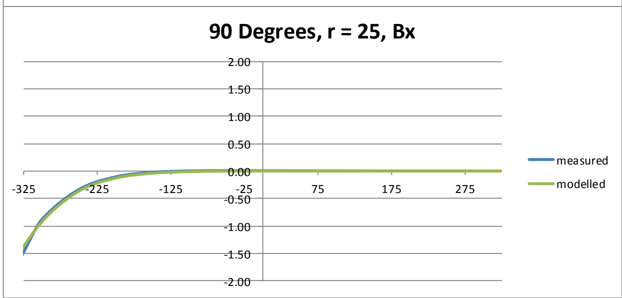
Saddle pair 2

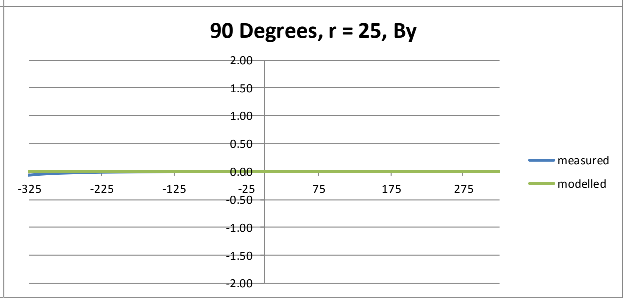


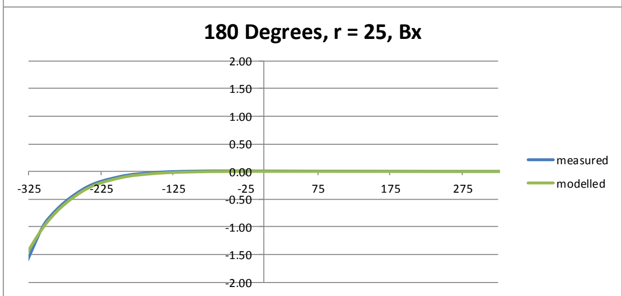


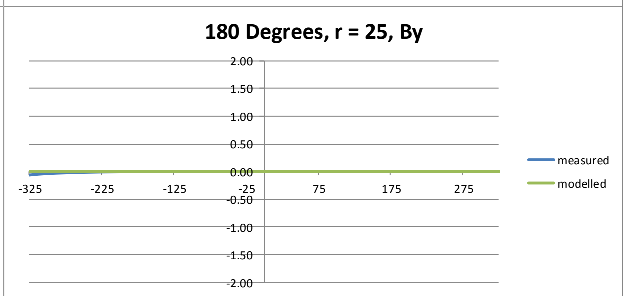


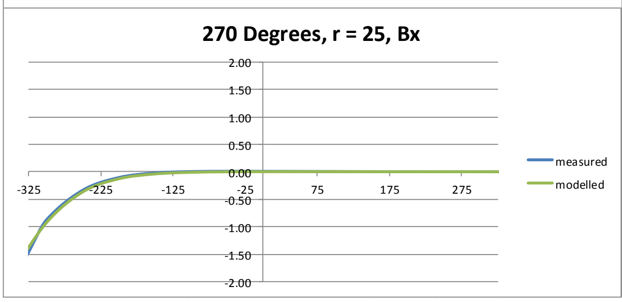


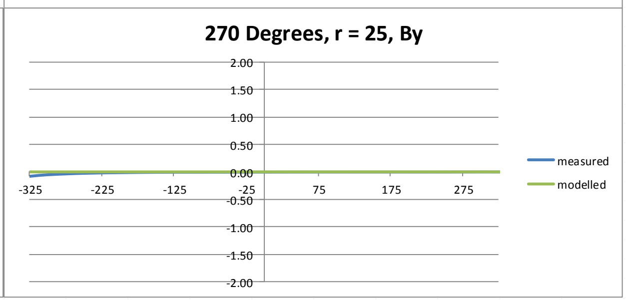












Circular coils