Measured and Nominal Current Analysis for MagneData99.

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Abstract

This paper describes the work completed during the author's internship with the SIST program at Fermilab, during the summer in 1999. The paper describes the Dipole Magnet data analyzed from the Main Injector and the results obtained. This was done in an effort to help in the progress of the MagneData99 project.

1 Introduction

MagneData99 is an effort to regularize Main Injector Magnet information. It is currently led by Dr. Bruce Brown of the Beams Division. Through Magnedata99 we are trying to gain a better understanding of the current magnet measurements in order to diagnose a current readout problem. The data which is being analyzed is Main Injector Dipole Magnet data extracted from the Sybase Database Management System, at the Magnet Test Facility (MTF).

An aim of MagneData99 is to record the differences in strength of each selected magnet run at six different measurement currents. The measurement currents will be of 500 A, 2000 A, 6000 A, and 9500 A taken on the upramp, and repeated measurements taken on the downramp at 500 A, and 0 A. The collected data will then be examined through mean deviations, standard deviations and other forms of comparison. The Dipole magnet data will also be examined for bad or unacceptable data points with the use of correlations. Ultimately the acceptable and useful Dipole magnet Data collected from the MTF database will be made accessible to Fermilab physicist. Hence, With the use of an SQL queries, physicist will have a quick and easy way to access needed data.

My assignment was to examine dipole magnet data (IDA090 - IDA100) by performing a linear regression analysis of the data. Through linear regression it is possible to do linear fits, analyzing the slope, intercept, and correlation of a set of variables. Using the data provided for IDA090-IDA100, I was able to examine the relation between measured and nominal current, which will provide a baseline for further examination of current. The results are described later on in the paper.

1.1 Sybase Database Management System

MTF, maintains a database system for magnet measurements, it stores information about measurement subjects and data collected on measurement subjects. The Main Injector magnet measurement data is stored in the MTF database. The database collects measurements on more than 1000 magnets and consists of about 2,000,000 rows of data.

Within the MTF system I work as a Data Clerk. This is basically a worker who uses data analysis on measurement data. My supervisor Bruce Brown on the other hand is a data user. He is a Magnet Physicist with use for data collected by the MTF system.

1.1.1 Dipole Magnets

Dipole Magnets play an important role at Fermilab. They are essential to the functioning of the Main Ring, Main Injector and most sychrotrons and storage rings since they make up about 80 percent of the magnets in use. This commonly used magnet is required for its bending function. A conventional Dipole magnet for example consists of iron poles and copper coils.

The Main Injector ring uses newly designed dipole magnets of two lengths to meet the geometric requirements of the lattice design. An ideal bending magnet or dipole will provide a uniform field over a length. In this uniform field, a particle will travel in a circle and the magnetic field will be almost everywhere perpendicular to the particle path. However, dipole magnets do not work alone; at Fermilab they work in conjunction with quadrupole magnets which provide the focusing function.

2 Experimental Details

Using, two programs 20/20 and Xmgr created for simple data analysis, I was assigned the task of creating Linear fits and Histograms of the Measured current (the value read from the transductor) vs. the Nominal current (the requested current). This involved learning how MTF works and what each column of data within the system represented. In order to examine the MTF database documentation, I also had to explore 20/20 and Xmgr spreadsheet programs. Through the use of these programs, I then had to learn about linear fitting with the Least Squares function (LSQ) and about making x-y graphs.

2.1 20/20 and Xmgr

The 20/20 and Xmgr systems are programs with simple graphics plus calculation capabilities. They both serve as types of data display and analysis programs. 20/20, unlike Xmgr is a spreadsheet program which can perform calculations and graphics on acquired database information formatted for display. Xmgr, uses formatted data from SQL queries and perl scripts. Nonetheless, both programs are available on many computers such as SunOS Unix.

2.1.1 Understanding and Fitting the MTF data

The first step in analyzing the Main Injector Dipole magnet data was to acquire the proper magnet information from MTF, see fig.1. When the information was obtained it was then transfered into 20/20 where the second step began to take place. The first two columns, which represent measured current and nominal current were given ranges and placed into and X-Y graph, hence a fit was created, see fig.2

I_ nominal	I_ measured	Meas_ strength	Meas_ error	ramp_ direction	I_ reset	I_ preset	ramp_ number
0.000	0.000	0.012309	0.000070	1.000	0.000	9478.19	0
100.000	102.625	0.132263	0.000070	1.000	0.000	9478.19	0
200.000	202.535	0.250465	0.000070	1.000	0.000	9478.19	0
300.000	302.125	0.368876	0.000070	1.000	0.000	9478.19	0
400.000	401.885	0.487647	0.000070	1.000	0.000	9478.19	0
500.000	501.505	0.606697	0.000070	1.000	0.000	9478.19	0

Table 1: MTF dipole magnet data

The creation of the fit then allowed us to enter step three and perform a linear regression analysis of data. Linear regression is composed by the Least Squares Method (LSQ).

Based on the linear equation $Y = a + bx$ three types of linear regression analysis (slope, intercept, and correlation) can be used to predict results on the known data.

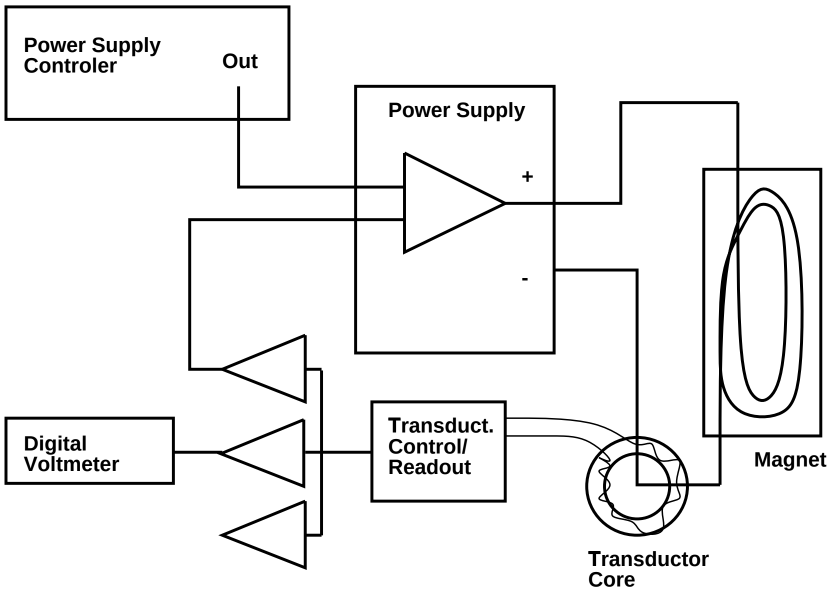

Figure 1: Design plan for current control and Readout Hardware at MTF. A nominal current (I_nominal) is sent to the power supply controller which generates an output signal. The 10,000 A power supply responds to the signal by regulating the current output through the magnet to produce a matching input via the response recorded by the Transductor. The measured current (I_meas) is obtained via the Digital Voltmeter from the transductor. Amplifiers isolate the various signal paths

The formulas used for each type are:

$$Slope = \frac{\sum_{i=1}^{n}\Big((x_i - \overline{x})(y_i - \overline{y})\Big)}{\sum_{i=1}^{n}\Big((x_i - \overline{x})^2\Big)} \tag{1}$$

$$Intercept = \overline{y} - (slope*)\overline{x} \tag{2}$$

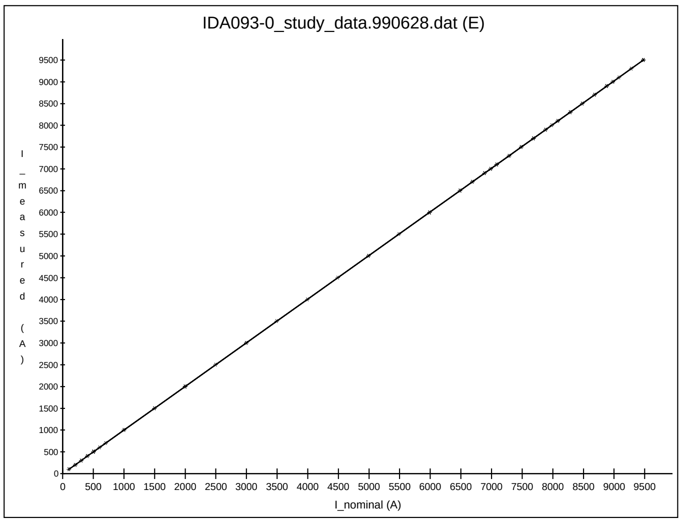

Figure 2: Measured Current vs. Nominal Current.

$$Correlation\ coefficient \ = \ \pm\sqrt{1-\left(\frac{\sum_{i=1}^{n}\left((y_i-\overline{y})^2\right)}{\sum_{i=1}^{n}\left((y_i-\widehat{y})^2\right)}\right)} \tag{3}$$

The result is positive or negative depending on the slope where:

$x_i \ = \ i$ th independent value
$y_i \ = \ i$ th dependent value
$\widehat{y}$ = predicted value of $y_i \ = \ slope * (x_i) \ + \ intercept$
$\overline{y}$ = mean of dependent value
$\overline{x}$ = mean of dependent value

When the linear regression analysis of data occurs with the help of 20/20 and Xmgr specific calculations occur. These calculations allow us to view the actual numbers for the slope, intercept and correlation. From these numbers it is possible to inquire about the offset, and break points found in the dipole magnet data. Hence, we

Type	Abbrev.	Definition
Slope	"SL"	The value b in the equation $Y = a + bx$
Intercept	"IN"	The value a in the equation $Y = a + bx$
Correlation	"CO"	An estimate of the improvement LSQ gives over using the mean of the y-values for y. A value of 0 means the values in range 1 do not depend on the values in range 2. A positive value means that range 1 and range 2 are positively correlated; a negative value indicates that they are inversely correlated. 1 and -1 indicate perfect positive and inverse correlation respectively.

Table 2: definition of the three outputs of linear regression

can analyze the data precisely and find any changes in the data points.

We finally want to inquire about the significance of zero current. In an effort to do so, the fourth step begins to take place. After attaining the data from MTF once again, it was then placed into Xmgr instead of 20/20. In Xmgr it was possible to see a histogram of the data points. These histograms clearly pointed out the differences and similarities within the magnet data collected (such results will be clearly explained further in the paper).

As all good research scientist Bruce Brown wished to double check on the accuracies of the linear fits. Therefore, the fifth and ultimate step which took place in this data analysis project was the calculation of the deviations of the dipole magnet data. With this calculation and no zero current the creation of fits between the nominal current and the calculated deviations could occur. This was done in order to check how linear the fits truly were in an effort to discover any bad data points or differences in data trend.

3 Experimental Results

The overall purpose of MagneData99 is to determine what might signal bad data runs through the analysis of data reproducibility checks. The method of plotting measured current vs. nominal current and performing linear regression was developed as a source for the dipole magnet data analysis. From these simple graphs and calculations many valuable results have been collected in an effort to determine the problem in the current offset variation.

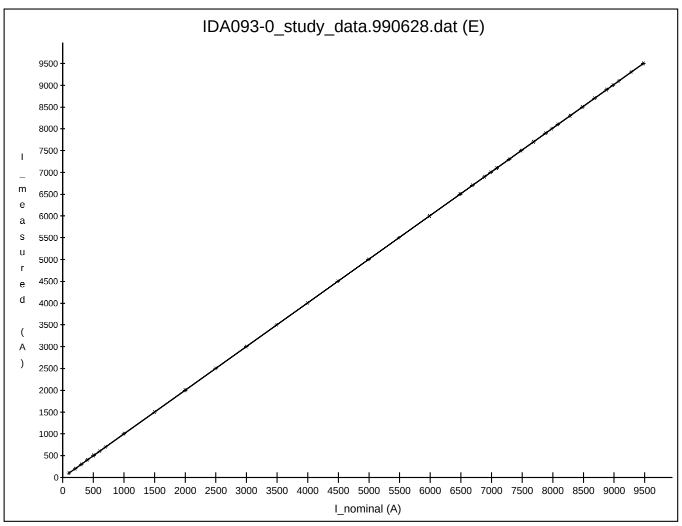

Figure 3: Measured Current vs. Nominal Current.

One of the most obvious results obtained through this data analysis is the fact that current is linearly related to the requested current. This implies that the plot shown of measured current (the value read from the transductor) and nominal current (the requested current) are directly linearly related, see fig.3. This fact was further enhanced by the calculation of the correlation through linear regression analysis. All ten dipole magnets (IDA090-IDA100) gave a calculated value of 1 for the correlation. In comparison this indicates perfect positive correlation to the accuracy reported.

It had been speculated that their was a problem with the current read back at 0 A. Therefore, linear regression was also performed on the dipole data excluding the measurements calculated at 0 A. When comparing both sets of calculations, it was found that their were significant differences in the root mean squared (RMS) and in the intercept values attained. Over all currents the intercept value varied by a little over 500 milliamps, and the RMS variation ran from 400milliamps to 600 milliamps. The slope, however, did not have a significant variation it was very similar in all cases. Therefore, the slope proves to be more stable than the intercept and RMS. In addition, it was realized that the readback at 0 A is almost completely unrelated.

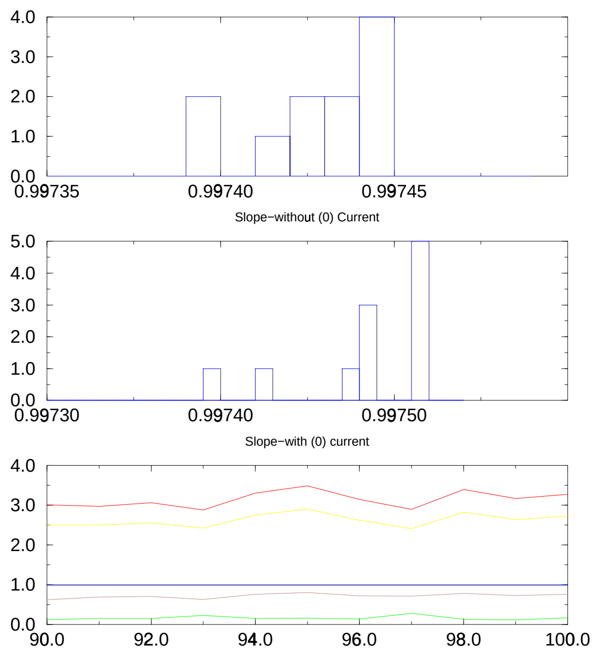

Figure 4: Histograms of linear regression data.

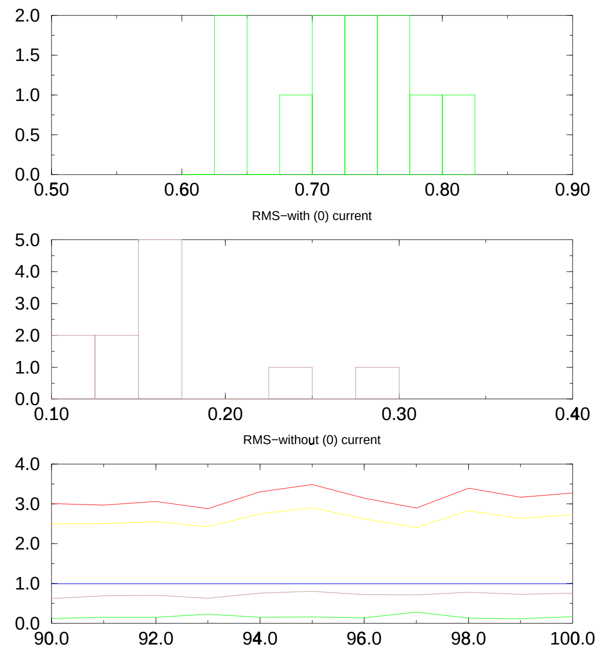

Figure 5: Histograms of linear regression data.

The results explained above can be viewed in the histograms presented in figs.4, 5 and 6 which depict the differences in the RMS and intercept, while clearly showing the similarity in the slope values.

In an attempt to get the best fit data the linear fits were all checked upon. This step was simply done by plotting nominal current vs. deviation. The graphs once again depicted the fact that the dipole currents data were definitely linearly related. The deviations where all very small and very similar, in fact the largest deviation was around 1.7e-12. This documented that the current control and read back system is quite linear.

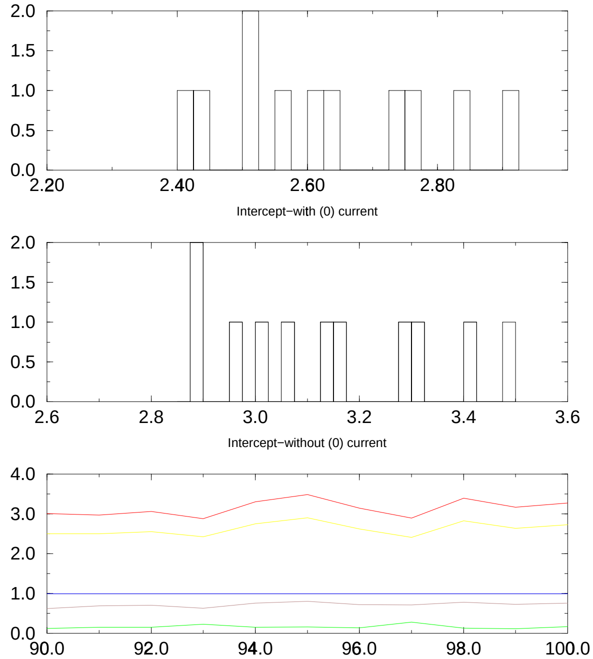

Figure 6: Histograms of linear regression data.

This formula shows the simple calculation for deviation followed by a graph of nominal current vs. deviation (see fig.7).

STD uses the formula:

$$Standard\ Deviation \;=\; \sqrt{\frac{\sum_{i=1}^{n}(V_i \;-\; AVG)^2}{n \;-\; 1}} \tag{4}$$

where:

$$\begin{aligned} n &= \text{number of items in list} \\ V_i &= i \text{ th item in list} \\ AVG &= \text{average of values in list} \end{aligned}$$

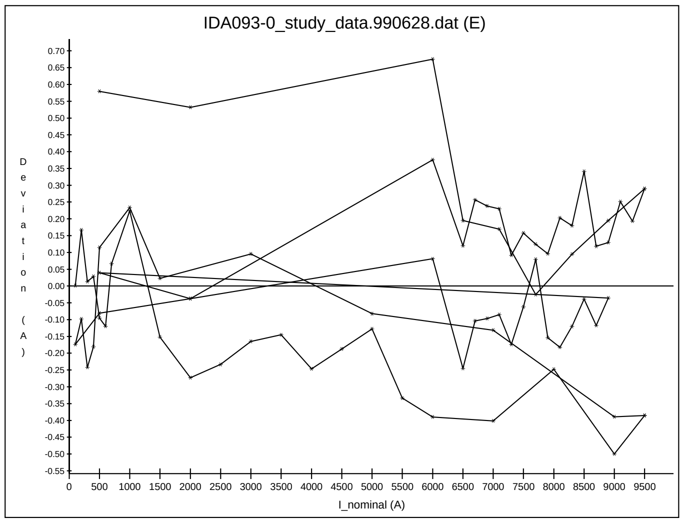

Figure 7: Nominal Current vs. Deviation

4 Conclusion

The Main Injector Dipole magnet data is still under analysis. A conclusion as to what specific factors are causing current offset and read back problems has not been reached. The analysis done thus far, however, is worthy of attention.

Through MagneData99 it has been found that offsets at very low currents are a little more that 1 A when compared to the offset at useful non-zero currents. Hence, the read back at 0 A is almost unrelated. In addition it has been tentatively concluded that the current is linearly related to the requested current. It is also believed that the RMS and intercept are less stable then the slope.

Nonetheless, many questions are still lurking. Such as, Can we use linear fits to determine an offset of actual current from nominal current? Is the measured current useful? In an attempt to answer these questions further analysis of data will take place with Harmonics, Flatcoils and perhaps pointscans. Likewise, we must also keep in mind that the Main Injector hardware might also be the cause of such problems in current read back.

Perhaps, some improvements should be made to the device. A detailed study should be continued to analyze both the hardware and the software. However, MagneData99 has helped in the data analysis progress thus far.

5 Acknowledgments

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