Testing of Raster Magnet for ESS

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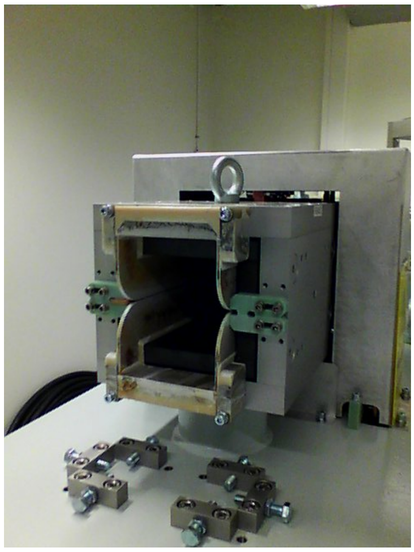
Abstract

This report describes the work done as part of my project with Heine Thomsen in the spring semester 2018. The project is about testing a magnet developed by Danfysik for the European Spallation Source (ESS) in Lund, Sweden. In the first part of this report the magnet and its purpose is described as well as the setup used for testing. This serves as a brief overview of the magnet and its purpose. The second part deals in much more detail with the software developed in LabVIEW, and is intended for people designing similar software. For my part the main purpose of this project was to get familiar with LabVIEW, with which I had limited prior experience.

1 Hardware

1.1 The ESS Facility

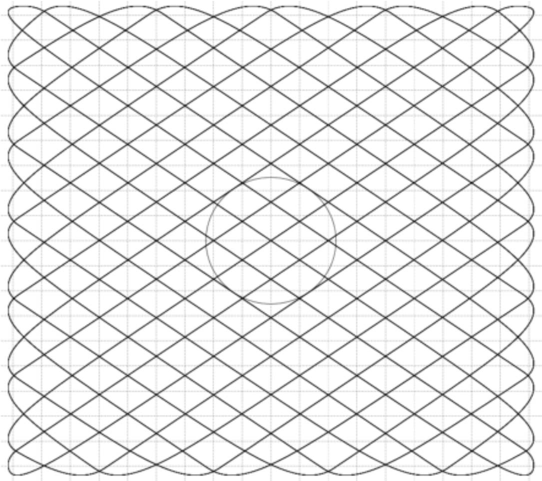
The ESS facility which is currently being constructed in Lund, Sweden, will use accelerated protons to create the worlds most powerful pulsed neutron source. Such a source has applications within physics, geology, chemistry, biology and medicine. With a frequency of 14 Hz the accelerated pulsed proton beam will hit a tungsten target, which will emit several neutrons (spallation). The target is a 2.6 m in diameter steel disk with bricks of tungsten. The total weight is 11 tonnes. Since the proton beam will be very energetic, a lot of heat is generated in the target. Even though the target will be cooled with liquid helium, the heat will destroy the target, if the beam is left on the same spot longer than a few pulses. The target will be rotating with around 23 rpm, and the beam will be scanning across the target as well. To move the beam a series of dipole magnets is placed around the beam before the target. A single dipole can bend the beam in one plane. By combining dipoles that can bend the beam horizontally and vertically, it is possible to steer the beam in both transverse directions. Each dipole is called a raster scanning magnet (RSM), and the entire system is referred to as the RSM system. The RSM system will "paint"a pattern with the beam to distribute it all over the target. The raster magnet consists of four vertical and four horizontal dipoles. Two of these dipoles have currently been produced by Danfysik and are being tested at Århus University. A picture of one of them is seen in figure 1. ESS requires the magnets to have a high level of stability. They have already been tested at Danfysik, but Århus University is testing them for an extended period of time (around 1000 hours).



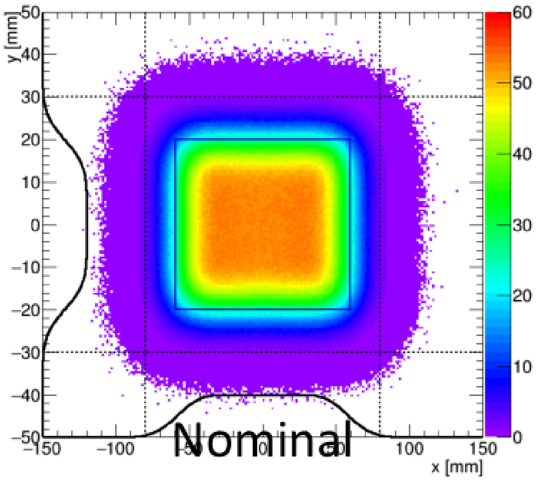
Figur 1: One of the dipoles in the test setup.

The Raster Magnet

The magnet is connected to a power supply delivering an AC signal, and it is designed to operate at a maximum of 340 A peak amplitude. At maximum current it can deliver a 16 mT magnetic field. The wires are magnetizing a ferrite yoke, which amplify the magnetic field. The RSM system is only turned on, when a beam pulse passes. Hence, the duty cycle of the system is around 5&. This relatively low duty cycle means that most of the system does not require more than passive air



Figur 2: Conceptual sketch of the beam pattern created by the raster magnet system. The circle in the centre is the width of the gaussian shape of the beam.



Figur 3: The beam intensity distribution over the target as a result of the scan pattern.

cooling despite the high currents. The termination box however needs to be water cooled.

The power supply delivers a burst AC current with a burst rate of 14 Hz. The frequency of the AC current is 29 and 40 kHz for the vertical and horizontal dipole respectively. A pulse will be delivered with a 14 Hz frequency, and it will take 3 ms for a proton burst to pass the raster magnet. Hence, the frequencies of the magnets will create a pattern like the one sketched in figure 2. The circle seen in the centre of the figure is the width of the gaussian shape of the beam. With the finite beam size the scan pattern will result in a intensity distribution like the one seen in figure 3

Test Setup

The size of the magnetic field delivered by the dipole is related to the current going through the coil, I, the number of turns, N, the magnetic permeability of the wire, μ_w, and the length of the material, L

$$B = NI\frac{\mu_w}{L} \tag{1}$$

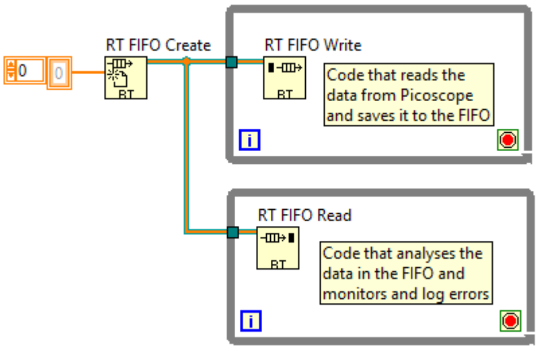
When amplified by the ferrite with magnetic permeability μ_f, the resulting magnetic field, H, is

$$H = \mu_f B \tag{2}$$

To monitor the strength of the magnetic field, a coil with a single turn is wrapped around the ferrite. The induced current in this test coil is read out by a Picoscope connected to a computer. The Picoscope is controlled by LabVIEW, which makes it possible to analyse and log the recorded signal.

2 Software

Since the proton beam will destroy the wolfram target if left at the same spot for too long, it is vital to respond quickly to any instabilities in the magnetic field. It is estimated that a few pulses delivered at the same spot would be enough to destroy the target. Hence, the recorded signal from the test coil has to be analysed live, and it has to be analysed quickly. The software used to read and analyse the signal is LabVIEW. Besides the data from the test coil LabVIEW was set up to communicate with the power supply. Errors on the power supply, which from now will be referred to as register errors, can therefore be read by LabVIEW as well. During testing a single program was reading and analysing all data. It is vital to record every burst from the power supply, but the analysis of each burst can be accepted to lack behind the reading of the data with some 10 ms. The program was therefore designed with a parallel structure, where the analysis part of the program would never block the reading part. A typical way of writing LabVIEW programs is to put all the code blocks inside a while loop, which iterates until the program is stopped. The execution logic of LabVIEW means that a slow analysis of a particular burst could prevent data code from being ready to read the incoming data from Picoscope, if all code were



Figur 4: Sketch of the parallel structure of the LabVIEW code. A part dedicated to read data from picoscope above, and a part dedicated to analysis and logging below.

placed in the same loop. The parallel structure of the program, where reading of the data is done in a separate while loop, prevents this from happening.

To pass elements between the two parts of the program, the "First In First Out"(FIFO) structure is used. The FIFO is essentially an array of elements, where new elements are added to the end of the FIFO, and elements are read from the beginning. When an element is read, it is removed from the FIFO. This creates a buffer for the analysis part of the program. As long as the analysis part on average is faster than the 14 Hz with which data are acquired, the analysis part will be able to catch up, should it fall behind. One could imagine two scenarios, which would cause the analysis part to fall behind. Either a particular burst takes a lot of processing power to analyse, or the computer is dedicating its power to other programs than LabVIEW. The latter could be a problem for the data acquisition as well, so during the testing a computer dedicated to the job has been used. It is recommended to set up hardware dedicated to the monitoring of the raster magnet. The occupied length of the FIFO has been monitored, and it has never seen to rise above 0 during testing, implying that the analysis is way faster than 14 Hz. A burst event consists of 45000 samples from each of the two magnets. The burst is passed around as a one dimensional array with a length of 90000, and the FIFO is set to be able to contain a maximum of 1000 bursts corresponding to around 71 seconds of beam. A sketch of the parallel structure of the program is seen in figure 4.

2.1 Analysis in Detail

The analysis of the data is supposed to reveal any instability in the current of the dipoles and thereby the magnetic field. The mean, root mean square (RMS), maximum and minimum value (over a 6 hour period) of the following parameters are being monitored:

- Current amplitude
- The frequency
- DC offset in the AC current
- RMS value of the rectified Bdot (time derivative of B-field) signal
- Phase of the signal

All parameters have to stay within certain thresholds. An alarm system has been set up to trigger, if the thresholds are violated. In case of an error (defined as the violation of a threshold or an register error) the burst is saved in a txt-file acting as en error log. The time of the error as well as the array containing register errors is added to the error log. A single burst written to a txt-file takes up 900 kB. One therefore has to take certain precautions to not cause an overflow of the harddisk. During testing a limit on the file size of the error log was set. This limit was set to 10 MB as a simple way of preventing harddisk overflow. An alternative restriction on the error logging, which was implemented as well, is the number of error occurred over a limited number of previous burst. If the average number of error over the last 10, 100 or 1000 burst exceeded 30%, the error would not be logged. The idea behind this precaution is to prevent a high number of similar "bad"burst to be logged. If for example an error flag is raised for a specific burst, it will continue to be raised for the following bursts, until the error has been dealt with.

In case of an error, the time of the error, the register error array and the burst information of the specific burst is written to a text file. The information about the previous four and following five burst are logged as well. The idea is that in this way it is possible to reconstruct the entire event chain around the error. During testing there was no need for reconstructing events, and the selected numbers of previous and following bursts logged are therefore somewhat arbitrary. To be able to log events that occur before an error, the FIFO structure is used again. A FIFO able of holding five bursts is created in the analysis part of the code. After a burst has been analysed, it is send to the FIFO. In case of an error the FIFO will hold the burst that caused the error and the previous four. All these are then written to the error log. It should be mentioned that the code will write all five bursts in the FIFO even if it would exceed to 10 MB size limit of the error log.

To monitor the overall status of the test, at status log is created every six hours. The status log contains all threshold values, the monitored values and the sum of all analysis and register error occurred during the test run. During the first 1000 test hours only 3 errors were detected, two of which were due to human intervention. The third error violated a threshold, which for a short time was set much lower than the required value. As the required value was not exceeded, the error is without importance.

3 Conclusion

Two of the dipoles developed for the ESS raster magnet system has been tested for 1000+ hours at Århus University. To monitor the magnetic field, a test coil was mounted on one of the magnets. The output from the test coil was read and analysed by LabVIEW. To make sure that LabVIEW would always be ready to read an incoming signal, and thereby avoid loss of data, a parallel structure of the LabVIEW code was developed. Separating the analysis part from the reading part allowed the code to deal with peak load on the performance. It is recommended that dedicated hardware is used for the monitoring of the raster magnet. During test no significant errors occurred.