

THE AUTOMATIC QUENCH ANALYSIS SOFTWARE FOR THE HIGH LUMINOSITY LHC MAGNETS EVALUATION AT CERN

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Abstract

The superconducting magnet test facility at CERN, (SM18), has been using the Automatic Quench Analysis (AQA) software to analyse the quench data during the Large Hadron Collider (LHC) magnet test campaign. This application was developed using LabVIEW™ in the early 2000's by the Measurement Test and Analysis section (MTA) at CERN. During the last few years, the SM18 has been upgraded for the High Luminosity LHC (HL-LHC) magnet prototypes. These HL-LHC magnets demand a high flexibility of the software. The new requirements were that the analysis algorithms should be open, allowing contributions from engineers and physicists with basic programming knowledge, execute automatically a large number of tests, generate reports and be maintainable by the MTA team. The paper contains the description, present status and future evolutions of the new AQA software that replaces the LabVIEW™ application.

INTRODUCTION

The superconducting magnet test facility at CERN, known as SM18, has been using the Automatic Quench Analysis (AQA) software to analyse the quench during the Large Hadron Collider (LHC) magnet test campaign [1]. Nowadays, the magnet test facility is being upgraded to test the High Luminosity LHC (HL-LHC) [2] magnet prototypes and AQA is not anymore compatible and not flexible enough for the multitude of future HL-LHC magnets.

This paper will describe the requirements, design and special features for the new AQA.

SOFTWARE REQUIREMENTS

The superconducting magnets of the LHC have been tested at the SM18 facility [3], and the results of the tests were analysed with the AQA tool. AQA is in turn integrated in another program known as Viewer, both developed in LabVIEW™ and available in the SM18 control system. The Viewer was specially designed to interpret and display the measurements from the collection of tailored binary files (for data) and ASCII files (for metadata) generated during the tests by the acquisition systems. Both tools were adapted specifically for the series of LHC magnet measurements, which now dates back to the early 2000's.

For the HL-LHC magnet prototypes tests [4] an upgrade of the SM18 analysis framework was required to ensure the flexibility in the analysis algorithms [5].

In the actual SM18 test facility, the upgraded data acquisition (DAQ) systems now produce TDMS (Technical

Data Management Streaming) files, which are not compatible with the previous generation analysis tools.

A new tool has been developed, which also satisfies the main requirements covered by the previous tool:

- Automatic detection of the quench location and energy released by the quench.
- Analysis of quench heater signals.
- Computation of the electric current derivative and identification of the functions that fit the electric current profile.
- Analysis of the magnet superconducting coil voltage signals.

The additional requirements that provides the new software are:

- Flexibility to accept different magnet types
- Compatibility with the new TDMS file format adopted in the SM18.
- Arrangement of the signals in the TDMS file to help the users to navigate through the data
- Concatenation of the magnet signals acquired by the DAQ system at high and medium frequencies before analysing.
- Ability to pre-select the coils, signals and parameters to analyse: inductive and resistive voltage, resistivity and its derivative, temperature, resistance and inductance, and energy.
- Automatic detection of the quench location and ability to allow the user to verify this location and manually modify it by his criteria.

The results must be saved as a TDMS file, but the tool should also be able to create a PDF report that summarizes and clearly displays the results of the analysis.

The new tool should give the possibility to the mechanical engineers, not expert programmers, to implement custom analysis algorithms in a user friendly language.

Implementation

National Instruments (NI) DIAdem® was introduced, in 2013, into the SM18 software framework to visualize and analyse existing data that had been previously converted to TDMS [6]. This first step of renovation was aiming to replace the legacy viewer, by using a commercial application and developing a converter for the binary files. A second step related to the new DAQ, gave the possibility to get directly the output files into TDMS [7].

As the NI DIAdem® environment offered the possibility of creating Visual Basic Script (VBScript) code, the new AQA tool could be developed in this language, which is also a standard language of the SM18 mechanical engineers.

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The AQA tool should be accessible from any of the operational Linux consoles of the SM18 control rooms, where the acquisition application runs. As NI DIAdem® can only run under Windows, the notion of virtualisation was introduced.

The CERN OpenStack deployment service was used to build and associate a Windows Virtual Machine (VM) to each Linux console, running the analysis application. The VM has NI DIAdem® installed, from where the analysis tool has to be launched. This action opens the main dialog to select the configuration.

SOFTWARE ARCHITECTURE

The architecture that suits this kind of analysis software is “pipe and filter”. Based on the concept where each component or module needs a data input to either modify, operate or filter the data. The generated output feeds the next component. [8]

The diagram shown in the Fig. 1 quickly summarizes the modules, components and the interactions between them. AQA runs within NI DIAdem® and communicates with the Network File System (NFS) server where the configuration and test files to analyse are located. Intermediate, final and report files are stored in the same location.

The AQA Graphical User Interface

When opened, the Graphical User Interface or GUI (Fig. 2) uses a configuration file with the settings present the last time the application was launched. This is very helpful for the operators in an extensive test campaign, when the DAQ system is constantly producing new files and the operator needs to analyse them as soon as they are produced, all of them under the same conditions. Additionally, AQA requires the name of the user that performs a magnet test analysis. It can be selected from a pull-down menu that already contains the list of all SM18 users predefined in a file.

After the user selects the settings and different analysis options, the pre-analysis module starts.

For the GUI design, the software architecture that better fits is the event-driven-programming. Each user action is

detected as an event in the GUI that triggers the execution of the dedicated function written in VBScript [8].

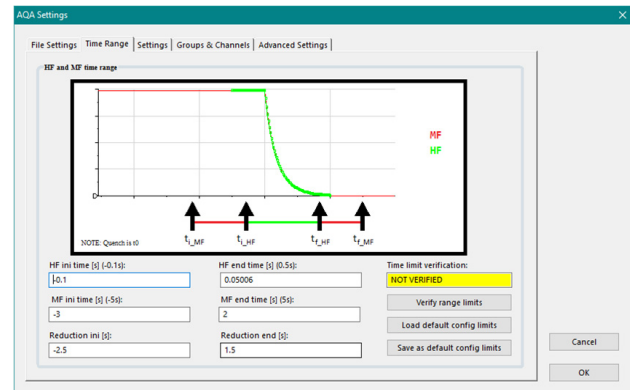


Figure 2: Example of AQA GUI dialog (Time Range tab).

The Pre-Analysis

The purpose of the pre-analysis intermediate module is to prepare the data for the analysis.

The DAQ system produces High (HF), Medium (MF) and Low (LF) Frequency data from the magnet tests. HF - typically 200 kHz for 1 second - and MF - typically 5 kHz for 10 seconds - data are analysed through the AQA tool, which allows the concatenation of HF and MF signals. The users define the time interval around the quench to analyse (Fig. 2), reducing the amount of data to be processed. The GUI allows selecting different intervals for HF and MF, merging them automatically. After this merge is done, an intermediate file is generated, saving upload and analysis time when the test file is re-used for further analysis.

The signals are then grouped in the Data Portal (window to view the internal NI DIAdem® data store [7]) according to its signal type (current, trigger, coil voltage, quench heater ...). One of the DAQ system features is that the operators can select the type of signal and this is stored as the ‘Analysis’ TDMS property. When this property is present, then the categorization of the signals into groups in the TDMS file is simply done using this information.

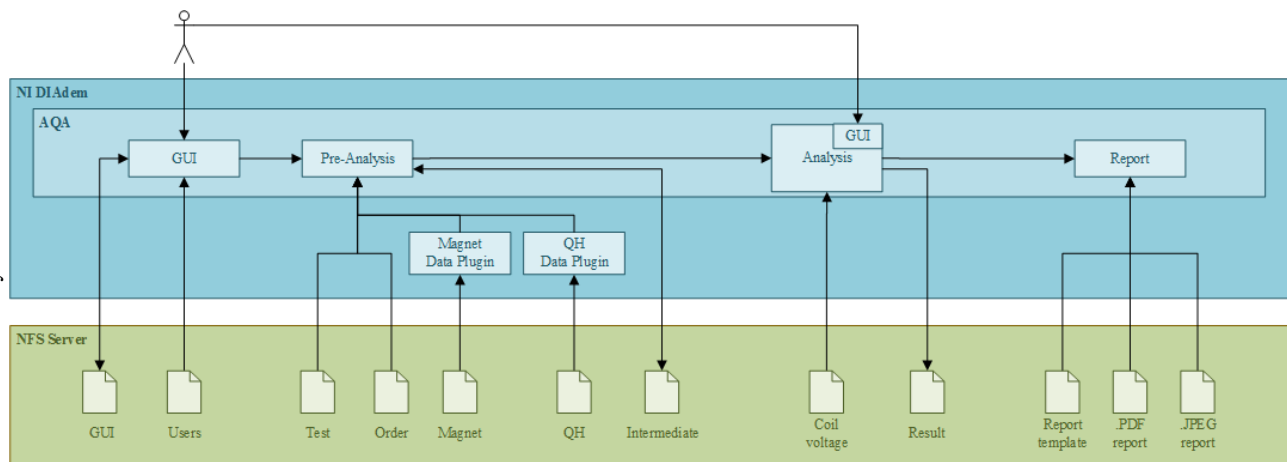


Figure 1: The software components, modules and their interactions.

The SM18 has standards for naming the signals. When ‘Analysis’ TDMS property is not defined, then it can be done using signal name pattern recognition. A configuration file contains the instructions to organise the signals by this method. For example, all quench heater voltage signal names must start by $U(Y$ or $V QH$, the configuration file specifies that these signals have to be sorted into the quench heater TDMS group.

This pre-analysis module is also in charge of loading the specific parameters to analyse the corresponding type of magnet and the quench heater limits. A data plugin for each file is responsible for loading an MS Excel® data sheet into the data portal. The raw data are now ready in the Data Portal for being analysed.

The left flow chart in Fig. 3 describes the pre-analysis module.

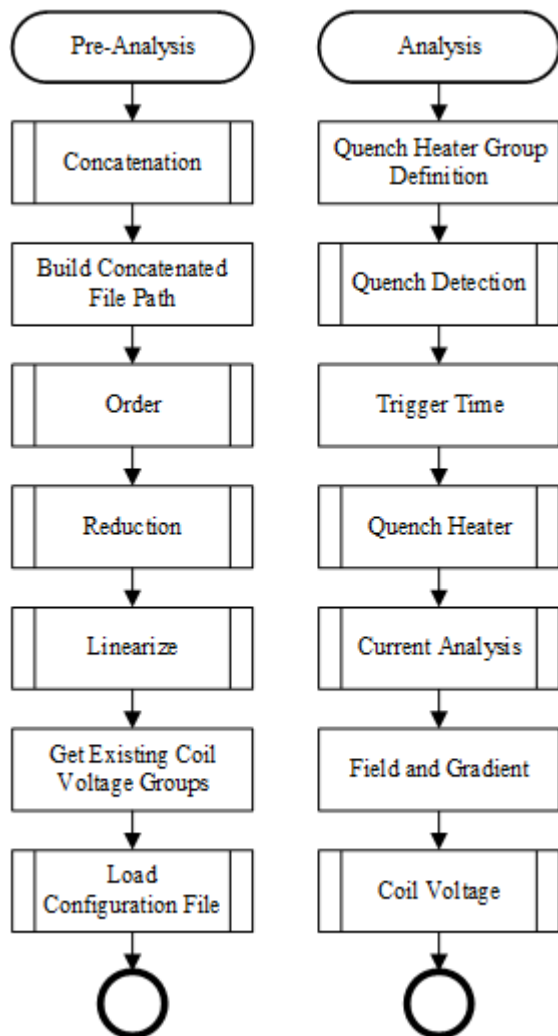


Figure 3: Simplified Pre-Analysis and Analysis activity diagrams.

The Analysis Module

The Analysis module consists of two blocks. Some analysis steps are always executed, like the quench detection or the quench heater analysis to get the quench heater resistance, temperature and energy.

Other steps are executed on demand depending on the operator request and they concern mainly the coil voltage signals. In this process, the user interaction is normally required to select the channels and type of analysis to perform (Fig. 4). The user can select a predefined mode to avoid any interaction at this level, allowing fully automatic analysis.

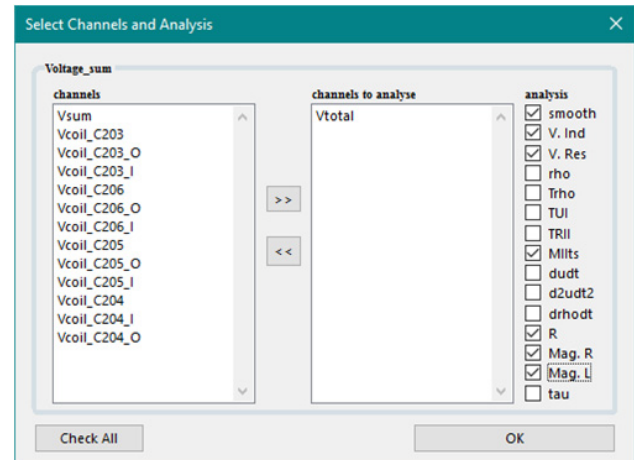


Figure 4: Interface to select the channels and indirect measurements.

To increase the flexibility, the software has been designed to automatically detect the magnet type and automatically load the corresponding configuration, each per magnet type. If a new magnet type arrives to the facility, then a new configuration file must be created following the documentation and template. The GUI contains an advanced settings tab reserved for the mechanical engineers to modify a set of these computational parameters to adjust the analysis.

Moreover, the user interaction might be required, depending on the user settings, to verify and correct the quench location. In this case, the user can use a graph display to verify it and modify if necessary to re-calculate the dissipated energy.

Finally, the results are saved in a TDMS file which can be used for future revisions.

The right flow chart in Fig. 3 shows the diagram that describes the analysis module.

Reporting

The last component is in charge of automatically loading the report templates, fill the graphs, texts, values and tables with the results of the quench analysis. The user can navigate through the different reporting tabs to examine the results (Fig. 5 shows the tab dedicated to the quench heater analysis results). The report is also saved as a PDF for future references. It has been proven in an early release that, for multiple tests on the same magnet, it is very useful to generate image reports to easily compare results between them.

It is possible to generate, based on the user selection, either basic or full reporting. The basic report gives only the general magnet test status, while the full report provides extensive details on all the magnet components.

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With full reports, the engineers can easily follow the magnet tests comparing graphs of the most relevant information like energy and quench location.

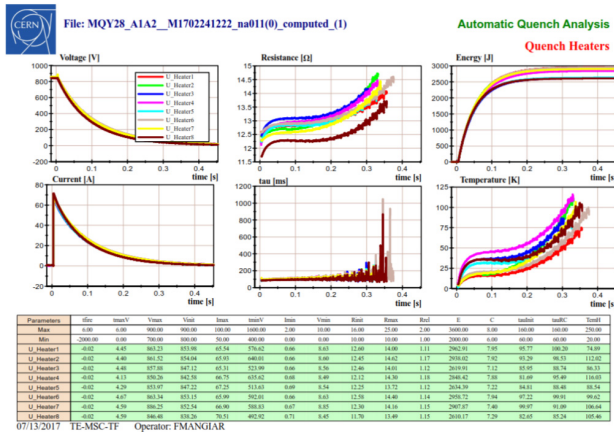


Figure 5: Example of quench heater signals summary report.

CONCLUSIONS

The upgrade of the SM18 superconducting magnet test facility for the HL-LHC magnets has created the need to design a new Automatic Quench Analysis (AQA) tool. This new tool developed in a user friendly language, VBScript, permits to analyse series of magnet tests in an automatic or semi-automatic way. High and medium frequency signals are merged to provide more information around the quench event. The analysis settings can easily be tuned by the mechanical engineers by editing the configuration files. The resulting data is arranged by grouping the results according to the signal category.

The new AQA has been the result of the collaboration of two teams, one providing the mechanical engineering expertise and the other the programming and software development competences.

Thanks to the new flexibility and modularity of the tool, as well as the documentation and guidelines for the VBScripts, it is now easier to expand the functionalities or modify existing analysis modules when new conditions are requested. The fact that these adaptations can now be done directly by the mechanical engineers, speeds-up the development cycle. This will also ensure the maintainability of the analysis over the lifetime of the HL-LHC magnets.

In the future, we will send the generated results to a database to improve the magnet traceability and the quality assurance. For this we are currently identifying the list of the pertinent results to store, and we are designing a SQL database.

REFERENCES

[1] B. Khomenko, private communication, Apr. 2001.
 [2] HiLumi HL-LHC Project, <http://hilumi.web.cern.ch>
 [3] A. Siemko and P. Pugnat, “Performance Evaluation and Quality Assurance Management During the Series Power Tests of LHC Main Lattice Magnets”, in *IEEE Trans. on Appl. Supercond.*, vol. 18, no. 2, Jun. 2008.

[4] G. P. Willering, “Cold Powering Performance of the First 2 m Nb3Sn DS11T Twin-Aperture Model Magnet at CERN”, in *IEEE Trans. on Appl. Supercond.*, vol. 27, no 4, Jun. 2017
 [5] M. F. Gomez de la Cruz et al., “New Analysis Framework Software for the CERN Superconducting Magnet Test Facility”, in *IEEE Trans. on Appl. Supercond.*, vol. 26, no. 4, Jun. 2016.
 [6] H. Reymond et al., “Unifying data diversity and conversion to common engineering analysis tools”, in *International Conf. Accelerator & Large Experimental Physics Control Systems*, San Francisco, CA, 2013.
 [7] National Instruments, <http://www.ni.org>
 [8] A. Balachandran Pillai, *Software Architecture with Python*, Packt Publishing, April 2017.