ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPTY059

FIRST OPERATIONAL EXPERIENCE OF DSL BASED ANALYSIS MODULES FOR LHC HARDWARE COMMISSIONING

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Abstract

The superconducting magnet system of the Large Hadron Collider (LHC) has been fully re-commissioned ahead of the second run of physics production in 2015. More than 20,000 tests had to be performed and analysed to qualify around 1600 electrical circuits for operation at 6.5TeV. Automated analysis modules, defined directly by the various system experts in an English-like domain specific language (DSL), have been used successfully within the Accelerator Testing framework (AccTesting) during the latest re-commissioning campaign. For this, the experts define pass criteria for the powering tests, which are automatically verified, via assertion modules, in order for the test to pass. These modules currently analyse 4 test types executed for more than 1000 systems and even allowed experts to identify issues, which were missed by manual analysis during previous campaigns. This paper describes the first operational experience with such kind of analysis modules, as well as a follow-up analysis of the results compared with previous commissioning campaigns. The analysis looks at potential shortcomings of the framework and attempts to improve the dependability of automated analysis with regards to high current (>1kA) circuits of the LHC are outlined.

INTRODUCTION

The AccTesting framework has been developed at CERN with the aim of providing dependable tracking and execution of the more than 20,000 tests that have to be performed on the magnet powering circuits of the Large Hadron Collider (LHC) to qualify it for operation after long technical stops or maintenance interventions. The need for orchestration tools was already identified during the first commissioning phase of the LHC in 2007/2008. For this first commissioning phase, over 5000 tests were completed, using a set of rather heterogeneous tools for the definition, execution, tracking and analysis of the various powering tests [1].

In subsequent (re-)commissioning campaigns the number of tests to be executed steadily increased due to the increase in individual system tests in the commissioning program. The experience gained, however, allowed for considerable improvements in both, the automation of execution of powering cycles on the electrical circuits as well as the automation of analysis for transient data recordings produced during these different validation steps. In 2010, the tracking and execution of tests has been amalgamated into a single Java based framework, which has been used successfully during multiple campaigns ever since.

In an effort to further progress towards a coherent set of tools for the operation and expert crews of the LHC, the most recent campaign has seen the inclusion of a new analysis layer within the AccTesting framework, based on the use of a DSL.

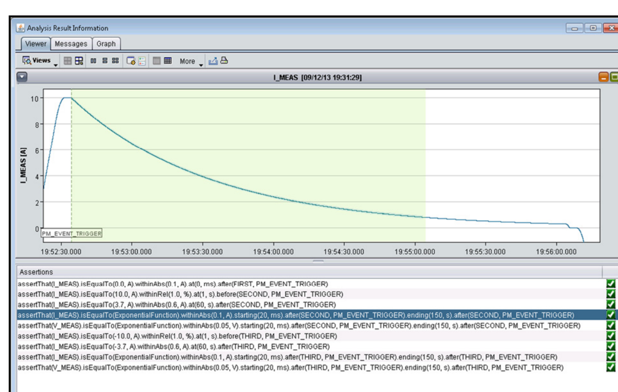
DOMAIN SPECIFIC LANGUAGE FOR AUTOMATED ANALYSIS

The use of a domain specific language for data analysis bears many advantages that are outlined in [2] [3]. When investigating first operational experience with DSL based analysis modules, emphasis is given to assess the experience relative to the main design goals of the DSL, namely:

- Facilitating analysis tasks for equipment experts and automation crews
- Increasing system reliability through dependable automated analysis
- Increased performance and test efficiency due to the removal of manual analysis

Analysis Abstraction

With the introduction of the domain specific language, a considerable abstraction and decoupling of the analysis task from software and coding knowledge can be achieved. Specific knowledge about the analysis framework is not required. Software specialists provide access to the available data sources, configuration data as well as the implementation of analysis functionality by providing a set of assertions that can be executed on the recorded data. Equipment experts can focus on the implementation of the analysis modules by constructing algorithms to satisfy specific pass criteria out of the set of assertions. Figure 1 depicts two analysis modules, each consisting of 6-9 individual assertions that validate absolute values of measurements, exponential decays or second derivatives against well-defined thresholds.



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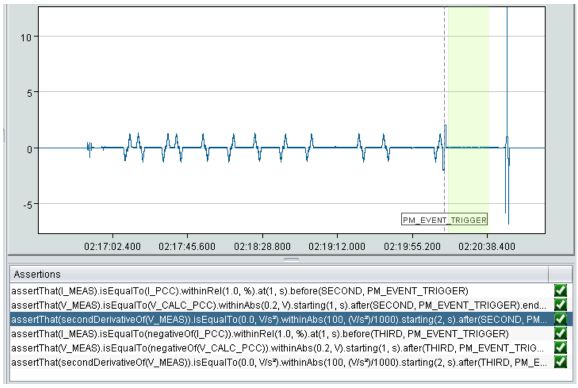

Figure 1: Analysis modules based on DSL, used for the analysis of current discharges (top) and converter configurations tests (bottom).

Dependability

The new approach to automated analysis has shown to result in a considerable increase of system dependability by negating human error. In particular, during intense periods of a commissioning phase, requiring experts to carry out several tasks in parallel. In order to validate the new analysis logic, the DSL based modules have been run on over 2500 corresponding data sets of previous commissioning campaigns, in particular those for the campaigns in 2011 and 2012. The efficiency and final gain in reliability is demonstrated by the fact that two major non-conformities were discovered in two different 60A dipole orbit corrector circuits, one of which is shown in Fig. 2 These deficiencies were present in the LHC machine for several years and were not revealed during any of the three consecutive commissioning campaigns (manual analysis), suggesting that similar non-nonconformities are also present in other circuits still.

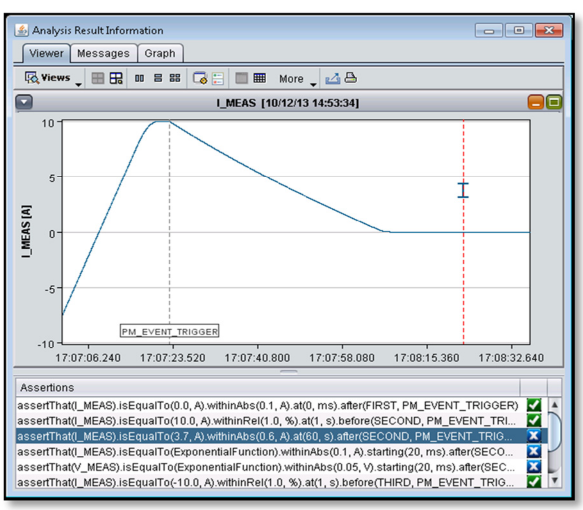

Figure 2: Current discharge curve of a 60A orbit corrector circuit with a faulty crowbar resistance not revealed during 3 previous (manual) analysis campaigns.

Post-analysis of previous campaigns will continue to be used in the future for integrity and functionality checks of new module versions as well as for trend analysis across campaigns. More importantly, this statistical analysis allowed discovering shortcomings in the analysis criteria, such as using measured equipment parameters as a reference rather than design values. Furthermore, expanding upon the available assertions language allowed for both, less failed tests as well as applying more stringent criteria, enhancing system validation.

Performance

An important metric of automated analysis is the reduction in analysis time, which in turn speeds up the overall commissioning duration and more importantly, frees expert resources for more important activities such as the resolution of revealed non-conformities. Figure 3 depicts a comparison of execution and analysis times for different test types executed during two recent powering test campaigns. As the 2011 campaign was only a partial re-commissioning campaign the absolute values may not be compared. Nonetheless, it is clearly visible that the introduction of an automated analysis for the test types PNO.d1 had a significant impact relative to the time spent for the manual analysis. Statistical analysis of test execution and analysis, as shown in Fig. 3 is important input in defining priorities for the future.

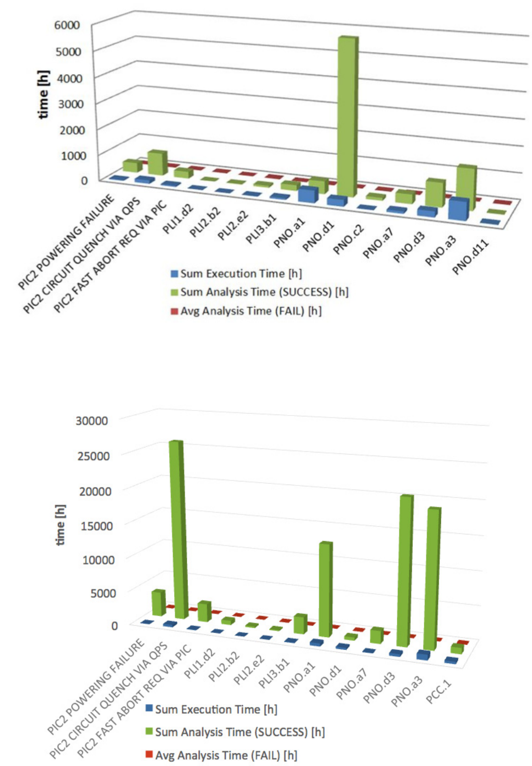

Figure 3: Comparison of execution and analysis times across different test types, for the 2011 campaign (top) and the recent post LS1 campaign (bottom).

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Table 1: Statistics of Test Outcomes using DSL Based Analysis Modules

	PNO.d1 60A	PNO.d1 80-120A	PCC.1 60A	PCC.1 80-120A
Total number	877	405	1042	425
Successful	831	291	862	299
Not successful	46	114	180	126
Failed execution	32	89	116	76
Failed analysis	1	7	2	7

Current Shortcomings

As shown in Table 1, between 70-95% of the executed tests passed both the execution as well as the analysis without the need of expert intervention. The majority of unsuccessful tests already failed during the execution phase, meaning that the foreseen current cycle could not be correctly executed on the superconducting magnet, e.g. as a result of magnet quenches during the test, the power converter not being properly configured, etc. Furthermore, 6-11% of the tests failed because of exceeding the defined analysis criteria and only less than 2% of the tests failed because of failures in the analysis logic. The latter could, in all cases, be traced back to a non-standard behavior of some specific circuits and circuit parameters that lead to exceptions in some of the defined assertions.

A more serious constraint of the current implementation is the high consumption of resources in terms of memory and processing power. Due to the generic implementation of assertion resolving, all intermediate results (nodes) of the analysis trees are stored in memory, leading to analysis times in the order of 2-3 minutes. While this is not an issue for automated analysis (for which parallel analysis has been limited to batches of 10 simultaneous tests), it is a serious constraint on the user experience for manual post-analysis. To improve the situation, a dedicated caching mechanism was introduced. Due to the high consumption of memory for a given event this in-memory caching is, however, still limited to the last 100 tests performed.

In general, feedback from user experience was very positive with the exception of the implementation of new functionality being slow, as it requires software experts.

OUTLOOK

While the past campaign has only seen the introduction of DSL based analysis modules for 2 of more than 20 test types, the initial experience was encouraging. This is of particular interest, as the DSL offers generic analysis tools which can be used, not only for the analysis of data originating from magnet powering equipment, but for any data type and analysis use-case across the very heterogeneous set of accelerator data. It has major advantages for code maintainability as it avoids the duplication of analysis functionality, specific user implementations and too many variants of tailor-made analysis modules that are difficult and time-consuming in their long-term maintenance. In addition, DSL modules can be easily integrated into continuous operation as they do not implement pre-knowledge of the executed test functions and can easily be parameterized with different starting conditions (such as operating currents).

Regarding the AccTesting framework itself, automated analysis will be extended beyond the boundaries of hardware commissioning (namely to machine checkout and beam commissioning phases). Use-cases which are already on the priority list for a future implementation are trend analysis (i.e. the comparison of analysis results over time/across campaigns), the continuous analysis of protection related powering events during operation (e.g. firing of quench heaters in superconducting magnets) as well as machine performance related analysis (such as a Beam Loss Monitor threshold and beam loss evolution throughout a run period).

CONCLUSIONS

In this contribution we describe the first operational experience with automated analysis of offline analysis for LHC commissioning, based on the use of a Domain Specific Language. Major benefits of the new approach have been presented, including the negation of human error and the optimisation of expert resources for the execution and analysis of powering and beam related tests. The current limitations of the implementation have been presented along with an outlook to new features and improvements that will be included in the framework for the next major commissioning campaign.

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