LHC MAINTENANCE POLICY AND REQUIREMENTS

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Abstract

In view of the very complex equipment making up the LHC machine and its many ancillary subsystems, equipment maintenance policies will play a primordial role to ensure an optimal availability. As access to most of the machine systems is strictly regulated, maintenance interventions will require global co-ordination and collaboration from both CERN equipment groups and industrial support teams. The talk will briefly touch on the different main systems and technical infrastructure involved and what is presently known about their operations and maintenance policy. Further extensions to the LHC QAP on the operations and maintenance phase will be mentioned. Issues like mean-time to repair, spares and contractual piquet service will become of major importance already in the installation phase. A rapid introduction and some examples from CERN's asset tracking and maintenance system (MP5) will show what support can be expected from an industrial approach to maintenance issues.

INTRODUCTION

The availability of the LHC depends not only on the LHC machine and its supporting services but also on the availability of the injector complex (LINAC, Booster, PS, SPS and LEIR when ions are accelerated) and of the technical infrastructure providing a large number of services to the various machines. A number of the installations concerned are completely new while others already have a long service and lifetime. The Booster and the PS have more than 40 years of intense activity and during these years, many main- and subsystems have been either upgraded or completely exchanged. The latest example of a large-scale intervention is the renovation of the PS main magnets during the winter shutdown 2004-2005.

It is obvious that the quality of the maintenance of this extensive chain of complex and not always new equipment has a direct impact on the availability of the LHC and thus has to be managed in a global perspective to permit optimal resource allocation. This approach to maintenance management of the LHC complex can be assimilated to the TQM concept widely used in industry since many years.

TOTAL QUALITY MANAGEMENT (TQM)

Not only the intrinsic quality of the LHC components but also the quality of the maintenance of these components will have on impact on the LHC operation. Maintenance quality involves everyone and concerns all the activities related to the operation of the accelerator complex. Quality in this context refers to the conformance of the delivered product or services to the requirements (you should get what you ask for…). Experience shows that the quality of maintenance can and must be managed in a fashion similar to the quality of a delivered item. Quality can and must be managed. The basic rules of the TQM concept are:

1. Everyone has a customer and is a supplier.
2. Processes, not people are the problem.
3. Every employee is responsible for quality.
4. Problems must be prevented, not just fixed.
5. Quality can and must be measured.
6. Quality improvements must be continuous.
7. The quality standard is defect free.
8. Goals are based on requirements, not negotiated.
9. Life cycle costs, not front end costs.
10. Management must be involved and lead.
11. Plan and organize for quality improvement.

COSTS

The overall LHC availability is directly related to the cost of the maintenance actually performed; the cost of a lost scheduled operational day can be calculated from the Cost-to-Completion of the machine and the experiments. The physicists are however more concerned about the loss of integrated luminosity in their experiments since the luminosity parameter is directly reflected in the quality of the statistics of the physics taken. The cost of maintenance must nevertheless be taken into account when looking at the overall performance of the LHC complex. If the maintenance is not sufficiently funded (average yearly cost should be expected to be of the order of 2% of the capital costs,*) the real performance of the accelerator complex will rapidly decrease. Using the appropriate maintenance management performance indicators can permit a coherent global maintenance policy.

PERFORMANCE INDICATORS

In addition to the global LHC performance indicator, days of actual operation vs. days of scheduled operation, more targeted indicators can be used to qualify the performance of the complex and in particular the actual performance of the maintenance management activities.

MTTR – Mean Time To Repair

This overall performance indicator is calculated by simply considering the time during which the LHC is not available for scheduled physics...

* Industry average, see also [2].

However, it is too general, as most repair interventions usually comprise multiple activities and actions. To enable the assessment and to possibly improve the total quality of the maintenance management activities, the MTTR can be divided into more meaning-full sub-indicators, see Table 1.

Table 1 - MTTR sub-indicators

Indicator/activity	Evaluation keys.
MTTR1 – Production reactivity	Users' motivation. Communication channels with the maintenance (have they access to the CMMS?). Knowledge and adequacy of the existing procedures.
MTTR2 – Maintenance reactivity	Workers' motivation. Organization: is there a helpdesk or a way to contact the responsible? Enough man power? Adequacy of existing procedures.
MTTR3 – Manpower availability	Number and competences required. Visibility and planning tools. No preventive maintenance = overwork peaks
MTTR4 – Diagnostic delay	Access to technical documents. Asset maintainability or complexity. Particular skills may be required.
MTTR5 – Preparation delay	Organization of the Maintenance Responsibility Center and competences. Relationship with contractor.
MTTR6 – Stock logistics delay	Logistics delays and buying procedures. Identification of critical and strategic stock
MTTR7 – Purchase logistics delay	Supplier identification. Purchase procedures. Integration of CMMS with purchasing systems?
MTTR8 – Actual work duration	Tools, transport, competences
MTTR9 – Administrative delay	Document flows and delays

EXAMPLES OF MAINTENANCE PLANNING FOR LHC

The various groups that provide equipment for the LHC have different approaches to the maintenance problem. Below are given a few examples of these approaches...

POWER CONVERTERS- DESIGNED FOR AVAILABILITY

The power converter group will install more than 1700 units in the LHC underground areas where access is difficult, distances are large and equipment surveillance cannot be done by the traditional "walk-about" method.

In addition to the power supplies principal design objective of high precision, another design objective was that the units should reach a high MTBF (mean time between failures) of 80.000 hours after the initial burn-in phase failures. In the first year of operation, AB/PO actually expects only a MTBF ≅ 8'000 h; a figure which is based on both LEP and RHIC power supply experiences.

For the specific case of the orbit corrector power converter units (752 such units in all), AB/PO expects to lose on average 1 orbit corrector power converter every 4:th day (100+ hours) when in operation.

Using an n+1 architecture, .i.e. systematically adding one supplementary unit, for the orbit corrector power supplies sufficient power will be available to drive the orbit correctors to permit LHC operation to continue without causing an unplanned stop. This design approach is expected to shift most of the equipment repair constraints to the scheduled machine stops. When access finally is permitted – everything has to be ready for a rapid intervention in the tunnel to exchange any failed supplies. A diagnostic interface module in each power converter will be used to pinpoint the failing module(s). Using a modular approach, each field replaceable part of an orbit corrector power supply weighs between 25-65 kg. Only one or two persons will be needed for any given intervention. Time to change a power converter module is of the order of 15 minutes. The faulty equipment will be repaired on the surface ("off-line"). The co-ordination of interventions in the LHC underground areas by the different equipment groups with varying logistics requirements will also have to be managed on a global level.

CRYOGENICS – MAINTENANCE NOW

For the extensive LHC cryogenics installations the maintenance plans, tasks and spare parts policy are presently being defined. They take into account the manufacturers' available information, the operational experience acquired until today and a detailed process knowledge. The plans and lists of spares are based on an industrial state-of-the-art approach and methodology, and they are prepared using CERN' computerised asset tracking and maintenance management system (CAMMS)[†].

The maintenance plans will be validated on the first LHC cryogenic installations that are now going into operation to be ready for LHC subsystem commissioning.

[†] The MP5 system is the world leader in CAMMS for large organizations.

The objective is to gather experience from LHC cryogenic equipment maintenance and to adjust the required stock levels of spares. Additionally, specific maintenance routines (preventive and corrective) will be optimised for the new cryogenic installations.

As the maintenance of the cryogenic installations is outsourced, extensive preparations of the respective contracts have been made. This is a general requirement for all maintenance contracts as the subcontractor's primary goal is generally different from that of the Organisation. All support contracts must contain clear objectives and performance indicators in order to get the expected results. The CAMMS provides many features to help ensure and verify that support contract stipulations are actually fulfilled.

Maintenance

Corrective maintenance is done as required during the LHC operational periods. The preventive maintenance is done in every winter shutdown and concerns rotating machines, oil level verifications, filters, inspections, etc.

Preventive maintenance and calibration of the cryogenic instrumentation and the many different actuators is done every second year. For safety devices verification and validation is expected to be required every second year.

Major overhauls of pumps are planned for every 20'000 hours and of compressors every 40'000 hours.

Issues

Some issues that still remain outstanding are related to equipment under warranty and/or in commissioning but that have already become critical for subsystem commissioning. The maintenance of such equipment requires special attention not only from a technical standpoint but also from a contractual one.

Another specific equipment issue is related to the definition of component criticality where no operational experience exists and where there is a manifest lack of support from the suppliers.

There is also a lack of resources to establish a complete and coherent maintenance plan, spare parts lists, component criticality, maintenance indicator to improve and optimize spare, preventive and corrective maintenance. The key performance indicator MTT3 can be used to flag this type of cases.

QUENCH PROTECTION EQUIPMENT

The AT/MEL group provides and supports the Quench Protection (QP and Energy Extraction (EE) systems that play a major equipment safety role in the LHC machine. These systems must be both reliable and available. The approach that will be taken is to perform a systematic repair of faults; make comprehensive analysis of equipment data, acquired in operation and during quenches. The data analyzed come from the magnet diodes, the quench heaters and beam loss monitors as well as from the LHC post-mortem system...

AT/MEL expects maintenance interventions in the machine at least monthly with an expected duration of 1-2 days. Corrective maintenance interventions will always be required since an LHC run may not start without a thorough control of the QP and EE Systems.

Spares for both systems are available at CERN and can be repaired/ replaced.

Maintenance

The principal issue here related to maintenance management is the lack of resources - MTTR3!

At HERA, there are 12 persons with experience available when the need arises (24h/24h, 7d/7d). In AT/ MEL 4 persons are available today (2 more persons are expected to join the team). No detailed plans have been made today; AT/MEL is waiting for field experience of the HW commissioning before commitments are made.

RADIO-FREQUENCY

The AB/RF group provides and supports all accelerating systems in the accelerator complex including the superconducting LHC cavities.

Detailed work on maintenance management issues will be undertaken by the time the RF hardware is being commissioned, i.e. towards end 2006.

The AB/RF group has a vast experience from running RF systems in other accelerators for guidance.

Spares for critical equipment are acquired as required already now.

TECHNICAL INFRASTRUCTURE

The old ST division was an early adapter of the CAMMS technology and much work has been done on issues to adapt the working methods to it.

Typical issues are:

Standardised terminology (vital effort absolutely required and to not to be underestimated).

Naming conventions….

The Top Ten of non-disposable equipment.

Maintenance cost par equipment or family.

Number of on-failure (corrective) maintenance per month.

Costs of spare parts on a monthly basis.

Mean Time Between Failure (MTBF) indicators

Mean Time To Repair per equipment (MTTR) indicators.

Preventive maintenance

The accelerator start-up and shutdown periods are used for preventive maintenance of the technical infrastructure. Process optimization and adaptation to user requirements is also scheduled into these periods. An overwhelming part of the technical infrastructure equipment is managed in the CAMMS. The system permits a planning of preventive equipment maintenance during the equipment's entire lifecycle. It is also used for extensive fault and breakdown reporting to improve the overall reliability and availability of the controlled processes.

Corrective maintenance

Operation and maintenance, both corrective and preventive, of the technical infrastructure equipment depends largely on industrial support contracts. These contracts assure the maintenance and repair interventions both during normal working hours and out of working hours (stand-by service). CERN staff is available to provide assistance to contract personnel particularly during breakdowns, where the competence and specific knowledge of the stand-by services maybe insufficient. The remote monitoring and operation of CERN’s technical infrastructure and the general services of the accelerator complex are handled by the Technical Control Room (TCR). The TCR operators also have the role of coordinating all interventions required when TS equipment breaks down or needs attention. Additionally, one of the two TCR operators on shift may carry out first-line on-site interventions when operational conditions so permit. This often results in a preliminary fault diagnosis and improves the handling of compensatory measures, possibly permitting a rapid fault recovery without the delaying intervention of a specialist or stand-by service.

All interventions related to the TS general services’ equipment are traced with the CAMMS, generating work-orders for CERN staff or the respective industrial service contractor(s). During office-hours, work orders are automatically directed to the service contractor by the CAMMS while for shift-hours the stand-by services and specialists are called for by the TCR operator.

MAINTENANCE STRATEGIES

Maintenance activities can in general be categorized in four main strategies:

On-Failure Maintenance (Corrective Maintenance).
Maintenance or rather repair, is done when the equipment fails to fulfil its function.

Fixed Time Maintenance (Preventive Maintenance).
The equipment maintenance is based upon fixed time – either calendar based, actual hours in operation, or the number of equipment cycles carried out.

Condition Based Maintenance.
Maintenance interventions are directly linked to the condition, the actual status, of the equipment. Maintenance on inspection or monitoring may have an economical advantage since work is only executed when the state of the equipment indicates that a failure to fulfil its function is imminent.

Design Out Maintenance
Design, or redesign, equipment to eliminate the root cause of failure and resulting failure modes so as to eliminate or minimise the need for maintenance.

MAINTENANCE PLANNING

Each of these strategies has a place within an optimised maintenance plan, but the distribution of the mix will depend upon many factors: the type of equipment to be maintained, the operational context- both in terms of production and in terms of the prevailing environmental conditions, the maintenance resources available, health and safety compliance, general practicalities and finally cost considerations.

At CERN in the TS department, the maintenance strategy for the majority of contracts is slightly biased towards preventive maintenance which may present a cost disadvantage. The alternative condition based maintenance and designing out of equipment that demand a more flexible approach to maintenance is less used.

RESULT ORIENTED MAINTENANCE CONTRACTS

Result orientated maintenance contracts are often based on a cost and fee basis using the following algorithm:

$R = F + C + [0.5 * (E – C) + f(Q)]$

where

F=Fixed Costs (Contract Management, Insurances, Office costs etc.);
E=Estimated Maintenance Costs;
C= Real (Executed) Maintenance Costs;
f(Q)= Quality coefficient .

The objective is to motivate the contractor to provide a better, faster and more professional equipment maintenance service by sharing the profits resulting from a lower executed maintenance [C] cost than estimated [E] cost between the contractor and CERN. One limit to this model is obviously that by constantly reducing the maintenance the number of breakdowns of equipment will increase. The use of performance indicators is here of major importance to get the right balance between a reasonable maintenance reduction and an acceptable equipment performance.

MAINTENANCE MANAGEMENT TOOLS

A world class CMMS already exists at CERN – MP5 (the new release is called D7i) is in production and is available with a support team to all equipment groups.

The LHC equipment that is being built and tracked by the MTF[‡] application will automatically be accessible in MP5/D7i. To enable the maintenance features of the CAMMS, the relevant equipment maintenance procedures and performance indicators must however still be created and activated in the system for each family of equipment. The system has no possibility to know beforehand which equipment requires what maintenance procedures.

Once the necessary equipment information has been created, users and industrial support services can use the

‡ https://edms.cern.ch/asbuilt/plsql/mtf.home

system to enter and extract the required data and information be it the work requests, the different performance indicator values or the actual work orders...
The technical infrastructure and the general accelerator services are today managed with MP5/D7i. Much valuable experience now exists and is available to all those would like to use the system.

DASHBOARDS AND OTHER EASY TO USE INDICATORS

The TQM concept is based on measurable observables – the quality (of the maintenance in this case) can and must be measured. But how is quality measured?
The number of work-orders issued for a given equipment maintenance work package and the actual duration of each work-order are two measures of quality – one indicating how much work is required over sometime period, the other indicates how long time the work takes to be executed.
By defining such sets of objective parameters or performance indicators, their standard intervals (good, bad, ok, pass, etc) that are uniquely relevant to each equipment family the CAMMS is given the possibility to generate dashboard style maintenance performance indicators, see Fig 1.

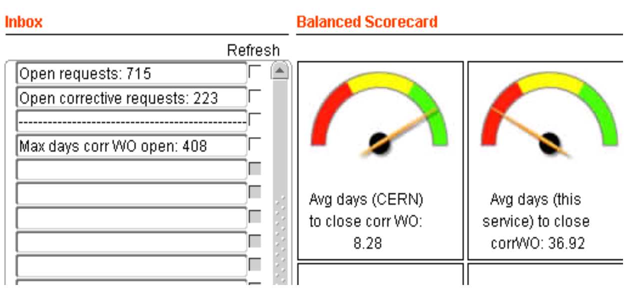

Figure 1- Maintenance performance dashboard

A measured poor maintenance performance implies in general that the situation has to be broken down into partial indicators (MTTRj), potential and real problems identified and the subsequent adoption of corrective and preventive measures.

COMMISSIONING AND MAINTENANCE?

The hardware commissioning activities could be the unique moment in the LHC project to validate the various maintenance management strategies defined. The manufacturer supplies many equipment maintenance procedures when the delivered equipment is installed and accepted by CERN. If an equipment breakdown (or any other condition requiring some kind of maintenance work) would occur during the commissioning phase, not only the maintenance procedure could be validated. Such events also offer the possibility to verify the list of spare parts; diagnostic delays, delivery delays etc. can be measured and validated. The advantages of moving into the LHC operation phase with such experience recorded in a maintenance management system are numerous and well worth contemplating. Although the initial effort to create the knowledge base required is not to be underestimated the return on that investment can be expected to justify it. Validating a set of parameters, procedures, and assumptions during the repair of new equipment represents an extra burden difficult to justify, especially under the stress conditions the hardware commissioning will take place. However, this effort will repay itself many times later, when repetitions of the problem are diagnosed and repaired in a faster and more efficient way.
The CAMSS support team will supply the tools to capture and correct the initial data and procedures and share the experience of the present user communities with new users. However, only efforts from the teams responsible for the LHC equipment and its maintenance will make CAMMS truly useful to LHC.

LHC MAINTENANCE MANAGEMENT

The very ambitious objective of the maintenance management policy should be – no LHC downtime except scheduled stops!
This implies that the status, location, the stocks of spare parts, maintenance procedures and all interventions on all equipment installed in the complex must be managed in a transparent manner using CAMMS.
The moment to acquire the status of all the installed equipment for the LHC is during the hardware commissioning phase and this is when it also should be recorded in the CAMMS.
By creating dashboards for all equipment families both costs incurred and services effectively supplied can be easily identified. The identification of the actual maintenance procedures along with potential bottlenecks should be done; the procedures should be split into sub-processes that can be measured and monitored.
Each and every intervention on all equipment must originate a work order – no action should be taken without a trace!
The performance indicators (MTTRj) should be analysed, evaluated and compared to improve the maintenance processes wherever possible.

CONCLUSION

Maintenance management of LHC equipment has already started. Keeping LHC available will be taxing resources in the various accelerator and technical departments. ALL groups that have contributed have expressed this!
A strict policy of keeping track of all equipment in the complex, their maintenance procedures and the interventions on any equipment related to the availability of LHC is required.
Use of a computerised tool is mandatory but manpower resources must also be made available to enable the creation of maintenance plans and prepare methodology...
Key performance indicators should be created to measure how well the quality aspects of the maintenance activities

are managed, i.e. they will indicate how well the LHC availability is being managed.
LHC QAWG will be asked to prepare general rules and advise on implementation issues for each equipment group.

ACKNOWLEDGEMENTS

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