CONTRIBUTION OF THE CLS CONTROL SYSTEM TO THE CLS ACCELERATOR SYSTEM RELIABILITY*

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Abstract

The control system software plays an increasingly important role in achieving overall accelerator system reliability, in this regard the CLS control system is no different. This paper reviews the two aspects of control system reliability (1) the reliability of the control system itself and it contribution to system reliability and (2) the use of the control system as a tool to aid in predicting and localizing system failure therefore providing an indirect impact on mean-time-between-failure and mean-time-to-repair. The paper provides a survey of metrics used at the CLS to evaluate system reliability, several failure modes that have been localized and removed from the system design to contribute to overall reliability. Recently CLS has deployed a new approach to alarm annunciation and fault location based on voice annunciation and nested dashboard display screens.

RELIABILITY

Reliability in the context of an accelerator is the extent to which an experiment, test, or measuring procedure yields the same results on repeated trials.

Our first goal: to reliability delivery beam when scheduled for the length of time scheduled.

Our second goal: to reliably reproduce the electron beam orbit and focusing to produce x-ray beams of constant energy, position and intensity. The beam position is determined by the reproducibility of the storage ring dipole magnets and the effectiveness of the orbit correction system. Beam intensity depends on the source size which in turn relies on reproducible beam focusing from the quadrupole and sextupole magnets.

OPERATIONAL EXPERIENCE

For scheduling purposes the CLS divides the calendar year into six month cycles and maintains two extended outages per year for major installation and maintenance activities.

Normal operation is at 2.9 GeV with injections either three or two times per day at 250 mA. From time to time special modes of user operation may be scheduled; this would include lower energy or single bunch operation with low current. Major outages are scheduled in the spring and fall for installation, upgrades and preventative maintenance activities.

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The total number of trips per technical area over the past three cycles is shown in Figure 1. By targeting resources in specific problem areas we have been able to reduce machine down time is an efficient way.

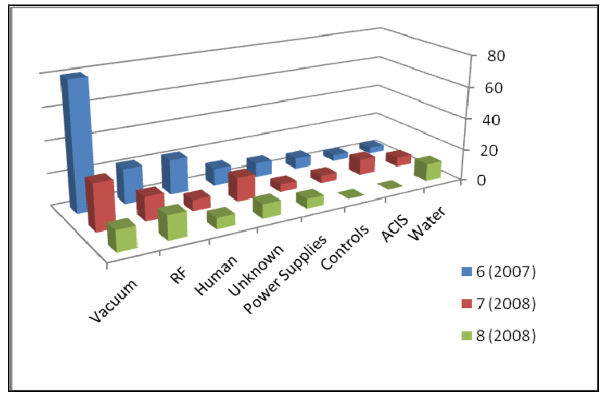

Figure 1: Number of trips per cycle and per area.

One specific area that was targeted between cycle 6 and 7 was vacuum trips. This was accomplished by modifying the control system to better debounce minor vacuum transients as well as implementing a staged response to beamline front-end vacuum transients.

ACHIEVING BEAM RELIABILITY ATTRIBUTES

Magnet Reliability (Reproducibility)

To consistently reproduce the same beam for the experimental beamlines from setup to setup the magnets have to produce (as best as possible) the same magnetic fields. The fields in the dipole magnets determine the energy of the stored beam. Dipole magnets have to be cycled to produce the same field. High precision is required for the magnet power supplies (1/105). As well, the dipole magnets have to be operated at the same temperature (within 1° C or 0.1° C depending on the system) to ensure the effective length does not change. The field gradients in the quadrupole (and sextupole) magnets determine the focusing of the beam. To achieve the same beam size the quadrupole fields should be reproduced as well as possible from setup to setup. Quadrupole magnets require cycling, high precision supplies and temperature control.

For critical magnets the control system embeds automated degauss routines that cycle the magnets. In addition CLS has a reference DC current transformer (DCCT) that is used as a lab reference for calibration of the internal DCCT within the power supplies. Recent enhancements include warning alarm displays when the set-point and feedback begin to drift apart.

The storage ring tunnel ventilation system has been designed to maintain air temperature within +/- 0.1° C of setpoint. The cooling water system also implements PID control to maintain low conductivity cooling water within +/- 0.1° C of setpoint.

Insertion Devices

Insertion devices (wigglers and undulators) are use to produce intense sources of radiation for experimental beamlines. Wiggler fields must be reproducible and the comments concerning dipole magnets apply to these devices. Undulators fields are varied by adjusting the magnetic gap. For reproducible undulator fields the gaps must be adjusted with high precision. Varying undulator gaps can cause undesirable kicks and focusing effects which effect the operation of other beamlines in the ring. To reduce these perturbations correction coils controlled by feed-forward tables are used.

The control system makes use of redundant high resolution absolute encoders to accurately measure the position of insertion devices.

Orbit Correction

Vibrations and thermal effects cause variations in the beam orbit. Since beamlines are extremely sensitive to angular and transverse alignment of the electron beam variations in the beam orbit must be corrected to a high precision. To ensure reproducibility of the orbit at many locations a large number of beam position monitors (BPMs) and orbit correctors are employed [1]. To achieve reliable readings the BPMs are placed in the vacuum chamber in such a way that little or no mechanical movement is allowed. As well, the BPM readings should be independent of the beam current. This is not always the case. Experience shows that there is possible movement of the BPMs due to thermal effects in the storage ring. After a long shut down, for example, the ring tunnel may not have reached thermal equilibrium and the BPM positions will shift with the expanding (or contracting) vacuum chamber. As well, changes in beam current result in local heating effects which may cause chamber distortions.

The thermal expansion and contraction of the storage ring chambers is also compensated for by the use of a slow closed loop feedback algorithm that adjusted RF frequency to reduce overall RMS deviation in the ring.

The Bergoz BPM electronics are used to condition the BPM signals, prior to installation a test bench was constructed to characterize the response of the BPM electronics [2]. The same tests have also been performed on the Libera BPM Electronics [3]. The use of an off-line test chamber permits us to calibrate and test BPM electronics under a controlled environment.

During a run it is not uncommon to have either a BPM channel or corrector channel fail. Under these cases provision exists within the control system for the operator to remove the failed BPM button or corrector from the orbit correction algorithm, permitting the remaining BPMs and correctors to compensate.

CONTROL SYSTEM RELIABILITY ATTRIBUTES

EPICS

The CLS has adopted the EPICS distributed control system framework for the accelerator and beamline control system [4]. By using EPICS CLS is able to build it's control system on a solid base of tested and field proven software. Care is still required to ensure that assumptions and differences between the CLS and other accelerator facilities are taken into account.

In a limited number of cases where hard real-time is required the RTEMS operating system is used [5].

Even running with non-redundant IOC we have experience a high level of reliability.

Most system software failures can be attributed to overloading of single board processors with EPICS Channel Access requests. These problems are rare, and avoided by configuring gateways between the accelerator control system and other networks to minimize unexpected changes in channel access connections. This problem is also easily addressed through the use of newer faster hardware.

Two commonly used EPICS applications have provide indispensable in understanding and characterizing the performance of the machine. The EPICS StripTool application that is commonly used at many facilities is critical for on-line analysis of machine performance. The EPICS Data Archiver is also used extensively at the CLS.

PLC Equipment

CLS early on adopted the use of PLC equipment for machine protection, process control and trip monitoring. In the case of CLS the Telemecanique Momentum and Siemens S7/300 and S7/400 platforms were selected.

Three of the key advantages of the commercial PLC platforms being use have been the ability to remotely connect to the PLC and perform on-line monitoring, override "jumper" logic or even make changes to the PLC programming while the system is still running.

In critical applications either a redundant PLC or redundant hard-wired interlocks have also been adopted.

Operational experience has been the once one of these PLC is installed and commissioned in the field that number of failed processor modules is extremely low (less than 1 per year out of an installed base of 30 units).

Instead of an industrial field-bus, Ethernet is used as the main PLC field bus. Care is required when configuring VLANs and establishing network security policies to provide adequate security of the PLCs for other network devices.

Safety Rated PLC Equipment

CLS adopted the use of IEC 61508 and the Siemens S7/400 F equipment for safety critical applications [6]. Currently these safety critical PLCs are being used in the ring/beamline lockup systems, and oxygen level monitoring system around cryogens.

Identification and Removal of Low Reliability Components

We have attempted to track failures and look to isolate and remove less reliable hardware. In most cases this is associated with older legacy equipment from the 1960s to 1980s. Over the past few years CLS has been progressively replacing older control hardware and power supplies.

Server Virtualization

A recent development in the enterprise information technology environment has been the move to virtualization of servers. Under this arrangement a VMWare based virtualization server is used.

Homogeneity

CLS has maintained a strong emphasis on standardization across the accelerator and beamline control system. This provides a significant operational advantage.

SYSTEM LEVEL APROACH TO RELIABILITY

Problem Tracking

CLS has adopted MKS Integrity Manager and Source Integrity as tools to track work associated with the control system. Though not a preventative maintenance management system, MKS provides the mechanics to track failures and monitor the workflow associated with control system changes and configuration management.

Human Factors

Human factors have consistently been important in the design of the control systems and operational procedures. We have taken into account human factors in developing operator screens, control room layout and task analysis.

Routinely CLS software development and engineering staff have undertake human factors training. Human factors attributes have been embedded into various CLS design standards. More recently we have developed Human Factors specific verification and validation procedures for some systems using NUREG-0700 as a basis.

Alarm Dash Board

In place of a traditional alarm handler, most interlocks and online monitoring instrumentation feed into a master dashboard screen using EPICS EDM. Systems operating within normal parameters show up as green, system that are drifting out of specification and may cause a potential trip are shown in yellow while actual items that are interlocking machine operation show up as red. A latching mechanism is provided so that the operator can identify the initiating event after a trip.

Figure 2 consists of a screen shot of the dashboard. Each row consists of a major accelerator system, while each column corresponds to a major service or sub-system of the accelerator. The ability to drill down is provided.

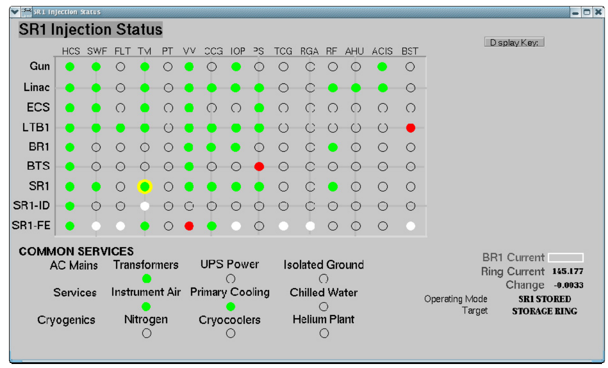

Figure 2: Control system dashboard.

The dashboard is augmented with a voice annunciation system for a limited number of critical alarms.

CONCLUSION

Operationally the control system plays an important role in achieving overall accelerator reliability both in terms of machine availability as well as ensuring that the accelerator meets operational performance requirements. Increasingly important is also achieving these goals in a predictable, cost effective and efficient manner.

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