PREDICTIVE DIAGNOSTICS FOR HIGH-AVAILABILITY ACCELERATORS

K. Žagar, D. Bokal, K. Strniša, Cosylab d.d., Ljubljana, Slovenia
M. Gašperin, University of West Bohemia, Pilsen, Czech Republic
G. Pajor, COBIK, Solkan, Slovenia
L. Medeiros-Romao, D. Vandeplassche, SKC-CEN, Mol, Belgium

Abstract

In Accelerator Driven Systems, high availability of the accelerator is one of its key requirements. Fortunately, not every beam trip is necessarily a failure. For example, in the proposed MYRRHA transmuter, absence of the beam for less than 3 seconds is still deemed acceptable. Predictive diagnostics strives to predict where a failure is likely to occur, so that a mitigating action can be taken in a more controlled manner, thus preventing failure of other components while exactly pinpointing the component that is about to fail. One approach to predictive diagnostics is to analyze process variables that quantify inputs and outputs of components as archived by the accelerator's distributed control system. By observing trends in their values an impending fault can be predicted. In addition, sensors measuring e.g., vibration, temperature or noise can be attached to critical components.

INTRODUCTION

This paper presents a conceptual design of a predictive diagnostics and health management framework (PHM) for accelerator systems. The task of the PHM system is to predict where a failure is likely to occur, so that a mitigating action can be taken in a more controlled manner, thus preventing failure of other components while exactly pinpointing the component that is about to fail. The effects of implementation of PHM systems are visible in decreased number of failures, shorter service intervals and optimal utilization of maintenance resources. The aim is to implement the methodology on the new MYRRHA reactor.

The multi-purpose research reactor MYRRHA is an accelerator driven system (ADS), where high availability of the accelerator is one of its key requirements. Therefore the MYRRHA linear accelerator has a significantly lower tolerance towards beam trips than comparable accelerators currently achieve [1]. However, absence of the beam for less than 3 seconds is still deemed acceptable. This presents one of the central challenges of MYRRHA which consequently reflects also on the accelerator control system [2][3].

The accelerator consists of several crucial components and subsystems which are subjected to wear, material stress and environmental influences. These eventually cause the equipment to fail and can result in beam trip or even emergency shutdown of the accelerator. Furthermore, if such a fault is unexpected and unanticipated, maintenance procedures take longer than necessary [4].

Improvements in reliability are obtained by following two directions. First one is to improve the reliability of individual components by increasing their mean time between failures (MTBF). Second one is to switch from preventive or reactive maintenance strategies to condition based maintenance, which ensures minimum system downtime in case of breakdowns and faults (mean time to recovery – MTTR).

Research shows that usually failures go through a distinct incipient phase [5]. This means that there are some noticeable indicators, which provide advanced warning about onset of failure. The role of automated condition monitoring (CM) is to timely detect this onset, localize the root-cause and, possibly, trend its progression over time. The remaining time until final breakdown can be long enough to allow for efficient maintenance service [6]. The goal of this paper is to present an overview and main design concepts for the PHM System, which will be targeted at the linear accelerator.

PROGNOSTICS AND HEALTH MANAGEMENT SYSTEM

The role of the automated prognostics and health management (PHM) system is to timely detect the presence of fault (fault detection), localize the root-cause (fault isolation) and estimate the future progress of fault and time of failure (prognostics).. Considering the success of the implementation of PHM methods in these industries, we deem it worthwhile to consider application also in the field of accelerators.

The basic stages of CM are feature extraction, feature evaluation and fault isolation. (Figure 1). A feature is a function of the measured signal and should be sensitive only to the fault while insensitive to the operating conditions [7]. An important feature of condition monitoring systems is the prediction of future evolution of the fault.

The PHM system is designed around the three main tasks, namely observation, analysis and action. The observation part includes appropriate hardware and software components for signal acquisition processing in order to compute the required feature values. The features are then analyzed for presence of fault and possible trends. Finally, the high level decision support system assesses the probability of specific faults, remaining useful life and proposes the appropriate action if required.

ISBN 978-3-95450-122-9

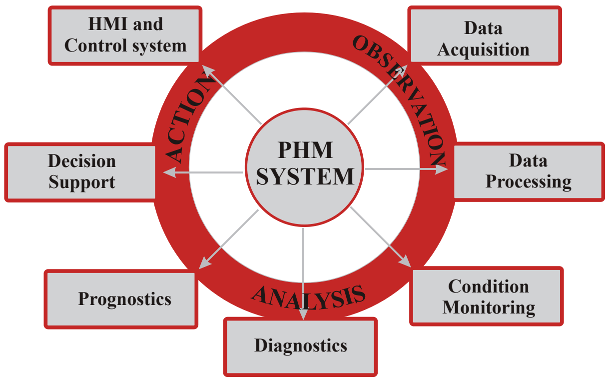

Figure 1: The PHM System.

MODEL-BASED PHM FOR ACCELERATOR COMPONENTS

Model-based fault detection relies on mathematical models to estimate the current condition of the system Depending on the available prior information about the system physics-of-failure, the model can be either passed on physical equations (white- or grey-box model) or data driven (black-box model). The basis for fault detection and identification are the residual values, which are computed from comparing the model output and measured values, or comparing nominal and estimated system parameter values.

Fault identification and localization is performed from Fault Signature Matrix (FSM), which connects faults and specific residuals (symptoms). Given a set of symptoms and a set of considered faults, the fault signature matrix (FSM) codes the relations between effects of a fault and each symptom. Then, fault isolation then consists of implementing an appropriate artificial intelligence method to search for the closest matching fault for the observed signature pattern.

PHM Methods for Mechanical Systems

Prognostics and health management of mechanical systems has been thoroughly investigated and standard components can nowadays be monitored with well-established tools and methods [8]. Mechanical components are components in assemblies for cooling and vacuum systems and consist of pumps, blowers, bearings and gearboxes. The main sources of diagnostic information for mechanical systems are vibration signals [5], acoustic emissions and temperature. Symptoms for fault detection and isolations include time domain methods (RMS, variance, kurtosis, crest factor and time synchronous averaging), frequency domain methods (FFT Spectrum and power spectrum) and time-frequency domain analysis (discrete and continuous wavelet analysis).

PHM Methods for Electronic Systems

The second big group of devices, prone to cause beam trips, consists of a large number of electronic components. These include power supplies, electric drives in blowers and pumps, electronic systems, Klystrons, etc. [9]. Systems for early fault detection and failure prediction continuously monitor current, voltage, and temperature signals. Along with sensor information, soft performance parameters such as loads, throughputs, queue lengths, and bit error rates can be tracked [10]. Feature values are computed from these signals either by signal processing techniques, or by using equivalent electric circuit models with on-line estimation of model parameters.

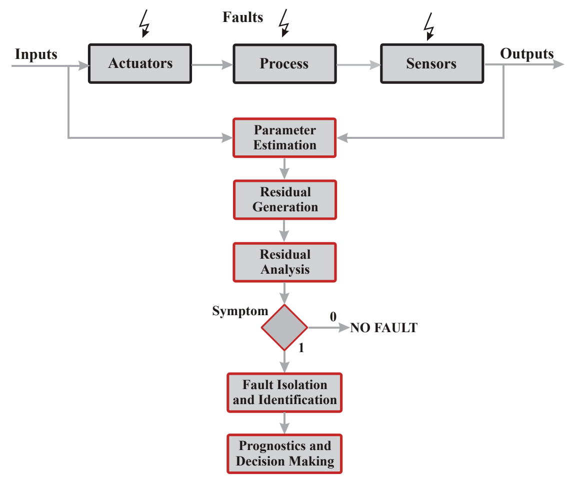

Figure 2: Model-based residual generation.

Prognostics

Prognostics deals with estimation of the Remaining Useful Life (RUL), i.e. the amount of time a component can be expected to continue operating within its given specifications [8]. The set of approaches can roughly be divided into physics-based models and data-based models. The physics-based models rely on detailed physical modeling by means of finite element method, which serves to compute spatial distributions of stresses in the material and their effect on the component health. The idea of data-driven methods is to make use of condition monitoring data to build the model and then use the model to predict future trend. (c.f. Figure 3).

EXPERIMENTAL EVENT FILTER ARCHITECTURE

The vector of all feature values defines the state of the accelerator, and the predicted values of features define the trend of this state. These vectors must lie in the safe operational region of the space of all possible accelerator states. The PHM system purpose is to detect when the state of the accelerator is moving towards the boundary of the safe operational region and either take a corrective action automatically, or trigger an appropriate alarm for the operator to correct the state.

Given the experimental nature of the MYRRHA and relatively new approach to predictive diagnostics in the accelerator control system domain, it is expected that the understanding of features, symptoms, and faults will be based on past data from existing accelerators. As this data

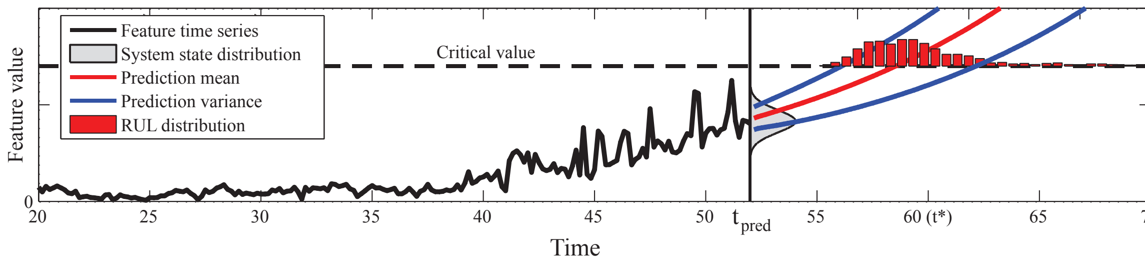

Figure 3: Example of prognostics output.

was not collected for the specific purpose of predictive fault diagnostic, it is expected to be incomplete, so refinement based on trial and error will be needed for optimal performance of the PHM system. In order to have all the required data available, we propose that standard PHM system is augmented by a tree-like architecture of event filters, similar to the one used by CERN's LHCb Event Filters and Event Triggers [11]. Their role in the PHM system would be to identify and store anomalies in feature values, use them to identify possible new faults prior to their occurrence, such as symptoms and their significant residuals that were not isolated in prior test-runs of the accelerator, or to allow for posterior identification of symptoms and diagnostic or prognostic features for a specific fault after it has occurred.

The event filters would be organized in three levels: the first level would keep track of signals' feature values and instances of the accelerator's state. These would include any possible deviations from either model-predicted, or from expected historical values. Events, detected at this level, would be logged for references in case of future faults, and checked by the second level event filters for severity as well as compared by symptoms leading to past faults. Any matches with past symptoms of faults or severe deviations would be forwarded to the third level event filters. These would encompass decision support systems, leading either to automated response (translating the state of the accelerator away from the nearest boundary of the safe operational zone) or to alarms for operators stating either a required immediate action to avoid beam termination.

CONCLUSION

The paper presented a roadmap for implementation of prognostics and health management for accelerator systems. PHM is a promising technology that can be used within the maintenance decision-making process to provide failure predictions, increase the operational availability of systems, lower sustainment costs by reducing the costs and duration of downtime, improve inspection and inventory management, and lengthen the intervals between maintenance actions.

ACKNOWLEDGMENT

Financial support for the work was provided by the project EXLIZ – CZ.1.07/2.3.00/30.0013, which is co-financed by the European Social Fund and the state budget of the Czech Republic, and by COBIK – the Centre of Excellence for Biosensors, Instrumentation and Process Control is an operation financed by the European Union, European Regional Development Fund and Republic of Slovenia, Ministry of Higher Education, Science and Technology.

REFERENCES

[1] D. Vanderplassche et al., "The MYRRHA Linear Accelerator" Proceedings of IPAC2011, San Sebastián, Spain, 2011.
[2] H. Podlech et al., "General Layout of the 17 MeV Injector for MYRRHA," Proceedings of IPAC2011, San Sebastián, Spain, 2011.
[3] H. A: Abderrahim et al., "MYRRHA – A multi-purpose fast spectrum research reactor," *Energy Conversion and Management*, 63 (2012) 4–10.
[4] H. Takei et al., "Estimation of Acceptable Beam Trip Frequencies of Accelerators for ADS and Comparison with experimental data of Accelerators," International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators, IAEA, Vienna, Austia, 2009.
[5] R. B. Randall, *Vibration based condition monitoring*, Wiley, Hoboken, NJ, 2011.
[6] S. Narasimhan, "Automated Diagnosis of Physical Systems," Proceedings of ICALEPCS07, Knoxville, Tennessee, USA, 2007.
[7] R. Kothamasu et al. *System health monitoring and prognostics–a review of current paradigms and practices*, Elsevier, 2009.
[8] J. Sikorska et al., "Prognostic modeling options for remaining useful life estimation by industry," Mechanical Systems and Signal Processing, vol. (25)2, pp. 1803–1836, 2010.
[9] S. L. Gold, "Klystron Gun Arcing and Modulator Protection," 5th Modulator-Klystron Workshop for Future Linear Colliders (MDK-2001).
[10] M. Pecht and R. Jaai, "A Prognostics and Health Management roadmap for Information and Electronics-rich Systems," *Microelectronics Reliability*, 50 (2010) 317–323.
[11] A. A. Alves et al., "The LHCb Detector at the LHC," JINST, vol. 3, p. S08005, 2008.