Condition-Based Maintenance:
Prospectives of the Regulators,
the Manufacturers and the Operators in the Power Industry*

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0. Abstract

As system designs become more complex and their integrated performance required for public safety as well as business financial success becomes more essential, the role of test and maintenance gains in importance. Strategically, test and maintenance consume high levels of resources, and if focused correctly, can assure the continued operation of systems within their design envelope. However, if an adaptive process is not in place, it can lead to false security and even aggravated system failure through realignment and calibration errors or early component wear out. As an example over the last 10 years the commercial nuclear power industry has been working toward an optimum Condition-Based maintenance in place of a scheduled test and maintenance process. This effort has concentrated on developing a better understanding of system performance under unanticipated environments, as well as the subtle changes brought about by the aging phenomena, developing analytical approaches that can be used to model the maintenance rule and risk-informed regulations.

This paper will discuss these independent efforts in an integrated manner. It will present the vision that all highly engineered systems have the same basic requirements for an effective test and maintenance program. As such, we engineers, manufacturers, operators, and regulators need to move, where practical, to a unified method to collect, store, analyze and share information about system performance and condition-based maintenance. Whether the system supports a process facility such as a nuclear power plant, aircraft, marine vessel, or spacecraft, common areas need to be identified and leveraged. Where true industry uniquenesses exist, they should be handled as the exception, not the norm.

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1. Introduction

The accelerated pace of technology, from conceptualization to commercialization, has created a business environment that places new pressures on how society operates its essential machines. As engineers and researchers we have an ever-increasing portfolio of technology to draw from when designing, operating and maintaining systems that make up the backbone of our society. We have seen analog give way to digital and then to hybrid, macro move to micro and in the near future nano, and the formation of a field of endeavor that is the subject of this conference – highly engineered systems. Systems that are, by this very nature, complex and difficult to work with. The new college edition of the American Heritage Dictionary of the American Language [1] defines complex as consisting of interconnected or interwoven parts, involved or intricate. Each of the end use fields or industries, represented at this conference must handle this complexity. Whether our efforts are in air transportation, chemical processing plants, or the electric power industry, whether they are focusing on availability and/or public safety, when dealing with a highly experienced system we are all in the same arena. It is my vision that only by approaching operational questions, across the industries represented by this conference, can we develop successful/efficient procedures. Only by implementing complex rather than simple strategies will we be successful in assuring the long term operability of our machines. This I am convinced requires a uniform sharing of measurement, data and analysis approaches.

When one looks at systems we can break out those with a much higher social impact these are systems that lack a tolerance for failure and have high-risk contributions. In his book, Probabilities Safety Assessment in the Chemical and Nuclear Industries, Dr. R. Fullwood [2] points out the history of how we, as engineers, have responded to high risk systems and the current need to consider a non line model, especially when we try to move away from simple period based test and maintenance. In an earlier text, Probabilistic Risk Assessment in the Nuclear Power Industry [3] it is pointed by Fullwood and Hall that use of only a time based period for performance for preventive maintenance or prescribed operational testing can lead not only to a dilution of resources on unneeded activities but also can be shown to lead to premature failure in selected systems. This was based on studies of the commercial nuclear power industry, however, the conclusion can be shown to correlate well to all complex systems.

This paper looks at the nuclear power industry as an example and discusses the effort to move from prescription maintenance practices to performance based. It touches on the role that performance data and risk modeling are playing and the need to account for the system aging characteristics. The paper also makes the case for the need to cut across industries, of course accounts for application difference, when developing a maintenance process that can increase availability and safety which at the same time reduce costs. The challenge is to develop a usable performance basis that applies deterministic measures and risk information. Keeping this approach tractable, understandable and practical has proven to be difficult in the nuclear industry but not impossible. By working across industries we should be able to share performance models for similar components, use each others measurement schemes and augment our data to increase its robustness, thus accounting for variations in use, environment and maintenance needs.

2. Maintenance Philosophy, Nuclear Power Plants in the US and Worldwide

The commercial nuclear power industry grew out of the post World War II "Atoms for Peace" program and the existing fossil powered electron generation industry. As such the maintenance philosophy from the fossil program was very much carried over intact. That is not to say that the early nuclear proponents did not understand the risk level that this new machine represented. To assure public safety many aspects of the commercial and military aircraft program were adopted, including the application of a philosophy of system diversity, independence, and defense in depth. This found its way into a maintenance program based on rigid "technical specification", that exist to this day. All aspects of safety grade (by definition) components and systems, have a set of prescribed preventive maintenance intervals, allowed outage times for corrective maintenance and surveillance test intervals, reference NUREG/CR6141 [4]. Application of these deterministic technical specifications, based primarily on expert judgement and some performance data from qualification tests served as the mainstay until in the late 1980 unexpected events started to turn up. Systems that were designed to be highly reliable began to show industry wide failures. One such system was the emergency diesel electric generator set. In 1987 a study was sponsored by the U.S. Nuclear Regulatory Committee [5] that resulted in the proposal of a formal reliability/performance based program for the diesel sets. It was recognized that the static test and maintenance requirements based only on time and past test results, were causing early wear out of the system.

With finding such as this in hand, the regulations began to pursue research on alternative ways to perform maintenance on safety systems. At the same time, based on the so-called Reactor Safety Study [6] headed by N. Rasmussen of MIT, of 1975, a new thought was maturing throughout the industry. Early attempts to use Probabilistic Risk Assessment methods, including fault trees and event trees meet marginal success at best with the focus in the 1980s on setting bottom line safety goals including the limitation on consequences. Years passed with a number of attempts to use this methodology, born in the aviation community (fault trees) and expanded by the nuclear (event trees).

In the early 1990s the regulator and the industry began to realize that bringing these two items together, the need for performance based maintenance and PRA analytical tools, made sense. A first attempt to look at ways to merge test and maintenance activities with system importance during an accident or transient was focused on the use of PRA, to allow one time exemptions to the technical specifications [reference 4], and to optimize inspection activities of the regulator [7]. It is my opinion that this success set the foundation for the current performance based maintenance and the Risk Informed Regulation that exists in the U.S. Nuclear Regulatory Commission today. The addition of the risk dimension allowed the quantification of system change during accidents and transients including the most important human error and recovery element. Priorities were seen to shift based on system alignments and event sequences, and the sparse, incomplete performance data that was available could be augmented by a logic model. Standard wear out theory could be incorporated into test and maintenance planning and in general, activities could be focused on systems important to safety instead of a predetermined safety or "Q" list. These approaches saw reasonable acceptance from both industry and the regulator.

3. Current Thinking

The past 10 years has seen the evolution of performance based approaches in the nuclear power industry to that of risk informed regulation and operation. The process of adding the risk prospective has taken longer than most had assumed and has required an educational element to shift the thinking of the industry.

Currently, the U.S. Nuclear Regulatory Commission has published a "Maintenance Rule" [8] along with a companion regulatory guide [9]. In 1996 an industry group, NUMAC, followed and published a guideline for monitoring the effectiveness of maintenance [10]. The ten year process has now served to integrate risk informed thinking throughout the industry and to better understand its limitations and strengths thereby, assuring that safety and availability has been approved.

Performance based maintenance now focuses on the redefined safety related component list and includes, non safety or support systems and components when they are needed to 1) mitigate an accident or transient; 2) are used in an emergency operating procedure; 3) have been found to represent a dependency; 4) one who's failure would cause a challenge to a safety related system. This represents an improvement that focuses resources on risk significant systems, in the time dependent or dynamic way. S. M. Wong of the U. S. Nuclear Regulatory Commission [11], states "Even though several technical issues were encountered in early inspection, it was found that the application of PRA methods played an important role in the successful implementation of the Maintenance Rule programs at many U.S. Nuclear plant sites. The resolution of these issues demonstrated the relative maturity of PRA methodology applications in risk-informed, risk-based regulatory environment."

As the industry has moved forward the engineering standards writing bodies have followed. This represents an important step, since all aspect of the design and maintenance depends on their documents. In the U.S. the American Society of Mechanical Engineers, ASME, has pursued rewriting its boiler and pressure vessel code to now endorse performance based/risk informed in-service testing and inspection of nuclear facilities. The ASME is also developing a new document that will standardize, as reasonable, the use of risk based and informed approaches, including test and maintenance in these facilities. This standard is currently under public ballot. In a similar way the Institute for Electrical and Electronics Engineers, IEEE, constituted approximately one year ago, a standards writing group under the Nuclear Power Engineering Committee. This body has the charter to risk inform the IEEE's nuclear standards including those governing the maintenance of electrical class 1E equipment. The IEEE group may also address the human element in the operational and maintenance phase of a plant from this point of view. On the international level the IEC, International Electro Technical Committee has long been a leader in this area for standards on plant instrumentation and control.

4. A Merging of Technologies

In the introduction to this paper the author presented a vision of approaches to performance based maintenance that would cut across industries. A vision that focuses on how to keep highly engineered, complex systems, performing their functions and measures the success of test and maintenance programs. The nuclear power industry adapted an approach in risk assessment and system modeling that has in this authors mind, general applicability. Although numerous differences exist between applications in the industries represented at this conference they all share common ground.

As an example, in some cases maintenance performed on line during operation may be more desirable from a risk and cost point of view. The nuclear plant is such a case. However, for aircraft systems this is impractical and off line activities at the gate or in a hanger are required. On the other side, both industries rely on electrical cables to monitor, control and activate systems and must tackle the difficult task of performance-based test and maintenance on these cables. In 1998 a conference was held in New York City titled “Probabilistic Safety Assessment and Management” where over 500 experts from around the world attended. This conference focused on this very issue. How to build the bridges between industries to support the flow of information. Although the conference was on assessment Vol. 4, Page 2607 of the transaction covers “Test, Maintenance and Reliability Optimization”. Reference 11 was taken from this document as edited by Mosleh, Hall and Bari. This meeting of experts saw the mix of the U.S. Coast Guard’s look at risk based near-miss reporting systems to the U.S. FAA’s discussion on performance data needs and the U.S. Nuclear Regulatory Committee presentation on risk informed work. All of which had similar messages. This theme was repeated in most of the 2900 pages of paper from around the world.

5. In Conclusion

The complexity of all highly engineered systems requires a rethinking of test and maintenance practices, one that includes the ability to evaluate system reconfigurations, time dependence and accident or incident progression. The method that has been adopted by the nuclear power industry rests on the use of detailed system modeling and risk assessment augmented by physical performance data. The applications of these approaches satisfy the need for public safety as well as cost reduction and should have general applicability across high risk/high reliability industries.

Disclaimer: The opinions expressed in this paper represent those of the author as presented as the keynote address for the symposium.

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