PMC reliability assessment and maintenance optimization

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Abstract. By analyzing the main functions of PMC, determining the task profile of each PMC component, establishing a PMC task reliability model, and combining internal and external feedback, the action unit components that have a significant impact on PMC failures and contribute to the critical path of major repairs are identified. Component reliability maintenance analysis and quantitative evaluation of the overall reliability of PMC were carried out. The analysis shows that the existing preventive maintenance strategy effectively identifies equipment hazards and proposes suggestions for reliability improvement.

1 Introduction

PMC (Fuel HANDLING AND STORAGE SYSTEM) consists of rail-mounted equipment such as the Manipulator crane and the Fuel transfer system. As PMC directly handles nuclear fuel, any malfunctions could affect the safety of the fuel. Some components of the PMC come into contact with the fuel, and there is a risk of high radiation dose during maintenance activities. Malfunctions in the PMC could impact the critical path for maintenance activities, directly affecting the operational and economic efficiency of the NPP. Therefore, improving the reliability of PMC is of both economic and safety significance.

Based on the theory of reliability engineering, the maintenance of the reliability of PMC depends on the reliability of its action units [1]. This paper focuses on the PMC of A NPP, The analysis process is shown in Figure 1.

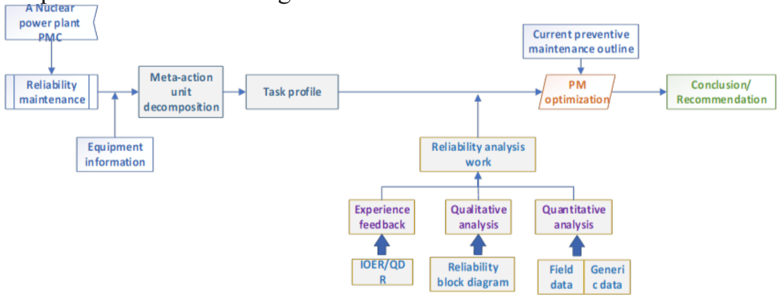

Fig. 1. PMC reliability evaluation and maintenance strategy optimization process.

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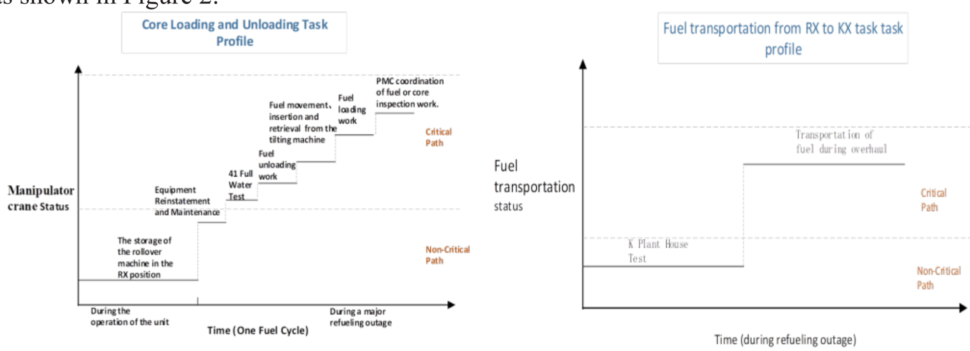
2 PMC functionality and task profile

Based on the analysis of technical manuals related to PMC loading and unloading, the functional breakdown of PMC is shown in Table 1:

Table 1. PMC function list.

	Numbering	Functions
Key Functions	**M1**	*Core discharge*
	M2	*Insert the components into the tipper fuel basket*
	M3	*Grab components from the dumper fuel basket*
	M4	*Fuel transfer function*

The above functions are summarized and organized to form the main task profile of PMC, as shown in Figure 2.



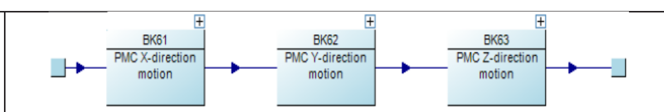
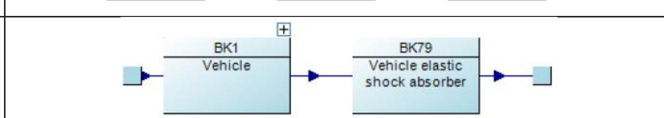
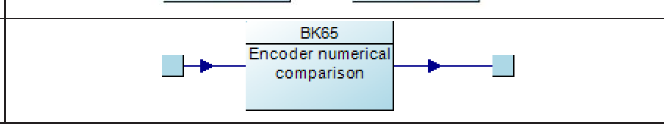
(a) (b)

Fig. 2. Core Loading and Unloading Task Profile (a) and Fuel transportation from RX to KX task task profile (b).

3 PMC reliability model

Analysis of the actions involved in executing the PMC task profile and decomposition of the components forming the equipment, results in the formation of the fuel handling task reliability block diagram (RBD, as shown in Table 2) and the fuel transfer from RX to KX task RBD.

Table 2. Core Loading and Unloading Reliability diagram.

Manipulator crane	
PMC X-direction motion	
Vehicle motion interlock and positioning system	

As can be seen from the RBD of the core loading and unloading task, the components of the PMC system are mainly in series, with little redundancy, which is consistent with the characteristics of mechanical equipment. The failure of components in series will directly affect the execution of the PMC loading and unloading function.

4 PMC experience feedback analysis

IOER: Incident, Outage and Event Report, mainly records failures that occur during the use of the PMC during major overhauls. Quality Deficiency Report (QDR) primarily documents the issues identified during the preventive maintenance prior to the major overhaul of the PMC .Searching the IOER of the group factories, up to the year 2022, PMC had a total of 17 failures that significantly impacted the critical path, with a total of approximately 280 hours. The statistics of the IOER of the PMC group factory, the IOER of the A NPP, and the number of QDR events of the A NPP are as Table 3.

Table 3. Comparison of PMC Data Statistics for Group Factory and A NPP.

Critical Path of Plant Overhaul	IOER "IOER of Critical Path for Plant Overhaul"	IOER of Critical Path for A NPP	A QDR for A NPP
Motion functional group components	*6*	*0*	*2*
clamps / cylinders and air hoses	*1*	*1*	*11*
tilting machine motor	*1*	*0*	*3*
tools	*2*	*1*	*2*
encoders	*1*	*1*	*35*
main lifting brake	*0*	*0*	*3*
underwater light	*0*	*0*	*8*
tilting machine limit	*0*	*0*	*37*
steel rope	*0*	*0*	*1*

The number of QDR events at NPP A is significantly higher than IOER events, indicating that the preventive maintenance work at NPP A has identified and eliminated a large number of faults and hidden dangers.

5 Qualitative and quantitative reliability analysis of PMC

5.1 Qualitative analysis

FMECA analysis was conducted on component categories that significantly affect the critical path of plant overhaul in PMC, as well as component categories with prominent issues identified during on-site interviews. The RPN (Risk Priority Factor) of PMC components is, from highest to lowest: tilting machine motor、clamps / cylinders and air hoses、Motion functional group components、encoders、tilting machine limit、main lifting brake、underwater light、steel rope [2]. Carry out an analysis of the effectiveness of maintenance procedures. maintenance procedure *Mechanical inspection before unloading of the refueling machine* include “7.0 Encoder check: Visually inspect the encoder gears of large and small turns”.

Analyses indicate that the selection of components such as encoders and limit switches did not sufficiently consider environmental adaptability, resulting in lower reliability. The supply of imported spare parts for encoders, grippers, and pneumatic power components is challenging. The components of the motion function group did not fully consider reliability and maintainability. Components such as steel cables did not fully adopt predictive maintenance, which to some extent affected the economy and safety of PMC refueling work, indicating room for reliability improvement.

Table 4. Failure rate statistics of PMC group plants and A NPPs.

PMC key components	Group plant overhaul PMC failure rate (times/hour)	A NPP overhaul PMC failure rate (times/hour)	Total failure rate of NPPs (QDR+IOER, times/hour)
Motion functional group components	*4.10E-04*	*0.00E+00*	*4.07E-04*
clamps / cylinders and air hoses	*6.83E-05*	*2.03E-04*	*2.44E-03*
tilting machine motor	*6.83E-05*	*0.00E+00*	*6.10E-04*
tools	*1.37E-04*	*2.03E-04*	*6.10E-04*
encoders	*6.83E-05*	*2.03E-04*	*7.32E-03*
main lifting brake	*0.00E+00*	*0.00E+00*	*6.10E-04*
underwater light	*0.00E+00*	*0.00E+00*	*1.63E-03*
tilting machine limit	*0.00E+00*	*0.00E+00*	*7.52E-03*
steel rope	*0.00E+00*	*0.00E+00*	*2.03E-04*

Table 5. Table of reliability calculation results for PMC during plant overhaul and NPP A overhaul.

task	Reliability data type	Group Plant Overhaul PMC Failure (IOER)	A NPP Overhaul PMC Failure (IOER)	A NPP failure rate compared to the whole plant	Total NPP failure (QDR+IOER)	The total data of A NPPs has increased compared to the overhaul data
the fuel handling task RBD	*Failure rate*	*1.94E-03*	*2.61E-03*	*26%*	*8.70E-02*	*97%*
	The number of expected failures	*0.208*	*0.287*	*28%*	*1.01*	*72%*
the fuel transfer from RX to KX task RBD	*Failure rate*	*5.88E-04*	*2.44E-04*	*-141%*	*1.59E-02*	*98%*
	The number of expected failures	*0.068*	*0.029*	*-134%*	*0.82*	*96%*

5.2 Quantitative analysis

According to statistics, from 2016 to the present, the plant group has carried out a total of 122 overhauls, and NPP A has carried out 41 overhauls. For the sake of data consistency and comparability, it is assumed that the PMC refueling equipment operates for an average of 120 hours for each overhaul. The classical calculation method is used. The operational failure rate λ (times/hour) refers to the number of times the equipment fails per unit time during operation [3].

λ = the total number of operational failures N (times) of a certain type of equipment in the collection time interval / the total operating time T (hours) of a certain type of equipment in the collection time interval.For the special case where no operational failure is observed, i.e., when N=0, the '50% rule of X^2' is used as an approximate estimation method, i.e., the operational failure rate λ is estimated by the following formula:

$$\lambda = \frac{\chi^2_{50\%(2\times N+2)}}{2\times T} \approx \frac{0.7}{T} \quad (1)$$

The failure data of each component is as follows: The failure rate data of other components of PMC is taken from the ISOgraph reliability database.

As can be seen from the above table, The probability of the core loading and unloading task (PMC l Manipulator crane) in NPP A affecting the critical path of the overhaul is higher compared to the plant group. if the QDR data is considered, the failure rate of PMC in a NPP A will increase a lot, indicating that most of the hidden dangers of PMC affecting the critical path of overhaul have been eliminated in preventive maintenance.

6 Summary

The analysis shows that the existing preventive maintenance strategy can effectively identify equipment hidden dangers, keeping the impact of PMC on the critical path of overhaul at a low level. For components with lower reliability, in addition to the existing reliability management maintenance strategy, reliability improvement work should be carried out in the future.

References

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