Availability Analysis of the ITER Blanket Remote Handling System*)

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The ITER blanket remote handling system (BRHS) is required to replace 440 blanket first wall panels in a two-year maintenance period. To investigate this capability, an availability analysis of the system was carried out. Following the analysis procedure defined by the ITER organization, the availability analysis consists of a functional analysis and a reliability block diagram analysis. In addition, three measures to improve availability were implemented: procurement of spare parts, in-vessel replacement of cameras, and simultaneous replacement of umbilical cables. The availability analysis confirmed those measures improve the availability and capability of the BRHS to replace 440 blanket first wall panels in two years.

Keywords: ITER, maintenance, remote handling, availability, RAMI

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1. Introduction

Availability, the ratio of the total time a system is capable of being used during a certain interval to the length of the interval itself, is an important factor of complex systems such as fusion reactors. In the ITER project, the RAMI approach, which stands for Reliability, Availability, Maintainability and Inspectability, was devised to assess the technical risks [1]. The availability target of the ITER machine as a whole is 60% for inherent availability and 32% for operational availability in the hydrogen operation phase. To achieve this target, the availability of all the main systems and functions of ITER must be quantified and also meet all system and functional requirements thereof.

Availability of the ITER blanket remote handling system (BRHS), which handles blanket modules inside the vacuum vessel and will be procured by Japan Atomic Energy Agency, does not affect the target availability of the ITER machine directly. However, the BRHS can affect the target availability if it fails to perform its duty within the assigned duration: replacing 440 blanket first wall panels in two years. Thus, the availability of the BRHS is an important factor and must be quantified and satisfy requirements. Figure 1 shows a CAD view of the BRHS during RH operations [2].

In this paper, the methods and results of availability analysis of the BRHS are described. Following the ITER RAMI analysis programme, which is defined by the ITER Organization, an availability analysis was performed via a functional analysis and reliability block diagram (RBD) analysis.

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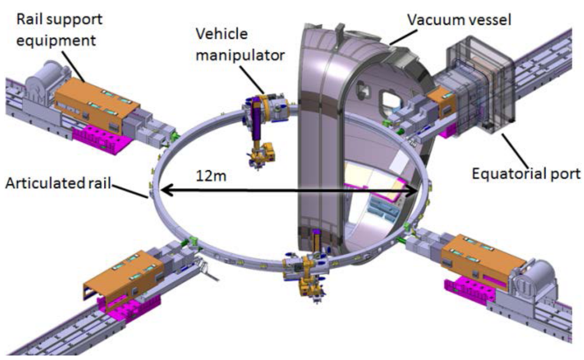

Fig. 1 CAD view of the BRHS during RH operations with the articulated rail deployed 360 degrees.

2. Methods

2.1 Functional analysis

The first step of this availability analysis is the functional breakdown of the system, which is a top-down description of the system as a hierarchy of functions. Functional analysis identifies all functions of a target system and provides input for the RBD analysis.

Table 1 shows the functional breakdown of the BRHS up to the third level. Functions were broken down to fifth level at maximum. The top function is 'A0 To maintain maintenance object by remote control', which is the purpose of the system. The BRHS consists of two kinds of components. Those for handling maintenance objects such as the vehicle manipulator, a large robot manipulator; the articulated rail which supports the vehicle manipulator; and the rail support which supports the articulated rail, and those for deploying said handling components into the vessel. Corresponding to those two types of compo-

Table 1 Functional breakdown of the ITER blanket remote handling system (BRHS) up to the third level.

A0 To maintain maintenance object by remote control
A1 To remotely control BRHS
A1.1 To control Remote Handling (RH) equipment
A1.2 To provide view
A1.3 To provide user interface for control
A1.4 To house controllers
A1.5 To comply with Plant Control Design
A1.5.1 To provide ITER protection of investment system
A1.5.2 To provide plant wide safety function
A1.5.3 To interface with RH supervisory control system
A2 To provide common function
A2.1 To provide base in Cask
A2.1.1 To move in direction of moving axis
A2.1.2 To connect main Cask Base Plate (CBP) with int-CBP
A2.1.3 To roll in direction of moving axis
A2.1.4 To connect main-CBP with port through int-CBP
A2.1.5 To house CBP components
A2.2 To move other RH equipment in Cask
A2.2.1 To move in direction of moving axis
A2.2.2 To house Tractor components
A2.2.3 To connect with other RH equipment
A2.3 To transfer electricity
A2.3.1 To transfer electricity from Cask
A2.3.2 To transfer electricity to Vehicle
A2.3.3 To deploy multicore cable
A2.3.4 To roll in direction of moving axis
A2.4 To supply gas
A2.5 To supply other utilities
A3 To install rails
A3.1 To deploy rails
A3.1.1 To carry rails
A3.1.2 To carry rails and support fixing arm
A3.1.3 To carry rails and Vehicle
A3.1.4 To position/ deploy rails
A3.1.5 To lock rails
A3.2 To support rails
A3.2.1 To adjust rail position and support rails
A3.2.2 To move rail support
A4 To transfer maintenance object/tool
A4.1 To move on rail and change Vehicle posture
A4.2 To Grip maintenance object/ manipulate tool in Vacuum Vessel
A4.3 To transfer maintenance object/tool in cask
A5 To provide tools
A5.1 To cut blanket cooling pipes
A5.2 To weld blanket cooling pipes
A5.3 To rescue failed component
A5.4 To fasten / unfasten central bolt
A5.5 To examine welded pipes

nents, there are two main functions under the top function: 'A3 To install rails' and 'A4 To transfer maintenance object/tool'. In addition, there are functions to control the system 'A1 To remotely control Blanket RH system', to provide functions commonly needed for the two kinds of components 'A2 To provide common function' and to provide tools necessary for operations 'A5 To provide tools'.

2.2 Reliability Block Diagram (RBD)

The next step of the availability analysis is a bottom-up approach using an RBD to estimate the reliability and availability of the system. The RBD approach uses the functional breakdown as a basis, and defines reliability-wise relationships between functions. In the RBD, the lowest level functions in the functional breakdown are further broken down into parts. For instance, a function for movement can be broken down into a motor, reducers, and gears. To calculate the availability using the RBD, reliability and maintenance characteristics of parts need to be defined. The reliability characteristics can be expressed as failure distribution functions. These functions give failure probabilities for certain times. Mean time between failures (MTBF) is derived from those functions. The maintenance characteristics can be expressed as mean time to repair (MTTR), which is the period from a failure to its recovery. The availability can be obtained using an RBD with failure distributions and MTTR defined for each part.

By following the ITER RAMI analysis programme, ReliaSoft BlockSim 9 was used to create the RBD and calculate the availability. The RBD describing the BRHS was created based on the functional breakdown. Failure distributions were defined for each part based on failure databases and judgements based on engineering experience. MTTRs were defined based on the estimated time of maintenance in the case of part failures.

Table 2 summarises the inputs into the RBD. Failure modes were determined first for each part to define those inputs. After determining the failure modes, failure distribution functions were determined. Parameters of these functions (including MTBFs) were determined based on specifications provided by vendors, the ITER failure database [3] collected from fusion machine experiments by the ITER organization, and judgements based on engineering experience. MTBFs of radiation failures were determined based on a 250 Gy/h radiation environment in which the BRHS is required to be operated in [4]. MTTRs include duration of retraction of the BRHS from the vessel, procurement of spare parts, repair and re-installation of the system into the vessel.

In this RBD analysis, two scenarios were considered: initial and expected. In the initial scenario, we assumed that only spare parts for the camera, umbilical cable, internal wiring, controller hardware and software, and interlock / safety system would be prepared. Since the camera and umbilical cable has the normal distribution and are

Table 2 Failure modes, and reliability and maintenance characteristics of BRHS parts.

Component	Failure mode	Failure distribution function	MTBF [hour]	MTTR in initial scenario [day]	MTTR in expected scenario [day]	Source of data
Camera	Radiation	Normal	1.60E+04	43.5	3	Vendor
Umbilical cable	Radiation	Normal	4.00E+03	43.5	43.5	Vendor
Internal wiring	Radiation	Lognormal	4.00E+03	90	43.5	Vendor
Grease (bearings and reducers)	Radiation	Lognormal	2.41E+05	113.5	43.5	ITER database
Motor, slip ring	Radiation	Lognormal	2.41E+05	113.5	43.5	Engineering judgement
Gear, ball screw, rack, linear guide, roller	Mechanical	Lognormal	6.01E+06	113.5	43.5	Engineering judgement
Limit switch	Mechanical	Lognormal	3.61E+07	113.5	43.5	Engineering judgement
Chassis, structure	Mechanical	Lognormal	3.33E+07	113.5	43.5	ITER database
Rail	Mechanical	Lognormal	1.00E+10	113.5	43.5	ITER database
Connector	Mechanical	Exponential	1.75E+08	113.5	43.5	Vendor
Signal cable	Electrical	Exponential	4.00E+05	113.5	43.5	ITER database
Power cable	Electrical	Exponential	1.41E+06	113.5	43.5	ITER database
Controller (hardware)	Electrical	Lognormal	2.78E+05	1 hour	1 hour	ITER database
Controller (software)	Software	Lognormal	1.49E+05	1 hour	1 hour	ITER database
Interlock / safety system	Software	Lognormal	1.00E+05	1 hour	1 hour	ITER database

special ordered components, which take long time to be procured, those spares were assumed. The internal wiring and controller hardware are parts commonly used in ITER, and their spare parts will be prepared. Thus, MTTRs of those failures exclude the procurement of spare parts, and are shorter than other non-spare parts. Since the BRHS does not have to be retracted to recover from failures of the controller and interlock / safety system, these MTTRs are much shorter than other parts. In the expected scenario, we implemented the following three measures to improve availability: procurement of more spare parts, in-vessel replacement of the cameras, and simultaneous replacement of the umbilical cables. The number of spare parts was determined through the initial scenario analysis to be sufficient enough so as not to affect the operation, and consequently, MTTRs of the parts were reduced as shown in Table 2. Cameras are one of the low-MTBF parts. In the case of camera failures, the movement functions of the BRHS remain intact although the operation cannot be continued. Considering these aspects, we decided to replace the failed camera in the vacuum vessel without retracting the BRHS and reduce MTTR of the cameras to 3 days. Replacement of cameras will be performed by the dexterous manipulator, which is used for handling light weight objects and rescuing. Details of the replacement will be developed. Regarding the umbilical cable, the BRHS has two and since its failure distribution is normal distribution, shortly after one cable fails the other cable is expected to fail. Hence, the simultaneous replacement of both the umbilical cables when one fails is expected to reduce the number of repair events and improve availability.

Since the RBD consists of a number of blocks and it is difficult to solve the availability analytically, we adopted the Monte Carlo simulation to calculate the availability. The availability for one two-year operation is obtained by one simulation. We performed 10,000 times simulation for the two-year operation and obtained the availability as an average.

3. Results

As described in the introduction, the main task of the BRHS is to replace 440 blanket first wall panels in two years. We estimated the replacement duration of that task, which excludes the installation and retraction of the BRHS (20 days each), at 277 days with 100% availability of the

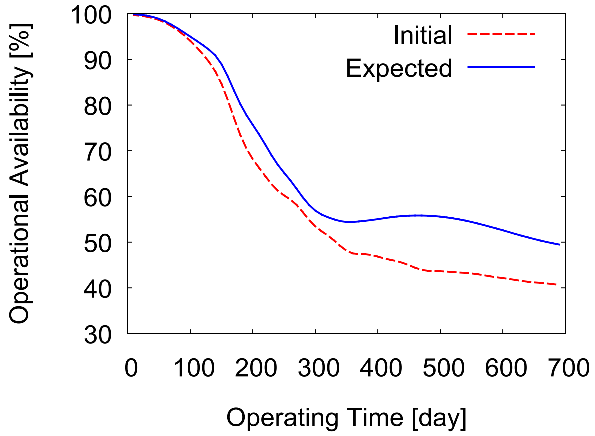

Fig. 2 Operational availability of replacement duration in the initial (red dotted line) and expected scenario (blue solid line).

system. '100% availability' means that there are no failures or maintenance, and thus there is no downtime of the system. To achieve a 227-day uptime in 690 days (two years minus 40 days for installation and retraction), the system needs to, at a minimum, attain 40% operational availability for the 690-day operation. Since the duration of installation and retraction is short, the availability of those tasks is higher than 99%. Thus, we only considered the availability of the replacement task.

Figure 2 shows the operational availability of replacement duration (690 days) in the initial and expected scenarios. Figure 2 indicates an improvement of the availability in the expected scenario. The 277-day uptime is reached after 680 days of operation in the initial scenario and after 500 days in the expected scenario. The target uptime is achieved in both scenarios; however, these uptimes are average values of 10,000 times simulation. It is worth considering task completion probability. In the initial scenario, there is only a 65% probability that the uptime will be longer than 277 days in the 690-day operation although the average uptime will be longer than 277 days. On the contrary, the probability increases to higher than 99% in the expected scenario. Therefore, we concluded that the availability of the BRHS was improved in the expected scenario, and its ability to replace 440 blanket first walls in two years is confirmed, due to this improvement.

4. Summary

The ITER BRHS must be capable of replacing 440 blanket first wall panels in two years. An availability analysis was performed to study the capability of the BRHS to perform this task. The availability analysis consists of a functional analysis and an RBD analysis. We broke down the functions of the BRHS via a functional analysis and created an RBD based on the functional breakdown. To perform the RBD analysis, we defined reliability and maintenance characteristics of each part of the system using data from vendors, the ITER database, and judgements based on engineering experience. We implemented three measures for the expected scenario to improve availability: procurement of spare parts, in-vessel replacement of the cameras, and simultaneous replacement of the umbilical cables. As a result, those measures improved the availability, and we confirmed the capability of the BRHS to replace 440 blanket first wall panels in two years.

The availability is sensitive to the inputs and there is some ambiguity in the reliability inputs, especially for radiation failures. To obtain more accurate reliability characteristics, we are carrying out a series of irradiation tests, the results of which will make the analysis more precise.

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Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organisation.

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