Fusion Engineering and Design 88 (2013) 887–890

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Prolegomena to the RAMI analysis of a conceptual LHCD system for DEMO

Francesco Mirizzi*

Associazione EURATOM-ENEA sulla Fusione, Consorzio CREATE, via Claudio 21, 80125 Napoli, Italy

ARTICLE INFO

Article history:
Received 13 September 2012
Received in revised form 10 January 2013
Accepted 15 March 2013
Available online 17 April 2013

Keywords:
LHCD
Reliability
Maintainability
Availability
Inspectability.

ABSTRACT

Future fusion reactors are asked to deliver large amount of energy in a continuative way to electrical power grids. In this frame it is very important to care the availability of the reactors since the preliminary phases of the design. Techniques to assure high levels of reliability must be extensively used and accurate programmes of maintenance must be studied, caring in the same time the training of maintenance personnel. Finally the layout of the reactor and of all its auxiliary systems must be carefully examined in order to assure an easy inspectability and a fast recovery of the power station after unavoidable failures. All the previously listed activities are summarized by the acronym RAMI (reliability, availability, maintainability and inspectability). The basics of the RAMI analysis for a conceptual LHCD system for DEMO are given in the paper.

1. Introduction

ITER is the next step toward the future thermonuclear fusion reactors; it will be followed by DEMO, a prototype class of reactors delivering energy to electrical power grids. Therefore a DEMO reactor, a really complex system including several auxiliary subsystems and plants, must assure continuity of operations for very long periods of time. It is therefore very important to care the RAMI aspects of DEMO, to be considered as a "conventional" power station. Usually the values of the parameters involved in the analytical computation of the RAMI branches of a system are determined starting from experimental data obtained from similar systems. Presently no one of the existing experimental fusion devices works in the expected DEMO regimes, hence data coming from these devices are really not useful for the RAMI evaluation of DEMO. In particular there are very few significant data related to LHCD systems. Therefore in this preliminary phase, where the LHCD system for DEMO has been only defined in its general outlines, data coming from generic, but well assessed, databases have been used. Techniques to increase the RAMI values of this system have been also examined.

2. Definitions and basic theory

2.1. Reliability

Reliability is the probability that an item (system, subsystem, unit or component) is correctly running over a given period of time.

The reliability $R(t)$ of whichever item is obtained starting from its "failure rate" $\lambda(t)$, defined as the number of items "dn" failing during the time interval $(t, t+dt)$ related to the number of items still in operation at the time t:

$$\lambda(t) = -\frac{1}{n(t)} \cdot \frac{dn}{dt} \tag{1}$$

the minus sign indicating a reduction of operational units determined by the failures.

Generally the failure rate as function of time follows the shape given in Fig. 1: the "bath tube" curve. In this curve three different life phases are discernible. The first phase is the early life, characterized by an initial high failure rate decreasing with time and the last one is the wear-out phase where the failure rate is increasing with time.

The intermediate phase is the useful life of the item, characterized by a constant failure rate at its lowest value. The failure distribution function of components in their useful life is therefore exponential and the reliability of the component, obtained by

* Tel.: +39 0694005259.
E-mail address: francesco.mirizzi@enea.it

0920-3796/$ – see front matter
http://dx.doi.org/10.1016/j.fusengdes.2013.03.053

integration of Eq. (1) in the time interval $(0, t)$, with initial condition $n(t=0)=N$, is simply given by:

$$R(t) = e^{-\lambda t} \tag{2}$$

For items with only two states (operational or failed) the probability of failure $F(t)$ is complementary to the reliability $R(t)$, that is:

$$F(t) = 1 - R(t) \tag{3}$$

The inverse of the failure rate is the mean time to failure (MTTF).

In this preliminary analysis of the DEMO LHCD system all the components have been considered in their useful life and with only two states.

An accurate and comprehensive treatise on the reliability theory and related statistical methods can be found in [1,2].

2.1.1. Experimental evaluation of λ

The failure rates of elemental components are statistically obtained either from existing operational systems including those components or by experimental "ad hoc" set-ups. In synthesis, considering N similar components, with $N \to \infty$, in operation for a given time t, their average failure rate can be determined according to Eq. (1). Usually, mainly due to economical reasons, the initial number of components N_0 is limited and the tests cannot be lasted for very long times, so that the failure of only a limited number of components can be observed and recorded during the tests. These limited data are then statistically elaborated [2] for obtaining reasonable evaluation of failure rates usable for reliability forecasts of systems since their initial design phases. Before starting the evaluation procedure for a batch of unprocessed components, an accurate "burn-in" process will be used to eliminate the fraction of those components subject to early failures (Fig. 1). On the other hand the evaluation procedure must be stopped just upon the beginning of the wear out phase (Fig. 1), pointed out by a consistent increase of failures per unit time.

2.1.2. Available databases for failure rates

In the preliminary design phases of a system, or when specific experimental or field data from existing system are not available, failure rates can be effectively obtained from specialized databases. For electronic components the most important and widely used is the MIL-HDBK-217F [3]. Even if not revised since the 1995 [4], this handbook is still considered an actual source of data. For each class of components it gives a failure rate model of the form:

$$\lambda = \lambda_B \cdot \prod_i \pi_i \cdot 10^{-6} \quad \text{failures/hour} \tag{4}$$

where λ_B is the base failure rate characterizing the specific components and π_i are correction factors (i.e. environmental, temperature, power rating, quality factors, etc.). In particular the quality factor depend on component screenings made according to well-defined rules given by military standard (MIL STD) publications issued by the US Department of Defence. A more recent database for electronic components and equipment is the FIDES Guide 2009 [5]. The very detailed mathematical models given by this handbook for the evaluation of the failure rates suggest the use of the FIDES guide only once a detailed system design, also including construction and environmental details, is available. Failure rate for fusion related components and subassemblies (vacuum units, heat transfer assemblies, etc.) could be found in [6]. Reliability data for electrical power units and subassemblies are collected in [7]. Failure data for non-electronic parts are given by the actually recent NPRD 2011 databook [8].

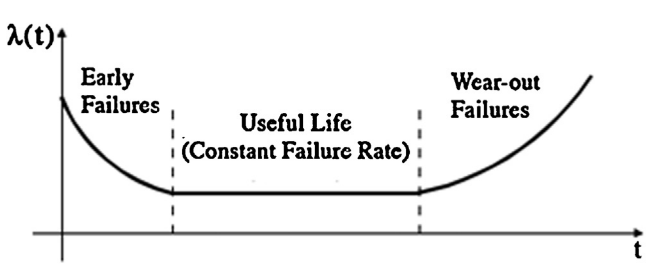

Fig. 1. Bath-tube curve.

2.2. Maintainability

Maintainability is defined as the probability of a failed item to be repaired in a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

The maintainability of reparable components or units is univocally defined by their "repair rate" $\mu(t)$. If the time needed for a maintenance action of a unit is independent from previous maintenances, the repair rate is constant with time and the related probability density function is exponential [1]. In this hypothesis the maintainability function is:

$$M(t) = 1 - e^{-\mu t} \tag{5}$$

The reciprocal of the repair rate is the "mean time to repair" (MTTR). MTTR includes diagnostic time, time for preparation and time for validation of the repair, but does not include administrative and other logistics delays. The MTTR of reparable complex units is given by:

$$\text{MTTR} = \frac{\sum_i \lambda_i \cdot \text{MTTR}_i}{\sum_i \lambda_i} \tag{6}$$

as shown in [1], where λ_i is the failure rate of the ith repairable component of the unit and MTTR_i the average mean time to repair of the same component.

Evaluation of the repair rate or MTTR of selected components can be found in some of the databases listed in Section 2.1.2 of this paper.

2.3. Availability

Availability is the probability that a repairable item, required to operate continuously for a given calendar time and considered to be in only two possible states: operating (up) or in repair after a failure (down), is satisfactorily operating at any random time t after the start of operation. The availability can be then expressed as the ratio of expected uptime to the expected aggregate values of up and down time:

$$A = \frac{E(\text{uptime})}{E(\text{uptime}) + E(\text{downtime})} \tag{7}$$

The availability of whichever item depends therefore on its reliability and maintainability. For reparable units the mean time between failure (MTBF), defined as the ratio of the total operating time to the number of failures, is used instead of MTTF. In case of constant failure rate and replacement upon failure MTBF = MTTF.

The intrinsic availability of a system, as defined in [1], can be then computed as:

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} = \frac{\mu}{\lambda + \mu} \tag{8}$$

2.4. Inspectability

Inspectability is a measure of productive time lost for inspection and testing of a failed item.