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Collection and Analysis of Data Related to Fusion Machines (JET and TLK) Operating Experience on Component Failure

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ABSTRACT

This paper presents the summary of the activities related to data collection on the operating experiences gained in the Joint European Torus (JET) for the Vacuum and Active Gas Handling Systems and in the Tritium Laboratory of Karlsruhe (TLK). Failures/malfunctions, including information on failure modes and, where possible, causes and consequences of the failures, have been identified, as well as, whole sets of components, which the failures/malfunctions are related to. Reference components installed in the plant/facility have been classified and counted in order to find out their amount, related operating hours and/or related demands to operate. Main reliability parameters, (such as the failure rate and the corresponding standard errors and confidence intervals), associated to the components have been estimated.

1. INTRODUCTION

Availability and reliability analyses will play a role in design and operation/maintenance of future fusion machines like the International Thermonuclear Experimental reactor (ITER) and commercial power plants, particularly, in demonstrating safety characteristics and in setting minimal downtime. So far, the ENEA-Euratom Association was committed to perform a collection of data related to fusion system operating experiences on component failure, in the frame of the JET Fusion Technology tasks. Data collection and analysis presented in this paper is related to Vacuum and Tritium Systems of the Joint European Torus (JET) and to facilities of the Tritium Laboratory of Karshrue (TLK). Details of the work are given in Reference [1].

2. APPLIED METHODOLOGY

For the type of work here proposed, historical failure data are usually searched in a number of sources specific to the plant, including: operation records, incident investigation reports, maintenance and repair records/database, plant personnel interview.

Once the picture on failed component is defined, to perform a correct statistic analysis on component failures the second step of the activity is to point out the complete “reference set” of components of which the faulted components are a sub-set. Operating life, for components in continuous operation, and/or operating demands, for component in intermittent operations, have to be determined, as well as components have to be classified according a fixed nomenclature. Process and instrumentation diagrams (P&ID), design documents and drawings have to be processed.

For component failed during operation, statistical data, such as failure rate λ, standard error s.e.(λ), and lower λ_L and upper λ_U limits of the 90% confidence interval, have been calculated assuming the Constant Failure Rate Model, U.S.N.R.C. [2]. As a sample, λ is evaluated applying the point estimate model (Poisson or exponential models) through the number of observed failures N, over time T of component operating experience, i.e.: by the formula $\lambda = N/T$.

For component operating on demand, failure probability on demands p_D have been determined on the base of the estimated amount of†“calls in operation” (demands), considering the binomial model [2]. The related standard error s.e.(p_D), and the lower p_{DL} and upper p_{DU} limits of the 90% confidence interval, have been calculated, too.

Collecting data, also information on causes of the failures/malfunctions and on related consequences and maintenance actions were searched. The statistical analysis was then supplemented with the founded out practical information on the operating experience gained.

2. JET DATA

JET started operation in 1983, the main tritium campaign was in 1997. In 1991 and then recently, in 2003, a D-T trace experiments were done, so significant amount of tritium have been introduced in AGHS.

The JET facility includes several systems identifiable by a functional or a hardware point of view. The Active Gas Handling System (AGHS) and the Vacuum System (VS) were chosen to start data collection on component failures, on the basis of operative experience.

2.1. JET AGHS DATA COLLECTION AND ANALYSIS

Information provided by the JET AGHS staff and the analysis of P&ID related to the different AGH sub-systems made possible to classify 6259 single AGHS components, operating for a total time of about 1.57 10^6 hours.

Historical failure data have been obtained from AGH log-books (hand-written). 130 failures/malfunctions have been pointed out since 1995 up to January 2002. Generally speaking, the overall of them do not effect on operations.

The largest number of failures/malfunctions (52) concerned “fail to open/close” and “external leaks” of small air actuated and solenoid valves, which were easily replaced. The aging of these valves required after 6 years of operation the starting of a dedicated preventative maintenance program.

Important in terms of amount of malfunctions were also “Erratic/No Output” of instrumentation and electronic components due to falures of different components, such as indicators, filaments of Catherometer, amplifier, thermocouples, sensors, switches, probe and transducers, control units. Particularly, to avoid one of the possible causes of the latter component failures, a dedicated preventative maintenance program started after 2 years of operation to replace every 12 months cooling fans of electrical boards.

Three of the five large Normetex vacuum pumps (capacity: 150 $m^3/h \div 600$ m^3/h), installed in the plant, stopped and then they were removed, respectively after about 29000, 22000 and 24000 hours of operating life. The failures were induced by the build up of debris inside the pump, probably due to corrosion.

Other failures concerned: metal bellow, rotary vane and turbo-molecular vacuum pumps; blowers; small peristaltic pumps; no-return and pressure regulator valves; oil pumps; Power Supply system.
Table 1 summarises the most significant failure rate values obtained for AGHS components and Table 2 the failure probability on demand values.

2.2. JET vs DATA COLLECTION AND ANALYSIS

Information on the “reference set” of data (i.e.: type and number of different components and their operating life) of the various sub-systems installed on VV ports (e.g.: diagnostics, plasma heating systems, pumping systems, in-viewing inspections, cooling lines, etc.) have been determined by an assessment of drawings stored in the JET archive and CATIA drawing database. In defining the “reference set” of components a detailed component breakdown has been set-up to classify the single components with a high level of definition: where possible, size ranges and shapes have been defined. A total of 4012 VS components has been identified.

The operation periods of VS components have been evaluated on the base of time in which the torus has been under vacuum, i.e.: during plasma commissioning, tokamak operations and pulse discharge cleaning phases. Such periods have been defined on the basis of JET Annual Reports, data provided by the JET Operator (e.g.: data sheet of pulses, VV wall temperatures) and staff interviews. A total of about 97700 hours of vacuum operation from March 1983 up to January 2002 has been estimated with a total operating time of the reference set of components of about 249 10^6 hours.

Data on leaks occurring in JET vacuum system are recorded by JET Operator in a dedicated database [3]. About 600 leaks have been detected and relative information recorded since 1983 up to January 2002. About half of them have been detected after vacuum intervention and after planned shutdowns, when the JET machine is leak tested. This leaks have been classified in the database as “Installation leaks”. The remaining 300 leaks occurred during operation activities and, they have been classified as “Operational leaks”. Further distinction has been used for these latter leaks:

a) *critical leaks* for the leaks that result in machine operation stop (about 90 leaks) and

b) *not-critical leaks*

for the leaks that result in no machine operation stop, either because the leaks were small and not interfering with the experimental program or, because it was possible to repair during operations the failed components, or it was possible to isolate the leaked component and repair it at the following shutdown.

Some information on operating experience has to be highlighted:

- Bellow leaks were mainly due to fatigue for excessive vibrations, differential expansion of bellows (stresses overcoming ultimate strength of material in limit sections) and defects in machined components. Double bellows and, where possible, enclosing of bellows in metal braiding reduce problems.
- Flanges gave problems after installation of the components (first installation or maintenance) mainly due to damage on sealing surfaces, O’ ring damage, debris through sealing surfaces. Operating leaks were probably due to uneven heating of flanges or uneven stresses on the sealing surfaces.
- Some leaks in electrical feedthroughs were caused by electrical discharge in guard vacuum volumes when the pressure ranged between 10 to 10^{-2} mbar; the use of noble gas or the use of a pressure below 10^{-5} mbar avoided such problems.

- Strong magnetic fields and “gauges left switched on at atmospheric pressure” were the causes for Penning gauges damages.
- Valves had the largest amount of problems due to debris lodged in the seat both during the venting (for valves in the vent lines) and during the vacuum vessel pump-down; the use of particle filters just upstream of valves reduced such problems.
- Water leaks inside the vessel, deposited on hot windows, caused several cracks in the windows for the thermal stress or for the attack of the demineralised water to the aluminium bonding. The use of gold seals avoided the water attack but increased leaks during the venting and pumping of the machine.

Table 3 summarises the most significant failure rate values for failures of VS components.

3. TLK DATA

The Tritium Laboratory Karlsruhe (TLK) is an approx. 3000 m^2 large research installation of the Research Center Karlsruhe presently committed exclusively to the needs of the ITER. The information on type of relevant component (about 600) of the TLK have been provided by the plant operation staff. 52 failures/malfunctions occurred in the facilities of the tritium laboratory have been classified. Even if at a reduced scale respect to JET data, operating data on some components could be considered of certain interest for statistical evaluation, i.e.: data for Automatic valves, Catalysts with heaters, Coolers, Electronic frequency converters, Molecular sieve beds, Permeators, Siemens gas ring blowers. Some estimated failure rates for generic or specified failure modes are summarized in Table 4.

CONCLUSIONS

Basing on 130 failures related to a set of 6259 components, about 50 different failure rate values were determined for the JET AGHS. While, on the basis of 600 failures related to a set of 4012 components were evaluated about 80 failure rate values for JET VS.

52 failures on a set of 584 components were pointed out for TLK. Even if at a reduced scale respect to JET data, about 20 failure rate values can be considered of certain interest for statistical evaluation.

The overall failure rates have been evaluated both in mean values and in uncertainty values. Component failure rates obtained by this study are in very good agreement with the corresponding ones existing in literature for similar applications (e.g.: nuclear power plants). It has to be highlighted that the present set of reliability data is one of the most consistent evaluated in the field of fusion facilities, both for the amount of components treated and for the total operating hours. The data here reported could be very useful to evaluate reliability parameters in support of safety assessment and for availability analyses of fusion machines.

The evaluated data useful for reliability, availability and safety assessment have been recorded on the “Fusion Component Failure Rate Database”, T. Pinna [4].

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Component	**Failure mode**	**Failure rate(1/h)**
Amplifier	Erratic/No Output	1.2E-06
Blower	Blower stop	2.2E-05
Catherometer	Erratic/No Output	9.6E-06
Control Unit	Erratic/No Output	3.6E-06
Controller	Erratic/No Output	1.1E-06
Fan of electrical board	Fan stop	1.7E-05
Filter	Blocked	3.1E-06
Heater	Loss of power	4.5E-07
Indicator	Erratic/No Output	9.8E-07
Ionization Chamber	Erratic/No Output	8.8E-07
Oil circulation pump	Pump stop	1.2E-05
Peristaltic Pump	Pump stop	1.7E-05
Site Power Supply (from national grid)	Loss of power	3.5E-05
Site Power Supply (from national grid)	Overvoltage	1.7E-05
Switch	Erratic/No Output	9.7E-08
Thermocouple	Erratic/No Output	4.0E-07
Thermoresistance	Erratic/No Output	9.5E-07
Transducer	Erratic/No Output	4.3E-07
Transformer (High Voltage)	Fail to operate	2.9E-06
Uninteruptable Power Supply	Loss of redundancy	1.7E-05
Vacuum Pump	External leak	1.1E-06
Vacuum Pump	Fail to start	5.3E-06
Vacuum Pump	Pump stop	6.4E-06
Valve	External leak	6.9E-07
Valve	Fail to open/close	3.2E-07
Valve	Internal Leak	1.9E-08
Valve - Pressure control	Fail to operate	1.8E-05
Valve - Pressure Regulator	Diaphragm rupture	1.6E-06

Table 1 – JET AGHS component failure rates

Component	Failure mode	p_D
Vacuum	Pump Fail to start	1.7E-05
Valve	Fail to open/close	3.2E-07

Table 2 – Failure probability on demands for JET AGHS components

Component	Failure mode	Failure rate (1/h)
Bellows	Leak	1.9E-6
Bellows	Water Leak	1.4E-6
Bellows	Generic leak	4.4E-7
Burst Disks	Leak	5.3E-6
F/T Cryolines	Leak	5.3E-6
F/T Electrical	Leak	2.0E-6
F/T Gas lines	Leak	1.8E-6
F/T Liquid lines	Leak	1.4E-6
F/T Liquid lines	Water Leak	8.6E-7
Generic F/Ts	Generic Leak	1.7E-6
Vacuum Gauges	Leak	2.9E-6
Cefilac (DNnnn)	Leak	4.2E-7
Bolted Flanges (RHnnn)	Leak	9.5E-7
Flanges (to be Remote Handled)	Leak	6.3E-7
Commercial flanges and fittings	Leak	4.5E-7
Generic Flanges & Fittings	Leak	5.8E-7
Vacuum valves	Fail to operate	1.1E-7
Vacuum valves	External Leak	7.5E-7
Vacuum valves	Internal Leak	5.3E-6
Vacuum valves	Generic Failure	6.1E-6
Vacuum pumps	Leak	3.2E-7
Butt Welds	Leak	2.4E-8
Fillet Welds	Leak	3.6E-7
Lip Welds	Leak	4.3E-7
Welds	Leak	2.8E-7
Windows	Leak	2.4E-6
Windows	Rupture	9.9E-7
Windows	Leak/Rupture	3.4E-6

Table 3 – Failure rates for JET VS components inducing operational leaks in the torus

Component	Failure mode	Failure rate (1/h)
Automatic valves	Generic leak	2.08E-5
Catalysts with heaters	Heater failure	7.18E-7
Coolers	Loss of coolant	6.21E-6
Electronic frequency converters	Generic failure	7.81E-6
Molecular sieve beds	Generic failure	3.56E-7
Permeators	Heater failure	2.22E-5
Siemens gas ring blowers	Generic failure	6.51E-7

Table 4 –Relevant failure rates from TLK components