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RELIABILITY OF HELIUM REFRIGERATION SYSTEMS FOR THE TRISTAN DETECTOR MAGNETS

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The He refrigeration systems for the TRISTAN detector magnets were constructed for cooling the superconducting solenoid magnets that are used in high energy particle physics experiments at the TRISTAN e^+e^- collider. Three superconducting magnets and the He refrigeration systems (VENUS, TOPAZ and AMY) are situated at different locations around the 1 km diameter TRISTAN ring. Test operations of the He refrigeration system and magnetic field measurements were carried out between 1985 and 1986. The TRISTAN physics experiments started at the end of 1986 and ended in May 1995. By the end of May 1995, the total cumulative operation hours reached 137,000 hrs. The failures during this long running period were analyzed and the reliability of He refrigeration systems was examined. The result of analysis: MTBF 909 hrs and MTTR 7.1 hrs. The calculated availability was 0.992 by using these values. This shows that the He refrigeration systems had a very high reliability.

INTRODUCTION

The detector magnets for electron-positron collider experiments had been installed for carrying out high energy particle physics experiments at 3 out of 4 collider experiment sites of TRISTAN electron-positron collider in KEK. Incorporating in the detectors large solenoid superconducting magnets for determination of the momentum of particles, helium refrigeration systems were set up with each of the detectors. The TRISTAN physics experiments ended in May 1995. From 1985 to May 1995, the cumulative hours of operation reached 137,000 hours (VENUS 49,000 hrs., TOPAZ 46,000 hrs., and AMY 42,000 hrs.). The failures during this long period have been analyzed and their reliability has been examined. For future improvement of the reliability of the helium refrigeration systems, the method of verifying reliability is described.

OUTLINE OF THE REFRIGERATION SYSTEM, OPERATIONAL RECORDS AND FAILURE DATA

Three refrigeration systems (VENUS, TOPAZ, AMY)[1-3] are used for cooling the superconducting magnets. The He refrigeration systems are designed such that they can be operated remotely from a central control station. Specifications of refrigeration systems are shown in Table 1.

The important features commonly shared by the three refrigeration systems are as follows:

(1) Claude cycle is used as refrigeration cycle with refrigeration capacity of 300~500W at 4.4 K. (2) Oil injection type screw compressor and gas-bearing expansion turbine of the rotating type are used for reliable continuous operation over a long period. (3) Medium pressure purification (pressure 1.6 MPa) is used.

For cooling of superconducting magnets, both VENUS and TOPAZ, 2-phase forced flow cooling and for AMY, pool boiling cooling is adopted.

Fig. 1 shows cumulative hours of operation attained by the three systems over a period of 10 years till May 1995. Each system operated roughly 42,000 ~ 49,000 hours. The figure shows test operation and operation conducted for measurement of magnetic field of the superconducting magnet till 1986 and continuous operation for 3 ~ 6 months since 1987 for TRISTAN physics runs.

Table 1 Main specifications of He refrigeration systems for the TRISTAN detector magnets

	VENUS	TOPAZ	AMY
	Refrigeration system	Refrigeration system	Refrigeration system
Cold box : Refrigeration	500 W at 4.2 K	300 W at 4.4 K	300 W at 4.4 K
Compressor : Flow rate	2300 Nm ³ /hr	1800 Nm ³ /hr	1500 Nm ³ /hr
Control dewar :			
LHe Storage capacity	1000 l	800 l	2400 l (Dewar)
Magnet : Cold mass	4.3 ton (Al)	4.5 ton (Al)	17 ton (Cu,SUS)
Thermal load	40 W + 17 l/hr	30 W + 17 l/hr	35 W + 25 l/hr
Cool down time	14 days	5 days	6 days

Table 2 Summary of the He refrigeration system failures

Origin of failures	Numbers of failure	Origin of failures	Numbers of failure
A) Utility	34 (12)	C) Impurities	19
Cooling water line	19 (3)		
Electric power line	15 (9)	D) Operation failure	15
B) Equipment	84		
Compressor	25	E) Construction work failure	9 (2)
Cold box	12		
Control device	7	F) Others	8
Monitor	23		
(flow meter, thermometer, etc.)			
Machine element	17		
(operated valve, check valve, etc.)			
Total failure times (Mar. '85 ~ May. '95)			169 (14)
() : Numbers of inevitable failure			

Table 2 shows number of failures of the systems during each period of operation. The failure data have been arranged according to the date of failure, nature of failure, causes, solution and repair times. Cumulative number of failures is 169, of which 114 failures (67 %) relate to the refrigerator system, 17 failures (10 %) to superconducting magnet system and 38 (23 %) to utility services. Table shows the failures arranged according to their origin in which as many as 50 % failures originated from the equipment followed by utility services and impurities. The failures also include those caused by external factors and 14 inevitable failures (failures due to power shut down in the power supply system and others which are uncontrollable within operation and maintenance management limits). For the above reasons, the following analysis is restricted to the failures of 155 cases of the refrigeration system with the exclusion of failures due to inevitable causes. The purpose is to evaluate true reliability of the refrigeration systems on the basis of the observations noted below.

RELIABILITY ANALYSIS OF THE REFRIGERATION SYSTEMS

Based on the data on the refrigeration system failures, evaluation of the reliability is conducted. The reliability of the refrigeration systems provided with repair techniques is evaluated in terms of mean time between failures (MTBF) and mean time to repair (MTTR) by calculating working rate and availability (A). Computation of MTBF, MTTR and A, based on the results of refrigeration system analysis have been described below.

MTBF (Mean Time Between Failures)

Fig. 2 shows the relationship between failure occurrence rate (failure rate) and cumulative operation hours. It becomes apparent from the failure rate change pattern in figure that the failure rate undergoes significant decrease from the start of test operation up to the cumulative operation hours of 15,000 hrs. The period during which this decreasing failure rate (DFR) occurs is called early failure period. [4]

Due to some variations occurring since the cumulative operation hours of 15,000 hrs, the failure rate becomes nearly constant and the period of this constant failure rate (CFR) is called random failure period. Mean failure rate during this random failure period is $\lambda = 1.1 \times 10^{-3}$ /hr. Since the following equation is valid for MTBF in CFR form, MTBF of the refrigeration systems will amount to 909 hours.

$$MTBF = \frac{1}{\lambda} \quad \text{where} \quad \lambda = \frac{\text{Random failure Number}}{\text{Cumulative operation Time}}$$

Decrease of failure rate occurring during early failure period, i.e., the reliability growth can be evaluated with the help of reliability growth test technique [5]. Applying the concept of reliability growth test, Duane [6] of G. E. Co. plotted on bi-logarithmic co-ordinates, the relationship between failure rate and test period at the start of operation of the engine, generator, fluid machines, etc. and formulated a quantitative relationship assuming almost a linear expression. This can be expressed as follows:

$$\text{Cumulative MTBF} = \frac{T^\alpha}{K}$$

Where, T represents cumulative test period (cumulative operation period), α , growth rate and K a constant. Duane found reliability growth rate inadequate when α is 0.1 ~ 0.2. Taking strong correction measures when α is 0.6 ~ 0.7, a standard was found at 0.5. Following the above test method, the present data on failures are presented as reliability growth rate curve of the relationship between cumulative operation hours and cumulative MTBF in Fig. 3. Calculating strong linearity of the logarithmic relationship at $\alpha = 0.65$, it may be shown that suitable repair of failures and effective maintenance management of improvements can be carried out.

MTTR (Mean Time To Repair)

The repair time includes time for thorough examination of the causes of failure and the time for executing remedial measures and restoration of the system operation. For example, restoration time includes completion of re-excitation in failures occurring during excitation of superconducting magnet and re-cooling operation in the refrigeration mechanism failure during cooling of the magnet. Fig. 4 shows the relationship between repair time (shown as mean time) and cumulative operation hours during every operation period. Considering repair time from the figures as random time since the cumulative operation hours of 31,000 hrs, its mean repair rate is calculated as $\mu = 0.14$ /hr. Further, the following equation holds when the repair time becomes random.

$$MTTR = \frac{1}{\mu} \quad \text{where} \quad \mu = \frac{\text{Total Number of Repair}}{\text{Cumulative Repair Time}}$$

MTTR of the refrigeration system can be evaluated at 7.1 hours.

Availability

Availability of refrigeration system (A) is obtained by the following equation:

$$A = \frac{MTBF}{MTBF + MTTR}$$

Applying the values of MTBF and MTTR obtained in the previous section, $A = 0.992$. This high availability shows that there would be practically no failures during the latter half period of continuous operation conducted for TRISTAN physics experiments.

SUMMARY

Failures during long period of operation were analyzed to examine the characteristics of reliability of the TRISTAN refrigeration system and its availability. The results of the analysis of the refrigeration systems are summarized below.

- (1) Although these refrigeration systems (having the same maintenance and operation management) are different from each other, they may be treated as similar refrigeration systems so far as reliability is concerned. Failures are classified into early failure period (when reliability shows constant growth rate) and random failure period (constant failure rate).
- (2) An early failure period of the refrigeration systems amounts to nearly 5,000 hours (i.e., 15,000 cumulative hours of operation of the three systems put together). Refrigeration systems equipped with repair systems such as the present ones provide reliability growth during early failure period. The refrigeration systems have a high growth rate of 0.65.
- (3) The availability of the refrigeration systems during random failure period is calculated at 99.2% on the basis of MTBF (909 hours) and MTTR (7.1 hours) of the same period. The achievement of such high availability is a result of using rotating type compressors, expansion turbines and intermediate pressure method for purification, as well as appropriate maintenance management. The availability level of these helium

refrigeration systems is considered higher than that of other refrigeration systems now working in Japan.

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Figure 1 Operation hours of He refrigeration systems

Figure 3 Reliability growth curve

Figure 2 Failure rate of the He refrigeration systems

Figure 4 Repair times during every operation period

REFERENCES

1. Arai, R., Araoka, O., Doi, Y., Haruyama, T., Ishihara, N. et al., Test operations of the VENUS superconducting magnet at KEK Nucl. Instrum. Methods A.254 (1987) 317
2. Doi, Y., Mito, T., Haruyama, et al., Cryogenic system of the TOPAZ thin superconducting solenoid Proc. of ICEC 11 (1986) 424
3. Doi, Y., Haruyama, T., Mito, T., Tsuchiya, et al., Cryogenic system of a 3 tesla superconducting solenoid for the AMY particle detector at TRISTAN Adv. Cryog. Eng. 33 (1987) 551
4. Shiomi, H., Reliability and Maintenance Concepts and their Advancement, Gijutsu Hyoronsha, Tokyo (1985) 52
5. MIL-STD-1635 Reliability Growth Testing (1978)
6. Duane, J. T. IEEE Trans. Aerosp. 24-2 (1964) 563