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Safety Analysis of Magnet Diagnostic System Based on FMEA and AHP

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1. Introduction

The superconducting magnet system is an essential subsystem of the magnetic confinement fusion device. Central Solenoid Coil is a part of the CFETR magnet system. The CSMC is a technical verification before the future full-size CS Coil. After the superconducting magnet manufacturing procedure completed, a performance test is required to ensure that the magnet performance meets the requirements. The large superconducting magnet testing platform provides a testing environment for the magnets and simulates their actual operating conditions, to test the performance of the magnet. The functions of the magnet diagnosis system are monitoring the temperature, pressure, mass flow rate and other parameters of the magnet during operation, storing and publishing data, also providing data for the analysis of experimental results. In order to find out potential failure mode to improve the robustness of the system, as well as set an example for other subsystems, FMEA and AHP were applied. FMEA helps us to analyze system components and identify potential failure modes of components, while AHP helps us with fault rating. Usually, FMEA uses Risk Priority Number (RPN) as the basis for fault rating, but RPN relies too much on expert analysis and needs enough samples to conduct Occurrence Severity Detection (OSD) marking, therefor, AHP are introduced to solve the problem.

Analytic Hierarchy Process (AHP), as a single factor safety evaluation method combining qualitative and quantitative analysis, has been used in many fields of safety and environmental science. AHP can effectively transform complex system problems into hierarchical ranking computing problems.

FMEA relies on sample capacity and expert analysis. Insufficient sample capacity would make RNP too subjective. Because of CSMC testing platform does not own enough failure history, so it is not quite suitable to use FMEA analysis directly. FMEA is a comprehensive risk evaluation method, while AHP is a single factor evaluation method. Therefore, we use FMEA to find potential failure mode, then use AHP to analysis each OSD level of each failure mode, to get hierarchical ranking of each risk. Finally, FMEA will be carried out for comprehensive system risk analysis.

2. System Description

The functions of the magnet diagnosis system are monitoring the temperature, pressure, mass flow rate and other parameters of the magnet during operation, storing and publishing data, also providing data for the analysis of experimental results. CSMC magnet diagnostic system is a modular and hierarchical system. It also follows the flexible design idea, which allows users to add, delete, edit channel and apparatus configuration during the operation. The communication protocol of the system is EPICS CA protocol, which makes the system has good extensibility. The MDS working principle is shown in Fig. 1.

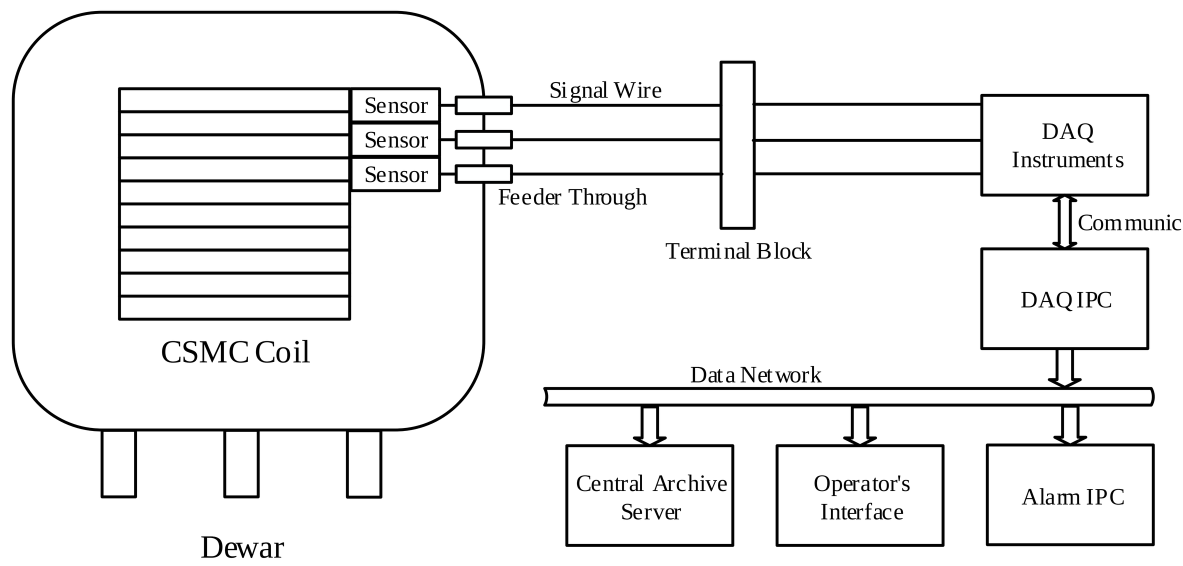

Fig.1. Magnet Diagnostic System

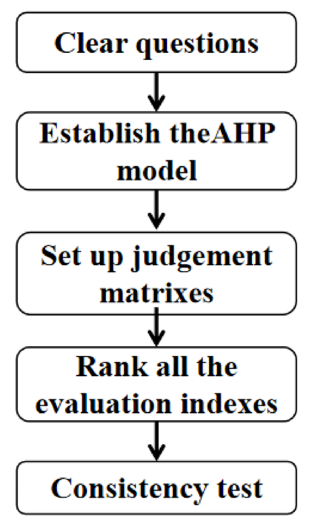

Fig.2. AHP Process

3. FMEA RESULT

Any failure that occurs when one or more intended functions no longer fulfills the requirements used as the evaluation criterion. Although during design status, a lot of optimizing measures have been taken to enhance the stability of system. However, potential failure may still happen. In order to find out the potential failure mode of system, FMEA has been introduced to find out each potential risk of a single device or component. FMEA is one of the important analysis methods in safety system engineering. It was developed through reliability engineering. It mainly analyzes the reliability and safety of the system and products. FMEA is based on system segmentation, to divide the system into several subsystems or components according to needs, then to analyze potential fault types and fault influence to the whole system. Traditional FMEA measures risk using the Risk Priority Number (RPN). RPN is a product of 3 indices: Occurrence (O), Severity (S), and Detection(D).Occurrence is defined as how frequently the specific failure cause is projected to occur and result in the "failure mode". Severity is typically defined as an assessment of the seriousness of the potential "end effects," and is assessed independently of the causes. The most common interpretation of detection is an assessment of the ability of the "design controls" to identify a potential cause or design weakness before the component, subsystem or system is released for production. RPN represents the degree of risk of the failure mode, the higher the RPN coefficient is, the more dangerous the corresponding fault mode is. Failure Modes and Effects Analysis (FMEA) is a tool widely used in the automotive, aerospace, and electronics industries to identify, prioritize, and eliminate known potential failures, problems, and errors from systems under designs before the product is released.

3. AHP RESULT

Analytic Hierarchy Process (AHP), as a comprehensive safety evaluation method combining qualitative and quantitative analysis, has been used in many fields of safety and environmental science. AHP can effectively transform complex system problems into hierarchical ranking computing problems. The operation procedure of AHP is shown in Figure 2. Due to the limited space, AHP won't describe here, only result will shown in the following table.

Table.1. FMEA Result

Component	Potential failure mode	Cause of Failure	Effect of Failure	Occurrence	Severity	Detection	RPN	Actions Recommended to Reduce RPN
Sensor	Solder joints fall off	Insufficient solder	No validate signal from a sensor	5	3	2	30	Keep the solder joint flat and smooth pull hard after welding to check the welding strength
	Sensor lead broke	Over strain on the lead	No validate signal from a sensor	3	3	2	18	Twine the lead before welding, and keep the solder joint flat and smooth.
	Sensor fall off from the sample surface	Disqualifies adhesive	Sensor value did not change with the physical parameter	3	3	4	36	Use glue that works well at low temperatures
	Sensor is Crushed	Improper installation	The sensor data are inaccurate	2	3	3	18	Minimize the placement of sensors in metal joints, and use sensor tooling where the strength of sensors is required
	Overvoltage or current	Sensor overexcitation current or voltage	No validate signal from a sensor	2	2	2	8	Use high precision digital source meter for power supply
Signal wire	Short circuit	Wire insulation damage	Sensor value become zero or extremely low	3	3	2	18	Signal wire insulated with teflon or polyimide
	Solder joints fall off	Wire break off	Sensor value become zero or extremely high	3	3	2	18	Keep the solder joint flat and smooth pull hard after welding to check the welding strength
	Breakage on wire	Scratches by sharp objects	No validate signal from a sensor	2	3	3	18	Arrange leads as far away from mechanical components as possible
	Miss wired	negligence of staff	Sensor value is strange or clearly not in line with real value	4	4	5	80	Be careful during installation and double-check the lead number after installation
Feeder through	Leak	Feeder through leak due to bad quality	The vacuum level cannot be maintained	3	6	4	72	Vacuum leak check before use of feeder through
	Pin to pin short	Improper installation	Sensor value become zero or extremely low	3	3	2	18	Use silicone sleeve to insulate the pins of feeder through
Terminal blocks	Open circuit	The screw or the clamp is not tightened	No validate signal from a sensor	3	3	2	18	After the lead is installed, use a multi-meter to measure whether the circuit is open or not
	Channel to channel short	Destruction of insulation	One or more sensor value is invalid	3	3	2	18	Use good quality terminals and test channels with a multi-meter after installation
DAQ equipment	Instrument crashes	Improper parameter from the controller	The computer can't get data from instrument, loss of data	4	5	2	40	Minimize the use of digital multimeters and instruments with mechanical switches, and use integrated instruments based on PCI or PXI
	Power down	The power plug is not properly fastened	The computer can't get data from instrument, loss of data	3	5	2	30	Check the power supply circuit regularly and use UPS to prevent power failure
	Apparatus overheat	Poor heat dissipation	The measurement data is not accurate, instruments may break down	3	3	3	27	Keep the heat dissipation channel open and monitor the temperature of the instrument
	Overcurrent or over voltage	Improper choose of apparatus	Apparatus broke, data will be lost	2	6	3	36	For dangerous signals such as joint and magnet terminal voltage, signal isolation amplifier is used
Computer	Program crashes	Program bug or memory overflow	All recent data lost	3	6	2	36	Conduct long term stability test and pressure test on the program
	Network cable lose	Network cable didn't well connected	Can't update data to the internet, other subsystems can't get fresh data	3	5	3	45	Make periodic inspection and use a high-quality network cable
	Power failure	The power supply is damaged	System crushed, all recently data will be lost	3	6	2	36	Check the power supply circuit regularly and use UPS to prevent power failure

Table.2. AHP Result

Component	Potential failure mode	Occurrence	Severity	Detection
Sensor	Solder joints fall off	0.0164	0.0281	0.0321
	Sensor lead broken	0.0097	0.0281	0.0321
	Sensor fall off from the sample surface	0.0052	0.0281	0.102
	Sensor is Crushed	0.0052	0.0281	0.0606
	Sensor burn out	0.0052	0.014	0.0321
Signal wire	Short circuit	0.0054	0.0236	0.0324
	Solder joints fall off	0.0095	0.0236	0.0348
	Breakage on wire	0.0035	0.0236	0.0585
	Miss wired	0.0149	0.0709	0.1333
Feeder through	Leak	0.0056	0.0789	0.1019
	Pin to pin short	0.0111	0.0263	0.034
Terminal blocks	Open circuit	0.0111	0.0289	0.0374
	Channel to channel short	0.0056	0.0289	0.0374
DAQ equipment	Instrument halted	0.0151	0.0465	0.0256
	Power down	0.0087	0.0565	0.0148
	Apparatus overheat	0.0056	0.025	0.0477
	Over current or over voltage	0.0039	0.0865	0.0477
Computer	Program crushes	0.0083	0.01457	0.034
	Network cable loose	0.0083	0.0729	0.0679
	Power failure	0.0083	0.01457	0.034

4. RESULT AND CONCLUSION

Component	Potential failure mode	Occurrence		Severity		Detection	
		FMEA Score	AHP Rank	FMEA Score	AHP Rank	FMEA Score	AHP Rank
Sensor	Solder joints fall off	5	1	3	8	2	12
	Sensor lead broken	3	6	3	8	2	12
	Sensor fall off from the sample surface	2	10	3	8	4	2
	Sensor is Crushed	3	11	3	8	3	5
	Sensor burn out	2	11	2	12	2	12
Signal wire	Short circuit	3	9	3	11	2	11
	Solder joints fall off	3	6	3	11	2	9
	Breakage on wire	2	13	3	11	3	6
	Miss wired	4	3	4	5	5	1
Feeder through	Leak	3	8	6	3	4	3
	Pin to pin short	3	4	3	9	2	10
Terminal blocks	Open circuit	3	5	3	7	2	8
	Channel to channel short	3	9	3	7	2	8
DAQ equipment	Instrument halted	4	2	5	6	2	13
	Power down	3	7	5	6	2	14
	Apparatus overheat	3	7	3	10	3	7
	Over current or over voltage	2	12	6	2	3	7
Computer	Program crushes	3	7	6	1	2	10
	Network cable loose	3	7	5	4	3	4
	Power failure	3	7	6	1	2	10

As shown above, both FMEA and AHP are used to perform a safety analysis to MDS. Considering, each of them has it's limits. FMEA requires enough sample capacity to get precise failure rank. AHP is a single factor safety analysis method and suitable for hierarchy system, but sometime we don't have enough failure records, or the system is a horizontal system. So both methods has been performed for many times to get as reliable results as possible. These results will help us to build a reliable system and also help us to solve problems when failure occurred.