Research on Fault Diagnosis of Power Supply Control System on BEPCII

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Introduction

The reliable and stable operation of the accelerator is the premise and foundation of physics experiments.For example, in the BEPCII(The Beijing Electron-Positron Collider II), the fault of the magnet power supply front-end electronics devices may cause accelerator energy instability and even lead to beam loss. Therefore, it is very necessary to diagnose and locate the device fault accurately and rapidly, that will induce the high cost of the accelerator operation. Faults diagnosis can not only improve the safety and reliability of the equipment, but also effectively reduce the equipment's cycle costing.The multi-signal flow model [1] proposed by Pattipati K.R is considered as the preferred method of industrial equipment faults detection.

Multi - Signal Flow Graph Method

Testing model analysis firstly performs FMECA(Failure Mode, Effects and Criticism Analysis) to determine all possible fault mode of various components of the system during the designing and manufacturing process through system analysis, and the causes and effects of each fault mode. According to this, the function and structure of the UUT (Unit under Test) are divided, and the correlation graph model is established by using the available test points. Then, the first-order correlation is established, furthermore the D-matrix model (also called the diagnosis matrix or dependency matrix) is acquired. After establishing the D-matrix model, the test points can be calculated, and the diagnosis tree and the fault dictionary can be established. Then the generated diagnosis strategy can be used to predict the system's fault detection rate and fault isolation rate.

APPLICATION OF MULTI - SIGNAL MODEL IN FAULT DIAGNOSIS

Supposing the correlation matrix of the simplified multi-signal model D = [d_{ij}] ($1 \le i \le m, 1 \le j \le n$, where m and n denotes the totality of the source of failure and the set of testing respectiively), $y=\{y_1, y_2, ..., y_m\}$ is the possible set of fault sources for the system, $T=\{t_1, t_2, ..., t_n\}$ is the set of testing. The essence of fault diagnosis is to find the most likely candidate set of faults ($X \in Y$) based on the structure of multi-signal model. And it is consistent with the test results, with the formula described as:

$$\max_{X \subseteq Y} \mathrm{Prob}(X \mid T_p, T_f)$$

In the above formula, Prob() represents probability function and T_p represents success and T_f represents fault during tests.

For the sake of description, we define a vector, $x=\{x_1, x_2, \ldots, x_m\}$, if $x_i=1$,that means $y_i \in X$; if $x_i=0$, that means $y_i \notin X$. After deleting the constant term $\mathrm{Prob}(T_p,T_f)$ according to the Bayesian theory, the question turns to find the max value of the formula below:

$$\mathrm{Prob}(T_p \mid X)\mathrm{Prob}(T_f \mid X)\mathrm{Prob}(X)$$

Among them,

$$\mathrm{Prob}(X) = \prod_{i=1}^{m} p(y_i)^{x_i}(1-p(y_i))^{(1-x_i)}$$

According to [3] ,after negating the left and taking natural logarithm and then deleting the constant term, this problem can be converted to an optimal set covering problem (SCP):

$$\frac{\min}{X \subseteq Y^-}\left(\sum_{y_i \subseteq Y^-} c_i x_i\right)$$

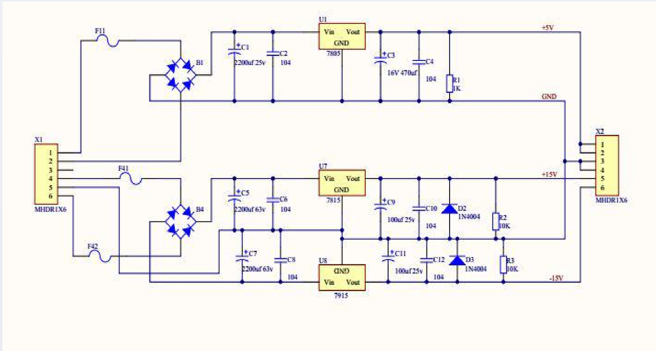
Where Y^- is the set of the source of failure which excluded the normal components. The restriction is : $D_x \ge e$, $x_i \in \{0,1\}$, i = 1, 2, …, m. D is the result matrix consisting of a series of fault sources tested. $e=[1,1,\ldots, 1]^T$. c_i represents the source of failure based on the probability of failure.

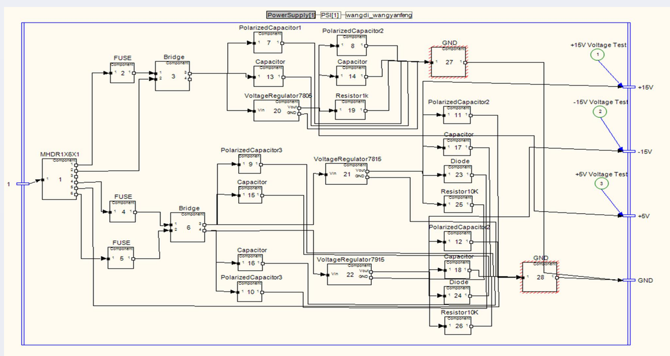
$$c_i = -\ln\left(\frac{p(y_i)}{1-p(y_i)}\right), \qquad i = 1, 2, \cdots, m$$

The optimal set covering problem is a kind of NP-hard problem, which can't acquire a complete solution in polynomial time. But we can obtain the lower bound of the SCP problem which can be generated by using the Lagrangian relaxation algorithm, and then the solution satisfying the requirements can be generated. The solution of the problem is obtained by a series of steps. The solution in detail is described in the paper [4,7] .

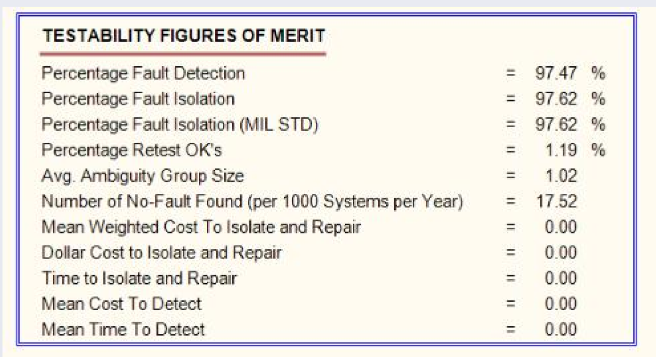
Modeling and Simulation of Magnet Power Supply Interface Equipment

There are about 400 various power supply for many types of magnets in the BEPCII accelerator storage rings, which provide a stable magnetic field for the beam. Power Supply Interface (PSI) is a key electronic device for controlling and monitoring the output and status of magnet power supply, which includes power supply, interface cards and other parts [9] . The overall model and the power supply model are showed below in Figures afte the multi-signal flow diagram of the power control system is modeled.

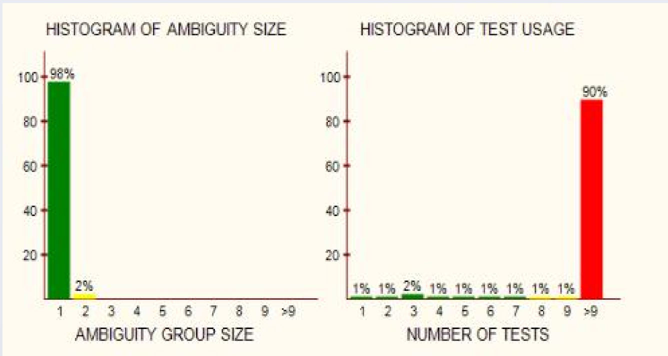




After modeling power control system for multi-signal flow diagram, the resulting model is showed in Figures below.



TESTABILITY FIGURES OF MERIT			
Percentage Fault Detection	=	97.47	%
Percentage Fault Isolation	=	97.62	%
Percentage Fault Isolation (MIL STD)	=	97.62	%
Percentage Retest OK's	=	1.19	%
Avg. Ambiguity Group Size	=	1.02	
Number of No-Fault Found (per 1000 Systems per Year)	=	17.52	
Mean Weighted Cost To Isolate and Repair	=	0.00	
Dollar Cost to Isolate and Repair	=	0.00	
Time to Isolate and Repair	=	0.00	
Mean Cost To Detect	=	0.00	
Mean Time To Detect	=	0.00	



Conclusions & Outlooks

This paper first introduces the application of the multi-signal flow method in fault diagnosis, and proposes the idea of improving the multi-signal flow diagnosis based on the fault probability of the fault mode. The confidence level of the latter is improved by modifying the probabilistic data with high confidence to the probability of the other confidence, and the multi-signal model is modified to improve the accuracy of the system's testability analysis and fault diagnosis strategy generation. At last, this method is used to the modeling and simulation of the front-end electronic devices, Power Supply Interface. It can be seen that the improved multi-signal model based on fault mode fault probability can effectively improve the testability of the system when dealing with system fault, which provides a new idea for fault diagnosis of multi-level and complex systems.

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