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Digital Processor Module Reliability Analysis of Nuclear Power Plant

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1. Introduction

The system used in plant, military equipment, satellite, etc. consists of many electronic parts as control module, which requires relatively high reliability than other commercial electronic products. Specially, Nuclear power plant related to the radiation safety requires high safety and reliability, so most parts apply to Military-Standard level.

Reliability prediction method provides the rational basis of system designs and also provides the safety significance of system operations. Thus various reliability prediction tools have been developed in recent decades, among of them, the MIL-HDBK-217 method has been widely used as a powerful tool for the prediction.

In this work, It is explained that reliability analysis work for Digital Processor Module (DPM, control module of SMART) is performed by Parts Stress Method based on MIL-HDBK-217F NOTICE2.

We are using the Relex 7.6 of Relex software corporation, because reliability analysis process requires enormous part libraries and data for failure rate calculation.

2. Design description

As application of DPM is broadly used to process the digital signal and can execute quickly sum of products operation, DPM is designed to process all signals of each system module(sub-rack) transmitted and received from Network Interface Card.

It is noted that current DPM design is under development , and therefore design and selected parts is changeable. Subsequently, DPM design may be changed to make a perfect module through the better design and parts of remarkable performance.

3. Reliability Prediction

3.1 Use of the MIL-HDBK-217F method

Generally, reliability of the control module including the electronic parts has consistent failure rate about time. Under that assumption, It can be expressed by following equation.

$$R(t) = \exp(-\lambda t) \quad (1)$$

It is known that physical characteristics, operating condition and installation environment determine the failure rate(λ) of the parts.

Reliability prediction of the control module is quantitative analysis in constituent parts to calculate the total reliability based on it. Consequently, that analysis can improve the design of related module and estimate the reliability according to the time.

There are many kinds of reliability prediction methods the same as MIL-HDBK-217F, Bellcore TR-332, NSWC-98/LE1 and RAC PRISM etc. we use the MIL-HDBK-217F(N2) among them, because parts complying with MIL-STD are attached to electronic circuit boards in nuclear power plant. we calculate the failure rate taking advantage of Parts Stress Method.

Part failure rate in Parts Stress Method is equal to follow .

$$\lambda_P = \lambda_b \pi_Q \pi_T \pi_E \pi_{oth} \quad (2)$$

λ_P = part failure rate (Failure/10e6 hours)

λ_b = base failure rate

π_Q = quality factor

π_T = temperature factor

π_E = environmental factor

π_{oth} = other factors

The general expression for module failure rate is represented as the following equation.

$$\lambda_M = \sum_{i=1}^{n} N_i (\lambda_p) i \quad (3)$$

λ_M = module failure rate

$(\lambda_P)_i$ = part failure rate for the i th specific part

N_i = quantity of the i th specific part

n = number of different specific part categories

Although Parts Counts Method to calculate the failure rate only considers inherent failure data, part quantity, quality level and operating environment, Parts Stress Method adds to much more factors. In accordance with the equation (2), Detailed information for part must be provided.

Temperature factor depend on the assumption and provided data. c_1, c_2 in other factors depend on the circuit complexity and the packing technology respectively. Other factors excluding stress factor also depends on data sheet and reliability reference provided by manufacturer. In case of the stress factor, we apply the value in MIL-HDBK-217.

3.2. Reliability calculation of DPM

In this paper, Assumption on part failure rate calculation is simply showed from below.
1) When we are calculating the failure rate, we assume the serial combination among parts.
2) MTBF is equaled to 1/Failure rate on the basis of 10e6 hours
3) Environmental factor is assumed that it's GB
(GB,-Ground Benign, Controlled)
4) Ambient temperature is 30 degrees C.
5) Quality factor is '1' that complies with MIL-STD , MIL-SPEC and operating temperature range (-55~+125 degree c). but, some parts apply the value of commercial level (including the parts that can't be replaced the military level)
6) We perform the reliability prediction except mechanical parts, construction material.

Through 1) ~ 6), applying MIL-HDBK-217F, We get the failure rate of each part in Relex.
Table 1 is part list of the DPM, The assumption(1) ~6)), table 1 and equation (2), (3) can make the failure rate. Using the equation(1), we estimate the reliability in DPM at time. Failure rate for respective parts and total failure rate for module is table 2. The result in Table 2 shows that MTBF for DPM is about 18 years. By the Figure 1, Table 3, you know that 'Memory', 'bus interface controller' and 'PLD' account for the high failure probability in order. The ratio of IC in failure rate of total module occupied 90.86%, It shows high failure rate of IC in digital module. Generally, IC is sensitive to temperature, When operating module in actual state, IC is predicted that its temperature increases in relatively much load. Much load results from software. Memory and PLD applied to commercial level because of the commercial product. But, they are made by major part manufacturer, so their quality is credible. Currently, it must be considered that even some place requiring the high quality level specification at the whole industry use and select the part of commercial level.

Part description	Category	Subcategory	Qty
DSP	IC	Microprocessor	1
PLD	IC	PAL, PLA	1
watchdog timer	IC	Linear	1
SRAM	IC	Memory	4
UVEPROM	IC	Memory	1
Bus interface controller	IC	VHSIC/VLSI CMOS	1
Transceiver	IC	Logic, CGA or ASIC	7
Inverter	IC	Logic, CGA or ASIC	1
D filp-flop	IC	Logic, CGA or ASIC	2
AND gate	IC	Logic, CGA or ASIC	2
quartz crystal1	Miscellaneous	Quartz Crystal	1
quartz crystal2	Miscellaneous	Quartz Crystal	1
dot-matrix	Semiconductor	Alphanumeric Display	1
LED	Semiconductor	Detector,Isolator, Emitter, LED Standard	2
Resistor	Resistor	RM	69
Capacitor	Capacitor	CDR	87
connector	Connection	PCB edge	1

Table1. DPM part list

No.	part type	Failure Rate, unit	Qty	Failure Rate
1	DSP	0,217492	1	0,217492
2	PLD	0,669228	1	0,669228
3	watchdog timer	0,082412	1	0,082412
4	SRAM	0,951749	4	3,806995
5	UVEPROM	0,061301	1	0,061301
6	Bus interface controller	0,835052	1	0,835052
7	Transceiver	0,008310	7	0,058173
8	Inverter	0,004152	1	0,004152
9	D filp-flop	0,004634	2	0,009269
10	AND gate	0,004152	2	0,008303
11	quartz crystal1	0,03336	1	0,03336
12	quartz crystal2	0,028849	1	0,028849
13	dot-matrix	0,001938	1	0,001938
14	LED	0,001714	2	0,003428
15	Resistor	0,003845	69	0,265305
16	Capacitor	0,002553	87	0,222103
17	connector	0,023873	1	0,023873
Module Total Failure Rate (per 10^6 hours)				6,331181E-6
MTBF[hours]				157948,4
years				18,03064

Table2. Failure rate results

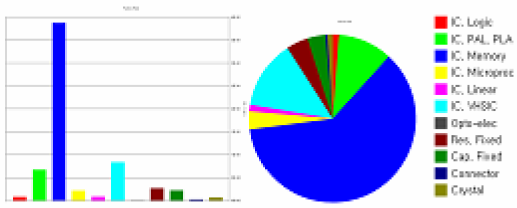

Figure 1 Failure rate according to the part category

category	Failure Rate	percentage(%)	
IC Logic	0,0798967	1,26196	IC 90,86%
IC PAL, PLA	0,669228	**10,570343**	
IC Memory	3,8683	**61,099147**	
IC Microprocessor	0,217492	3,435249	
IC Linear	0,0824121	1,301684	
IC VHSIC/VLSI CMOS	0,835052	13,189506	
Opto-elec(LED)	0,00536673	0,084771	9,14%
Resister(chip type)	0,265276	4,18999	
Capacitor(chip type)	0,222103	3,508079	
PCB Edge Connector	0,0238729	0,37707	
Crystal	0,0621852	0,982202	

Table 3. The percentage of part failure rate in module

4. Conclusion

The reliability prediction is currently recognized as an essential need in safe and economic operation of nuclear power plant. It can provide the quantitative prediction data on system safety and reliable system design. The calculation result shows that the Memory and VHSIC/VLSI CMOS are the most critical component affecting to system reliability from each 61.09%, 13.18% in module failure rate. Base on work, it is expected that the result will contribute to safe operation in nuclear power plant and improving the design of the module.

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