FAULT DIAGNOSIS OF THE APS REAL-TIME ORBIT FEEDBACK SYSTEM BASED ON FTA *

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Abstract

The Advanced Photon Source (APS) real-time orbit feedback system is complex, and faults are difficult to diagnose. This paper presents a diagnostic method based on fault tree analysis (FTA). The fault tree is created based on more than ten years of operating experience on the system. The method is described to analyze the fault tree. The operator interface to the diagnostic tool is discussed.

INTRODUCTION

The Advanced Photon Source (APS) is the foremost third-generation synchrotron light source in the western hemisphere, delivering intense x-ray to as many as 35 insertion devices and 35 bending magnet beamlines. Orbit stability is critical to achieving optimum performance for the x-ray users. The APS real-time orbit feedback system plays an important role in maintaining the orbit stability and is very complex. The orbit feedback hardware is distributed around the 1.1-km storage ring with a total of 20 slave VME crates accessing beam position monitors (BPMs) and correctors and performing orbit feedback calculations. A separate master VME crate controls the slaves and performs real-time data analysis [1]. Fast real-time data transfer between these crates is implemented through a dedicated reflective memory network. All the crates are also connected to the APS controls network for slow remote control and data monitoring.

The user interface for the real-time orbit feedback system provides some indicators on the system status, but there are no existing tools to produce a diagnostic procedure when the system fails. This paper presents a method for producing a diagnostic procedure based on fault tree analysis.

PRINCIPLE OF THE IMPLEMENTATION

Fault tree analysis is a top-down deductive analytical method to evaluate system reliability and safety. It can be qualitative or quantitative, depending on whether failure event probabilities are unknown or known. On the fault tree, fault basic components are connected through logic gates to the top event. Based on the system's fault tree and the basic components' failure probability knowledge, the system's diagnosis decision tree can be built: the Binary Decision Diagram (BDD) can be created from the fault tree; a Diagnostic Importance Factor (DIF) for each basic component can be calculated from the BDD; and the diagnostic model can be constructed by DIF ordering [2].

A BDD was introduced to represent a Boolean function as a decision graph. It is based on Shannon decomposition, which is defined in the form of an If-Then-Else (ITE) connective

$$f = ite(e, f1, f0) = ef1 + \bar{e}f0,$$

where f is a Boolean function, and e is the variable. The function f_1 is f evaluated with e=1; f_0 is f evaluated with e=0. By recursively applying the Shannon decomposition over all the variables, the Boolean function f can be graphically represented as a binary tree.

Once the BDD is constructed, two importance factors for each basic element the Marginal Importance Factor (MIF) and the DIF can be calculated according to the following equations [2,3]:

$$MIF(S,e) = p(S/e) - p(S/\bar{e}),$$
$$DIF(S,e) = p(e/S),$$

$$DIF(S,e) = \frac{p(e)p(\bar{e})MIF(S,e)}{p(S)}.$$

The MIF(S,e) is the difference in unreliability of the system S with component e failed, p(S/e) and the unreliability of the system S with component e functioning, p(S/$\bar{e}$). The DIF(S,e) measures the probability that a certain component e has failed when the system S fails [2]. The diagnosis procedure can be produced by calculating the DIFs for all basic components.

IMPLEMENTATION

Fault Tree Creation

There are a lot of commercially available tools for creating a fault tree. An open source tool, openFTA [4], was used to generate the fault tree for the APS real-time orbit feedback system. An internal database file for each fault tree is used to store basic event information. Each basic event has the following attributes: id, probability, type, and description. Middle event, basic event, and its probability were generated by more than ten years operations experience at the APS. The APS Controls group maintains a logbook in which many kinds of fault events and their occurrences, observations, actions, and guidance are recorded. The overall fault tree for the real-time orbit feedback system is shown in Figure 1.

Based on the fault tree information, a fault tree database in SDDS [5] format was generated by a Tcl script. Each

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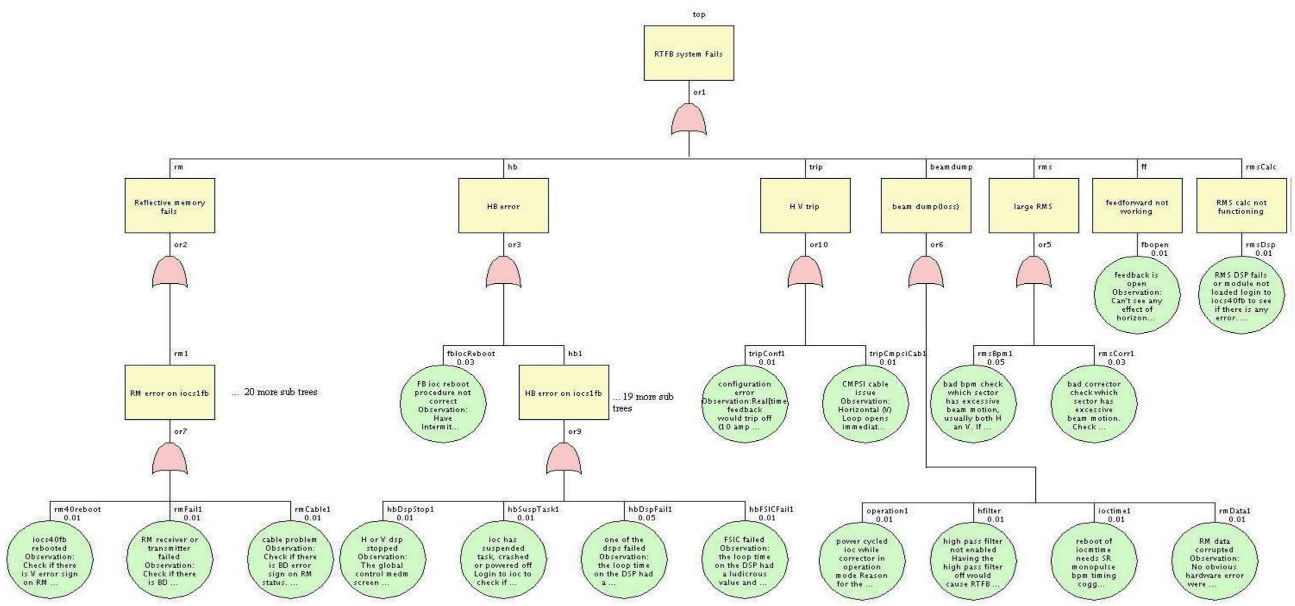

top
RTFB system Fails
or1
rm
hb
trip
beamdump
rms
ff
rmsCalc
Reflective memory fails
HB error
H V trip
beam dump(loss)
large RMS
feedforward not working
RMS calc not functioning
or2
or3
or10
or6
or5
fbopen 0.01
rmsDsp 0.01
feedback is open Observation: Can't see any effect of horizon...
RMS DSP fails or module not loaded login to iocs40fb to see if there is any error. ...
rm1
RM error on iocs1fb
... 20 more sub trees
fblocReboot 0.03
FB ioc reboot procedure not correct Observation: Have Intermit...
hb1
HB error on iocs1fb
... 19 more sub trees
tripConf1 0.01
configuration error Observation:Real[time feedback would trip off (10 amp ...
tripCmpsiCab1 0.01
CMPSI cable issue Observation: Horizontal (V) Loop opens immediat...
rmsBpm1 0.05
bad bpm check which sector has excessive beam motion, usually both H an V. If ...
rmsCorr1 0.03
bad corrector check which sector has excessive beam motion. Check ...
or7
or9
rm40reboot 0.01
iocs40fb rebooted Observation: Check if there is V error sign on RM ...
rmFail1 0.01
RM receiver or transmitter failed Observation: Check if there is BD ...
rmCable1 0.01
cable problem Observation: Check if there is BD error sign on RM status. ...
hbDspStop1 0.01
H or V dsp stopped Observation: The global control medm screen ...
hbSuspTask1 0.01
ioc has suspended task, crashed or powered off Login to ioc to check if ...
hbDspFail1 0.05
one of the dsps failed Observation: the loop time on the DSP had a ...
hbFSICFail1 0.01
FSIC failed Observation: the loop time on the DSP had a ludicrous value and ...
operation1 0.01
power cycled ioc while corrector in operation mode Reason for the ...
hfilter 0.01
high pass filter not enabled Having the high pass filter off would cause RTFB ...
ioctime1 0.01
reboot of iocmtime needs SR monopulse bpm timing cogg...
rmData1 0.01
RM data corrupted Observation: No obvious hardware error were ...

Figure 1: Fault tree for real-time orbit feedback system.

page of the database represents the elements of one subtree. The database's parameters describe the properties of the subtree. The parameters are:

- Label -- the unique label of the subtree.
- ID -- the ID of the subtree; each ID is unique and has a corresponding label.
- LogicalType -- the logical type of the subtree, either "OR" or "AND". It represents the relationship of the elements of the subtree.
- Description -- the description of the subtree.

The elements of the subtree are represented by rows and columns. The number of rows represents the number of elements in the subtree, and the columns represent the properties of each element. The columns are:

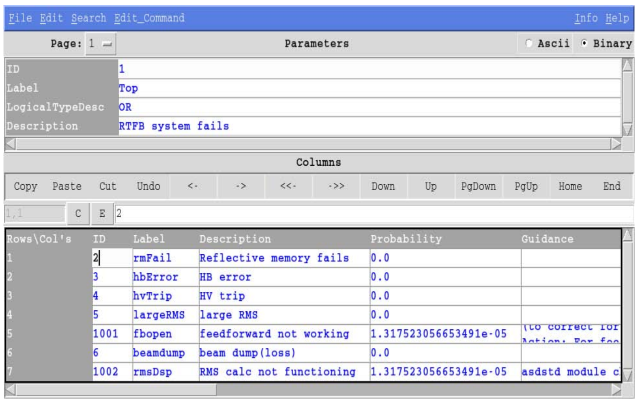
- ID -- a unique number that represents the elements. If it is greater than 1000, the element is a base element; otherwise, it is also a subtree and its properties will be shown in subsequent pages.
- Label – a unique label for the element.
- Description -- a description of the element.
- Probability -- the fault probability of the element.
- Guidance -- guidance for checking and fixing the fault elements.

The database can be edited by a Tcl/Tk tool sddsedit, as shown in Figure 2.

Algorithm Implementation

The core algorithm was implemented by a C routine convert_to_bdd(). It reads the fault tree SDDS database, converts the fault tree into BDD, and then calculates the DIF for each basic element of all failed subtrees. It can also displays the BDD map of subtrees.

The conversion from fault tree to BDD involves the recursive operation of two ITE connectives: AND and OR. The calculation of DIF involves computing MIF and system failure probability $p(S)$. These are also implemented by recursive subroutines.


File Edit Search Edit_Command
Info Help
Page: 1
Parameters
Ascii
Binary
Columns
Copy Paste Cut Undo <- -> <<- ->> Down Up PgDown PgUp Home End
1,1
C
E
2

ID	1
Label	Top
LogicalTypeDesc	OR
Description	RTFB system fails

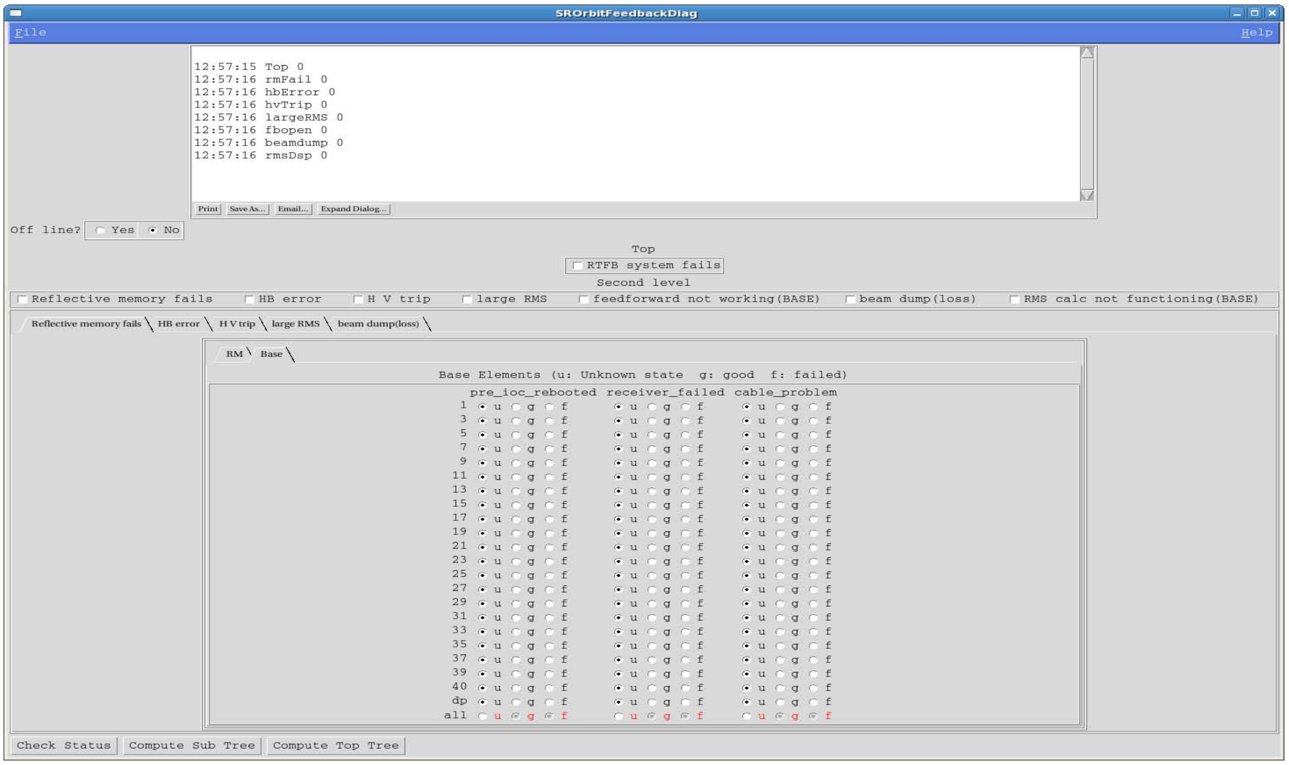
Rows\Col's	ID	Label	Description	Probability	Guidance
1	2	rmFail	Reflective memory fails	0.0	
2	3	hbError	HB error	0.0	
3	4	hvTrip	HV trip	0.0	
4	5	largeRMS	large RMS	0.0	
5	1001	fbopen	feedforward not working	1.317523056653491e-05	(to correct for Action: For foo
6	6	beamdump	beam dump(loss)	0.0	
7	1002	rmsDsp	RMS calc not functioning	1.317523056653491e-05	asdstd module c

Figure 2: Fault tree SDDS database.

The algorithm can also incorporate evidence into the DIF calculation. This means it can accept a list of parameters that shows some basic elements are known failed ($p(e)$=1) and some basic elements are known no-failure ($p(e)$=0).

User Interface

The user interface for the diagnosis of the APS storage ring real-time feedback system is shown in Figure 3. It was created in Tcl/Tk. and can display the fault tree structure including subtrees and basic elements. It can operate in two modes: online or offline. For online operation, some subtrees and basic elements have process variables (PVs) linked to the real system indicating their failure status. For offline operation, a user has to select which parts have failed, either subtrees or top tree. Once the diagnosis command is issued, the diagnosis



```
12:57:15 Top 0
12:57:16 rmFail 0
12:57:16 hbError 0
12:57:16 hvTrip 0
12:57:16 largeRMS 0
12:57:16 fbopen 0
12:57:16 beamdump 0
12:57:16 rmsDsp 0
```

Off line? Yes [✓ No]

Top

RTFB system fails

Second level

Reflective memory fails · HB error · H V trip · large RMS · feedforward not working(BASE) · beam dump(loss) · RMS calc not functioning(BASE)

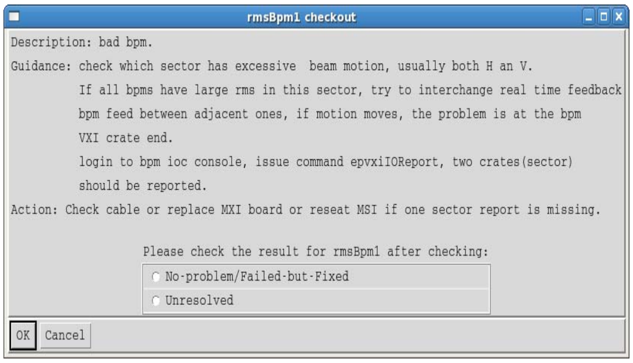
Reflective memory fails | HB error | H V trip | large RMS | beam dump(loss)

RM | Base

Base Elements (u: Unknown state g: good f: failed)

	pre_ioc_rebooted	receiver_failed	cable_problem
1	[✓ u] g f	[✓ u] g f	[✓ u] g f
3	[✓ u] g f	[✓ u] g f	[✓ u] g f
5	[✓ u] g f	[✓ u] g f	[✓ u] g f
7	[✓ u] g f	[✓ u] g f	[✓ u] g f
9	[✓ u] g f	[✓ u] g f	[✓ u] g f
11	[✓ u] g f	[✓ u] g f	[✓ u] g f
13	[✓ u] g f	[✓ u] g f	[✓ u] g f
15	[✓ u] g f	[✓ u] g f	[✓ u] g f
17	[✓ u] g f	[✓ u] g f	[✓ u] g f
19	[✓ u] g f	[✓ u] g f	[✓ u] g f
21	[✓ u] g f	[✓ u] g f	[✓ u] g f
23	[✓ u] g f	[✓ u] g f	[✓ u] g f
25	[✓ u] g f	[✓ u] g f	[✓ u] g f
27	[✓ u] g f	[✓ u] g f	[✓ u] g f
29	[✓ u] g f	[✓ u] g f	[✓ u] g f
31	[✓ u] g f	[✓ u] g f	[✓ u] g f
33	[✓ u] g f	[✓ u] g f	[✓ u] g f
35	[✓ u] g f	[✓ u] g f	[✓ u] g f
37	[✓ u] g f	[✓ u] g f	[✓ u] g f
39	[✓ u] g f	[✓ u] g f	[✓ u] g f
40	[✓ u] g f	[✓ u] g f	[✓ u] g f
dp	[✓ u] g f	[✓ u] g f	[✓ u] g f
all	u g f	u g f	u g f

Figure 3: User interface for real-time feedback system diagnostic tool.



```
Description: bad bpm.
Guidance: check which sector has excessive  beam motion, usually both H an V.
          If all bpms have large rms in this sector, try to interchange real time feedback
          bpm feed between adjacent ones, if motion moves, the problem is at the bpm
          VXI crate end.
          login to bpm ioc console, issue command epvxiIOReport, two crates(sector)
          should be reported.
Action: Check cable or replace MXI board or reseat MSI if one sector report is missing.

                   Please check the result for rmsBpm1 after checking:
                   No-problem/Failed-but-Fixed
                   Unresolved
```

Figure 4: Guidance window.

decision tree will be generated. A series of windows will pop up, one by one, showing the guidance for checking or repairing each possible failure basic element. Figure 4 shows one of the guidance windows.

SUMMARY

This paper presents a direct way to diagnose faults in the APS real-time orbit feedback system. This should help reduce the MTTR of the whole APS. The offline mode of the user interface has been tested. The online mode will be tested as time becomes available. The failure probability for each basic element of the fault tree is completely determined by past experience; this probability may need to be adjusted in the future as further experience is gained.

REFERENCES

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