An Expert System for the Fault Diagnosis of Hard Disk Drive Test System

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Abstract: Hard Disk Drive (HDD) test system is the equipment for the final test of HDD product by iterative read/write/seek test. This paper proposes an expert system for the fault diagnosis of HDD test systems. The purposed expert system is composed with two cascade inference, fuzzy logic and conventional binary logic. The fuzzy logic determines the possibility of the system fault using the test history data, then, the binary logic inferences the fault location of the test system. The proposed expert system is tested in SAMSUNG HDD product line, KUMI, KOREA, and shows satisfactory results.

Keywords: Expert System, Faults Diagnosis, Fuzzy Logic, Hard Disk Drive.

1. INTRODUCTION

Expert system is an automation technique with accumulated experience and knowledge of a human expert. It has been widely applied to various field; prediction, diagnosis, prescription, etc [1]. Since the fuzzy theory is advocated by Zadeh [2], Fuzzy Expert System (FES) that can logically process the obscure condition with fuzzy logic has been researched [3]-[10]. This leads various kinds of application of fuzzy theory to the expert system.

Choi and others established a fuzzy relation of alarm relation structure for nuclear power generation, and developed a real time FES that perform alarm processing form those fuzzy inferences [7]. Choi and others composed sagittal diagram that is based the fuzzy relation and presented FES method that diagnosis fault of power system by the sagittal diagram [8]. Lee and others set up the relation between relay and fault as fuzzy relation, present the FES method to diagnosis the fault [9]. El-Shal and Morris present a FES method to apply fuzzy to statistical process control problem of the process industry [10], and Moon presents a FES to use fault observation of the glass furnace.

This paper presents an expert system using fuzzy logic for fault diagnosis of Hard Disk Drive (HDD) test system. HDD test system is a production system that executes iterative read/write/seek test for the final product examination. The fault of a test system means the case that the system can not start the test or decides a normal HDD (defective HDD) as a defective HDD (normal HDD). When results of the HDD test are continuously defective, it is difficult whether those results are stem from the fault of the HDD test system itself or from defective HDD. The fault diagnosis of test system is executed by experienced human operators.

In this study, the diagnosis rules of human operators are collected and arranged to develop an expert system for the diagnosis of HDD test system. Then, rules are divided into a rule base to decide the fault of test system and a rule base to pursue the fault location when the fault is occurred. According to the characteristic of the rule base, the rule to decide the fault occurrence is inferred with fuzzy logic, and the rule base to decide the fault location is inferred with conventional binary logic. The proposed fuzzy expert system is coded with C-language in the personal computer environment and applied to the production line of Samsung electronics in KUMI.

2. HDD Test System

HDD test system is a system that tests the final product to Pass/Fail by iterative read/write/seek test. Figure1 shows an appearance of a HDD test system. That is a chamber that connects about 100 HDD sets and processes read/write/seek test simultaneously after feeding the HDD sets. During the test, the test system is heated gradually to realize the severe environment.

a) Front Side View b) Rear Side View

Fig. 1. Appearance of a HDD Test System .

Fig.2 shows the architecture of a HDD test system. A host PC controls 20 test boards. Each test board is a kind of a main board of personal computer. Each test board is equipped with three IDE cards and each IDE cards is connected two HDD. Therefore, a test system tests 20*6=120 HDD simultaneously. A file server saves the data occurred during test processing in the data base via the host PC. A test history file in data base includes various settings, fault history and test results of test systems, test board, IDE card and tested HDD, respectively.

Fig.3 is the architecture of a test board. Each test board is connected a power control card and three IDE cards. Each IDE card is equipped with two ports, each port performs the test of connected HDD set.

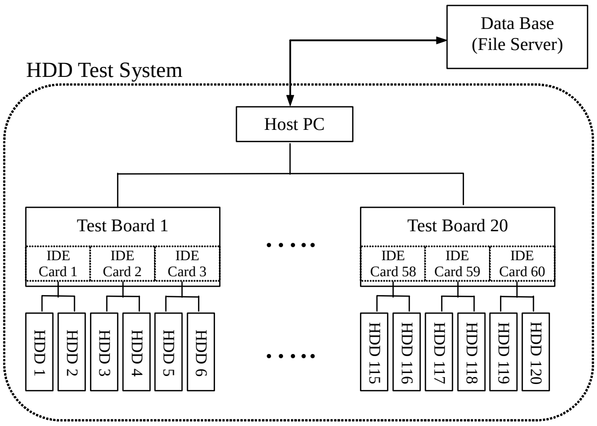


Fig. 2. Architecture of a HDD Test System

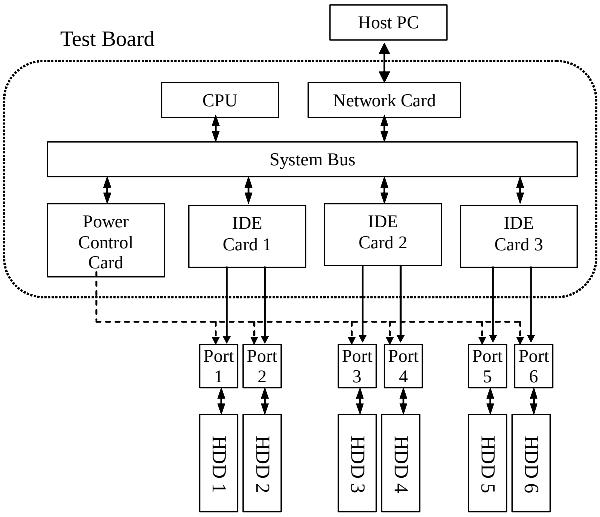


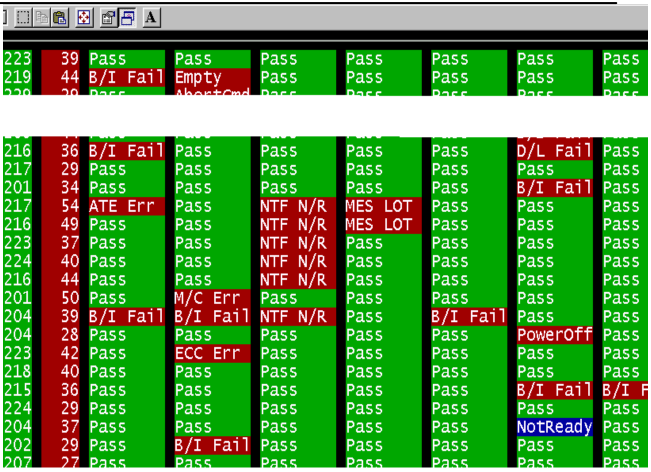
Fig. 3. Architecture of a Test Board

3. An Expert System for the Fault Diagnosis

3.1 Diagnosis Knowledge of Human Operator

The operator of the test system observes test history file of file sever regularly, decides occurrence of test system faults. Fig. 4 is an example of a test history form a server. Fig.4 shows the past 7-th test results in every port. In the Fig., the HDD passed in the test is expressed as "pass" and failed in a test is expressed as "fail". The first row shows that all HDDs are passed in the latest 7 times test in 39-th port of 223-th test system. And the second row shows that HDDs are failed at the past 6-th and 7-th test in 44-th port of 219-th test system.

If the latest results of a port shows remarkable difference from those of the past test result, a fault of the test system is suspected. When the fault is suspected**,** the fault location is confirmed via host PC by inspecting the possibility of S/W Accesses and various sensor values, such as temperature, voltage, current, etc. Then, fault component is repaired or replaced. Finally, the result of the repair is confirmed by testing a passed HDD.



223	39	Pass	Pass	Pass	Pass	Pass	Pass	Pass
219	44	B/I Fail	Empty	Pass	Pass	Pass	Pass	Pass
216	36	B/I Fail	Pass	Pass	Pass	Pass	D/L Fail	Pass
217	29	Pass	Pass	Pass	Pass	Pass	Pass	Pass
201	34	Pass	Pass	Pass	Pass	Pass	B/I Fail	Pass
217	54	ATE Err	Pass	NTF N/R	MES LOT	Pass	Pass	Pass
216	49	Pass	Pass	NTF N/R	MES LOT	Pass	Pass	Pass
223	37	Pass	Pass	NTF N/R	Pass	Pass	Pass	Pass
224	40	Pass	Pass	NTF N/R	Pass	Pass	Pass	Pass
216	44	Pass	Pass	NTF N/R	Pass	Pass	Pass	Pass
201	50	Pass	M/C Err	Pass	Pass	Pass	Pass	Pass
204	39	B/I Fail	B/I Fail	NTF N/R	Pass	B/I Fail	Pass	Pass
204	28	Pass	Pass	Pass	Pass	Pass	PowerOff	Pass
223	42	Pass	ECC Err	Pass	Pass	Pass	Pass	Pass
218	40	Pass	Pass	Pass	Pass	Pass	Pass	Pass
215	36	Pass	Pass	Pass	Pass	Pass	B/I Fail	B/I F
224	29	Pass	Pass	Pass	Pass	Pass	Pass	Pass
204	37	Pass	Pass	Pass	Pass	Pass	NotReady	Pass
202	29	Pass	B/I Fail	Pass	Pass	Pass	Pass	Pass
207	27	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Fig. 4. A HDD Test History Data

In this study, knowledge and experience of system operator are collected by interview, and those are confirmed by comparing with the history file.

The collected knowledge are divided into a rule base to decides the occurrence of fault and a rule base to pursue the fault location when the fault is occurred.

Some examples of rules to decide the occurrence of fault in a test system are as follows.

Rule 1) If the "fail" rate of the each port is high, the possibility of the test system fault is high. (1)

Rule 2) If the "fail" is occurred continuously in a port, the possibility of the test system fault is high. (2)

Rule 3) Though the "fail" rate is not high, the test system fault can be suspected by some kinds of HDD fails. (3)

In case of the fault occurrence, some rules to find the fault location are as follows.

Rule 4) If the power supply card is a fault, All HDDs of that card are not fed. (4)

Rule 5) If all HDDs of an IDE card are "fail" then, that IDE card is fault. (5)

Rule 6) If PIN connection is bad, then, it is impossible to access to registry of the HDD. (6)

3.2 Structure of the expert system

Rules 1), 2) and 3) to decide a fault occurrence include the facts such as "fail" rate of the each port, continuous occurrence, high possibility, etc, therefore, it is difficult to process them with the conventional binary logic. Rules 4), 5) and 6) are composed with facts such as feeding the HDD, "fail" of all HDDs and access of registry value etc, therefore, they can be processed clearly with binary logic according to characteristic of those rules, overall structure of the proposed expert system is drawn in Fig. 5.

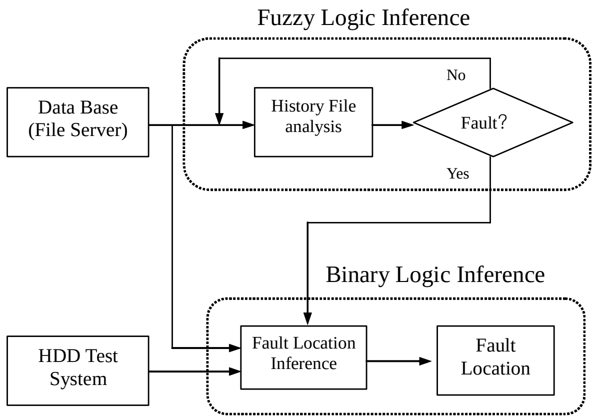


Fig 5. Overall structure of the Expert System

When HDD test of a port is finished, the fault occurrence is inferred by fuzzy logic with test history. If a fault is decided to be occurred, the test board number with fault is delivered to binary inference part and fault location is examined with the test board. A binary inference part accesses a test history file and host PC. Then, the information such as the sensor values of fault occurred test board, S/W access is transferred to the binary inference part. Finally, the fault location of test board is inferred.

3.3 Fuzzy Inference of a Fault Occurrence

When the test of a HDD is completed, test results are stored in a test history file. Then, the possibility of fault occurrence is inferred with the test history file. Three inputs and an output are defined in this fuzzy inference system on the basis of experience and knowledge of operator. Table 1 shows the input-output of fuzzy inference.

Table 1. Input-Output of Fuzzy Inference

Input	NF	The number of Fail in the latest tests
	NCF	The number of continuous Fail in the latest tests
	DFS	The possibility of test system fault from the type of the Fail
Output	POSF	The possibility fault occurrence

In the table 1, NF is defined as the numbers of Fails in the past 7 tests of each port. Therefore, NF is defined by an integer between zero and seven. NCF is defined by the largest numbers of continuous Fails in the past 7 tests of each port. Therefore, NCF is defined by an integer between zero and seven. For example, if there is no Fail in the past 7 tests, NCF is zero and if first, third and seventh test results are Fails, NCF is 1. The DFS is possibility of Fail resulted at test system. The DFS is defined according to type of HDD Fail. With the experience of skilled expert, the type of every HDD Fail is classified as an integer between of 0 and 10 according to possibility of test system fault. The DFS is defined as 10 for the type of HDD Fail that closely related with the test system fault. While the DFS is defined as 0 for the type of HDD Fail that has no relation with test system fault. DFS is determined, according to type of the latest Fail. Finally, POSF, output of fuzzy inference, is expressed by a real number between 0 and 10. If the possibility of fault occurrence is high, then the POSF has large value.

Each input is represented with 3 linguistic variables, and output is represented with 5 language variables. The linguistic variables of input and output are shown in Fig.6. In the Fig.6, two input variables NF and NCF are defined by same linguistic variables. 27 fuzzy rules are created by combination of linguistic three input variables. Table 2 shows some example of those fuzzy rules.

The POSF, output of the fuzzy system, is inference with Mamdani method [J.S.R.Jang, C.T.Sun and Eiji Mizutani C"Neuro-Fuzzy And Soft Computing"]. When POSF is larger than predefined critical value, it is determined the test system has a fault. When a fault is occurred, the port of fuzzy inference sends system number to binary inference parts and binary inference start to infer of the fault location.

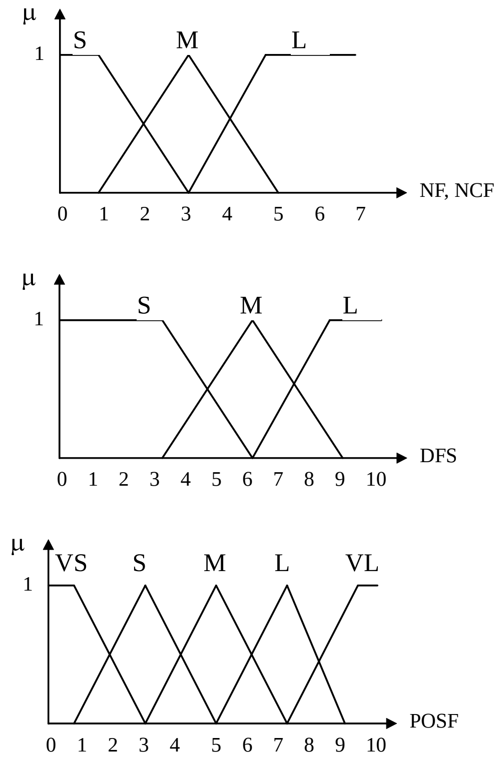


Fig. 6. Membership functions of Input and Output.

Table 2. Examples of fuzzy rules

Rule	input variables			Output variables
	NF	NCF	DFS	POSF
1	S	S	S	VS
2	S	S	M	VS
3	M	S	S	S
4	M	M	S	M
5	L	M	M	L

3.4 Binary inference of a fault

A fault location of n-th test board is inferred with the binary logic when the fault is occurred n-th test board.

This study applied the forward reasoning that infer final fault location from facts of many conditions. The knowledge of operator about fault location is arranged as follows.

$$\text{If (Condition) Then (Fault location)} \quad (7)$$

The If (Condition) part of each rule is expressed a logic combination form of various facts. Then, the Facts are abstracted form every rules of (7) form and the input values of binary inference are arranged.

Table 3 shows input and output of binary inference. In the table 3, each STATE_BOARD and STATE_IDE shows present test boards and numbers of Pass/Fail HDD. STATE_PORT is the S/W Accesses possibility of HDD. VOLT_SMP300 is the output of power control cards, shows whether the output of that card is proper to 5% permission limit of 5 Volt / 12 Volt or not. All inputs of CMOS_PM, … , FILE_LAN are values that can read with program in the host PC. Therefore, those can be clearly processed with the past binary logic. Outputs of binary inference are fault occurrence location, fault test board and number of the test system.

Table 3. Input and output of binary inference

particular		detail
INPUT	STATE_BOARD	Total HDD state of a test board
	STATE_IDE	Total HDD state connected an IDE card
	STATE_PORT	HDD state of a port
	HISTORY_BOARD	Test history of total HDD connected a test board
	VOLT_SMPS300	5V/12V output voltage of SMPS300
	CMOS_PM	"CMOS Power Management" settings of test boards
	CMOS_MAIN	"CMOS Main" settings of test boards
	PB_ID	"Power Control Board ID" settings
	PB_HDD	"Power Control Board HDD" state
	FILE_TEST	State of files related test
	FILE_LAN	State of files related network
OUT-PUT	FAULT	Name of location to need repair
	TEST_BOARD	Number of test board
	TEST_SYSTEM	Number of test system

On the basis of inputs of table 3, the fault location is inferred with the evaluation of condition part. A fact which composes the (condition) part of each rule is coded as a function( ) of C-language. Because a function( ) is a fact, the value of the function( ) is on/off or yes/no. And, (condition) part of each rule is expressed as a logical combination of the independent functions.

Inference of fault location of a test board is divided with the type of faults into "Faults related with test board", "Faults related with IDE" and "Faults related with port", this is showed in Fig. 8. In Fig. 8, "Faults related with test board" includes the faults affect the whole ports such as CPU of test board, COMS, Power control card, etc. "Faults related with IDE" and "Faults related with port" affect the IDE card or Port, respectively, such as IDE Card, Pin connection, Cooling pan and S/W Accesses denied, etc.

In the Fig.8, A feedback loop means to execute of sequential inference of each two IDE cards and six ports when the fault is related with IDE card or port. Fig.9 is a part of binary inference flow when fault is related with test board.

The Fig 8 shows the inference about fault of n-th test board in m-th test system. First, function T_B_file( ) is a fact to determine S/W Accesses possible to a buffer file in test board. If the buffer file is inaccessible, it means that the test board doesn't operate correctly. In this case, outputs are Fault: CPU, Test: Board, and Test System: m. Those outputs mean that problem is occurred at CPU of n-th test board in m-th test system.

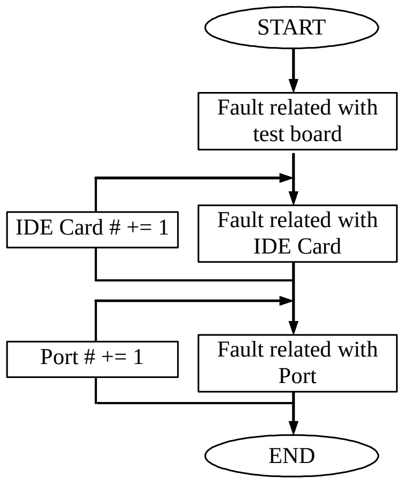


Fig. 8. Binary Inference Flow.

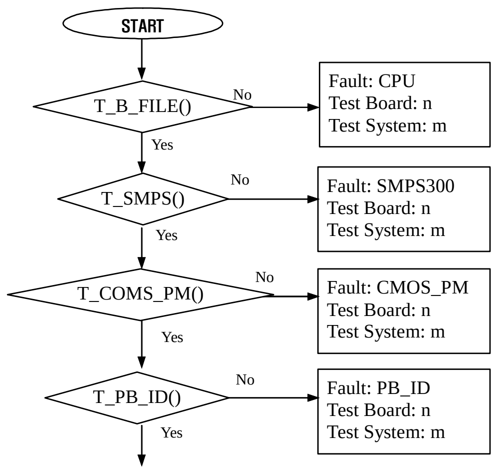


Fig. 9. A Part of Binary Inference Flow.

If buffer file is accessible, function T_SMPS ( ) confirms whether the output voltage is in fixed standard.

If the voltage value is out of the standard, outputs are Fault: SMPS300, Test Board: n, and Test System: m. Those outputs mean the fault of the SMPS300 to feed HDD of n-th test board.

If the voltage value is suitable, T_CMOS_PM( ) is performed. A function T_CMOS_PM ( ) examines settings of "CMOS Power Management" value in CMOS settings of a test board. If the value is abnormal, Outputs are Fault: CMOS_PM, Test Board: n, and Test System: m. Those outputs mean the fault of CMOS_PM value. If that value is normal, next function T_PB_ID( ) is performed. The A T_PB_ID ( ) confirms whether ID of power control card equals to ID of test board, if that ID differ form ID of test board, Outputs are Fault: PB_ID, Test Board: n, and Test System: m and settings of power control card is examined. If that ID is equal to ID of test board, inference is processed with the flow of the rest faults diagnosis. As result of final inference, if a fault of a IDE card or port is inferred, both the fault location and the number of the equipment are outputted at Fault: and IDE card or location of the port be known.

If the binary inference can not infer the fault location, the outputs are Fault: M/T, Test Board: n, and Test System: m. The Fault: M/T means that fault location isn't inferred. Though a fault of n-th test board is inferred with the fuzzy inference, the fault location can not be inferred with the binary inference. In that case, hand examination is demanded to n-th test board.

4. Simulation Results

In this study, the fuzzy expert system is applied 20 test equipment of real product line of storage division factory of Samsung electronics in KUMI.

The expert system is coded by C-language, it is accessed the test system via server. First, the POSF was acquired by test history file of the test equipment, and that was compared with fault record of test history file. Fig.10 is comparison inferred fault with the fuzzy inference and acquired fault with test history file in 142 conditions at each port. In Fig. 10, a cross axis shows 142 conditions, a vertical axis shows the POSF. A real fault is expressed by 10, the no real fault is expressed by 0. And the POSF is showed by a dot.

In Fig10, the real fault is expressed just 10 and POSF is appeared highly. And, in the case of no real fault, the POSF is inferred lowly relatively. Therefore, the accuracy of the fuzzy inference is confirmed.

An optimal value 6.5 is selected to distinguish a fault and a no fault. The expert system determines fault of test system when POSF is larger than 6.5.

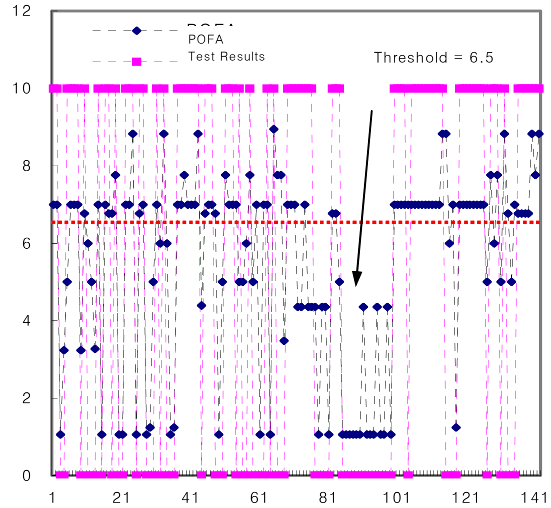


Fig. 10. Comparison of Real Fault and POSF

Table 4. Comparison of the Inference Results

System	Port	FN	NCF	DFS	POSF	Inferred fault location	Examination result	Inference result
320	10	6	4	7	7.8	Port	Port PIN Bad contecting	Correct inference
320	58	2	2	4	3.4	-	Test OK	Correct inference
320	84	6	3	6	7.0	COOLING FAN	COOLING FAN	Correct inference
333	30	5	5	8	8.8	POWER B/D	POWER B/D	Correct inference
336	59	4	2	7	7.2	IDE CARD	TEST OK	Incorrect inference
333	85	6	4	7	7.8	M/T	Test OK	Correct inference
323	24	5	3	5	6.8	M/T	COOLING FAN	Incorrect inference

In this study, the equality of inferred fault location with expert system and real fault location is designated as "correct inference". That is either a fault location is correctly inferred in the fault case or a no fault is determined in no fault case. Also, the incorrect inference of fault location or inferred fault from no fault is designated as "incorrect inference".

Table 4 is a result of application of proposed expert system.

NF, NCF and DFS of 10-th port in 320-th test system are expressed as each 6, 4, and 7 at the first row of the table 4. Those values shows six Fails in the latest tests, continuous 4 Fails and Fail type as fault possibility of test equipment. In this case, the inferred POPF 7.8 is larger than 6.5, it was determined to fault of test equipment. And the binary inference shows that fault of the port is determined. That case is the correct inference of proposed expert system because the bad connection of port pin is showed in the real examination.

In the table 4, the POSF appears to 3.4 at 2-nd row, and it can be correct inference. As a incorrect inference, the expert system determine fault of IDE card at 5-th row, but it is not fault in fact. Final two rows express the binary inference as M/T. It is determined to fault but can not infer fault location. In this case, no fault of real system is classified "correct inference" and fault of real system is classified "incorrect inference".

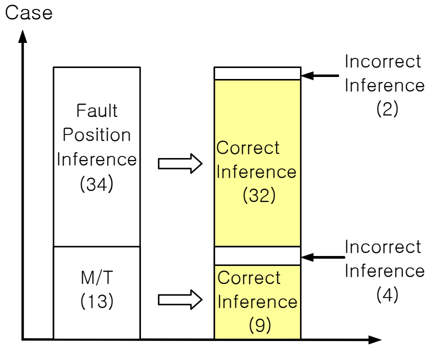


Fig. 11. Test Results of Proposed Expert System.

During the examination process, 47 faults were determined with inference of the fuzzy system, and Fig.11 shows analysis of those cases. In the Fig.11, 34 fault locations are presented in the 47 binary inferences. And not inferred 13 fault locations were presented with M/T. The 32 cases were correct inference, the 2 case were incorrect inference in the 34 fault location inferences. The 9 cases were determined correct inference and the 4 cases were determined incorrect inference in the 13 fault location inferences. Therefore, right probability in the 47 inferences that determine fault were appeared 41/47=87% by correct 32+9=41 inferences.

Though quantitative statistics wasn't reported by reference, the right probability of the early step of a test system operator about fault occurrence is known about 40%. It is regarded that the human operator can not decide a lot of test system equipment with concentration and it is not easy for unskilled operator to diagnose correctly. Therefore, the presented expert system shows right probability of considerable level than those operators.

5. Conclusion And Discussion

This paper presents expert system for the fault diagnosis of HDD test system. First, fault decision roles of an expert is collected and arranged. A fuzzy rule base is presented to be proper to characteristic of collected rules. And a sequential inference is presented by a binary rule base.

A fuzzy inference is designed to determine fault occurrence. A fault location is inferred by the binary logic when a fault is determined. In a binary inference, the collected expert rules are arranged as "If (situation) then (fault location)" form of forward inference, and it determines a final fault location. A presented expert system is applied test system of real HDD production process and effective fault diagnosis is proved.

The result of this study can reduced the time to decide of fault location by automatize of many process, and can improve the HDD productivity as preventing of incorrect fault diagnosis by human operator.

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