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AN EXPERT FAULT DIAGNOSIS SYSTEM FOR AUTO WIRE BOND MACHINE

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Abstract. In the modern world, computing is essential in all aspects of manufacturing activity. Computers have brought to life terms like artificial intelligence, and have played a critical role in reinvention of manufacturing industry. In continuing quest to decrease the interval time between conceptualization of a product, information technology has been fused with manufacturing practice. This paper describes the use of expert system shell to develop a rule-based expert for an auto wire bond machine fault diagnosis system for hi-tech semiconductor industry. The main aim of the expert fault diagnosis system is to diagnose the problem of auto wire bond machine. In semiconductor industry, production equipment and machine have depended heavily on the use of human expertise for maintenance and it is costly. Without an expert system, his/her experience is lost when human is unavailable. With the developed expert system, the diagnosis process for the auto wire bond machine is standardized and accuracy will be increased compared to the conventional way. Therefore, the quality of products that are produced will improve. The constrains values for the fault diagnosis are based on design data and experience of the engineer. The expert fault diagnosis system is to improve bonding quality by reducing the production yield loss.

Keywords: Auto wire bond machine, fault diagnosis, expert system shell

Abstrak. Dalam dunia moden, pengkomputeran adalah penting dalam semua aspek aktiviti pembuatan. Komputer telah melahirkan istilah seperti kepintaran maya, dan mempunyai peranan penting dalam mengubah industri pembuatan. Dalam usaha untuk mengurangkan masa selang antara pengkonsepan produk, teknologi maklumat telah berkait rapat dengan pengamalan pembuatan. Kertas kerja ini membincangkan penggunaan sistem pakar untuk membangunkan sistem untuk mendiagnosis masalah mesin ikatan wayar automatik pakar yang berdasarkan peraturan untuk industri semikonduktor yang berteknologi tinggi. Tujuan utama sistem pakar ini ialah mendiagnosis mesin ikatan wayar automatik. Dalam industri semikonduktor, peralatan dan mesin penghasilan adalah sangat bergantung kepada kepakaran manusia untuk penyelenggaraan dan keadaan ini adalah berkos tinggi. Tanpa sistem pakar, pengalaman pakar akan hilang apabila dia tiada. Dengan adanya sistem pakar, proses diagnosis boleh dipiawaikan dan ketepatan akan bertambah berbanding dengan cara lama. Dengan itu, kualiti produk akan bertambah baik. Nilai kekangan untuk diagnosis masalah adalah berdasarkan data reka bentuk dan pengalaman jurutera. Sistem pakar untuk mendiagnosis masalah adalah untuk menambahkan kualiti ikatan wayar dengan mengurangkan kehilangan alah produksi.

Kata kunci: Mesin ikatan wayar automatik, diagnosis masalah, kerangka sistem pakar

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1.0 INTRODUCTION

In the new millennium, computer-aided engineering will focus on its original objective, the integration of engineering functions and in particular, the co-coordinating function of manufacturing engineering. Engineering and its associated technologies are necessity evolving into a production support function, in which internal customers represent the end user in terms of quality (ease of manufacture), cost (robust designs and processes), and delivery (efficient communication) [1].

In semiconductor industry, production equipment and machinery have depended heavily on the use of human expertise for maintenance and repair. In order to develop the expertise, considerable effort is required to train the work force. In some situation, expertise is not available on a reliable and continuing basis. Experts are expensive, scarce and in high demand. It is also easy to lose expertise through separation, job transfer and retirement. Knowledge based expert system had emerged in the field of artificial intelligence (AI) with strong potential and capability for reducing training cost, maintaining consistent expert knowledge and improving productivity and the quality of the task performed [2].

This research was done in a multinational semiconductor company. Auto wire bonder is used for aluminium wedge bonding process by the Dpak production line. Dpak product is a power transistor manufacturing line. It includes the process of assembling and testing Dpak power transistor. Dpak power transistors are mainly used in automotive industry as a controlling device for auto-braking system (ABS), ignition system and power window.

The developed ruled based expert fault diagnosis system consists of several modules such as knowledge acquisition module, inference engine module and a user interface module. The backward chaining method is used in the development of the system. The developed system provides systematic fault diagnosis guide for the machine operator and technician. A user-friendly interface consisting of images, menu and buttons was designed to ease user in data input to the system, and obtaining the complete results. The process engineers can choose the right solutions to solve the problem during wire bond process and hence reducing time loss.

2.0 EXPERT SYSTEM

Artificial intelligence (AI) is a technology developed to ease the activities of human and human replacement in conducting a task [3]. There is a wide scope in AI field; for instance, there are expert system (ES), fuzzy logic, neural network, genetic algorithm, etc.

An expert system is a computer system that comprises computerized knowledge of an expert in a particular subject domain in order to provide fast and easily accessible knowledge in a useful and practical manner. In the absence of the experts, the ES acts as a support system for the experts in an interactive way [3-5]. An expert system is an interactive system consisting of three core components as shown in Figure 1 [6]:

(1) A knowledge base of facts and heuristics that can be applied to a specific case.
(2) An inference engine (or control system), which selects the appropriate knowledge rules and recommendations for the solutions of the problem.
(3) A working memory (or global database) which contains, in temporary storage, observations or evidence provided by the user about specific case, and all derived information about the case.

In addition to the three core components, the other support modules are (refer to Figure 1): user interface, knowledge acquisition module and explanation module.

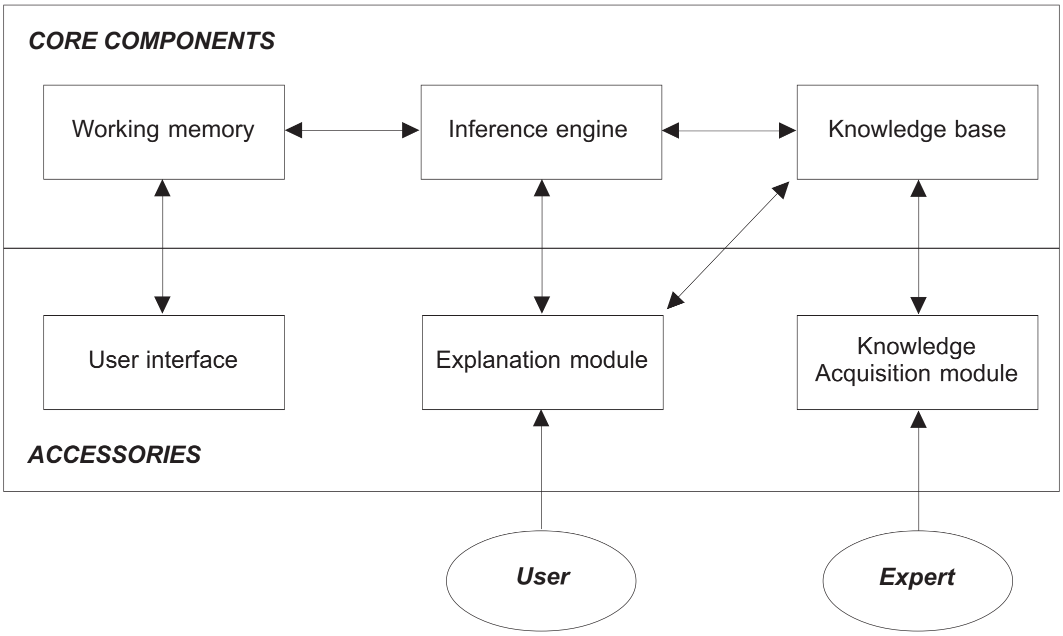

Figure 1 Components of an expert system [6]

An expert system (ES) is a computer that emulates the behaviour of human expert within well-defined, narrow domain of knowledge [7]. In the past, ES had been used by various investigators to select engineering parts, process and materials in the industry. Arezoo *et al.* [8] developed an ES for selection of cutting tools and conditions of turning operation. The ES has been developed by Sapuan *et al.* [9] for material selection of ceramic matrix composites for engine components such as piston and piston ring. Er and Dias [10] has developed rule-based ES approach for casting process selection, and described an ongoing rule prototype development. Mookherjee and Bhattacharyya [11] has developed an ES, namely EXTOOL, which automatically select turning/insert or milling insert, the material and the geometry, based on the requirement of users.

Similar studies on the expert system of fault diagnosis were carried out by Wu *et al.*, [12] and Wu *et al.,* [13] but the expert system served as consultants for fault diagnosis of vehicle engines. Afgan *et al.*, [14] has developed an expert system to diagnose the fault and monitoring the gas turbine combustion chambers. Chan [15] developed the expert decision support system for monitoring, control and diagnosis of a petroleum production and separation plant. Yang *et al.*, [16] has proposed an expert system called VIBEX (VIBration EXpert) to aid plant operators in diagnosing the cause of abnormal vibration for rotating machinery. Qian *et al.,* [17] has developed an expert system for fault diagnosis of chemical processes.

3.0 FRONT END ASSEMBLY

The wire bonding process is one of the processes in Front End Assembly as shown in Figure 2.

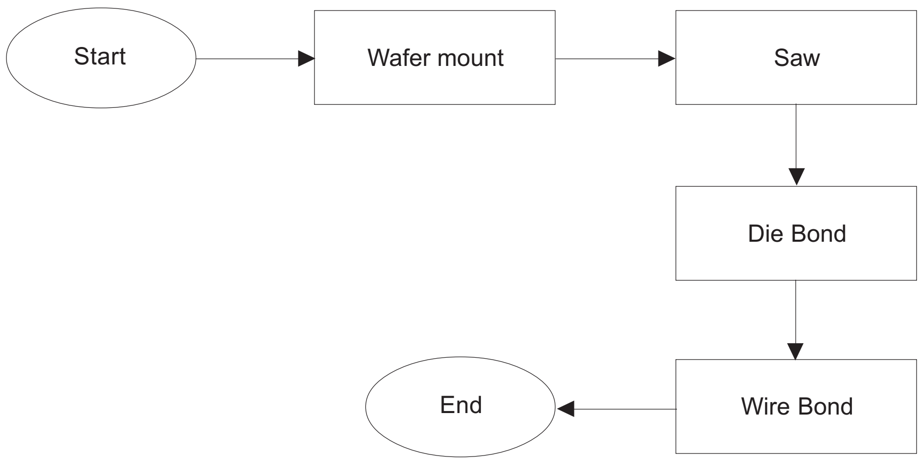

Figure 2 Front End Assembly Process

This assembly consists of four types of machines: Wafer Mounter, Saw, Die Bond and Wire Bond. The Integrated Circuits (IC), which is also known as 'die' in the assembly/production floor, comes in wafer shape from the wafer fabricators. The wafer is mounted to wafer ring using Mylar tape before it is taken to the saw machine to cut the wafer into die form. At the Die Bond machine the dies are attached to lead frame flag using glue known as epoxy. The Wire Bond machine will attach wire to the input/output (I/O) of the die to the leads of the frame. The I/O point on the die is known as pad or bond pad. Figure 3 shows the basic step in the Front End Assembly.

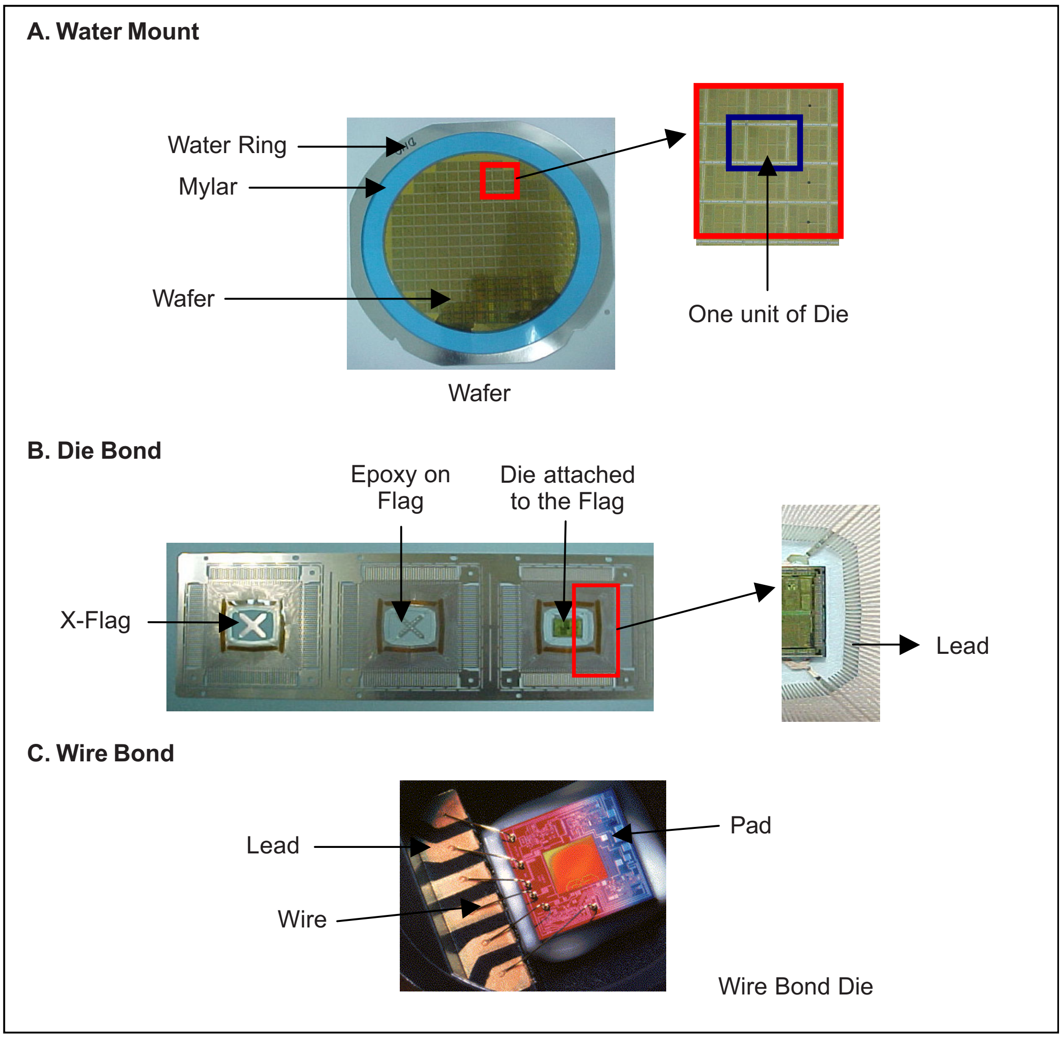

Figure 3 Basic Step in Front End Assembly: A. Wafer Mount, B. Die Bond, C. Wire bond

4.0 INTRODUCTION TO WIRE BONDING

Wire Bonding is a critical stage in the assembly process. At this stage, it absorbs most of the device cost; thus the success of the remaining processes is critical. The wire bonding process is an interconnection technology linking the die to the lead within the micro-scheme. The four main phases of the cycle are shown in Figure 4.

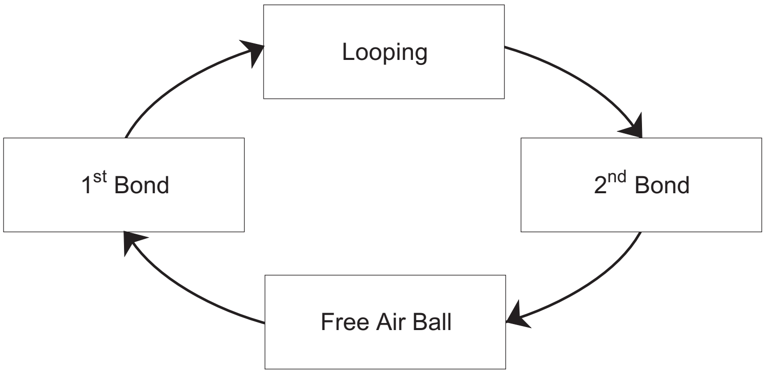

Figure 4 Four-Main Phase of Wire Bond Cycle

Each phase is the result of several operations performed by the capillary. These operations can be defined by eight stages that complete the ball bonding cycle as follows:

Free air ball (FAB) is captured in the capillary

(i) 1st bond formation
(ii) Capillary rises to loop height position
(iii) Formation of the loop
(iv) Formation of the 2nd bond
(v) Creation of the tail length
(vi) Disconnection of the tail bond
(vii) Formation of new FAB

5.0 AUTO WIRE BONDER

The auto wire bond machine used in this research is fully automatic high-speed ultrasonic bonder. It bonds the wire between die and lead frame using an ultrasonic energy. The major systems of the machines are electronic and mechanical. They are linked with a variety of interchangeable tooling, process control and electronic accessories. The machine will enable a fully automatic process using pattern recognition system with the automatic lead frame handling system.

6.0 EXPERT SYSTEM DEVELOPMENT

The designing and development of an expert system for wire bond machine involves five major phases. The following sections illustrate the five phases of designing and developing an expert system.

6.1 Phase 1: Knowledge acquisition

The objective of the knowledge acquisition phase is to acquire knowledge on the problem which will be used to guide the development effort. This knowledge is used to provide both insights into the problem and as the raw material for designing expert system. The process of acquiring knowledge from the expert is known as knowledge acquisition. This phase involves meetings held with the expert where some aspect of the problem is discussed.

6.2 Phase 2: Design

During the design phase, the overall structure and organization of the system's knowledge are defined. Methods are also defined for processing the knowledge. A software tool is chosen where it can represent and reason with the system's knowledge in a manner that is similar to the approach taken by the human expert. During the design phase, an initial prototype system is built. By first building this prototype system, which then used to review the test results with the domain expert, insight is gained into additional system requirement.

6.3 Testing and Validation of System

The testing phase is a continuous process throughout the project. Following each interview with the domain expert, new knowledge is added to the system. This is followed by additional testing where the system's knowledge may be again modified. The major objective of testing is to validate the overall structure of the system and its knowledge. In addition, this phase studies the acceptability of the system by the end-user. Throughout the testing, the designer works closely with both the domain expert who serves to guide the growth of the knowledge and the end-user who provides guidance to the development of the system's interface.

6.4 Documentation

The documentation phase addresses the need to compile all of the project's information into a document that can meet the requirements of both the user and developer of the expert system.

6.5 Maintenance

The maintenance of the system relies on the effectiveness of documentation system. The documentation must be well organized and enable the maintenance individual perform the job easily. The system will be developed in modular form to provide easy maintenance task.

7.0 OVERALL DESCRIPTION OF THE EXPERT SYSTEM FOR AUTO WIRE BOND MACHINE

A Rule Based Expert Fault Diagnosis System For Auto Wire Bond Machine involves a number of major steps or phases. This includes knowledge acquisition, choosing the selection criteria, selection of user interface; define the knowledge hierarchy, program codes writing, program validating and testing, documentation, and maintenance. The following described the development of the expert system.

7.1 Phase 1: Knowledge Acquisition

The development of an expert system requires many problems to be solved. The expert knowledge is heuristic and difficult to gather. The most dominant source for this project is the domain expert. The sources for knowledge acquisition are from:

(1) Session with Experts
The domain experts involved in this knowledge acquisition process were senior equipment engineer, technical specialist and senior staff engineer. The knowledge from the domain experts were extracted from the discussion and meeting. The fish bone diagram was used to record all the root causes. To ensure the highest level of creativity and participation by domain experts, criticization, praise or discussion on the root causes carried out at each meeting. For each root cause, the domain expert needs to clarify it.

(2) Machine Record Card
The machine record is used to record the problems occurred, and the solution for the problem in auto wire bond machine. These records were documented by the line technicians wherever they attended the machine problem. These records were analysed and commented by the experts.

(3) Manufacturer Operating Manuals
The machine operating manuals contained technical information about the wire bonder and its operation. The manual was considered as in-depth knowledge or technical knowledge of the domain, as compared to the heuristic knowledge, which is primarily based on the experience.

(4) Process and Equipment Specification
These specification were developed internally by maintenance and process engineers. It contain general procedure for wire bond process, machine start-up procedures and operating procedures.

(5) Total Control Methodology
It is a comprehensive document that was created for each and every process. This documents contains process and equipment database to operate a machine. It also contain preventive maintenance program and activities related to machine diagnosis.

7.2 Phase 2: Design

After the knowledge acquisition from the domain expert, the next task is to select the knowledge representation technique and control strategy. A prototype system is built to validate the research and to provide guidance for future work. Figure 5 shows the general configuration of the proposed system.

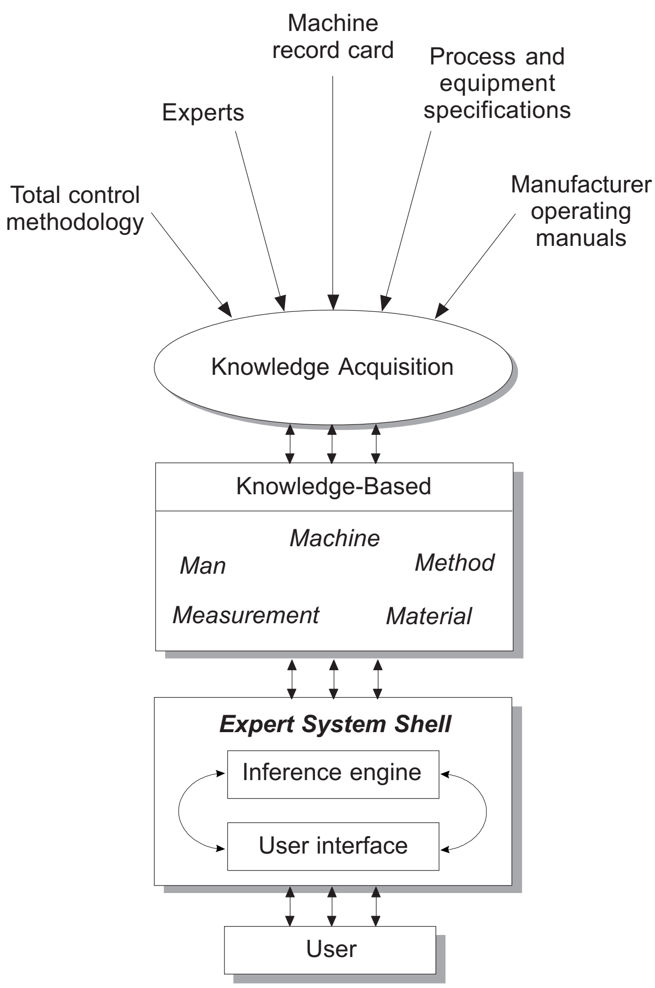

Figure 5 The structure of the proposed system

The following stages are in the design phase.

(1) Selection of Prototype Development Tool
The selection of development tool for expert system must satisfy certain criteria in order to save time and effort in fulfilling its objective. For the present problem, selection must satisfy the following basic conditions:
(a) It must support hybrid knowledge representation techniques.
(b) It must have varied inferencing facility.
(c) It must support good interface facilities with external programs and systems.

Considering the above criteria, Kappa-PC expert system shell [18] was chosen for the present problem. Apart from its powerful object oriented capabilities, Kappa-PC allows for the representation of knowledge using production rules. It enables the knowledge base to be built by using heuristic knowledge, as well as permitting work with algorithms. It also provides a variety of user options.

(2) Selection of Knowledge Representation Technique
In this stage, a knowledge representation technique that best matches the way the expert mentally models the wire bond problems was required. Therefore, a ruled-based system was chosen to design the expert system. The IF-THEN rule is used in the research. Figure 6 shows a rule structure, which is used in

```
IF
defect              = lifted_pad_&_post    AND
deformation         = deformation          AND
cut_wire            = yes                  AND
bond_angle          = yes                  AND
wire_guide          = yes                  AND
wedge_height        = yes                  AND
wire_free_flow      = no_binding           AND
pivot_s_play        = no_side_play         AND
pivot_binding       = no_binding           AND
heat_sink_clamp     = yes                  AND
bond_head           = not_binding          AND
heater_block_firm   = yes                  AND
touch_down_sensor   = yes                  AND
overtravel_height   = yes                  AND
table_side_play     = side_play

THEN
Action              = inform_equip_group_to_service_table;
```

Figure 6 Rule structure for the expert fault diagnosis system fault diagnosis for the auto wire bond machine. If the condition of the rule is satisfied, then the conclusion of the rule is set as the result.

(3) Selection of Control Technique
Backward chaining is used in this research project because the expert first considers some conclusion (defects mode) then attempts to prove it by searching for supporting information. The expert is mainly concerned with proving some hypothesis or recommendations.

(4) Develop the Prototype
The system development was used expert system shell. The prototype is a model of the final system. Its basic structure, in terms of the way it represents and processes the problem's knowledge, is the same as in the final system.

(5) Develop the Interface
The user interface is developed to provide easy access and avoid confusion to the user. The language used in the interface is a consensus of that used by operators and engineers. Figures 7 and 8 show the user interfaces of the system. Figure 9 shows the defect help module.

Figure 7 The main window

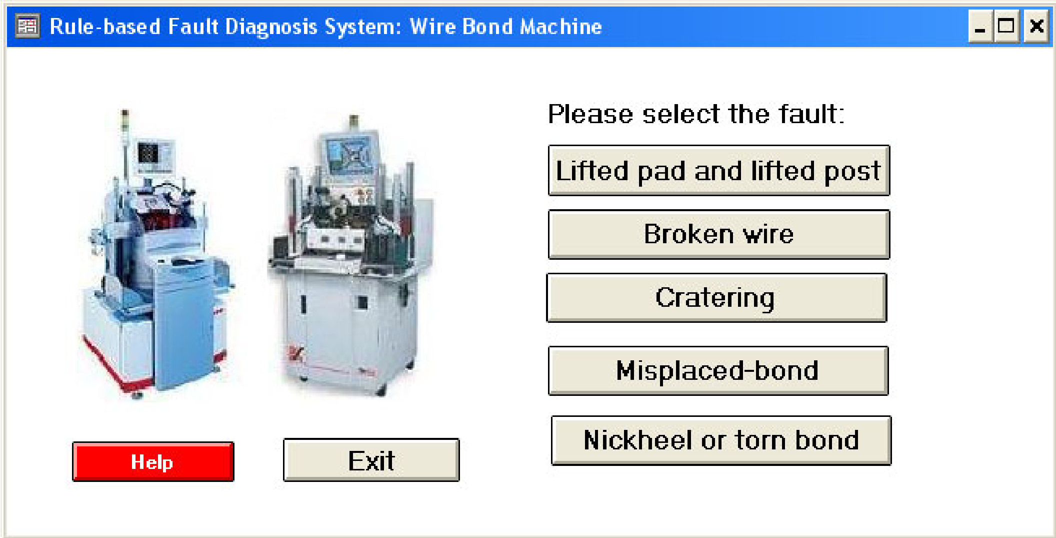

Figure 8 The fault selection window

(6) Develop the Product
The developed system should provide the user update the system when there are new rules or techniques that available.

All information about the maintenance and fault diagnosis are stored in knowledge base. An inference engine will scan the storage by using Kappa-PC tool and applying "if-then-rules" in order to find the suitable solutions of the problem. The inference engine interacts with knowledge base in backward chain method to solve the problem. The user interacts with the system through user interface as shown in Figures 7 and 8. Figure 9 shows the inference browser for the system

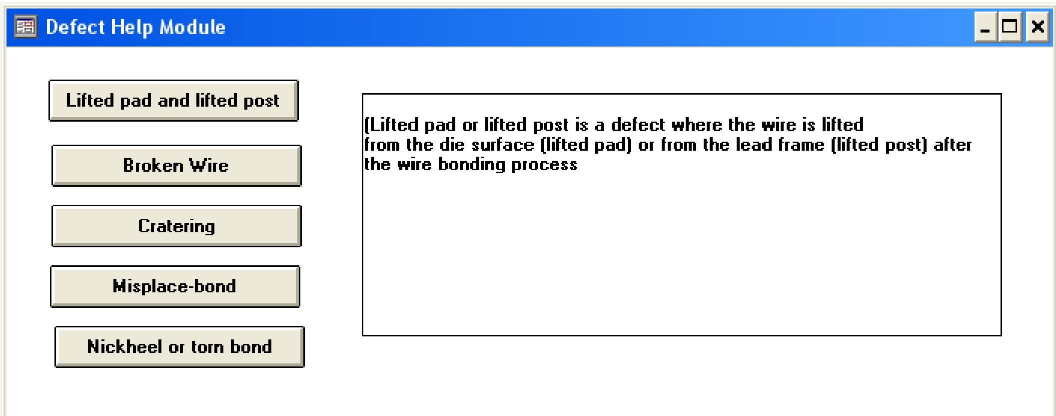

Figure 9 The defect help module

7.3 Phase 3: Testing and Validation

The developed expert system is tested and evaluated to ensure the software performance is converging towards established goals. The evaluation process is more concerned with system validation and user acceptance. Validation efforts determine if the system satisfactory performs the intended task. User acceptance efforts are concerned with issues that impact how well the system addresses the needs of the user. There are three testing that involve in the development of expert system.

(1) Preliminary Testing
This test is to evaluate the complete knowledge base. The test applies all possible combinations of answers to the questions asked by the system. The test provides early verification of the system. The developed system was tested separately based on module.

(2) Informal Validation Testing
The system was tested against real problems from its domain. The objectives are to determine the effectiveness of the system in solving the wire bond defects and uncover system deficiencies. Past cases had been used for the testing.

(3) Field Testing
The developed system is deployed into the work environment and exposed to wire bond real world problem. A few technicians are requested to use the expert system to trouble shoot the wire bonder. The objective of the test is to determine if the system meets its original goals. This test is also determined the validation of the system and assessment of the user's acceptance.

7.4 Phase 4: Documentation

The documentation serves as a diary of the project. It contains all the material collected during the project that used as reference. Information that needs to retain and record in the documentation serves three purposes: reference for developing expert system, reference for writing final report and reference for maintaining the expert system.

7.5 Phase 5: Maintenance

The final phase of this research project is system maintenance. Maintenance is required since most expert systems contain knowledge that is evolving overtime. The company may require new equipment or develop new products or change the procedures. This changing state requires appropriate modifications to the system. Due to security purposes, it is important that only designated individuals are allowed for maintaining the system.

8.0 RESULTS AND DISCUSSION

An expert fault diagnosis system for Auto Wire Bond Machine was developed and tested. The developed expert fault diagnosis system has the ability to diagnose machine problems thus recommend precise and systematic troubleshooting procedure. The database of the system can be changed and upgraded easily by user. The program was tested for all possible scenarios such as the defect on misplaced bond as shown in Figure 10. The system will give an error message if the user makes mistake in entering the required data or answering the question. Therefore, the system was tested to validate the proposed system. It involves three stages where the first stage will test the complete knowledge base for logic and consistency. The next stage is to demonstrate the system to the domain expert. While in the third stage, the developed system is deployed into work environment and exposed to wire bond real world problem.

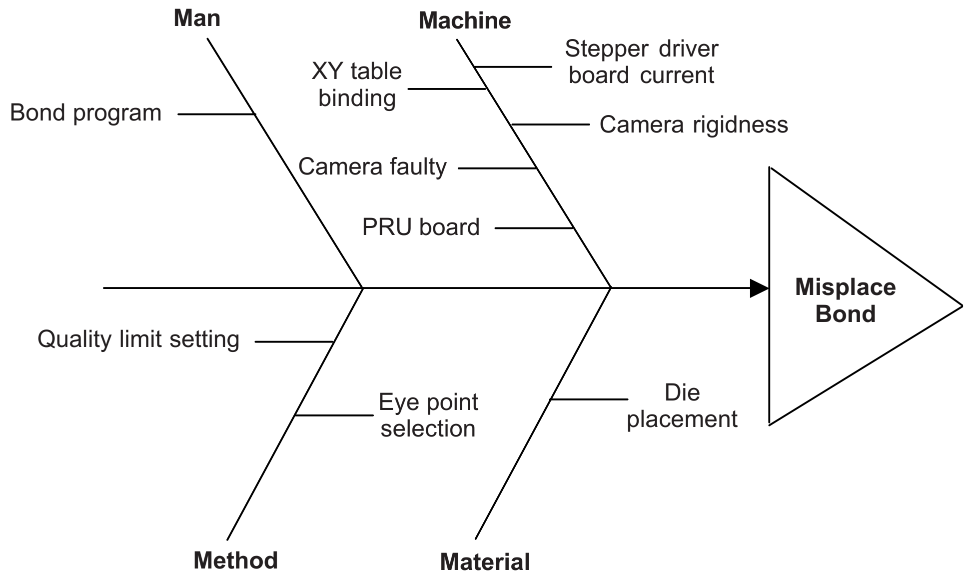

Figure 10 Example of defects on misplaced bond in fish bond diagram

8.1 Case Study

As the project proceeds, the developed expert system is periodically tested and evaluated to assure that its performance is converging towards established goals. The evaluation process is more concerned with system validation and user acceptance. Validations efforts determine if the system satisfactorily performs the intended task. User acceptance efforts are concerned with issues that impact how well the system addresses the needs of the user. There are several testing stages during the development of the system.

8.1.1 Stage 1: Preliminary Testing

Immediately following the development of prototype system, an informal test of the system is conducted that evaluates the complete knowledge base. The test applies all possible combinations of answer to the question asked by the system. System-derived solutions are verified for each set of answers. This type of test provides early verification of the system. Since the expert system is designed using several separate modules, each module is tested separately. This approach not only makes it easier to test the entire system, but also permits the author to continue to perform a complete test later in the projects as the knowledge base grows. Figure 11 shows a typical data input form for lifted pad and post module. Figure 12 shows the result screen with recommendation.

Figure 11 A typical data input form for lifted pad and post module

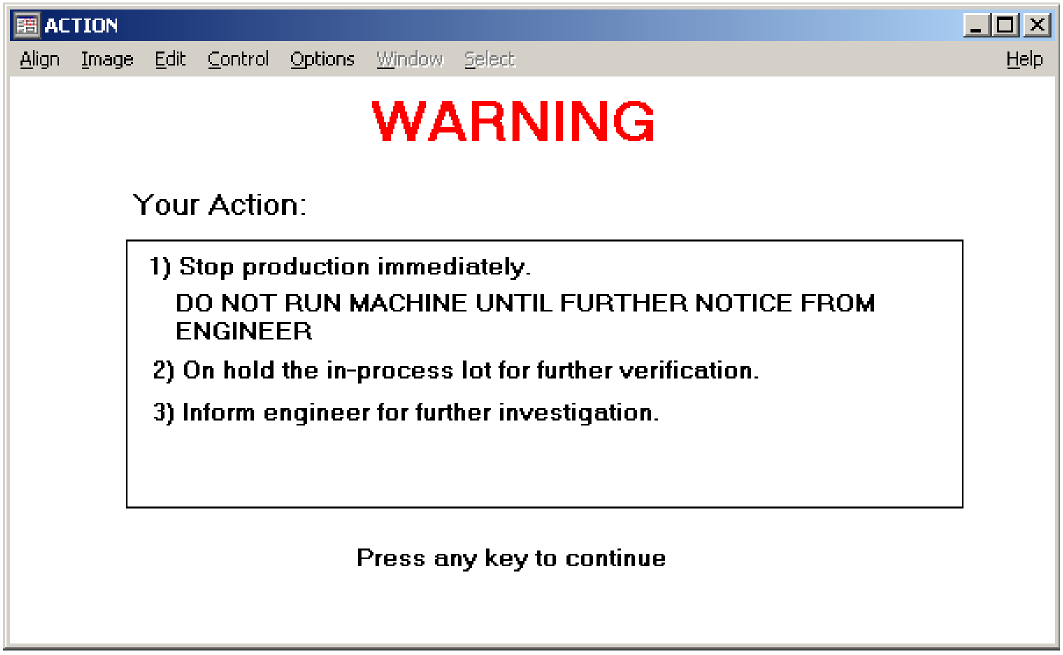

Figure 12 The result screen for lifted pad and post module

8.1.2 Stage 2: Informal Validation Testing

The purpose of stage two is to determine the effectiveness of the system in solving the wire bond defects and to uncover system deficiencies by using off-line method. Table 1 shows the results of ES when it is used to diagnose past cases.

There were certain incorrect result that provided by the expert system. This incorrect result was discussed and reasoned out with domain expert. The mistake is corrected immediately by changing the knowledge base.

Table 1 Informal Validation Test Results

Case no.	Defect	Actual Root Cause	ES Result	Match
1	Broken wire	Wire clamp solenoid	Adjust solenoid gap	Yes
2	Broken wire	Wire flow path	Clear wire path	Yes
3	Misplaced bond	XY table	Service XY table	Yes
4	Misplaced bond	Eye-point	Re-teach eye point	Yes
5	Lifted pad & post	Shinning surface	Inform engineer	No
6	Lifted pad & post	Bond head	Calibrate bond head USG	Yes

8.1.3 Stage 3: Field Testing

While the stage three testing was conducted in the field. There will be some degree of uncertainty in the performance and acceptability of the system. During this study, the system is deployed into the work environment and exposed to wire bond real world problem. A few technicians are requested to use the ES to trouble shoot wire bonder and the results are shown in Table 2.

During the field test, there were other defects such as no die and missing metallization was detected. These defects rarely happened in wire bonding and are not included in the expert system. The expert fault diagnosis system has improved by adding in "other defects" and changing the knowledge base.

Table 2 Field Case Study Results

Technician no.	Defect	Root Cause	Problem solved by ES?
1	Broken wire	Capillary out of alignment	Yes
2	Broken wire	Service wire	Yes
3	Misplaced bond	Die placement	Yes
4	Misplaced bond	Eye-point	Yes
5	Lifted pad & post	Adjust clamping station	Yes
6	Lifted pad & post	Adjust bond angle	Yes
7	Lifted pad & post	No die	No
8	Lifted pad & post	Missing metallization	No

9.0 OVERALL EVALUATION OF THE SYSTEM

The fault diagnosis process of the developed system is reasonably satisfactory and systematic to the knowledge engineers. The flow of the diagnosis is flexible, allowing the user to reset conclusions, to go back for a new diagnosis, to review input values until he/she is satisfied with the results. The developed expert fault diagnosis system for auto wire bond machine is able to run under Windows operating system.

10.0 CONCLUSIONS AND RECOMMENDATIONS

An expert system for auto wire bonder machine has been developed. The system enables the user to diagnose the problems in the auto wire bonder machine that used in hi-tech industries. The developed system is to guide the experienced and non-experienced technicians in troubleshooting wire bonder machine fault. In addition, it also served as a tutor to new technician in order for them to acquire their wire bonder fault diagnosis skills.

The developed system has the following characteristics: (i) using knowledge dictionary; (ii) flexible and modular type where the fault diagnosis database can be upgraded and integrated with other system such as scheduling process; (iii) using multiple input forms to avoid input error; and (iv) using explanation technique.

The recommendations for the future development for the system are: (i) allowing a great number of users to use the system and collecting their feedback and criticism to improve it; (ii) training a new generation of technician or engineers in the field through utilization of the education system; (iii) encouraging the utilization of computer technologies in this field; and (iv) inclusion of further aspects of latest auto wire bond machine.

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