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# Study on Fault Diagnosis of Optical Measurement Equipment Based on Fault Tree Analysis

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# Study on Fault Diagnosis of Optical Measurement Equipment Based on Fault Tree Analysis

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**Abstract.** A kind of method about fault diagnosis of optical measurement equipment based on fault tree analysis(FTA) is proposed. Firstly the system is decomposed into several subsystems by control loop, and then generated the fault tree for each control loop. The whole fault tree of the system is obtained by the event status with fault tree of all control loops deduced. Moreover, a set of system platform was developed with the Visual Basic software. Finally, a photoelectric encoder fault case of optical measurement equipment is analysed with the platform and method. It shows that the proposed method in this paper improves the automation of fault tree construction and has certain utility and better future for application.

## 1. Introduction

Optical measurement equipment is an important component of space measurement and control system, It is of great significance for reliability analysis and fault diagnosis [1-2], especially for quickly and accurately locating the faults occurred in the test process and quickly elimination[3]. At present, there are many methods for fault diagnosis.The knowledge-based method is based on the prior probability data of the object, and does not require an accurate mathematical model. There are intelligent features in the analysis process, such as fault tree methods, expert systems, fuzzy and neural network methods.Fault tree analysis can construct a reasonable fault transmission path, obtain higher fault diagnosis accuracy, and achieve optimal design of fault detection and management procedures[4-5]. Moreover fault tree analysis is widely used in the reliability design and fault diagnosis of aviation, aerospace systems and weapons and equipment[6]. This project analyzes and studies the fault tree method, analyzes and summarizes the case of optical measurement equipment, and forms a fault tree-based diagnostic analysis method of optical measurement equipment. The main idea of this method is as follows: Firstly, the top event of the entire system fault tree is determined, and the target system is divided into several subsystems (control loops) according to the control loop. Secondly, the top structure model of each loop fault tree is established, and the events that can be further expanded in the top structure model are used to generate the small fault tree by using the analytic structure model method. Thirdly, the top fault tree model of each loop is connected with the small fault tree and integrated to obtain the loop fault tree. Finally, the fault tree of all circuits is synthesized and simplified to obtain the system fault tree. The computer-aided tree-building method proposed in this topic simplifies the construction of fault trees for large and complex systems to a certain extent, and reduces the labor intensity of engineering and technical personnel in the construction of fault trees. It is easy to understand and implement. Meanwhile the generated system fault tree is also convenient for understanding and analysis.

## 2. Theoretical Basis of Fault Tree

*2.1Introduction of Fault Tree*

Fault tree analysis（FTA） technology was developed by Bell Telegraph's telephone laboratory in 1962. It uses a logical method to visually analyze the dangers, of which the characteristic is intuitive and clear, with clear thinking and strong logic. Then the qualitative and quantitative analysis could be done. It is one of the main analysis methods of safety system engineering[7].

The fault tree diagram is a kind of logical cause-effect diagram, which shows the state of the fault tree analysis system (top event) according to the state of the element (basic event). A fault tree diagram is a tree built from top to bottom and connected according to the events. It uses a graphical model path method, which can cause the system a predictable or unpredictable failure event. The events and states at the intersection of paths are represented by standard logical notation[8]. The most basic building blocks in the fault tree diagram are gates and events. These events have the same meaning as in the reliability diagram and gates are conditions. The FTA selects the most undesired event of the target system as the top event of the system fault tree, and then firstly find out the direct cause of the top event in certain external environment and working conditions. These events including system component hardware failure, human error and other factors, are viewing as the second layer of the fault tree. The second level event is the intermediate event in the transition state, and then the direct factors that lead to the occurrence of the second level event are found as the third level event, and so on, until the event is the most basic fault event that cannot be expanded or need not be further studied, which is called the bottom event.

Finally, all the top events, intermediate events and bottom events are connected layer by layer with appropriate logic gates to get an inverted tree graph called fault tree, which is as shown in figure 1.

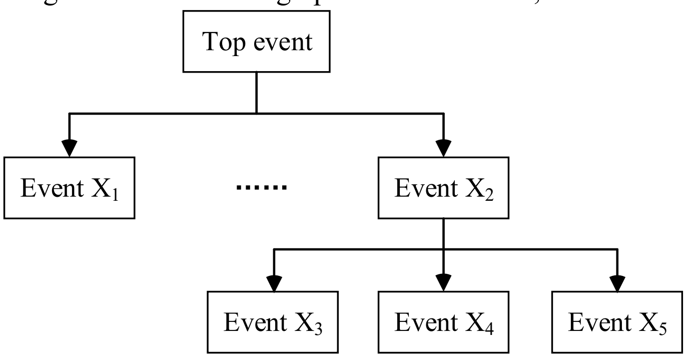


Figure 1. Example of fault tree

*2.2Steps for fault tree analysis*

The main analysis steps of fault tree analysis are shown in Figure 2.

The first step of FTA is to determine the top event of the fault tree, and then based on the selected top event, reasonably determine the boundary conditions of the tree to determine the scope of the tree[9]. The boundary condition includes the following three state networks.

（1）Initial state: When the component parts of the system have multiple working states, the working states of the part related to the occurrence of the top event should be indicated.

（2）Inadmissible events: Events that are considered to be inadmissible during the construction of the tree.

（3）Inevitable event: An event that must occur and must not occur under certain conditions when the system is working.

The purpose of qualitative analysis is to find the smallest cut set that causes a failure, and to find all failure modes that cause a system failure. During the system design phase, find possible failures to improve the system design. In the system use phase, guide the system's fault diagnosis to improve and maintain the use plan.

The purpose of quantitative analysis is to evaluate the occurrence of the top event by the known occurrence probability and frequency of the bottom event, and to calculate the probability of all the minimum cut sets, so as to modify the design and improve the reliability and security of the system. Find out the importance of the occurrence of bottom event to top event, provide a theoretical basis for the correct selection of component level, understand the impact of the change of the occurrence probability of each bottom event on the occurrence probability of top event, reduce the impact on top event, in order to improve economic benefits.

The process of FTA analysis is also a process for analysts to get familiar with the system and deepen their understanding of the system[10]. In this process, weak links can be found and solved to avoid failures. However, due to the huge workload of FTA analysis of complex systems, the accuracy and efficiency of analysis can be improved by using computer aided analysis method after fault tree is established.

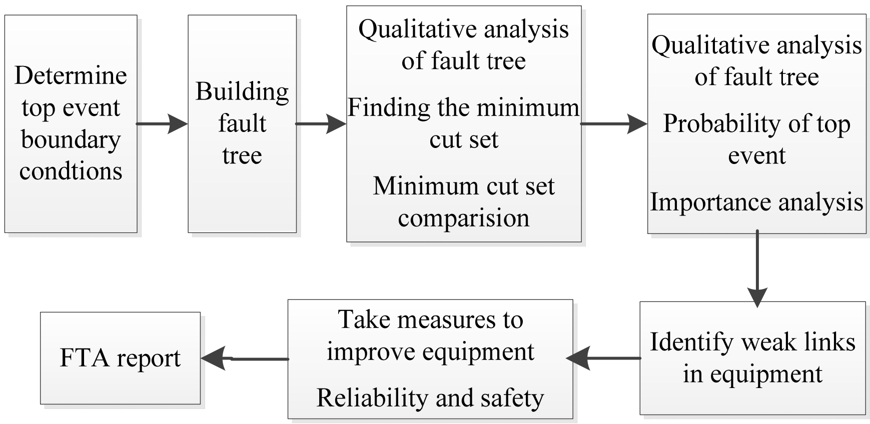


Figure 2. Fault tree analysis steps

## 3. Method for generating process system fault tree

### *3.1 The basic idea*

For the actual project whose research object is a process system, as a result the component of the object system is much more and the logical relationship is very complicated, if common tree building methods such as directed graphs and decision table methods are adopted, the establishment of the complete directed graph and decision table of the process system is complex and difficult to implement[7]. To solve this problem, it is a good choice to divide the process system into several subsystems (control circuits) and deal with them separately. That is the idea of dividing the object system with the control loop as the unit, firstly the object system is divided organically, then some typical intermediate events are used as the top events to establish the sub-fault tree, and then the sub-fault tree synthesis method is implemented, which can greatly simplify the generation process of fault tree of large complex process system[8]. In this process, the accuracy and rationality of sub-fault tree synthesis become one of the important factors of fault tree generation. Making full use of the relevant information in the sub-fault tree generation, developing the synthesis algorithm of the sub-fault tree based on the information will make the system fault tree generation algorithm have the characteristics of good logic, easy understanding, simple and smooth algorithm, etc.

This project proposes a fault tree generation method for the process system with the following main ideas. Firstly, determine the top event of the whole system, which is generally obtained by analyzing the system function and risk, and usually choose the most undesirable event or accident. Then analyze the signal flow chart of the system, identify the type and number of system loops studied, and determine the external uncontrollable disturbance of the system at the same time. Secondly, the top fault tree model of each loop is established, and the small fault tree is generated by the analytic structure model method for the further expandable events in the top structure model. And then connect the top fault tree model of each loop with a small fault tree, and integrate to obtain a loop fault tree. Finally, the fault tree of each loop is synthesized and simplified to deduce the state of the fault event and obtain the system fault tree. The Figure 3 is the flow of the fault tree generation method proposed by the project.

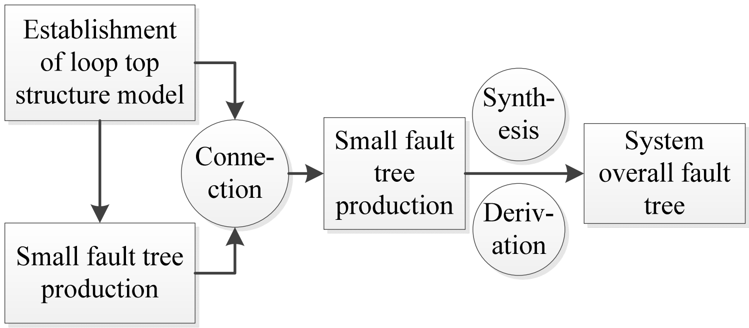


Figure 3. Fault tree generation method flow

*3.2 Control loop fault tree generation*

The method is mainly divided into three steps.

（1）The top structure model of the loop is generated, and the fault tree top structure model of each typical control loop is established and stored. The corresponding top structure model can be called according to different loop types.

（2）According to the flow chart of the control system, the established adjacency matrix is used to establish a causal model describing the components forming the loop and the event transfer between them. Through the analysis and calculation of the adjacency matrix, the hierarchy and logical relationship between events are determined. And then generate a small fault tree with events needing further expansion in the top model as top events.

（3）According to the determined loop fault tree top event, combined with loop type, event logic relationship and external disturbance, the control loop fault tree generation of structural model is determined.

*3.3 Computer Aided Building Platform Design*

The fault tree generation system is a visual system building platform developed by Visual Basic software according to the building algorithm proposed earlier. The system is an application software based on Windows operating system and has the characteristics of friendly interface, simple operation and fast operation. According to the algorithm mentioned above, the application system needs to decompose the object system into several control loops, build the fault tree of each loop and then synthesis. The whole system completes the generation of the fault tree through the program algorithm written in the background. This software completes the main steps of fault tree generation: generating control loop fault tree and system fault tree. There are other preparatory work such as system name, top event and external disturbance, call of system structure file, etc.

## 4. Case analysis

*4.1 Failure phenomenon*

During the test of a certain kind of photoelectric theodolite, the encoder system showed equipment azimuth jitter on August 26, 2016. After many times of adjustments, it was found that the failure still existed, which affected the normal operation of the equipment.

*4.2 Failure mode analysis*

According to the information flow chart, the program control flow chart and the source code, a problem elimination flow chart is established. Due to the lack of relevant information on the design intent of part of the system structure, the operation procedures of the integrated components and the process structure of the software "black box", it is necessary to make necessary assumptions according to the requirements of the task and the actual situation to make up for this deficiency. The basic assumptions are as follows.

（1）Device failure, component failure, board failure and software failure are taken as basic events, and no further analysis of proven causes is carried out to ensure the appropriate scale of the fault tree and locate the fault as soon as possible.

（2）Under the fault condition, the azimuth rotation experiment is repeatedly carried out, and the problem phenomenon remains. However, this phenomenon did not occur in the previous use process when the problem occurred. Therefore, it is suspected that the encoder has not collected data.

（3）The listed faults do not include permanent faults such as device failure that cannot be recovered.

（4）Human factors are excluded after repeated verification.

After the fault tree is normalized and simplified, a fault tree is built as shown in Figure 4.

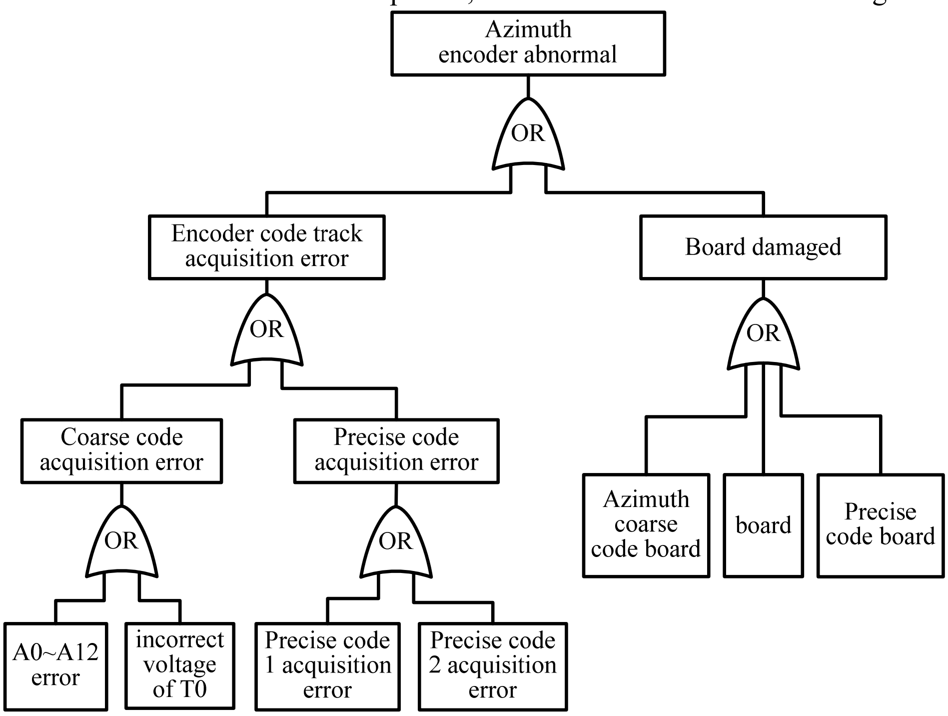


Figure 4. Encoder carry error fault tree diagram

*4.3 Production fault cut set table*

By analyzing the above fault tree chart, a fault table can be generated as shown in Table 1.

Table 1. Failure table

| step | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | Equipment azimuth jitter | Board damaged | Azimuth coarse code board fault | Azimuth coarse code board fault |
| 2 | | | Precise code Board damaged | Precise code board damaged |
| 3 | | | Main board damaged | Main board damaged |

| | | | |
|---|---|---|---|
| 4 | Encoder code track acquisition error | coarse code acquisition error | A0-A12 error |
| 5 | | | Incorrect voltage of T0 |
| 6 | | precise code acquisition error | precise code1 acquisition error |
| 7 | | | precise code2 acquisition error |

According to the above-mentioned fault table, the fault can be obtained and the troubleshooting scheme can be basically determined.

## 5. Conclusion

A kind of method about fault diagnosis of optical measurement equipment based on f FTA is presented. The method decomposes the system into several subsystems according to control loops, an then generates fault trees of each loop respectively. Finally it synthesizes all information to obtain a system fault tree. For the generation of loop fault tree, the top structure model of the loop is established firstly, and for the further expandable events in the model, the analytic structure model method is used to generate its small fault tree. Then connect the top fault tree model of each loop with the small fault tree, and integrate to obtain the loop fault tree. After synthesizing and simplifying all loop fault trees, the state of fault events is deduced, and finally the system fault tree is obtained. The method does not depend on the specific system structure and characteristics, and has strong portability. Furthermore, the developed visual fault tree generation system platform has simple and reasonable interface design, which makes it very convenient to use.

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