Failure Analysis of Asphalt Foaming Device Based on FMEA and FTA

Zhun Luo¹ and Hai-Ying Cheng¹
¹Department of Mechanical Engineering,Inner Mongolia University of Technology of China,Hohhot, Inner Mongolia, 010051, P.R. China
E-mail: chyktz@sina.com

Abstract. The FMEA method is a bottom-up method, and the FTA method is a top-down method. This paper proposes to combine the two methods, using the complementarity of the FMEA method and the FTA method, and targeting the innovative product-The six subsystems of the bubble device perform fault analysis, grasp the key parts of the fault, and propose corresponding solutions based on a comprehensive analysis of the fault. The analysis results show that the failures of the asphalt foaming device mainly occur before and during the asphalt foaming. The FMEA table reflects that the RPN value of the two failure factors of the blockage of the asphalt pipeline and the blockage of the water nozzle is the largest. The three failure factors with the highest severity level (SER) are heater damage, motor damage and PLC control device failure.

1. Introduction
Asphalt foaming equipment is a special equipment for preparing foamed asphalt, and it is also the core equipment in foamed asphalt regeneration equipment. Its reliability directly affects the implementation of foamed asphalt regeneration technology. Asphalt foaming equipment is a new type of equipment in road construction machinery. Due to the complicated asphalt foaming process, the structure of the asphalt foaming equipment is complicated, and because of the harsh working environment, it is easy to cause malfunctions, lose working performance, and cause economic losses.

In recent years, Fault Tree Analysis (FTA) Failure Mode and Effects Analysis, (FMEA) and other fault analysis methods have been applied in mechanical design, manufacture, use, evaluation and other aspects. For example, Zhang et al.[1] summarized the steps and processes of applying the comprehensive analysis method of FMEA and FTA, and initially applied this method to the reliability analysis and evaluation of an aircraft flap mechanism system. Taking the machining center as an example, Li [2] uses FMEA method to find out the fault mode which affects the whole machine, and designs the appropriate equipment maintenance scheme. Hu [3], Shen et al. [4] used the FMEA method to determine the main failure modes and weak links in the design and use of mechanical products, which further laid the foundation for reliability assessment and failure analysis. Zhang [5] first defined the failure mode, the cause of the failure, the impact of the failure, and the boundaries and levels of system research based on the system reliability block diagram and fault tree, combined with brainstorming, fishbone diagram and other tools, and proposed the probability of information entropy in traditional FMEA. Basically solved the defects existing in the traditional FMEA analysis. Peeters, J. F. W. et al.[6] Proposed a method of recursively using FMEA and FTA, and applied this method to additive manufacturing systems, which provided new ideas for the combination of FMEA
and FTA. Hidayat, A. A. [7] and ho, h. D. [8] comprehensively used FMEA and FTA methods to carry out fault analysis for the manufacture and use of mechanical equipment and products, and proposed detailed solutions based on the analysis results. On the other hand, Wessiani, N. A [9] implements the comprehensive method as a risk management method to evaluate the risk of mechanical equipment and products, which lays a theoretical foundation for preventing the risk of mechanical products. Fault mode and impact analysis (FMEA) and fault tree analysis (FTA) are two commonly used fault analysis methods. The FMEA method is a bottom-up method, and the FTA method is a top-down method. Compared with the key structure of the main analysis device of the FTA, the FMEA method requires more expert human knowledge analysis. Using the FMEA method and the FTA method to analyze the failure of the asphalt foaming device alone requires a lot of manpower and material resources. However, using the FMEA method and the FTA method comprehensively and using the complementarity of the two methods, it is easy to grasp the key parts of the failure, and it is easy to analyze the cause of the failure in depth and comprehensively.

This paper intends to comprehensively use FMEA and FTA methods for fault analysis of asphalt foaming plant, and formulate fault relief measures.

2. Fault Analysis of Asphalt Foaming Unit Based on FMEA

2.1. FMEA Analysis Process
When the FMEA method is implemented, it takes the severity, fault occurrence probability and fault detection probability as the scoring objects, calculates the risk priority number through scoring, and ranks the importance of the events according to the risk priority number, so as to accurately judge the weakness of the device design or manufacture, and then make targeted improvements to eliminate the adverse effects.

The FMEA analysis process of this paper is as follows: (1) fully understand the structure of the asphalt foaming device and analyze the specific functions of the device in detail. (2) deeply analyze the failure modes, causes and effects of all the components of the asphalt foaming unit. (3) taking the severity, failure probability, fault detection probability and difficulty of fault detection as the evaluation criteria, the importance of all parts of asphalt foaming device is analyzed, and the risk priority number is calculated. (4) make the FMEA table and put forward the improvement measures to the equipment.

![FMEA work flow chart](image)

**Figure 1.** FMEA work flow chart.

2.2. Fault Scoring Standard
Based on an in-depth analysis of each component of the asphalt foaming device, the rating of the asphalt foaming device is formulated based on the scoring criteria and details of the severity, the probability of failure occurrence, the difficulty of finding the fault, and the risk evaluation of the asphalt foaming device. Detailed rules and scoring rules are shown in Table 1, Table 2, and Table 3.
Table 1. Severity SER score basis and details

| Category | Severity influence | The severity of the impact of the failure | SER rating |
|----------|--------------------|------------------------------------------|------------|
| I        | Minimum influence  | It has little impact on the function of the component. The parts of the equipment are slightly damaged and there is no obvious failure in a short time. Resulting in a decline in the performance of the device system | 1, 2       |
| II       | Slight influence   |                                          | 3, 4       |
| III      | Medium influence   |                                          | 5, 6       |
| IV       | Serious influence  | Lead to the destruction of the important functions of the device. The equipment can not be repaired and has been paralyzed. | 7, 8       |
| V        | Disaster influence |                                          | 9, 10      |

Table 2. PFO rules of failure probability

| The possibility of failure | Extremely low | Lower | Medium | High | Very high |
|----------------------------|---------------|-------|--------|------|-----------|
| PFO rating                 | 1, 2          | 3, 4  | 5, 6   | 7, 8 | 9, 10     |

Table 3. PD scoring details of fault detection probability

| Detection probability | The degree of failure mode discovery | PD rating |
|-----------------------|--------------------------------------|-----------|
| Almost impossible to find | No way to figure out the failure | 9, 10     |
| Detection rate is very low | The possibility of finding the failure mode is slim. | 7, 8     |
| Low detection rate | Finding failure modes is less likely | 5, 6     |
| Medium detection rate | It is more likely to find out the failure mode. | 3, 4     |
| High                  | The possibility of finding | 1, 2     |
3. Risk Priority Evaluation

The possible failure modes of asphalt foaming plant are analyzed comprehensively, and the causes, effects and potential faults of each failure mode are analyzed. Based on Tables 1, 2, and 3, scoring criteria were developed for risk assessment. Risk assessment is a comprehensive judgment of the risk of the system, and it is a comprehensive consideration of the severity, occurrence probability and the degree of difficulty of discovery. The calculation method is like formula (1). The higher the value of risk priority number, the higher the risk of failure and the higher the importance. On the contrary, the lower the risk of failure, the lower the importance.

$$RPN = S \times O \times D$$  \hspace{1cm} (1)

In the formula: S is the hazard degree, the value range is 1-10; O is the occurrence probability, the value range is 1-10; D is the failure detection probability, the value range is 1-10. The key to calculating RPN is to determine the evaluation principle of S, O, D, which is determined by statistical method or experience.

4. Make FMEA Table

The fully automatic foamed asphalt preparation device includes asphalt piping system, foaming water system, compressed air system, asphalt heating and heat preservation system, foamed asphalt preparation device and PLC automatic control device [13]. According to the basic principle of FMEA, the structure and function, fault mode, fault cause, fault impact analysis and each score value of the asphalt foaming device are summarized, and the FMEA analysis table is formed, such as Table 4, which visually displays the analysis results, and puts forward the corresponding preventive measures.

Table 4. FMEA analysis table

| Failure mode       | Cause of failure                        | Consequences of failure                        | SER | PFO | PD  | RPN | Preventive measures                                      |
|--------------------|----------------------------------------|-----------------------------------------------|-----|-----|-----|-----|---------------------------------------------------------|
| Heater damage      | Improper use, the temperature exceeds  | The temperature does not meet the requirements.| 8   | 6   | 2   | 96  | Periodic maintenance to prevent damage to device         |
|                    | the bearing range                       |                                                |     |     |     |     | components                                             |
| Asphalt pump       | The sealing ring is not installed       | The amount of asphalt can not meet the foaming | 6   | 3   | 3   | 54  | Check and test the reliability of the grounding system  |
| leakage            | correctly                               | requirement.                                   |     |     |     |     | periodically periodically                               |
| Crack of asphalt   | Improper use or unreasonable design    | Cause the waste of asphalt resources           | 2   | 2   | 1   | 4   | The tank body is made of high material and maintained   |
| tank               |                                        |                                               |     |     |     |     | regularly. When designing and installing, use           |
| Water pump         | Interaction between denudation and     | The water consumption of foaming can not meet| 5   | 4   | 2   | 40  | anticorrosive                                          |
| corrosion          | corrosion on                           | the                                           |     |     |     |     |                                                         |
| Problem Description | Cause | Solution |
|---------------------|-------|----------|
| The seal of asphalt one-way valve is not tight. | The valve ball and the inlet are not tightly sealed. | Speed up the failure life of asphalt one-way valve |
| Asphalt one-way valve damage | Wear of spool sealing ring and damage of valve stem and seat after long-term use | There is a reflux phenomenon, and the amount of asphalt can not meet the foaming requirements. Unable to transport asphalt, asphalt foaming cannot be completed |
| Asphalt pipeline blockage | The asphalt is solidified in the inner wall of the pipe. | |
| Asphalt pipeline leakage | Corrosion perforation of pipeline | Asphalt leakage |
| Air nozzle opening deformation | The thickness of the opening is small and the strength is not enough. | The foaming effect of asphalt is not sufficient. |
| Water nozzle clogging | The asphalt solidified near the water nozzle. | Increase the probability of asphalt foaming failure |
| Water tank cracking | Water tank structure aging | Cause water leakage |
| Conical rod end fracture | The rod is too long or too thin, and the strength is not | Increase the probability of asphalt foaming failure |

- **materials and coatings, and check regularly. Regular inspection and maintenance of asphalt one-way valve**
- **Check and maintain the one-way valve regularly and clean the one-way valve in time**
- **Clean up the asphalt pipeline with appropriate tools in time**
- **Reasonable design and installation, and regular inspection and maintenance**
- **Reasonable design of air nozzles to increase the strength of air nozzles**
- **Reasonable design of water nozzle to reduce the possibility of asphalt adhesion to water nozzle**
- **The tank body is made of high material to control the water pressure.**
- **Reasonable design of rod length and diameter**
Damage to pump motor

| Condition Description | Cause | Prevention Measures |
|------------------------|-------|---------------------|
| Long-term use without paying attention to maintenance | Unable to transport water and raw materials in time | Keep the motor clean; keep running at rated power; check the motor regularly. When selecting the motor, the configuration should be greater than the working requirements; regular maintenance and maintenance should be carried out. Increase the thickness of the foaming cavity; increase the strength of the foaming cavity wall. Check the tightness of the nut regularly and use the release nut or spring gasket. Avoid empty burning when in use; ensure sufficient heat dissipation space to avoid local overheating. Regularly check the PLC system; maintain the stability of the PLC. |

Asphalt pump motor damage

| Condition Description | Cause | Prevention Measures |
|------------------------|-------|---------------------|
| The specific gravity of viscous asphalt exceeds the motor of asphalt pump. | Unable to transport asphalt raw materials in time | When selecting the motor, the configuration should be greater than the working requirements; regular maintenance and maintenance should be carried out. Increase the thickness of the foaming cavity; increase the strength of the foaming cavity wall. Check the tightness of the nut regularly and use the release nut or spring gasket. Avoid empty burning when in use; ensure sufficient heat dissipation space to avoid local overheating. Regularly check the PLC system; maintain the stability of the PLC. |

Deformation of asphalt foaming cavity

| Condition Description | Cause | Prevention Measures |
|------------------------|-------|---------------------|
| Asphalt collides with the inner surface of the foaming cavity | Changing the foaming space of asphalt, the foaming of asphalt is unstable. | Increase the thickness of the foaming cavity; increase the strength of the foaming cavity wall. Check the tightness of the nut regularly and use the release nut or spring gasket. Avoid empty burning when in use; ensure sufficient heat dissipation space to avoid local overheating. Regularly check the PLC system; maintain the stability of the PLC. |

Loose ball screw nut

| Condition Description | Cause | Prevention Measures |
|------------------------|-------|---------------------|
| Vibration causes nut loosening | Speed up the service life of ball screw | Check the tightness of the nut regularly and use the release nut or spring gasket. Avoid empty burning when in use; ensure sufficient heat dissipation space to avoid local overheating. Regularly check the PLC system; maintain the stability of the PLC. |

Electric coil damage

| Condition Description | Cause | Prevention Measures |
|------------------------|-------|---------------------|
| Improper use of electric heating ring | The temperature cannot be guaranteed. | Avoid empty burning when in use; ensure sufficient heat dissipation space to avoid local overheating. Regularly check the PLC system; maintain the stability of the PLC. |

PLC control device burnt out

| Condition Description | Cause | Prevention Measures |
|------------------------|-------|---------------------|
| Improper use of PLC | PLC failure | Regularly check the PLC system; maintain the stability of the PLC. |
Compressed air nozzle blockage  

Waste asphalt blocks the nozzle  
The cleaning asphalt is not in place.  
4 5 4 80

Breakage of water one-way valve  

Wear of spool sealing ring and damage of valve stem and seat after long-term use  
Water backflow, increasing the probability of asphalt foaming failure  
7 4 3 84

Damage of floating ball level gauge  

There is no cleaning, wiping and derusting of the parts.  
The control of asphalt liquid level is not accurate.  
5 3 3 45

Asphalt Flowmeter failure  

High and low limit switch failure of asphalt tank  
Inaccurate bitumen flow control; insufficient foaming  
5 3 4 60

Water pressure transmitter failure  

Transmitter settings are incorrect; system equipment is incomplete  
The amount of foaming water can not be controlled and the foaming is not sufficient.  
6 3 3 54

From the table analysis, it can be seen that the RPN value of asphalt pipeline blockage and water nozzle blockage is the highest. Therefore, emphasis should be placed on monitoring in the use and maintenance of asphalt foaming plant, and control and prevention should be carried out according to corresponding measures to eliminate or reduce the failure mode. The highest

power supply system and its working environment  

Regularly check and clean compressed air nozzles  

Reasonable installation of one-way valve, regular maintenance  

Regularly disassemble the floating ball level meter, clean, wipe and remove rust on the disassembled parts; replace the gasket, supplement and replace the packing and lubricating grease  

Regularly clean and inspect equipment to delay gate valve opening and closing times  

Check and reset; regular maintenance to ensure that the system is in good condition
severity level of (SER) is heater damage, motor damage and PLC control device. This kind of failure mode should be avoided in the use of asphalt foaming unit. The faults of asphalt one-way valve, heater and electric coil are also risk factors that can not be ignored. Although these faults will not directly cause serious accidents, they will greatly increase the probability of asphalt foaming failure, and eventually lead to the failure of the whole plant, so we must pay attention to daily inspection and replacement in order to reduce the incidence of failure.

5. Fault Analysis of Asphalt Foaming Unit Based on FTA

In the FTA analysis, the most unwanted failure mode is taken as the top event T, and each factor that leads to the top event T is found as the lower middle event or bottom event of the top event, and a logical relation connection is adopted, and the logical relationship is represented by the logic gate symbol. Foaming failure T of foamed asphalt is caused by pre-foaming fault T1 of foamed asphalt plant and fault T2 in foaming of foamed asphalt plant, either of which leads to the occurrence of event T. Therefore, the pre-foaming fault T1 and the foaming failure T2 of the foamed asphalt unit are regarded as the lower intermediate events of the foamed asphalt foaming failure T and are connected through the OR door. By analogy, faults T1 before foaming of the foamed asphalt plant are caused by fault A of the conveying system, faults B of the foaming water system, faults C of the compressed air system, and heating and insulation system D of the asphalt; leading to fault T2 during foaming of the foamed asphalt The fault E of the foamed asphalt preparation system and the fault F of the PLC automatic control device occurred. The above faults are regarded as the intermediate events in the second room, and according to the FMEA analysis, the bottom events that lead to the intermediate events on the second floor are recorded in the FMEA table, and the mixer structure fault tree is established. As shown in Table 5.

![Figure 3. Fault tree of asphalt foaming device](image)

Logic gate in the figure is an OR gate, which means that any occurrence of a lower-level event will cause an upper-level event to occur.

| Code | Corresponding | Code name | Corresponding |
|------|---------------|-----------|---------------|

Table 5. bottom event table corresponding to each code of the fault tree
The purpose of fault tree qualitative analysis is to find the factors that lead to the top event, to express the cause of the failure of the system objectively and directly, and to find out all the possible failure modes that lead to the top event, that is, to find out the cause set that can cause the top event to occur-cut set day. The set of indispensable bottom events that cause the top event to occur is called the minimum cut set. According to the characteristics of the fault tree of the asphalt foaming device, the minimum cut set of the fault tree is obtained by the descending method. The descending method is performed from the top event from top to bottom, and each step is simplified by using the set algorithm, and the minimum cut set is calculated at the end. Because each bottom event in the asphalt foaming plant system is "or", so each bottom event is a minimum cut set, so the minimum cut set in the fault tree of the asphalt foaming plant is each bottom event shown in Table 5. The definition of the minimum cut set has clearly pointed out that each minimum cut set represents a possibility that leads to the top event, in other words, the more the minimum cut set, the more likely the system is to fail.

### 6. Conclusion

Aiming at the failure analysis of the asphalt foaming device, a qualitative analysis method combining fault mode impact analysis (FMEA) and fault tree analysis (FTA) was proposed.

The main contents are as follows:

(1) aiming at the six subsystems of asphalt foaming plant, the fault mode, fault consequence and fault detection method are analyzed by FMEA method, and the fault prevention measures of asphalt foaming plant are listed respectively. According to the FMEA table, the RPN value of the blockage of the asphalt pipeline and the blockage of the water nozzle is the largest, so it is important to monitor this failure mode during the use and maintenance of the asphalt foaming...
device, and control and prevent it in time according to corresponding measures to eliminate or reduce the failure in failure mode. The highest severity level of (SER) is heater damage, motor damage and PLC control device failure. These failure modes should be avoided in the use of asphalt foaming unit.

(2) establish the fault tree of the asphalt foaming plant and find the minimum cut set of the fault tree of the asphalt foaming plant as each bottom event. The results show that the more the number of bottom events in the asphalt foaming unit, the greater the failure probability of the asphalt foaming unit system.

The fault analysis of asphalt foaming plant provides a new idea for the design and manufacture of asphalt foaming plant, and provides a theoretical basis for condition monitoring and fault diagnosis.

Acknowledgments
The author thanks the National Natural Science Foundation of China (No. 51265033) and the Natural Science Foundation of Inner Mongolia Autonomous Region (No. 2019MS05077) for supporting the research.

References
[1] Zhang J G and Huang W M 2000 Comprehensive Analysis method of FMEA and FTA for large Mechanical products, Machinery Design and Manufacture 47 1-3
[2] Li J W 2006 Research on the Application of FMEA in equipment maintenance, Southwest Jiaotong University
[3] Hu T S 2015 Reliability evaluation and distribution of large mine excavator based on fault maintenance data University of Electronic Science and Technology of China
[4] Sheng Z, Niu C M and Deng L X 2012 Application of FMEA in reliability design of construction machinery system Construction Machinery and Equipment 27 38-42
[5] Zhang K 2017 Improvement of failure mode and influence analysis taking medium and thin plate straightener as an example Tianjin University
[6] Peeters J F W, Basten R J I and Tinga T 2017 Improving failure analysis efficiency by combining FTA and FMEA in a recursive manner Reliability Engineering and System Safety 71 36-44
[7] Hidayat A A, Kholil M and Suhaeri 2018 The Implementation of FTA (Fault Tree Analysis) and FMEA (Failure Mode And Effect Analysis) Methods to Improve the Quality of Jumbo Roll Products In International Conference on Design Engineering and Computer Sciences 21 453-7
[8] Ho h d and Soon K F 2019 Fault-tree based reliability analysis for bidirectional converter Journal of IEEE 254-260
[9] Wessiani N A and Yoshio F 2018 Failure mode effect analysis and fault tree analysis as a combined methodology in risk management In International Conference on Industrial and Systems Engineering 237 337-343
[10] Zhao H G 2018 Failure reasons and maintenance measures of road construction machinery Plant Maintenance Engineering 79 81-82
[11] Li H 2017 Causes of failure of road construction machinery and maintenance measures Transpoworld 19 210-1
[12] Huang Z 2018 Causes and maintenance measures of road construction machinery failure China Highway 36 106-7
[13] Cheng H Y, Yan T Y and Li Z Q 2012 Foam asphalt preparation device and automatic foam asphalt preparation device CN102587257A