Fault Analysis and Solution on Bucket Dropping Accident in Hoisting System

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Abstract: Overwinding was the main accident in lifting systems of coal mine and bucket dropping accident was the most serious overwinding accident. According to the cause and mechanism of the bucket dropping accident in main shaft hoisting systems, the conclusion that overloading promotion was the main cause of bucket crash accident was obtained with the fault tree analysis method. One theoretical analysis model was established in order to prevent the occurrence of overloaded bucket dropping accident. The model provided scientific basis and steps in theory for qualitative and quantitative analysis on the cause of falling bucket accident and for the study on accident prediction and prevention. This article proposed several feasible technical measures to prevent the bucket crash accident, which had important guiding significance in practical application.

Keywords: Overwinding, Bucket Dropping Accident, Fault Tree Analysis Method, Accident Model, Feasible Technical Measure.

1. Introduction

Overwinding is the main cause of accidents in lifting systems of coal mine. Overwinding accident almost exists in all multi-rope friction hoist mine. Slightly overwinding has no direct damage but delaying coal’s lifting time. However, seriously overwinding may crash anti-collision beams and hoist vessels, break wire rope then cause bucket falling. The latter can cause great economic losses. So bucket dropping was the most serious accident in main shaft lifting systems. According to the severity degree of the accident causes, it can be divided into low speed overwinding, full speed overwinding and overspeed overwinding [1].

Low speed overwinding. The hoist vessel has entered the normal decelerating phase before overwinding. Stop switch out of order and control error are main causes of low speed overwinding.

Full speed overwinding. The hoist vessel passes the stop position at the top hoisting speed without decelerating. Full speed overwinding has different consequences when wedge guide and winch emergency brake in different condition. One is that the emergency brake in good condition and wedge guide designed reasonably and maintained properly, they can absorbed the energy of the overwinding system completely then they can make the hoist vessel stop at the end of the wedge guide. In this case, overwinding won't cause greater economic loss. The
other is that one or both of emergency brake and wedge guide are faultiness, they can not absorbed the energy of the overwinding system completely, thus the hoist vessel will hit the anti-collision beam, serious overwinding accident will happen.

Overspeed overwinding. The lifting speed is higher than the top hoisting speed when overwinding happening. In this case, serious overwinding accident will happen almost without exception whether emergency brake and wedge guide are reliable [2]. The reasons of this kind of overwinding are mainly divided into three kinds. The first one is that overloaded container slides downward when it is lifted and drops more and more fast. The second one is that wrong operation to opposite direction when the heavy bucket is lifted to intermediate. The third one is that electric control system and hoisting out of control.

In this paper, all kinds of basic events leading to overwinding accident will be analyzed in detail to build fault tree chart of main shaft lifting accidents. The structure importance will be calculated out to analyze each basic event’s influence on the bucket crash accidents. In order to prevent bucket crash accidents in main shaft lifting systems, the theoretical analysis model of bucket dropping accidents will be built. Several feasible ways to avoid the bucket crash accident will be put forward based on the analysis of theoretical accident model.

2. Research Method

In this section, fault tree analysis method of analyzing bucket dropping accidents in main shaft lifting systems will be introduced in detail.

2.1. Common Types of Malfunction in Main Shaft Lifting System

Several common electromechanical malfunctions are shown in Fig. 1.

MEM – electromechanical malfunction types in main lifting system
M1 – bucket overwinding
M2 – winch overspeed
M3 – serious overload
M4 – long space of disc brake shoe [3]
M5 – long time of lost motion
M6 – hydraulic pressure stands fault
M7 – electromagnetic valve fault
M8 – cylinder liner friction small
M9 – brake disc oil polluted heavily
M10 – high residual pressure
M11 – deceleration switch damaged
M12 – speed limit protection device failure
M13 – depth indicator failure
M14 – bucket stuck
M15 – overwinding protection device failure
M16 – electrical control system failure
M17 – signal processing system failure

2.2. Building Accident Tree of Main Shaft Lifting System [4]

The conclusion that bucket dropping accident after serious overwinding is the most undesired event in main shaft lifting systems can be got based on the analysis of all kinds of overwinding accidents. So, bucket dropping was determined as the top event. The top event together with 9 intermediate events and 13 basic events form the accident tree according to the logical relationship [5]. The structural table of accident tree is shown in Table 1 and the accident tree is shown in Fig. 2.

In Fig. 2, T represents the top event, i.e., bucket crash, A to I represent the intermediate events, Z1 to Z13 represent the basic events.

A – wire rope serious skid
B – winch brake failure
C – wire rope tension ratio big
D – the small friction coefficient between wire rope and pulley gasket
E – disc brake torque small
F – positive pressure small
G – small friction coefficient between brake shoe and brake disc
Table 1. The structural table of fault tree.

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Gate name</th>
<th>Gate type</th>
<th>Event Number</th>
<th>Basic events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T</td>
<td>OR</td>
<td>2</td>
<td>A B</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>AND</td>
<td>2</td>
<td>C D</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>AND</td>
<td>2</td>
<td>01 E</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>OR</td>
<td>3</td>
<td>01 02 03</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>OR</td>
<td>2</td>
<td>04 05</td>
</tr>
<tr>
<td>6</td>
<td>E</td>
<td>OR</td>
<td>2</td>
<td>F G</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>OR</td>
<td>4</td>
<td>H 06 07 1</td>
</tr>
<tr>
<td>8</td>
<td>G</td>
<td>OR</td>
<td>2</td>
<td>8 9</td>
</tr>
<tr>
<td>9</td>
<td>H</td>
<td>OR</td>
<td>2</td>
<td>10 11</td>
</tr>
<tr>
<td>10</td>
<td>I</td>
<td>OR</td>
<td>2</td>
<td>12 13</td>
</tr>
</tbody>
</table>

2.3. Deducing Fault Tree Minimum Cut Sets

Fault tree’s structure function can be deduced according to the logical relationship in Fig. 2.

\[ T = A + B = CD + ZE \]
\[ = (Z_1 + Z_2 + Z_3)(Z_4 + Z_5) + Z_6(F + G) \]
\[ = (Z_1 + Z_2 + Z_3)(Z_4 + Z_5) + Z_6(Z + Z_7 + I) + Z_7G \]
\[ = (Z_1 + Z_2 + Z_3)(Z_4 + Z_5) + Z_6(Z_9 + Z_10 + Z_11 + Z_12 + Z_13) + Z_6(Z_8 + Z_6) \]
\[ = Z_9 Z_9 + Z_10 Z_9 + Z_7 Z_9 + Z_8 Z_9 + Z_9 Z_9 + Z_9 Z_8 \]
\[ = Z_9 Z_9 + Z_9 Z_9 + Z_9 Z_8 + Z_9 Z_9 + Z_9 Z_8 \]
\[ = Z_9 Z_9 + Z_9 Z_9 + Z_9 Z_8 + Z_9 Z_8 + Z_9 Z_8 \]
\[ = Z_9 Z_9 + Z_9 Z_9 + Z_9 Z_8 + Z_9 Z_8 + Z_9 Z_8 \]
\[ = Z_9 Z_9 + Z_9 Z_9 + Z_9 Z_8 + Z_9 Z_8 + Z_9 Z_8 \]

According to the definition of the minimum cut set, the top event (i.e. bucket crash) has 14 sets of basic events.

\[ K_1 = \{Z_1, Z_4\}, K_2 = \{Z_1, Z_5\}, K_3 = \{Z_2, Z_3\}, K_4 = \{Z_2, Z_1\} \]
\[ K_5 = \{Z_2, Z_4\}, K_6 = \{Z_2, Z_5\}, K_7 = \{Z_3, Z_2\}, K_8 = \{Z_3, Z_1\} \]
\[ K_9 = \{Z_3, Z_6\}, K_{10} = \{Z_3, Z_9\}, K_{11} = \{Z_4, Z_7\}, K_{12} = \{Z_4, Z_8\} \]
\[ K_{13} = \{Z_4, Z_9\}, K_{14} = \{Z_5, Z_{13}\} \]

2.4. Deducing Fault Tree Minimum Path Sets

The first step of deducing minimum path sets is to build the success tree of main shaft lifting system. The success tree can be built by using AND instead of OR, using OR instead of AND, using complementary events instead of basic events.

The success tree is shown in Fig. 3.

According to the definition of the minimum path set, the minimum cut sets of success tree are the minimum path sets of the fault tree.

\[ T' = A' B' = (C + D')(Z_1' + E') \]
\[ = (C + D')(Z_1' + F' G') \]
\[ = (C + D')(Z_1' + Z_2' Z_3' + Z_4' Z_5' + Z_6' Z_7' Z_8' Z_9') \]
\[ = (Z_1' Z_2' Z_3' + Z_4' Z_5' + Z_6' Z_7' Z_8' Z_9') \]
\[ = Z_1' Z_2' Z_3' + Z_4' Z_5' + Z_6' Z_7' Z_8' Z_9' \]
\[ + Z_1' Z_2' Z_3' + Z_4' Z_5' + Z_6' Z_7' Z_8' Z_9' \]
\[ + Z_1' Z_2' Z_3' + Z_4' Z_5' + Z_6' Z_7' Z_8' Z_9' \]

The success tree has 3 sets of basic events as following.

\[ K_1' = \{Z_1', Z_2', Z_3', Z_4'\}, K_2' = \{Z_1', Z_6', Z_8'\} \]
\[ K_3' = \{Z_4', Z_5', Z_6', Z_7', Z_9', Z_10', Z_11', Z_12', Z_13'\} \]
The success tree chart of lifting accidents.

So the fault tree’s minimum path sets can be written out as following.

\[ P_1 = \{Z_1, Z_2, Z_3, Z_4\}, \quad P_2 = \{Z_4, Z_5, Z_6\} \]
\[ P_3 = \{Z_7, Z_8, Z_9, Z_{10}, Z_{11}, Z_{12}, Z_{13}\} \]

2.5. Calculation of Structure Importance Degree

The structural importance is the basic events’ important degree on the fault tree. Basic events’ structure importance is higher and its effect on the top event is greater. Sorting the basic events’ structure importance order by using the minimum cut sets is the usual method of calculating structure importance. The basic events’ structure importance is calculated out according to structural importance’s computational formula [6].

\[ I_\phi(1) = 10 \times \frac{1}{2^{2-1}} = \frac{10}{2} = 5 \]
\[ I_\phi(2) = I_\phi(3) = 2 \times \frac{1}{2^{2-2}} = \frac{2}{2} = 1 \]
\[ I_\phi(4) = I_\phi(5) = 3 \times \frac{1}{2^{2-2}} = \frac{3}{2} = 1.5 \]
\[ I_\phi(6) = I_\phi(7) = I_\phi(8) = I_\phi(9) \]
\[ = I_\phi(10) = I_\phi(11) = I_\phi(12) = I_\phi(13) \]
\[ = 1 \times \frac{1}{2^{2-1}} = \frac{1}{2} = 0.5 \]

It is obvious that the Z1 event’s structure importance is the highest. Bucket overloading should be given enough attention.

3. Results and Analysis

There are 9 intermediate events and 13 basic events leading to bucket crash accident (i.e. top event). The above events independent function or combination could lead to accidents. So the risk of system must cause enough attention.

There are 10 logic gates consisting in the fault tree, 8 OR gates and 2 AND gates. From the fault tree’s component ratio of logic gates to see, the risk of bucket crash accident happening is very high.

The number of minimum cut sets is 14 and the number of minimum path sets is 3. It means that there are 14 “possible ways” leading to bucket crash accident and there are only 3 “prevention ways”. Moreover, basic events in minimum cut sets are less than that in minimum path sets. Thus the bucket dropping accident in main shaft lifting system is easy to happen and difficult to control.

The following analysis is given by considering the structure importance. Firstly, the Z1 (bucket overload) event’s structure importance is the highest one that show Z1 is the most serious cause of the bucket dropping accident. Promotion should be prohibited and be processed immediately if bucket was overloaded. In order to ensure the safety of hoisting system, security measures should be taken in underground loading operation in shaft. If fixed-quantity bucket installed constant weight automatic loading system, the safety performance will be better. Secondly, Z4 and Z5 have serious impact on bucket dropping accident. Bad gasket material quality (Z4) will directly cause wire rope slipping and winch brake out of action. The problem of gasket material quality can be solved in the purchase links. Gasket oil pollution (Z5) will reduce the friction coefficient thus it will influence promotion safety. The problem of gasket oil pollution can be solved by frequent maintenance in practical application. Thirdly, Z2 and Z3 also have great influence on falling bucket accident. Although bucket stuck (Z2) events seldom occur, once appear will cause a serious accident. Acceleration and deceleration fast (Z3) will bring great impulse to heavy bucket. So electronic control circuit must be well designed, acceleration and deceleration speed can not exceed the value specified in Safety Regulations in Coal Mine. Finally, the rest events from Z6 to Z13 don’t have great influence on bucket crash accident, but they should be given enough attention too. Any one occurs alone does not
seem to have a significant impact on the top event, but two or more events occur at the same time will directly lead to the occurrence of the top event. So, various parts should be given careful maintenance and regular testing to eliminate all potential risk factors.

4. Solution

The theoretical analysis model of bucket dropping accidents has been built based on the full analysis of the accident causes [7]. At the same time, the model is the result of practical application of safety system engineering theory. The model provides a theoretical basis on qualitative and quantitative analysis on the accident causes. It also provides scientific theoretical basis on accident prediction and prevention. The model of bucket dropping accidents in main shaft lifting systems is shown in Fig. 4.

It can be seen that bucket overloading is very easy to happen with only manual control if there are no constant weight devices. Bucket overweight is “potential hidden trouble” which will lead to falling bucket accident. If there are no promotion signals in main shaft and no constant weight automatic loading systems, the weight of coal in bucket may be higher than winch safe lifting load. Winch overload is “direct hidden trouble” which will lead to falling bucket accident. If hoistman could not stop overloaded winch lifting in time for his human negligence, the overloaded bucket will slide down in ascension process. The hoisting of violation of regulation should be forbidden absolutely when the weight of loaded bucket is higher than winch loading capacity. Once the overweight buckets slide down in ascension process, the only way that may avoid falling bucket accident is perfect brake system. However, perfect brake system can not skid the winch when it is serious overloaded. So, it is described with dotted line in Fig. 4.

The feasible ways to avoid the bucket crash accident can be found out based on the analysis of theoretical accident model. Using reliable quantitative bucket weighing equipments can eliminate “potential hidden trouble” of falling bucket accident [8]. Using shaft signal and automatic loading systems with high performance can prevent “direct hidden trouble” of falling bucket accident [9]. In addition, the final way to avoid the bucket crash accident is that hoistman must completely eradicate violation of regulation.

5. Conclusions

The fault tree chart of main shaft lifting accidents was built based on the analysis of all kinds of overwinding accidents. Comprehensive analysis on causes of the accident was given in this article combined with the fault tree structure. The structure importance was calculated out to analyze each basic event’s influence on the bucket crash accident. Several feasible technical measures were proposed to avoid the bucket crash accident on analysis of bucket dropping accident model. It has important guiding significance to accident prediction and prevention in main shaft lifting systems.

![Figure 4](https://example.com/fig4.png)

**Fig. 4.** The theoretical analysis model of bucket accidents.

References


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