Research on safety input research model for preventing coal gas explosion*

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Abstract

The paper dedicates to analysis of the main reasons of the mine gas explosion accident through the statistics of mine gas explosion accidents at home and abroad. The inner logic relationship between accidents and the causes of accidents is explored by using fault tree analysis method. The relationship between the safety input and accident occurrence frequency is discussed, and the function relationship between which is established with GongBo curve. On the basis of settled safety investment, using the influence of basic event on top accident’s occurrence probability, the safety input optimization allocation model is established for the goal of making the accident occurrence probability minimum, which can be solved by using Lingo software based on historical data.

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1. Introduction

In the process of mining coal, many disaster accidents occur frequently, such as gas coal-dust explosion, fire, floods, roof take fell, coal and gas outburst, impact pressure, poisoning, choking, and so on. From the statistics of accidents of each year, the great majority of coal mine accidents each of which caused 10 or more deaths is gas explosion, accounting for about 70% of the total number of great

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accidents. At present, the most of key state-owned coal mines are methane mines in our country, and the number of high gas mines and gas outburst mines accounts for 44% of the total. And the key of coal mine safety production is to prevent and control gas explosion, which is the top priority of our work. Therefore, in order to ensure the safety of coal production, strong measures must be taken to prevent and treat great coal mine gas accidents effectively.

The implementation of safety measures preventing accidents need certain safety input. The safety input for preventing coal gas explosion can be divided into engineering physical input and human behavior input. Engineering physical input refers to the use of physic engineering technology means to eliminate unsafe factors and make production process, mechanical equipments and other production conditions safe. Human behavior input refers to use of education and implementation of safety management rules and regulations to make the production process safe. The effect of different content of safety input on system safety is different. In this paper, the allocation of all safety investments according to the probability of the basic events has been discussed, which will realize reasonable allocation of funds among various activities and realize safety input optimization with a limited total safety input, and which has an important significance to prevent gas explosion.

2. Analysis on the cause of accident Based on the FTA

2.1 Analysis on the reason of the mine gas explosion

According to the theory of gas explosion, there must be three basic conditions for gas explosion: one is the gas concentration (the limit concentration of gas explosion is general 5%~16%), the second is the supply of oxygen (the oxygen content is more than 12%), and the last is the source of fire to ignite the gas (general above 650 ℃ ~750 ℃, many kinds of fire can cause gas explosion, such as the flame, the spontaneous combustion of the coal, electric spark, the hot metal surface, blasting, and so on.) The three conditions must be coexisted simultaneously. Usually, the oxygen supply is satisfied naturally, because the concentration of oxygen is generally greater than 20% in normal ventilation. So in most conditions, as long as the certain concentration of gas and the spark origin are coexisted at the same time, gas explosion is inevitable. Therefore, oxygen concentrations will not be analyzed as a basic event when analysis of the gas explosion accident tree in section 2.2.

According to the mine gas explosion at home and abroad, it is showed that the main reasons of mine gas explosion are caused by following aspects.

1) the explosive gas is formed

The main cause of formation explosive gas is the mine ventilation system can't meet the actual need, and the mine gas cannot be pulled out promptly. The configurations of mine safety equipments are insufficient. These policies had not been fully implemented: "mining after pumping, monitoring, the yield of mining is determined by air volume." A lot of coal mines are not equipped with the gas drainage systems or drainage systems can't operate effectively, such as the power failure, the wind ability of ventilator is not enough or the ventilation system is unreasonable, which cause lack of wind in mine and make mine gas accumulation, and which eventually causes serious mine gas explosion accidents. Anything else, the monitoring system can't effectively work too, then the explosive gas is formed.

2) existing spark origins

In some coal mines, the problem of spark origin is still existed. For example, some mines still have open wire circuits and flames, some electrical equipments of mines existed explosion phenomenon, even some electricians removed or damaged the explosion-proof closed circle and caused the explosion because they don't understand technology or are irresponsible. The main sources of detonating gas
explosion are blasting sparks, electric sparks, strike sparks, friction sparks, electrostatic sparks, coal spontaneous combustion, smoking, use miner’s, high power light bulb, etc.

(3) management defects

The profound reason of gas explosion accidents is the defected management, and which cause the operational staffs violate their own duties. According to the data analysis, the majority of the coal mine gas explosion is because the staffs’ violating operation, and most of the gas explosion is caused by the “three violations”\[10\]. Many of the coal mine workers are low degree of culture, and they do not accept formal safety training well. Workers’ safety consciousness are weak, they often use the way of “teacher led the disciple” in mining operations, they are lack of basic knowledge about safety production, they do not understand ventilation safety managements and operating rules, and they have seriously phenomenon, such as thought paralysis, against the rules and adventure foolhardy.

2.2 building gas explosion tree

On the basis of the above cause analysis of the mine gas explosion accident, hazard is identified following the relevant principles of Fault Tree. The mine gas explosion is the top event of the fault tree T, then find the basic influence events Xi which caused the accident, and eventually construct the coal gas explosion fault tree according to the logical relationship among events as shown in figure 1.

According to the method of fault tree analysis, this fault tree has 24 minimum cut sets, which represent the 24 kinds of ways for gas explosion. If the probabilities of the basic events are known, the probability of the top event on the fault tree can be calculated according to some relevant formulas. Obviously, the probability of the basic event is larger, and it is more serious to the top event. If all basic events can be prevented, the top event can never occur. Therefore, taking corresponding safety input to reduce the probabilities of the basic events will reduce the occurrence probability of the top event.

Different enterprises can establish different fault trees according to their environments and the conditions of safe production. In order to facilitate the calculation of safety input allocation model in the next step, the division of the basic event may not have to be too thin to analysis of the fault tree, and the safety inputs which can prevent the basic events in the accidents tree will be classified as 2 kinds of safety
input projects of coal mine gas explosion prevention, namely engineering physical inputs and human behavior inputs.

In the fault tree of figure 1, the necessary inputs for preventing basic events belonging to engineering physical inputs are: X1 power failure, X2 insufficient of wind, X4 gas leak, X6 miner's use, X8 high power light bulbs, X10 electrical fire; the necessary inputs for preventing basic events belonging to human behavior inputs are: X3 not ventilation in time, X5 smoking, X7 blasting flame, X9 strike sparks and friction sparks, etc. Of course, these two types of investments are not totally independent of each other, some items of safety input for preventing the occurrence of basic events may contain both engineering physical input and human behavior input. In practical applications, the safety input items can be divided according to the specific situations and indicate it.

3. Building safety input optimal distribution model

If the safety input used to prevent mine gas explosion is known as D yuan (according to ALARP principles) [11-14]. Through the fault tree analysis, the probability of each minimum cut set Mi of the top event T is \( P_i = P(x_1, x_2, ..., x_j) \), in which, \( i = 1, 2, ..., n \), said the number of minimum cut set, \( x_j \) is said to the probability of basic event \( X_j \) which belongs to minimum cut set \( M_i \), \( 0 \leq x_j \leq 1 \). Then, according to probability calculation method of the fault tree, the probability of the top event —— gas explosion accident is \( P \):

\[
P = 1 - \prod_{i=1}^{n} (1 - P_i) \tag{1}
\]

\[
P_i = \prod x_j \tag{2}
\]

\((x_j \text{ is the probability of the basic events } X_j, \text{ which belongs to the minimum cut set } P_i)\)

Due to the input of prevention gas explosion has an effect on the basic events, and which mainly shown as reduced probability of the accident, so the relationship between probability of the accident and the safety input is reduction function, and with the increasing of the safety input, the declined rate of probability of the accident is more and more slow. If the probability of accident wants to be approached to 0, the safety input should be closed to infinity. Therefore, this trend can be described with GongBo curve. If the basic events are independent on the influence of the accident’s probability, it is:

\[
x_j = K_j a_j^{b_j x_j} \tag{3}
\]

In the formula, \( K_j, a_j, b_j \) are all parameters, and \( 0 < a_j < 1, \ b_j > 1 \), these parameters can be determined by analysis and fitting previous accident statistics data. \( C_j \) is the safety input for reducing the occurrence probability of basic event \( X_j \). From the formula, the relationship between safety input \( c_j \) and the occurrence probability of basic event \( x_j \) is:

\[
c_j = \frac{1}{\ln b_j} \ln \frac{x_j}{K_j} \tag{4}
\]

The total safety input for preventing gas explosion is D, there are constraint conditions to safety input costs:
To achieve safety input distribution optimization, namely when the safety input is certain, make the probability of accident to be minimum, namely the objective function is $\min P$, the following mathematical model was built up according to constraint conditions (1)-(5):

The objective function:

$$\min P = 1 - \prod_{i=1}^{n}(1 - p_i)$$

Constraint conditions:

$$P_i = \prod x_j \quad (x_j \text{ is the probability of the basic events } X_j, \text{ which belongs to the minimum cut set } P_i)$$

$$x_j = K_j a_j^{b_j} \quad (c_j \text{ is the safety input for reducing the occurrence probability of basic event } X_j)$$

$$\sum_{j=1}^{n} c_j = \sum_{j=1}^{n} \frac{1}{\ln b_j} \ln \frac{k_j}{\ln a_j} = D$$

In practical operation, $x_j$ can be calculated from the model by Lingo software, and then $c_j$ can be get too, which is the safety input used to make the minimum occurrence probability of each basic event. Then according to the types of the safety input for preventing the occurrence of event, these input can be divided into the the two kinds of items, namely engineering physical input and human behavior input described herein. In each kind of item, those safety inputs for prevention there basic events is aggregated, then the safety input optimization allocation plan for preventing mine gas explosion is get eventually.

4. Conclusions

The purpose of this paper is to prevent coal gas explosion. Through studying the safety input optimal distribution among all measures which can prevent coal gas explosion, we obtained the following conclusions:

1) The main reasons of mine gas explosion accident are the gas accumulation caused by ventilation problems and fire existence in mine. The logic relationship between gas explosion accident and its causes was expressed by using fault tree analysis method, and then the mine gas explosion tree was established.

2) Different safety input compositions have a different effect on preventing gas explosion under the condition of a certain total safety input. The safety input optimization allocation model was established for the goal of making the gas explosion accident occurrence probability minimum. And the function relationship between the safety input and accident occurrence frequency was established with GongBo curve.

Because the solution of the model needs relatively perfect historical data, the test of the model remains need to the aftermath of empirical analysis.

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