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Application of Grey System Theory in Prediction of Coal and Gas Outburst

XIE Shuai-long

School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo 454003, China

Abstract Gas, as the biggest hidden danger of underground safety production, is the first killer of coal mine safety production. This paper, based on the principle of grey system theory, analyze the related indexes of coal and gas outburst and the correlation calculation, the parameters such as gas emission set up GM (1, 1) model analysis, the results show that the gas drilling speed and drilling cuttings at the beginning of the gas desorption index correlation is the biggest, and drilling cuttings volume correlation times, associated with drilling gas analytical index is minimal. The conclusion obtained by the grey model is feasible in practice and conforms to the relevant prediction requirements in the gas treatment process.

Keywords Grey system, grey modeling, prediction and gas content

Introduction

Coal is an important basic energy and raw material in China, making a significant contribution to the development of national economy [1]. China is a country with coal as the main energy source. With the rapid development of the economy, the demand for energy is increasing and the amount of coal mining is also increasing. The severe situation of coal mine safety production in China is becoming more and more obvious. Most of these accidents were gas accidents [2-6]. Gas is an associated gas in the formation process of coal. Due to its inflammable and explosive nature, gas disaster is a major safety hazard in the production process of coal mine. If improper prevention and management measures are not in place, gas accident will occur [7-11]. In the past 10 years, gas accidents accounted for 57 major coal mine accidents. The gas accident has been one of the major disasters threatening the safety of coal mine in China. In 2006, the death toll from coal mine gas accidents in China was 1,319, and by 2015 it had dropped to 171.However, in the future for a long time, coal mine gas prevention and control is still a difficult problem in China's coal mining. Therefore, in order to ensure the safety of mine production and improve economic benefits, it is imperative to effectively prevent and control coal and gas outburst, and it is particularly important to study the coal and gas outburst mechanism, its prediction and pretreatment theory and method.

At present, although there are many methods for coal mine outburst prediction in China, each of these methods has its own advantages and inevitable defects. This paper will use the grey system theory to partially predict coal and gas outburst in coal mine, and use the advantages of grey system theory to obtain the accuracy of prediction. By using the grey system theory on the influencing factors of coal seam gas content, grey correlation analysis to find the main influence factors and secondary influence factors, and to establish a GM (1, 1) grey prediction model of coal bed gas content prediction under the influence of many factors, the effective prevention and control of gas explosion accident, the development of coal industry of our country has important realistic and economic significance.

2. Grey system theory

Grey system theory is a new field of control theory. It is the product of the view and method of cybernetics applied to the social and economic system, and also the product of the combination of control theory and operations research. It takes the gray system as the research object, takes the whitening, desalination, quantization, modeling and optimization of the gray system as the core, and aims at the prediction and control of the development of various gray systems. Its main research contents include: grey system modeling theory, grey factor correlation analysis theory, grey prediction theory and decision theory, grey system analysis and control theory, grey system optimization theory and so on.

2.1. Introduction and development of grey system theory

In 1981, Chinese cybernetics expert professor Deng Julong first proposed the concept of grey system, and later published many papers and monographs on grey system, and established the grey system theory. Since 1982, grey system theory has been successfully applied in agriculture, industry, meteorology and other fields. It is widely used in agriculture, geology, meteorology and so on.

In 1982, Chinese scholar professor Deng Julong established the grey system theory, which is a new method to study the uncertainty of minority data and poor information. In the same year, the journal system and control communication published by north Holland publishing company published the first paper of Chinese scholar professor Deng Julong on grey system "the control problem of grey system". The publication of these two pioneering papers marked the beginning of the grey system theory. This as soon as a new theory was born, was domestic academia, foreign academics and the general practitioners of positive attention, many famous scholars and experts give full affirmation and support, many young and middle-aged scholars have join the grey system theory research, with great enthusiasm to carry out the theoretical exploration and application research in different fields. In particular, its successful application in many scientific fields has won the recognition and attention of the international academic community. At present, the United Kingdom, the United States, Germany, Japan, Australia, Canada, Austria, Russia, Taiwan, Hong Kong, the United Nations and other countries, regions and international organizations have many famous scholars engaged in the research and application of gray system.

In recent years, many countries have included grey system theory in their discussions. For example, the annual meeting of the world organization of systems and control and the joint meeting of the annual meeting of the international society for general systems studies were held in Pittsburgh in the United States. The first international conference on computer and industrial engineering, held in limerick, Ireland, arranged a special session on grey systems theory. Grey system theory has become the focus of many important international conferences, which will undoubtedly play a positive role in the further understanding of grey system theory among the world system scientific colleagues.

2.2. Main contents of grey system theory

After years of development, grey system theory has basically established the structure system of a new discipline. Its main contents include algebra system with gray, gray equation and grey matrix based on the theory of system, method system, based on the grey sequence for based on grey relational space analysis system, grey model as the core of the model system, with system analysis, evaluation, modeling, forecasting, decision-making, control and optimization as the main body of technology system [12-16].

(1) Ash generation

Gray sequence generation is the mapping, transformation and processing of data. It is the basic technical method of grey system theory. Its function in grey system theory is equivalent to the method of establishing fuzzy sets in statistics and fuzzy mathematics of probability theory.

(2) Grey analysis

Grey analysis is grey correlation analysis. A measure of the degree of correlation between factors in two systems that varies from time to time or from object to object is called the degree of correlation.In the process of system development, if the trend of change of the two factors is consistent, that is, the degree of synchronous

change is high, that is, the degree of correlation between the two factors is high, and vice versa. Therefore, the grey correlation analysis method is a method to measure the degree of correlation among factors according to the degree of similarity or difference of development trend among factors, i.e. "grey correlation degree".

(3) Grey modeling
Grey modeling is based on the law of grey ginkgo, the difference information principle and the principle of plane emission. The aim is to establish a partial differential equation model by imitating differential equation under the condition of finite data sequence.

(4) Grey prediction
The gray prediction is the prediction made with respect to the gray system. The grey system theory holds that the prediction of the system with both known information and unknown or non-certain information is the prediction of the grey process varying in a certain direction and related to time. Although the phenomena shown in the process are random and random, they are orderly and bounded after all. Therefore, this data set has the potential law, which is used to build a gray model to predict the gray system.

(5) Grey decision
Grey decision is the grey correlation in the unified measurement space of data according to the target, in order to find the satisfactory countermeasures to deal with the event.

(6) Grey control
Grey control is mainly grey predictive control. Grey predictive control is a rolling model built on the time axis, through which the predicted value of the behavior development of the system is obtained, and then the predicted value is used to control the system.

(7) Grey assessment
Grey assessment is the assessment of the grey category of things.

2.3. Main concepts and basic principles of grey system theory
In cybernetics, people commonly used color shades described the clear degree of information, such as ash than the internal information of the unknown object called a black box this term has again as it is widely accepted as in political life, the people want to know information about the decision and its forming process, it is put forward to increase "transparency" we expressed in "black" information is unknown, use "white" said information completely clear, use "clear grey,, said part of the information, some information is not clear, in turn, messages completely clear system called white, information of the unknown system known as the black. A system in which part of the information is clear and part of the information is not clear is called a grey system [1].
The research object of grey system theory is the "small sample" and "poor information" uncertainty system with "partial information already known and partial information unknown".
In people's social, economic activity, or scientific research activities, will often meet with incomplete information, such as in the agricultural production, even sowing area, seed, fertilizer, irrigation and other information is completely clear, but due to the labor technology level, natural environment, climate conditions, such as market information is not clear, is still difficult to accurately estimated output, output value such as biological control system again, although the relationship between the pests and their natural enemies is clear, but it is often because people fear and bait, natural enemy of insect pests and bait, a natural predators and other predators, a link between insects and other information is not enough, Expected effect makes it hard for biological control received the adjustment of the price system or reform, often due to a lack of public information psychological endurance, and on the impact of changes in prices of certain goods on other commodities accurate information and struggling in the securities market, even the best systems analysts also difficult to be a shoo-in, because you are the uncertainty of financial policy, the political upheavals of the

interest rate policy, enterprise reform, changes in the international market price fluctuation and some plate impact on other sectors of the exact information of the general social and economic system, because of its "within", there is no clear relationship "outside", System itself and the system environment, almost imperceptible fineness systems inside and outside of the boundaries, is difficult to analyze the influence of input to output and the same economic variables, some researchers put it as endogenous variables, other researchers have put it as exogenous variables, it is because the lack of system structure, system model and system function of information.

In summary, the incomplete information of the system can be divided into the following four types:

(1) incomplete element parameter information
(2) incomplete structural information
(3) incomplete boundary information
(4) incomplete information of operation behavior

Basic Principles

In the process of the establishment and development of grey system theory, professor Deng Julong discovered and refined the basic principles of six grey systems [1], as follows:

(1) Principle of difference information

"Difference" is information, where there is a difference in information. We say that "things are different from things", that is, they contain information about the particularity of things relative to things. Information changes our view or understanding of a complex thing, and information differs from people's original knowledge of the thing. Major breakthroughs in scientific research have provided people with important information about how to understand and change the world, which is different from the original information. The greater the information content of the information, the greater the difference between it and the original information.

(2) Non-uniqueness principle of solutions

Solutions with incomplete, uncertain information are not unique. The non-uniqueness principle of solution is reflected in the grey target thought in decision making. Grey target is the unity of the target which is not unique and can be constrained. For instance enter a school to fill in a wish, the examinee that identified "not certain school does not go up", if test score does not have absolute superiority, its wish is likely to come to nothing. The same conditions for the willing to settle for its "time", more goals, more choice of examinees, the chances of its admission more. "The non-uniqueness principle of solutions" is also a concrete embodiment of approachable goals, complementary information, perfect plans, coordinated relations, multi-directional thinking, deepening understanding and optimized approaches. In the face of a variety of possible solutions, through qualitative analysis, supplementary information, to determine one or several satisfactory solutions. Therefore, the solution approach of "non-uniqueness" is the combination of qualitative analysis and quantitative analysis.

(3) Minimum information principle

The characteristic of grey system theory is to make full use of the "least information".

The "least information principle" is a dialectical unity of "less" and "more", and the characteristic of the grey system theory is to study the uncertainty problems of "small sample" and "poor information". Its foothold is "limited information space", and "minimum information" is the basic criterion of grey system. The amount of information available is the dividing line between grey and non-grey, and the basic idea of grey system theory is to make full use of the least information available.

(4) According to the principle of cognition

Information is the basis of cognition. Cognition must be based on information. Without information, there is no way for cognition to be based on complete and certain information, so a completely certain cognition can be obtained, while incomplete and uncertain information can only be based on incomplete and uncertain grey cognition.

(5) New information precedence principle

New information has a greater effect on cognition than old information."New information priority principle" is the information view of the grey system theory. Giving new information a large weight can improve the efficiency of grey modeling, grey prediction, grey analysis, grey assessment and grey decision making. The "metabolic" model embodies the "new information first principle". The new information provides the scientific basis for ash albinism. The "new information priority principle" is the concrete embodiment of the timeliness of information.

(6) Principle of immutability of ash

"Incomplete information" grey is absolute. Information is incomplete, uncertainty is universal information is completely relative, temporary, the original uncertainty disappeared, new uncertainty quickly appear. Human understanding of the objective world, through the continuous supplement of information and again and again sublimate the infinite information, the infinite cognition, the grey never die.

It is on this basis that we can accurately predict the relevant parameters in coal mines.

Its specific meaning is: if all the information of a system is known as white system, all the information is unknown as black box system, some information is known, some information is unknown, then the system is gray system. Generally speaking, social system, economic system and ecological system are all grey systems. For example, in the price system, there are many factors that lead to the price rise, but there are not many known factors. Therefore, the gray forecasting method can be used to predict the price of this gray system.

The grey system theory holds that the prediction of the system with both known information and unknown or non-certain information is the prediction of the grey process varying in a certain direction and related to time. Although the phenomena shown in the process are random and random, they are orderly and bounded after all. Therefore, this data set has the potential law, which is used to build a gray model to predict the gray system.

By identifying the degree of difference between the development trend of system factors, grey prediction makes correlation analysis, and generates the original data to find the law of system change, generates the data sequence with strong regularity, and then establishes the corresponding differential equation model, so as to predict the future development trend of things. The grey prediction model is constructed by using a series of quantitative values of the characteristics of the predicted objects observed at equal time intervals to predict the characteristic quantity at a certain time in the future or the time to reach a certain characteristic quantity.

3. Correlation index analysis of coal and gas outburst

There are various kinds of systems in the objective world, large and small, which are composed of many factors. The relationship between these systems and their factors is very complex. In particular, the randomness of the change of surface phenomena is likely to confuse people's intuition and conceal the essence of things, which means that people cannot obtain sufficient and comprehensive information when they understand, analyze, predict and make decisions, and it is not easy to form clear concepts. Therefore, not only the relationship between different systems is grey, but also the relationship between different factors in the system. For a moment, people cannot distinguish which factors are closely related and which factors are not. That is to say, it is difficult to find the main contradiction and grasp the main characteristics and main relations. Therefore, grey system theory puts forward the concept of relational degree analysis, which aims to clarify the main relationship among various factors in the system, find out the most influential factors and grasp the main aspects of contradiction by certain methods.

Mine belongs to a system which exists in the objective world. Outburst is one of the most natural disasters threatening mine safety. All kinds of indicators to judge mine outburst risk naturally belong to this system. For example, the initial velocity of gas emission from drilling hole, the amount of cuttings and several indicators of cuttings gas desorption. Among these indexes, the initial velocity of gas emission from borehole is one of the direct indexes to judge whether there is outburst danger or not. In this paper, the initial velocity of gas emission from borehole ii is used as a reference sequence to carry out grey relational degree analysis, and other indexes are sorted out in the order closest to the geometric similarity of two.

4. Specific application examples

This paper analyzes the main control factors of coal and gas outburst in jituansihe mine of jincheng coal industry, Shanxi Province, and determines important characteristic indexes for data analysis. In this paper, two to four indicators were selected by calculating the grey correlation degree between multiple index sequences and the main factor sequences, and then the selected index sequences were used to make quantitative prediction of prominent main control factors and indirectly predict the outburst risk.

The outburst risk index used to predict the working face mainly includes the coal cuttings gas desorption index K_1, the drilling gas gushing initial velocity index q, the drilling cuttings quantity index S and the R value index. In this paper, the coal cuttings gas desorption index and the initial velocity of gas emission from boreholes listed in the detailed rules for the prevention and control of coal and gas outburst are taken as the main indicators, and the grey relational degree analysis is carried out for the reference sequence.

4.1. Calculation of correlation degree

Table 1: Original data of gas content

The serial number	$q_m(L/\min)$	$K_1(ml/g\cdot\min^{0.5})$	$\Delta h_2(Pa)$	$S(Kg/m)$
1	0.0	0.18	30	5.4
2	6.5	0.52	60	5.0
3	0.0	0.14	20	2.8
4	5.8	0.23	90	9.4
5	1.7	0.14	30	3.4
6	3.2	0.08	70	4.7
7	2.8	0.14	80	3.7
8	1.4	0.13	30	2.9
9	5.3	0.15	260	7.7
10	0.0	0.12	70	3.7
11	12.6	0.37	300	9.7
12	0.0	0.28	110	4.1
13	1.9	0.85	220	9.8
14	1.9	0.22	70	3.7
15	3.3	0.46	100	10.0
16	1.4	0.11	40	2.5
17	13.7	0.28	680	7.3
18	1.4	0.13	40	2.7
19	1.5	0.34	80	2.9
20	2.7	0.49	340	2.8

(1) Normalize the above data, and the results are shown in table 2:

Table 2: Results of normalization treatment

The serial number	$\bar{q}_m$	$\bar{K}_1$	$\Delta\bar{h}_2$	$\bar{S}$
1	0.000	0.130	0.015	0.403
2	0.474	0.571	0.061	0.347
3	0.000	0.078	0.000	0.042
4	0.423	0.195	0.106	0.958
5	0.124	0.078	0.015	0.125
6	0.234	0.000	0.076	0.306
7	0.204	0.078	0.091	0.167
8	0.102	0.065	0.015	0.056
9	0.387	0.091	0.364	0.722
10	0.000	0.052	0.076	0.167

11	0.920	0.377	0.424	1.000
12	0.000	0.260	0.136	0.222
13	0.139	1.000	0.303	1.014
14	0.139	0.182	0.076	0.167
15	0.241	0.494	0.121	1.042
16	0.102	0.039	0.030	0.000
17	1.000	0.260	1.000	0.667
18	0.102	0.065	0.030	0.028
19	0.109	0.338	0.091	0.056
20	0.197	0.532	0.485	0.042

(2) Calculate the difference sequence for the above data, as shown in table 3

Table 3: Difference sequence

The serial number	$\bar{q}_m$	$abs(\bar{K}_1-\bar{q}_m)$	$abs(\Delta\bar{h}_2-\bar{q}_m)$	$abs(\bar{S}-\bar{q}_m)$
1	0.000	0.130	0.015	0.403
2	0.474	0.097	0.414	0.127
3	0.000	0.078	0.000	0.042
4	0.423	0.229	0.317	0.535
5	0.124	0.046	0.109	0.001
6	0.234	0.234	0.158	0.072
7	0.204	0.126	0.113	0.038
8	0.102	0.037	0.087	0.047
9	0.387	0.296	0.023	0.335
10	0.000	0.052	0.076	0.167
11	0.920	0.543	0.459	0.080
12	0.000	0.260	0.136	0.222
13	0.139	0.861	0.164	0.875
14	0.139	0.043	0.063	0.028
15	0.241	0.253	0.120	0.801
16	0.102	0.063	0.072	0.102
17	1.000	0.740	0.000	0.333
18	0.102	0.037	0.072	0.074
19	0.109	0.228	0.019	0.054
20	0.197	0.335	0.288	0.155

(3) Find the correlation coefficient

Table 4: Correlation coefficients

The serial number	$\bar{q}_m$	$\gamma_{qk}(i)$	$\gamma_{qh}(i)$	$\gamma_{qs}(i)$
1	0.000	0.771	0.967	0.521
2	0.474	0.819	0.514	0.775
3	0.000	0.849	1.000	0.913
4	0.423	0.657	0.580	0.450
5	0.124	0.905	0.801	0.998
6	0.234	0.652	0.735	0.859
7	0.204	0.776	0.794	0.921
8	0.102	0.922	0.834	0.904
9	0.387	0.596	0.950	0.566
10	0.000	0.894	0.852	0.724
11	0.920	0.446	0.469	0.845
12	0.000	0.627	0.762	0.663

13	0.139	0.337	0.727	0.333
14	0.139	0.910	0.874	0.940
15	0.241	0.634	0.785	0.353
16	0.102	0.874	0.859	0.811
17	1.000	0.371	1.000	0.568
18	0.102	0.922	0.859	0.855
19	0.109	0.657	0.959	0.890
20	0.197	0.566	0.603	0.738

(4) Calculate the correlation degree

Table 5: Calculation of correlation degree

The serial number	$\bar{q}_m$	γ_{qk}	γ_{qh}	γ_{qs}
1	1	0.691	0.791	0.730

From the above data, we can draw the following conclusions:

The correlation degree of initial gas gushing velocity and cuttings gas desorption index Δh_2 is the highest, followed by the correlation degree of cuttings, and the least correlation with the value K_1 of drilling gas analytical index.

4.2. Carry out grey modeling for q

GM(1,1) was used to model the initial velocity q of gas emission from borehole

(1) Original sequence

$$q^{(0)} = \{q^{(0)}(1), q^{(0)}(2) \dots \dots q^{(0)}(n)\}$$

$$= \{0,6.5,5.8,1.7,3.2,2.8,1.4,5.3,0,12.6,0,1.9,1.9,3.3,1.4,13.7,1.4,1.5,2.7\}$$

(2) The first order accumulation sequence of q(0) is obtained as (1-AGO).

$$q^{(1)} = \{q^{(1)}(1), q^{(1)}(2) \dots \dots q^{(1)}(n)\}$$

$$= \begin{Bmatrix} 0,6.5,6.5,12.3,14,17.2,20,21.4,26.7,26.7,39.3,39.3,41.2,43.2,46.4,47.8,61.5, \\ 62.9,64.4,67.1 \end{Bmatrix}$$

(3) Find parameters a (grey system development coefficient) and B(grey action amount)

According to the least square method, a, B and y_N can be calculated as follows:

$$B = \begin{bmatrix} -\frac{1}{2}\left(x_1^{(1)}(1) + x_1^{(1)}(2)\right) & 1 \\ -\frac{1}{2}\left(x_1^{(1)}(2) + x_1^{(1)}(3)\right) & 1 \\ \dots\dots\dots & \\ -\frac{1}{2}\left(x_1^{(1)}(n-1) + x_1^{(1)}(n)\right) & 1 \end{bmatrix}$$

$$y_N = \left[x_1^{(0)}(2), x_1^{(0)}(3) \dots \dots x_1^{(0)}(n)\right]^T$$

a =-0.0987, B=12.8473

Residual inspection accuracy is 78.5%

The development coefficient of a grey system is analyzed according to:

(1) when -a<0.3, GM (1,1) can be predicted in the medium and long term;

(2) when 0.3<-a<0.5, GM(1,1) can be used for short-term forecasting;

(3) when 0.5<-a<0.8, the error of GM(1,1) in short-term prediction is relatively large;

(4) When 0.8<-a<1, GM (1, 1) model is modified by residual error.

(5) When 1<-a, GM (1,1) model is not suitable for prediction.

As -a<0.3, medium and long term prediction can be made in GM (1,1) model

5. Conclusion

Through to the coal gas desorption index K_1, drill cuttings at the beginning of the gas emission rate index q, sludge volume index S and R value indicators such as the determination of data, using the method of grey correlation, can draw, borehole gas emission velocity correlation the biggest factor is the amount of drilling

cuttings, the conclusion is completely consistent with the result measured by laboratory, through the grey model, the feasibility of the conclusion has actually conform to the requirements of the relevant prediction in the process of gas control.

At the same time, with the data measured by GM(1,1) method, the model was modeled again with the improved method when the accuracy of the gray GM(l,l) model was not satisfied, and the accuracy was improved. If the collected data are more reliable, the prediction accuracy will be greatly improved. By continuously improving the model, the data accuracy is further improved and the prediction results are more accurate and reliable.

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