Proceedings of the 10th World Congress on Mechanical, Chemical, and Material Engineering (MCM'24)
Barcelona, Spain - August 22-24, 2024
Paper No. MMME 104
DOI: 10.11159/mmme24.104

Research On Gas Explosion Pressure Relief Effect Of Explosion Proof Covers With Different Opening Structures

Ren Jingzhang[1,2],Gao Jianliang[1], Zhang Xuebo[1], Fang Yingxiang[1]
[1] College of Safety Science and Engineering,
Henan Polytechnic University, Jiaozuo, Henan 454003, China
renjingzhang@126.com; gao@hpu.edu.cn; zhxb@hpu.edu.cn; fyx294527@163.com
[2] School of Safety Engineering and Emergency Management,
Shijiazhuang Tiedao University, Shijiazhuang,Hebei 050043,China

Abstract **-** The explosion proof covers opening process under the action of the gas explosion shock wave have been numerically simulated with three different opening structures: up-down moving type, external rotation type, internal rotation type. It has been obtained that an explosion proof cover opening structure that is conducive to rapid pressure relief from explosive shock waves. First of all, a small-size air shaft fan explosion proof cover explosion propagation experimental system was set up, and gas explosion shock wave propagation experiments were carried out. The mathematical models of gas explosion shock wave propagation were determined by comparing the experimental results with the numerical simulation results. A numerical simulation study was conducted on the response of explosion proof covers with three types of opening structures under the impact load of gas explosion. The study shows that the explosion proof cover with up-down moving opening structure opens the fastest under the disaster conditions, and the overpressure values both on the explosion proof cover and on the blades of the main ventilator are the smallest. When a gas explosion occurs in the underground, the explosion proof cover with up-down moving opening structure can open more quickly to relieve the explosion shock wave.

Keywords**:** Explosive shock wave, Explosion prove cover, Opening structure, Opening process, Shock load

1. Introduction

The main ventilation fan is the "lungs" of the mine, which is responsible for transporting fresh air and discharging toxic and harmful gases to the underground. In order to ensure that the main mine ventilation can operate continuously, safely and reliably in the event of underground disasters such as protrusion, explosion and fire, many countries, such as China, Canada, South Africa and Australia, stipulate that "explosion proof covers should be installed at the outlet of the main ventilator"[1-4].The purpose of installing explosion proof covers in the shafts equipped with the main ventilators in mines is that when an explosion occurs underground, the explosion proof covers will open to relieve the pressure and protect the fans from being damaged by the explosion shock wave, and the ventilators will be able to ventilate normally.

However, there are phenomena such as the explosion proof cover not being opened in time or not being able to be opened after an underground explosion disaster accident, the gas explosion pressure not being able to be quickly relieved, resulting in damage to the ventilator; the explosion proof cover being seriously deformed or thrown out and not being able to be reset in time, resulting in a short-circuit of the airflow and affecting normal ventilation; there are also phenomena such as the explosion proof cover being thrown out under the action of the explosion shockwave, and the blades of the mine ventilator being seriously deformed and damaged, etc.

Joonwon L conducted full-scale on-site tests to study the structural dynamic response characteristics of explosion proof covers under single and multiple explosion loads. They predicted and analysed the distribution of explosion proof covers under dynamic explosion loads, as well as their bending deformation characteristics and boundary tearing effects under explosion shock waves[5].Some scholars have studied the explosion proof cover load and deformation under the action of the blast wave. For example: Choi et al [6] carried an experimental study to explore the characteristics of explosion proof covers under the impact of the blast wave, found that in the explosion proof cover by the action of the blast wave, the cover will be bent to form an elliptical opening. An Changhe [7] used finite element analysis software to analyse the stress and strain of self-repeating explosion proof covers under the action of blast loads, and found that the maximum deformation of the explosion proof cover appeared in the middle part of the cover plate under the action of the blast shock wave. Wu Jun et al [8] numerically simulated the stress load, impact pressure, and propagation speed of explosion proof covers during the opening process, and studied the component failure mode and anti-explosion performance of explosion proof covers under explosive shock waves. Song Weibin [17] studied the dynamic response characteristics and laws of the new type of explosion proof cover invented by him in the process of explosion impact, and formed two new design schemes for coal mine explosion proof covers: "guided buffer explosion proof cover" and "double cover explosion proof cover".

On the basis of the dynamic response characteristics of explosion proof covers and fan blades in vertical shafts under the action of explosion shock wave [10], the author carried out numerical simulation of the opening process of explosion proof covers of three different opening structure forms, namely up-down moving type, external rotating type and internal rotating type, under the action of gas explosion shock wave. The distribution and variation characteristics of the impact load acting on the explosion proof cover and the main ventilation fan blades during the opening process of the explosion proof cover were obtained, and the explosion proof cover opening structure with good impact resistance and pressure relief effect was determined.

2. Numerical model selection and experimental validation of gas explosion

2.1. Experiments on explosion of air shafts - fans - explosion proof covers

The diameter of the mine return air shaft is 6m. According to a 1:15 similarity ratio of shaft diameter, a small-sized air shaft fan explosion proof cover explosion propagation experimental system was designed and constructed. The experimental system consists of four parts: explosion propagation pipeline system, gas mixing system, data acquisition system, and ignition device. The experimental system diagram and section are shown in Fig. 1.

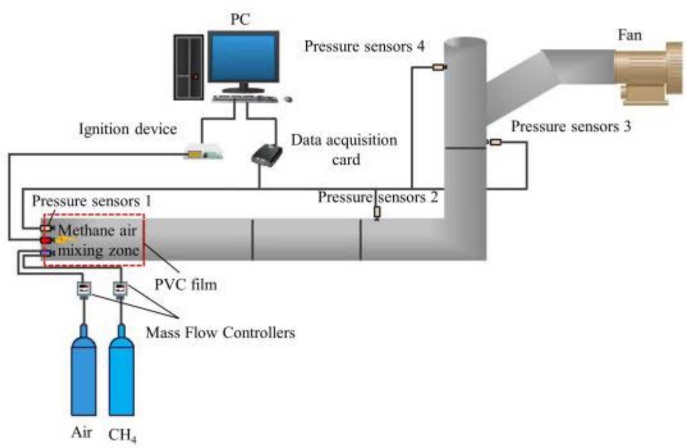


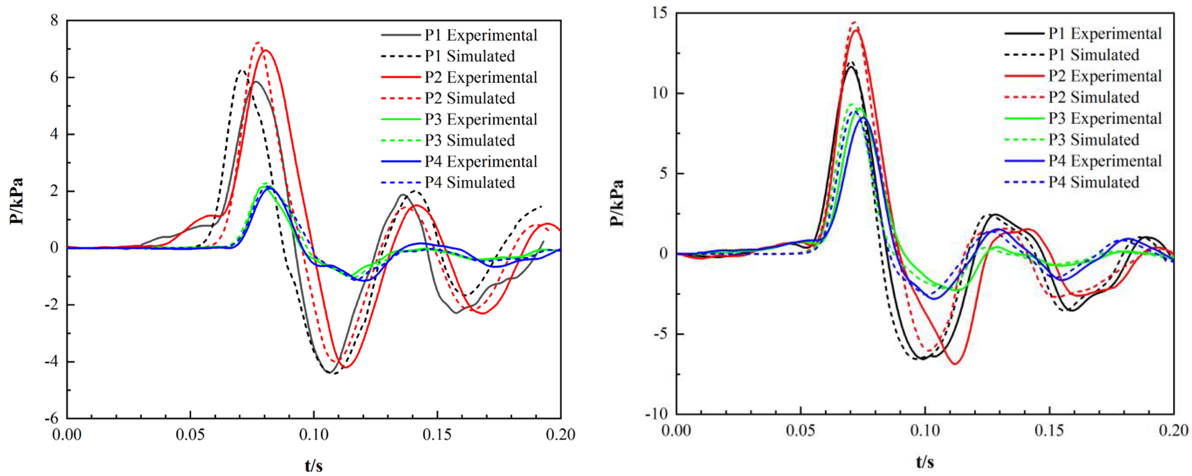
Fig. 1 Explosion propagation experiment system diagram of air shaft fan explosion proof cover

The gas filling length is 1m. Experimental research on explosion propagation characteristics is conducted under the conditions of methane/air mixture gas concentration of 8% and 9.5%, respectively. Three sets of experiments are conducted for each gas concentration, and the average of the three sets of experimental data are taken as the experimental results.

2.2. Determination of the mathematical model of gas explosion propagation

Gas explosion propagation involves chemical, physical and other processes which is a complex thermodynamic process. There are multiple mathematical models used to describe the gas explosion process and the propagation of explosion shock wave, such as Direct Numerical Simulation (DNS), Large Eddy Simulation (LES) and Reynolds-Averaged N-S equations (RANS) model, etc.. The combustion models mainly include laminar Finite Rate model (Finite Rate), laminar Finite Rate/Eddy Dissipation model (Finite Rate/Eddy Dissipation), Eddy Dissipation Model (EDM), and Eddy Eissipation Concept model (EDC). Through comparative analysis, this paper adopts Large Eddy Simulation (LES) and Eddy Dissipation model (EDM)

Numerical simulations were conducted on the gas explosion shock propagation process in the experimental system model shown in Fig. 1 when the gas filling length was 1m and the methane concentration was 8.0% and 9.5%, respectively. The variation of overpressure at monitoring points from numerical simulation and experimental measurements with time is shown in Fig. 2.



a. Gas concentration : 8.0% b. Gas concentration : 9.5%

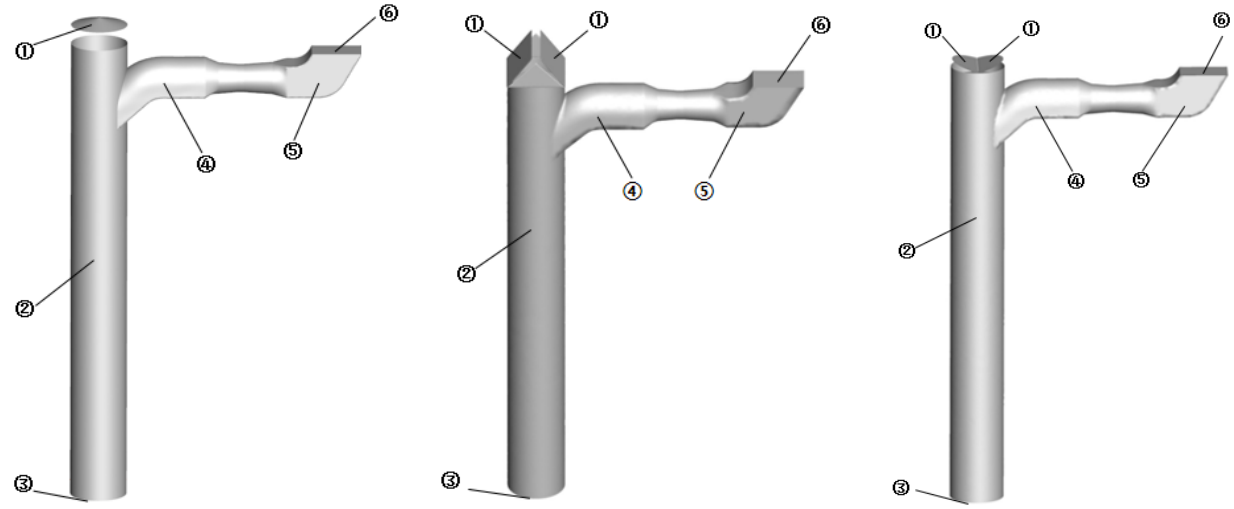
Fig.2 Comparison between overpressure experimental values and numerical simulation values

As can be seen from Fig. 2, the shape of the numerically simulated overpressure curves at each measurement point is consistent with the experimentally measured overpressure curves, and the trend of the shock wave overpressure rise and decay is consistent; the relative error of the maximum overpressure value at each measurement point obtained from numerical simulation and experiment is 3.60% ~ 7.18%. Therefore, it is verified that the Large Eddy Turbulence Model (LES) and Eddy Dissipation Combustion Model (EDM) can be used to simulate the propagation process of gas explosions and shock waves in the shaft-fan-explosion proof -cover system.

3.Comparison of explosion proof covers with different opening structures

At present, there are usually three types of opening structures for vertical shaft explosion proof covers (up-down moving type, external rotation type, and internal rotation type). The three-dimensional physical models of the shaft explosion proof cover wind tunnel fan connection structure are shown in Fig. 3. By comparing the simulation results of different grid sizes, it was determined that the three-dimensional physical models for the three types of explosion proof cover opening structures in the solution area were divided into 6817858, 6707858, and 6637858 mixed elements, respectively.

Assuming that the explosion proof cover quality of 1000kg, the counterweight quality of 1200kg. The opening height range of the up-down moving type explosion proof cover is 0~4m; The angle between the cover body and the horizontal plane of the outward rotation type explosion proof cover is 45 °, and the opening angle range of the outward rotation type explosion proof cover is from 45 ° to 90 °; The opening angle range of the internally rotation type explosion proof cover is from 0 ° to 90 °



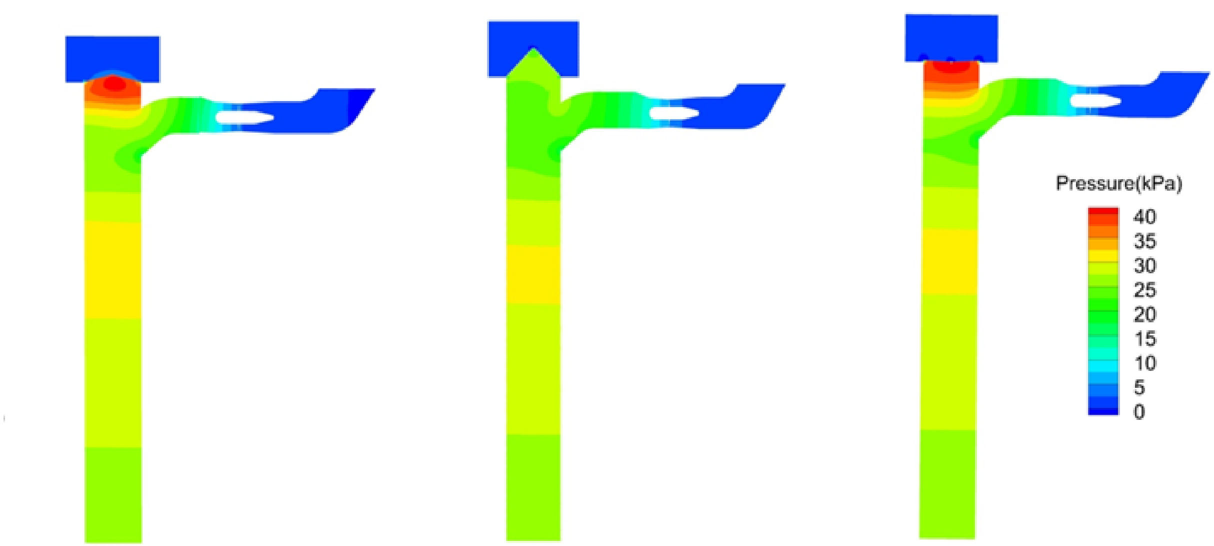
a. Up-down moving type b. External rotation type c. Internal rotation type

where ①- explosion proof cover; ②- return air shaft; ③- inlet boundary (pressure-inlet); ④- air refuge; ⑤- fan diffuser; ⑥- diffuser outlet (pressure-outlet)

Fig.3 Three-dimensional models of explosion proof covers with different opening configurations

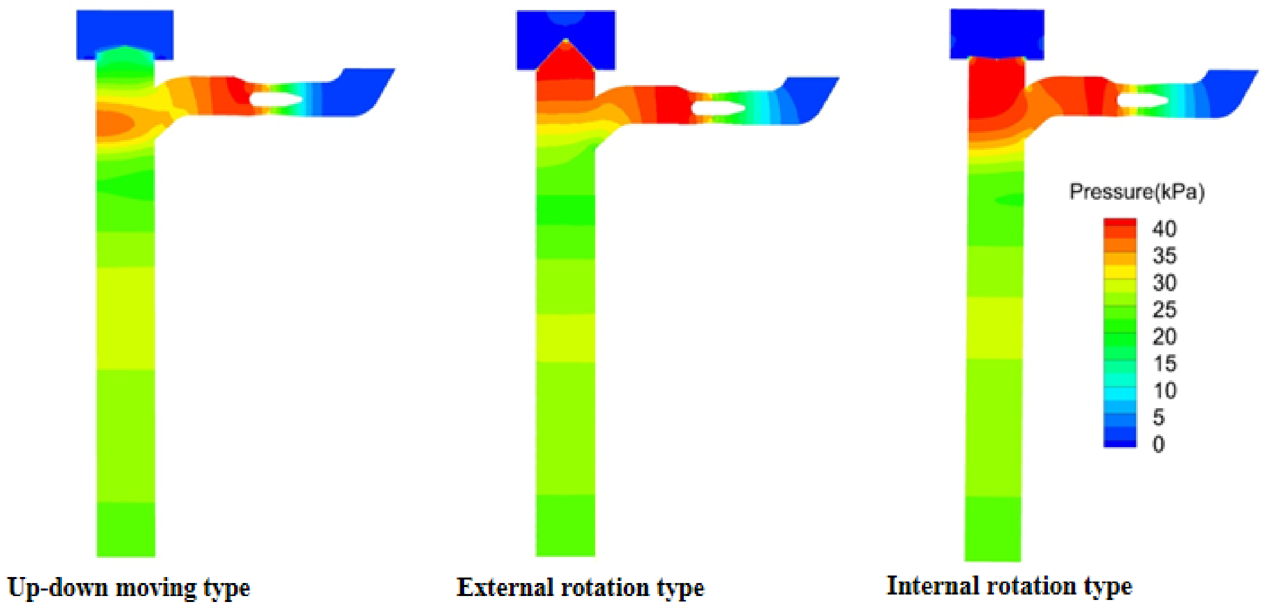
3.1. Distribution of overpressure with different opening structure covers

The distribution of shock wave overpressure on the cross section through the axial of the fan and the vertical shaft are shown in Fig.4. At t=0.184s, during the initial opening of the three structural forms of explosion proof covers, a high-pressure zone was formed near the explosion proof covers. The overpressure in the high-pressure area near the explosion proof cover with an external rotation opening structure is relatively small. In the early stage of opening the explosion proof cover, the external rotation opening structure explosion proof cover is beneficial for pressure relief.

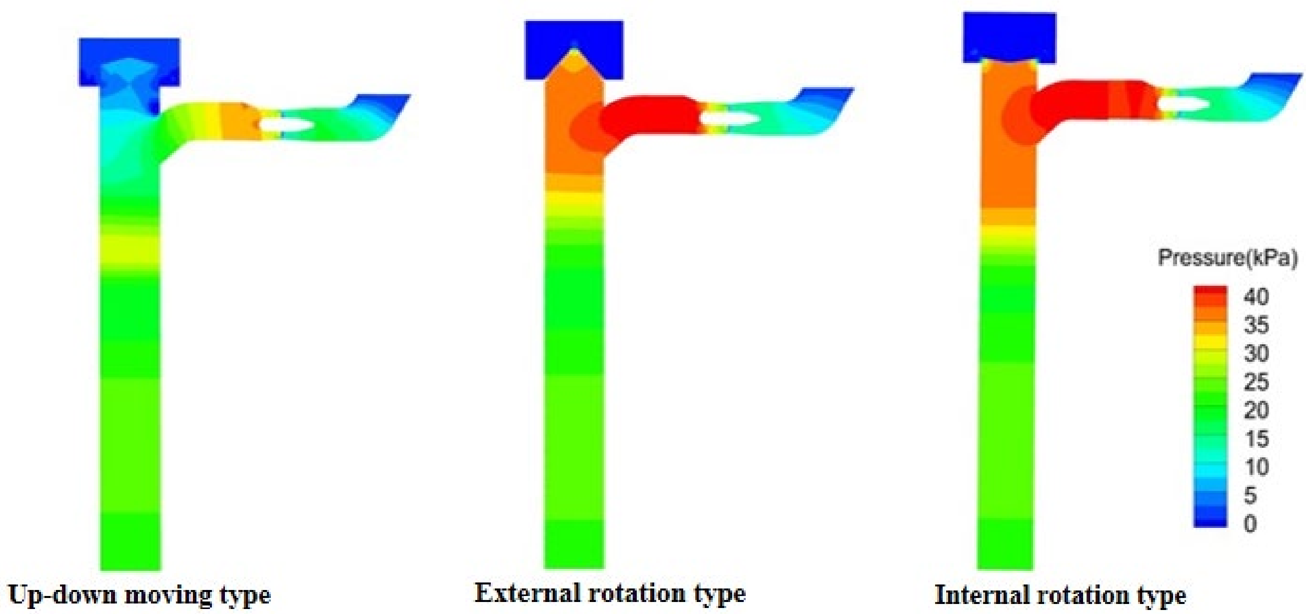


Up-down moving type **External rotation type** **Internal rotation type**

a. t=0.184s



b. t=0.204s



c. t=0.224s

Fig.4 Distributions of overpressure at different moments

At t=0.204 seconds, as the degree of opening increases, the explosion proof cover with up-down moving opening structure opens upwards, forming a larger pressure relief outlet area, and the pressure near the shaft head decreases. Due to the small pressure relief outlet area formed by the opening of explosion proof covers with external and internal rotating opening structures, the pressure inside the wellbore cannot be released, and the range of high-pressure zones formed near the shaft head increases.

At t=0.224 seconds, the opening height of the explosion proof cover with an upward and downward moving opening structure further increases, and the obstruction of high-pressure airflow from the shaft head becomes smaller. The pressure near the shaft head and inside the wind tunnel rapidly decreases; For explosion proof covers with external and internal rotating opening structures, the opening degree of the explosion proof cover increases slowly, and the pressure inside the shaft cannot be effectively released. The overpressure value near the shaft head is much higher than that of the up-down moving structure. In summary, the up-down moving type opening structure is faster to release pressure, and the internal and external rotation type opening structure is slower to release pressure.

3.2 Evolution of impact load on explosion proof covers with different opening structure covers

(1) The variation of impact load on explosion proof covers with time under different opening structures

Fig. 5 shows the variation curve of the impact load on the explosion proof over with time during the opening process of three types of explosion proof covers with different opening structures.

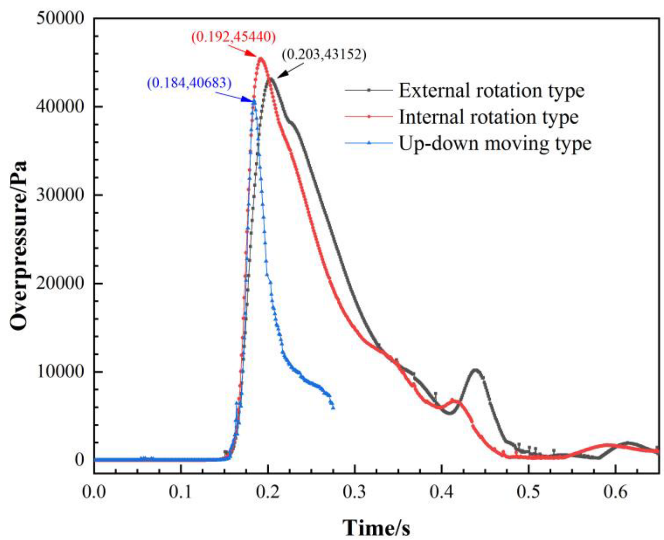


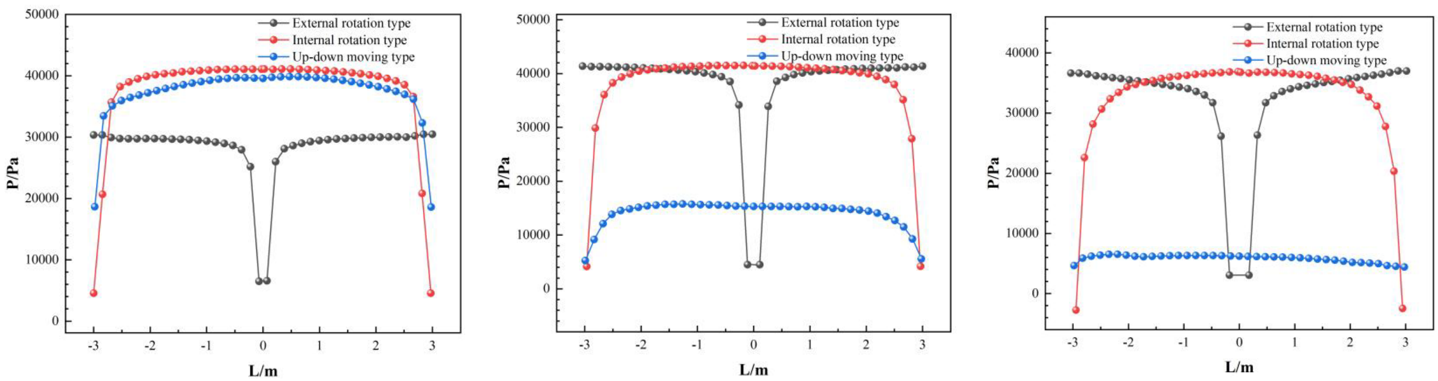
Fig. 5 Variation of impact load on explosion proof cover with time

As can be seen from the figure, the impact load on the explosion proof cover with up-down moving type opening structure reaches its peak first, and the peak impact load is the lowest. After reaching the peak of the impact load on the explosion proof cover, it rapidly decays, and the impact load on the up-down moving type explosion proof cover decays faster, resulting in rapid pressure relief.

(2) Distribution of impact loads on explosion prof covers at different times

The impact load distribution on the explosion proof cover with three different opening structures at different times is shown in Fig. 6. The impact load on the explosion proof cover with three different opening structures is symmetrically distributed on the left and right half of the explosion proof cover. The middle part of explosion proof covers with up-down moving and internal rotating opening structures bears the maximum intermediate load, gradually decreasing from the middle to the edge; The maximum impact load on the edge of the external rotating explosion proof cover gradually decreases towards the middle.

After the explosion from 0.184s to 0.224s moments, the up-down moving type explosion proof cover on the overpressure bear a rapid reduction than the external rotating type ratios of internal rotation type to open the structure of the explosion proof cover to relieve the pressure effect is good. After the explosion, from 0.184 seconds to 0.224 seconds, the up-down moving explosion proof cover bears a rapid decrease in overpressure, and its pressure relief effect is better than that of the external and internal rotating explosion proof cover opening structure.



a. t=0.184s b. t=0.204s c. t=0.224s

Fig. 6 Distribution of overpressure on the explosion proof cover at different times

3.3. Evolution of impact load on fan blades with different opening structure covers

Fig. 7 shows the time-dependent variation curve of the root bending moment caused by the impact load on the main ventilation fan blades during the opening process of explosion proof covers with different opening structures.

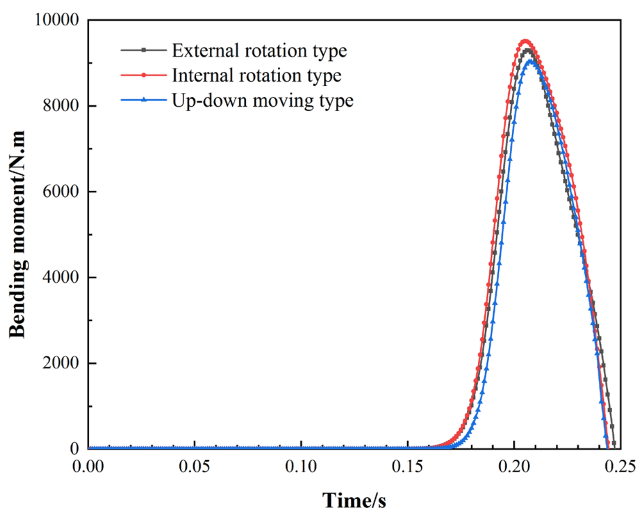


Fig. 7 Curve of blade root bending moment versus time

The explosion proof cover with an up-down moving type opening structure has the smallest impact load on the blades, and the time when the impact load reaches its peak is the latest. The maximum bending moments generated by the impact load on the fan blade root under the explosion proof cover with three types of opening structures: upward movement, internal rotation, and external rotation are 9027.51 *N. m*, 9511.51 *N. m*, and 9292.69 *N. m*, respectively. The impact load on the fan blades using the internal rotating explosion proof cover is about 5.12% and 2.30% higher than that of the up-down moving and external rotating explosion proof covers, respectively.

4. Conclusion

Numerical simulation of the opening process of vertical shaft explosion proof covers with three types of opening structures: up-down moving, external rotation, and internal rotation, under the action of gas explosion shock waves. By comparing and analyzing the changes in overpressure in the shaft and wind tunnel, as well as the impact loads on the explosion proof cover and main ventilation fan blades, it was found that under the same explosion intensity, the peak impact load on the explosion proof cover with an up-down moving opening structure was the smallest, and the attenuation speed of the shock wave was fast; The explosion proof cover adopts an up-down movable opening structure fan blades are subjected to the minimum impact load; Compared with the other two types of explosion proof covers, the explosion proof cover with an up-down movable opening structure can quickly release pressure after a gas explosion, which is more conducive to protecting the main ventilation fan from damage.

Acknowledgements
Thanks for the funding from the National Natural Science Foundation of China. Project approval number: 52274187.

References

[1] Coal mine safety regulations, *China State Administration of Coal Mine Safety.* Beijing: Coal Industry Press, 2016.
[2] Canada G O. Coal Mining Occupational Health and Safety Regulations (SOR/90-97), Z. 2015.
[3] Department of Minerals And Energy.(1996), Mine health and safety act 29 of 1996,[Online]. Available: http://www.acts.co.za/mine-health-and-safety-act-1996.
[4] NSW government.(2006).Coal mine health and safety regulation (NSW),[Online]. Available:.https://jade.barnet.com.au/Jade.html#! a=outline&id=277813.
[5] L. Joonwon and C.Youngsik, "Effects of a Near-Field Explosion in a Tunnel Behind a Blast Proof Cover",*J. Precision Engineering and Manufacturing,* vol. 19, no. 4, pp.625-630, 2018.
[6] Y. Choi and J. Lee, " A Study on the behavior of blast proof cover under blast load",*J. Precision Engineering and Manufacturing*, vol. 17, no. 1, pp. 119-124, 2016.
[7] C.H. An, "Finite element simulation analysis of mine self-reclosing explosion proof covers",*J. Coal Mine Machinery* ,vol. 34, no. 8, pp.104-106, 2013.
[8] J. Wu and Q.S. Yan, "Structural design and damage assessment of a chamber for internal blast with explosion vent",*J. Mechanics of Advanced Materials and Structures*, vol. 27, no. 24, pp.2052-2058, 2020.
[9] W.B. Song,2018. "Research on the theory and technology of safety protection of explosion proof covers in coal mine vertical air shafts", Ph.D. dissertation, Sch. *Energy.Sci. Eng.,* Henan Polytechnic Univ., Jiaozuo, China.
[10] J.L. Gao and J.Z. Ren, "Impact load characteristics of gas explosion on fan blades and explosion proof cover",*J. China University of Mining & Technology*,Vol. 50, No.4, pp. 624-632, 2021.