Vibration Comparison of Carbon Dioxide Phase Transition Blasting and Explosive Blasting

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ABSTRACT. Vibration, the most widespread environmental harmful effect during engineering blasting, is often given special attention and strictly controlled. In order to explore the difference between seismic waves excited by carbon dioxide phase transition blasting and explosive blasting, a comparative study was carried out through on-site vibration monitoring and signal analysis. The results show that under the same explosion energy condition, the peak particle velocity of ground vibration caused by a dry ice fracturing cylinder is far lower than that of an emulsified explosive; Although the former's vibration duration is slightly longer, the primary frequency of FFT is higher, and the proportion of low-frequency energy is small, which is not easy to cause resonance of buildings (structures). When carrying out engineering rock-breaking operations in complex and sensitive environments, carbon dioxide phase change blasting technology can be prioritized.

Keywords: blasting; vibration; phase transition of carbon dioxide; signal analysis

1 INTRODUCTION

Carbon dioxide phase transition blasting is a nonexplosive physicochemical rock-breaking technology that utilizes high-pressure gas generated by liquid carbon dioxide heat absorption gasification to apply a load on the target medium. The earliest related research can be traced back to the exploration of high-pressure gas blasting technology by Long Air-Dox in the United States in 1938. In the 1950s, CARDOX, a British company, developed a liquid carbon dioxide phase transition cracking device called the Cardox Tube System (Kristina 1995)[3]. This technology was initially only applied to gas drainage and coal mining. It has now been promoted to fields such as pipeline cleaning and rock and soil excavation (Mellor 1972, Miller 1994)[7,8].

Like explosive blasting, carbon dioxide phase transition blasting is accompanied by dust, noise, flying rocks, seismic waves, and other harmful environmental effects. Based on the theoretical comparison of the rock-breaking mechanism, gas generation, and environmental impact, carbon dioxide phase transition blasting improves rock-

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breaking energy utilization and controls blasting hazards compared to explosive blasting (Tao 2018)[9]. It has no flying stones, low noise, and reduces dust and smoke by 50% (Li 2018, Liu 2018)[5,6]. The peak particle velocity of carbon dioxide phase transition blasting also follows the attenuation form of a power function (Li 2021, Ye 2022)[4,11]. Still, its main vibration frequency band is between 0 ~ 4 Hz, which is very close to the natural vibration frequency of the building, and special attention should be paid to potential vibration disasters (Chen 2018)[1]. Overall, the harmful effects of carbon dioxide phase transition blasting, such as flying rocks, noise, dust, and air pollution, are relatively low, and the advantages of safety and environmental protection are apparent.

Given the enormous influence range of seismic waves and the prominent environmental hazards, this paper will further compare the seismic effects caused by carbon dioxide phase transition blasting and explosive blasting through field tests and signal analysis, reveal the vibration characteristics of carbon dioxide phase transition blasting, to guide the design and construction of engineering rock breaking in complex and sensitive environments.

2 FIELD VIBRATION TESTS

2.1 Explosive Materials

The carbon dioxide phase transition cracking device selected for on-site vibration testing is a dry ice fracturing cylinder developed by Jiangsu Zhongkong Energy Science and Technology (Hu 2019)[2], as shown in Figure 1. Compared to previous devices, this dry ice fracturing cylinder has made the following two improvements: (1) selecting dry ice as the initial filling material to reduce the danger of high-pressure filling of liquid CO_2; (2) Replacing the original chemical agent with an intrinsically safe energy agent as a heat source avoids the transportation, storage, and use of hazardous chemicals, and improves the overall market access of the equipment. Table 1 lists the parameters of different types of dry ice fracturing cylinders.

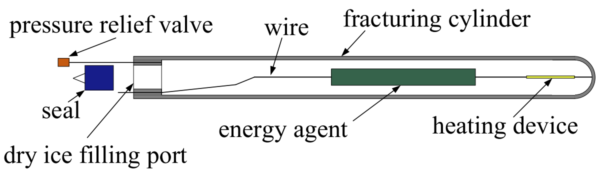


Fig. 1. Dry ice fracturing cylinder

Table 1. Parameters of different dry ice fracturing cylinder

Model	Diameter	Length	Rupture pressure	Maximum filling mass of dry ice
ZLQ-Φ89×600	89mm	600mm	60MPa	2kg
ZLQ-Φ89×800	89mm	800mm	60MPa	3kg

ZLQ-Φ89×1000	89mm	1000mm	60MPa	4kg
ZLQ-Φ89×1200	89mm	1200mm	60MPa	5kg

The explosive vibration source used for comparison is the No. 2 rock emulsion explosive (with a diameter of 32mm), and the corresponding excitation equipment is a digital electronic detonator.

2.2 Test Site and Explosion Source Parameters

Considering the consistency of the testing site, on-site vibration tests were arranged in specific areas within a lime mine in Beijing. The experimental area has a flat field, consistent geological structure, and uniform bedding.

Before the experiment, two independent vertical boreholes were laid out on the site and filled with ZLQ-Φ89×1200 dry ice fracturing cylinder and No. 2 rock emulsion explosive separately. According to the calculation method for the explosion energy of pressure vessels, as shown in equation (1), The explosion energy of ZLQ-Φ89×1200 dry ice fracturing cylinder is about 1164 kJ, and the corresponding emulsion explosive equivalent is about 0.4 kg (the explosion energy per kg of emulsion explosive is about 3009 kJ) (Wang 2022)[10].

$$E = \frac{P_1 V}{K-1}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \tag{1}$$

Where, E is the explosive energy of the fracturing cylinder, J; P_1 is the absolute pressure of the gas inside the fracturing cylinder, Pa; P_2 is the standard atmospheric pressure, taken as 101 325 Pa; V is the volume of the fracturing cylinder, m^3; K is the heat capacity ratio of carbon dioxide, taken as 1.295.

When filling the dry ice fracturing cylinder and No. 2 rock emulsion explosive, the coupling and position of the charge center between the two should be consistent. The specific explosion source parameters are shown in Table 2.

Table 2. Explosion Source Parameters

Type	Hole depth	Aperture	Charge	Depth of charge center	Sealing height
Dry ice fracturing cylinder	2000mm	110mm	1	1400mm	800mm
Emulsified explosive	1600mm	40mm	0.4 kg	1400mm	1000mm

2.3 Vibration Monitoring System and Scheme

The separated blasting vibration monitoring system usually includes the acquisition recorder and the vibration sensor. TC-4850N wireless network vibration meter and TCS-

B3 vibration sensor provided by the Zhongke (Chengdu) instruments Co., Ltd, are selected, as shown in Figure 2. The technical indicators are shown in Table 3 and Table 4, respectively.

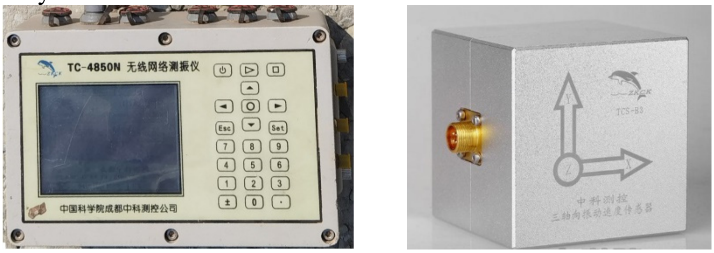


Fig. 2. Wireless network vibration meter TC-4850N and TCS-B3 sensor

Table 3. Technical index of wireless network vibration meter TC-4850N

Technology index	Parameter value	Technology index	Parameter value
Channel number	4	Sampling rate	100~100kHz
A/D resolution	16Bit	Frequency range	0~10kHz
Record duration	1~5000s	Trigger mode	Internal triggering
Range	±10V	Storage capacity	256MB
Recording accuracy	0.01cm/s	Reading accuracy	1‰

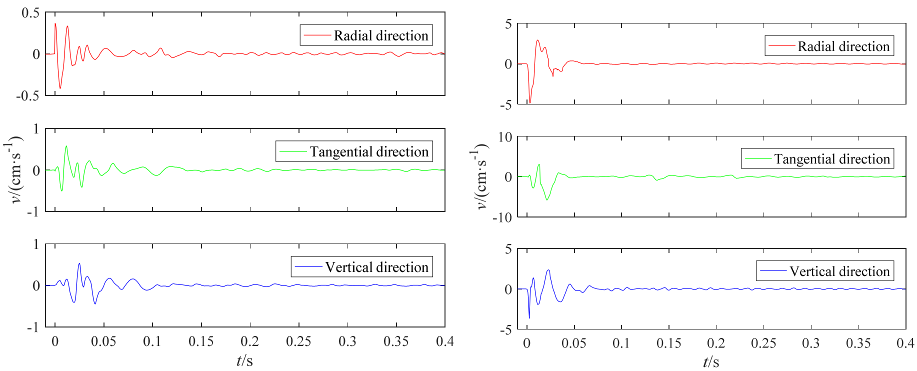
Table 4. Main technical indexes of TCS-B3 sensor

Frequency range	Sensitivity	Damping coefficient	Output impedance	Harmonic distortion	Working temperature	Maximum displacement
5~300Hz	28V/m/s	0.6	380Ω	≤0.2%	-20~75℃	4mm

During the field test, the above vibration monitoring system is fixed on the ground surface 7m from the independent blast hole to monitor the seismic wave excited by dry ice fracturing cylinder and emulsion explosive.

3 VIBRATION SIGNAL ANALYSIS

The surface vibration caused by the excitation of a single dry ice fracturing cylinder and a 0.4kg emulsion explosive is shown in Figure 3 and Figure 4, respectively. Table 5 shows the three-direction peak particle velocity, FFT primary frequency, and duration of the two. It can be seen that under the same explosion energy conditions, the peak particle velocity caused by a dry ice fracturing cylinder is far lower than that of emulsion explosives (about its 1/10). It can use for breaking rocks with relatively more energy, judged by combining the Conservation of energy; In addition, in terms of FFT primary frequency, dry ice fracturing cylinders are generally higher in all directions, greater than the natural frequency of buildings (structures). Still, their duration is slightly longer, about four times that of emulsion explosives. If the low-frequency vibration component content is high, it may still cause resonance of buildings (structures).



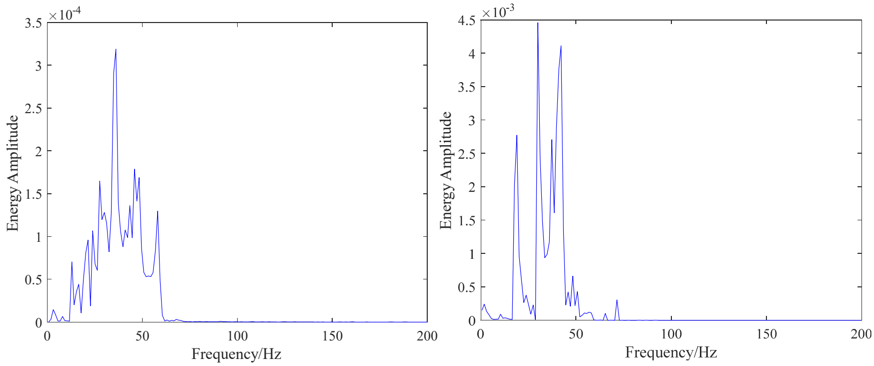
(a) Dry ice fracturing cylinder (b) Emulsified explosive

Fig. 3. Vibration velocity waveform in ground surface

Table 5. Peak particle velocity, FFT main frequency, and duration of ground vibration

Element	Type	Direction	Value
Peak particle velocity /(cm•s^{-1})	Dry ice fracturing cylinder	Radial direction	0.42
		Tangential direction	0.58
		Vertical direction	0.53
	Emulsified explosive	Radial direction	4.88
		Tangential direction	5.78
		Vertical direction	3.65
FFT main frequency /Hz	Dry ice fracturing cylinder	Radial direction	73.17
		Tangential direction	41.46
		Vertical direction	41.46
	Emulsified explosive	Radial direction	31.71
		Tangential direction	9.76
		Vertical direction	41.46
Duration /s	Dry ice fracturing cylinder	Radial direction	0.0345
		Tangential direction	0.1025
		Vertical direction	0.0930
	Emulsified explosive	Radial direction	0.0270
		Tangential direction	0.0255
		Vertical direction	0.0390

To further investigate the distribution of surface vibration components in various frequency bands, MEEMD (Multivariate Ensemble Empirical Mode Decomposition) was used to decompose the recorded vibration signals, and the corresponding marginal energy spectrum was calculated using the Hilbert transform, as shown in Figure 4. Given that the directionality of the sensor in the vertical direction is more precise, and the dominant frequencies of the two are closest in that direction, only the marginal energy spectrum of the vertical vibration signal is shown in the figure. Table 6 calculates each frequency band's energy proportion based on the vibration signal's marginal energy spectrum.



(a) Dry ice fracturing cylinder (b) Emulsified explosive

Fig. 4. Marginal energy spectrum of vertical direction vibration signals

Table 6. The proportion of each frequency band

Frequency band \ Type	Dry ice fracturing cylinder	Emulsified explosive
0~20Hz	6.8%	14.3%
20~40Hz	53.1%	53.7%
40~60Hz	39.1%	29.9%
60~80Hz	0.7%	1.1%
80~100Hz	0.1%	0%
>100Hz	0.2%	1%

Figure 4 and Table 6 show that although the FFT primary frequency caused by dry ice fracturing cylinder in the vertical direction is not significantly different from that of emulsion explosives, its low-frequency (below 20Hz) energy proportion is relatively small. High-frequency components above 40Hz are abundant, far from the natural frequency of buildings (structures), which can effectively avoid resonance formation.

4 CONCLUSIONS

Through field tests and signal analysis, the seismic effects caused by carbon dioxide phase transition blasting and explosive blasting are compared. The results show that under the same explosion energy condition, the peak particle velocity caused by dry ice fracturing cylinder excitation is about 1/10 of that of emulsion explosive, and the energy that can be used for rock breaking is relatively more; In terms of frequency, the FFT primary frequency of surface vibration caused by dry ice fracturing cylinder is generally higher in all directions, and the low-frequency (below 20Hz) energy accounts for a relatively small proportion. The high-frequency components above 40Hz are abundant, far from the natural frequency of buildings (structures). Therefore, although its duration is extended, it is challenging to cause structural resonance. When carrying out engineering rock-breaking in complex and sensitive environments, carbon dioxide phase transition blasting technology can be preferred.

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REFERENCES

1. Chen, G., Li, Q.Y., Liu, X.X. et al (2018) Research on energy distribution characters about liquid CO_2 phase-transition broken rock vibration signal. Blasting, 35:155-163. DOI:10.3963 / j.issn.1001-487X.2018.02.027.
2. Hu, S.B., Pang, S.G., Yan, Z.Y. (2019) A new dynamic fracturing method: deflagration fracturing technology with carbon dioxide. International Journal of Fracture, 220:99-111. https://doi.org/ 10.1007/s10704-019-00403-8.
3. Kristina, P., John, M.S., Farrukh, A. et al (1995) Cardox system brings benefits in the mining of large coal. International Journal of Rock Mechanics and Mining Sciences, 243:27−28. DIO: 10.1016/0148-9062(95)93366-w.
4. Li, B.L., Wang, E.Y., Hu, S.B. et al (2021) A study of vibration velocity attenuation induced by pneumatic rock breaking with carbon dioxide ice powder for safety assessment. Rock Mechanics and Rock Engineering, 54:6481–6493. https://doi.org/10.1007/s00603-021-02637-2.
5. Li, Q.Y., Liu, X.X., Wu, Z.Y. et al (2018) Application of liquid CO_2 phase change rock breaking technology in metro foundation pit excavation. Journal of Railway Science and Engineering, 15:163-169. DOI: 10.3969/j.issn.1672-7029.2018.01.023.
6. Liu, G.H., Wang, H.L. (2018) Application of carbon dioxide fracturing technology. Highway, 63:72-75. https://kns.cnki.net/kcms/detail/11.1668.U.20181221.1440.026.html
7. Mellor, M., Kovacs, A. (1972) Breakage of floating ice by compressed gas blasting. Special Report, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover. https://netl.istic.ac.cn/site/objdata/4CA889BC2C064E8CA0D04C5FB986866E/0520090900628832.
8. Miller, R.C. (1994) Fundamental Study of Carbon Dioxide Blasting: An experimental and numerical analysis of surface cleaning by a particle-laden turbulent jet. Michigan Technological University, Houghton. https://netl.istic.ac.cn/site/objdata/0F0AA8B220F54B10B53ABFBFD73317E1/0320151100411074
9. Tao, M., Zhao, H.T., Li, X.B. et al (2018) Comprehensive comparative analysis of liquid CO_2 phase change fracturing and explosive rock fracturing. Blasting, 35:41-49. DOI: CNKI: SUN: BOPO.0.2018-02-008.
10. Wang, J., Zhang, Y.P., Ge, X.D. et al (2022) Study on rock breaking parameters and numerical simulation of phase transition of liquid CO_2. Explosive Materials, 51:16-22. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=BPQC202204003&DbName=CJFQ2022
11. Ye, W., Lu, Y., Xi, L.Z. et al (2022) Vibration effect induced by rock breaking technology based on dry ice and energy-gathered agent in trench excavation. Journal of Physics: Conference Series, 2148:1-11. DOI:10.1088/1742-6596/2148/1/012023