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*Research Article*

# Method Improvement and Effect Analysis of Triaxial Compression Acoustic Emission Test for Coal and Rock

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In the study of the acoustic emission (AE) characteristics of rock samples or coal samples under triaxial compression conditions, most scholars carry out relevant experiments by placing the AE detector on the outer wall of the triaxial chamber of the rock mechanics test system. Owing to the continuous obstruction of AE signals by hydraulic oil in the triaxial chamber and the frequent interference of external noises, the final experimental data cannot objectively and truly reflect the essential characteristics of AE of rock or coal under triaxial compression conditions. It is difficult to scientifically guide and accurately predict precursory information of rock's or coal's rupture and instability. Based on this, a series of improvements and optimizations were made to the original triaxial compression AE test method, which is based on the modification of the communication interface of the rock mechanics test system, a test head which can put the AE detector into the triaxial chamber and withstands high confining pressure, in order to obtain the true, comprehensive, and reliable AE signals. It is of considerable significance to the scientific determination of the precursory characteristics of rock's or coal's rupture and instability.

## 1. Introduction

The damage and evolution process of rocks under external loads is accompanied by signals of sound, light, electricity, heat, and magnetism, which have become extremely important indicators of disaster prediction and early warning in the fields of geotechnical engineering or mining engineering and other fields [1–5]. In particular, it has played a significant role in the prediction and early warning of various kinds of engineering disasters, including tunnel engineering, water conservancy, and hydropower engineering. As a technology of nondestructive testing, AE technology has been applied and developed for more than half a century [6, 7]. During the process of rock failure, the microcracks will occur within the rock, and at the same time, the closure of the original cracks will occur, and the new cracks will continue to generate, expand, break, and coalesce [8, 9]. During the period, the phenomenon of stress and strain energy released in the form of elastic waves is called AE [10–14]. On the basis of AE information, the changes in the nature of the rock can be deduced and the failure mechanism of the rock can be retrieved [15–17].

In the use of MTS815 electrohydraulic servo rock mechanics test system and AE21C acoustic emission detector for all types of rock triaxial compression AE tests, the AE signals from the rock samples or coal samples could not be directly transmitted from the inside of the triaxial chamber to the outside. Meanwhile, the rock samples or coal samples in the triaxial chamber must be wrapped with heat-shrinkable plastic to prevent the penetration of high-pressure oil so that the AE detector in the triaxial chamber was not in direct contact with the rock samples or coal samples. Therefore, the AE detector at the previous triaxial compression AE tests was usually placed directly on the outer wall of the triaxial chamber [18–20], as shown in Figure 1. In this case, the shear pulse wave (S-wave) generated by the compression fracture could not directly pass through the hydraulic oil, and the received event number and energy were greatly reduced, owing to the diffraction and reflection of the propagation path, seriously

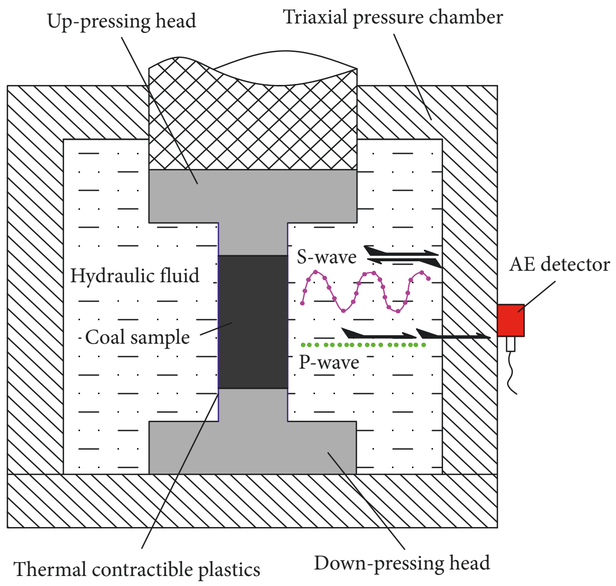



Figure 1: AE detector placed on the outer wall of the triaxial chamber.

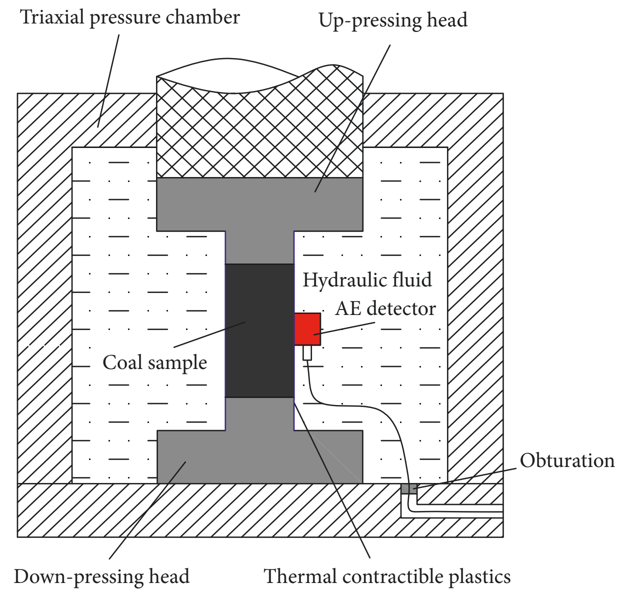



Figure 2: AE detector placed on the surface of rock samples or coal samples in the triaxial chamber.

affecting the accuracy of test results. Although the compressed wave (P-wave) could be normally spread in the liquid such as hydraulic oil, the AE energy also greatly attenuated due to the increase of the transmission distance and the reflection of the triaxial chamber cylinder. At the same time, when the detector was placed at the outer wall of the triaxial chamber, the electromagnetic noise received by the detector was relatively large, and the received AE signals were relatively low. Therefore, it was difficult to obtain the comprehensive and reliable AE detection signals.

As shown in Figure 2, although there were experiments in which the detector was placed in the triaxial chamber, it was directly placed on the surface of rock samples or coal samples in the triaxial chamber hydraulic oil. The working performance under such conditions is extremely affected only for short-term test and low confining pressure conditions, but for a long time fatigue test with high confining pressure, it is difficult to realize it. Based on this, the communication interface of the MTS815 rock servo test system was modified. Furthermore, developing a triaxial AE test head capable of sealing the AE detector, placing the AE detector inside the triaxial chamber and enabling the AE detector to work normally under high confining pressure is of considerable significance to ensure the authenticity and reliability of the AE signals during triaxial compression AE test.

## 2. Test System Overview

The rock's or coal's triaxial compression AE test in this study was carried out on MTS815.02 electrohydraulic servo rock test system independently developed by MTS company of America and AE21C acoustic emission tester developed and manufactured by Shenyang Computer Technology Research and Design Institute.

*2.1. MTS815.02 Electrohydraulic Servo Rock Mechanics Test System.* MTS815.02 electrohydraulic servo rock mechanics test system is shown in Figure 3. Its main features are as follows: (1) full computer control, enabling automatic data acquisition and processing; (2) equipped with three separate servo systems controlling axial pressure, confining pressure and pore (osmosis) pressure, respectively; (3) solid steel frame only to store a small elastic in order to achieve rigid pressure test; (4) quick reaction servo valve, high precision test; (5) the extensometer (patent products of MTS company in the United States) with direct contact with the specimen can work normally under high temperature and high pressure, so as to accurately measure the stress and strain of rock under high temperature and high pressure; (6) to choose any loading waveform and loading rate for tests.

*2.2. AE21C Acoustic Emission Detection System.* AE21C acoustic emission detection system developed by the Shenyang Computer Technology Research and Design Institute is a small system with a minimum of 2 channels, which can be extended to a super large system with a maximum of 128 channels, as shown in Figure 4.

The system can record the time of each AE impact as well as ring count, rise time, duration, amplitude, effective value, and average voltage level. Taking the time as the count variable to record the counting rate of AE parameters, accumulative number as well as the relationship between the external simulation and the AE parameters, one-dimensional and two-dimensional AE source positioning can be done, including linear positioning, plane positioning, cylindrical positioning, spherical positioning, and regional positioning. In dealing with conventional AE parameters, high-speed data acquisition card is also equipped to record the AE waveform of 1~2 channel, and spectrum analysis and wavelet analysis can be carried out. The AE21C acoustic

Figure 3: MTS815.02 electrohydraulic servo rock mechanics test system.

Figure 4: AE21C acoustic emission test device.

emission detection system is suitable for both burst AE waves generated by the cracking of the material and continuous AE waves generated by leakage, friction, and so on.

## 3. Study on Reasonable Triaxial Compression AE Test Method

According to the characteristics of communication interface of MTS815 electrohydraulic servo rock mechanics test system, the communication interface of the MTS815 rock servo test system was modified so that the AE detector can be placed inside the triaxial chamber and the signal goes smoothly from inside to outside of the triaxial chamber. At the same time, in order to solve the problem that the detector could not withstand the pressure of the hydraulic oil in the triaxial chamber and ensure the working performance of the AE detector, the high confining pressure triaxial AE test head was developed which can seal the AE detector inside the triaxial chamber so that the detector can work normally under high confining pressure (Figure 5). Based on this, the triaxial compression AE test method for rock can be improved and optimized, which is convenient for researchers to use a more reasonable AE test method to carry out the AE test of different loading paths (rock compression, unloading confining pressure, cyclic loading, etc.) under the triaxial condition.

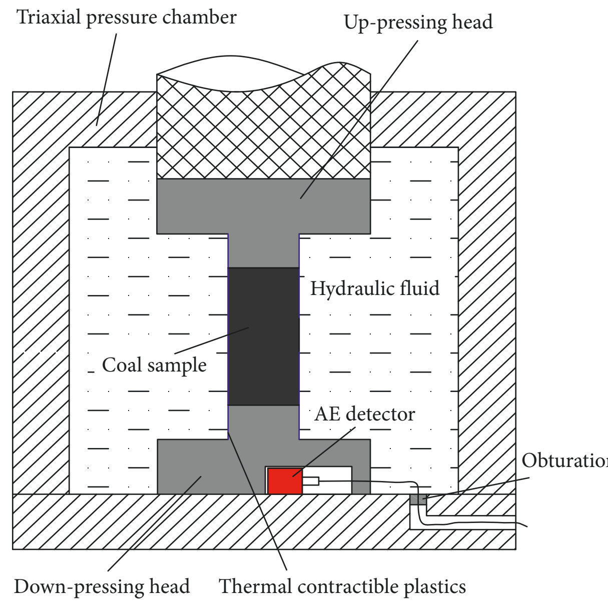
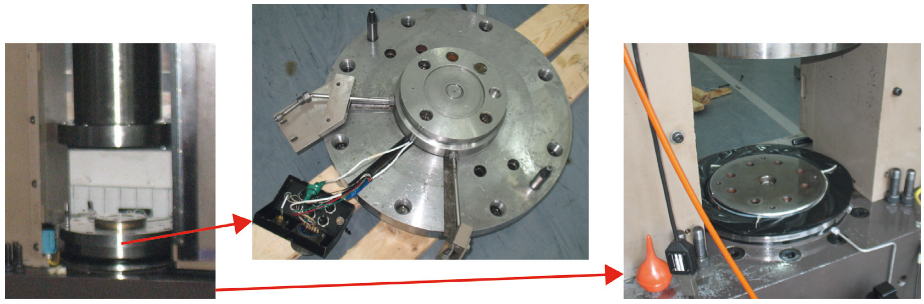



Figure 5: AE detector placed in a triaxial chamber head.

*3.1. Electrohydraulic Servo Rock Mechanics Test System Modification.* The AE signals from rock samples or coal samples in the triaxial chamber could not be transmitted outdoors effectively, coupled with the AE detector which was not in direct contact with the rock or coal samples. In the triaxial compression AE test with the probe placed on the outer wall of the triaxial chamber, there were many problems such as the type of the wave and the propagation path conversion, the attenuation of the vibrational energy, and the interference of the electromagnetic noise signal, which could not receive the AE direct wave signals, and most of the strong signals were shielded. Therefore, in order to realize the AE detector, it can be placed inside the triaxial chamber, and the signal goes out smoothly from the triaxial chamber; according to MTS815 rock servo test system's own communication interface characteristics, the test system communication interface was modified. Specific modification steps are as follows.

*3.1.1. Test System Pressure Base and Communication Base Decomposition.* The signal lines connected test system and test base, hydraulic components and other components were disassembled, and a small forklift was used to unload the test base from the test system. Then, the communication pressure base mounted on the test base was removed and the signal lines on the communication pressure base were dismantled, as shown in Figures 6(a) and 6(b).

*3.1.2. Transformation of Communication Holes on the Base of Communication Pressure.* Remove the communication connector of the three communication holes on the communication pressure base and the three plugs that plug the backup hole, as shown in Figure 7. After cleaning the three spare holes, the two of them were plugged again with the original plungers and the other spare hole was used as the entrance passage for the transmission line of the AE sensor.



(a)

(b)

Figure 6: The breakdown diagram of the pressure base and the communication base of the test system: (a) test base decomposition and (b) communication base dismantling.

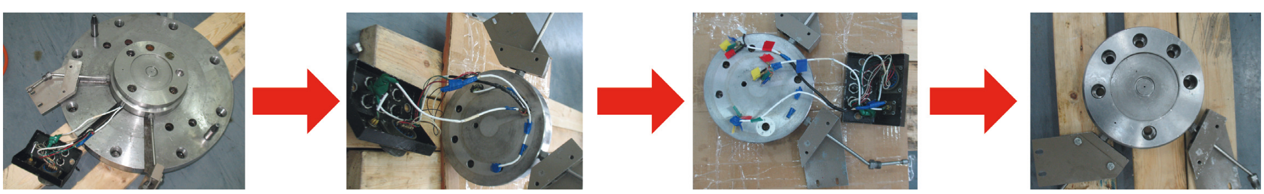


Figure 7: Removing the communication hole plugging device.

The plunger used therein was a hollow plunger, and the transmission line was able to pass through the center of the plunger, as shown in Figure 8.

*3.1.3. AE Detector Transmission Line Transformation.* Since the original transmission line of the AE sensor was immersed in the hydraulic oil for a long time, under the action of immersion, corrosion, and high pressure of hydraulic oil, the elasticity of the transmission line decreases and its brittleness increases, and it can get easily damaged. Therefore, a new type of transmission line, which is resistant to pressure, oil, and corrosion resistance, is required.

The corrosion-resistant transmission line was passed through the center hole of the hollow plunger and the protective rubber hose was also passed through the transmission line. The communication connector was connected with the corrosion-resistant transmission line. Finally, the new transmission line was connected with the geophone and AE host phase connection, for the effectiveness of testing, as shown in Figure 9.

*3.1.4. Communication Access Hole Transformation.* Install the plunger with AE transmission line in the center hole in the communication hole and reserve a certain length for the AE transmission line passing through the plunger for adjustment and use during test.

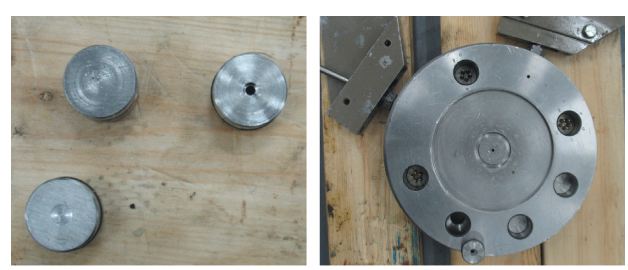


Figure 8: AE communication hole transformation.

After setting the reserved length, put the protective rubber hose along the transmission line on the plunger of the communication hole, pour the epoxy resin inside the communication hole, and close the hollow plunger penetrating the transmission wire, and at the same time, pour the protective rubber tube with the epoxy resin together to ensure the high-pressure hydraulic oil did not leak during the test, and the other two communication holes were plugged again with a solid plunger, as shown in Figure 10.

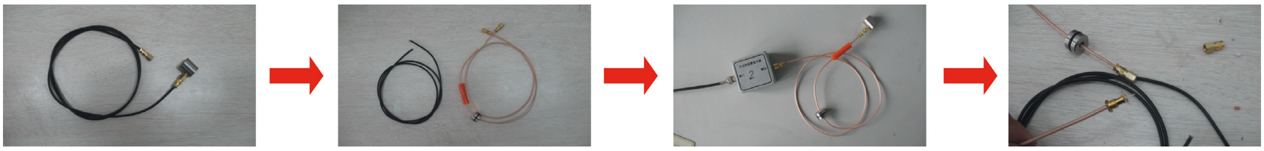


Figure 9: Sensor transmission line transformation.

Figure 10: Communication hole assembly.

*3.1.5. Test System Installation.* After the epoxy resin was completely cured, connect the communication transmission line to the communication pressure base, and then reposition the communication pressure base to the test base and tighten the bolts. Note that when installing, do not crush the transmission lines and signal lines under the communication pressure base. The transmission lines and signal lines were led out from under the communication pressure base along the groove of the pressure base, as shown in Figure 11.

After the installation was completed and the test was qualified, reinstall the test base on the MTS815 rock servo test system, tighten the fixing bolts, and connect the communication lines and hydraulic pipelines.

So far, the modification of the communication interface of the MTS815 rock servo test system has been completed, which can make the AE signals inside the triaxial chamber normally transmitted to the outdoor.

*3.2. High Confining Pressure Triaxial AE Test Head.* When the AE detector is placed on the outer wall of the sample in the triaxial chamber, long-term immersion detector in hydraulic oil not only affects the use effect but also reduces the service life. Meanwhile, the AE detector cannot withstand the high confining pressure, and the piezoelectric ceramic pieces on the surface of the detector will be cracked, as shown in Figure 12. Therefore, it is necessary to develop a new type of test head that can meet the requirements of triaxial AE test so that the detector can be placed inside the test head to obtain the comprehensive and reliable AE signals.

*3.2.1. High Confining Pressure Test Head Design.* The new high confining pressure triaxial AE test head can be divided into the main part and the closed part:

*(1) The Main Part.* It is designed for AE detector placement cavity, transmission line hole, storage slot, seal hole, and so on, as shown in Figures 13(a) and 14.

The AE detector transmission line gets deep inside the head through the transmission line hole, connected with the detector in the installation cavity, and reserving part of the transmission line in the storage tank for maintenance. A hollow plunger is installed in the sealing hole (the transmission line passes through the hollow plunger), and the sealing hole is potted and sealed with epoxy resin. An elastic fixing device is used to fix the detector in the space cavity to make tight contact with the head and coupling with the coupling agent.

*(2) The Closed Part.* The sealed part was designed with a sealing groove, an insulating paper pad, a screw hole, and so on, as shown in Figures 13(b) and 14. The circular sealing rubber ring was installed in the sealing groove, as the MTS815 rock mechanics test machine has static electricity generated during the test process; it will pass through the test head and then affect the normal work of the AE detector, so it is necessary to insulate the test head. The test head insulating paper pad is covered above the closed part, so that the two parts of the test head are insulated, and the fixed bolt is also insulated.

*3.2.2. High Confining Pressure Test Head Production.* Owing to the head in the test process which will be subjected to the high stress action of the test machine, if the material rigidity of the head is relatively low, it will affect the test results. And, it needs to use the material with large rigidity to make the head, so the #5 steel is used for processing. According to the design drawings, a series of machining processes such as cutting, milling, and drilling are processed, and then the test head is quenched to ensure that the head has large stiffness. When the main part and the closed part are finished, the assembly is carried out. The process of the high confining pressure test head and the object are shown in Figure 15.

## 4. Comparison of AE Parameters with AE Detector inside and outside the Triaxial Chamber

In order to better compare the detection results of AE signals with AE detector inside and outside the triaxial chamber, with confining pressure 3 MPa as an example, using the method of AE detector installed inside and outside the triaxial chamber, the AE tests of limestone and

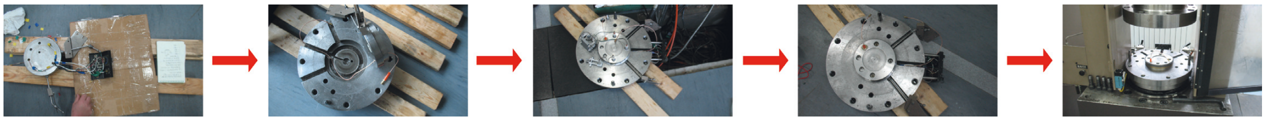
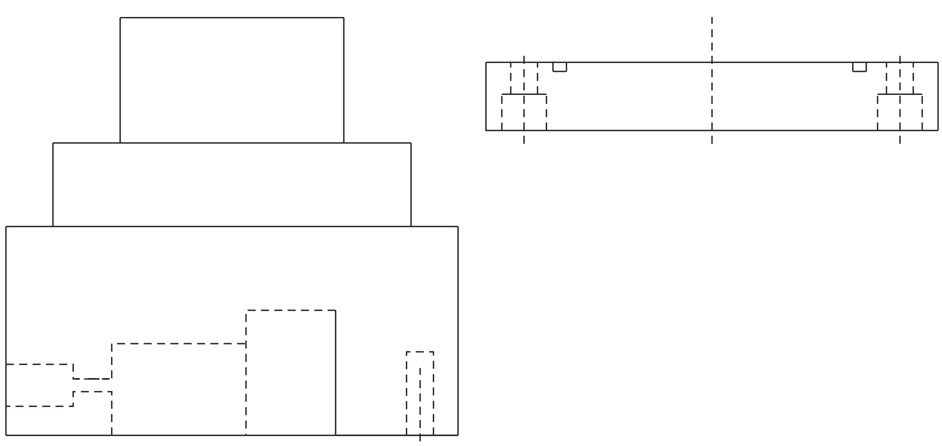


Figure 11: Test and installation.

Figure 12: Damaged AE detector.



(a) (b)

Figure 13: Test head side view: (a) main part and (b) closed part.

coal samples under triaxial compression conditions were carried out, respectively. Figures 16 and 17 show the comparison curves of AE parameters of limestone and coal samples with AE detector inside and outside the triaxial chamber, respectively.

As shown in figures above, the left and right sides represent the AE parameter curves with AE detector outside and inside the triaxial chamber, respectively. In all loading process, the AE parameter curves detected outside the triaxial chamber have the similar trend with AE parameter

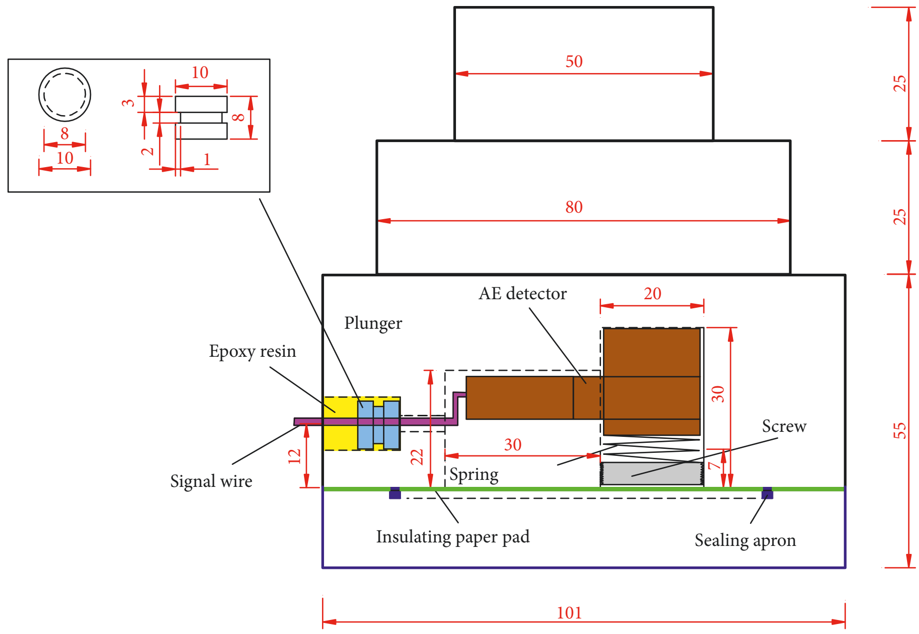



Figure 14: Test head combination renderings.

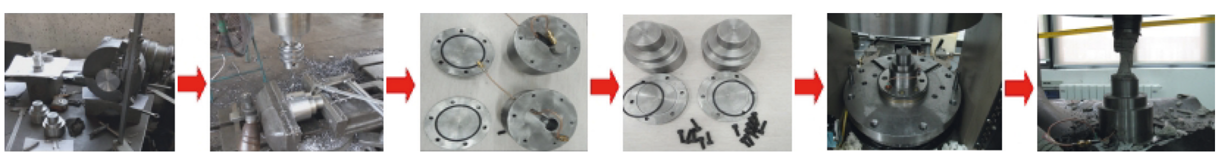


Figure 15: Head processing and assembly applications.

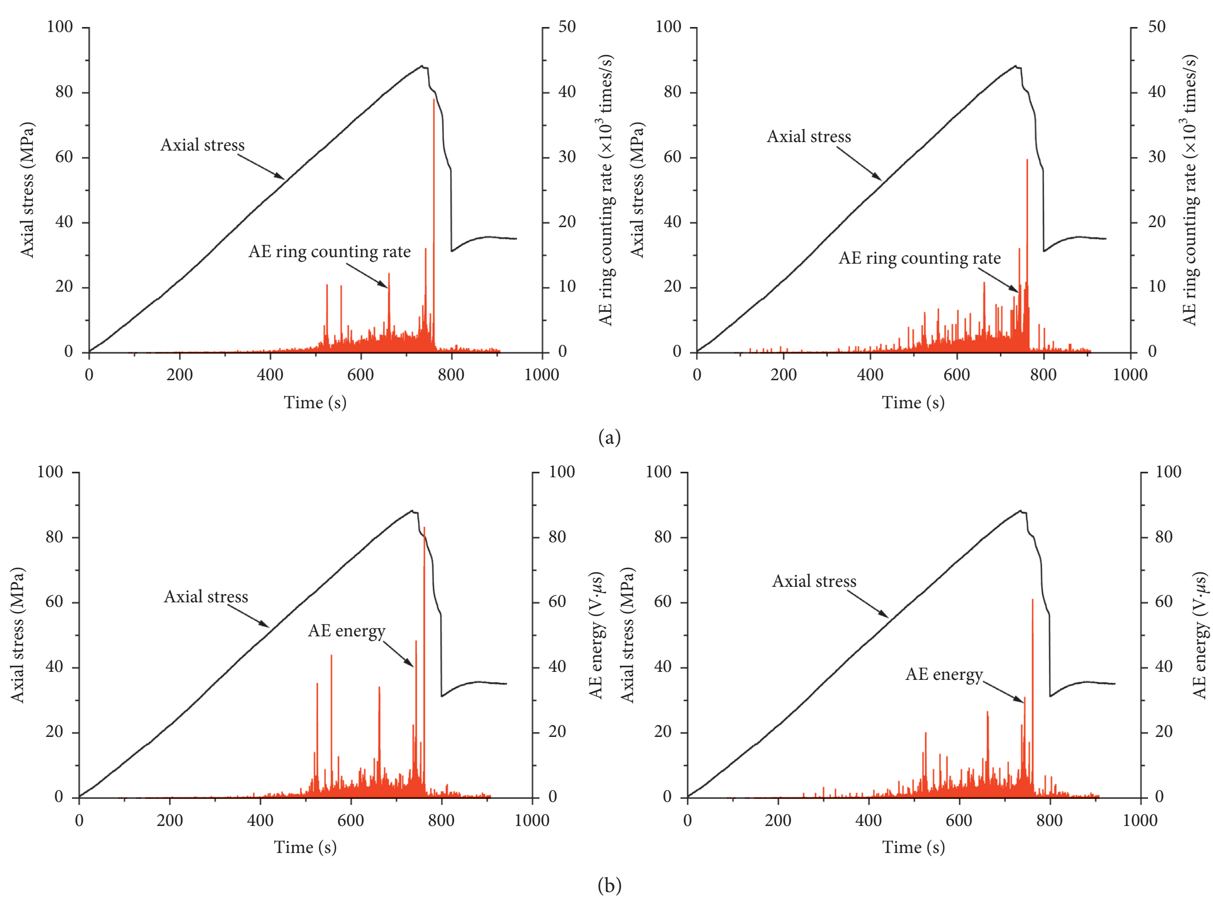
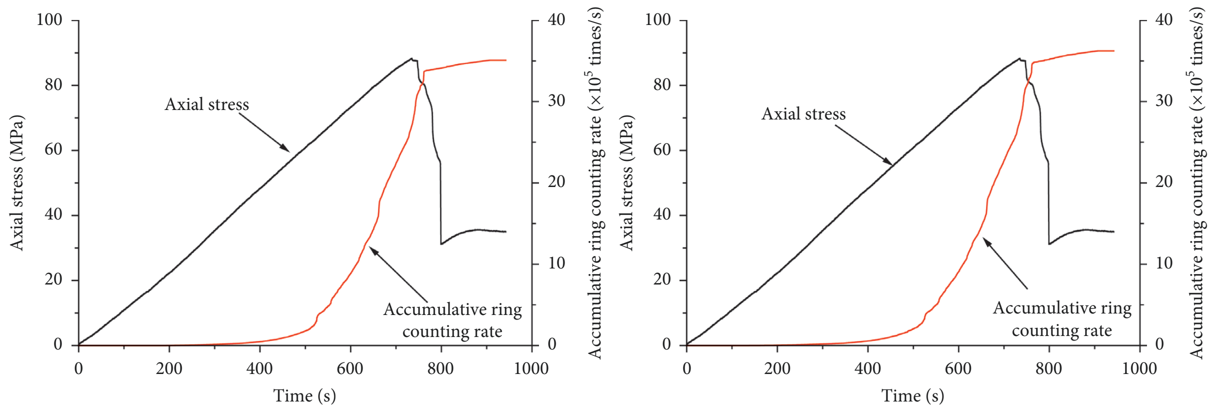



Figure 16: Continued.




(c)

Figure 16: AE parameter curves of limestone with AE detector outside and inside the triaxial chamber, respectively: (a) AE ringing count; (b) AE energy; (c) accumulative ringing count.

curves detected inside the triaxial chamber, which also can reflect all stages of rock damage and failure. The difference is that more accurate AE information can be detected inside the triaxial chamber. The maximum ringing count of limestone sample is 38,959 with AE detector inside the triaxial chamber, while 29,700 outside the triaxial chamber. The maximum AE energy is 83,162 mV with AE detector inside the triaxial chamber, while 60,900 mV outside the triaxial chamber. The maximum number of ringing counts with AE detector inside the triaxial chamber is 31.2% higher than that with AE detector outside the triaxial chamber, and the energy is 36.5% higher than that with AE detector outside the triaxial chamber. The maximum ringing count of coal sample is 21,912 with AE detector inside the triaxial chamber, while 15,700 outside the triaxial chamber. The maximum AE energy is 45,487 mV with AE detector inside the triaxial chamber, while 32,500 mV outside the triaxial chamber. The maximum number of ringing counts with AE detector inside the triaxial chamber is 39.5% higher than that with AE detector outside the triaxial chamber, and the energy is 39.9% higher than that outside the triaxial chamber. From the above data, it is not difficult to find that the shear pulse wave (S-wave) produced during the compression and fracture of the limestone which cannot pass through the hydraulic cylinder and being lost. The energy of the compressed wave (P-wave) is greatly weakened owing to the increase of the transmission distance, and the real and reliable AE signals are not possible to be obtained.

However, the cumulative ringing count shows that the monitoring value with AE detector outside the triaxial chamber is higher than that inside the triaxial chamber by comparison. When the limestone sample was destroyed, the indoor total ringing count was 3,509,458 and the outdoor count was 3,623,610. When the coal sample was destroyed, the indoor total ringing count was 1,331,029, while the outdoor count was 1,412,270. The reason is that, during the detection of AE signals, the detector outside the triaxial chamber is disturbed more by the noise, which makes the total ringing count of the outer wall of the triaxial chamber relatively high.

## 5. Discussion

Through modified the structure of the MTS815.02 electrohydraulic servo rock mechanics test system, the built-in AE detector is realized. By comparison of the AE characteristic parameters detected by limestone samples and coal samples in the same test process and different detection positions, it is shown that the AE signals received inside the triaxial chamber have the advantages of being more accurate and direct and having less noise interference.

The modified testing system is not only suitable for coal and limestone but also for other kinds of rocks, such as sandstone, shale, and limestone.

## 6. Conclusions

The modification of communication interface of MTS815.02 electrohydraulic servo rock mechanics test system was carried out, so that the AE detector can be placed inside the triaxial chamber, realizing that the signal is smoothly emitted from the triaxial chamber.

A high confining pressure triaxial AE test head which can seal the AE detector and be put inside the chamber and make the detector work normally under high confining pressure is developed.

In order to verify the reliability of the modified test system and test head, the AE tests were carried out on the limestone and coal samples under the triaxial compression condition by installing the AE detector inside and outside the triaxial chamber. The results show that the maximum value of ringing count for indoor AE of limestone samples and coal samples are 31.2% and 36.5% higher than that of outdoor ones, respectively, and the energy are 39.5% and 39.9% higher than that of outdoor ones. Therefore, the AE signal obtained by the improved test method is more accurate and true.

In terms of the cumulative ringing count of the triaxial compression tests for limestone and coal samples, when the detector is placed inside the triaxial chamber

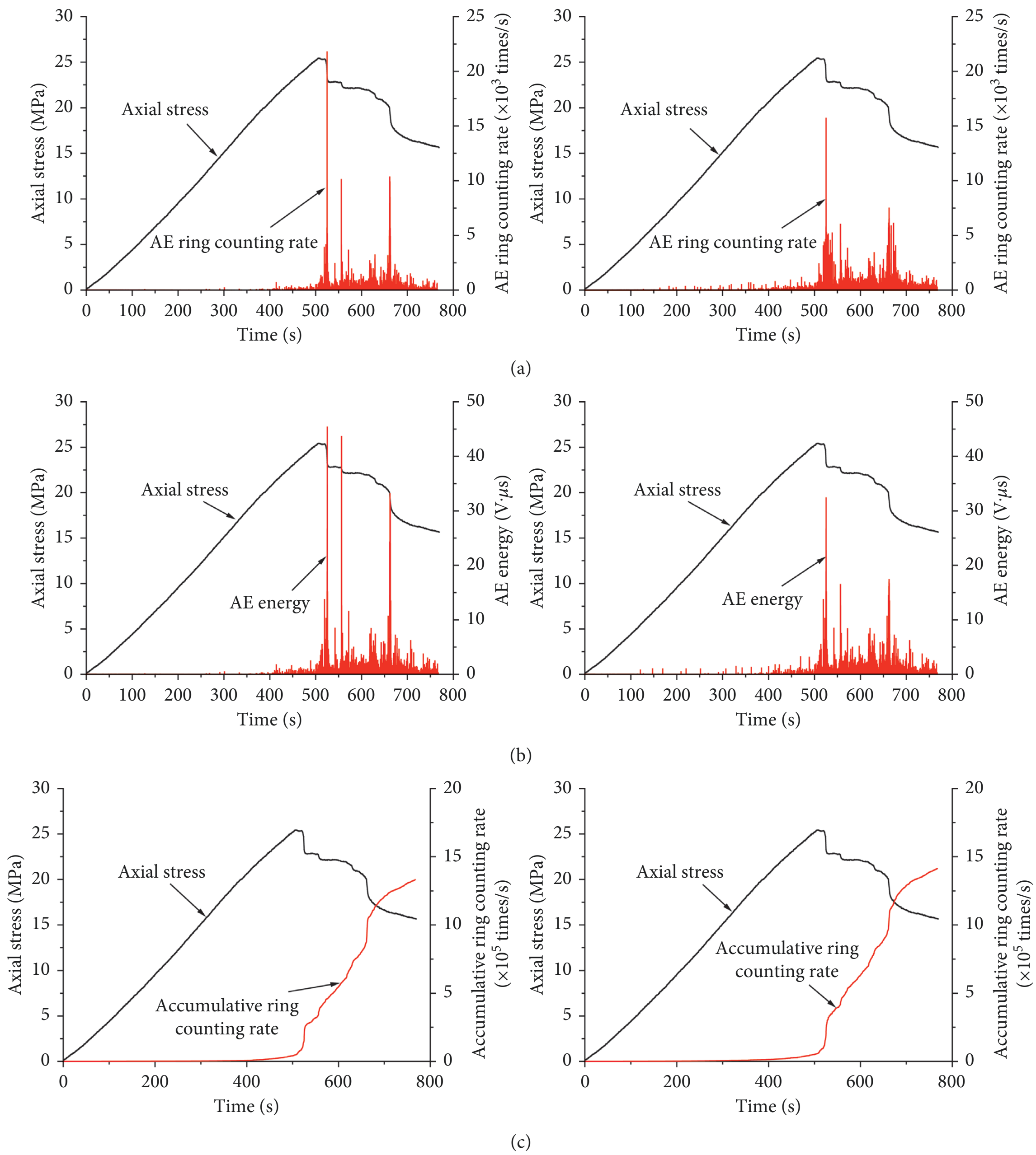



Figure 17: AE parameter curves of coal sample with AE detector outside and inside the triaxial chamber, respectively: (a) AE ringing count; (b) AE energy; (c) accumulative ringing count.

head, the test result is relatively lower compared with the external test of the triaxial chamber, owing to avoiding a great deal of noise interference from outside, which further demonstrates that a series of experimental results of AE testing of rock samples or coal samples previously with detector placed outside the triaxial chamber are not objective.

The improvement and optimization of the triaxial AE test method is of considerable significance for the application of AE technology to scientifically determine the precursory characteristics of rock's or coal's rupture and instability and to ensure the safe and efficient production of coal mines.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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