Wireless device for the detection of explosions and activation of a shock wave absorber

David Khomeriki[1*], *Nikoloz* Chikhradze[1] , *Edgar* Mataradze[1] , *Mikheil* Chikhradze[1] , *Karlo* Tavlalashvili[1] , and *Shalva* Marjanishvili[2]

[1]1G.Tsulukidze Mining Institute, Tbilisi, Georgia

[2] Hinman Consulting Engineers, inc., San Francisco, CA, USA

Abstract. Existing problems of security is strongly connected to terrorist and accident explosions and fires. Physical protection of critical infrastructure requires the creation of reliable system providing quick and accurate identification of the hazards and subsequent transmission of the alarm signal to the protection device. The paper describes the basic requirements and structure of the wireless device for the detection of explosions. Proposed wireless device consists of transmitter and receiver modules. A transmitter module contains the sensors and a microprocessor equipped with a blast identification software. A receiver module produces an activation signal for the operation of protection devices. The paper presents the test results of the proposed wireless device, carried out in the underground experimental base of the G. Tsulukidze Mining Institute.

1 Introduction

The consequences of an explosion are particularly severe in confined spaces, such as tunnels and other underground structures, where air-blast waves are amplified and therefore, are more destructive compared to open air explosions. The underground facilities that are most susceptible to accidental explosions are coal mines, where methane and/or air-coal media explosions result in fatalities. Furthermore, there is a great concern about increased terrorist activity in recent years targeting civilian population in mass transit systems. Therefore, explosion mitigation techniques need to be applied in civilian facilities such as motorway and rail tunnels and stations. There are countless tunnels in operation throughout the world and many more are under construction, or at the design stage.

Recently in coal mines and other industrial sites started using automated explosion protection systems [1-4]. These systems include a blast identification module (optical, thermo or pressure sensors and electric device generating a trigger signal), a blast energy absorber that has a blast suppressing agent dispenser, and a device to eject the liquid or dust into the protected space. However, the low reliability of blast detection and delayed generation of a start signal for the activation of an absorber are the major disadvantages of currently deployed protective devices. Furthermore, these devices transmit an activation

* Corresponding author: davitkhomeriki@yahoo.com

signal using cables. These cables are usually damaged during the explosion (or can be sabotaged during a terrorist attack) rendering the whole system inoperable.

The research presented in this paper includes the selection of a suitable and reliable methodology for explosion identification in underground facilities, the selection of reliable wireless transmission properties, and the verification and validation test of a prototype wireless system.

2 Basic requirements for the detection systems

The development of contemporary detection systems is oriented to the creation of integrated systems ensuring monitoring of threats that may endanger facilities to be protected as well as respective measures for threat prevention. A security system must enable identification of emergency conditions and have Wi-Fi modes of operation. The system must quick-acting and reliable and not impede the normal functioning of the underground facility. In order to achieve reliability, the system must not depend on the external power. It must have a possibility controlling in a test mode. Detection system shall meet the requirements on equipment and protective systems intended for use in potentially explosive atmospheres (ATEX).

System design process requires the following stages:

- Risk analysis of the facility to be protected; definition of the function of the system;
- Determination of emergency and pre-emergency identification parameters and definition of respective limiting values;
- Selection of sensors;
- Development of identification module and electric scheme of emergency signal generation;
- Selection of a wireless technology of data transmission and determination of working frequency ensuring signal transmission at a required distance;
- Selection of main technical properties of signal transmission and reception modules and development of their electric scheme;
- Selection of a power supply source for the system;
- System testing, adjustment and determination of its reliability.

3 Structure of the wireless device

The protective system composed of: a) detector block with sensors and signal transmitter and b) absorber with signal receiver and control block (Fig.1). An absorber contains a water tank with a built-in gas generator and nozzles. A signal generated in a detector block transmitter is received by an absorber control block receiver, which produces a start signal and sends it to the electrical initiator of a gas generator. High gas pressure is generated in a chamber is transferred to the water in containers. Together with the development of pressure in container, nozzles begin to discharge water creating a dispersed water mist in an area to be protected.

The blast detector and system activation block design is based on the following principle: the blast detector provides constant monitoring of explosion and fire identification parameters. When reaching the ceiling values of these parameters, the detector generates a high-frequency electric signal that will be transmitted to the receiving module of activation block. The activation block instantly transmits the start signal to the absorber control block. According to the circuit diagram developed a prototype model of a blast detector and an activation block.

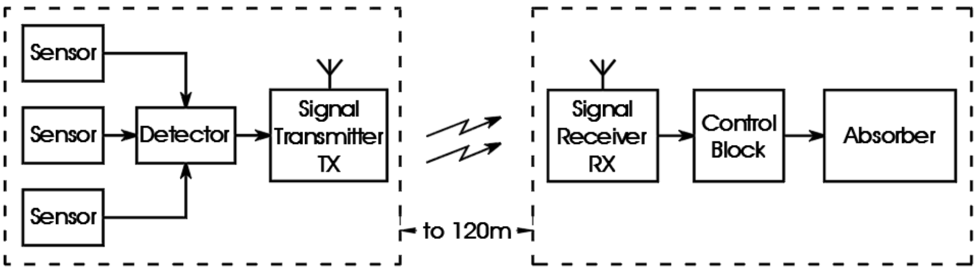


Figure 1. Circuit of the protective device

Blast detector specifications:

1. Has four outputs: overpressure sensors and flame IR sensors;
2. limiting value:
- for blast detection: overpressure above than 12 kPa
- for fire detection: the area of the site of the fire exceeds 0,5m2
3. Output power: + 30dBm;
4. Type of modulation: Amplitude-impulse modulation (PAM);
5. Frequency of operation: 433.92 MHz;
6. The data transfer rate: 12kB/s;
7. Source voltage: 220 V +/- 10%, in emergency state – 12.6 V;
8. Antenna type: Quarter-wave dipole antenna;
9. Overall dimensions: 220*220*83 mm
10. Weight:1.5 kg

Activation block specifications:

1. Output for absorber control block: +300V, energy of 14.85 joules, 50 ms time interval;
2. Input sensitivity: 115 dBm;
3. Type of modulation: Amplitude-impulse modulation (PAM);
4. Frequency of operation: 433.92 MHz
5. Antenna type: Quarter-wave dipole antenna;
6. Source voltage: 220 V +/- 10%, in emergency state – 12.6 V;
7. Overall dimensions: 220*220*83 mm
8. Weight: 1.5 kg

The blast detector and the activation block can provide constant monitoring of sensors, connecting cables and the power voltage and has alarm audio signals.

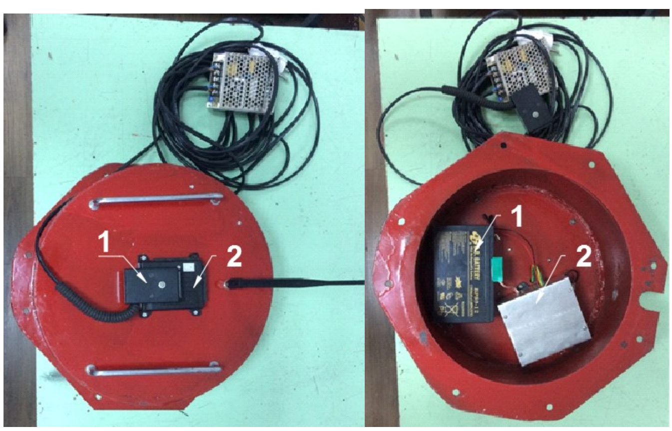
4 The results of testing

The test methodology included the definition of the distance between the transmission module and the receiver module for the reliable signal transfer and of time characteristics in the open space and in a tunnel.

The experiment in the open space was performed in the vicinity of the Mining Institute. During experiments, the transmission module generated imitated blast signals that were recorded by the receiver module. The experiment showed that the signal transmission distance in the open space exceeds 1 km. The power of the signal (-47.19 dBm) exceeds the receiver sensitivity (-115 dBm), which ensures the reliable reception of the signal.

At the next stage of testing, the time characteristics and reliability of the detection system during real explosions were determined. The tests were carried out in the underground facility of the Mining Institute. In the experiments, the shock wave absorber was used with the proposed wireless device. An absorber consists of a water container, nozzles, system activation block with signal receiver, pyrotechnic device and electrical initiator. Water container represents the steel tube, in which, in the one end is installed system activation block and in the other end is installed pyrotechnic device. The tube length is 1.99 m, the diameter is 0.27m, the thickness is 0.01m. The volume of the water container is 111 liters. In the tube are installed 73 nozzles- model BETE P120 (Figure 2, 3).

Figure 2. Photo of the absorber in the tunnel of the underground experimental base. 1 –water container, 2 - system activation block, 3 – pyrotechnic device, 4- nozzles



A B

Figure 3. The system activation block. A – Appearance. 1- complex display, 2 - noncontact battery charging. B – Inside view. 1-signal receiving module and control means, 2- battery

A signal generated in a detector block transmitter is received in an absorber, which produces a start signal and sends it to the electrical initiator of a gas generator. High gas pressure is generated in chamber and is transferred to the water in containers. Together with the development of pressure in hydro containers, begin water discharge from nozzles creating a dispersed water mist in an area to be protected.

The response time of the system during small charge explosion at 33 m from the absorber were determined (Figure 4).

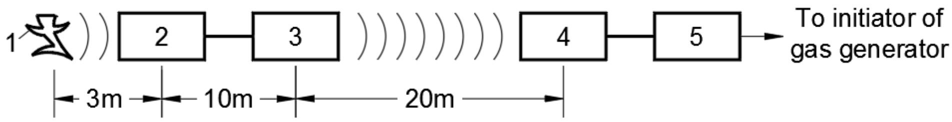


Figure 4. Plan of experiments for determining the response time. 1-explosion, 2- sensor, 3 – signal processing and transmission module, 4 - signal receiving module, 5 –absorber control block

Over 17 explosion tests cycles were conducted. In the process of experiments the formation of a false signal or ignoring the explosion was not observed. Time history of alarm signal generation and response of shock wave absorber is show in Figure 5.

Figure 5. The response time of the shock wave absorber

The testing showed that the time of the activation of shock wave absorber is 22 ms from the blast moment, which ensures the fast action of the presented system. After activation, the absorber produced tailored protection water barrier evenly distributed along cross-section of a tunnel.

5 Conclusions

Based on this study, the following conclusions are drawn:

• The devices currently used to protect from accidental or deliberate explosions in underground facilities often fail to meet modern requirements. The development of effective automated protective facilities requires the improvement of the reliability of the identification and reduction in the commutation time for rapid response of the component of the system;

• The elected methodology facilitates rapid generation of a trigger signal at the initial stage of the explosion and creates favorable conditions for the wireless signal transmission from a transmitter module to a receiver module;

• The proposed system has the following characteristics:

- Time between blast detection and start signal generation does not exceed 22 ms, which enables the activation of a protective system before the arrival of a shock wave into the underground opening;
- High reliability of detection when reaching the threshold of 12 kPa;
- Trigger signal ensures the activation of an electric initiator of a pyrotechnical element of a protective device;
- For reliable signal transmission distance between the transmitter and a receiver in a direct tunnel - 150m; in a tunnel with a 900 angle - 50m;
- Use of wireless system will rule out the threat of cable damage from mechanical impact accident, sabotage or during the explosion.

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