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A FAIL-SAFE CONTROL SYSTEM FOR A MINE METHANE PIPELINE

by

M. C. Irani,[1] F. F. Kapsch,[2] P. W. Jeran,[3] and S. J. Pepperney[4]

ABSTRACT

The Bureau of Mines has designed and put into operation a fail-safe control system for use in underground coal mines equipped with methane drainage pipelines. This control system can detect certain unsafe conditions and respond by automatically shutting off the flow of methane from the degasification borehole to the drainage pipeline. Methane flow is shut off when the methane content in the return airways reaches a predetermined level (typically 1.5 pct), when the methane drainage pipeline is ruptured by roof fall, or when there is an electric power failure.

The fail-safe control system was designed using commercially available components and a methane analyzer system previously developed by the Bureau. The fail-safe system consists of a unit that combines a shutoff valve and pneumatic valve actuator, and electronic and mechanical equipment designed to detect hazards and effect shutdown.

The fail-safe control system was designed to meet regulatory requirements issued by the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, and State regulatory bodies for the safe operation of underground methane pipelines used for mine degasification. MSHA has inspected and tested this system and permitted its use in two mines. The Bureau installed the fail-safe system in two working coal mines, where successful performance has been demonstrated.

INTRODUCTION

The Bureau of Mines has conducted research on methane control in bituminous coal mines since it was first organized. This research has been carried out on an accelerated basis since 1964. An important objective of this

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research is to reduce the hazard of methane emissions during mining (3).[5] One successful approach is to drain methane using degasification boreholes drilled horizontally into the coalbed from underground locations (4-7). Boreholes are drilled from locations near active workings and from the bottom of shafts dug for future use at locations remote from active workings. The boreholes provide low-resistance channels to conduct methane from the coalbed. Advantages of this borehole method of degasification are increased ventilation and production efficiency that can reduce mining cost.

Efficiency is improved because the borehole method of degasification reduces methane emissions from the face area, allowing mining machinery to be safely operated for more total time than if degasification is not used. The modern high-capacity coal mining machines that are used to mine very gassy coalbeds are designed to shut down automatically when methane concentrations exceed a predetermined safe level. With borehole degasification, methane concentrations are kept at lower levels, and so the machines can operate more of the time than if degasification were not used.

In the past, methane drainage boreholes were 100 to 150 feet long, and so the quantities of methane they drained were relatively small. With the successful development of techniques for drilling boreholes as long as 2,500 feet, the quantities of methane drained became excessive from a safety and economics standpoint. It is hazardous to discharge large quantities of methane into the mine atmosphere, because of the potential for explosion. Furthermore, this methane has potential use as a source of energy, although sometimes there are certain economic constraints and legal problems regarding ownership of the methane. At one project site, the methane drained by seven boreholes has been used for industrial and residential purposes (5). Large-scale production over several years has demonstrated the economic potential of methane produced in this manner. To make use of methane drained from mines, it is necessary to design and build underground pipelines to safely collect and convey the methane from the boreholes to the surface.

Federal and State regulatory bodies have prepared specifications and other design requirements for a safe methane collection system for use in underground coal mines (8). Included in these design requirements is a fail-safe control system to close the methane drainage pipeline when unsafe conditions develop in the mine. A system is required that will stop the flow of methane from the coalbed to the drainage pipeline when there is methane leakage due to corrosion, rupture of the pipeline resulting from a roof fall, or for other reasons. In order to design a system that would meet these regulatory and performance requirements, the Bureau drew upon knowledge derived from years of research in methane monitoring systems. Particularly useful was a methane analyzer system (6) previously developed by the Bureau and incorporated into the fail-safe system.

The fail-safe control system that resulted from the Bureau's efforts has successfully detected and responded to unsafe conditions in field installations

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[5]Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

at Bethlehem Mines Corp.'s Marianna 58 mine in Washington County, Pa., and Maple Meadow Mining Co.'s Maple Meadow mine near Beckley, W. Va.

Under applicable Federal and State safety regulations, methane drainage pipelines used for mine degasification are illegal unless equipped with a system such as the one described in this report. Therefore, safety control systems such as this are essential if long, horizontal boreholes are to be used for methane drainage from gassy coalbeds.

GENERAL DESCRIPTION OF SYSTEM OPERATION

The fail-safe control system uses a pneumatically actuated valve (fig. 1) to shut off the flow of methane from the degasification borehole to the methane drainage pipeline when the system detects an unsafe condition. As long as conditions in the mine are safe, air pressure supplied by a modified air compressor holds the borehole valve open, allowing methane to flow into the drainage pipeline. The system is designed so that the pressure drops in the system's air lines when an unsafe condition--such as a leak in the methane pipeline--is detected. The pressure drop allows a return spring to close the borehole valve, shutting off the flow of methane. The borehole valve remains open only when the fail-safe system is pressurized.

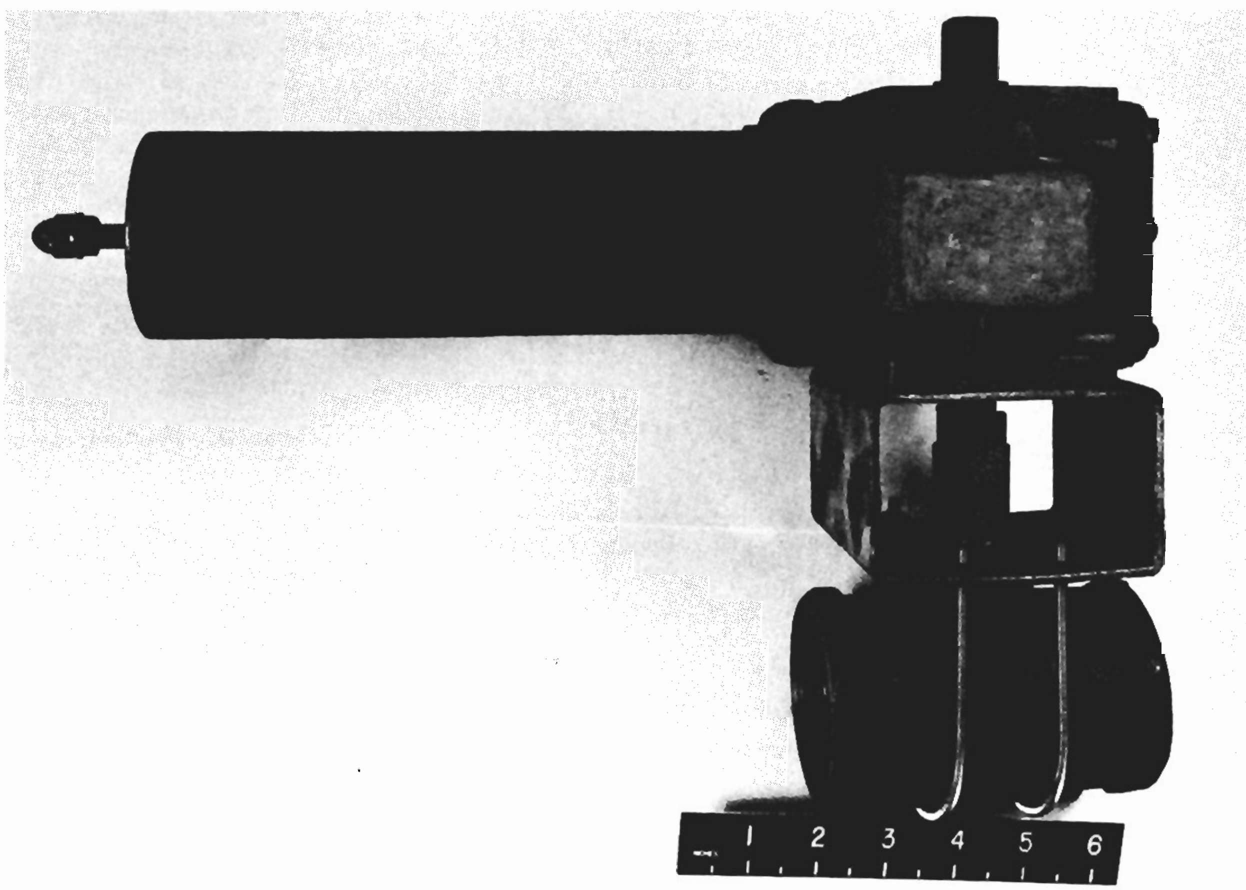

FIGURE 1. - Actuator mounted on threaded ball valve.

FIGURE 2. - Methane sensor assembly.

Regardless of the nature of the unsafe condition, methane flow is always shut off in the same way: a drop in air pressure allows the borehole valve to close. However, the system uses several different methods to detect different kinds of unsafe conditions.

Methane content is monitored by sensors (fig. 2) at various locations along the methane pipeline. When the sensors detect a hazardous concentration of gas, the system acts to shut down the methane pipeline.

For detection of roof falls, a brittle polyvinyl chloride (PVC) tube is strapped to the methane pipeline (as indicated in the diagram in fig. 3). This tube carries compressed air, and is shattered by the

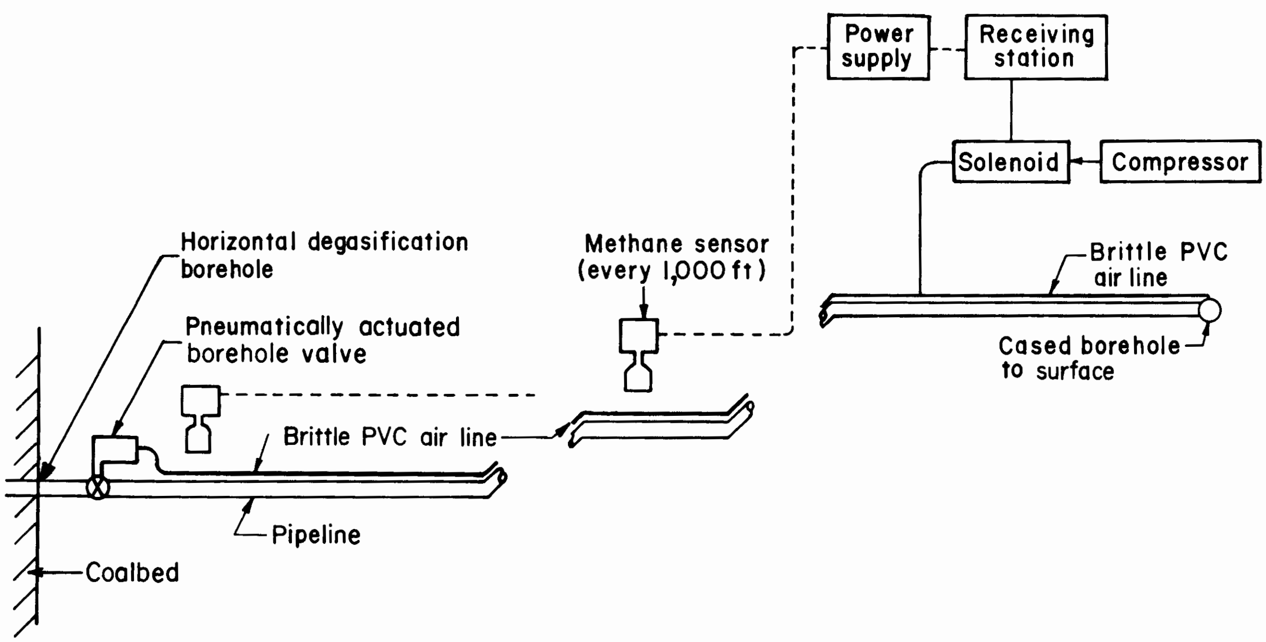

FIGURE 3. - Diagram of mine installation.

impact of a roof fall. When the tube shatters, air pressure drops throughout the system, causing the borehole valve to close.

In case of power failure, the air compressor will stop functioning. This, too, will result in a drop in air pressure, and the borehole valve will close off the flow of methane. The system is also designed so that any failure in electronic circuitry will result in shutdown of the methane pipeline.

MAJOR COMPONENTS OF THE SYSTEM

The electronic equipment used for methane detection and shutdown was developed by the Bureau of Mines and the Mine Safety Appliances Co., and is now commercially manufactured. The equipment was originally developed to record continuously the methane content of mine air (6). This equipment was later modified to actuate control devices, cut off electric power, and sound alarms.

For the fail-safe control system, this electronic detection and shutdown equipment has the capability of (1) indicating continuously, on meters, the methane content of the mine air at each sensor, (2) recording this methane data on individual strip charts, (3) flashing a red warning light when the methane content of the sampled mine air reaches a predetermined level (usually 1.0 pct), (4) opening a solenoid valve to release air pressure so that the borehole valve will close when the methane content reaches a higher predetermined level (usually 1.5 pct), and (5) cutting off power to the air compressor when pressure in the air lines drops below 40 psi. This electronic equipment works together with the mechanical components of the fail-safe system, such as the borehole valve and the brittle PVC tube.

Detection Equipment

The methane analyzer system is used in the fail-safe control system to detect dangerous levels of methane in the air along the drainage pipeline. The analyzer system consists of methane sensors, a power supply, and a receiving station. Figure 4 shows the relationship of these components to each other and to other components of the fail-safe system. Components of the methane analyzer system are commercially available in a package that includes four methane sensors.

The Methane Sensors

The methane sensors (fig. 2) are located along the underground methane pipeline to detect leakage. They are hung downwind from the boreholes at 1,000-foot intervals, to the point where the pipeline exits the mine. These sensors continuously monitor the methane content of the ventilation air, operating on the principle of catalytic combustion.

The sensing element is enclosed in a circular air deflector for dust and moisture protection. A rectangular box houses the sensing circuits, a two-stage signal-voltage amplifier, the amplifier power supply, and a nickel-cadmium battery that can operate the unit for up to 6 hours if power fails.

When the sensors detect a hazardous concentration of methane, the red warning light flashes and the solenoid valve is automatically tripped. The

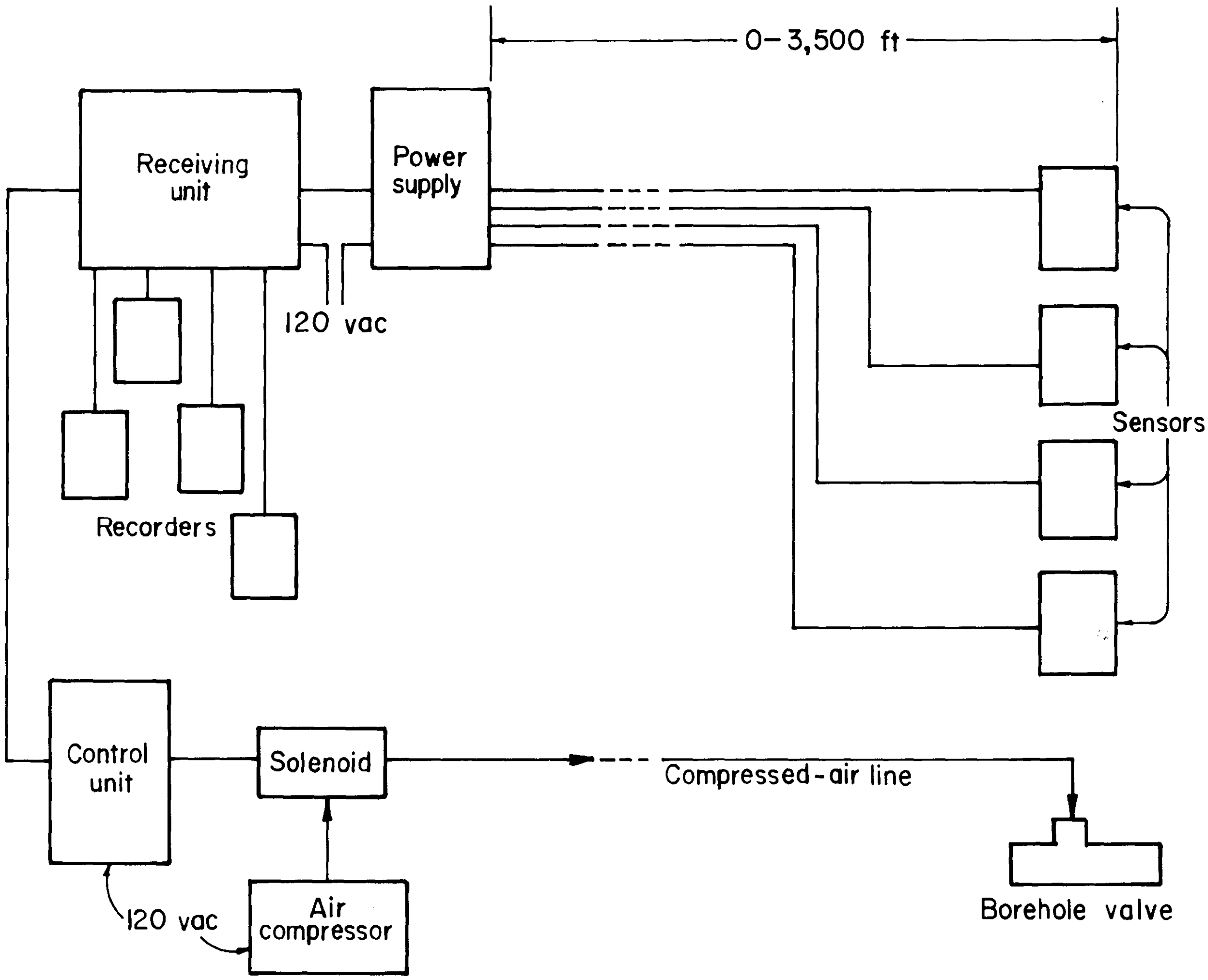

FIGURE 4. - Schematic of detection and shutdown equipment.

solenoid valve causes a pressure release from the air lines of the fail-safe system, and this closes the borehole valve.

External Power Supply

The 120-vac power supply is used to operate up to four methane sensors. Power supply output is limited to 13.5 vdc at a maximum current rate of 800 ma. The cable carries operating current to the sensor and methane signals from the sensor to the power supply. From there the signals are directed to the receiving station via another cable.

Because the sensor assemblies are intrinsically safe, they may be placed anywhere in the mine up to 3,500 feet from the power supply. Requirements for the size of the connecting cables between the power supply and sensors vary according to distance.

The Receiving Station

The receiving station (fig. 5) is located above ground to allow surface observation of data generated by the sensors. It can monitor as many as

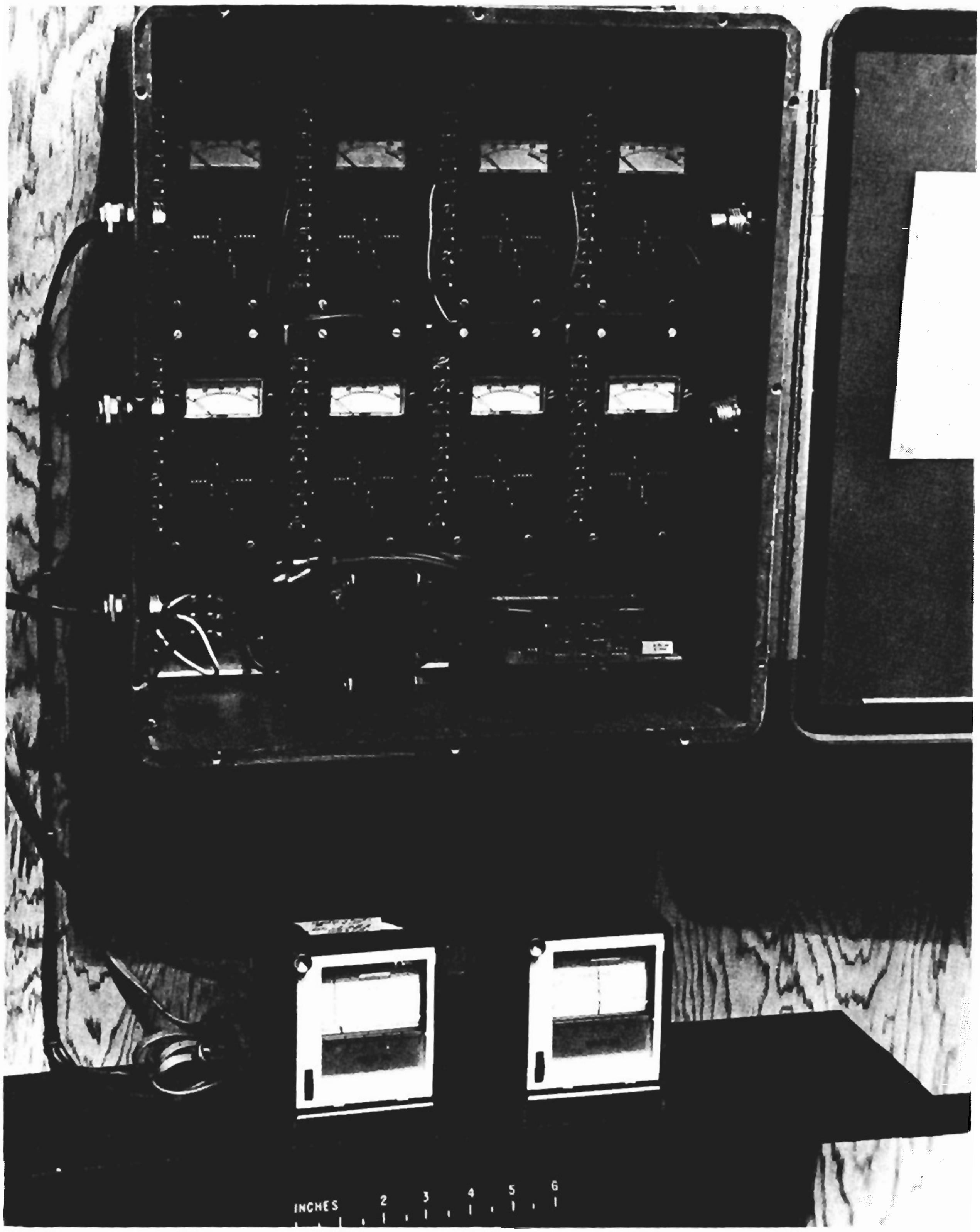

FIGURE 5. - Aboveground receiving station.

four sensors, and is independently powered by a 120-vac source. At the receiving station, methane content can be visually read from meters, and input from the sensors is continuously recorded on strip charts.

Shutdown Equipment

Shutdown equipment of the fail-safe control system consists of an air compressor, power supply, electronic and mechanical components, the brittle air line made of PVC tubing, and the pneumatically actuated borehole valve. These components effect shutdown of the methane pipeline when a hazard is discovered by the detection equipment. In some situations, such as a roof fall, the shutdown equipment can react independently of the detection equipment. As a precaution against methane ignitions, the air compressor, power supply, and certain electronic and mechanical components are located in a fresh air entry (fig. 6).

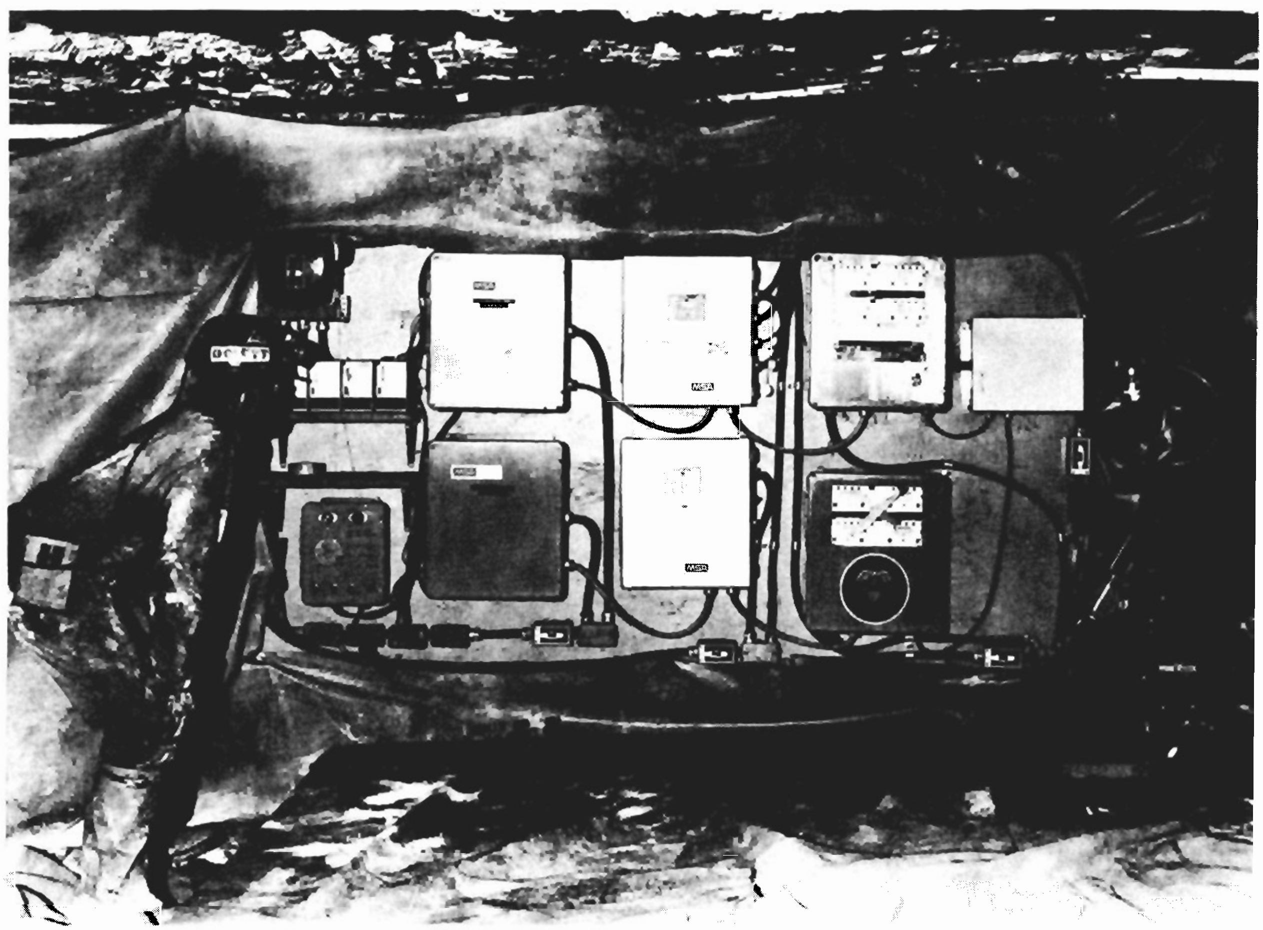

FIGURE 6. - Underground installation of shutdown equipment (not including system of brittle PVC tubing; the brattice cloth shown here was used for photographic purposes and is not necessary for operation of the system).

Borehole Valve and Pneumatic Actuator

The pneumatically actuated ball valve (the borehole valve) is located in the pipeline, near the junction of the pipeline and the borehole, as shown in figure 3. Here, the flow of methane can be shut off as closely as possible to the borehole opening. To permit installation in the pipeline, the valve and actuator are combined into a single unit, as shown in figure 1.

The force required to open the borehole valve is provided by the pneumatic actuator (fig. 7). The valve is closed by a return spring.

Air pressure from the system's air compressor acts on a piston in the valve actuator to hold the borehole valve open as long as no unsafe condition is detected in the mine. A mechanical linkage converts the lateral motion of the piston into the rotational motion of the output shaft that turns the valve on or off. As the piston moves to open the valve, it compresses the return spring. When air pressure is released, the return spring expands, reverses the motion of the piston, and causes the valve to close. It is this sequence of events that closes off the methane flow when a drop in air pressure indicates an unsafe condition in the mine.

An indicator on the actuator shows when the valve is closed. Maximum rotation is one-quarter turn of the shaft. Operating pressure is from 40 to 100 psi; the return spring will close the valve when pressure drops below 40 psi.

All moving parts of the actuator are enclosed to eliminate the possibility of dirt accumulation, which could cause failure. Interior porting is used to conduct the compressed air. External tubing was not used because it would be subject to damage that could cause a failure in valve operation.

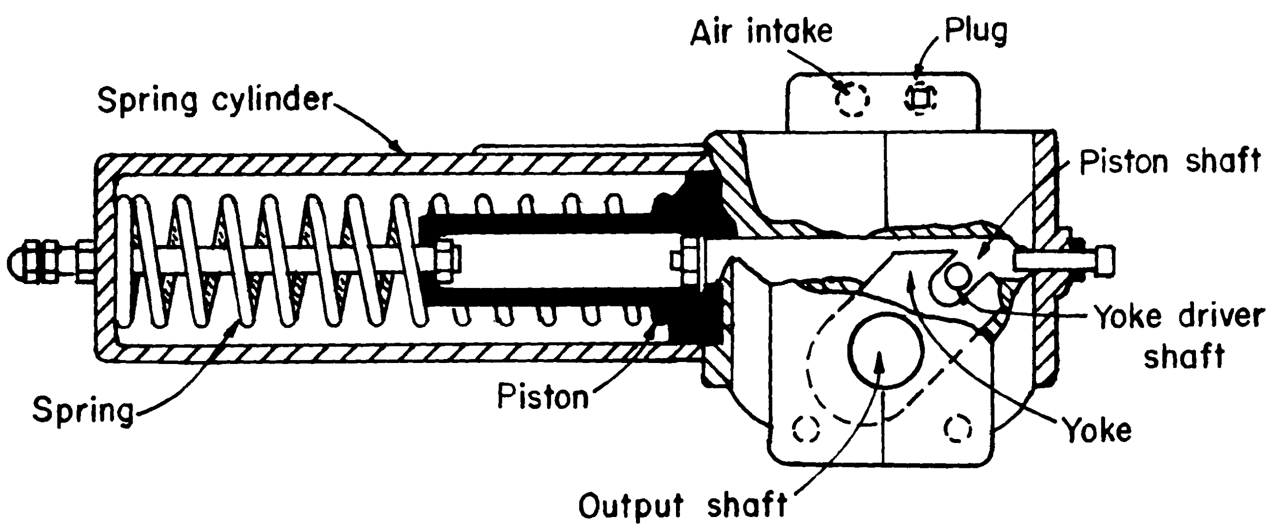

FIGURE 7. - Cutaway view of valve actuator (shown in closed position).

Air Line Made of Brittle PVC Tubing

A system independent of the methane detection system was designed to react to roof falls. Its primary component is a brittle PVC tube securely strapped to the top of the methane pipeline. This tube carries compressed air and is connected to the compressor and the borehole valve actuator by branch lines made of flexible plastic tubing.

The impact of a roof fall easily shatters the brittle PVC tube, and the result is a drop in air pressure that triggers a limiting switch that controls the compressor. When air pressure drops below 40 psi, as it would if the brittle tube were shattered, the limiting switch cuts off power to the compressor.[6] At this pressure, the borehole valve will close.

CONCLUSIONS

The fail-safe control system was built as a safety system for an underground coal mine degasification pipeline. The system was designed to satisfy the safety requirements of Federal and State regulatory bodies, particularly those of the Mine Safety and Health Administration. It has been inspected and tested by MSHA, and MSHA has permitted its use in working mines. This system has successfully detected and responded to methane hazards in two working coal mines where it is now in use. The fail-safe control system is a necessary part of the technology required to safely pipe methane from coal mines for degasification and for use as a source of energy.

[6]To maintain air pressure in the system while mine conditions are safe, the compressor starts automatically when the pressure drops to 50 psi. However, if the brittle tube is shattered, the loss of air pressure is too great to allow the compressor to start. Therefore, the compressor cannot counteract the operation of other components of the system as they work to close the borehole valve.

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