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Microprocessor based dynamic pressure neutralization system for control of fire in sealed-off area in underground coal mines

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The technique of pressure balancing to combat/control underground coal mine fires is universally accepted. The technique is used in many coal mines in India and results are encouraging. However, presently adopted manual pressure balancing technique is a tedious process and sometimes calls for expert attention over a long period. To overcome these difficulties a microprocessor based automatic pressure neutralization device eliminating the need for continuous human attention is proposed. The detailed functions of the proposed device, control logic, and its flow chart are highlighted. The theory of pressure balancing technique and limitations of the manual system of pressure balancing technique are also dealt with. The salient features of the device and its placement in the mine are illustrated with suitable schematic diagram. Advantages of the system and necessary precautions to be taken while fabricating the same are also outlined. The program logic of the proposed device is illustrated in the form of a flow chart.

Keywords: Mine fires, Sealed-off area, Pressure balancing technique, Differential pressure sensor, Stepper motor

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Introduction

Fire is one of the most feared hazards in underground coal mines. The recent successful control of fire in Jhanjra 1and 2 incline, AW1 longwall panel, ECL (2000), in Kottadih colliery, ECL (1997) and Ningha colliery, ECL (1995) has provided ample evidence that the pressure balancing is one of the most effective tools for combating underground mine fire[1]. Pressure balancing technique has also been successfully tried in various countries for prevention of heating as well as combating fire in sealed off areas in underground coal mines[2-4].

Fires that occur in old workings or goaf, called concealed fires, are generally isolated by erection of fire stoppings or repair of old stoppings. To deal with these fires any of the following three approaches are adopted for cutting off supply of oxygen to the fire area. Thus, concentration of oxygen would gradually fall in sealed off area and fire dies down.

- Increasing the resistance of leakage path that can be achieved by injection of sodium silicate, silica gel, and cement slurry in coal pillars, sides, and roof of galleries around the sealed area.
- The sealed off area be maintained at a higher pressure than the galleries outbye. For this purpose of infusion of inert gases like, N_2 or CO_2 is recommended. In this case, air can only leak out of the sealed area but no air can enter into it. Further the inert gases also help in controlling the fire by reducing the concentration of oxygen. This process is known as inertisation.
- Pressure difference across the stoppings be maintained as small as possible.

Pressure difference across the sealed off area/ stoppings can be minimised by a technique called pressure balancing. In this technique, balancing of pressure is achieved by judicious adjustment of airflow rate, first through the different branches of the ventilation network around the affected zone and secondly the remaining

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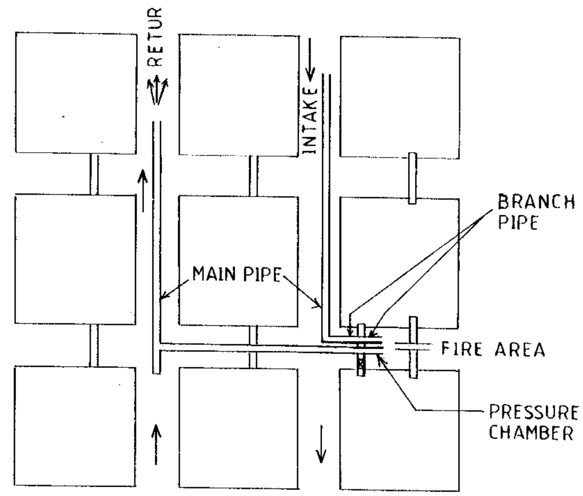


Figure 1 — Dynamic balancing of pressure in a Bord and Pillar working

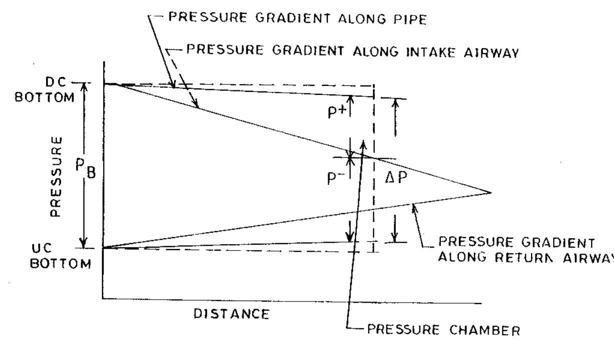


Figure 2 — Pressure diagram

pressure is balanced by adjustment of airflow rates through pipes and pressure chambers, specially designed for this purpose.

Theory of Pressure Equalisation

Pressure chamber for the purpose of pressure balancing is generally constructed by erecting a thin brick stopping at a distance of 2-3 m from the isolation stopping. A schematic layout of arrangement for establishment of dynamic balancing of pressure in a bord and pillar working is shown in Figure 1.

For neutralization of pressure differential across a fire stopping the following procedure are to be adopted:

- Pressure drop across the fire stopping should be monitored carefully for 24 h and establish the range of pressure variation.
- Airflow rates through relevant circuits of the mine are then adjusted to an extent possible (without unduly affecting ventilation of any working district) and in a manner such that pressure differential across the fire stopping is reduced to minimum possible value.
- The remnant pressure across the fire stopping and that is caused by diurnal variation of atmospheric pressure or produced by any change in ventilation system of the mine is to be neutralized by adjustment of airflow rate

through the pressure chamber made for that purpose and pipes connecting the pressure chamber to main intake as well as return airway.

For successful application of the method of dynamic balancing of pressure following conditions need be satisfied:

(a) Sealed area should not have connection to surface through cracks and fissures.

(b) The amount of pressure difference that can be neutralized by adjustment of airflow through ventilation circuits is dependent on the ventilation layout, location of the affected zone and extent of airflow adjustment possible through ventilation circuits without adversely affecting the ventilation of the mine.

(c) The range of remnant pressure variations across the stopping should be less than ΔP (Figure 2)[5],

where $$\Delta P = P_B - r\,(l_I + l_r)\,(\sum_{i=1}^{n} Q_i)^2 - (r_i + r_r)\,Q_i^2,$$

and P_B is pit bottom water gauge, Pa; r is resistance per unit length of connecting pipes, Ns^2/m^9; l_I and l_r are lengths of pipes on the intake and return airways up to pit bottom, m; r_i and r_r are resistances of branch pipes connecting chamber i and pipes laid along intake and return airway, Ns^2/m^8; Q_i is airflow rate through chamber i, m^3/s; and n is number of chambers.

(d) The variation in positive or negative pressure across a stopping should not be more than P+ and P–, respectively. For chamber located near intake airway;

$$P^+ = P_i - rli\,(\sum_{i=1}^{n} Q_i)^2 - r_i\,Q_i^2,$$

$$P^- = P_B - P_i - rl_r\,(\sum_{i=1}^{n} Q_i)^2 - (r_r + r_i)\,Q_i^2,$$

where P_i is pressure drop along the intake airway from downcast bottom to pressure chamber.

Similar relations for the chambers located near the return airways can also be derived. It may be interesting to note that balancing of low-pressure variation may not require pipelines right up to the pit bottom. If it is necessary, only to lower or raise pressure in the chamber, this can be achieved by laying pipes along return or intake and not along both airways.

Figure 3 represents a bord and pillar working with multiple stoppings where dynamic balancing of pressure can be adopted. In this case, a big chamber consisting of several stoppings can be made. Pressure characteristics of the stoppings that are very close to each other, are quite similar. Therefore, putting them into one chamber solve the purpose. However, if needed multiple chambers can be used.

Airflow rates through pipes in the pressure chamber are presently adjusted manually which is a tedious process and needs skilled personnel. There is therefore a need for a device that can automatically adjust the airflow rate through the pipes so that pressure balancing is achieved and maintained.

Status of Present Knowledge and Limitations

Presently the following procedures are being adopted for implementation of dynamic balancing of pressure technique to combat fire in underground coal mines.

First, a pressure chamber is made outside of the isolation stopping sealing the fire affected zone, by building a thin brick stopping provided with a small door at about 2-3 m from the isolation stopping. Two pipes are laid, connecting the pressure chamber to main intake as well as return airways. Air sampling pipe through the isolation stopping is used to measure the pressure differential across the isolation stopping by a manometer. Difference in pressure across the stopping, if any, is balanced by adjusting airflow rates through these pipes. This pressure balancing technique has successfully been implemented in Kottadih colliery, ECL[6], Jhanjra 1and 2 incline, ECL[7] and Sijua colliery, TISCO[8]. It has been observed that for control of fire, balancing has to be maintained round the clock for several days, extending to over a year in some cases. Evidently, maintenance of perfect balancing calls for expert attention over a long period. This is one of the main constraints of the system. To overcome these problems and to make maintenance of perfect balancing over a long period, an easy task, a device for automatic balancing of pressure has been proposed.

The Proposed System

The proposed device is capable of balancing pressure by automatic adjustment of airflow to pressure chamber by controlling valves in the pipes through a microprocessor based system[9]. The microprocessor is actuated by signals received from a differential pressure sensor connected to a sampling pipe laid across the fire stopping.

The microprocessor based automatic pressure balancing system consists of the following three parts:

(a) Differential pressure sensor,

(b) A microprocessor programmed to receive and process the signal from the differential pressure sensor and then activate airflow control system, and

(c) Airflow control system comprising two pipes fitted with stepper motor controlled valves, guided by signals from the microprocessor.

Functioning of the System

The device is placed in the pressure chamber. The general arrangement of the device in a fire zone of a coal

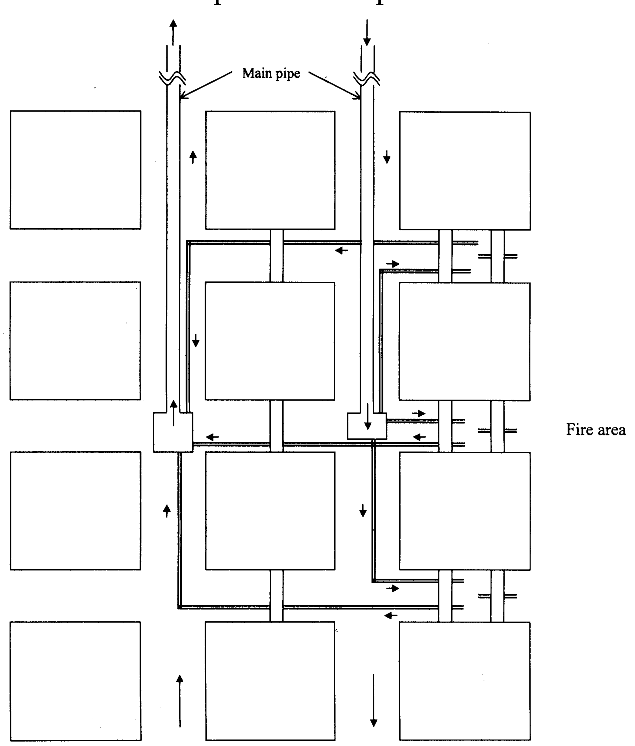


Figure 3 — Dynamic balancing of pressure in a Bord and Pillar working having multiple stoppings

mine is shown in Figure 4. Two pipes are provided in the pressure chamber. One pipe extends from the pressure chamber along the main intake of the mine and the other extends from the pressure chamber to the main return of the mine through the ventilation stopping. The isolation stopping is provided with a small sampling pipe for drawing air samples from the fire affected area and for connection with inlet port of differential pressure sensor by means of polythene or rubber tube. Ventilation pressure difference in the mine between the main intake and return galleries drives a small quantity of air into the pressure chamber through the pipes. Pressure in the pressure chamber is balanced with respect to fire area by adjustment of airflow through the pipes by regulating the valves, using stepper motors. These motors are controlled by microprocessor, depending on pressure imbalance signal received from the output of differential pressure sensor.

The differential pressure sensor is basically a thin metallic diaphragm with two metallic needles on its either sides, supported at the middle of a rectangular enclosure but insulated from it. The enclosure has two ports on either side of the diaphragm for connecting to pressure sources whose pressure difference is to be measured. The metallic needles like the diaphragm are also insulated from the enclosure. The needles and the diaphragm are connected to resistors and a source of electrical power, as shown in Figure 5. Two sectional views of this figure are shown in Figure 6 and 7 (Legends are given in Figure 4). A small pressure difference applied through one of the ports causes the diaphragm to deform and touch the metallic needle situated opposite to that port. As the diaphragm touches the needle the electric circuit becomes closed and as a result, a small potential difference develops across the resistors connected to the circuit. This voltage drop across the resistor acts as the output signal of the pressure sensor, which is fed to one of the input channels of the analogue-to-digital converter (ADC) of the microprocessor. As long as the pressure difference exists in the port the output signal continues and corresponding input persists in this channel of the ADC. When the pressure difference is applied in the reverse direction the diaphragm deforms in the opposite direction and establishes contact with the other needle that energizes the electric circuit connected with it and the consequent voltage developed is applied to a second channel of the ADC of the processor. When the applied pressure ceases the diaphragm returns to its original position and the electric circuit is broken. Consequently, no input is available to any channel of the ADC of the microprocessor. The processor continuously scans these two input channels of the ADC and compares the status of the channel, i.e., whether positive or zero. Depending on status of the channel, corresponding control signal is sent to the

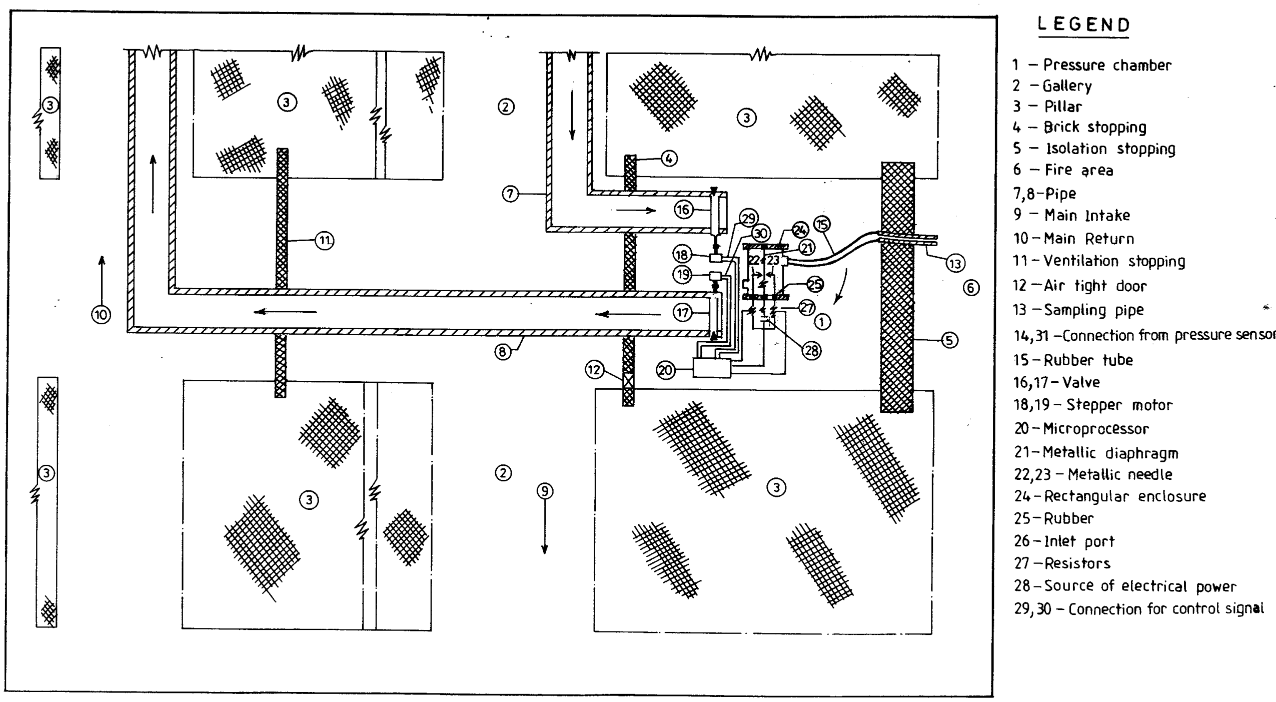
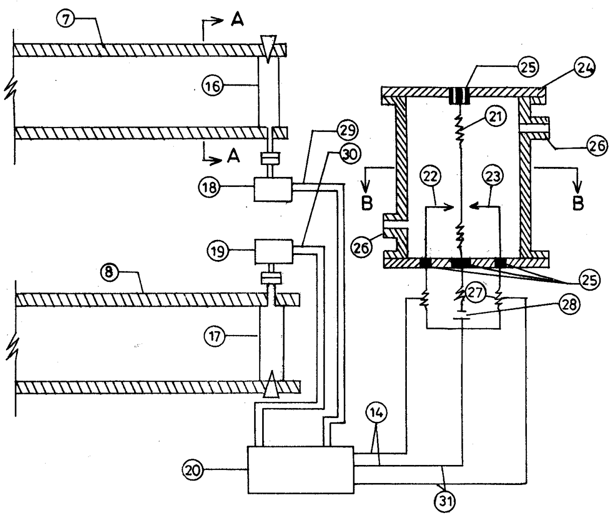


Figure 4 — General arrangement of the proposed device in a fire zone of a coal mine



oes provided with airflow control valves are operated by ignals coming from parallel I/O ports of the processor. Two ts of the 8255 I/O parallel ports. Separate windings of the 255 I/O ports through optocoupler and a power transistor other is connected to main return of the mine. Air from main intake, enters the pressure chamber and flows out to main e chamber to the return. When both the valves are in open If one of the valves is closed and the other opened, there is e in the pressure chamber attains the pressure prevailing at position. On the other hand, if the open valve is now closed rflow in the pipes and through the pressure chamber. The e at the free end of the pipe with the open valve. For any chamber can be adjusted to any value inbetween these two t of the valve connected with intake pipe while the other stepper motor controls the movement of the valve connected with return pipe.

Figure 5 — Sectional elevation of the device

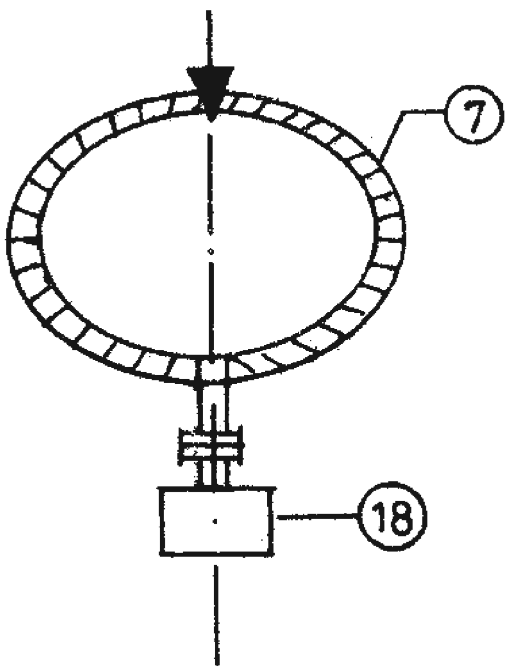


Figure 6 — Sectional side view at AA

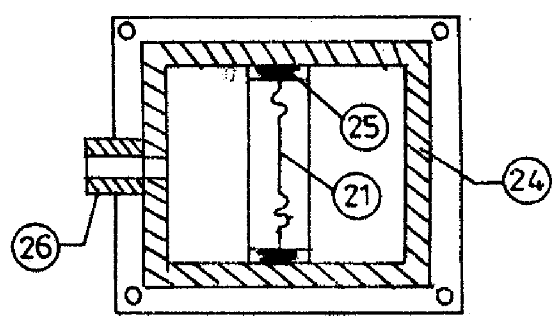


Figure 7 — Sectional plan at BB

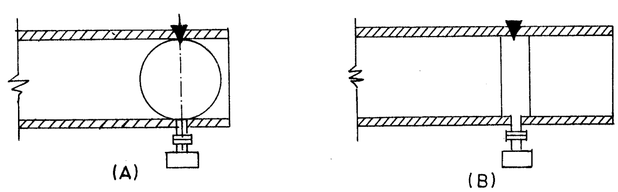


Figure 8 — Sectional view of the valve in open condition (A) and closed condition (B)

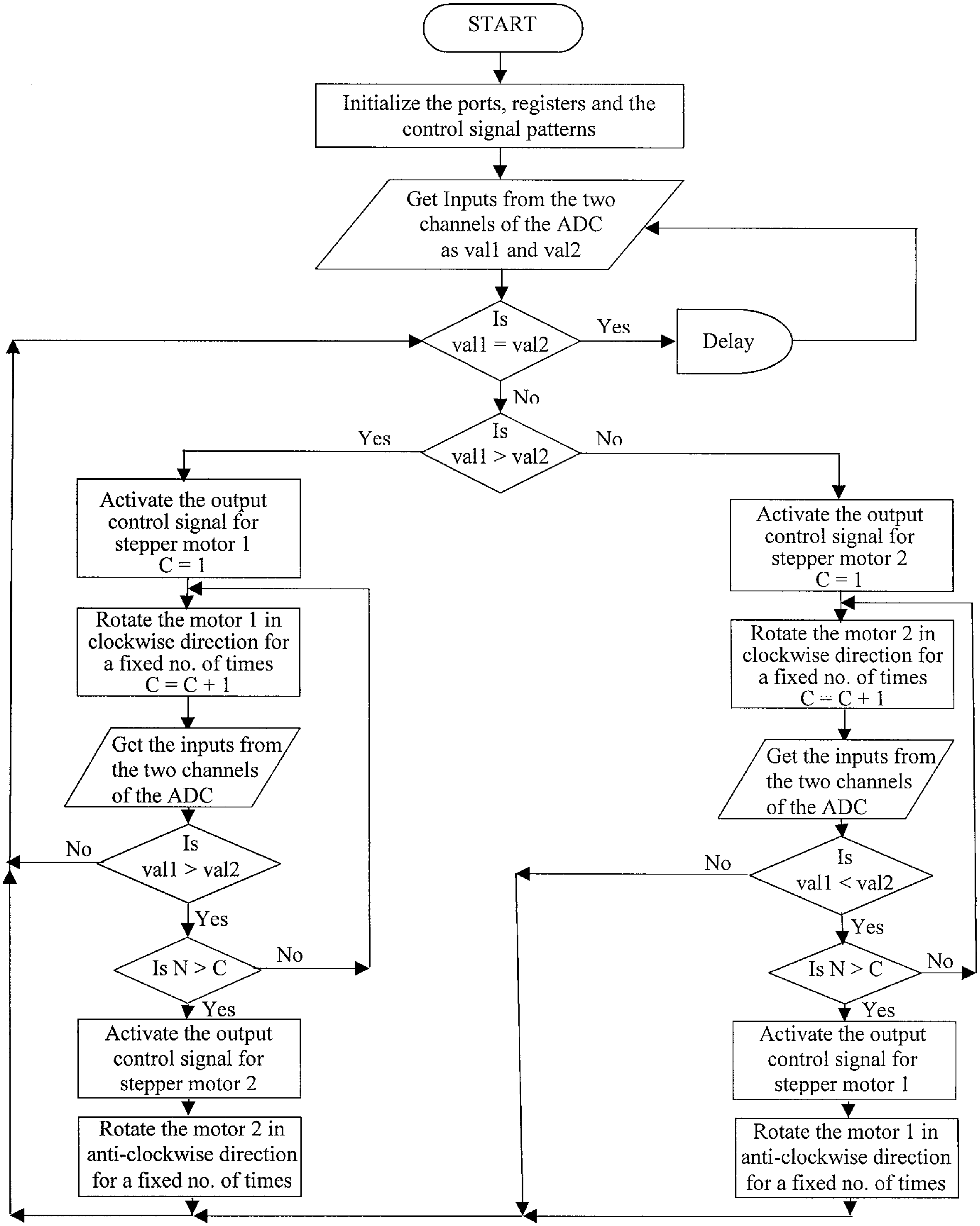


Figure 9 — Flowchart for the program logic of the proposed device

The necessary power for driving the microprocessor along with the peripherals chips and the stepper motors would be taken from 5V/12V intrinsically safe power available from underground flameproof supply unit.

Program Logic

The program logic of the proposed device is illustrated in Figure 9. The main program initializes the I/O 8255 ports, sets up a processor internal register as a counter to count certain prefixed number to give appropriate rotation of the valve, and calls for a subroutine which outputs fixed bit patterns that are stored in predestined memory location. This particular bit pattern enables to rotate the stepper motor for the number of prefixed steps as stored in the processor register. At the start of the program the processor scans the two ADC input channels. If it finds that both the input channels have zero input voltage the processor does not effect any change in the output bit patterns of the 8255 I/O ports, i.e., the control valves remain in the same position. When the processor finds that the input at first channel is positive, it activates output control signal, thereby controlling the corresponding stepper motor and rotates the stepper motor a fixed number of steps in clockwise direction. After a certain delay, again the processor compares the first and second channel of ADC input. If still the first channel is positive the processor activates the control signal corresponding to the same stepper motor for further movement of the valve. This process would continue for a certain prefixed number of times (N) of driving this stepper motor and after every driving the processor would check whether the pressure balancing is achieved by comparing the ADC inputs. If it fails to achieve balanced condition and still the first channel of ADC is positive while second channel is zero, the processor would drive the other stepper motor in the reverse direction through control signal. Similarly, if the diaphragm makes contact with right side needle the second channel of the ADC is positive and first channel is zero the processor rotates the second stepper motor in clockwise direction through control signal for a prefixed number of drives, simultaneously comparing the ADC inputs after each drive, so as to attain pressure balancing. If after the prefixed number of drives of the stepper motor does not impart pressure balancing, the processor drives the first stepper motor in reverse direction. Thus, by controlling the appropriate valve the processor regulates the pressure inside the chamber and maintains pressure balancing without intervention of expert personnel.

Conclusions

Automatic pressure balancing device which would remove the difficulties presently faced by the manual dynamic pressure balancing technique for control of fire in underground coal mines is designed. It facilitates control of fire in mines in quickest possible time without intervention of expert personnel. The proposed device seems to be promising in a way that it is simple, robust, and cost-effective. Proper care should, however, be taken while fabricating the different subsystems of the device because of its potential utility in hazardous, dusty, and humid underground environment. One of the important subsystems of the device is the differential pressure sensor. The differential pressure sensor used is highly sensitive so that even a small pressure difference (about 10 pa) across the fire zone enables it to send a signal to the microprocessor. Thus the developed system has the capacity to maintain pressure differential across fire zone balanced to the extent of 10 pa.

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