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Dynamic modelling and performance analysis of underground mine ventilation system

Electrical equivalent circuit of mine roadways is considered to develop transfer function of mine ventilation system in the present article. Block diagram model of mine ventilation system is presented in the article. Performance of the developed model is determined in MATLAB environment. A PID controller is introduced to improve performance of the developed model.

Keywords: *Mine ventilation, step response, PID controller.*

Introduction

Most underground mines involve an interconnected network of roadways and working areas that evolves in size and complexity with time. Air is necessary not only for breathing but also to disperse chemical and physical contaminants (gases, dusts, heat, and humidity). A ventilation requirement for the sustenance of human life is about 20 cfm (0.01 m^3/s) [1]. Per person and natural ventilation inside underground mines is usually insufficient for human respiration. Therefore, to ensure adequate ventilation of underground mines, provision is made for suitable paths (airways or air courses) for the air to flow down the mine to the working places. In the control of both the chemical and physical contaminants clean fresh air must be supplied. To ensure adequate ventilation of a mine, fresh air must therefore be forced or more usually induced around the network by a main ventilating fan. Transfer function model of the entire mine ventilation system is presented in the article.

Theoretical background

Electrical model of mine roadway is represented in Fig.1. [2].

where,

P_i = pressure applied at initial left side,

Q = flow through pressure source,

R = Total roadway resistance,

V = Total volume of roadway,

P = Pressure in whole volume v,

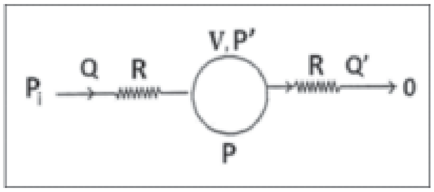

Fig.1 Electrical analog model of mine roadways

P' = atmospheric pressure,

Q' = flow at right side roadway end.

Air volume flow is usually measured in cubic feet per minute (CFM) [1].

Dynamic impedance of mine roadways can be expressed in S-domain [2] by equation (1):

$$Z(s) = \frac{2R\left(1+\frac{Ts}{2}\right)}{1+Ts} \quad \text{... ... (1)}$$

Here Z(s) relates applied pressure to the flow adjacent to the pressure source, where time constant T is given by expression $T = \frac{VR}{P'}$. The pressure source is the ventilation fan in the present article. Isothermal condition is assumed, where P' is atmospheric pressure and the applied pressure $P_i \ll P'$. Transfer function of mine ventilation fan can be represented as:

$$\frac{K_f}{R_f\left[1+TmS\right]}$$

The block diagram of the system can be represented in Fig.2 [2].

The simplified block diagram of the mine ventilation system is shown in Fig.3. The numerical values of different parameter of the mine ventilation system is considered as [2] T = 2, K_m = 1.5, K_f = 2, R = 1, T_m = 1.5s, R_f = 0.000025. Where K_f = motor or fan coefficient, T_m = motor time constant, R_f = fan resistance.

Hence the block diagram of the system can be expressed as Fig.4.

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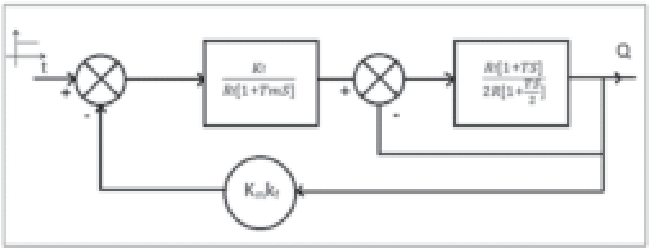

Fig.2 Block diagram of underground mine ventilation system

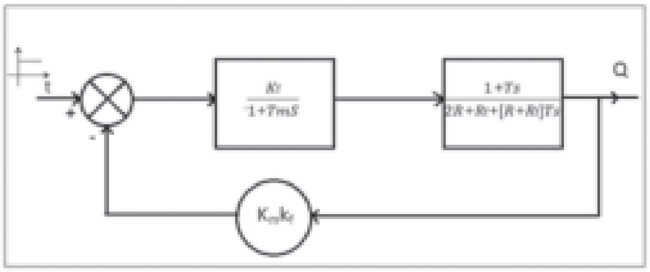

Fig.3 Simplified block diagram of the mine ventilation system

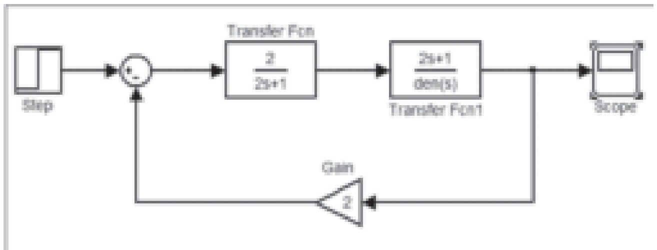

Fig.4 Block diagram of mine ventilation system with numerical value of different parameter

Simulation results

The block diagram of the mine ventilation system is simulated in MATLAB environment. The step response of the system is shown in Fig.5.

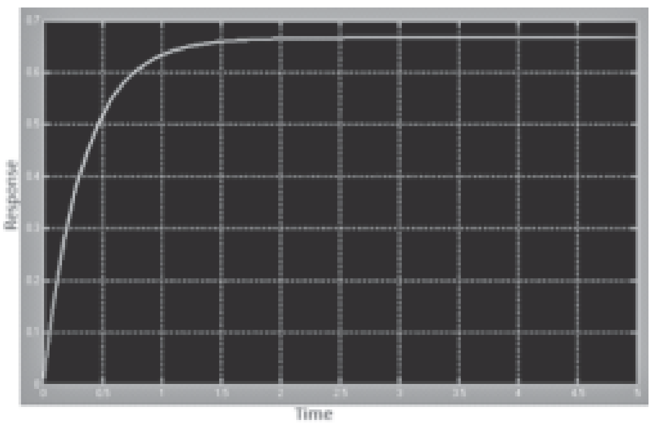

Fig.5 Step response of mine ventilation system

The step response shows considerable amount of steady state error which deteriorate the performance of the ventilation system. To eliminate steady state error a PID controller is introduced. The integrator inside the PID controller will integrate the steady state error and signal to the ventilation fan will increase. As the signal of the fan increased the output will increase and feed to the input and steady state will be reduced. The block diagram model with controller is shown below in the Fig.6.

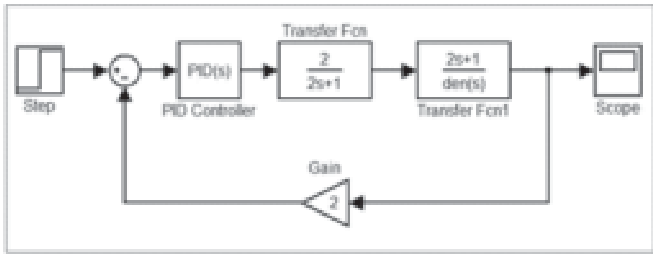

Fig.6. Block diagram model with PID controller

The response with integral controller with integral controller gain 1 and all other gain 0 is shown in the Fig.7.

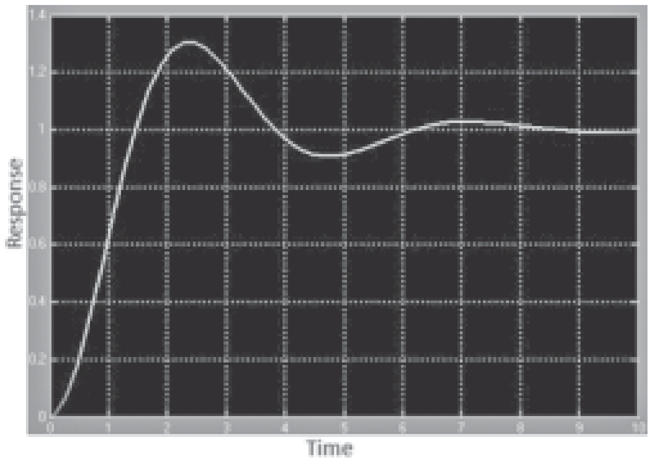

Fig.7 Step response with Integral controller

Although the steady state error is eliminated the response shows considerable amount of oscillation at the output, which indicate poor performance of the ventilation system. To eliminate oscillations proportional-integral (PI) controller is introduced with proportional gain 4 and integral gain 2. The

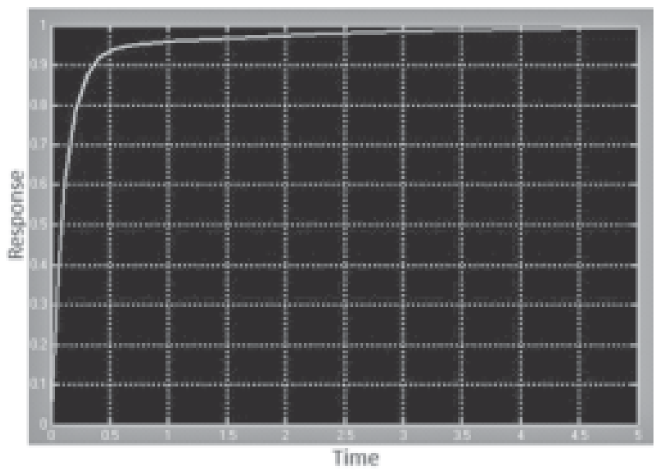

Fig.8 Step response of mine ventilation system with PI controller

simulation result is shown in Fig.8 where oscillation is completely removed with no steady state error.

Conclusions

Dynamic model of mine ventilation system is presented in the article. Performance of the mine ventilation system is analyzed in MATLAB environment. The performance of the system can be improved considerably by introducing PI controller.

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