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Proceedings of the 6th JFPS International
Symposium on Fluid Power, TSUKUBA 2005
November 7-10, 2005

The Simulation of the Sampling Pipes and Sampling Holes Network with an Aspirating Smoke Detector

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ABSTRACT

Aspirating smoke detector uses aspirating fan to draw air from the protected area via a network of the sampling pipes and holes, analyses the air and generates warning signals when the concentration of the smoke in the air is over the limit. After the analysis from the view of hydrodynamics, the physical and mathematical models are established. By programming and calculating, the sampling holes' flow rate and the transport time in which the air is drawn from the sampling holes to the detector are got. If each sampling hole's flow rate is not balanceable or the longest calculated transport time exceed 120 seconds (according to NFPA 72), the diameters of the sampling holes are optimized. The calculated results are compared with the experiments, the errors are less than 10%. It is proved that the physical and mathematical models can be used practically.

KEY WORDS

Simulation, Network, Mathematical Model

NOMENCLATURE

p	:	the pressure
Q	:	the flow rate
v	:	the velocity
A	:	the area
μ	:	flow coefficient
λ	:	frictional resistance coefficient
ζ	:	local resistance coefficient

INTRODUCTION

In order to reduce the danger of fire, fire autoalarm is required on many occasions. Aspirating smoke detector is one kind of fire autoalarm and is invented in the 1970's in Australia. Aspirating smoke detector does not sense smoke, temperature, flame passively, but aspirate and sample smoke actively. This kind of detector can quickly and dynamically identify various polymer molecule and smoke particle in the air and can give an alarm duly.

Aspirating smoke detector is a system that uses an aspirating fan to draw air from the protected area via a network of the sampling pipes and sampling holes. It is shown in figure 1. The sampled air is then passed through a high sensitivity precision detector that analyzes the air and generates warning signals when the concentration of the smoke in the air is over the limit. The network of the sampling pipes and sampling holes is the passage of the sampled air. Not only the air near the detector but also the air in the whole room which is high-speed or quiescent can be analyzed by the network.[1,2]

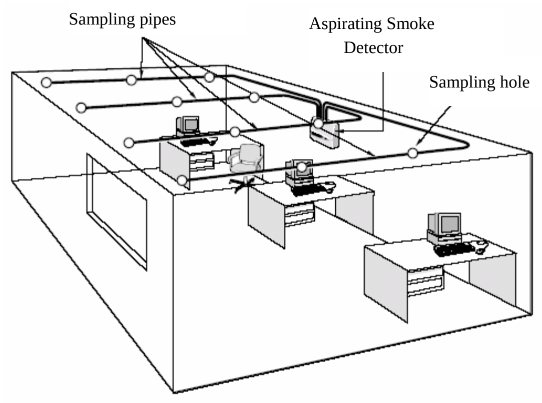


Figure 1 The sampling pipes and sampling holes network with an aspirating smoke detector

The network of the sampling pipes and sampling holes is regarded as the impedance of the aspirating smoke detector and we can analyze it from the point of view of hydrodynamics. The air flow rate percentage of every sampling hole can be got. Together with the characteristic curve of the aspirating smoke detector, the sampling holes' flow rate and the transport time in which the air is drawn from the sampling holes to the detector are got. [3-5]

MATHEMATICAL MODELS

The sketch of the sampling pipe and sampling holes is shown in figure 2. Point '0' is a sampling hole in the end cap of the sampling pipe and it can make the sensitivity of every sampling hole nearly equivalent. Point '1', point '2' to point 'n-1' is sampling hole in the sampling pipe. Air is drawn to the detector through them. Point 'n' is the place where the sampling pipe connects to the detector. After the analysis of air's flow in the whole room and in the network of the sampling pipe and sampling holes, the physical and mathematical models are established based on the continuity equation and Bernoulli equation.

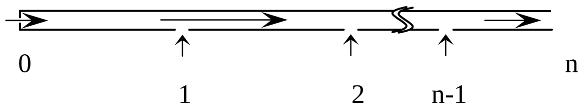


Figure 2 The sketch of the sampling pipe and sampling holes

For point '0', the equation is shown as:

$$0 = p_0 + \frac{\rho v_0^{\ 2}}{2} + p_0' \tag{1}$$

p_0 is the pressure inside the sampling pipe at point '0', v_0 is the air velocity in the sampling pipe at point '0', ρ is air density, $p_0^{'}$ is the resistance at point '0'.
For the other sampling holes, the equation is shown as:

$$p_i + \frac{\rho v_i^{\ 2}}{2} = p_{i+1} + \frac{\rho v_{i+1}^{\ 2}}{2} + p_{li} \tag{2}$$

p_i is the pressure inside the sampling pipe at point 'i', and the differential pressure between the inside and outside of the sampling pipe is the reason why air can be drawn. p_i is:

$$p_i = \mu \cdot \frac{\rho}{2} \cdot \left(\frac{Q_i}{A_i}\right)^2 \tag{3}$$

where μ is flow coefficient, Q_i is the air flow rate in the sampling hole 'i', A_i is the area of the sampling hole 'i'. v_i is the air velocity in the sampling pipe at point 'i' and v_i is:

$$v_i = \frac{Q_{li}}{A_p} \tag{4}$$

where Q_{li} is the air flow rate inside the sampling pipe between the point 'i' and point 'i+1' and it is the sum of the air flow rate Q_0, Q_1, Q_2 to Q_i, A_p is the sectional area of the sampling pipe.
p_{li} is the resistance to air inside the sampling pipe between the point 'i' and point 'i+1' and consists of frictional resistance p_y and local resistance p_j.

$$p_y = \lambda \frac{l}{d_p} \frac{\rho v_i^{\ 2}}{2} \tag{5}$$

$$p_j = \zeta \frac{\rho v_i^{\ 2}}{2} \tag{6}$$

where λ is frictional resistance coefficient, l is the pipe length, d_p is the diameter of sampling pipe, ζ is local resistance coefficient.
From point 'n-1' to point 'n':

$$p_{n-1} = p_n + p_{\ln-1} \quad (7)$$

Provided that the flow rate of the sampling hole in the ending cap, Q_0, is 1, the flow rates of the sampling holes in the sampling holes, Q_1 to Q_{n-1}, can be got by equation (1), equation (2) and equation (7). The flow rate percentage of each sampling hole can be got.
Based on the theory of hydrodynamics, the characteristic equation of the whole network is:

$$\sum p = SQ^2 \quad (8)$$

where Σp is the whole resistance of the network, S is the impedance of the network and decided by the network, If the sampling holes and the sampling pipe in the network are the same S is the same. Q is the whole flow rate of the network.
When the detector is connected with the network and runs, the pressure which the detector provides will compensate the resistance of the network. And here the flow rate is the practical flow rate of the whole network and the detector. Combined the equation (8) with the actual characteristic curve of the detector, the flow rate is got. The actual characteristic curve of the detector is got by the experiment and is shown in figure 3.

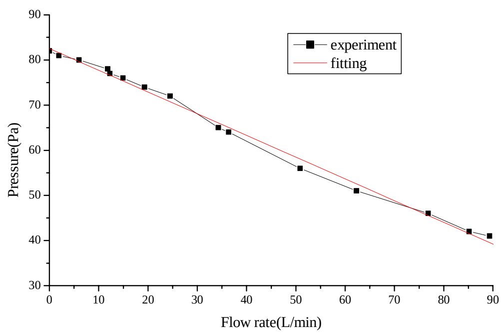


Figure 3 The actual characteristic curve of the detector

With the whole flow rate of the network, Q, and the flow rate percentage of each sampling hole, each sampling hole's flow rate, Q_i, can be got. And by equation (4), the air velocity in the sampling pipe can be got. The transport time in which the air is drawn from the sampling holes to the detector will be calculated.
If the flow rate in each sampling hole is very different, the sensitivity and stress of each sampling hole are not balanceable. Then the diameters of the sampling holes should be optimized to make the network balanceable. Suppose that each sampling hole's flow rate, Q_i, is alike and:

$$Q_i = Q_a = \frac{Q}{n} \quad (9)$$

Q_a is the average of each sampling hole's flow rate. The area of the sampling hole 'n-1', i.e. the area of the sampling hole near the detector can be calculated. Then the area of the sampling hole 'i' (i=n-2, ... ,1,0) can be got. The diameter d_i of the sampling holes 'i' is:

$$d_i = \sqrt{\frac{4A_i}{\pi}} \quad (10)$$

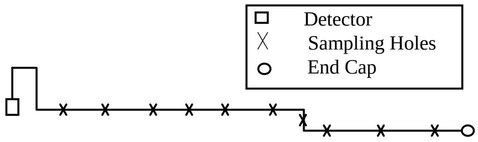
In order to make the design and installation easy, d_i should be adjusted. The span of value is 2.5mm to 6mm and the interval of value is 0.5mm. d_i equals to the most approximate value. The sampling holes' flow rate and the transport time in which the air is drawn from the sampling holes to the detector based on the new diameter of the sampling holes d_i are got. The flow rate in each sampling hole of the network is the most balanceable in this way.
If the calculated transport time from the end cap of the network to the detector exceeds 120 seconds (according to the National Fire Protection Association, NFPA 72), the diameter should be adjusted. And at the same time, the balance of the sampling holes' flow rate should be taken into account. Provided that the diameter of the sampling hole in the end cap is the maximum, here the diameter is 6mm, and the other sampling holes' flow rate is the same as the flow rate of the sampling hole in the end cap, here the flow rate is 1, we can calculate the diameter of the sampling hole 'i' (i=1,2, ... ,n-1), d_i. Then adjust d_i. The span of value is 2.5mm to 6mm and the interval of value is 0.5mm. d_i is the most approximate value. The sampling holes' flow rate and the transport time in which the air is drawn from the sampling holes to the detector based on the new diameter of the sampling holes d_i are got. If the calculated transport time from the end cap of the network to the detector still exceeds 120 seconds, we must change the structure of the network, such as the length of the sampling pipe, the number of the sampling holes.

EXPERIMENTAL STUDY AND RESULTS

Four different suits of networks of the sampling pipes and sampling holes are built in a large room. And a set of aspirating smoke detector is used. When the smoke nears to the end cap the timing begins and when the detector generates warning signals the timing ends. The transport time is got and compared with the caculated one.
The sketches and the records of the networks in experiment are shown in Table 1. In order to be explicit, the experiments are numbered. The comparison of transport time is shown in Table 2. The errors of transport time between the experiments and the calculated are small.

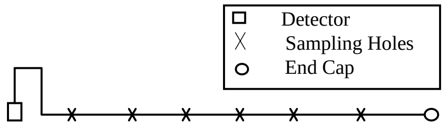
Table 1 The sketches and the records of the networks in experiments

No.1 Experiment



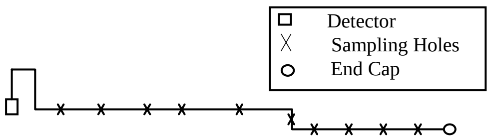
Experiment parameter and result:
The number of the sampling holes: 11.
The length of the sampling pipe: 48.5m.
The bend (from the end cap): 11.2m, 15.8m, 40,7m, 43.7m, 45.7m.
The space between the sampling holes (from the end cap):2.2m, 3.4m, 4.3m, 3.6m, 5.7m, 4.0m, 3.6m, 4.2m, 4.0m, 3.6m, 9.9m.
The diameter of the sampling hole (from the end cap): 4mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm, 4mm, 4mm, 3mm, 3mm.

No.2 Experiment



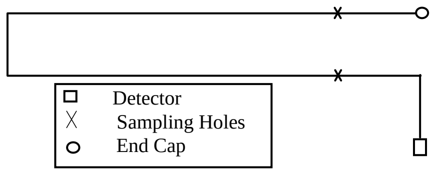
Experiment parameter and result:
The number of the sampling holes: 7.
The length of the sampling pipe: 39.3m.
The bend (from the end cap): 26.7m, 35.1m, 36.5m.
The space between the sampling holes (from the end cap):4.5m, 4m, 4m, 4m, 3.8m, 4.1m, 14.9m.
The diameter of the sampling hole (from the end cap): 4mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm.

No.3 Experiment



Experiment parameter and result:
The number of the sampling holes: 11.
The length of the sampling pipe: 46.05m.
The bend (from the end cap): 17.2m, 19.2m, 38.95m, 41.85m, 43.25m.
The space between the sampling holes (from the end cap):2.7m, 3.6m, 3.9m, 4.3m, 3.9 m, 4.3m, 4.5m, 4.2m, 1.75m, 3.3m, 9.6m.
The diameter of the sampling hole (from the end cap): 4mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm, 3mm.

No.4 Experiment



Experiment parameter and result:
The number of the sampling holes: 3.
The length of the sampling pipe: 41.13m.
The bend (from the end cap): 20.19m, 20.9m.
The space between the sampling holes (from the end cap):4.19m, 32.71m, 4.23m.
The diameter of the sampling hole (from the end cap): 3.5mm, 3.2mm, 3.2mm.

Table 2 The comparison of the transport time

Experiment:	No. 1	No. 2	No. 3	No. 4
Transport time (experiment): [s]	77.72	57.97	64.03	77
Transport time (calculated): [s]	82.3	60.52	66.03	79.25
Error: [s]	4.58	2.55	2	2.25

CONCLUSION

The transport time based on the mathematical models accords with the experiment by and large. The choice of flow coefficient μ, frictional resistance coefficient λ and local resistance coefficient ζ is based on empirical formulas and they are simplified while calculating. It is the main reason caused the errors of the transport time between the calculated and the measured. The errors are less than 10% and the precision can be accepted in engineering calculation. The mathematical models are correct and available. They can be used to forecast the transport time of the network and direct the design and the installation of the network.

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