Based on pressure gradient model to determine leakage point in heating pipe network

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Abstract

This paper describes a calculation method based on pressure gradient model to determine leakage point in central heating pipe network which decreases the effect of the ratio frictional resistance. In the calculation method, a pipe resistance characteristic coefficient is introduced. This characteristic coefficient is corrected by hybrid adaptive genetic algorithm. With the characteristic coefficient and the pressure value of each node in heating pipe network, the leakage point orientation in central heating pipe network can be done with the positioning analysis on the heating pipe network leak. The pressure value is calculated using the theory of graph algorithms. In this analysis, the pressure gradient is the most important analytical method. According to the data monitored by supervisory control and data acquisition (SCADA) system, the leak position can be located. The experimented results show that the method to locate the leakage point in the thermal system pipe network meets the theoretical need and the experimental one.

Keywords: Heating pipe network, Leakage location, Drag coefficient, Pressure gradient

1 Introduction

Nowadays, with the rapid development of modern heating industry in big cities, a variety of heating pipe networks have covered the subsurface of the city. But there are some problems of the heating pipe network in the heating system such as pipeline leakage. When the leakage occurred because of corrosion, natural disaster, the destructive activities of human beings and other reasons, it would lead to economic and thermal resource loss. And even more, the residents' lives would be impacted seriously [1].

At present, heating pipe network is so large that it is impossible for people to determine the pipe leakage only by person. The computer monitoring must be introduced to the heat pipe network analysis. There are many detection and location methods [2-4]. However, many of these methods have constraints. For example, the negative pressure wave method can detect the leakage of sudden. It is not accurate for the leakage point orientation in pipe network with a slow leak or a small leak. Moreover, it is much dependent on the measured value of node. Currently the model of pipeline leak detection and location is divided into transient model and homeostasis model. The homeostasis model is the leakage location by calculating the turning point of pressure gradient in leaking pipeline [5-8].

In this paper, the homeostasis model is used to locate the leakage of pipe segment. The drag coefficient (M) is used to reduce the computational difficulty of homeostasis model. Then the hybrid adaptive genetic algorithms and the graph theory calculation method are introduced to calculate the data of nodes. After the calculation, the hydraulic model is used to derive the leak location of pipe network when the leakage is less than the amount of maximum fill water.

2 Methodology

2.1 HYDRAULIC MODEL

The pressure gradient hydraulic model shows that the pressure diagram is straight line along with the pipeline when leakage does not occur in the pipe network. However, when the pipe segment appears a leakage, the water flow before the leak point in pipe segment will increase. At the same time, in the segment, the pressure gradient is bigger and the friction is riser. On the contrary, water flow after the leak point in pipe segment will decrease. Then, the pressure gradient becomes lesser and the friction becomes lower in the later segment. Therefore, the pressure diagram in the pipe section changes from the straight line into a fold line when the leakage occurs in pipe segment. The turning point in this fold line can be determined as the leakage point of the pipe section [9]. The change of pressure diagram is shown in Figure 1.

According to this change of pressure data of each point in the pipe section, the distance from the former node of the leak segment to the leakage point can be calculated as Equation 1.

$$X = \frac{P_1 - P_2 - LR_2}{R_1 - R_2}, \quad (1)$$

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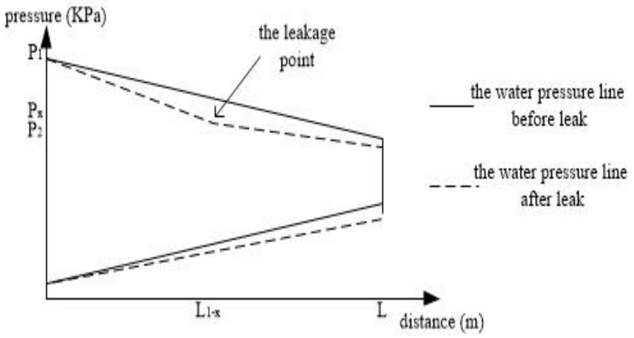

FIGURE 1 The Change of Pressure Diagram

where, X is the distance from the former node to the leakage point. P1 is the pressure of the former node of this pipe segment. P2 is the pressure of the latter node of this pipe segment. R1 is the proportion friction resistant from the former node to the leakage point. R2 is the proportion friction resistant from the leakage point to the latter node. L is the length of this pipe segment.

In order to get the distance from the former node to the leakage point, the proportion friction resistant is necessary. However, it is not always the same. In actual operation of the pipe network, the pipeline corrosion and deposition of microorganisms lead to the changes of hydraulic condition along with the pipeline. They cause the changes of the proportion friction resistant in the pipe segments. Therefore, it is necessary to consider the pressure drop of fluid in different pipeline along with the changes of proportion friction resistant [10-12].

The pressure drop of the pipe section is calculated to Equation 2.

$$\Delta P = R(L+L_d) = 0.0625\frac{\lambda G_t^2}{\rho d^5}(L+L_d)\,, \qquad (2)$$

where: ΔP is the pressure drop of the pipe section; R is the ratio frictional resistance; λ is the coefficient of resistance along the way; G_t is the flow rata of fluid in the pipe segment, t/h; d is the inner diameter of the pipe, m; L is the length of the pipe section, m; L_d is the local resistance equivalent length in the pipeline, *m*. *R* is expressed as Equation 3.

$$R = 0.0625\frac{\lambda G_t^2}{\rho d^5}\,. \qquad (3)$$

The rule that R is proportional to λ is obvious in Equation 3. During the actual operation of heat pipe network, the impact of hot water's quality in the pipe network, the useful life of heat pipe and the coefficient of resistance along the pipeline will change with the pipeline conditions. In order to determine the leakage point, a drag coefficient M of heat pipe network is introduced as Equation 4:

$$M = \frac{0.0625\lambda}{\rho d^5}\,. \qquad (4)$$

Then, the Equation 3 could be expressed as Equation 5:

$$R = MG_t^2\,. \qquad (5)$$

The introduction of drag coefficient M makes the calculation of ratio frictional resistance more simple and accurate.

2.2 DRAG COEFFICIENT

The drag coefficient M is used to analyse the leakage point of pipe network. During this analysis, a straight pipe section with pipe branch is selected to be a case study. It has the same diameter, material, and applicable life. The nodes' positions on this pipe section are shown in Fig.2. In this pipe section, the pressure of node 1 is P_1 and the flow of it is Q. The pressure of node 2 is P_2 and the flow in the branched pipe is q. The pressure of node 3 is P_3 and the flow is Q-q. The length of tube segment 1~2 is L_1. And the length of tube segment 2~3 is L_2. The friction of the tube segment 1~2 is R_1, and the friction of the tube segment 2~3 is R_2.

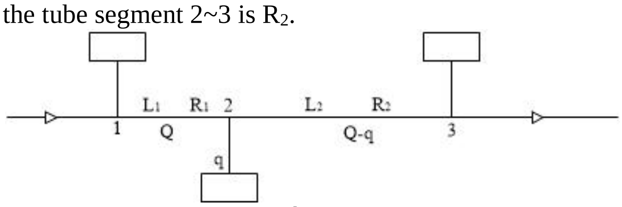

FIGURE 2 the Pipe Diagram

According to Equation 2 to Equation 5, the following equation is obtained:

$$R = \frac{\Delta P}{LP+L_d} = MG_t^2\,. \qquad (6)$$

Then the drag coefficient M could be calculated.

$$M = \left(\frac{\sqrt{R_1}-\sqrt{R_2}}{q}\right)^2 = \left(\frac{\sqrt{\frac{P_1-P_2}{L_1+L_{d1}}}-\sqrt{\frac{P_2-P_3}{L_2+L_{d2}}}}{q}\right)^2. \qquad (7)$$

In the Equation 7, when the pressure data and flow data of node 1, 2, 3 are known, the drag coefficient M of this pipe segment could be calculated.

2.3 HYBRID ADAPTIVE GENETIC ALGORITHM MODEL

In actual heat pipe network running, the drag coefficient M is not always constant. It must be corrected along with the changes of working conditions of heat pipe network.

Herein the hybrid adaptive genetic algorithm is introduced to correct M.

A characteristic of genetic algorithm is that the next search information could be got with the objective function only. The use of objective function is based on the evaluation of the fitness of individual. The individuals which have a high fitness have a high probability to inherit to the next generation. The individuals which have a low fitness have a lower probability to inherit to the next generation. The measure individual fitness is called to fitness function, and the fitness function is objective function in optimization problem [13-15]. In this analysis, the following fitness function is defined to:

$$\min F(S) = \sum_{i=1}^{N} (P_{ic} - P_{is})^2 . \quad (8)$$

The constraint conditions in objective function include the following formulas:

$$\begin{cases} \sum G_{m,ij} + Q_i = 0 & (i = 1, 2 \cdots, N) \\ P_{ij} = S_{ij} \left| G_{m,ij} \right| G_{m,ij} - dH_{ij} & (i = 1, 2 \cdots, N) \\ S_{\min} \le S_{ij} \le S_{\max} & (i = 1, 2 \cdots, N) \end{cases} , \quad (9)$$

wherein:

- P_{ic} is the pressure value of detection point measured in the pipe network system, *Pa*;
- P_{is} is the pressure value of monitoring point calculated by the graph theory, *Pa*;
- $G_{m,ij}$ is the flow in the pipes connected with the node i, m^3/h;
- Q_i is the leak flow of node i, m^3/h;
- N is the number of node;
- dH_{ij} is the pump head connected to the node i, *m*;
- S_{min} is the lowest limit of the coefficient of drag characteristics of each pipe section in the pipe network vector, $Pa \cdot h^2/t^2$;
- S_{max} is the supreme limit of the coefficient of drag characteristics of each pipe section in the pipe network vector, $Pa \cdot h^{2/}t^2$.

In these constraints, the coefficient of drag characteristics of each pipe section in the heat pipe network can be corrected within engineering error when the balance of heat pipe network hydraulic can be kept. The deviation between the node pressure data, which is measured and calculated by figure in the pipe network can be decreased.

2.4 POSITIONING OF LEAKAGE POINT

According to the M, which is corrected by hybrid adaptive genetic algorithm, a homeostasis model is established for the pipeline leakage detection. The model is used to find out the leakage point in the pipe network, which is a single pipe section. There is a leakage point between the node 2 and the node 3 in this pipe section, which is shown in Figure 3.

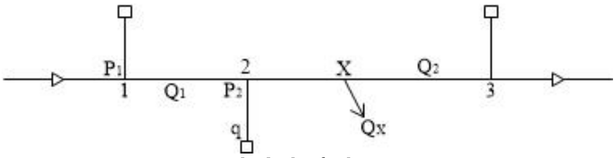

FIGURE 3 the leak of tube section 2 to 3

In Figure 3, the flow rate of node 3 is Q_2. The leak point is X. The amount of leakage is Q_x. The flow rate of node 1 can be calculated as $Q_1=Q_x+Q_2+q$. The position of the X can be determined as long as the $L_{2\sim X}$ or $L_{X\sim 3}$ is calculated. The calculated process is as follows:

$$L_{2\sim X} = \frac{P_2 - P_3 - MQ_2{}^2 L_{2\sim 3}}{M\left[\left(Q_1 - q\right)^2 - Q_2{}^2\right]} , \quad (10)$$

where, $L_{2\sim X}$ represents the length that includes all the resistance loss between the node 2 to the leakage point. $L_{X\sim 3}$ represents the length that includes all the resistance loss between the leakage points to the node 3. $L_{2\sim 3}$ represents the length that includes all the resistance loss between node 2 to node 3 when the pipe do not occur leak.

3 Case studies

In order to verify the accuracy of the pressure gradient method, a heating pipe network leak detection system is used. This system is used to simulate the running conditions of actual heating pipe network. The photograph of it is showed in Figure 5. Its running sketch is shown as Figure 4. The SCADA in this system could monitor the data of the constant pressure point, and the pressure of import and export of circulating water pump. At the same time the total flow data in heat export and the flow data of individual (or heat transfer station) and the pressure data of heat exchanger could be monitored by SCADA.

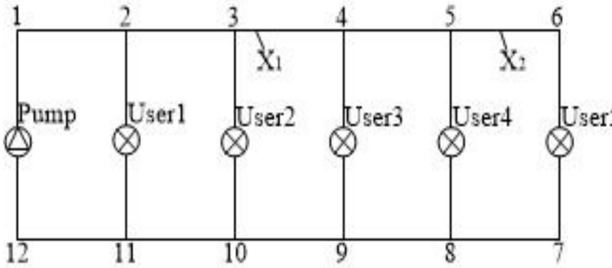

FIGURE 4 The running sketch

FIGURE 5 The photograph of pipe network

The data, which is used in calculation process is gotten after the experiment. The data of constant pressure point in the experimental pipe network system is 120595*Pa*. The first step researchers let the leakage is on point X_1 and the flow of this point is 0.491m^3/h. And then researchers record the data of monitoring points. The second step researchers let the leakage point is X_2 and the flow of it is 0.489m^3/h. The data to be recorded are shown in Table1. With the experimental data, the hybrid adaptive genetic algorithm is used to correct the drag coefficient M of the pipe network. After that, the graph theory is used to calculate the pressure data of nodes. The results are shown in Table 1, and the computation of leakage point is shown in Table 2.

TABLE 1 The calculate data of node pressure

Node number	Actual measurement value (Pa)	Graph theory that has not been corrected calculated (Pa)	Error rate	Calculated value of the graph theory after the genetic algorithm Corrected (Pa)	Error rate
3	342301	337270	1.47%	338540	1.10%
4	331651	327530	1.24%	327870	1.14%
5	311185	307201.8	1.28%	308695.5	0.8%

TABLE 2 The calculate value of the leakage point

	The characteristics breakdown of the tube network M	$L_{3\sim X1}$ (m)	Error rate
operating conditions not optimized	1.397493	23.3557	42.68%
operating conditions optimized	1.5794	9.289978	6.707%
	The characteristics breakdown of the tube network M	**$L_{4\sim X2}$ (m)**	**Error rate**
operating conditions not optimized	1.4967	31.5594	32.91%
operating conditions optimized	1.6882	43.2569	8.76%

In the Table 2 the error rate of operating condition without optimizing is big; on the other hand it with optimizing is low. From the Table 1 and Table 2, it can be seen that the calculation accuracy of the node's pressure is improved after using the corrected drag coefficient M of pipe network. Thus, the error that caused by the pressure gradient model which used in leak point positioning is decreased. Therefore, the method in this paper is effective in the leak location of heating pipe network. Moreover, it shortens the time to check the leak points and reduces the heat wasting.

4 Conclusions

This paper introduces a pipe drag coefficient M. In the calculation process, the drag coefficient M, which is corrected by hybrid adaptive genetic algorithm, avoids the influencing factors of the coefficient of drag characteristic, the pipe frictional, resistance coefficient and the inner diameter in this pipe. It makes the calculation of leak location easier and more accurate. The model of pressure gradient is proved to be effective in leakage location in heating pipe with the heating pipe network leakage detection system. Compared with the fact, the average error rate of the calculation in experiment is 7.7335%. This error meets project need.

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