Identification of the Flow Resistance Coefficient and Validation of a Building Air Conditioning System

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Abstract The fundamental parameter that characterizes the hydraulic state of a water pipeline and largely determines the efficiency of the water-transport process is the hydraulic resistance coefficient (HRC). The actual values of the HRC may be different from the theoretical values because of the complexity of the actual situation. A novel method — multi-goal optimization (MGO) strategy — for HRC estimation in building air conditioning systems is described in this paper. First, the basic principle of the approach is presented. Then the strategy is validated using a numerical example.

Keywords: Flow Resistance Coefficient, Parameter Identification, Air Conditioning System

1 INTRODUCTION

Loop networks have been developed and used widely in the heating, ventilation and air-conditioning (HVAC) field. The complexity of modern air conditioning system may make the balancing process quite involved. Some persons frequently are unaware of the difficulties and requirements of balancing. In the past it was often possible to get by with making a few adjustments and checking if people were comfortable. This is no longer satisfactory on large systems. Organized procedures are required to balanced system so that it will result in comfort in all reasons. Furthermore, the increased need for minimizing energy waste also requires correct balancing techniques. An improperly balanced system will almost certainly use excess energy. In addition, the variable frequency driver (VFD) is being used as a new adjustment implement. The control of variable-speed pumps on hot- and chilled-water systems must be based upon a hydraulic analysis of the water system. Hydraulic analysis enables the control manufacturer to select and program the variable-speed and pump addition and subtraction controls to achieve the maximum system efficiency [1]. Furthermore, hydraulic process faults, such as blockage in the network, may be occurred in loop networks.

Many researches have been investigated about hydraulic state in HVAC field. Hydraulic process fault diagnosis and parameter identification based on resistance coefficient region contraction in district heating networks is discussed in literature [2]. Xuzhong Qin etc.[3] presented a quantitative definition of hydraulic stability and its calculating method according to the network's structure and hydraulic condition or the measured data online. It is important to find a way to evaluate these networks, and hydraulic state is one of the basic criteria. The fundamental parameter that characterizes the hydraulic state of a water pipeline and largely determines the efficiency of the water-transport process is the hydraulic resistance coefficient (HRC). Since there are many pipe bends, manual valves, etc., of which the flow resistance performance depends on the installation or local initial regulation, the actual values of the HRC may be different from the theoretical values. In addition, a service engineer wishes to check if the proper flow rate is circulating in the chilled water piping on a job. All these problems would be easily solved if the HRC of piping were known. A novel method—multi-goal optimization(MGO) strategy—for HRC estimation and hydraulic process fault diagnosis in building air conditioning system is presented in this paper. First, the basic principle of the approach is presented. Then the strategy is validated using the simulation data.

2 BASIC APPROACH OF MULTI-GOAL OPTIMIZATION

2.1 The analysis of hydraulic state of chilled water system

In order to have the water temperature to each air handling unit (AHU) equal to the temperature at which it is generated, two pipe arrangements are usually used in HVAC system. Figure 1 is an arrangement of central chilling water system.

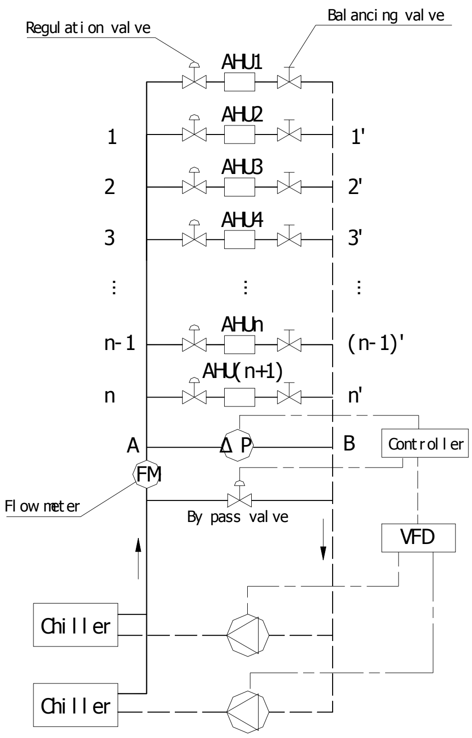

Fig.1 The schematic of chilled water system

There are two mains, one for supply and one for return. Individual supply branches feed each unit. Return branches deliver water back to the return main. The hydraulic balancing problem could be resolved by throttling a balancing valve in each branch. And flow regulation valves can be used to meet the room comfort requirement with the change of cooling load. The pump is automatically controlled according to differential pressure of chilled water loop. Chilled water flow meter is available for the total water supply.

For piping system, the turbulent flow exists in HVAC system and the pressure loss due to friction is given as expression (1)

$$H = SQ^2 \tag{1}$$

where, S is the flow resistance coefficient of pipe,kPa.S^2/ m^6; Q is the flow rate, m^3/s;H is pressure loss, kPa.

The S value can be assumed as independent flow rate in chilled water piping system. In addition, pressure drop of heat exchanger can be determined from equation (2)

$$\Delta H = Bw^m = B(\frac{Q}{A})^m \tag{2}$$

Where, ΔH is the water resistance of heat exchanger. B and m are coefficients obtained from experiments. A is sectional area of water pipe in heat exchanger. In practice, the value of m may be close to 2 and not be equal to 2. As a result, the pressure loss-flow relation may not be following equation (1).

2.2 The strategy of multi-goal optimization

In order to illustrate the strategy of multi-goal optimization, firstly, only AHU1 and AHU2, as shown in figure 1, are considered and others are stopped flow. It is assumed that the values of HRC through 1-AHU1-1' and 1-AHU2-1' are S_1 and S_2 respectively. And let the flow resistance coefficient of through A-AHU1-1 and 1'-AHU2-B is S. Before identification, some data have to be obtained according to following procedures:

1) Close the by-pass valve;
2) Shut off flow of AHU2;
3) Adjust the drive frequency of pump and let the value of flow meter equal to designed flow rate (Q_1) of AHU1. And the pressure drop (Δh_1) from A to B can be obtained;
4) Stop flow of AHU1 and make a comeback for AHU2;

5) Adjust the drive frequency of pump and let the value of flow meter equal to the designed flow rate (Q_2) of AHU2. And the pressure loss (Δh_2) from A to B can be obtained;
6) Make a comeback for AHU1and AHU2.
7) Adjust the drive frequency of pump and let the value of flow meter equal to the sum of Q_1 and Q_2. At the same time, the corresponding pressure loss (Δh_3) from A to B can be measured.

According to the analysis of hydraulic state above mentioned. The pressure loss-flow relation may not be following equation (1). For this reason, expression(3)-(5) are used to identify S1,S2 and S in this paper.

$$Minimize \quad \left| S + S_1 - \frac{\Delta h_1}{Q_1^2} \right| \qquad (3)$$

$$Minimize \quad \left| S + S_2 - \frac{\Delta h_2}{Q_2^2} \right| \qquad (4)$$

$$Minimize \quad \left| S + \frac{S_1 * S_2}{(\sqrt{S_1} + \sqrt{S_2})^2} - \frac{\Delta h_3}{(Q_1 + Q_2)^2} \right| \qquad (5)$$

Seen from expression (3)-(5), the HRC estimation is based on multi-goal optimization (MGO) principle. "m is close to 2" is assumed for AHU1 and AHU2. Once S, S1 and S2 are estimated, the HRC of other branch and main section can be estimated based on same principle.

3 VALIDATION BY SIMULATION

The strategy of MGO is validated by the simulation of AHU1 and AHU2. The parameters are shown in table 1.

Tab. 1 The parameters of AHU for simulation

	AHU1	AHU2
通水断面积(m^2)	A_1=0.00407	A_2=0.00553
Water resistance of Heat exchanger(*kPa*)	$15.48w^{1.97}$	$64.68w^{1.854}$
Designed flow rate (m^3/s)	0.003	0.006

Balancing is the process of proportioning the correct flow of air and water throughout the system, through mains, branches and equipment. What actually happens is that in balancing the system the contractor will throttle valves in the path of less resistance to increase the pressure drop and produce the proper flow in that circuit.

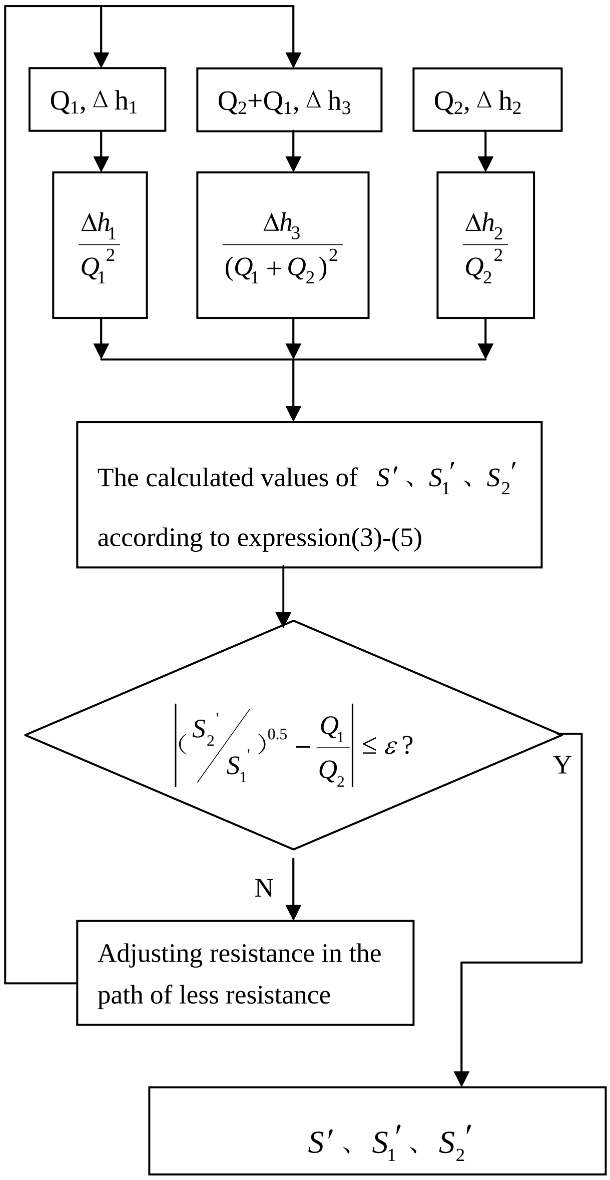

Fig.2 Flow of balancing

Tab.2 Experiment 1: The simulation results for S equal 50000 kPa.s^2/m^6

ΔS_1	Q'_2	s_1'	s_2'	s'	$(s_1'/s_2')^{0.5}$
0	0.00354	927066	2073975	66031	0.669
2000000	0.00485	2927411	2074320	65686	1.188
5000000	0.00564	5935109	2082018	57987	1.689
7000000	0.00595	7940742	2087651	52354	1.950

7500000	**0.00601**	**8441917**	**2088826**	**51180**	**2.010**
7650000	0.00603	8592617	2089526	50480	2.028
7800000	0.00604	8743125	2090033	49972	2.045
8000000	0.00607	8943590	2090499	49507	2.068

Figure 2 illustrates the flow of balancing.Three conditions are simulated to investigate and the data of adjusting are shown in table 2, 3 and 4 respectively. And table 5 shows the performance of identification.

Tab.3 Experiment 2: The simulation results for S equal 50000 kPa.s^2/m^6

ΔS_1	Q'_2	s_1'	s_2'	s'	$(s_1'/s_2')^{0.5}$
0	0.00354	17322	1640726	730269	0.103
2000000	0.00485	2927411	2074320	115686	1.188
5000000	0.00564	5935109	2082019	107987	1.688
7000000	0.00595	7940742	2087652	102354	1.950
7500000	**0.00601**	**8441917**	**2088826**	**101180**	**2.010**
7650000	0.00603	8592617	2089526	100480	2.028
8000000	0.00607	8943589	2090501	96901	2.068

Tab.4 Experiment 3: The simulation results for S equal 400000 kPa.s^2/m^6

ΔS_1	Q'_2	s_1'	s_2'	s'	$(s_1'/s_2')^{0.5}$
0	0.00354	927066	2073975	416031	0.670
2000000	0.00485	2927411	2074320	415686	1.188
5000000	0.00564	5935109	2082019	407987	1.688
7000000	0.00595	7940742	2087652	402354	1.950
7500000	**0.00601**	**8441917**	**2088826**	**401180**	**2.010**
7650000	0.00603	8592617	2089526	400480	2.028
7800000	0.00604	8743125	2090034	399972	2.045

Tab.5 The estimated values of hydraulic resistance under design flux

Experiment		HRC		
		$S_1+\Delta S$	S_2	S
1	Actual Value	8443097	2090006	50000
	Identified Value	**8441917**	**2088826**	**51180**
	Error	**1180**	**1180**	**11780**
	Relative error	**0.014**%	**0.056**%	**2.359**%
2	Actual Value	8443100	2090006	100000
	Identified Value	**8441917**	**2088826**	**101180**
	Error	**1180**	**1180**	**1180**
	Relative error,%	**0.014**	**0.056**	**1.18**
3	Actual Value	8443100	2090006	400000
	Identified Value	**8441917**	**2088826**	**401180**
	Error	**1180**	**1180**	**1180**
	Relative error,%	**0.014**	**0.0564**	**0.295**

It is seen from table 5 that the HRC by identifying are very closed to the actual values, which indicates that the strategy of MGO can be used for balancing, hydraulic process fault diagnosis and provide the base for the maximum system efficiency.

4 CONCLUSION

Multi-goal optimization strategy for HRC estimation is investigated in this paper. And some conclusions can be got as follows:

1) The MGO method is applicable for S value identification. The method is based on the principle for multi goal optimization. The process can be widely used in engineering practice.

2) Traditionally, the success of balancing depends on adequate instrumentation. These instruments are used for measuring temperature, pressure, velocity, flow rate, speed, heat flow, and electrical energy. Whereas, the MGO method can be achieved by the identification of HRC, which only depends on the parameters of water flow and pressure drop. As a result, it is accord with the actual situation in HVAC system.

3) HRC is the fundamental parameter that characterizes the hydraulic state. The identification result of HRC can be used to hydraulic fault diagnosis and provide the base for the maximum efficiency of the water-transport process.

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