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Analysis of the Diagnostic Methods of the Performance Failure of Heating and Air Conditioning Systems

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Abstract: The paper introduces some diagnostic methods for the performance failure of heating and air conditioning, analyzes the principle by an example, gives the application characteristics of different methods and supplies the guide for the application of fault detection and diagnostic technology.

Keywords: heating and air conditioning failure diagnosis methods

1. INTRODUCTION

The HVAC systems become extremely complicated along with the development of economy and the advent of multifunctional districts. There are a lot of malfunctions in the process of operation due to different types and quantities of the equipment. Malfunctions include the pipes and valves leaking, the coil incrustation, the filter stopping, the fans and pumps burn, the air dampers failure and the straps of the fans becoming flexible. Malfunctions do greatly harm to the performance of equipments. It not only makes the parameters diverge the set point and influences the comfort of the room but also increases the energy consumption, shorten the life of equipments. So it is an imperative task how checks and measures the malfunctions of the system quickly, enhance the safety and reliability of air conditioning system, avoids advent of the malfunctions and diffusing. Currently AFTDT (automatic fault detection and diagnosis technology) is an important way for advancing the safety and reliability of the equipments.

2. THE CONVENTIONAL REASONING METHODS OF FAULT DIAGNOSIS

Conflict recognition, alternate generation, local diagnosis, restriction separating, optimal measure point and state trend analysis are used in the process of diagnosis by esoteric knowledge in AFTDT system so that improving the precision of the diagnosis.

2.1 Conflict Recognition

At first, diagnosis is at the stage of conflict recognition of esoteric knowledge after the diagnosis of low knowledge is defeated. From intuitionist, a conflict is an assumptive aggregation sustaining some one symptom. And there is a factor at the stage of fault at least when the symptom exits. The process of diagnosis is leaded by the symptom. Each of symptoms indicates one or more of the assumptions are false. The following Fig.1, an air conditioning system is the example that illustrates the conflict recognition.

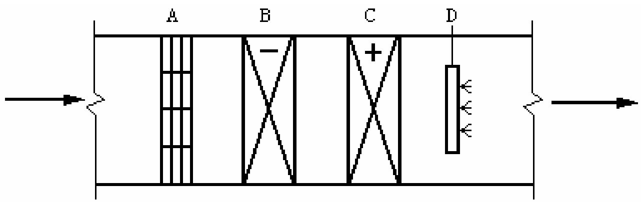

Fig.1 Diagram of air dealing system

A——filter B——evaporator，C——heater D——humidifier

The temperature, the relative humidity and the air flow of outlet of the air dealing chamber are normal if the A, B, C, D work normally. There is a fault in the A、B、C、D at least if the air flow reduces. So the aggregation ＜A，B，C，D＞ is a conflict of the symptom. All of the superset of ＜A，B，C，D＞ are the conflict of the symptom as a result of the monotonicity of reasoning. But all of the subset of ＜A，B，C，D＞ are not the conflict of the symptom.

There are a lot of conflicts in the thermodynamic system look as air conditioning system. So the compact way is used for dealing with conflicts. The paper uses the way of minimal conflict. (Minimal conflict is the conflict that the any subset of the conflict is not conflict, any other conflict is the superset of the minimal conflict).

2.2 Alternation Generation

An alternation is a special suppose. It indicates the factor in suppose already are fault. It can interpret all symptoms, each conflict. Namely the alternation has an intersection that is not empty with the conflict. The aim of fault diagnosis is that finding the alternation aggregation keeping the agreement with measuring. Like the conflict, any possible alternation superset is the alternation for a group of symptom. So the alternation space can be expressed by the minimal alternation.

Fault diagnosis is an increasing process. The process refines the alternation space continuously and guides the next measurement when measurement is doing. Minimal alternation aggregation is altered continuously. The old alternation that can not interpret this conflict must be altered by the minimal superset that can interpret it when the conflict is found. Taking into account the air dealing system, there is not any conflict in the beginning. So the minimal alternation ［ • ］(empty) can explain all of conflict. The single alternation is denied when the conflict ＜A、B、C、D＞appears as a result of the symptom 1 – air flow reducing. Its minimal superset that can interpret the new conflict ＜A、B、C、D＞ is [A]、[B]、[C] and [D]. So the new minimal alternation is [A], [B], [C] and [D]. the minimal alternation [A] is deleted when the second conflict ＜B、C、D＞ appears as a result of the symptom 2- the temperature of outlet increasing. So the minimal alternation that can interpret conflict ＜A、B、C、D＞ and ＜B、C、D＞ are [B]、[C]、[D].

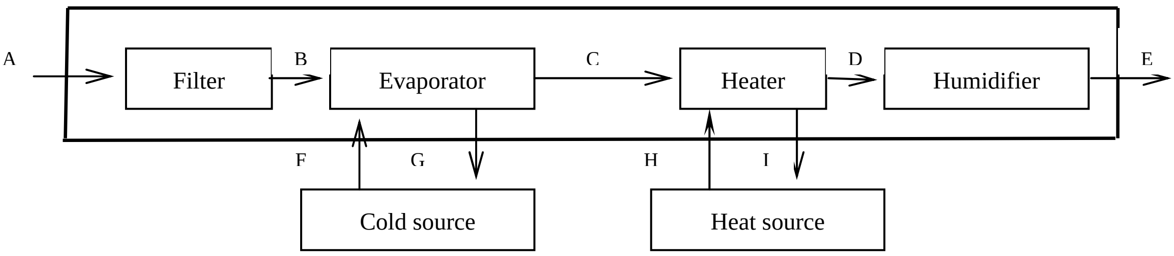

Fig.2 Diagram of the air dealing subsystem

2.3 Local Diagnosis

After conflict recognition and alternation generation, on the premise of all parameters of alternation object already gained, local diagnosis can detect contradiction for the qualitative physics equation of the alternation fault object. Taking the air dealing system for example is indicated Fig. 2.

A、B、C、D、E、F、G、H、I —the temperature of outlet

The qualitative physics equations:

$$[dA]=[dB] \tag{2.1}$$

$$[dB]+[dF]=[dC] \tag{2.2}$$

$$[dB]+[dF]=[dG] \tag{2.3}$$

$$[dC]+[dH]=[dD] \tag{2.4}$$

$$[dC]+[dH]=[dI] \tag{2.5}$$

$$[dD]=[dE] \tag{2.6}$$

The parameters of measurement point:

Normal value: [dA]=[dF]=[dH]=0

Abnormal value: [dG]=－，[dI]=+，[dE]=+

The above state indicates the water temperature of outlet of the evaporator decreasing, the water temperature of outlet of the heater increasing. Local diagnosis is stated concretely as following.

Substituting the parameters of measurement point to Eq. (2.1)——(2.6), there are [dB] =0，[dF] =0 and [dC] =+. And [dB]+[dF] ≠ [dC]. It is ambivalent to Eq. (3.2). [dB]=0，[dF]=0，[dG]=－. [dB]+[dF]≠[dG]. It is ambivalent to Eq. (3.2). Thus the evaporator is fault. Matching the model of the fault qualitative, the evaporator already encrusts.

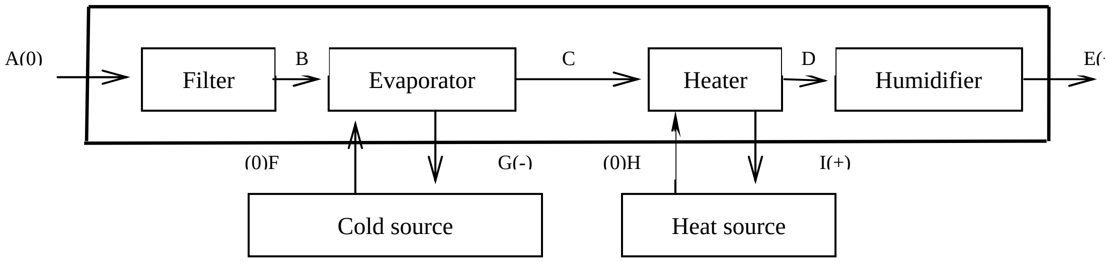

Fig.3 Diagram of the air dealing

From the above process of diagnosis, all state parameters must achieve when judging the qualitative equations of every object. It is not practical in real system. There are limited measurement points in the real system. So the information of diagnosis is not enough due to the local information is only used and the given information about the object in the system is not used. The paper utilizes the technology of restriction separation so that solving the issue of the diagnosis depended on the measurement point.

2.4 Restriction Separation

The essence of restriction separation diagnosis is that judging the consistency of rest part of system by canceling the influence of the state parameters of the current alternation object to the quantitative equations of the rest objects in the system, diagnosis the object is fault or not directly. If the result is consistency, it is fault. If the result is not consistency, the contradiction exits in rest system. At this time, the alternation object works at proper state. Then the next alternation object acts is detected continuously.

Taking the air dealing system explains the process of restriction separation diagnosis as follows Fig.3.

The state of actual measurement:

Normal: [dA]=[dF]=[dH]=0

Abnormal: [dG]=－，[dI]=+，[dE]=+

Alternation fault object, evaporator, heater and humidifier are given by conflict recognition and alternation generation according to the abnormal state parameters. Separation diagnosis is applied to alternation fault object.

(1)Selecting the alternation fault object-----evaporator, turning off its quantitative equations, the local parameters of the rest objects of system are simulated.

From (2.4)、(2.5)、(2.6):

[dI]=[dD]=[dE]=+

And

[dI]=[dD]=[dE]=+

The result is consistent. And the evaporator is the fault object, matches with the fault model. Then incrustation fault with evaporator is conformed. The process of diagnosis is over.

(2)Selecting the alternation fault object-----heater, turning off its quantitative equations, the local parameters of the rest objects of system are simulated.

From (2.1)、(2.3)、(2.6)

[dA]=[dB]=[dG]=0

And

[dG]=－

The result is contrary. So the heater is not fault object.

From the above, the restriction separation diagnosis is a kind of global reasoning. The inner state is achieved by simulating. The parameters of inner state do not be need. But the boundary state of system needs. However the local diagnosis need each of state parameters. This demonstrates the restriction separation diagnosis conquers the disadvantage that the local diagnosis depends on the parameters of measurement points severely.

2.5 Optimal Measure Point Selection

Integration diagnosis strategy that combines the simultaneous diagnosis to sequential diagnosis is unique method in the process of diagnosis due to the simultaneous diagnosis requires measuring all measurement points at one time but sequential diagnosis need a lot of computational resources in the initial stage. When the stage of closed solving is unsuccessful, the diagnosis changes to the stage of opening solving. The method of one-step minimal entropy is applied to selecting next optimal measurement point.

The evaluation function is applied to judging the difficulties for the next selected testing for the possible result of each testing. From the decision and information theory, the function of a better computing cost is based on the entropy of cost weight. For example, in the model of textual hierarchical decomposition, the testing entropy of the node D_{Ji} is calculated:

$$H = -\sum_{j=1}^{n} W_j P_j Ln P_j \qquad (2.7)$$

Here

$$W_j \geqslant 0, \quad \sum_{j=1}^{n} W_j = 1$$

Weighting factor W based testing cost is a normalized cost. It is achieved by the summation of all of node testing cost at J+1 layer reducing the actual cost of testing a node. P_j is the probability value supposing $D_{J+1,L}$ is reason causing D_{ji} and the measurement result of D_{ji} is given.

The next optimal measurement node is selected by applying the entropy based cost weighting, and the unit measurement cost possesses maximum fault discrimination. The entropy of next measurement node is minimal.

2.6 State Trend Analysis

The current state of system relates with the historical state in the system of fault diagnosis. The historical information of system performance that reflects the historical state of equipments is very useful to diagnosis. The state trend analysis can recognize the trend of development of state and predict the fault according to the symptom and the state. The paper applies the method of single parameter predict and the method of fuzzy clustering diagnosis.

2.6.1 Method of Single Parameter Predict

The method of single parameter predicting is the state predict to equipments according to the relation of state of equipments and time（$y_i = F_i(t)$（i=1，2，3，4））. There are four kind of model according to the changing of the state parameters of equipments.

Over upper limited——the measurement value of parameters exceed the setting upper limited.

Over lower limited——the measurement value of parameters exceed the setting lower limited.

Fluctuation — — the measurement value of parameters changes in the scope of upper and lower limited.

mutation — — the measurement value of parameters changes in the scope upper and lower limited abruptly.

According to the above model:

(1) Making the judgment and adopting action when the state parameters exceed the predicted set threshold value.

(2) Making the diagnosis and adopting action when the state parameters do not exceed the upper and lower limited, but the variable rate is very large.

2.6.2 The Method of Multiparameter Fuzzy Clustering Diagnosis

The essence of fuzzy clustering diagnosis is that the process of diagnosis is done by comparing the sample of current fault symptom with the symptom of the historical log of fault remedy, finding the fault that is similar with the current fault. The approving result is achieved that current fault is reasoned by the historical experience. The step of fuzzy clustering is following.

（1）determining the objects to be classified, viz. the domain.

$$U = \{x_1, x_2, \cdots, x_n\} \qquad (2.8)$$

thereinto

n is the number of object to be classified. Each of object to be classified refers to as a sample and supposes each sample X_I is illustrated by m indicator:

$$x_i = \left(x'_{i1}, x'_{i2}, \cdots, x'_{im}\right) \tag{2.9}$$

The selection of each object indictor has specific, real meaning, strong solving power and representativeness. The indicator data is achieved by the direct observing or historical information.

(2) Standardizing the indicator data for analysis and comparing, avoiding the function of indicator is buried due to few of data. This step is named normalization. The way is illustrated as follows.

$$x_{ij} = \frac{x'_{ij} - \bigcap_{i=1}^{n} x'_{ij}}{\bigcup_{i=1}^{n} x'_{ij} - \bigcap_{i=1}^{n} x'_{ij}} \tag{2.10}$$

Thereinto

$\bigcap_{i=1}^{n} x'_{ij}$ -- The minimal value of each element of j list

$\bigcup_{i=1}^{n} x'_{ij}$ -- The maximal value of each element of j list

(3) Building up affinity relation matrix. Each row of standardized matrix looks as the fuzzy set of classified objects in index set.

$$\tilde{X}_i = \left(x_{i1}, x_{i2}, \cdots, x_{im}\right), \quad i=1, 2, \cdots, m \tag{2.11}$$

The similar degree r_{ij} (i, j=1, 2, …, n) of X_I and X_j is confirmed by the method of distance, method of dot product and method of pressing close to.
Consequently the relation matrix R is confirmed in the domain U.

$$\tilde{R} = \left\lfloor r_{ij} \right\rfloor_{n\times n} \tag{2.12}$$

(4) Cluster analysis. Its purpose is grouping the historical diagnosis log, corresponding to building some clinical models, then doing pattern recognition to the current diagnosis state. The method of square translates the fuzzy relation matrix $\tilde{R}$ to the fuzzy equivalent matrix $\tilde{R}^*$, then classifies according to the given $\lambda \in [0, 1]$.

(5)Different methods for calculating similarity coefficient r_{ij} are adopted for constituting the relation matrix $\tilde{R}$, solving the equivalent matrix $\tilde{R}^*$, doing cluster so that furthermore approving the above cluster is correct.

3 CONCLUSIONS

The scale of HVAC increases continuously along with the scale of construction. When the faults happen due to many kinds and numbers of system, multiform fault appears at the same time.

The textual reasoning way for the system of HVAC fault diagnosis is based on the method of hybrid reasoning to regular esoteric knowledge and low knowledge. The characteristics are that the reasoning controlling skills--Conflict recognition, alternate generation, local diagnosis, restriction separating, optimal measure point and state trend analysis are discussed

(1)Conflict recognition and alternate generation avoid the aimlessness of selecting fault alternation objects in the course of diagnosis, and simplify the alternation space, quicken the speed of diagnosis.

(2) Local diagnosis can deal extensive fault without building up the relation between the fault and symptom. Restriction reduces the dependence of diagnosis to the measurement points.

(3)the selection of optimal measurement point makes the selected measurement point having maximal discrimination, and embodies the cost effective requirement of building up diagnosis system.

(4) State trend analyses can detect the fault of diagnosis equipment beforehand, and detect the kind of fault according to the historical log.

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