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DIAGNOSING TROUBLES IN REFRIGERATION UNITS WITH SCREW COMPRESSORS

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ABSTRACT

A system for diagnosing troubles encountered in large scale industrial refrigeration units with screw compressors, is presented by introducing the concept "probable state" of a component. The diagnosis process is implemented by examining the expert methods of trouble-shooting, accordingly generating the abstract representations of the units. The proposed system is readily utilized and tested, showing its applicability to practical uses.

INTRODUCTION

The refrigeration units with screw compressors installation usually operate under various conditions and environments and encounter many kinds of problems. Most problems are associated with the phase changes in cooling processes rather than with the structures of the units themselves [1]. To diagnose these troubles in detail requires experienced workers. Recently increase in demand for developing a practical diagnosis system incorporating a wide range of expert knowledge [2], has been expressed by users and operators.

We here propose a computerized system for diagnosing troubles in large scale industrial refrigeration units with screw compressors, by introducing the concept "probable state (qualitative knowledge about functions/characters)" of a component. This system examines the units by simulating qualitatively similar units diagnosed by experienced specialists [3].

The proposed system is also tested for various problems requiring trouble-shooting, and is shown to be useful for even novices to determine the malfunctioning components.

BASIC CONSIDERATIONS

Since the troubles in the units are associated with the phase changes in cooling processes, the experienced specialists usually attempt to identify the malfunctioning components by picturing in their minds the present states of and the structural inter-relationship among the components. By this type observation, a computerized system for diagnosing troubles can be implemented by considering probable states of the components. Probable state data are a kind of qualitative knowledge about functions/characters of a component and are derived by ordering and classifying the components running under various operational conditions.

The diagnosis process is based on the simulation of obtaining the qualitative expressions of input values and of determining the probable states of every component. This qualitative simulation facilitates generating the possible combinations of the component states, i.e., the abstract representations of the units. Thus troubles can be identified by viewing these generated abstract representations of the units.

REFRIGERATION UNIT WITH SCREW COMPRESSOR

Fig. 1 shows the structure of a brine cooling refrigeration unit with a screw compressor whose troubles are to be analyzed. The overall unit includes: refrigerant, oil, cooling water, and brine circuits which are inter-related with each other.

Low temperature/pressure refrigerant gas evaporated in the brine cooler flows to the screw compressor and then becomes high temperature/pressure gas. The gas next passes through the oil separator to the condenser where it is changed to low temperature/high pressure liquid. The liquid refrigerant passing through the valve with an enthalpic expansion function becomes low temperature/pressure mixture of gas and liquid. This mixture passes to the brine cooler and again returns to the initial low temperature/pressure.

Pumped oil is injected into the screw compressor to seal the compression chambers, lubricate frictional parts and reduce the heat of compression. The oil together with the refrigerant gas then flows to the oil separator, where the oil is separated from the refrigerant gas. It finally returns to the oil pump through the oil filter and oil cooler.

Pumped cooling water flows to the condenser and the oil cooler, where they cool the refrigerant and the oil, respectively. The cooling water then returns to the cooling tower water pump.

Pumped brine flows to the brine cooler where the brine is cooled by latent heat of the refrigerant evaporation then passes to the respective chiller and returns to the brine pump.

DIAGNOSIS SYSTEM

We consider two levels of the brine cooling refrigeration unit to get the abstract representations of the unit being examined. One is the higher level, where the unit consists of equipments such as the screw compressor, the oil pump, etc., and the other the lower level, where parts of each equipment become the components.

At the higher level, each concrete equipment is abstracted as several probable states by its functions/characters observed under various practical operational situations. The screw compressor, for example, has a function of compressing refrigerant, and characters of requiring input of electric power, and of maintaining mechanical movement by flowing lubricant. Thus the probable states of the screw compressor and of the other equipments can be expressed as shown in Table 1.

At the lower level, every part is abstracted similarly in order to keep the consistency of the qualitative simulation at both levels. For example, the male and female screw rotors, being integral parts of the screw compressor, have, when they together are rotating, a function of forming a compression chamber with axial and radial directions, and a character of maintaining a clearance between them. Table 2 lists probable states of several parts of the screw compressor.

The diagnosis proceeds by simulating qualitatively the movements of the components at each level. This is done by: (i) inferring the qualitative expressions of the values measured by physical sensors and observed through human sensories, (ii) by determining the probable states of the components via the inferred qualitative value expressions, and (iii) generating the possible combinations of the component states corresponding to the abstract representations of the unit.

Production rules, a kind of expertise, can be employed to infer the qualitative expressions of the measured/observed values, and to determine the states of the components. A rule for getting a qualitative expression of the screw compressor is given as follows:

```
IF
   refrigerant super heat at inlet is under 10 degrees  and
   frost condition at inlet is not good  and
   refrigerant temperature at outlet is lower than usual
THEN
   compression state is abnormal-2   [CF: 0.7]
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Here CF is a certainty factor corresponding to a probability of deducing the conclusion when the conditions are satisfied [4].

It should be noted that the components are physically combined with each other by way of transferring media such as lubricant (or vibration and driving-force) at the equipment (part) level. The abstract representations of the unit (or equipment) thus can be generated by a qualitative simulation of finding the possible combinations of the probable states of the equipments (parts). For this purpose each concrete medium is qualitatively treated by the same ways in the above and is abstracted as probable states (see Tables 3 and 4).

The simulation is also proceeded by the production rules of checking the legal combinations between the probable states of every component and that of its transferring media. An example of the simulation rules for the screw compressor is as follows:

IF
compression state is abnormal-1 **and**
refrigerant quantity at inlet is more than usual
THEN
refrigerant quantity at outlet is not more than usual.

IF
compression state is abnormal-1 **and**
refrigerant quantity at inlet is usual
THEN
refrigerant quantity at outlet is less than usual.

IF
compression state is abnormal-1 **and**
refrigerant quantity at inlet is less than usual
THEN
refrigerant quantity at outlet is less than usual.

IF
compression state is abnormal-1 **and**
refrigerant phase at inlet is gas
THEN
refrigerant phase at outlet is gas.

The simulation results are the possible combinations of the probable states, one of which will represent the actual situation of the unit. During the simulation the production rules with high certainty factors will be checked first in order to generate first the combination which will best represent the unit being examined. Since the component not taking the normal state becomes a candidate for repair, the problems can be analyzed by viewing the generated abstract representations of the unit.

EXAMPLES

Some of the diagnosis results by the system are compared with those by the experienced specialists in Table 5.

The first example is the case where symptoms of insufficient cooling, oil temperature dropping, liquid-back, etc., are observed simultaneously. In such a complicated case, since even an equipment without troubles pretends being in troubles, it is difficult for the experts to identify correctly the malfunctioning components. The proposed system, on the other hand, finds successfully that the thrust bearing in the screw compressor and the brine cooler are under the abnormal situations.

The second example shows the case of the unit with the abnormal compressor noise. To analyze the troubles, the specialists usually employ a Fourier transformation analyzer to have a frequency characteristics of the noise. The system outputs the similar results as the specialists through the qualitative treatments of the input noise.

CONCLUSIONS

Several other trouble cases in addition to the above were also examined. When there were full measured values available, the resulting representations correctly reflected the situation of the unit. Even for the cases without the full measured values and/or with the complicated symptoms, the proposed diagnostic system resulted in the abstract representations given understandable simple guidelines, from which the malfunctioning components could be pinpointed even by novices. Further the qualitative simulation helped the system check the consistency of the newly added expertise with the already existing one by not generating legal combinations of the probable states.

It can be concluded that the notion of a probable state is a viable concept and the proposed system is a powerful tool in trouble-shooting for the screw compressor refrigeration units.

The proposed system will be upgraded by establishing a fast simulation procedure for coping with the cases where few measured values are observed, and by incorporating qualitative knowledge about transitional movements of each component.

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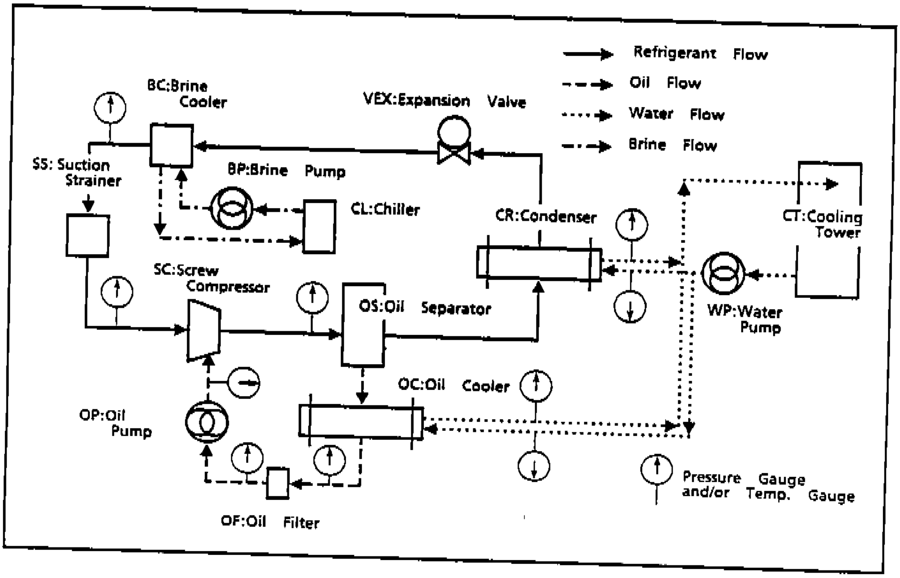

Fig.1 Brine Refrigeration Unit with Screw Compressor

Table 1. Probable States of Components

Component	Function Character	Probable state
screw compressor	compression lubrication power	N A1 A2 N A1 A2 A3 A4 N A1 A2
oil separator	oil separation	N A1 A2
condenser	condensation	N A1 A2
regulation	refrigerant flow rate	N A1 A2
brine cooler	evaporation	N A1 A2
suction strainer	scale separation	N A1 A2
oil cooler	cooling	N A1 A2
oil filter	scale separation	N A1 A2
oil pump	compression lubrication power	N A1 A2 N A1 A2 A3 N A1 A2
brine pump	compression lubrication power	N A1 A2 N A1 A2 A3 N A1 A2
water pump	compression lubrication power	N A1 A2 N A1 A2 A3 N A1 A2
cooling tower	cooling	N A1 A2

N: Normal, Ai: Abnormal-i

Table 2. Probable States of Parts in Screw Compressor

Part	Function Character	Probable state
coupling for motor and a male rotor	alignment	N A
male rotor	meshing radial clearance axial clearance	N A N A N A
female rotor	meshing radial clearance axial clearance	N A N A N A
radial bearing for male (female) rotor	surface roughness	N A
thrust bearing for male (female) rotor	rolling resistance	N A
mechanical seal	sealing	N A
unloader piston	driving force transmitting	N A
unloader pushrod	fix	N A
unloader slide valve	positioning	N A

N: Normal, A: Abnormal

Table 3. Probable States of Fluids

Fluid	Character	Probable states
refrigerant	quantity	+ 0 −
	phase	L M G
	oil quantity	+ 0 −
	scale quantity	+ 0 −
oil	quantity	+ 0 −
	refrigerant quantity	+ 0 −
	scale quantity	+ 0 −
cooling water	quantity	+ 0 −
	scale quantity	+ 0 −
brine water	quantity	+ 0 −
	scale quantity	+ 0 −

+: larger than usual, 0: usual, −: smaller than usual
L: liquid phase, M: mixture phase, G: gas phase

Table 4. Probable States of Media in Screw Compressor

Medium	Character	Probable state
vibration	rotational	+ 0 −
	radial	+ 0 −
	axial	+ 0 −
driving force	linear	+ 0 −

+: larger than usual, 0: usual, −: smaller than usual

Table 5. Comparative Evaluation

Actual Symptom	Domain Specialist	Diagnostic System
Insufficient cooling. Drop in refrigerant temperature/ pressure and oil temperature at the screw compressor inlet. Increase of vibration/ noise on the screw compressor. Unloader controlling is failed.	Liquid-back caused by brine cooler failure (or increase of oil quantity at the screw compressor inlet) and dropp in oil temperature at the screw compressor inlet caused by oil cooler failure, which results in screw compressor bearing failure.	(1) Abnormal "evaporation" of the brine cooler. (2) Abnormal "compression," "lubrication," and "power" of the screw compressor. (3) Abnormal "meshing" of the male rotor of the screw compressor.
High frequency noise in the case of the unloaded compressor.	Noise caused by oil-hammer, but not by thrust bearing failure. (Decided by a Fourie transformation analysis.)	(1) Normal "compression," "power," and "lubrication" of the screw compressor with a high certainty factor. (2) Abnormal "rolling resistance" of the thrust bearing with a low certainty factor.