An expert system based on multi-source signal integration for reciprocating compressor

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Abstract: - In refining, pipeline, and metallurgical enterprises, reciprocating compressor fault diagnosis is hard work and requires a high level of expertise; only a few experts have the ability to do the work. This paper describes an expert system (ES), which is designed to apply a composite diagnosis main structure based on multi-source signal integration for reciprocating compressor, for reciprocating compressor fault diagnosis. For automatically diagnosing 39 faults of the reciprocating compressor and other auxiliary system, the ES includes 67 facts and over 400 rules. The ES has been developed as part of an on-line monitoring system that has been used in various factories and successfully diagnosed many realistic faults.

Key-Words: - Reciprocating compressor; Fault diagnosis; Expert system; Composite diagnosis; Multi-source signal integration

1 Introduction

One of the greatest challenges in refining, pipeline, metallurgical, and other industrial enterprises is keeping the key equipment in good operating conditions. As one type of key equipment in the industrial enterprises, the reciprocating compressor conveys high-pressure gas for production. The operating conditions of reciprocating compressors directly affect the production and safety. Every year in China, many of the accidents in refineries are caused by the common faults of reciprocating compressors. However, the fault diagnosis of reciprocating compressors is still a difficult task.

At present, almost all domestic process industrial enterprises still apply the Periodic Maintenance and Breakdown Maintenance mode in the maintenance and management of reciprocating compressors. Only a few reciprocating compressors have been installed the on-line monitoring system with different transducers to monitor valves temperatures, piston rods displacement, and vibrations of the crossheads and the crankcase. However, the practical effect of the on-line monitoring system is unsatisfactory because only a few experts can diagnose the faults of reciprocating compressors. Thus, developing an automatic fault diagnosis expert system (ES) to assist industrial plants in equipment management is a very urgent task.

Researchers paid more attention to small-scale reciprocating compressors in refrigeration, air conditioning, and automotive, and less to large-scale reciprocating compressors. Most researchers paid attention to the field of intelligent diagnosis algorithms and feature extraction, support vector machines, neural networks and other methods have been used in fault feature extraction and classification of reciprocating compressor and motor [1, 2, 3, 4]. Some researchers focused on the working principle and efficiency of the mechanism system. Different theoretical analysis models have been built to calculate compression efficiency and other parameters [5]. Theoretical simulation and experimental study also have been used to analyze the motion characteristics of the key components [6, 7]. Today, on-line monitoring system for rotating and reciprocating machinery is another popular research area. The system for reciprocating compressor will monitor crankcase vibration, crosshead impact, valve temperature, piston rod drop and dynamic pressure. The transducers' positions will affect data acquisition directly [8]. The alarm methods will affect the diagnosis results [9].

However, there is very little research on the automatic ES and automatic diagnosis logic for reciprocating compressors. There is no report on the integration of on-line monitoring system and ES.

In order to improve the level of fault diagnosis for reciprocating compressors, we present an ES model that was designed using a composite diagnosis main structure based on multi-source signal integration.

ES is defined as one that contains information obtained from human experts and represents information in the form of rules [10]. ES find wide applications. A fuzzy ES was applied to the knowledge analysis of industrial biotechnological process performance [11]. In other research fields, such as communication system fault diagnosis [12], health sciences [13], and sensor control [14], ESs are widely used. We also developed a rule-based ES and integrated it into an on-line monitoring system for reciprocating compressors. The ES can diagnose the common faults of mechanical system, cooling system, and instrument system, providing assistance for the operation, maintenance, and management of the compressors.

2 Structure design of the ES

Different reciprocating compressors work in different conditions, and have special features. Working condition, structure, drive equipment, pressure range and medium of each reciprocating compressor are significant different. How to deal with the differences between the compressors is the difficult task in the ES design. Section 2 gives the Structure of the ES.

2.1 Overall structure of the ES

In the process of designing the ES, we gave full consideration to the situation that only a few reciprocating compressors were installed with the online monitoring system, and we designed three operation modes for the knowledge acquisition of the ES.

- Manual diagnosis mode: users select different fault diagnosis tasks and set the property values of all facts through the man-machine interactive interface manually.
- Automatic diagnosis mode: the ES is integrated into the online monitoring system and acquires the property values of all facts from the online monitoring system automatically.
- Semi-automatic diagnosis mode: we combine the automatic mode with the man-machine interactive mode to acquire the property values of some facts that are out of the scale of monitoring through the man-machine interactive interface, such as the compressor load, lubricating oil pressure, and discharge pressure.

Different modes fit different situations. The first mode is the most intelligent and automatic, the second mode is the most accurate but less automatic than the first, and the last mode can be used any time, especially without the online monitoring system.

The overall structure of the ES is shown in Fig.1, and the kernel is in the dashed box. The ES can be activated in different modes.

- Automatic mode: the ES diagnoses automatically when the on-line monitoring system detects the abnormal situation of the equipment.
- Manual mode: operators can activate the ES at any time and select the abnormal period for diagnosing manually.

As shown in Fig.1, whatever the mode is, the property values of all facts will be sent to the ES kernel at last. The corresponding rules in the rule base will be activated and called by the reasoning engine, and the fault diagnosis results will be shown in the man-machine interactive interface.

2.2 Knowledge base structure

2.2.1 Overall structure of knowledge base

As a universal fault ES for different kinds of reciprocating compressors in the processing plants, the knowledge base structure of the ES must satisfy the fault diagnosis needs of reciprocating compressors with different structures and working environments. For example, more than 70 percent of the faults of a medium pressure reciprocating compressor happen in the valves, support rings, piston rings, and stuffing boxes. For a hyper compressor for polyethylene with a plunger structure, the faults primarily happen in the stuffing boxes, auxiliary crossheads, and modular valves. For a horizontal reciprocating compressor working on offshore platforms for gas delivering, the common faults include pipeline and foundation faults in addition to the faults of the compressor components.

In order to satisfy the diagnosis requirements, the ES applies the Task-Based Expert System (TBES) structure based on the traditional production rule reasoning framework. The TBES has been used in the field of pump diagnosis [15]. According to the diagnosis objects, we established the equipment information base, the diagnosis task base, the fault base, the rule base, the fact base, the fact property base, and the inspection and maintenance recommendation base. All these bases compose the ES knowledge base of reciprocating compressors, as shown in Fig.2.

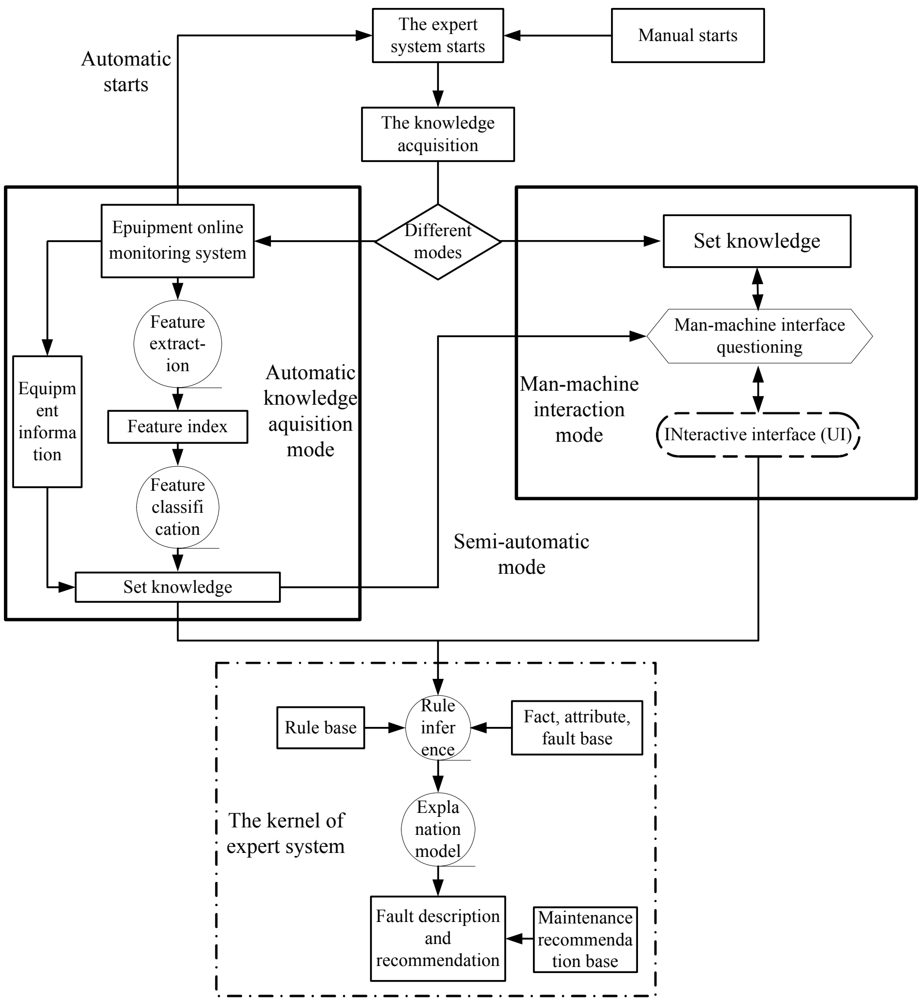

Fig.1 Schematic overview of expert system

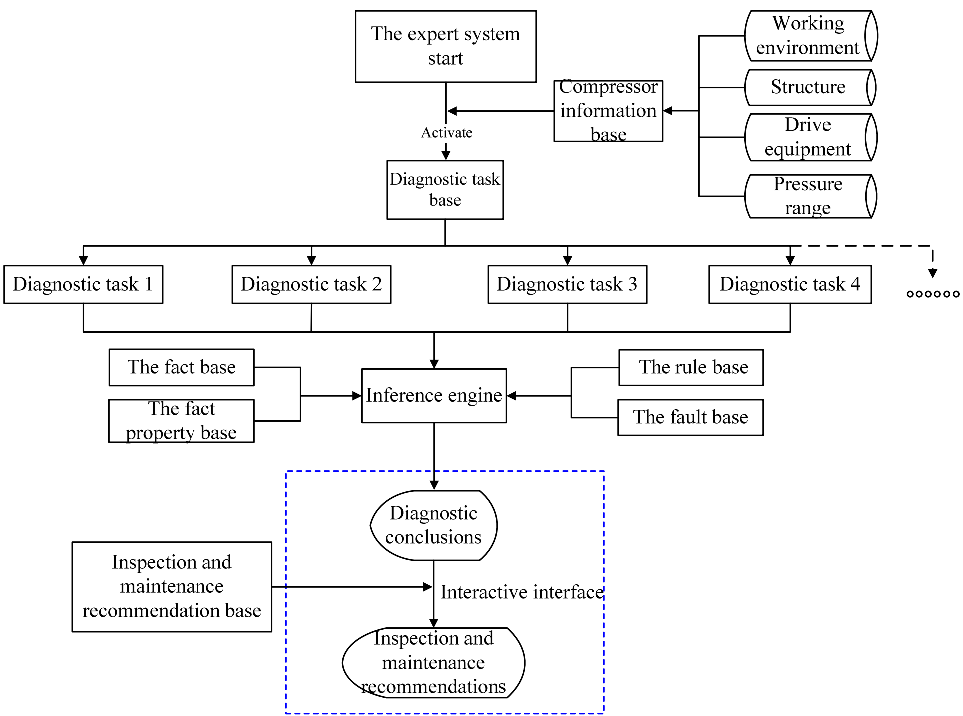

Fig.2 Schematic overview of expert system knowledge base

2.2.2 The rule base

A composite diagnosis main structure based on multi-source signal integration is applied to design the rule base of the ES. The fault diagnosis methods of reciprocating compressors are different from those of rotating machines. The motion of a reciprocating compressor is much more complex than that of a rotating machine. Under the combined effect of the complex motion consisting of the rotation of the crankshaft, the swaying motion of the connecting rods, and the reciprocating motion of the crossheads, piston rods, and pistons, the vibration signals of a reciprocating compressor are significantly nonlinear and non-stationary.

At present, in the field of vibration signal analysis of reciprocating compressor, spectrum analysis methods are applied more in the fault analyses of pipelines and valves [16, 17, 18], less in the fault analysis of key moving components.

The domestic online monitoring systems of reciprocating compressors usually include the following transducers: accelerometer, proximity probe, temperature transducer and key-phase transducer. There are more transducers in the online monitoring systems of reciprocating compressors than in those of rotating machines and pumps. As a result, reciprocating compressor fault diagnosis integrates the signals of vibration, impact, displacement, temperature, and key phase; the fault diagnosis cannot be completed by any one signal.

We established the rule base structure and the diagnosis flow chart, which are shown in Fig.3. The structure consists of independent diagnosis rule packets, which will be activated according to different diagnosis tasks. This structure has superiorities: high efficiency of diagnosis and convenience in increasing, modifying, and deleting the rule packages.

We adopted the general rule structure (GRS) instead of the production rule structure to represent the rules in the packages. GRS utilizes variable precision logic, adjusts rules dynamically depending on the tasks and the facts, and supports forward and backward reasoning [19]. In the rule base, we used a triple structure, object-attribute-value, for the representation of facts [20]. For example, for the fact “piston rod drop”, the property is “displacement”, and the values include “lower than the alarm line; higher than the alarm line, but lower than the danger line; higher than the danger line, but lower than the transducer range; higher than the transducer range”.

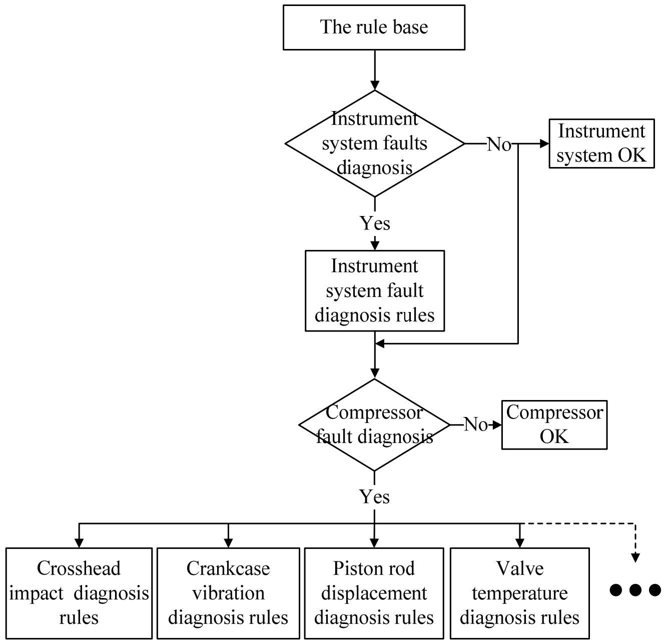

Fig.3 The rule base structure

2.2.3 The fault base

The common faults of reciprocating compressor can be mainly divided into two kinds: mechanical system faults and auxiliary systems faults. The auxiliary systems include cooling system, lubrication system, filtration system and instrument system.

The moving components in a reciprocating compressor are more than those of a rotating machine. The mechanical system faults are the critical faults of reciprocating compressor. The mechanical system includes: valve, piston, piston rod, crosshead, connecting rod, crankshaft, cylinder, pipeline, body parts and packing. In these components, the valve faults are the commonest, and the piston rod and cylinder faults are the most dangerous. Comprehensively utilizing practical diagnosis cases and the research results, we classified the common faults of reciprocating compressor and established the fault base with 39 faults of the ES, as shown in Table 1.

2.2.4 The maintenance recommendation base

The operators must choose appropriate operations to deal with the faults existing on reciprocating compressor. We built the maintenance recommendation base, which could give suggestions on maintenance, with experience of experts. In this base, we also define the destructive power (from 0 to 1) and the risk level of all faults. In Table 2, maintenance recommendations of common faults have been shown.

Table 1 Classification of common faults of reciprocating compressor

Mechanical system faults	Valve	Leakage, jam, fracture, choking
	Piston	Abrasion of support ring, abrasion of piston ring, fracture of support ring, fracture of piston ring, loosening of piston nut, leakage of piston ring
	Piston rod	Loosening of the piston rod locknut, abrasion of piston rod, fracture of piston rod
	Crosshead	Abrasion of crosshead shoes, abrasion of crosshead pin, abrasion of crosshead pin bushing
	Connecting rod	Fracture of connecting rod, abrasion of connecting rod pin bushing, abrasion of crankpin bearing
	Crankshaft	Fracture of crankshaft, abrasion of main bearing, coupling misalignment, imbalance
	Pipeline	Mechanical resonance, gas column resonance, resonance of gas column and mechanism
	Cylinder	Misalignment of cylinder with crosshead shoes, liquid hit, collision on cylinder, abrasion of cylinder
	Body parts	Loosening of anchor bolts
	Packing	Leakage, abrasion
Auxiliary systems faults	Cooling system failure, lubrication system failure, filtration system failure, loosening of transducer or circuit, unreasonable installation position of transducer, electromagnetic interference	

Table 2 Maintenance recommendations of common faults

Fault	Destructive power	Risk level	Maintenance recommendation
Fracture of piston rod	1	Extreme	Immediately stop and check the damage of piston rod, piston and cylinder
Collision on cylinder	0.9	Extreme	Immediately stop and check the damage of piston rod, piston and cylinder
Abrasion of cylinder	0.8	Severe	Immediately stop and check the damage of cylinder and piston components
Loosening of the piston rod locknut	0.7	Severe	Immediately stop and check the failures of the piston rod locknut
Fracture of valve plate	0.6	Moderate	Continue Running in short time, stop and take maintenance on valve
Abrasion of support ring	0.5	Moderate	Continue Running in short time, stop and take maintenance on support ring and piston ring
Abrasion of piston ring	0.3	Slight	Continue Running in short time, stop and take maintenance on support ring and piston ring
Leakage of valve	0.2	Slight	Continue running and monitoring the temperature of valve

3. Realization of intelligent diagnosis logic

The Diagnosis reasoning logic is the kernel of the ES. Because the fault mechanisms of reciprocating compressors are very complex, it has not found a method to diagnose the fault of reciprocating compressors comprehensively, and there is not any diagnosis reasoning logic which can be applied in realistic fault diagnosis in past decade.

One of the objectives of this research focuses on the faults principles to build diagnosis reasoning logic. With the logic, we developed the fault diagnosis ES which can be applied in realistic operation.

3.1 Principles for designing diagnosis logic
In order to improve the accuracy, availability, and maintainability of the ES, we present three principles for designing the diagnosis logic of ES.

(1) ***Optimizing the rules and facts based on the differences in reciprocating compressors*.**

At present, in refining, pipeline, and other industries, the structures and drive patterns of reciprocating compressors are significantly different. Large-scale, high-speed, and high-pressure reciprocating compressors driven by gas engines are widely used in the pipeline industry; motor-driven reciprocating compressors are widely used in the petrochemical industry. The fault types and diagnosis methods of different reciprocating compressors are also different. The task-based ES structure is designed with unique diagnosis knowledge to meet the diagnosis requirements of different reciprocating compressors. The ES first obtains the unit information and then calls the specific rules according to the diagnosis task. The advantage is that we can establish a relatively independent diagnosis knowledge base to avoid the unnecessary confusion and conflict in using the same knowledge base to diagnose different faults.

(2) ***Establishing the composite diagnosis structure based on the integration of multi-source signals.***

Based on the online monitoring system for reciprocating compressors, we integrated the crosshead impact, the crankcase vibration, the piston rod displacement, and the valve temperature to establish the composite diagnosis structure of the ES. Taking advantage of the diagnosis rule packages, we separated the different faults of the auxiliary systems and components of the compressor to ensure that the diagnosis processes are independent and non-interfering. The advantage of the composite diagnosis structure is that the increase, modification, and deletion of a single diagnosis rule package have no effect on other diagnosis rule packages, so we can adjust the diagnosis rule packages according to the installation of transducers on the compressor.

(3) ***Diagnosing from coarse-to-fine and improving the efficiency and accuracy.***

On the one hand, the diagnosis efficiency and accuracy of the ES depend on the correctness of the diagnosis rules; on the other hand, they depend on the degree of completeness of the fault characteristics. Because different reciprocating compressors are installed with different transducers, we cannot obtain the complete relationship of failure vs. signal characteristics for every compressor. Most of the compressors are installed with the key phase, piston rod drop, and vibration transducers. As a result, we utilized the coarse-to-fine diagnosis principle to analysis step by step the compressor operating status and faults.

3.2 Fault simulation experiments
The collection of practical fault case is so slow in realistic operation. We have finished different fault simulation experiments on the reciprocating compressor experimental platform shown in Fig.4, to get faults data and features. The experiments include:

- Valve fault simulation experiments
- Moving component fault simulation experiments
- Piston fault simulation experiments
- Packing fault simulation experiments
- Body part fault simulation experiments
- Transducer fault simulation experiments

Fig.4 Experimental platform for reciprocating compressor

(1) Valve fault simulation experiments

Because fluctuations will always exist in the operation process of reciprocating compressor, the working condition of valve is unstable. The fluctuations lead to valve faults which include leakage and fracture. In the experiments, we damaged the valve plate and springs worse and worse to simulate leakage and fracture in different degrees. The assembly and disassembly of valve are relatively simple, and the experiments' duration is relatively short. We monitored and analyzed the impact vibration of cylinder and valves.

(2) Moving component fault simulation experiments

The moving components: piston rod, crosshead, connecting rod, crankshaft, are the key components of a reciprocating compressor. Fracture of piston rod, loosening of the piston rod locknut, abrasion of connecting rod pin bushing and crankpin bearing belong to the highest risk level of the faults. Taking into the danger in experiments, we planned to simulate loosening of the piston rod locknut, abrasion of connect rod pin bushing and abrasion of crankpin bearing. The assembly and disassembly of piston rod, connect rod, and crankshaft are complex and hard, the experiments' duration is relatively long.

(3) Piston fault simulation experiments

Abrasion of support ring and abrasion of piston ring are common faults of a reciprocating compressor. Because the medium contains different impurities, the working state and operation life of piston components in different plants are not identical. For the most plants, the operation life of piston components is in six months to one year. However, when the working conditions become bad, the life of support ring and piston ring will decrease to a short time. Serious faults even fracture of piston rod and collision on cylinder will happen. Therefore, the experiments on piston components faults are significant important. Taking into the cost of the assembly and disassembly, we spent the longest time on the faults simulation of abrasion and fracture of support ring and piston ring. We monitored and analyzed the piston rod displacement and the vibration of cylinder.

(4) Packing fault simulation experiments

Packing faults often exist accompanying with abrasion of the support ring and piston ring. The faults will easily lead leakage of dangerous gas: hydrogen, methane and ethylene. In the process of the experiments planning, for making different degrees of abrasions to simulate different degrees of leakages, we planned to increase and decrease the packing sealing rings with damage to simulate the abrasion faults.

(5) Body part fault simulation experiments

Foundation loosening is a common fault of reciprocating compressor on offshore platforms. Because the foundation stiffness on an offshore platform is weaker than that of a reinforced concrete structure on the land, the loosing of fastening elements and the lacking of support stiffness often exist. The experimental platform shown in Fig.4 is applied with a support mode: using rigid supports and elastic supports in combination. This support mode is similar to that on an offshore platform. So the actual operating conditions on offshore platform can be simulated in a certain extent. In addition, we also planned to loosen the fastening bolts to simulate the body part faults of reciprocating compressor. We monitored the vibration signals of crankcase and cylinder to analyze the fault features.

(6) Transducer fault simulation experiments

The quality of instruments working status determines the accuracy of fault diagnosis. With the practical application and experience in the petroleum and petrochemical enterprises, the faults of an online monitoring system mainly include the faults of transducers, installation mistakes and looseness faults of signal lines. These different fault types will exist on different transducers.

The Fig.5 is one of the pictures of the experiments.

Fig.5 Experiments of piston components

3.3 Diagnosis reasoning logic

Based on the fault simulation experiments and the accumulation of actual fault diagnosis for process industrial enterprises, we established different types of packages for a fault diagnosis rule base with over 400 rules according to the composite diagnosis structure. Now we present the diagnosis logic of the crosshead accelerometer for instrument faults and the diagnosis logic of crankcase vibration and crosshead impact for compressor faults, as follows:

(1) Diagnosis logic of crosshead accelerometer

In realistic operation, we found that perhaps 30% faults of auxiliary systems happened on the transducers, such as accelerometers, proximity transducers and temperature transducers. As shown in Fig.3, we require that all instrument fault diagnosis should be completed before machine fault diagnosis to exclude the effect of abnormal instruments and improve diagnosis accuracy. The diagnosis logic for the instrument faults of crosshead impact transducer is shown in Fig.6. The signal characteristics that need to be extracted include the impact signal frequency, the impact signal peak, and the wave bias.

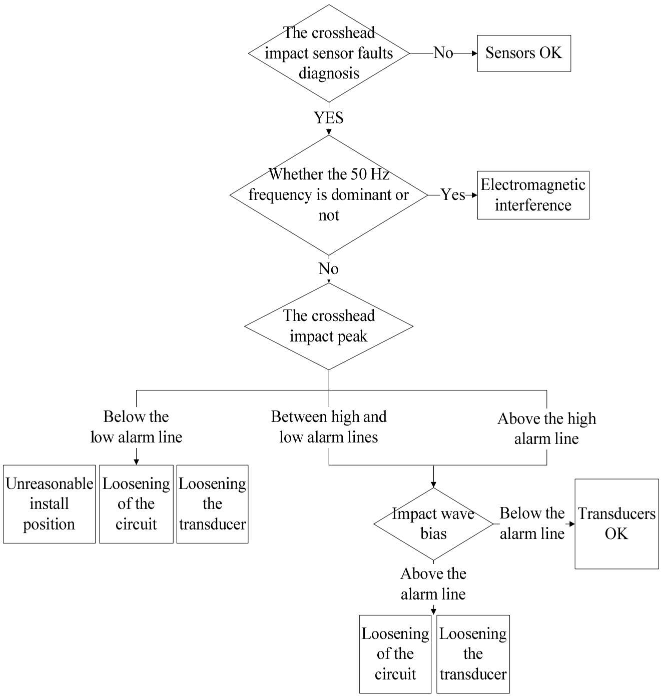

Fig.6 Diagnosis logic of crosshead accelerometer

(2) Diagnosis logic of crankcase vibration

The crankcase of a reciprocating compressor connects all cylinders. The crankcase vibration transducers are installed on the both sides of the crankcase to monitor the vibration signals. If serious faults happen in any cylinder, the faults' features will be obviously reflected on the vibration signal of crankcase. For example, the vibration RMS will increase rapidly when the piston rod in any cylinder has broken, and severe impacts will appear at the piston reversal points. Therefore, the vibration signal of crankcase plays an important role in the fault diagnosis of reciprocating compressor.

Fig.7 shows the diagnosis logic chart of crankcase vibration for compressor faults. The characteristics that need to be extracted include the crankcase vibration RMS, the vibration signal frequency, and the bearing temperature.

(3) Diagnosis logic of crosshead impact

The crosshead impact transducer is installed above the crosshead of each cylinder, monitoring signals of impacts on the crosshead and cylinder. The impact transducer is sensitive to these faults: fracture of piston rod, collision on cylinder, abrasion of cylinder and fracture of valve plate. Similar to other vibration and displacement signals, the crosshead impact signals have the phase characteristics. Normally, big impact signals in specific phases will appear when the valves open, these impact signals are not caused by faults. However, once the impact signals appear at the 0 °and 180 °, which are the piston reversal points, the operators should pay more attention to faults of compressor, such as fracture of piston rod and collision on cylinder.

Fig.8 shows the diagnosis logic chart of crosshead impact for compressor faults. The characteristics that need to be extracted include the crosshead impact peak, the number of impact, the lubricating oil pressure and the impact phase.

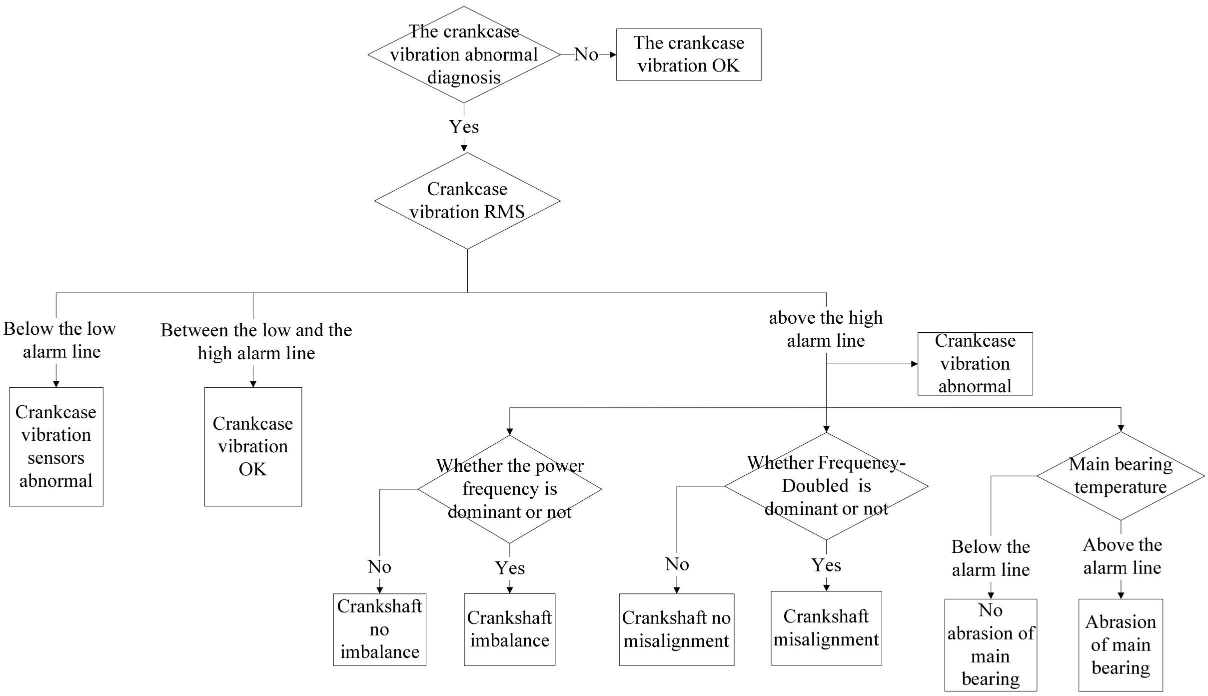

Fig.7 Diagnosis logic of crankcase vibration

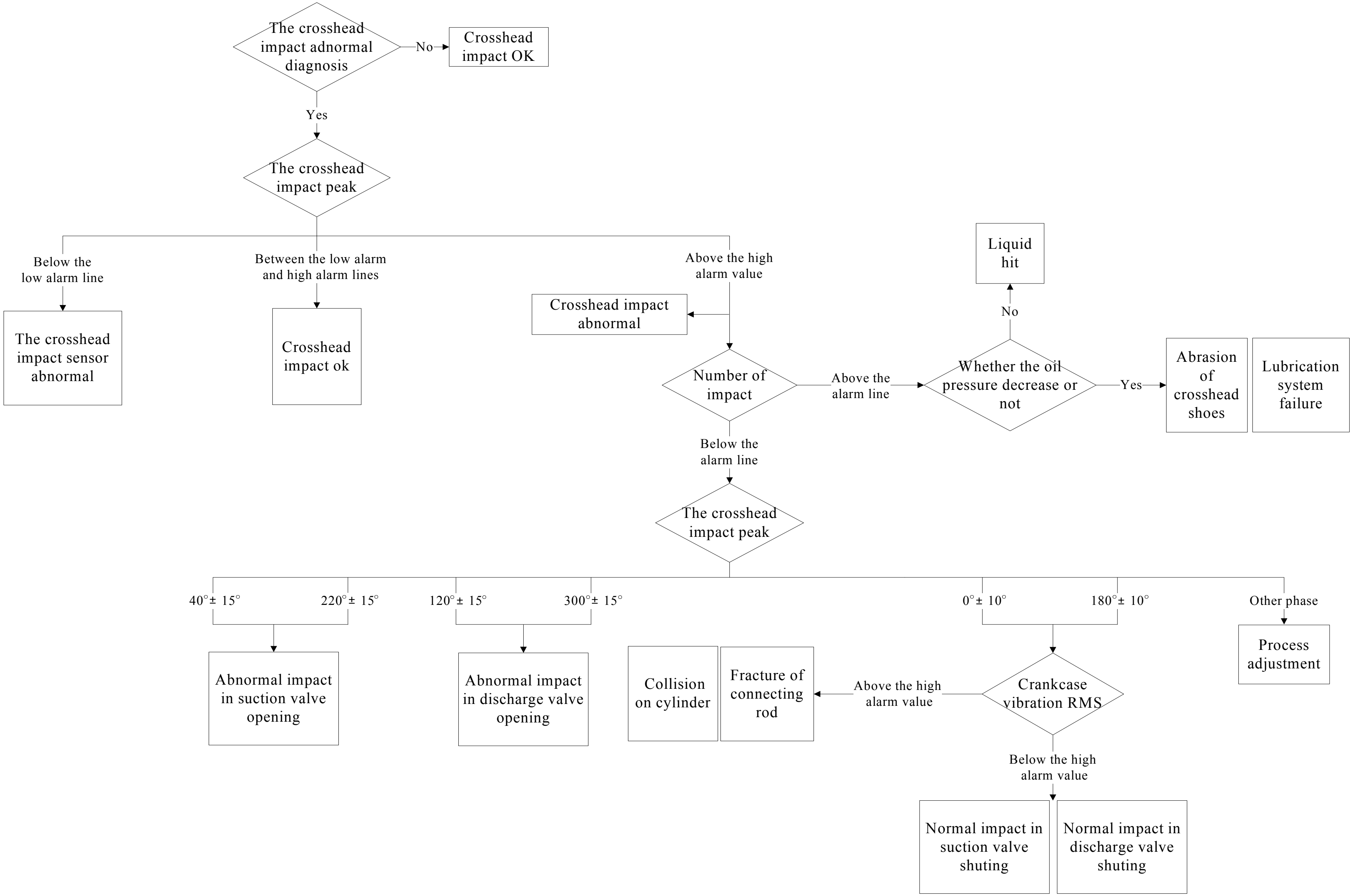

Fig.8 Diagnosis logic of crosshead impact

4. Development and applications

4.1 Development of the ES

On the basis of diagnosis logic, we developed an ES and integrated it into an online monitoring system for different reciprocating compressors. The ES mainly includes four parts as follows：

(1) Configuration software

Configuration software is an important part of a rule-based reasoning ES. The reasoning engine will diagnose automatically according to the configuration of rules, and the diagnosis will follow the logic of the human experts. The users can modify the knowledge base according to the operating situations by the configuration software, to improve the accuracy of diagnosis result. The knowledge base, which includes the equipment information base, is the core part of the ES of reciprocating compressor. The knowledge base includes the diagnosis task base, the fault base, the rule base, the fact base, the fact property base, and the inspection and maintenance recommendation base. Users can create, modify and delete all the knowledge through the configuration software.

(2) The acquisition and calculation software

The acquisition and calculation of knowledge within different conditions can be divided into automatic mode and manual mode.

- Automatic mode

The ES has been integrated into the online monitoring system. Data of online monitoring system can be acquired by the ES. The acquisition and calculation software will calculate the parameters based on the properties of facts, such as the peak value and phase of impact vibration of crosshead and cylinder, the temperature of valves, the displacement changes of piston rod. According to the calculation results, the values of fact properties in knowledge base will be assigned to activate the response rules automatically.

- Manual mode

Users can finish the assignment through the man-machine interface manually. The manual mode is suitable for that the online monitoring system is unable to get the information of working conditions of a reciprocating compressor. For example, the pressure of lubrication system and the load of the compressor will not be monitored by the online monitoring system. The manual mode is a good choice to deal with these problems. Additionally, if the reciprocating compressor is not installed with the online monitoring system, the users can assign all the values of the fact properties in the ES knowledge base.

(3) The reasoning engine

The reasoning engine is the brain of the fault diagnosis ES of reciprocating compressor. The engine uses the input data of fault status, calls the knowledge in knowledge base, infers according to the strategies, and gets the fault diagnosis results.

The rule-based reasoning method summarizes the experience of the diagnosis experts, builds the rules, infers through experience and knowledge. It has a clear premise and will obtain certain results. The reasoning process of the ES was completed through pattern matching, in which the facts refer to the compressor information and the characteristics of the monitoring data, the rules refer to the judgement of “IF...THEN...”. The engine constantly checks the facts and rules of the knowledge base to search the judgement which has been satisfied. In rule-based reasoning, this process is repeated. In general, the facts list will be modified to add new facts or to delete the old facts. In each cycle, as the facts adding and removing, the judgements which have been satisfied must be updated.

In Fig.9, the rule-based reasoning model of the ES has been shown.

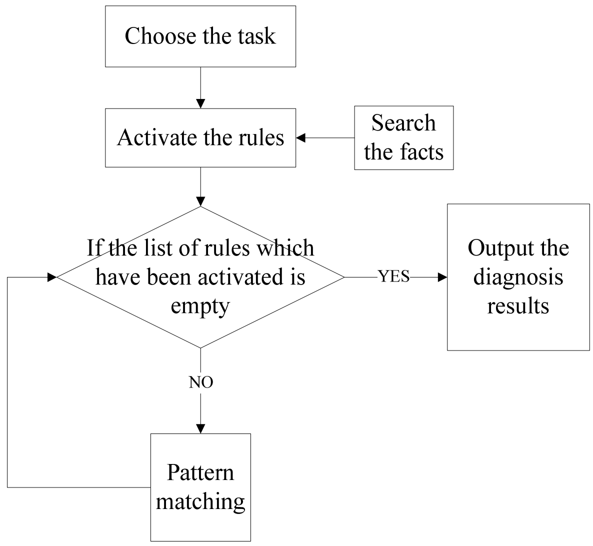

Fig.9 The rule-based reasoning model

(4) The operation interface

As a part of the online monitoring system, the ES has an independent analysis and diagnosis interface. In this interface, the users can search the historical data of the operation of the compressor to get information of alarm and abnormal tendency, as shown in Fig.11, Fig.13 and Fig.14. The data include: piston rod displacement, crank case vibration, crosshead impact, valve temperature, the operating speed. Once there are alarms, users can activate the ES to do automatic or semi-automatic diagnosis.

The ES also can be activated independently to the online monitoring system. There are few reciprocating compressors having been installed with the online monitoring system. In order to satisfy the diagnosis requirements in practical applications, we have developed the independent man-machine interface used for manual diagnosis.

4.2 Applications

At present, the ES has been used for a good part of the reciprocating compressors in the refineries of China. We selected two typical diagnosis cases to describe the practical application.

4.2.1 Abrasion fault of piston rings and supporting rings

As the reciprocating motion of piston, abrasion fault of piston rings and supporting rings always happen in realistic operation. This case involves a gas reciprocating compressor at a plant of Petrochina in 2011. The compressor information is shown in Table 3. As shown in Fig.10, many transducers have been installed on the compressor.

Table 3 Compressor information for first case

Unit number	Unit type	Operating speed	Discharge pressure	Drive
K203	horizontal, 2-cylinder	330 r/min	2 MPa	motor

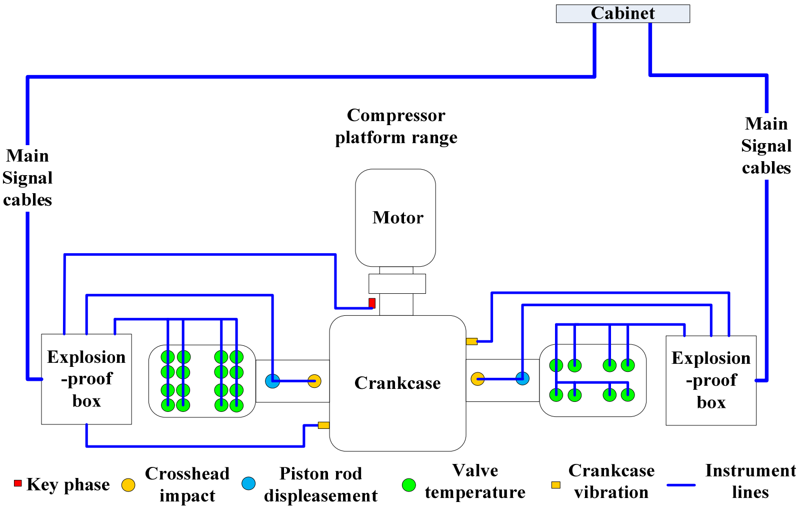

Fig.10 Schematic diagram showing transducer positions

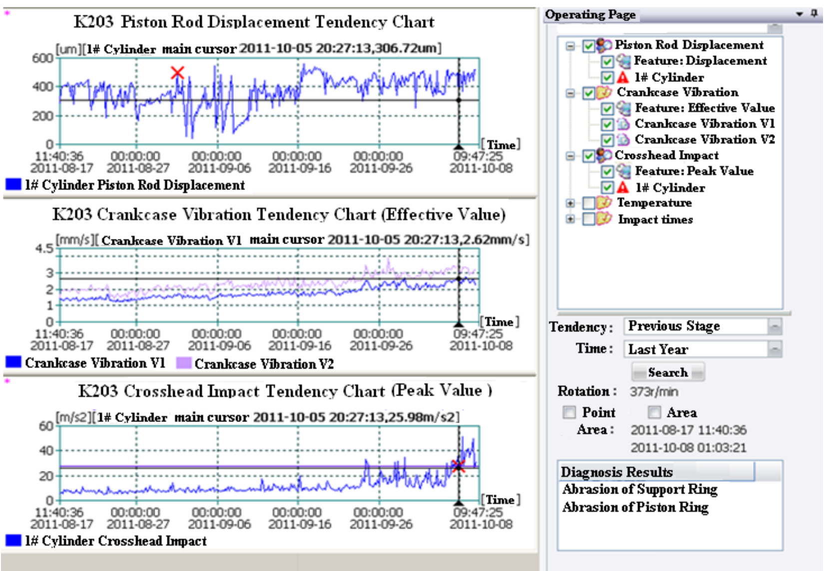

Fig.11 Fault diagnosis results

We can see from the historical trends shown in Fig.11 that the piston rod drop of cylinder No.1 gradually increased by more than 500 μm from July 17 to September 1, exceeding the alarm line. The crosshead impact of cylinder No.1 increased unexpectedly after September 20 and first exceeded the alarm line on October 5. We selected the data from July 17 to October 8 for automatic diagnosis and found that the support rings and piston rings had serious abrasion. After a maintenance check, we found that the fault was consistent with the diagnosis result.

4.2.2 Fracture fault of valve

The valve faults are the most common faults of reciprocating compressor. This case was about a gas reciprocating compressor at another plant of Petrochina in 2011. The compressor information is shown in Table 4. As shown in Fig.12, valve temperature and crosshead impact transducers have been installed on the compressor.

Table 4 Compressor information for second case

Unit number	Unit type	Operating speed	Discharge pressure	Drive
C301	vertical, 4-cylinder	750 r/min	4 MPa	motor

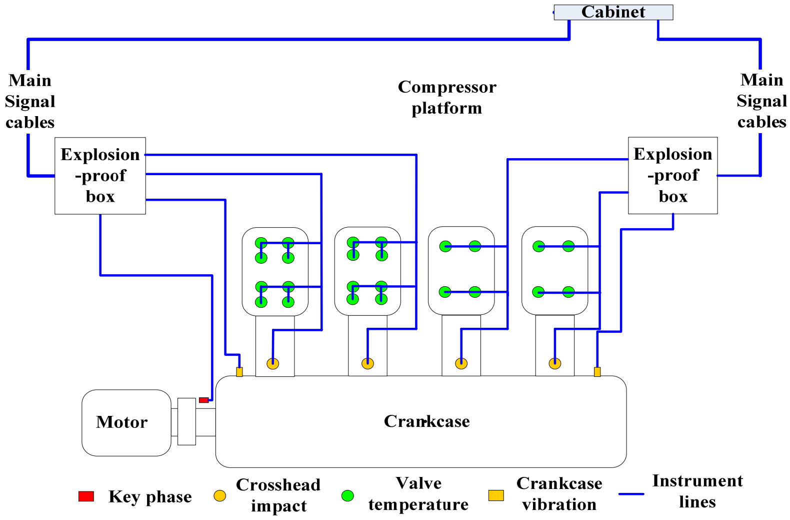

Fig.12 Schematic diagram showing transducer positions

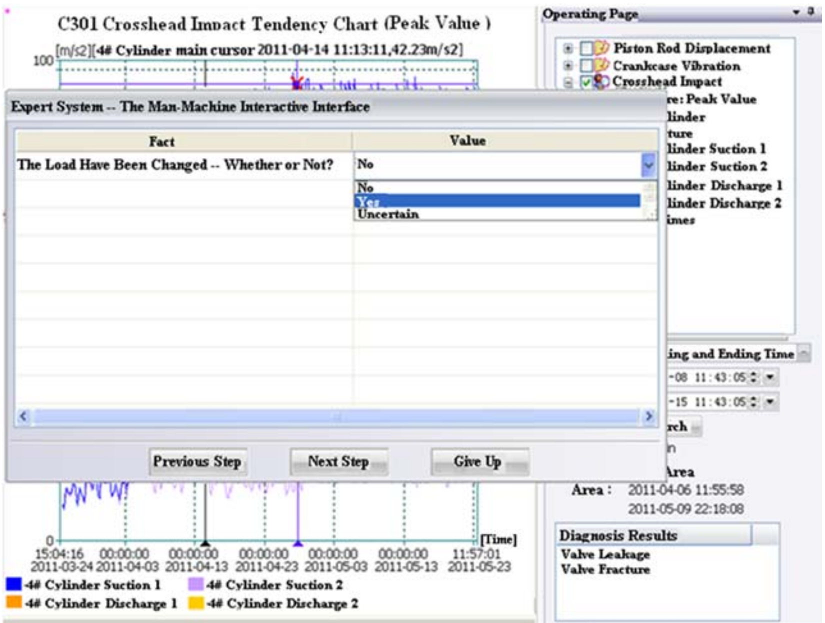

Fig.13 Semi-automatic mode for diagnosis

Because the valve faults are often closely related to operating condition changes of the compressor, we selected the semi-automatic mode to diagnose the fault as shown in Fig.13. From the historical trends, we found that the temperature of suction valve No.1 of cylinder No.4 increased to the alarm line from March 25 to April 27. At the same time, the crosshead impact abnormally increased too. We selected the semi-automatic mode to get information on the compressor's load. We should choose one value for the fact:" The Load Have Been Changed – Whether or Not". The diagnosis result was that suction valve No.1 was broken as shown in Fig.14, consistent with the maintenance result.

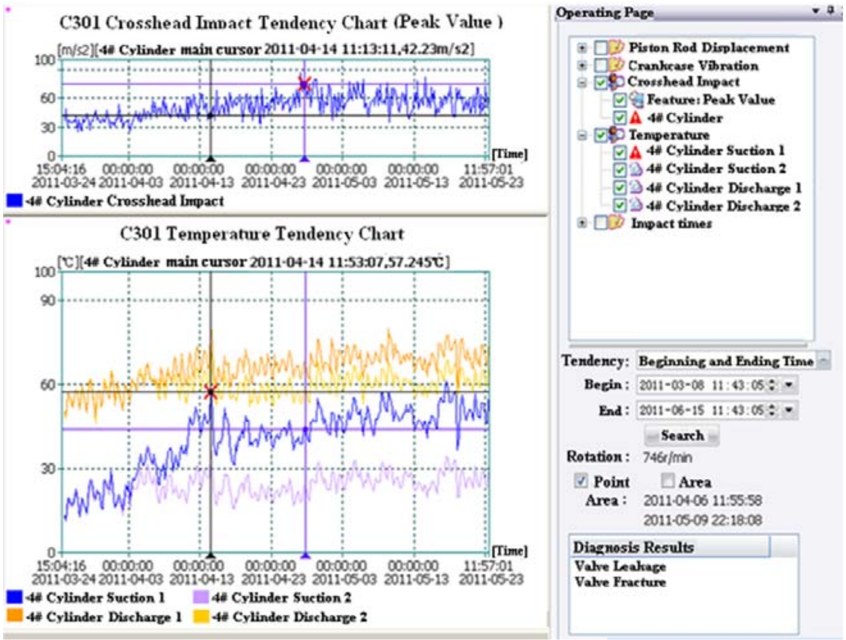

Fig.14 Fault diagnosis results

5. Conclusions

A fault diagnosis ES integrated with an online monitoring system for reciprocating compressors is urgently needed to improve the level of fault diagnosis and to avoid security incidents in domestic processing plants.

As the first fault ES for reciprocating compressor used in domestic industries, the ES has fully considered the uniqueness of reciprocating compressor fault diagnosis in the design process of the overall structure, the knowledge base structure, and the intelligent fault diagnosis logic. With several years of experience on reciprocating compressor actual fault diagnosis, we presented and applied the composite diagnosis concept based on the integration of multi-source signal, designed the relatively independent fault diagnosis rule packages, and established the ES rule base.

With the verification of different actual faults, this ES can diagnose the common faults of reciprocating compressor and auxiliary systems accurately and provide direct and reliable assistance to industrial plants to develop condition-based maintenance.

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