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Fault Diagnosis System for Reciprocating Air Compressor Based on Support Vector Machine

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***Abstract*—Reciprocating air compressor's structure is complex, and it has various excitation sources when running, moreover, there are a few fault samples in actual fault diagnosis, so it is difficult to implement intelligent diagnosis. Support Vector Machine based on Statistical Learning Theory just overcomes this deficiency, and it provides a new approach for diagnosis technology to develop into intelligent diagnosis. The application of Support Vector Machine on fault diagnosis for reciprocating air compressor and a concrete implementation scheme are discussed in this paper. A fault diagnosis system for reciprocating air compressor is established, and the vibration signals of rolling bear in reciprocating air compressor's crankcase are simulated in a test-bed. The test result shows that this system has strong adaptability for reciprocating air compressor diagnosis of a few samples and could recognize fault rapidly and accurately.**

***Index Terms*—reciprocating air compressor, Support Vector Machine, fault diagnosis**

I. Introduction

Air compressor is one of the main large-scale equipments in coal mine and it is charged with the task of power supply for pneumatic machinery in the whole mine. Once a fault, it will not only affect the production, but also bring hidden dangers to the mine safety, so it is of great significance to implement fault diagnosis for air compressor [1].

Reciprocating air compressor is applied most commonly in the mine air compressor. Because of its complex structure and various excitation sources, it is difficult to implement fault diagnosis. Although some research has been done and some research results have been made [2], because of imperfect on theoretical studies or the complexity in actual operation, it's still difficult to meet the practical needs in field. Diagnostic method based on knowledge is a promising approach. However, the inadequate number of the fault samples severely restricts the practical promotion of this technology. But for reciprocating air compressor, a fault will result in great economic losses, so it will not have a lot of fault samples. Therefore, these excellent diagnostic methods in theory are difficult to have good performance in practical application. The birth of statistical learning theory and support vector machine has opened a new approach to solve this problem

II. Theory and Algorithms of Support Vector Machine

Support Vector Machine method (Support Vector Machine) is based on VC dimension theory of statistical learning theory and the principle of minimum structural risk. According to the limited information of samples, the best compromise is found between the model complexity and the learning ability to get the best promotion ability [3].

SVM develops from the optimal classification surface under the condition of linearly separation, and its basic idea can be shown by the two-dimensional case in Fig.1. Given that sample points x_i of classification can be divided into two categories, and its corresponding sample set is (x_i , y_i), among which the y_i corresponding x_i belonging to the first category is positive and the y_i corresponding x_i belonging to the second category is negative. Classification line is a classification criterion that is able to correctly separate the two types (training error rate is 0). Normalization for the sample set, given that the classification surface is $\omega \cdot x + b = 0$, so

$\omega \cdot x_i + b > 0$ x_i belonging to the first category, $y_i = 1$

$\omega \cdot x_i + b < 0$ x_i belonging to the second category, $y_i = -1$

In figure 1, solid points and the dots are respectively on behalf of a class of samples. H is the optimal

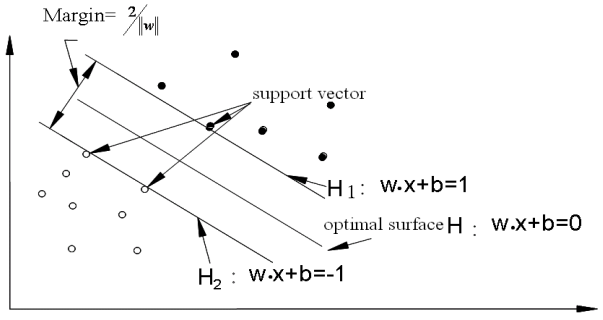

Fig.1 Two dimension SVM

classification surface. H1 and H2 are respectively the straight-lines through the nearest samples from the classification surface and parallel to the classification surface. The distance between them is called margin (margin). The so-called optimal classification surface is the surface that is not only requested to correctly (Training error rate is 0) classify the two types, but also the margin is largest. According to Vapnik's statistical learning theory, given that the equations of H1 and H2 respectively are $w\cdot x+b=1$ and $w\cdot x+b=-1$, so there is the formula (1):

$\omega \cdot x_i + b \geq 1$ x_i belonging to the first category, $y_i = 1$

$\omega \cdot x_i + b \leq -1$ x_i belonging to the second category, $y_i = -1$ (1)

Formula (1) can be expressed as $y_i(\omega \cdot x_i + b) \geq 1$, at this time the margin is the distance between $\omega \cdot x + b = 1$ and $\omega \cdot x + b = -1$: $2 / \| \omega \| = 2 / \sqrt{\omega^T \omega}$, to make the largest margin is equivalent to make the smallest $\frac{1}{2}\omega^T \omega$. Therefore, the classification surface determined by ω and b meeting the formula (1) and the smallest $\frac{1}{2}\omega^T \omega$ is the optimal classification surface, and the training sample points on H1 and H2 are the support vectors.

III. T Fault Diagnosis System design for Reciprocating Air Compressor Based on Support Vector Machine

The system consists of three functional modules: data acquisition module, feature extraction module and SVM diagnostic module. Data acquisition module acquiring real-time data is completed by the condition monitoring software developed on Kingview. Feature extraction module extracting feature of signal data is used to analyze signal in the way of time series modeling (AR module). SVM fault diagnosis module diagnoses and outputs fault results. The composition principle of early warning software of fault diagnosis is shown in Fig. 2.

According to the function, the software of system can be divided into five parts, data preparation area, feature extraction area, model training area of SVM, fault forecast area and data display area, and the interface is shown in Fig. 3.

Data preparation area has the button to read data and the button to save data, its function is to choose the original data to be diagnosed and save it into text files, and the data can be displayed in data display area.

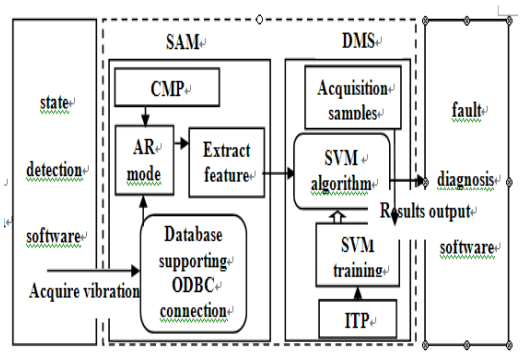

Fig.2 The composing of the fault

Comments: Signal acquisition module(SAM)、

C] Input training parameters(ITP) 、Diagnosis module of SVM(DMS)

Feature can be extracted from the data preserved in the previous step through clicking the "AR feature analysis" in the feature extraction area. Furthermore, the time domain and frequency domain waveform can be drawn, and the eigenvalue calculated can be displayed.

Model training area of SVM includes selecting the training samples, seeking the optimization parameters and training model. The part of selecting the training samples: ① choose the training samples: display the path of training samples in the column at the bottom through

Fig.3 The main page of diagnosis system

choosing ②read the training samples: read the selecting training samples data and display them in the data display area ③detect the data normalization: judge whether the data need to be normalized ④normalize the data: scale and normalize the data which need to be normalized. The part of seeking optimal parameters of SVM: ①seek to optimize the parameters: try to find the optimal parameters C and γ of classification for the sample data ②optimize the structure of the parameters: display the optimized C and γ and their corresponding classification accuracy in the data display area ③choose the training parameters area according to the optimization parameters: input appropriate training parameters C and γ into the text box according to optimized parameters. The SVM training part of model: get the training model through training the samples according to the offered parameters.

Fault forecast area's main function is to predict fault for the data samples to Therefore, the fault diagnosis method based on SVM is fast and accurate.acquired data according to the model after training ② classification result: input the prediction type number into the text box ③ fault type: output the fault type of the corresponding type number.

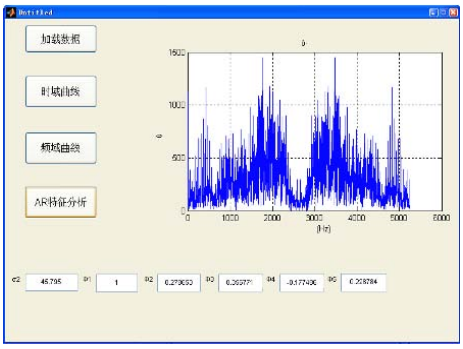

Fig.4 Feature extraction

IV. Experiment and Analysis

In this paper, some experiments were carried out in a test-bed simulating crankcase bearing fault of reciprocating air compressor. In this test, 5 set of vibration data were respectively acquired from the normal bearing, the bearing with both inside and outside ball pitting and the bearing with outside ring pitting, the acquisition frequency was 3K Hz, the number of acquisition point is 2048. And then, AR module features were respectively extracted from each set of data, at the same moment the time domain and frequency domain waveforms can be drawn. Interface of extraction calculation feature is shown in Fig. 4.

5 sets of feature data of each fault type were respectively acquired after calculating, as shown in table 1. 4 sets of feature data from each type, ie 12 sets of feature data, were retrieved as the training samples of SVM, and the remaining set of feature data from each type (a total of 3 sets) were retrieved as the samples to be diagnosed.

4 sets of sample data (pattern vector) of each type (3 types) were input into SVM module and trained, and the classification result could be obtained after training and saved as model document with the model extension and used as the basis for fault diagnosis. And then the classification result could be trained following the steps introduced in the block of SVM diagnostic module, and after that the fifth set of samples would be diagnosed, then the result would be output, as shown in Fig. 5.

A sample of any type of fault could be diagnosed as well, and the correct diagnosis result could be obtained. The fault diagnosis method of SVM proved by the test is effective. Furthermore, the number of samples has a very small influence on the training speed of SVM. Therefore, the fault diagnosis method based on SVM is fast and accurate.

Fig.5 Show test result

Type 1（Both inside and outside faults in balls of bearing）

	$\sigma_a^2(p)$	ϕ_{p1}	ϕ_{p2}	ϕ_{p3}	ϕ_{p4}	ϕ_{p5}
1	45.7950	0.27865	0.35677	-0.17749	0.22878	-0.15079
2	48.0709	0.27863	0.3619	-0.20473	0.25232	-0.21187
3	42.8278	0.26504	0.4306	-0.18399	0.31071	-0.11472
4	46.8947	0.23803	0.36111	-0.18694	0.25631	-0.14399
5	48.0967	0.28824	0.42253	-0.20653	0.26332	-0.19215

Type 3（Outside ring fault of bearing）

	$\sigma_a^2(p)$	ϕ_{p1}	ϕ_{p2}	ϕ_{p3}	ϕ_{p4}	ϕ_{p5}
1	9.9778	0.26529	0.68048	-0.35968	0.22959	-0.30789
2	12.3833	0.44023	0.67617	-0.29151	0.056495	-0.4115
3	9.317	0.42802	0.63736	-0.35713	0.1057	-0.38715
4	8.8624	0.36463	0.57436	-0.38969	0.16901	-0.39775
5	9.5211	0.36392	0.62501	-0.35259	0.11018	-0.42904

Table 1 Parameter of AR model

Type 2（Normal）

	$\sigma_a^2(p)$	ϕ_{p1}	ϕ_{p2}	ϕ_{p3}	ϕ_{p4}	ϕ_{p5}
1	0.077373	-0.38122	-0.22471	-0.42157	-0.16838	-0.02415
2	0.092524	-0.30798	-0.12612	-0.45255	-0.22995	-0.071001
3	0.11306	-0.29575	-0.062628	-0.55416	-0.25343	-0.084958
4	0.13784	-0.16455	-0.19295	-0.37764	-0.44293	-0.036126
5	0.10605	-0.33497	-0.10543	-0.50687	-0.22704	-0.016204

V. Conclusion

The air comp ith examples, proving that the method has good classification ability with a small number of samples. The application of SVM provides a new approach on fault diagnosis for reciprocating machinery to develop into the intelligent direction. However, the application and research of SVM in the field of fault diagnosis is still in its early stage, there is a lot of work on fault diagnosis based on SVM for reciprocating machinery to be in-depth studied. Through further study on relative problems, the application of SVM method in the field of fault diagnosis will have a broader prospect.

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