Research on Fault Diagnosis of Centrifugal Compressor Based on Ant Colony Algorithm

Qingbo Ran [a, *], Jialiang Miao [b] and Ze Ma [c]

College of Mechanical Engineering, North China University of Science and Technology, Hebei, China.

[a]ranqingbo@126.com, [b]483127675@qq.com, [c]2560566719@qq.com

Abstract

Centrifugal compressor as a kind of rotating machinery, the working condition of the rotor has a great influence on the stable operation of the compressor. Mainly to the oil whirl, surge, rotor imbalance of three kinds of typical faults of centrifugal compressor as the research object in this paper, based on the radial vibration signal of compressor fault condition analysis, the research on the vibration characteristics, and as a basis for diagnosis, further study the application of ant colony algorithm in fault diagnosis of centrifugal compressors. This paper uses MATLAB to establish model of ant colony algorithm, and the simulation experiment, analyze the characteristics of the measured vibration data, the fault diagnosis of rolling bearing, verify the feasibility of ant colony algorithm in fault diagnosis of rotating machinery, study the diagnostic characteristics and diagnostic methods to further optimize the extension, analysis and fault diagnosis of centrifugal compressor actual fault conditions, comparing the diagnosis results with the actual situation, the diagnosis result is good, the program is stable and accurate.

Keywords

Centrifugal Compressor,Fault Diagnosis,Ant Colony Algorithm.

1. Introduction

Centrifugal compressor is widely applied in industrial field. As an important power equipment, its working state and operation reliability have important influence on the whole production system. With the equipment manufacturing and production process improvement of centrifugal compressor in the working environment is more and more severe challenges, high temperature and high pressure, large load, corrosion and other environmental factors bring to the compressor on-line monitoring and fault diagnosis system[1], to ensure efficient and reliable operation of the compressor become the goal of many scientific workers. Intelligent fault diagnosis based on ant colony algorithm is a method of mechanical fault diagnosis [2], it uses ant colony algorithm principle to deal with the analysis of the corresponding mechanical parameters, through research, analysis of the current mechanical working condition, so as to realize the prediction and discovery of mechanical failure. Ant colony algorithm has a strong ability of pattern recognition [3]. It can be used to deal with the vibration signals of equipment under different working conditions, and it can achieve the purpose of fault diagnosis. This paper verifies the actual diagnosis effect of ant colony algorithm in mechanical fault diagnosis, and applies ant colony algorithm to cluster analysis of centrifugal compressor failure, and studies its practical application effect [4].

2. Fault Diagnosis Method for Centrifugal Compressor

2.1 Main Fault Types of Centrifugal Compressor

During the operation of centrifugal compressor, there are various reasons for malfunction and different faults. The main faults are rotor imbalance, rotor misalignment, rotor crack, oil whirlpool, and surge and so on [5].

(1) Rotor unbalance

Rotor imbalance refers to the uneven distribution of rotor mass around its rotating shaft, resulting in unbalanced rotor. The main reason is that the rotor dynamic balancing accuracy is not up to standard, impeller fouling or corrosion, rotor bending and so on.

(2) The rotor is not in the middle

The rotor misalignment refers to the inclination or offset of the axis of the compressor rotor and the axis of the output shaft of the gearbox.

(3) Rotor crack

Metal materials will produce metal fatigue during long time operation. Metal fatigue will cause cracks in the equipment, and even cause breakage and breakage of the components, which will seriously threaten the safety of the equipment.

(4) Oil film vorticity

Oil whirling is the rotation of rotor journal when it is running at high speed, and it also revolves around another balancing position of the journal, which is mainly caused by the excitation effect of lubricant oil film force.

(5) Surging

When the centrifugal compressor runs, if the air intake is less than the normal working range of the compressor, the surge will occur. The change of pressure in the pipe system, the change of gas temperature, and the operation of irregularities will produce compressor surge [6].

2.2 Fault Diagnosis Method of Centrifugal Compressor

With the development and progress of centrifugal compressor, centrifugal compressor fault diagnosis from the initial simple maintenance now developed into set of on-line condition monitoring and trend analysis and fault prediction of integrated fault diagnosis system of centrifugal compressor is a kind of modern theory of comprehensive use of technology, which mainly comprises four parts: data collection, data analysis and processing, fault diagnosis, decision intervention.

3. Ant Colony Algorithm

3.1 Basic Concepts Of Ant Colony Algorithm

Ant colony algorithm is the inspiration from the real ant colony to find the best path principle. In ant colony algorithm, information about path is composed of pheromone track, and it is the medium for ants to communicate with each other. The first ant left the pheromone on the ground, and the pheromone became a track along with its footprints. The movement of an ant is random. It can identify the information trajectories left by the ants, select a highly concentrated path, and use their information to enhance the trajectory [7].

Figure 1 demonstrates the process of the ant colony screening the shortest path. Among them, (a) means that ants walk between A and E. (b) indicates that a barrier suddenly appears, ants can bypass or go along the way; (c) indicates that ants choose the shortest path after path optimization.

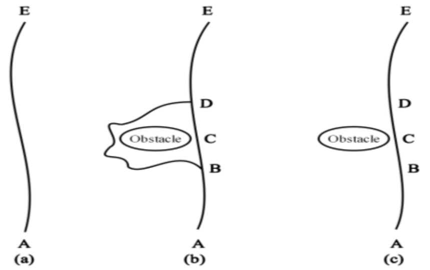

Figure 1. Ant colony path optimization

To increase the computational complexity of the individual according to the demand, the algorithm can avoid the local optimal and improve the adaptability of the system. The pheromone left by the feedback rules makes it easy for the following ants to find the first path to the target ant, but it may not be the optimal solution. If we don't set up the natural reality model as the goal and find the path effectiveness as the goal, we need to increase the complexity of individuals, which will lead to the increase of computation. This requires us to find out the balance between the individual ability and the amount of calculation, so as to ensure the applicability of the ant colony optimization.

3.2 Ant Colony Clustering Algorithm

Clustering analysis is a traditional multivariable statistical classification method, which is used to classify the collected objects, so that the same population has high similarity, while different groups are highly different. Clustering analysis is applied in many areas, such as image processing, data detection, pattern recognition, medical diagnosis and so on, and plays an important role in these fields. Because ant colony algorithm can be applied to all kinds of optimization problems, it can be used to solve the problem of clustering analysis. Clustering analysis based on ant colony algorithm on, there are two main categories: first, the number of clusters is known; second, the clustering number is unknown, in the research on the fault diagnosis methods, the main use of the first class, the number of known ant colony clustering algorithm [8].

For clustering analysis, we need to construct pheromone matrix, and have N samples to be classified, and then divide them into M classes. Pheromone is a N×M matrix updated continuously during iteration.

At the initial stage, each pheromone value τ will be initialized, that is, at the beginning of cluster analysis, each pheromone value is τ_0, τ_{ij} indicating that the sample i is assigned to the pheromone value of the class j.

The known sample set {X} has N samples and M pattern classification $\{S_j, j=1,2,\cdots,M\}$ each sample has n characteristics. The sum of the distance between each pattern sample and the cluster center is minimal as the objective function, and the mathematical model expression is as follows:

$$\min J(\omega,c)=\sum_{j=1}^{m}\sum_{i=1}^{N_j}\sum_{p=1}^{n}\omega_{ij}\parallel x_{ip}-c_{jp}\parallel^2$$

$$c_{jp}=\frac{\sum_{i=1}^{N_j}\omega_{ij}x_{ip}}{\sum_{i=1}^{N_j}\omega_{ij}}(j=1,\cdots,M;P=1,\cdots,n)$$

$$\omega_{ij}=\begin{cases}1,\text{sample i belongs to the j class}\\0,else\end{cases}(j=1,\cdots,M;i=1,\cdots,N_j)$$

In this, xip is the p property of the i sample, and cjp is the p attribute of the center of the j class.

In each ant colony update, the ant will divide the N samples into an approximate partition of the m class through the indirect communication of pheromone. When the M ants are all iterated over, the local search is added to further improve the quality of the partition, and then the pheromone matrix is updated according to the quality of the partition. These steps are circulated until the cycle conditions are finally met and the cycle is finished [9].

The update of pheromones requires a process that uses T to represent the number of iterations. Each ant relies on the information provided by the T-1 iteration to implement the classification. The pheromone matrix inherited in this iteration is the initial pheromone matrix. For each sample made by every ant, the system generates a random number q. The probability q0 (0<q0<1) is defined in advance. There are two ways to update every ant according to the probability q0.

If the random number is less than q0, and select samples with maximum pheromone for sample belonging to the class.

(2) if the random number is greater than q0, according to the transition probability of randomly selected samples to convert class. The conversion probability of the calculated sample i to the class j is pij:

$$p_{ij} = \frac{\tau_{ij}}{\sum_{i=1}^{M} \tau_i} (j = 1, \cdots, M)$$

Here τ_{ij} is the standardized pheromone between the sample i and the class j. Each sample i selects the class to be converted to according to the transformation probability distribution[10].

The solution sets corresponding to all ants are calculated according to the above method. In order to improve the efficiency of finding approximate solutions by ants in ant colony algorithm, many ant colony algorithms have been improved, and local search has been added. Especially when the heuristic information of problem domain is not easy to obtain, adding local search can help to find better solutions[11].

4. Fault Diagnosis Based on Ant Colony Algorithm

4.1 Frequency Domain Characteristic Analysis

Calculation of frequency characteristic parameters under normal condition of centrifugal compressor training data frequency characteristic parameters are shown in table 1, the surge of centrifugal compressor under the condition of training data frequency feature parameters are shown in table 2, the oil whirl condition of centrifugal compressor training data frequency characteristic parameters are shown in table 3, the rotor unbalance conditions of centrifugal compressor training data in frequency domain the characteristic parameters are shown in table 4. This set of data is used for the training of ant colony algorithm.

Table 1. Frequency domain characteristic parameters under normal condition

P1	P2	P3	P4	P5	P6	P7
8442.3143	17798.899	0.474316	112.41526	0.0138312	0.0003910	823.75271
9392.9944	19122.568	0.491199	114.10522	0.0125091	0.0003241	868.32027
8928.5529	18106.580	0.493110	110.14723	0.0124901	0.0003394	860.08342
8776.2958	18441.684	0.475894	111.32843	0.0139324	0.0003883	818.17738
9550.9169	18603.091	0.513404	122.14908	0.0100092	0.0002349	1019.9527

Table 2. Frequency domain characteristic parameters under surge condition

P1	P2	P3	P4	P5	P6	P7
7881.6450	14554.995	0.5415	187.6630	0.0051	0.0001	2718.3200
7324.5240	13974.019	0.5242	178.4480	0.0061	0.0001	2368.3200
7678.3680	14569.127	0.5270	178.9320	0.0060	0.0001	2524.3300
7660.9990	14476.070	0.5292	194.1620	0.0054	0.0001	2711.3000
7799.3180	14385.185	0.5422	172.2090	0.0057	0.0001	2408.5000

Table 3. Frequency domain characteristic parameters of oil film under the whirl condition

P1	P2	P3	P4	P5	P6	P7
7016.6654	16615.743	0.4223	190.4400	0.0116	0.0002	1400.9988
6329.5066	14250.150	0.4442	208.1543	0.0087	0.0002	1877.2125
7413.1551	15631.151	0.4743	166.8602	0.0093	0.0002	1417.9789
5620.5595	14438.404	0.3893	245.3337	0.0105	0.0002	1916.2218
7167.7273	14909.123	0.4808	140.6233	0.0101	0.0002	1246.4353

Table 4. Frequency domain characteristic parameters under unbalanced rotor condition

P1	P2	P3	P4	P5	P6	P7
3885.2357	16668.287	0.2331	307.0645	0.0245	0.0008	1336.2940
3478.0098	15794.671	0.2202	402.4951	0.0201	0.0005	1926.7530
4316.8753	14290.102	0.3021	249.9797	0.0175	0.0005	1471.7220
3594.8886	17119.192	0.2100	408.5475	0.0230	0.0007	1677.5660
4139.3002	17238.165	0.2401	324.8635	0.0224	0.0007	1465.9750

4.2 Ant Colony Training

The frequency domain characteristic parameters comparison under four cases, P1, P2, P7 in the numerical difference respectively reach 103, 104 and 105, far more than the other parameters in the numerical difference in ant colony operation process, P1, P2, P7, the difference is more obvious, more likely to be sensitive to ant colony recognition. Therefore, P1, P2, P7 three parameters as inputs to the ant colony program. The three eigenvalues calculated from the first measured data are subdivided into the ant colony training program. After training and debugging, some of the pheromone matrices with 800 iterations are calculated as follows:

Table 5. Ant clustering training pheromone matrix based on frequency domain analysis

Number	Normal	Surge	Oil film vorticity	Rotor unbalance
1	0.1119	0.0000	0.0000	0.0000
2	0.1119	0.0000	0.0000	0.0000
⋮	⋮	⋮	⋮	⋮
19	0.0000	0.0000	0.0000	0.1119
20	0.0000	0.0000	0.0000	0.1119

4.3 Diagnosis Result Verification

The eigenvalues P1, P2 and P7 calculated from the second measured data are introduced into the ant colony pattern recognition program. After iterating for 800 times, the pheromone matrix is obtained, as shown in table6.

Table 6. Result verification

Number	Normal	Surge	Oil film vorticity	Rotor unbalance
1	0.9644	0.0000	0.0000	0.0000
2	0.9644	0.0000	0.0000	0.0000
⋮	⋮	⋮	⋮	⋮
19	0.0000	0.0000	0.0000	0.9644
20	0.0000	0.0000	0.0000	0.9644

In twenty samples, 1 samples were identified and 19 samples were identified correctly. The correct rate of fault recognition based on frequency domain analysis was 95% in centrifugal compressor fault diagnosis.

5. Conclusion

This chapter mainly studies the application of ant colony algorithm in centrifugal compressor fault diagnosis. Ant colony algorithm is applied to pattern recognition and fault diagnosis for centrifugal compressor under normal working condition, surge condition, oil whirling condition and rotor unbalanced condition. The time-domain analysis and frequency-domain analysis are used to process the vibration signal preliminarily, and the time domain characteristic parameters and frequency domain characteristic parameters are calculated, which is used as the input of the ant colony program. Through training, the clustering center ant colony algorithm clear and accurate classification and identification verification of ant colony trained, are consistent with the pattern recognition pheromone matrix and training matrix, diagnosis of the 20 sample accuracy rate reached more than 90%, has a certain practical value.

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