

Gear Fault Diagnosis Based on BP Neural Network

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Abstract: Gear transmission is more complex, widely used in machinery fields, which form of fault has some nonlinear characteristics. This paper uses BP neural network to train the gear of four typical failure modes, and achieves satisfactory results. Tested by using test data, test results have an agreement with the actual results. The results show that the BP neural network can effectively solve the complex state of gear fault in the gear fault diagnosis.

1. Introductions

With the development of machinery manufacturing industry, it is put forward to higher requirements for the safety, reliability of equipment operation. The gears are widely used in machinery and equipment as the transmission components, often by high-speed, heavy and large impact force, so it is easy to crack and collapse teeth (broken teeth) phenomenon. For these phenomena, if its faults are not able to be checked in time, the serious hidden danger will be extremely easy to cause. Therefore it is very important significance to judge the fault of gear. To understand the gear fault, we need to understand the running status of the running state, signal mainly depends on its operation process transfer out, and time domain, the frequency domain analysis methods to get the signal feature.

In order to improve the accuracy and speed of the gear fault diagnosis, neural network, expert system, Bayes method, support vector machine technology in this area has been widely used. In this paper, using theoretical analysis of traditional signal and test results, the application of BP neural network diagnosis gear fault. This method is mainly a predetermined number of classification standards and types, through a large number of known samples of "learning" to find out the law, be discriminated model, and then use another set of known belonging to "unknown samples to test the mathematical model. If the test result is satisfactory, we can classify the unknown sample actually.

2. The failure mechanism of the gear

Gear fault can be divided into two kinds, one kind is bearing damage, imbalance, forces, gear eccentricity, shaft bending, another kind is the fault of gear is formed in the process of transmission, the broken teeth, pitting corrosion, wear and scuffing. We mainly discuss the fault caused by the gear transmission in this paper. The common faults of gear tooth, generally occurs in the root, mainly because of the tooth root stress concentration phenomenon exists. Broken tooth form mainly has three kinds, namely fatigue fracture of teeth, overload tooth broken, local tooth broken. The pitting corrosion damage in the form of closed gear transmission is common, often appearing in the root



surface near the section line. The reason is that the surface fluctuation cycle contact stress exceeds the material's ultimate stress of tooth, its performance in the form of initial pitting corrosion and expansion. Tooth wear is due to the working surface of metal particles, dust and sand into the teeth. Tooth surface rough, poor lubrication is another cause of tooth wear. In addition, the misalignment, shaft wear and tensional resonance, can cause large changes in the torque of the gear meshing point, or to make more impact, will accelerate the gear wear. After gear wear, tooth thickness becoming thinner, tooth profile becoming deformation, lateral gap becoming large, will cause the gear dynamic load increase, not only to increase the vibration and noise, but also likely to lead to broken teeth. Tooth bonding (scratches) is due to the rupture of oil film in sliding contact tooth surfaces, direct contact with the tooth surface contact area, the friction force and the pressure produced by the action of high temperature instant, local adhere and stripping the metal surface.

3. The principle and algorithm of BP neural network

BP neural network (Back-Propagation Network), is a kind of back propagation network, it consists of the back propagation and error information communication two processes, proposed by Rumelhart and McClelland in 1986. BP neural network includes three layers, input layer, hidden layer and output layer. Input layer mainly accepts signal input, the middle layer is information processing and conversion layer, mainly processes input signal, it can include one or more intermediate layers. Through a large number of data training to find a more reasonable weight, can correctly identify a variety of signals, and can correctly output the results.

(1) Output node model

$$\text{The hidden nodes and output model: } O_j = f\left(\sum W_{ij} * x_i + \theta_j\right) \quad (1)$$

$$\text{Output node model: } Y_k = f\left(\sum T_{jk} * O_j - q_k\right) \quad (2)$$

F is a non linear function; Q neural unit threshold.

(2) Function model

Function is to reflect the lower input function to the upper node stimulation intensity and stimulation function, general admission for the (0,1) values of Sigmoid continuous function.

$$f(x) = 1/(1 + e^{-x}) \quad (3)$$

(3) Error model

The error model is a reflection of the error function between the desired output and the output of the neural network calculation.

$$E_p = 1/2 \times \sum (t_{pi} - O_{pi})^2 \quad (4)$$

t_{pi} As the expected output value of the i node; O_{pi} To calculate the output value for the i node.

(4) Self learning model

Neural network learning process is the process which sets the weight matrix W_{ij} and updates the error connected between the lower and upper node. BP network learning mode - the need to set expectations and unsupervised learning - just enter the mode. Self learning model is

$$\Delta W_{ij}(n+1) = h \times \Phi_i \times O_j + \alpha \times \Delta W_{ij}(n) \quad (5)$$

h - Learning factor; Φ_i - the calculation error of the output node i; O_j - Calculate the output node j; α - Momentum factor.

4. Gear fault diagnosis of BP neural network

Gear fault diagnosis in the application of BP neural network needs to choose some parameters. In this paper selection main parameters are peak value, mean value, the absolute mean value, RMS, RMS, amplitude, RMS amplitude, variance, degree of skew, Waveform index Peak index, pulse index, margin index, skew, steepness, total of 15 parameters.

(1) The input layer.

Through the analysis of the above 15 parameters to determine the fault type, and selecting 8 training samples to train the neural network, the training sample data are shown in table 1.

(2) The hidden layer

The number of hidden layer nodes is the key of solving the problems. It has a direct impact on the BP network model identification ability of sample. The selection method is not yet conclusive, general according to experience and learning through training, combined with the number of times and the sample to determine. According to the experience in this paper, in this case because the input parameters of the eye have 15, so the hidden nodes are 31.

(3) The output layer.

According to the output of the network, there are 4 typical fault conditions, to encode these typical fault, using the normalized, select the network output layer nodes is 4, respectively $Y_1 Y_2 Y_3 Y_4$, in Table 2 for all types of faults in the desired output.

Table 1 choose 8 training samples, feature normalization

| Sample No | Sample characteristic | | | | | | Fault type |
|-----------|-----------------------|--------|--------|--------|--------|--------|-------------------|
| 1 | 0.2286 | 0.1292 | 0.0720 | 0.1592 | 0.1335 | 0.0733 | Broken teeth |
| | 0.1159 | 0.0940 | 0.0522 | 0.1345 | 0.0090 | 0.1260 | |
| | 0.3619 | 0.0690 | 0.1828 | | | | |
| 2 | 0.2090 | 0.0947 | 0.1393 | 0.1387 | 0.2558 | 0.0900 | Broken teeth |
| | 0.0771 | 0.0882 | 0.0393 | 0.1430 | 0.0126 | 0.1670 | |
| | 0.2450 | 0.0508 | 0.1328 | | | | |
| 3 | 0.0442 | 0.0880 | 0.1147 | 0.0563 | 0.3347 | 0.1150 | Pitting corrosion |
| | 0.1453 | 0.0429 | 0.1818 | 0.0378 | 0.0092 | 0.2251 | |
| | 0.1516 | 0.0858 | 0.0670 | | | | |
| 4 | 0.2603 | 0.1715 | 0.0702 | 0.2711 | 0.1491 | 0.1330 | Pitting corrosion |
| | 0.0968 | 0.1911 | 0.2545 | 0.0871 | 0.0060 | 0.1793 | |
| | 0.1002 | 0.0789 | 0.0909 | | | | |
| 5 | 0.3690 | 0.2222 | 0.0562 | 0.5157 | 0.1872 | 0.1614 | Wear |
| | 0.1425 | 0.1506 | 0.1310 | 0.0500 | 0.0078 | 0.0348 | |
| | 0.0451 | 0.0707 | 0.0880 | | | | |
| 6 | 0.0359 | 0.1149 | 0.1230 | 0.5460 | 0.1977 | 0.1248 | Wear |
| | 0.0624 | 0.0832 | 0.1640 | 0.1002 | 0.0059 | 0.1503 | |
| | 0.1837 | 0.1295 | 0.0700 | | | | |
| 7 | 0.1759 | 0.2347 | 0.1829 | 0.1811 | 0.2922 | 0.0655 | Glue |
| | 0.0774 | 0.0227 | 0.2056 | 0.0925 | 0.0078 | 0.1852 | |
| | 0.3501 | 0.1680 | 0.2668 | | | | |
| 8 | 0.0724 | 0.1909 | 0.1340 | 0.2409 | 0.2842 | 0.0450 | Glue |
| | 0.0824 | 0.1064 | 0.1909 | 0.1586 | 0.0116 | 0.1698 | |
| | 0.3644 | 0.2718 | 0.2494 | | | | |

Table 2 kinds of fault type the desired output

| No | State | Y1, Y2, Y3, Y4 |
|----|-------------------|----------------|
| 1 | Normal | 0, 0, 0, 0 |
| | Broken teeth | 1, 0, 0, 0 |
| 2 | Pitting corrosion | 0, 1, 0, 0 |
| 3 | Wear | 0, 0, 1, 0 |
| 4 | Glue | 0, 0, 0, 1 |

Table 3 test samples

| Sample No | Sample characteristic | | | | | | Fault type |
|-----------|-----------------------|--------|--------|--------|--------|--------|-------------------|
| 1 | 0.2101 | 0.0950 | 0.1298 | 0.1359 | 0.2601 | 0.1001 | Broken teeth |
| | 0.0753 | 0.0890 | 0.0389 | 0.1451 | 0.0128 | 0.1590 | |
| | 0.2452 | 0.0512 | 0.1319 | | | | |
| 2 | 0.2593 | 0.1800 | 0.0711 | 0.2801 | 0.1501 | 0.1298 | Pitting corrosion |
| | 0.1001 | 0.1891 | 0.2531 | 0.0875 | 0.0058 | 0.1803 | |
| | 0.0992 | 0.0802 | 0.1002 | | | | |
| 3 | 0.2599 | 0.2235 | 0.1201 | 0.0071 | 0.1102 | 0.0683 | Wear |
| | 0.0621 | 0.2597 | 0.2602 | 0.1167 | 0.0048 | 0.1002 | |
| | 0.1521 | 0.2281 | 0.3205 | | | | |

The training number of times is 2000 times, the training goal is 0.01, the learning rate is 0.1, the middle layer (hidden layer node number is 31), after training the weights of the test data, the prediction results:

$$Y = \begin{bmatrix} 0.9979 & 0.0001 & 0.0202 \\ 0.0058 & 0.9998 & 0.0580 \\ 0.0000 & 0.0383 & 0.8029 \\ 0.0194 & 0.0038 & 0.0025 \end{bmatrix}$$

Table 4 Comparison of the results with the ideal output

| Sample No | The ideal output | | | The actual output results | | | Fault type |
|-----------|------------------|----|----|---------------------------|--------|--------|-------------------|
| | Y1 Y4 | Y2 | Y3 | Y1 Y4 | Y2 | Y3 | |
| 1 | 1 0 | 0 | 0 | 0.9979 0.0194 | 0.0058 | 0.0000 | Broken teeth |
| 2 | 0 0 | 1 | 0 | 0.0001 0.0038 | 0.9998 | 0.0383 | Pitting corrosion |
| 3 | 0 0 | 0 | 1 | 0.0202 0.0025 | 0.0580 | 0.8029 | Wear |

5. Conclusion

In this paper, based on the theory of neural network, the gear signal as the input signal, , to overcome the previous multi input, single output neural network system, the paper designs the neural network fault diagnosis system 15-31-4. Through a large number of samples of the input verified by the experimental samples to train the neural network, , the neural network proves that the design has high recognition ability, better diagnostic capability in fault diagnosis of gears.

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