Broken Rotor Bar Fault Diagnosis of Squirrel Cage Asynchronous Motor Based on Vibration Spectrum and Current Spectrum

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Abstract. In this paper, the vibration spectrum and current spectrum analysis technology are used to accurately diagnose the broken rotor bar fault of the slurry circulating pump motor. This paper elaborates on the mechanism of broken rotor bar fault, deduces the common motor pole pass frequency calculation formula, introduces the specific diagnosis process and disintegration of the broken slurry circulating pump motor’s rotor bar breakage fault. The cause of the fault is analyzed, and this type of the fault diagnosis method is also summarized.

1. Introduction
Slurry circulation pump is one of the most important equipment type for desulfurization system in thermal power plants. The main function is to ensure the continuous circulation of the slurry in the absorption tower, to make the sulfur dioxide in the flue gas be completely absorbed. The running state of the slurry circulating pump directly affects the pollutant emission index, determines whether the economic and environmental parameters of coal-fired power plants meet the standards. The slurry circulating pump motor used by a certain power plant is a YKK500-4 squirrel cage asynchronous motor which is manufactured by Lanzhou Electric Corporation, because of operating conditions, long-term frequent start-up and shutdown are likely to cause rotor bar breakage faults, which poses a safety threat to the power plant. In order to ensure safety and economical operation of equipment and meet environmental protection requirements, slurry circulation pump motor’s rotor bar breakage fault should be discovered and resolved in time. In this paper, the fault diagnosis and analysis process of the rotor bar of a slurry circulating pump motor based on vibration spectrum and current spectrum analysis technology is elaborated in detail, furthermore, the diagnosis method of motor’s rotor bar breakage fault is summarized, which has reference and guiding significance for the fault diagnosis of squirrel cage asynchronous motor’s rotor bar.

2. Diagnosis and Analysis
2.1 Fault phenomenon
In initial stage, the slurry circulation pump motor had a sudden rise in the temperature of the stator coil, the internal temperature measurement point of the motor showed the maximum temperature of 131.6 °C, the field test temperature also reached 98.5 °C, temperature limit for safe operation had been exceeded; motor drive side bearing vibration became larger, vibration displacement was 144 um, significantly higher than historical data.
2.2 Preliminary diagnosis of fault
The motor bearing, the coupling and the motor cooling system were troubleshot, the nozzle was flushed, the temperature was still high and the bearing vibration was not significantly improved.

2.3 Fine diagnostic and analytical methods and processes

2.3.1 The mechanism of squirrel cage asynchronous motor’s rotor bar fault. The ideal frequency of squirrel cage asynchronous motor’s stator current is a single power frequency $f_L$, sideband frequency appears at a specified distance on both sides of the power frequency on the stator current spectrum when the rotor current loop is faulty, the specified distance is twice the speed difference frequency[1]. Power frequency is $f_L$, when a squirrel cage asynchronous motor with 2P poles is running, the stator winding’s magnetomotive force fundamental formula $m_s$ is:

$$m_s = K_s N_s I_s \sin(\omega t - P \theta)$$

(1)

In the formula, $K_s$ is a constant which is related to the motor pole number and winding coefficient; $N_s$ is the number of per phase turns of stator winding; $I_s$ is stator current; $\omega$ is angular frequency of power; $\theta$ is phase angle.

The phase angle $\varphi$ of the rotor winding is:

$$\varphi = \theta - \omega_r t$$

(2)

In the formula, $\omega_r$ is rotor rotational angular velocity.

When $P = 1$, the magnetomotive force of the two-pole motor is:

$$m_s = K_s N_s I_s [\sin((\omega - \omega_r) t - \varphi)]$$

(3)

Due to the action of the rotating magnetic field of the stator, rotor winding produces induced current[2], and then establishes a rotor magnetomotive force $m_r$ which is balanced with the stator magnetomotive force, its fundamental formula is:

$$m_r = K_r N_r I_r \sin([\omega - \omega_r] t - \varphi)$$

(4)

In the formula, $K_r$ is a constant which is related to the motor pole number and winding coefficient; $N_r$ is the number of per phase turns of rotor winding; $I_r$ is rotor current.

When there is a fault in the rotor winding, for example, there is a broken rotor bar, the magnetomotive force of the rotor current will be modulated[3], at this time, the magnetomotive force of the rotor winding is:

$$m_r = K_r N_r I_r [\sin([\omega - \omega_r] t - \varphi)] \sin 2 \varphi$$

(5)

Therefore

$$m_r = \frac{1}{2} K_r N_r I_r \cos((\omega - \omega_r) t - 3 \varphi) - \cos((\omega - \omega_r) t + \varphi)$$

(6)

Since the magnetomotive force of the stator and the rotor is balanced, the formula (2) is brought in to obtain an expression of the magnetomotive force of the stator:

$$m_r = m_s = \frac{1}{2} K_r N_r I_r \left\{ \cos((\omega + 2 \omega_r) t - 3 \theta) - \cos((\omega - 2 \omega_r) t + \theta) \right\}$$

(7)

The difference between the stator magnetic field rotation speed and the rotor magnetic field rotation speed is defined as the slip, in terms of two-pole motors, its slip rate is:

$$s = \frac{\omega - \omega_r}{\omega}$$

(8)

$$\omega_r = (1 - s) \omega$$

(9)

Substituting formula (9) into formula (7), the $m_s$ is obtained:

$$m_s = \frac{1}{2} K_r N_r I_r \left\{ \cos((3 - 2s) \omega t - 3 \theta) - \cos((2s - 1) \omega t + \theta) \right\}$$

(10)

It can be found from formula (10) that the first part of the stator magnetomotive force expression contains $3 \omega t$ and $3 \theta$, this produces a zero-sequence electromotive force in the three-phase stator winding, this electromotive force has no effect on the power current[4]. The second part of the magnetomotive force expression contains a component which causes a three-phase current in the stator winding of the squirrel cage asynchronous motor, the current angular frequency is different from the power current angular frequency by $2s \omega$. As this frequency has a small difference from the power line
frequency, the modulation is generated, this modulation causes the stator current to change in beats and causes the torque of the motor to fluctuate accordingly, thereby the rotor speed of the squirrel cage asynchronous motor also fluctuates by 2 times the slip frequency[5].

   Power frequency expression is as follows:

   \[ f = \frac{np}{60} \]  

   In the expression, \( n \) is the synchronous speed of the motor.

   The pole pass frequency can be converted as follows:

   \[ PPF = 2p \frac{n-n_0}{60} = 2 \times \frac{n-n_0}{n} \times \frac{np}{60} = 2sf \]  

   In the expression, \( PPF \) is the pole pass frequency, \( n_0 \) is the actual motor speed.

2.3.2 Broken rotor bar fault diagnosis based on vibration spectrum analysis technique. The vibration data was collected and analyzed, and it was found that there were sidebands with a size of 1.37 Hz on both sides of the rotational speed frequency of the motor in the vibration spectrum, as shown in Figure 1. The actual motor speed measured by the vibration spectrum is 1478 rmp, the synchronous motor speed is 1500 rmp, and the motor is a 4-pole motor, the above parameters were substituted into formula (12), the calculation result is 1.47 Hz, its value has a small difference from the above-mentioned pole pass frequency value, it can be roughly determined that the rotor bar is faulty.

![Figure 1. Vibration spectrum of the slurry circulating pump motor](image)

2.3.3 Broken rotor bar fault diagnosis based on current spectrum analysis technique. In the current spectrum, the sideband value of the power frequency is the motor pole pass frequency, peaks occur at both the power frequency and the pole pass frequency, the difference between the power frequency peak and the pole pass frequency peak is the health indicator of the rotor bar. The data was collected and analyzed, the actual motor speed measured by the current spectrum is 1486.9 rmp, these parameters were substituted into formula (12), the calculation result is 0.87 Hz, this is consistent with the measured sideband value, the difference in amplitude between the power frequency peak and the pole pass frequency sideband peak is 35.7 dB, as shown in Figure 2, motor has rotor bar breakage problem[6].
2.3.4 Precision diagnosis, disintegration verification, cause analysis. Through the comprehensive analysis of the vibration spectrum and current spectrum, combined with the field situation, it was finally determined that the rotor bar of the motor has broken. Through the disintegration inspection, it was found that there were many breaks in the rotor bars of the motor, as shown in Figure 3, and the above analysis and judgment were verified[7].

![Figure 3. Disintegration of the slurry circulating pump motor](image)

The current flow of the slurry circulation pump motor through the rotor bar is too large at the starting point, which makes the rotor bar not only withstand large impact force and centrifugal force but also endure the thermal stresses due to rapid heating. The frequent start and stop of the motor cause the rotor bar to be frequently stressed and further deformed, the rotor bar would be broken eventually due to uneven distribution of force. In addition, from the perspective of electromagnetic torque, the acceleration torque at start-up is generated by the rotor bar, the rotor bar is subjected to braking torque during deceleration, due to load changes and voltage fluctuations, the rotor bars are subjected to alternating loads and are prone to metal fatigue. When the casting quality of the cage coil, the material of the rotor bar and the welding quality are defective, the rotor bar is more susceptible to breakage and open welding. If not handled in time, the fault will further deteriorate and multiple rotor bars will break, as a result, the motor will burn out, in severe cases, the stator core will be scratched due to the rotor broom, resulting in the scrapping of the whole machine[8].

3. Summary of fault diagnosis of rotor bar

For the rotor fault of the motor, the first step is to analyze the fault phenomenon, to confirm whether there is any phenomenon that the motor body and bearing are overheated, the current fluctuation is large, the starting time is long, and the pump or fan torque is reduced, if the above phenomenon occurs, there is a possibility that the rotor bar is faulty.
Secondly, further analysis and diagnosis through vibration spectrum and current spectrum are conducted, considering that the sampling frequency value and the number of sampling points are relatively large when the current spectrum test is performed, the current spectrum is sensitive to the pole pass frequency and has higher accuracy, therefore, it is recommended that the rotor bar fault of the motor is mainly analyzed and diagnosed by current spectrum technology. The vibration spectrum does not have high sensitivity in analyzing electrical faults due to reasons for sampling parameter settings and inherent characteristics, therefore, vibration spectrum technology can be used as an important auxiliary means for fault diagnosis of motor rotor bars.

If the motor has non-electrical faults, such as the bearing wear, the coupling misalign as well as the rotor imbalance, the vibration spectrum will be more intuitive. In actual production, the motor is also likely to have multiple faults at the same time, flexible use of vibration spectrum and current spectrum technology, combined with actual operating conditions of equipments and systems, not only the fault category can be accurately identified, but also the accuracy and timeliness of fault diagnosis can be improved.

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