EFFICIENCY MONITORING IN INDUCTION MOTORS

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ABSTRACT
The relationship between motor faults and motor efficiency is studied in this paper. The input power, electrical power, is calculated from voltage and current measurements. The motor current data is also utilized to determine rotor speed. Then, torque-speed characteristic curves are used to find torque and mechanical power values respectively. Motor efficiency is compared under fault and no fault situations.
Keywords: kInduction motors, motor faults, and motor current signature.

1. INTRODUCTION
Industrial circuit monitors are used to monitor individual motor loads. The current and voltage data they provide can be used to gather both power measurements and diagnostic information on the motor. In this paper, induction motor efficiency is measured from the current and voltage data collected by circuit monitors. The decrease in the efficiency of motors may be related to mechanical faults such as broken rotor bars, bearing faults, and insulation faults. Therefore, it is important to monitor the changes in motor efficiency. Some of the industrial circuit monitors already have motor condition monitoring feature [1-2]. The efficiency information may be combined with diagnostic information to improve the performance of condition monitoring algorithms.
The efficiency, η, is give by the ratio of output power to input power.

$$\eta = \frac{P_{OUT}}{P_{IN}} \quad (1)$$

The power flow diagram for an induction motor is given in figure 1.

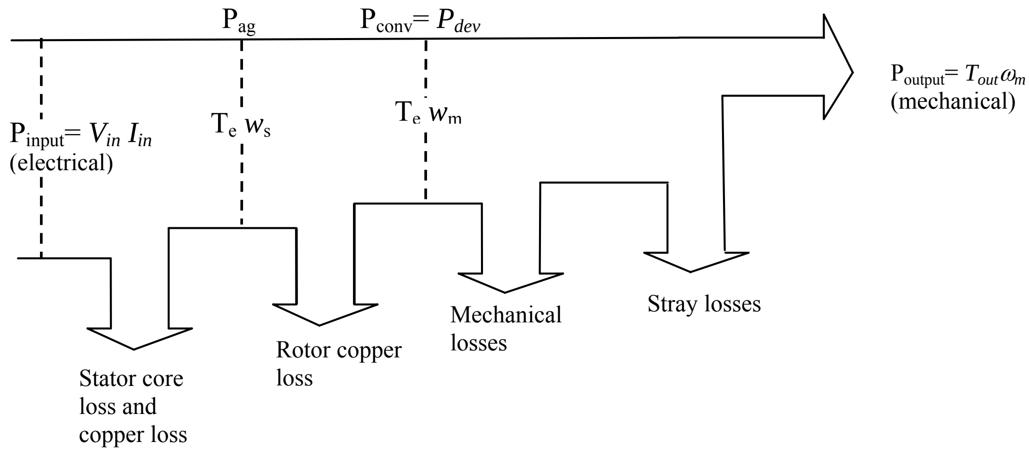

Figure 1. Power flow diagram for an induction motor

Input power (electrical power) can be easily computed using the voltage and current data collected by the industrial circuit monitor.

$$P_{IN} = \sum_{k=0}^{N-1} v_k i_k \qquad (2)$$

where N is the number of points per power frequency cycle, and v_k and i_k are voltage and current samples respectively.

Output power (electrical power) can be computed using equation (3) where T_{OUT} is the output torque and w_m rotor speed respectively.

$$P_{OUT} = T_{OUT} w_m \qquad (3)$$

The process in determining the output power (mechanical power) is more complicated and requires some signal processing. The procedure will be explained in the next section.

2. MECHANICAL POWER COMPUTATION

First, we need to determine the motor speed. Then, speed versus torque characteristic of the motor can be used to estimate the mechanical power.

The rotor speed sidebands show up in the current spectrum due to rotor eccentricities. All motors have some degree of rotor eccentricity permitting possible speed detection [3-5]. The speed resolution depends on the length of the current data. In this project, the current data is captured at 32 points per power system cycle for 12 seconds using the waveform capture capability of SquareD CM4000 Circuit Monitor. The Circuit Monitor has an onboard memory chip that provides storage for captured data. Then, the data is uploaded to a PC via the serial communication port. The frequency resolution in the spectrum will be 0.1 Hz for current data length of 10 seconds. Here, the second order notch filter is used for suppressing fundamental harmonic so that rotor speed sidebands are more pronounced in the spectrum.

The captured current data and the corresponding spectrum analysis are shown in figure 2. Here the speed sidebands show up at 31Hz and 89Hz in the motor current spectrum. The speed will be 1740 rpm for a one-hp four pole induction machine operating at system frequency of 60Hz.

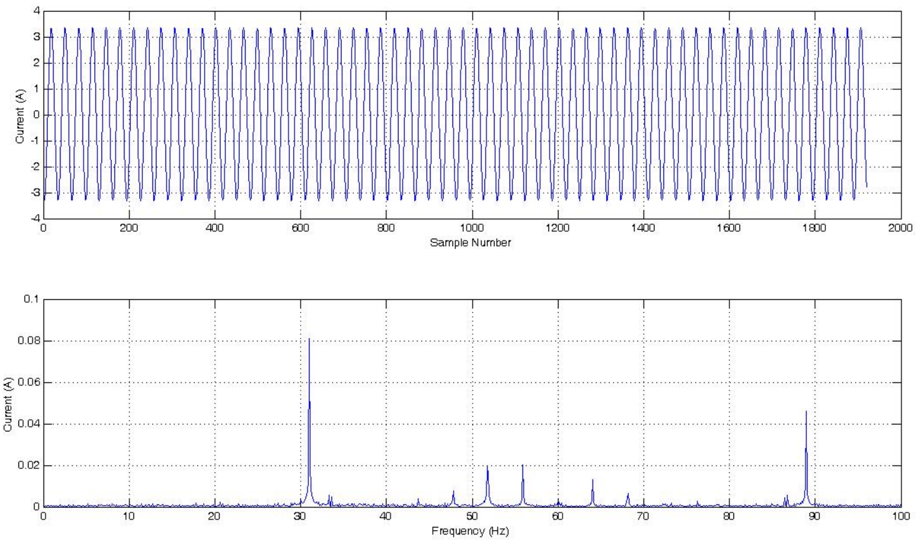

Figure 2. motor current and its spectrum

Once the speed is determined, the torque can be estimated from the torque vs. speed curve with reasonable accuracy. Figure 3 depicts the torque vs. speed curve for a typical induction motor. The normal operating range of a motor has a fairly linear relationship between torque and current. Thus, it is possible to analyze the current data for the load conditions.

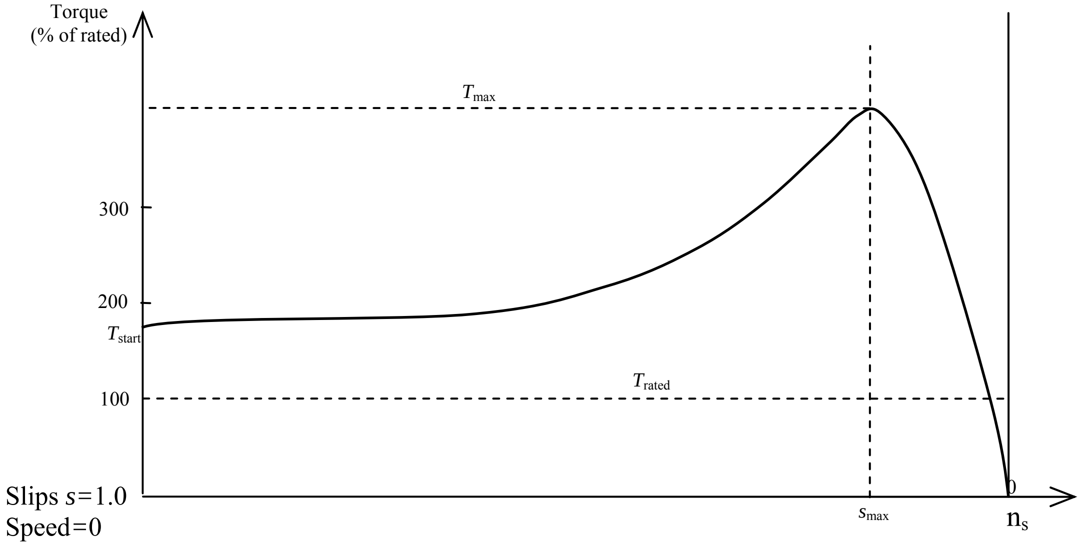

Figure 3. Induction motor torque vs. speed curve

Mechanical power (output power) can then be calculated using torque and speed. The final stage is computing the efficiency from electrical and mechanical powers.
Electrical and mechanical faults can cause noticeable drops in motor efficiency. As a result, the efficiency value can be monitored for an induction motor to detect abnormalities in its operation. In the next section, broken rotor bar is example is presented to show the relation between efficiency and motor faults.

3. MOTOR EFFICIENCY TEST FOR MOTOR FAULT CONDITION

The test motor is a 1 hp, 200 V, 60 Hz, 1750 rpm, four-pole induction motor (US Motors Frame 143T). The broken rotor bar fault is produced by drilling one of the bars on both ends. The rotor with the broken bar is depicted in figure 4.

Figure 4. Induction motor with a broken rotor bar

In testing, the steady state motor current data were captured, at 32 points per cycle for15 seconds, using a Square D series 4000 Circuit Monitor at various load conditions before and after the fault was introduced. The captured signals were first notch filtered to remove power system harmonics.

Input power for a healthy motor and a motor with broken rotor bar under the same load conditions were calculated. In the case of a motor with a broken rotor bar, higher magnitude line currents are withdrawn to provide the same amount of mechanical power as the healthy motor case. The results summarized in table one clearly indicate that broken rotor bar causes a considerable amount of drop in efficiency.

Table 1. Efficiency for induction motor

	Healthy	Faulty
Pin	911.2W	955.3W
Pout	369.4W	369.4W
Efficiency	0.405	0.387

4. CONCLUSION

Industrial circuit monitors are seeing a wider usage in industry. The current and voltage data they provide can be used for condition monitoring of critical equipment in addition to measuring power quality parameters. Addition of efficiency measurement feature to CM4000 is proposed in this study. Efficiency can be monitored to detect any mechanical faults. Basically, drops in efficiency levels can indicate that the motor may have some mechanical faults such as broken rotor bar or bearing fault. In testing, efficiency drop due to broken rotor bar was shown. The authors intend to explore the effects bearing and insulation faults in the full paper.

5. REFERENCES

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