A Motor Efficiency Measurement System Design Based on Loss Segregation Method

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Abstract. There are many methods about efficiency measurement for introductive motors in international standards, among which the loss segregation method assumes that the stray loss and iron core loss can be treated as constants, and then the process of efficiency estimation can be simplified. This paper designed a motor efficiency measurement system based on loss segregation method. It's a calculation module based on a micro-processor. The motor current is the only variable for motor efficiency calculation, this system can calculate and read the result on-line. The deviation between the loss segregation method and the direct method is very small.

Introduction

With the promotion of energy saving policy and the development of energy saving products, energy efficiency problems of running motors are becoming much more concerned in today's world, but motor efficiency measurement methods are always very complex, it's hard to do batch measurement in a large factory. Therefore it's necessary to develop a simple but practical system for motor efficiency measurement, it can obtain the efficiency data easily whatever when the motors are in any kind of running condition[1,2]. From the view of international standards and methods for motor efficiency measurement we can see that iron core loss, friction and wind resistance loss and some others can be treated as constants in a specific range, it has nothing concern with the motor load. To some extent, the main international standards all agree with this kind of measurement method[3]. According to this theory, this article designed a real on-line system for motor efficiency measurement. This system is based on loss segregation method, in this method, only the copper loss will be measured in real time, others will be given a certain value according to international standards. This system only measures the motor parameters and current. Its performance has been tested by a direct current shunt excitation motor. Compared with the result of direct method, the deviation is very small.

Standards and Methods for Motor Efficiency Measurement

Measurement Standards

There are many standards for three phase induction motor efficiency measurement in the world, mainly including American standard IEEE Std.112, European Union standard IEC60034-2,Canadian standard CSA C390, Japanese standard JEC 37, Chinese standard GB/T 1032-2012, etc., and they all have their own efficiency measurement methods which are widely used in the whole world. For example, there are many methods in IEEE Std.112, such as A, B, B1, C, E, E1, F, F1, C/F, E/F, E1/F1, etc., among which the B method segregates all the motor losses into traditional defined types and is most widely used, EU IEC 60034-2 standard ever constrained 0.5% input power to be stray loss in a very long period. This standard was replaced by a new standard named IEC 60034-2-1. The new one stipulates that the stray loss must be real tested, which also offers the theory and method for real testing. It treats the stray loss as the function of rated motor parameters. In CSA standard, the method for stray loss test is to use a specific process of IEEE 112B, In JEC 37, stray loss is ignored.
**Measurement Method**

Generally, all the motor efficiency measurement methods mentioned above can be concluded to two types:

1. **Direct method**
   In this method, the input electric power and the output mechanic power are measured directly. The input and output power can both be real measured through a sensor and a measurement system. The motor efficiency is the ratio of output power and input power, as shown in equation (1):
   \[
   \eta = \frac{P_o}{P_i} \tag{1}
   \]
   \(P_i\) is input power, \(P_o\) is output power.

2. **Indirect method**
   In this method, some special rules are adopted to confirm all the components of motor losses, and then calculate the sum to obtain the motor efficiency, as shown in equation (2):
   \[
   \eta = \frac{P_i - P_L}{P_i} \tag{2}
   \]
   \(P_i\) is input power, \(P_o\) is output power, \(P_L\) is the sum of motor losses, all the losses can be obtained from equation (3):
   \[
   P_L = P_c + P_m + P_e + P_h + P_s \tag{3}
   \]
   \(P_c\) is copper loss, \(P_m\) is mechanic loss, \(P_e\) is eddy loss, \(P_h\) is hysteresis loss, \(P_s\) is stray loss, all of them are explained as following:
   a) **Copper loss (\(P_c\))**
      This loss appears in motor stator winding, as shown in equation (4):
      \[
      P_c = I^2 R \tag{4}
      \]
      \(I\) is stator winding current, \(R\) is stator winding resistance.
   b) **Mechanical loss (\(P_m\))**
      It includes friction loss and wind resistance loss, which have something concern with the rotor velocity. If the variation range of rotor velocity is very small, then \(P_m\) can be treated as a constant from zero load to full load in real situation.
   c) **Magnetic loss (\(P_e, P_h\))**
      Magnetic loss is also called iron core loss, it is produced by the variation of magnetic flux density in iron core, it includes eddy loss \(P_e\) and hysteresis loss \(P_h\), as is shown in equation (5) and (6).
      \[
      P_e = K_e (B_m f)^2 \tag{5}
      \]
      \[
      P_h = K_h B_m^4 \tag{6}
      \]
      \(B_m\) is the magnetic flux density of the max air-gap, \(f\) is the current frequency, \(K_e\) and \(K_h\) are proportional constants, magnetic loss is influenced by iron material and current frequency, but they have nothing concern with rotor velocity, in a direct current excitation motor, these losses are all from armature.
   d) **Stray loss (\(P_s\))**
      Stray loss is caused by the distortion of load current, because stray loss is greatly influenced by the geometric structure of motor slot, it's hard to simulate and predict, but it can be assumed to be a constant in a certain load range.

**The Motor Efficiency Measurement System Design Based on Loss Segregation Method**

Because all the estimated component values are from various standards and experience, so generally the result is very accurate, the deviation can be within 2%, so loss segregation method is always being used for motor efficiency testing in practical [4].
Standards for Loss Segregation

IEEE Std.-112 Method E1, this is a normal loss segregation method, it gives the assumed stray loss values for different motors at rated load, as shown in table 1.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Rated motor power</th>
<th>Stray loss (rated load proportion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-90KW</td>
<td>1.8%</td>
</tr>
<tr>
<td>2</td>
<td>91-375KW</td>
<td>1.5%</td>
</tr>
<tr>
<td>3</td>
<td>376-1850KW</td>
<td>1.2%</td>
</tr>
<tr>
<td>4</td>
<td>≥1851KW</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

Efficiency Calculation Method

Efficiency Calculation Based on Loss Segregation Method. Motor losses are variable when it is in running, but loss segregation method assumes that stray loss, iron core loss are constants according to standards above, this assumption bases on the motor’s long period steady running situation[5,6], and the accuracy will not suffer a obvious loss. The copper loss will change along with motor current. This method is very simple, but the accuracy is very high according to testing result. Take the direct current shunt excitation motor as an example, the motor equivalent circuit is shown in figure 1.

Figure 1. Direct Current Shunt Excitation Motor Circuit in Steady State.

\[ V_s = I_s R_a + I_f R_f \]

\[ P_i = V_s I_s \] (7)

All the copper losses can be calculated by the equation below:

\[ P_c = I_s^2 R_a + I_f^2 R_f \] (8)

All the constant losses can be calculated by the equation below:

\[ P_k = I_f^2 R_f + P_e + P_h + P_m + P_s \] (9)

\[ P_k \] is the sum of all constant losses.

According to (2), (7), (8), (9), the direct current shunt excitation motor efficiency can be expressed below:

\[ \eta = 1 - \frac{P_k + (I_s - I_f)^2 R_a}{V_s I_s} \] (10)

After giving every parameter in equation (10) a certain value according to the standards above, the only thing needed is to input the motor current which is measured in real time.

Efficiency Measurement Based on Direct Method. Direct method needn’t calculate any losses, but rotator torque and angular velocity measurement is necessary, motor efficiency can be calculated according to the equation below:
\[ \eta = \frac{p_o}{p_i} = \frac{T_L \omega_m}{V_E H} \]  

(11)

T_L is output torque available, \( \omega_m \) is angular velocity of rotator.

**Motor Efficiency Measurement System**

**Measurement System Module.** Efficiency measurement module is shown in figure 2, motor current is obtained from a Hall effect sensor, The advantage of this real time measurement system is that only one current sensor is needed. Compared with direct method, it's simple but practical, and suite to any load situation.

![Figure 2. Motor Efficiency Estimation System Module.](image)

**Operation Procedure.** All the processes of motor efficiency measurement such as taking samples, calculation can be displayed and can be interrupted by a observer, the program flow chart is shown in figure 3.

![Figure 3. Operation Procedure for Motor Efficiency Measurement.](image)

**The Site Tests and Its Results**

**Facilities for Testing**

An experiment was conducted to test the performance of the efficiency measurement system, it used a 110v, 220w direct current shunt excitation motor for efficiency measurement and a power meter for load simulation, the mechanical torque can be adjusted by changing the current of the power meter, and then the motor load can be changed in a large range.

Firstly, with the help of the motor efficiency measurement system designed by this article, the motor efficiency was measured. Secondly, the motor efficiency was measured again using direct method, then compared the results of each measurement method. To the direct method, the way of measuring voltage and current was the same as above, the efficiency variations between the two methods with different loads are shown in table 2.
Table 2. Efficiency Deviations Between the Two Methods with Different Loads.

<table>
<thead>
<tr>
<th>Load rate [%]</th>
<th>Direct method</th>
<th>Loss segregation method</th>
<th>Deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>58.3</td>
<td>55</td>
<td>-3.3</td>
</tr>
<tr>
<td>50</td>
<td>73.3</td>
<td>70.8</td>
<td>-2.5</td>
</tr>
<tr>
<td>60</td>
<td>82.5</td>
<td>80.2</td>
<td>-2.3</td>
</tr>
<tr>
<td>70</td>
<td>86.6</td>
<td>84.8</td>
<td>-1.8</td>
</tr>
<tr>
<td>80</td>
<td>88.3</td>
<td>86.7</td>
<td>-1.6</td>
</tr>
<tr>
<td>90</td>
<td>85</td>
<td>87</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>82.5</td>
<td>84.8</td>
<td>2.3</td>
</tr>
<tr>
<td>105</td>
<td>80.2</td>
<td>83.3</td>
<td>3.1</td>
</tr>
<tr>
<td>110</td>
<td>78.3</td>
<td>82.1</td>
<td>3.8</td>
</tr>
</tbody>
</table>

From table 2 we can see that when the load range was from 50% to 100%, the accuracy of this motor efficiency measurement system based on loss segregation method is very high, compared with the direct method, the deviation is no more than 2.5%.

Conclusion

This article has identified every kind of motor losses and its causes, it analyzed several international standards about motor efficiency measurement. According to the agreement that those standards treat most motor losses as constants, this article gave magnetic loss, mechanical loss and stray loss certain values from zero to full load, and designed a motor efficiency measurement system based on loss segregation method. This system connected to the motor only with a current sensor, so this system is a very simple interface unit. Through this unit the motor efficiency can be obtained in real time. We tested a direct current shunt excitation motor using this system, and compared the result to the one of direct method, it has been proved that the deviation is very small. In addition, in order to get a simple but reasonable motor efficiency measurement system, all the losses could be certain values according to international standards except armature loss.

References