Experimental Investigation of the Capacitor Influence on the Single Phase Induction Motor: A Labview Approach

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Abstract: - In this article, experimental results with a single phase induction motor are presented. For the motor’s maximum efficiency, the capacitor has to vary based on torque. It was determined the optimum value of the capacitor at an optimal efficiency for different torques. Due to the motor’s special construction the measurements were made with a large number of capacitors for both motor windings. The graphs were determined using a computer calculus program. A data acquisition system was used in order to obtain the voltage and current signals and were processed off-line and saved in a database. A Labview program was built in order to acquire determine the speed versus torque graphs.

Keywords: Single phase induction motor, data acquisition, Labview, data base.

1 Introduction

Single phase induction motors are used in most of household applications. They are preferred in applications that do not require a variable speed drive due to the low cost and rugged construction. The three main types of single phase induction motors are [1]:
- Split phase induction motors;
- Capacitor induction motors;
- Shaded pole induction motors.

The electrical drive used in the experiments is a capacitor induction motor. The category includes the capacitor-start and capacitor-run motors. In the first case a centrifugal switch disconnects the capacitor after a percentage of the synchronous speed was reached. The efficiency of this kind of drive is relatively low. This type of drive can have two or more capacitors [2], a large value of the capacitor ensure a high starting torque, and once the steady state is reached the capacitor is switched off. Due to the possible malfunction of the switch and the high and the high cost of the solution it is rarely used. The single phase induction motor operation with great capacitor values decreases the motor’s overall performances as it will be proven with the experimental part. The various experimental curves were determined with a hysteresis brake. Using a great number of fixed value capacitors the output power was measured and with a multichannel data acquisition system the drive’s input currents and voltages signals were acquired. Using a calculus program the efficiency and electrical parameters were determined and afterwards saved in a database.

2 Single phase induction motor and experimental setup description

2.1 Detailed description of Capacitor-Run Single Phase Induction Motor

The advantages of using a CRSPIM are the maximum torque improvement by 5-10%, the increase of efficiency and power factor close to unity and reduced noise. The studied CRSPIM operates in two conditions related to a washing machine: a steady state used for spinning and discontinuous dynamic regime specific for a washing cycle. The drive’s special construction includes two independent windings both inserted in the stator slots. The windings are distinct, one has 2 poles and the other one has 12. Specific to the 12 pole configuration are the symmetrical windings necessary to operate in both directions. The drive tested is MSP-311 produced By Romanian Company ANA IMEP Pitești. Electrical properties are presented in Table 1 and Table 2.

Table 1

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Rated supply voltage</td>
<td>V</td>
<td>230</td>
</tr>
<tr>
<td>2.</td>
<td>Rated frequency</td>
<td>Hz</td>
<td>50</td>
</tr>
<tr>
<td>3.</td>
<td>Rated speed</td>
<td>rot/min</td>
<td>2840/420</td>
</tr>
<tr>
<td>4.</td>
<td>Pairs of poles number</td>
<td>-</td>
<td>1/6</td>
</tr>
<tr>
<td>5.</td>
<td>Capacitor-run value</td>
<td>μF</td>
<td>14</td>
</tr>
</tbody>
</table>
### Table 2
Motor Parameters for 2 and 12 pole configuration.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2 pole principal winding resistance</td>
<td>( R_{d1} )</td>
<td>Ω</td>
<td>20.8</td>
</tr>
<tr>
<td>2.</td>
<td>2 pole auxiliary winding resistance</td>
<td>( R_{q1} )</td>
<td>Ω</td>
<td>57.5</td>
</tr>
<tr>
<td>3.</td>
<td>12 pole principal winding resistance</td>
<td>( R_{d2} )</td>
<td>Ω</td>
<td>73</td>
</tr>
<tr>
<td>4.</td>
<td>12 pole auxiliary winding resistance</td>
<td>( R_{q2} )</td>
<td>Ω</td>
<td>73</td>
</tr>
<tr>
<td>5.</td>
<td>Cage slot number</td>
<td>( Z_R )</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>6.</td>
<td>Stator slot number</td>
<td>( Z_S )</td>
<td>-</td>
<td>48</td>
</tr>
<tr>
<td>7.</td>
<td>Air gap dimension</td>
<td>( \delta )</td>
<td>mm</td>
<td>0.15</td>
</tr>
<tr>
<td>8.</td>
<td>2 pole principal winding turn number</td>
<td>( w_{d1} )</td>
<td>-</td>
<td>218</td>
</tr>
<tr>
<td>9.</td>
<td>2 pole auxiliary winding turn number</td>
<td>( w_{q1} )</td>
<td>-</td>
<td>316</td>
</tr>
<tr>
<td>10.</td>
<td>12 pole principal winding turn number</td>
<td>( w_{d2} )</td>
<td>-</td>
<td>1140</td>
</tr>
<tr>
<td>11.</td>
<td>12 pole auxiliary winding turn number</td>
<td>( w_{q2} )</td>
<td>-</td>
<td>1460</td>
</tr>
</tbody>
</table>

#### 2.2 Experimental setup description

The test constructed bench was composed by: hysteresis brake, CRSPIM, fixtures and couplings, brake controller, measurement, data acquisition systems and connection wires. Due to motor’s special housing the fixture has a complex structure. The experimental tests performed on the hysteresis brake were compared to the data sets obtained using two different brakes, a powder brake and an unstandardized eddy currents brake. The first two brakes are constructed by Magtrol. The serial number of the hysteresis dynamometer (HD) and the powder brake (PB) are HD-805-8NA, respectively PB-43. A torque/speed conditioner (TSC 401) and a DES power supply were necessary for the proper operation of the powder brake. Magtrol dynamometers are designed for low-power, high speed accurate measurements.

The brakes were programmed using a high speed programmable controller, DSP 6001 [3] also by Magtrol.

The mechanical problems that occurred in the case of all brakes were determined by a rigid coupling which generated vibrations that affected the brakes torque sensor and produced measurement errors. A flexible coupling was implemented between the axes and reduces almost completely the vibrations generated by rotor eccentricity and misalignment: angular or parallel offset [4], [5].

For the post experimental data analysis necessary to determine the optimal capacitor value a data acquisition system was used. The acquisition system contains a transducers board, a connection board, the data acquisition board, a computer and the Labview program. In Fig. 1 is depicted the complete data acquisition system.

**Fig.1. Complete experimental setup.**

The data acquisition board NI USB 6251 Mass Termination is produced by National Instruments and the voltage and current transducers are produced by LEM and use the Hall Effect. The connection board is also manufactured by National Instruments. The brake’s errors are indicated to be between 0.25-0.5 percent on full scale [4].

#### 3 Labview program

The Labview program was used for data acquisition and to program the DSP 6001 high speed controller. The set on commands supported by the controller are indicated in [3]. The serial interface RS-232 is used for communications. The maximum baud-rate supported by the controller is 19,200.

The program is Tab structured, and the first one is used for the initialization of the controller and the PID setup. The block diagram is depicted in Fig. 2.

**Fig.2. Initialization of the DSP 6001 controller and PID setup.**

The set of command is read from a text file and then sent line by line to the controller. Because of the limited communication rate specific to the serial protocol in the Labview program will be usually...
seen timers in repetitive structures or in set of command to delay the data transfer.

In fig. 3 is presented a first part of the data acquisition tab. From the Labview program the controller sets a resistive torque to the drive. The data are acquired only when the imposed torque is reached within a user defined tolerance. The controller returns in a string the value of the speed and the torque. The While loop is used to extract the two variables from the string and to compare the torque with the imposed value.

In Fig. 3 is presented the data acquisition block diagram. After the imposed torque is reached the motor’s input currents and voltages will be acquired previously depicted in Fig. 1. The data acquisition is configurable a series of parameters can be changed: sample mode, samples per channel, sampling rate. The data acquisition system contains an analog trigger to have all the acquired data start from the same point of the waveform. After the samples were read, the motor returns to free run and the data are plotted on a chart and saved in text files.

In Fig. 4 is presented the data acquisition block diagram. After the imposed torque is reached the motor’s input currents and voltages will be acquired previously depicted in Fig. 1. The data acquisition is configurable a series of parameters can be changed: sample mode, samples per channel, sampling rate. The data acquisition system contains an analog trigger to have all the acquired data start from the same point of the waveform. After the samples were read, the motor returns to free run and the data are plotted on a chart and saved in text files.

In Fig. 5 is presented the Front Panel of the data acquisition system. It includes the controls for the block diagrams described in Fig. 3 and Fig. 4. The acquired waveforms are for the 2 pole configuration with a torque of 50 Ncm and a capacitor of 16μF.

The last part of the Labview program determines the torque versus speed characteristic of the CRSPIM. The block diagram is indicated in Fig. 6. To gather data for this chart the program sends a set of three commands to the controller: maximum speed, minimum speed and the rate of speed decrease in rpm/second during ramping down. To read the speed and torque a command has to be continuously sent to the controller and it returns the sting containing the two values. Hence a While loop is necessary to extract the speed and torque from the sting.

A Shift Register was created in the While loop to retain the previous values of torque and speed. These values were built into an array and plotted on a XY Graph.

In Fig. 7 and Fig. 8 are presented the torque versus speed characteristics of the SPIM. The PID values remain unchanged, only the deceleration rate is different.
It can be observed by comparing the two figures that changing the deceleration rate at the same derivative value of the PID constants the CRSPIM’s oscillations severely change. A high deceleration rate reduces the oscillations. Also this kind of deceleration rate minimizes the time delay in the loop. Errors generated with the serial at a high communication rate were significant.

Compared to the deceleration rate the derivative component of the PID controller has a significant part regarding the oscillations. It is indicated in the controller’s manual that a 1/100 value of the derivative component is necessary for minimal oscillations. Further research will correlate the change in the PID with the torque versus speed chart and it will also contain the acceleration component.

4 Experimental results

Due to the differences of the windings resistances, for the 2 pole winding the maximum capacitor value was 20 μF. At this capacity the drive’s thermal protection disconnected it from the power supply. For the 12 pole winding the experiments were performed until the capacitor reached 30 μF. The torque values for the following graphs are not integers due to the fact that the brake was initially set to kgfcm. The rated torque for the 2 pole winding is 19.6 Ncm (2 kgfcm), respectively 88.2 Ncm (9 kgfcm) for 12 poles winding.

The graphs obtained using a computer calculus program are:
- Input power versus capacitor;
- Efficiency versus capacitor;
- Power factor versus capacitor.

The least squares method was used for a continuous representation. The circles on the graphs represent the measured values. In Fig. 8 and Fig. 9 is presented the absorbed power as a function of capacitor. Due to the low electrical winding resistance the power absorbed by the 2 pole is double compared to the one absorbed at 12 poles. In both cases there are different values of the capacitor for minimal absorbed power.
In Fig. 10 and Fig. 11 is presented the efficiency versus capacitor. There is an optimal capacitor value for each torque.

For the 2 pole winding the capacitor variation is smaller compared to the 12 pole configuration. The significant increase of torque determines a large variation of the capacitor for an optimum efficiency in both cases.

On the 12 pole winding the capacitor variation according to an optimal efficiency is wider to the large number of the maximum torque. Comparing with Fig. 8 and Fig. 9, figures that indicate the power input versus capacitor, the optimal capacitor value determines the least input power absorbed for both windings. For the 2 pole winding the absorbed power is twice the value compared to the 12 pole, and due to the high speed the efficiency is superior compared to 12 pole configuration. The capacitor value indicated by the manufacturer is not selected for an optimal efficiency. The selected value determines a minimum starting torque required for the application.

In Fig. 12 and Fig. 13 is presented the power factor versus capacitor. For both winding configurations the power factor is not minimum for the optimal capacitor value. The power factor has a minimum value for a capacitor below the optimal value.

Increasing significantly the capacitor the power factor gets close to unity. For the 2 pole configuration it reaches value 1. A very large capacitor value decreases the power factor as seen from Fig. 13.

5 Data base

The acquired waveforms were saved in Labview measurement (.lvm) files and offline analyzed using a computer calculus program, MATLAB. The RMS values were determined from the motor’s input signals, the phase angle, the input and output power were calculated. All the electrical and mechanical values were acquired using the Labview program previously described. Due to the large number of experiments made a database was created. For the database
programming and administration two open source programs were used, Eclipse and PostgreSQL.

In fig 14 is presented the Java application window that allows the data selection using 4 criteria: brake number, number of poles, motor number and rotating direction.

![Fig.14. Database Java application.](image)

After the 4 selections were made the sorted data can be seen in the next tab as in Fig. 15. Also the Java interface allows manually insertion of values into the database.

![Fig.15. The sorted experimental data.](image)

Since the experimental data were analyzed using MATLAB, a connection between the program and the database was created. Using SQL specific routines was possible database sorting and data import/export from the workspace into the database.

For the tested CRSPIM there is no optimal value for all operating regimes. The rated capacitor value indicated by the manufacturer assures a high starting torque. For the 2 pole winding the capacitor variation is around 5 μF, respectively 10 μF for the 12 pole winding.

Hence the construction of a electronically controlled capacitor is necessary for the efficiency improvement of all operating cycles. Also an automated data acquisition and off-line analysis system was created.

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References


6 Conclusions

Based on the experimental results, the optimal capacitor values change significantly according to torque for both windings.