A RELIABLE COMPUTATIONAL SYSTEM FOR ESTIMATE THE PERFORMANCE CURVE OF PMDC MOTORS

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Abstract

This paper proposes a reliable methodology to automatically evaluate the main aspects of an electrical motor, based on the signals generated from a bench test. In order to achieve this challenge, was developed a computational system to calculate and verify the permanent magnetic direct current motors' linearization reliability. The characteristic curve of the motors (current vs. torque) and (speed vs. torque) are plotted based on some real points of the curve, which are measured through some equipment, for instance, the Hysteresis Dynamometer. A drawback of the Dynamometer is its susceptibility for several external factors, which contribute directly for the data dispersion. These factors can be: voltage flotiation, temperature, errors in the internal devices (voltage source, voltmeter, and ammeter) and mainly, variation in the internal temperature of the motor, during the test. The Least Square Method was employed to calculate the residues between the measured curve and the linearized curve. For this computation was used the LabView as a programming tool. The linearized curve utilization, by the motors performance analyses, guarantees more precision in the design for several applications in the PMDC motor. In this way, the overload and an eventual motor burn can be avoided, increasing its lifetime.

1. Introduction

The permanent magnet DC motors (PMDC), presents the features of current and linear speed in an increasing and decreasing rates, respectively, according to the resistant torque growing and the constant potential difference [1]. These features: current, torque, and speed, are measured in Dynamometers to obtain the performance data.

A reliable linearization, with the lowest possible residue, assures the correct analysis of the motor's functional features, in any working range [2]. In this way, the motor will always work inside of the work range, as designed, avoiding over dimension, overload, lifetime reduction and burning motors.

For this research, were used the programming tool LabView, acronyms of Laboratory Virtual Instrument Engineering Workbench. The LabView is a graphic programming language that uses icons, instead of text line, to create the applications. Different from languages based on text, which instructions determine the program execution, LabView uses a programming based on data flow that determines the processing. The user interface is built by a set of tools and objects. It is possible to create test, simulation, measures, data acquisition, instruments controls, data register, analysis and report generation’s application. Also executable files and shared libraries can be generated, as DLLs - Dynamic-link library, since this it is a 32 bits compiler [3], [4].

The main goal of this paper is describe the reliable computational analysis developed, in order to verify the performance curve linearization of the PMDC motors.

2. PMDC Motor

The PMDC motor is considered affordable and one of the most efficient motors, due to the stator that generates its own magnetic field [5].

In the PMDC motors, the field winding conventionally applied in other electrical machines of DC (direct current), are replaced by the permanent magnetic. The rotor is composed of armature windings connected to the switch segments, which are connected to the brushes. The Figure 1 shows the main components of this electrical machine.
2.1 Torque and speed’s features in the PMDC Motors

In the PMDC motors, the features of velocity and current are linear according to the torque rising, for a constant potential difference, as shown in the Figure 2. Based on this characteristic, the performance’s curve of the PMDC motors can be plotted [1].

3. Methodology

There are situations where a table of points is obtained experimentally, and obtaining the analytical expression of some curve that better fits the set of elements is desirable.

The analyses performed in this paper are related to the magnitudes of the PMDC motors, obtained through the dynamometer. This equipment provides a database, where is necessary adjusting, to get the characteristic among torque, current and speed. In this way, the motor can be analyzed in any work condition, giving the current level or resistant torque.

In the Figure 3, is presented a general diagram of the proposal methodology, in order to obtain the measures of speed, current and torque of the motor in the dynamometer, and also estimate the linearization curve of the PMDC motor performance.

Initially, in the set-up step, the nominal features of the motor, such as: voltage, current, speed and mechanic power, are loaded in the database of the control unit of the dynamometer. This procedure it intends to avoid damages to the motor.

After the set-up, the dynamometer provides the data of current, rotation, torque and voltage, based on his gradual increase or decrease of the resistant torque. During the extraction of the data, it is always checked if the values are inside of the working range, as specified in the set-up. In case of any discrepancies in these values happens, new configuration are carried in the set-up.

After performing the measures, the generated data is stored in a log file. This data presents great dispersion, so a process of linearization of the curve, and finally generate the complete curve performance of the PMDC motor is need.

Basically, there are three mains methods of linearization: Least Square [6], Least Absolute [7] and Bisquare [8], commonly applied for the linear adjust. The least square method is commonly used as linear regression and provides a solution to find the best fit of the curve, through a set of point. Due to its robustness and its simplicity of implementation, was adopted the Least Square Method in this paper.
3.1 Least Square Method

The Least Square Method (LSM) is a technique used to determine the parameters of a functional relation between two magnitudes. The LSM also can be defined as the most probable value of a unique magnitude, measured several times [9]. The methodology is a mathematic procedure, which determines the best adjust of the curve for a set of points, minimizing the sum of the deviation square [10].

The technique of linear adjusts of the least square, is generally applied as linear regression, and provides a solution for the problem of finding out the best adjust of the line through a set of points.

3.2 Adjust of the line

The method is used for adjust a set of points to the line \( y = ax + by \), where \( a \) and \( b \) are parameters to be determined. In summary, we are interested in minimizing the distance of each point \((x_i, y_i)\) measured in each point \((x_i, a + bx_i)\) of the line, as shown in the Figure 4.

![Figure 4: Distance between a point until a line.](image)

As Mathematic language we can describe the least square problem as following:

Consider: \( x = [x_1, x_2, x_3, \ldots, x_n] \)

Given a vector function \( f : R^n \rightarrow R^m \) with \( m \geq n \), we want to minimize \( \| f(x) \| \), or equivalent, to find \( x^* = \text{local minimum for} \ F(x) \), where:

\[
F(x) = \frac{1}{2} \sum_{i=1}^{m} (f l(x))^2 = \frac{1}{2} \left\| f(x) \right\|^2 = \frac{1}{2} f(x)^T f(x)
\]

4. Experimental Results

In this section are presented and discussed the experiments accomplished to validate the proposal methodology.

4.1 Test Set-up

The Figure 5 [11] shows the bench-test, where it was performed all the tests. This characterization unit is composed mainly of three basic systems: a) Controller: Responsible for managing the bench test functionality, receiving all information and features of the motors. Also it work in the dynamometer control (handling the sensors spreading in the bench), the energy supply and protecting the dynamometer and PMDC motor; b) Dynamometer: applies the resistant torque in the motor (in test) and the c) Supervisory: in charge of the visualization, generation and data log export.

![Figure 5: Set-up test - Magtrol 2003.](image)

4.2 Program interface

The Figures 6 and 7 presents the program interface of the methodology. Basically, it can be divided in two main steps: **Step I.** Data input and processing: after the data acquisition, from the dynamometer, they are stored in the log file and delivered to the system. In this step, it starts the data processing and the linearization calculus; **Step II.** Error calculus: with the new data, is calculated the error for each method of linearization.
In this kind of programming each block represents a little structure of the text command (codes). In this way, the programming becomes more efficient, reliable and faster because it increases the reusability.

Figure 6: Program interface – Step I.

Figure 7: Program interface – Step II.

4.3 Results

In the Table 1 are shown the achieved results, using the LMS method for the linearization of the curves: Torque, Velocity and Current. In order to evaluate the quality of the methodology, the RMSE (Root Mean Square Error) and percentile were calculated, according to the real data. The RMSE was chosen due to be the most common measure to evaluate numeric prediction [12].

Table 1: Results of the linearization

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>RMSE</th>
<th>Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque</td>
<td>0.06</td>
<td>6.26</td>
</tr>
<tr>
<td>Speed</td>
<td>76.9</td>
<td>2.40</td>
</tr>
<tr>
<td>Current</td>
<td>1.58</td>
<td>5.11</td>
</tr>
<tr>
<td>Voltage</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The results indicate good levels of accuracy, obtaining a global error of 3.44%.

The Figure 8 presents the graphs of the linearization and the measures in the motor. The measured points are characterized by the little squares and the red line is the linearization performed by the method. The graphs 1a, 1b, 1c and 1d, represent: torque, velocity, current and voltage, respectively.

Figure 8: Measure data and curve adjust.

Through the curves, presented at the Figure 8, the complete performance curve of the PMDC motor can be obtained from some calculus. The graphic, in Figure 9, shows that curve. In this curve is possible to visualize the measure data, which is represented by squares, in relation with the linearization, that is represented by continue lines.
Were performed tests with 15 motors, with different features. In all tests, was found results closer or even better, than the presents in Table 1. The reliability of the results, can be attributed mainly to two factors: the methodology employs the Least Square Method, which is very robust in this case, and the high-quality of data acquisition.

5. Conclusions

In this paper we proposed to do the analysis of a reliable mathematic-computational method and the linearization of the measure curves of a PMDC motor, in dynamometer. The performance curve is essential for the functional analysis, applicability and also for the motor validation, after its conception. The residual values observed in the Table 1, show that the method proposed by the curves adjusts of torque, current, voltage and speed has low variability in relation to the measured data. So, the method shows itself useful in the analysis for the motors application, being possible to analyze the performance of the PMDC motor in any operating range, given the current or torque of the motor, based on the performance curve.

The result indicates an error rate between the methodologies and the real measured values which were below 7%. This result is a great achievement, once the variability for the performance characteristic in an industrial scale manufacture is about 10%.

6. References