

# Measurements on a DC Motor using Imaging and Virtual Instrumentation Techniques

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**Abstract** – The paper presents an experimental system that implements different measurement techniques of some parameters related to a DC motor. The measurement is not made in a classical way. Thus, the measured values like speed, vibrations, temperature and geometrical sizes are taken from images or are illustrated in distinct colors so the user has a friendly interface to relate with. The proposed applications can be of two types: static measurements on a motor that is not running, and dynamic monitoring tests, on the same motor while it is in operation. The system is a combination of hardware and software elements for data acquisition, vision inspection and virtual instrumentation techniques. The proposed monitoring methods could work together, and the correlated measured data could be used in a comprehensive predictive maintenance program.

**Keywords** – *Imaging, Sensors, Virtual instrumentation, motor testing, maintenance, LabVIEW*

## I. INTRODUCTION

In measurements, the using of an image like source of consistent information is used more and more because of the development of modern hardware and software systems. As a result, vision based methods consisting of image acquisition, processing or of phenomena image representation are the start point in creating a new type of measurement systems other than the classical. Among their various applications, such systems are also more likely to be used by researchers and practitioners as generic instruments to measure and/or monitor physical phenomena [1].

We cannot imagine today's world without the presence of electric engines, whether they be motors or power generators. Today's technological world cannot be imagined without them and their contribution in most common applications: vacuum cleaners, sewing machines, hair dryers, digital cameras, car alternators up to high complexity like industrial actuators, transport, elevators, industrial power generators, wind generators.

Damage to the above mentioned equipment is normal and this process starts from the installation. If this is not detected in time, it may cause electrical failures and liabilities. The purpose of preventive maintenance and

testing programs is to identify the factors that lead to malfunction and to provide remedies. With such programs, potential elements that can cause equipment failure are detected and corrected. Appropriately maintained equipment reduces stagnation by minimizing catastrophic damage. In order to have a good functioning of the electrical equipment it is essential to implement effective testing and maintenance programs.

The aim of this paper is to present a complex measurement system dedicated to a DC motor in static and dynamic conditions using exclusively images and virtual instrumentation techniques. The key features of this stand were: to check the motor conditions, to measure its geometric sizes, to measure the motor speed, to check the temperature at the case surface and to monitor the vibrations of the motor during the start, run and stop time. The reason for choosing to test a DC motor is that of its wide field of applications and of its features: high torque, speed controllability, portability, good speed-torque characteristics, easier and accurate modelling, adaptability to several types of control methods [2].

Correct monitoring of motor performance and predictive maintenance of motor systems are necessary to improve reliability and to extend the motor life and reduce the overall operating cost of the facility [3][4].

## II. OFF-LINE TESTING OF THE MOTOR

In a preventive maintenance program, an off-line inspection of an electric motor at the right time extends its lifespan and relieves the user of unnecessary repair costs. This avoids problems caused by unplanned interruptions and, implicitly, low productivity.

An indication about the condition of the electric motor can be given by making a visual inspection on it. In this process, some physical and mechanical conditions are checked: the mounting holes and feet attached to the motor, the debris in the openings, external damages like the discolored paint on the motor that could indicate an overheating, the bearings, the fan etc. Often it is difficult to get a direct view or measurement of the element to be inspected. This kind of work takes a long time and is inaccurate [5]. That's why an imaging system using diverse types of cameras can be a solution in the off-line motor testing.

The proposed experimental system is dedicated to visual checking and to the dimensional measurement of the tested dc motor, being configured for two types of images. The first one is obtained using amicroscope DNTcamera typefor checking the physical and mechanical conditions, like in Fig.1. Here the user can easily observe and evaluate the motor commutator condition after some image processing is made.

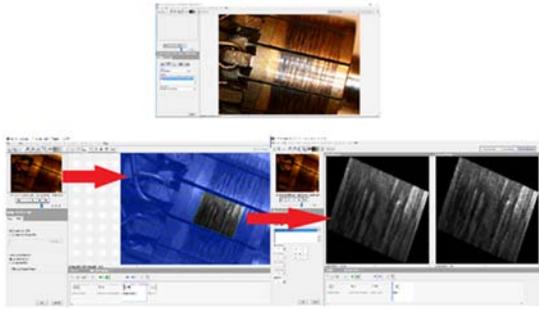


Fig.1 The commutator condition

The second type of images were obtained with a TOPICA TS-1002DS camera, configured for dimensional measurements, like in Fig.2.

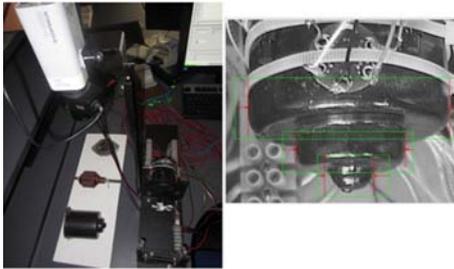


Fig. 2. The dimensional measurement system

The main characteristics like lengths, relative positions, areas and angles can be measured and compared with those from motor specifications.

The virtual instrumentation software LabVIEW and its dedicated add-on LabVIEW Vision and Vision Assistant from National Instruments can be used in image acquisition and processing. The images can be captured in two steps: directly on the entire system and then separately on each mechanical part of the motor.

The images based offline system can improve the quality of classical human examination and can be easily integrated in an automated vision inspection environment.

### III. ON-LINE TESTING OF THE MOTOR

#### A. Motor speed measurement using the stroboscopic method

Many applications with dc motors need to detect the rotational speed. Conventionally, the speed measurement is made using devices attached to the motor shaft such as

encoders, tachometers and Hall sensors. All of these can be a source of failures and they increase cost and maintenance [6]. Sensorless methods have the advantage of not requiring any external devices to be attached to the motor.

A stroboscope is an instrument used to make a cyclically moving object appear to be slow-moving, or stationary. It consists of either a rotating disk with holes or a flashtube which produces brief repetitive flashes of light. Usually the rate of the stroboscope is adjustable to different frequencies. When a rotating or vibrating object is observed with the stroboscope at its vibration frequency (or a submultiple of it), it appears stationary.

In the proposed system, the stroboscopic principle applied in the motor speed measurement is illustrated in Fig. 3.

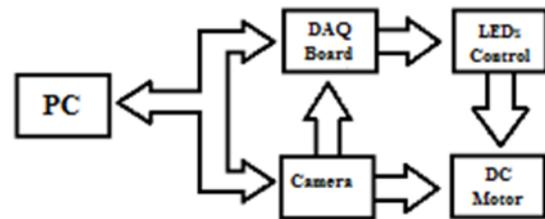


Fig.3. Motor speed measurement system based on stroboscopic method

The implementation of the stroboscopic system is illustrated in Fig 4. The camera, LEDs and rotor shaft propeller are positioned in a straight line. The camera permanently records the status of the propeller. The four LEDs are mounted on a special stand, so they do not enter in the camera's field of view, but at the same time they can light the propeller [7]. LEDs are controlled via the data acquisition board.

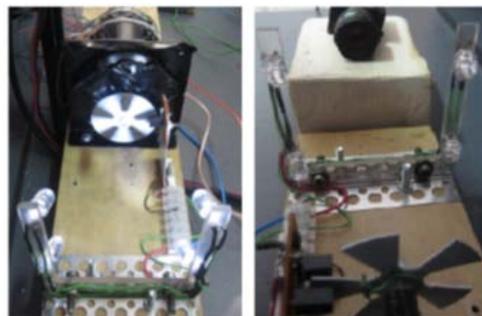


Fig 4 The motor speed measurement system

Frequency and duty cycle values are automatically established using an algorithm implemented in LabVIEW. The algorithm determines when the value of the light illumination pulses frequency is equal to the motor rotation speed. When these two frequencies are equal, the camera perceives that the propeller stays in place and thus the stroboscopic phenomenon occurs. The algorithm permanently changes the frequency and duty

cycle (PWM) of the light illumination pulses until it receives the command based on the propeller image stability. At that time, on the front panel of the application in Fig. 5, the speed value will be displayed.

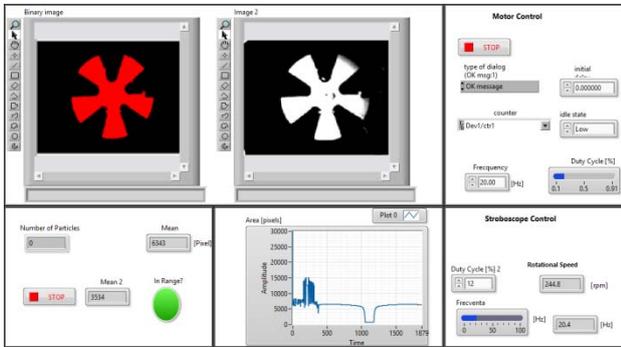


Fig.5 Motor speed measurement. The front panel application

When the image of the propeller is stable it is sensed by using the image processing techniques. During the acquisition process, a mean of the last five frames is realized and the resulted image is processed. First the image is binarized, then two morphological operators are applied: one for removing small particles and next one for rejecting border objects. Finally, a particle analysis is made as it is represented in Fig.6. The computed area (in pixels) is compared with an upper limit and a lower limit (5%) and when it is inside this interval it means that the frequency of the lighting LEDs is the same with the rotational speed. In that moment, the virtual instrument stops and the value of the speed can be read.

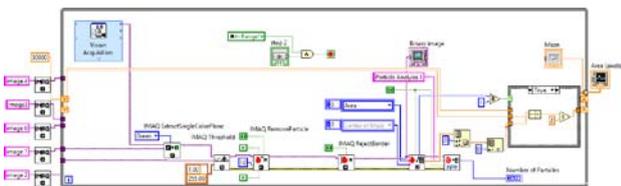


Fig.6 Imageprocessing inapplied stroboscopic method

When the image is stationary and a multiple of propeller area occurs, the speed can be also measured, but for accuracy, the algorithm will change automatically the lighting LED flashes in such a way that the frequency will be in a one to one ratio with the motor rotational speed.

The system is design in such a way that the speed of the motor is controlled using a pulse width modulation (PWM) principle and a data acquisition board configured on counters outputs. The rotational speed was measured in parallel with an encoder measurement method and the results were very close. The method is robust and completely automated.

### B. Temperature measurement of the motor case

A noncontact thermal inspection of a motor, using images, is safe and it can give a glance of what kind of

heat signature the system is giving off. By comparing images obtained in different moments the differences in temperature will indicate what to measure first with other measurement tools. A motor's heat signature is an indication of its quality and condition. If a motor is overheating, the windings will rapidly deteriorate. The overheating could have different electrical causes: phase unbalance, bad connections, abnormal heating on the electrical supply. On the mechanical side, there could be some shaft bearings issues. In that sense the bearings tend to run hot for several days before fully failing. Motor case temperature can also be a good measurement point. To correctly interpret the motor case temperature and to have a baseline for comparison, the temperature measurements of the motor are taken when it is running under normal parameters.

In the proposed experimental system, the thermal image of the motor case is obtained. Thus, twelve LM35 type temperature sensors, a data acquisition board and LabView software are used. The sensors are evenly positioned on the motor case like in Fig. 7.

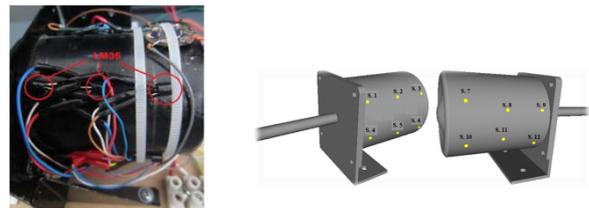


Fig. 7. The temperature sensors placement on the motor case

The sensors outputs go directly into the data acquisition board. For temperature monitoring, a 3D motor model (wrl file), was implemented in SolidWorks. The sensors are placed virtually on the model in the same positions like in reality. By using the LabVIEW Sensor Mapping application, a real-time mapping of the temperature values on the motor case was obtained like in Fig. 8.

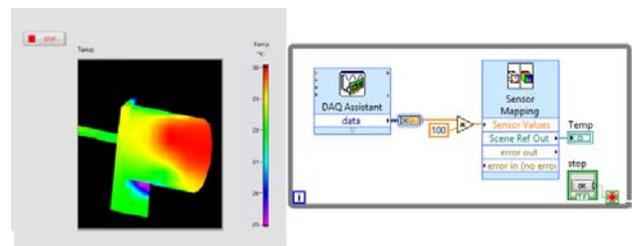


Fig. 8 Temperature monitoring of the motor case

### C. Vibration measurement during the operation of the motor

In case of rotating machines, most of the mechanical failures come from unbalances (50%), misalignments (45%), roller bearing problems (60%), and improper dimensional fittings. By adding these percentages, it results a value over one hundred percent. And this is

because the unbalance and the misalignment can both lead to the roller bearing wear and early failure. The vibration is one of the earliest indicators of motor health. The vibration inspection is a very sensitive method and by using it one can detect an issue much earlier than thermal inspection, long before components are damaged.

Vibration analysis techniques, in particular for determining mechanical faults are used to make the diagnosis of faults in motors using vibration signals from three spatial axes. The measurement of vibrations is made using accelerometers as primary sensors. The vibration signals are then acquired with the data acquisition boards and analyzed with special algorithms that detect the characteristics associated with different fault conditions.

Vibration analysis techniques are grouped in three categories, time domain, frequency domain and time-frequency domain [8]. The last type of technique has the advantage that the vibration signals are represented in both time and frequency domain. This characteristic can help in analyzing vibration signals which are non-stationary. Among the various time-frequency analysis techniques the Short Time Fourier Transform (STFT) is one of best, easiest and the fastest used for monitoring the conditions of a machinery [9]. By using the spectrogram images, one can easily compare the vibration signatures of the motor at different moments.

In the proposed experimental system, the vibration analysis is made using a three-axis ADXL335 accelerometer. The sensor uses a single X, Y and Z axis detection structure. Mechanical alignment can be calibrated at the system level. The sensor is placed on the motor case at its highest point, in order to better perceive engine vibrations like in Fig. 9.

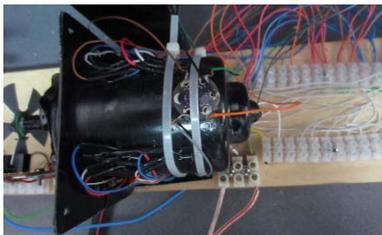


Fig. 9 Accelerometer placement on the motor case

Signals on the three axes are acquired in the LabView programming environment and analyzed in the frequency-time domain using the spectrograms obtained using the STFT method. The analyzed signal on one of the accelerometer axes is shown in Fig.10.

The image of the obtained spectrogram is a good reflection on the motor vibrations at start-up, during operation and in the stopping moment. The color depicts the magnitude of the energy of the signal at time,  $t$ , and frequency,  $f$ . The spectrum from red to blue corresponds to the energy level from strongest to weakest. Each accelerometer axis has in this way a vibration time-frequency signature.

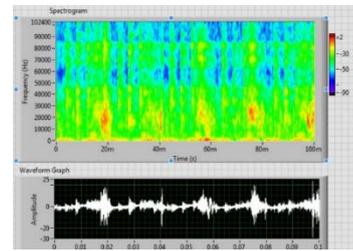


Fig.10 Time-frequency analysis of motor vibrations

#### IV. CONCLUSIONS

Off-line and on-line testing of dc motors are very important for successful implementation of predictive maintenance programs. Combined, they present a comprehensive picture of motor health. We propose that this picture to be composed of different images that reflects the motor physical and mechanical conditions, rotational speed, case heating or vibration signature. With image processing, monitoring will be much simpler and more intuitive, allowing to quickly detect damages.

Monitoring the operation of an electric motor through imaging and virtual instrumentation techniques can be important in achieving reliable and good quality devices.

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