

A VI FOR THE AUTOMATIC TEST OF INDUCTION MOTORS

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Abstract: The paper proposes a Vi-based method for the automatic determination of the mechanical characteristic of induction motors. The signals coming from an inertial start-up transient are acquired and digitally processed, instead of processing the signals from the traditional load Tests. In order to overcome the inaccuracy given by the stator winding resistance variation due to the temperature variations, the stator winding resistance is constantly measured by means of a dedicated circuit and processed together with the other signals. The results of experimental tests are shown and the method accuracy is discussed.

Keywords: Induction Motor Test, Vi-based Method

1 INTRODUCTION

The determination of the mechanical (torque vs. speed) characteristic of the induction motors is seldom obtained by means of direct tests, essentially because of the practical difficulty in performing such tests when the power of the motor under test is larger than hundreds of kW. Moreover, only the part of the characteristic related to stable operating conditions can be obtained, although also the other part is of interest in assessing the motor performance.

Indirect tests are therefore usually employed, although their accuracy is deeply limited by the approximations typical of these methods and the conventional estimation of many parameters of the motor model.

An alternate method is based on the acceleration tests, and in particular on the inertial start-up transient. This method was first proposed by [1,2] and applied by [3] to an automatic measurement equipment. The major inaccuracy sources of this method are the deviation between the "dynamic" mechanical characteristic obtained by the start-up transient and the desired "static" one, and the difficulty in keeping into account the actual stator winding resistance during the transient.

The following sections will briefly recall the theoretical fundamentals of the employed method, propose a solution to monitor the winding resistance during the start-up transient, show the realized experimental set-up and the results of the experimental tests performed on a test motor and finally discuss the method accuracy.

2 THEORETICAL FUNDAMENTALS

During the motor inertial start-up, the torque balance on the motor shaft is expressed by the equation:

$$T = J \cdot \frac{d\Omega}{dt} + T_f(\Omega) + T_v(\Omega) \quad (1)$$

where:

- T : driving torque.
- J : moment of inertia or the rotating parts.
- Ω : rotating speed.
- T_f : constraining torque due to the friction.
- T_v : constraining torque due to the ventilation.

The term $J \cdot \frac{d\Omega}{dt}$ in (1) represents the inertial torque during the start-up transient and varies from an initial value equal to the motor start-up torque to a zero final value. This consideration suggests that, during the start-up transient, the instantaneous motor operating conditions equal the steady-state

operating conditions corresponding to a mechanical load equal to the inertial torque in each instant plus the related friction and ventilation torque values.

The study of the induction motor dynamic showed [1,2] that this assumption is verified if the motor mechanical start-up transient begins after the end of the electrical insertion transient and if the mechanical start-up transient is properly slowed down.

Both conditions can be experimentally obtained. The first one can be obtained by keeping the rotor still till the electrical insertion transient is over by means of a brake, or by supplying the motor after having put it in reverse rotation. The second condition can be obtained by increasing the moment of inertia of the rotating parts by means of a flywheel coupled to the motor shaft. Indications are given in [1] on how to dimension the flywheel.

Although, from a strict theoretical point of view, the more the start-up transient is slowed down, the more the dynamic characteristic approaches the static one, from the practical point of view slowing down the start-up transient results in an unpredictable increase of the stator winding temperature and hence in a Variation of their resistance. This means that the stator losses vary during the start-up transient and therefore this Variation must be kept into account in order to evaluate the motor driving torque correctly.

The modern Virtual Instruments (VIs) feature enough digital signal processing capability [4] to allow for tracking the stator winding resistance through the start-up transient and keep it properly into account in the determination of the motor mechanical characteristic. The test method and equipment proposed in [3] has been hence reconsidered in order to improve its accuracy by keeping into account the actual stator winding resistance values.

3 MEASURING EQUIPMENT AND PROCEDURE

The measuring equipment is schematically depicted in Fig. 1. The induction motor under test (M) is coupled, through a joint (J), to a flywheel (F). Two line-to-line voltages and two line currents (according to the Aron connection) are acquired by an Analog-to-Digital Conversion Board (ADCB) together with the speed signal. The same ADCB acquires also a dc current injected into the stator windings and the dc voltage drop across the same windings.

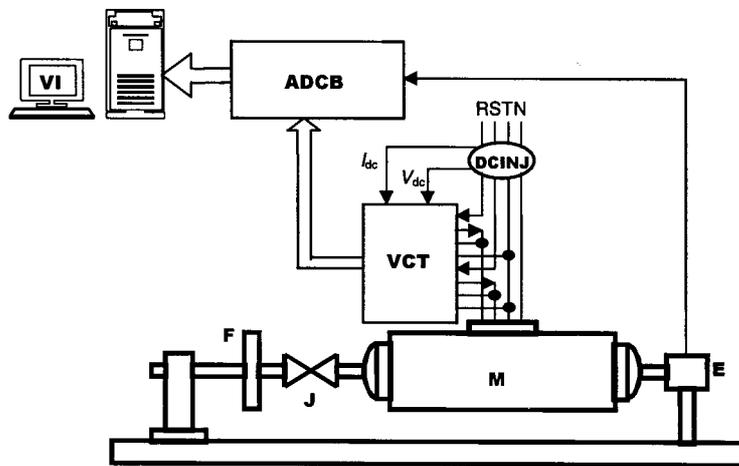


Figure 1. The realized measuring equipment

The injection circuit of the dc current (DCINJ) is a modification of the circuit proposed by [5] and is schematically reported in Fig. 2, together with the circuit employed to extract the dc voltage drop across the stator winding.

The speed signal is transduced by an optical incremental encoder (E) featuring 250 pulses/revolution and then converted into an analog voltage by means of a Frequency-to-Voltage Converter.

The ADCB is equipped with 8 single-ended input channels in the range ± 10 V. The input channels are simultaneously sampled and converted into digital by means of a 12-bit ADC. The maximum sampling rate is 500 kHz on a single channel.

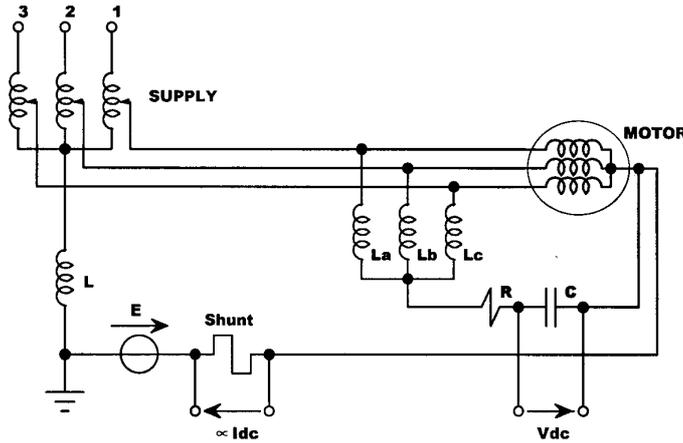


Figure 2. Employed circuit for the on-line measurement of the stator winding resistance

Due to the above specifications for the ADCB, all acquired voltage and current signals must be adjusted to the input channel dynamic and insulated. Since the motor currents can be distorted, the bandwidth of the transducers must be as high as possible. Hence the electronic transducers (VCT) shown in Fig. 3 have been realized. High-precision non inductive resistors have been used for the voltage divider in the transducer voltage section, followed by an AD215BY isolation amplifier that ensures a 1.5 kV insulation level. With the employed components, the gain inaccuracy, after calibration, is in the range $\pm 0.2\%$, which corresponds to a 0.12% gain uncertainty. The zero-flux current transformer ensures an insulation level of 3 kV and the gain inaccuracy is in the range $\pm 0.4\%$, which corresponds to a 0.23% gain uncertainty. The phase displacements between the input and output signals in the voltage and current transducers result in a phase displacement, between the voltage and current channels, in the range $\pm 2 \times 10^{-3}$ rad, which gives a phase uncertainty of 1.5×10^{-3} rad.

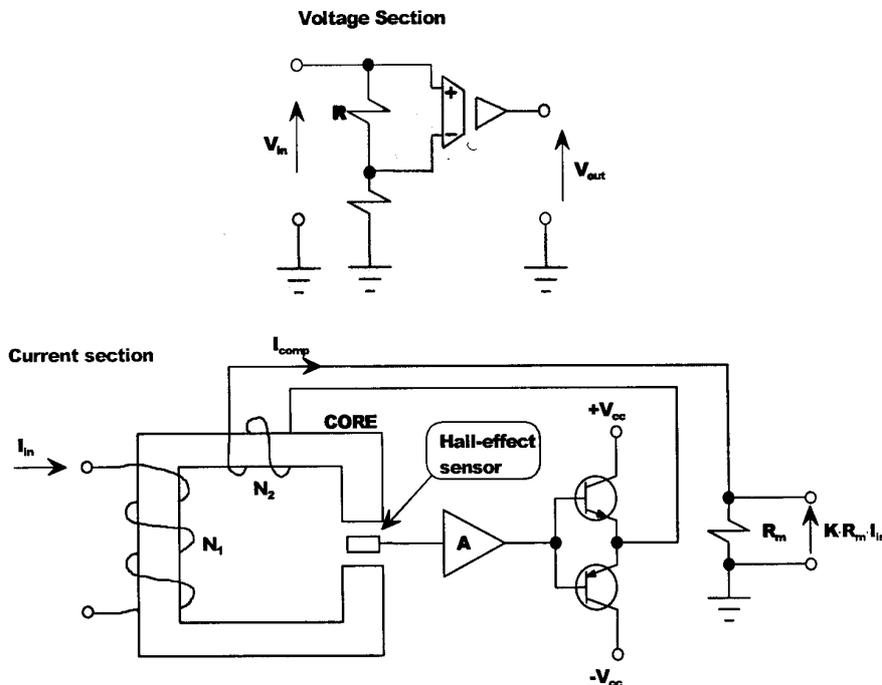


Figure 3. Realized voltage and current electronic transducer

The realized VI acquires the test signals coming from the start-up transient with a 12.8 kHz sampling rate, which corresponds to a coherent sampling condition of 256 samples/period with a supply voltage frequency of 50 Hz. Once the whole transient has been acquired, the VI starts processing the acquired signals and, for each period of the supply voltages, evaluates:

- the rms values of the voltages and currents;
- the active power drawn by the motor, obtained as the mean value of the instantaneous power determined from the acquired line-to-line voltages and line currents, according to the Aron theorem;
- the mean value I_{dc} of the injected dc current and V_{dc} of the related dc voltage drop. In this way, the residual alternate component is removed and the resistance of the stator windings can be determined as $R_s = 3 V_{dc} / I_{dc}$;
- the losses in the stator windings are evaluated as $p_s = 3 R_s I^2$, where I is the mean value of the rms values of the two acquired line currents;
- the stator winding losses and the iron losses (predetermined by means of no-load tests [3]) are subtracted by the measured active power, so that the power transmitted from stator to rotor is determined;
- the transmitted power is divided by the synchronism speed, so that the electromagnetic torque transmitted from stator to rotor is determined;
- keeping into account the mechanical losses (predetermined by means of no-load tests [31]) the motor torque is finally determined and associated to the mean value of the speed signal in the considered period of the electrical signals.

The VI displays all above measured quantities both in numerical and graphical format (Fig. 4). It continues to acquire the input signals also after the transient is over and to evaluate the rms values of voltages and currents, the motor active power, the stator winding resistance and the motor speed (Fig. 5), so that the motor steady-state operating conditions can be monitored and the measured values employed also in no-load tests or direct tests.

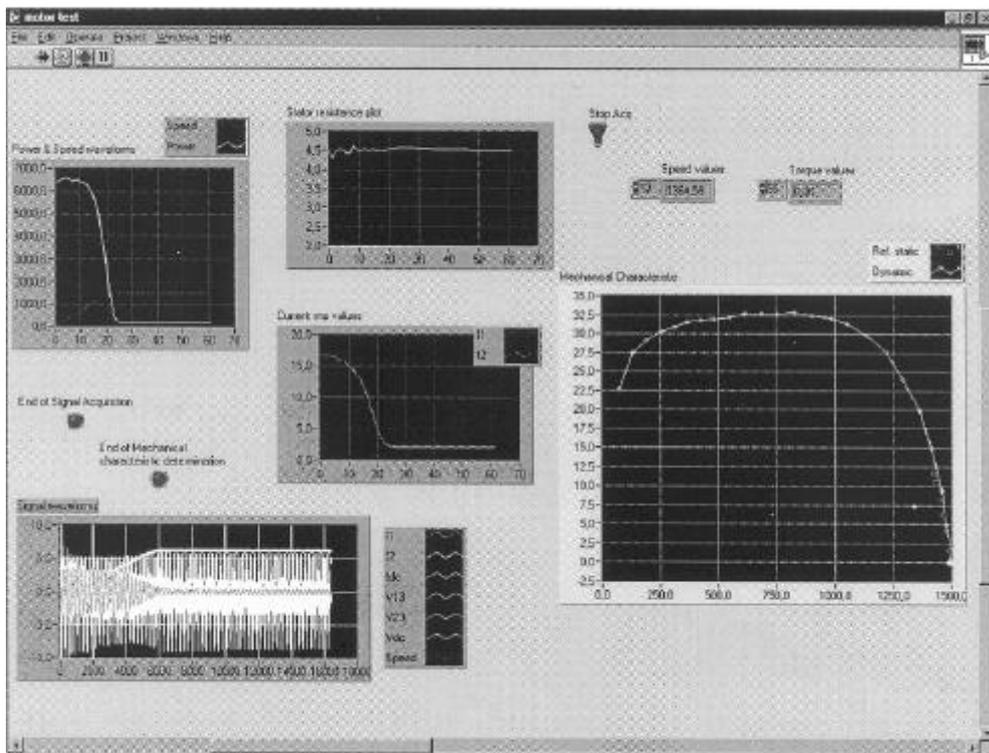


Figure 4. Front panel of the realized VI, showing the measured mechanical characteristic

4 EXPERIMENTAL RESULTS

The proposed method and equipment was tested on a 4 pole, 1.5 kW induction motor, with 380/220 V rated voltage. Before acquiring the start-up transient signals, the motor was loaded with its rated load until it reached its thermal steady-state, so that all measurements could be referred to this condition. No-load tests at the rated voltage and at lower voltages were then performed in order to evaluate the iron losses and the mechanical losses.

The start-up transient was then generated and all above reported computations performed on the acquired signals. The VI front panel in Fig. 4 shows the obtained mechanical characteristic, as well as the plot of all other considered quantities during the start-up transient.

5 MEASUREMENT UNCERTAINTY

The estimation of the measurement uncertainty starting from the uncertainty of the single measurements is not totally significant with the proposed method, since its capability in approaching the static mechanical characteristic depends on how much the start-up transient is slowed down.

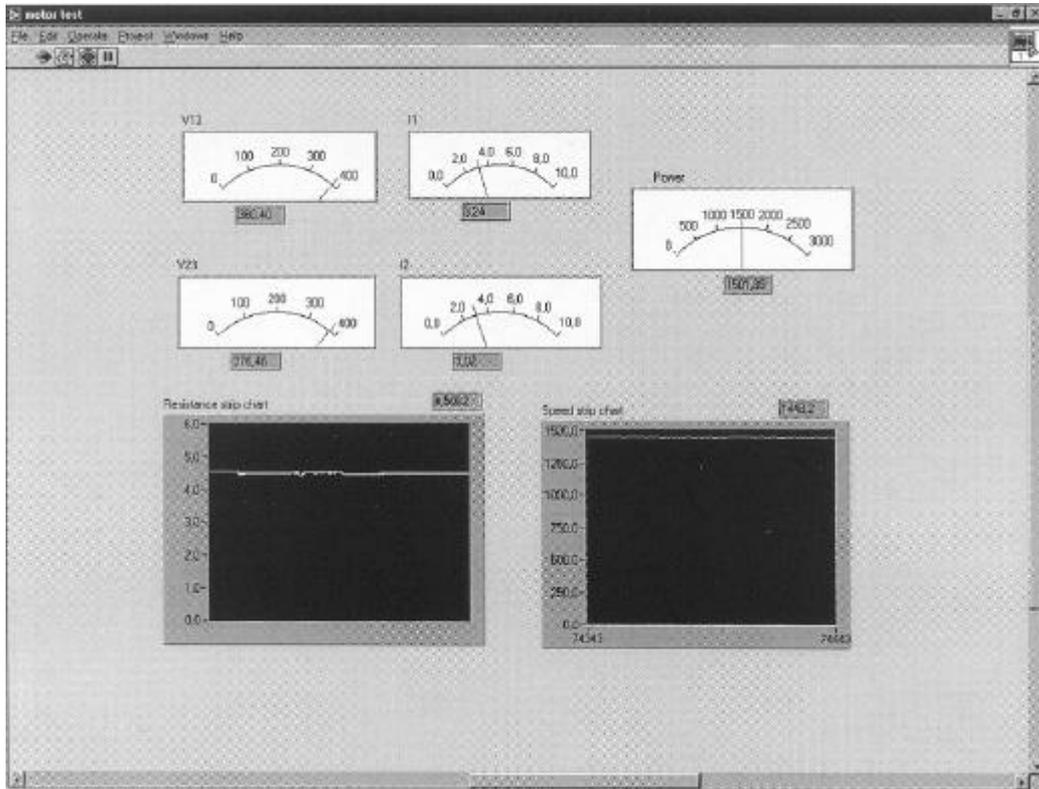


Figure 5. VI Front Panel section dedicated to steady-state measurement

Nevertheless, the uncertainty in the measurement of the voltage and current rms values and in the measurement of the active power can be estimated starting from the calibration data of the voltage and current transducers reported in the above section 3. According to these data and under the assumption of coherent sampling conditions, the uncertainty in the voltage, current and power measurements can be totally attributed to the gain and phase uncertainty of the VCT. Under the additional assumption that no correlation is present (the possible correlation cannot be easily taken into account and its effect will be considered by properly setting the coverage factor) the relative uncertainty in the voltage rms value measurement is 0.12%, the relative uncertainty in the current rms value measurement is 0.23% and the relative uncertainty in the active power measurement is 0.37%. The uncertainty in the speed measurement was estimated by measuring the incremental encoder output frequency, at constant rotation speed, by means of an electronic counter featuring a relative uncertainty, in the selected range for the frequency measurement, of 0.05%. The relative uncertainty in the speed measurement is therefore 0.16%.

As for the uncertainty in the measurement of the stator winding resistance, it was estimated by measuring the winding resistance with an automatic bridge with a 0.1% relative uncertainty and comparing this value with the value obtained from the employed circuit. The estimated relative uncertainty of the measured values is 0.17%.

The above estimated uncertainty values allow for stating that the torque values are expected to be evaluated with an uncertainty of 0.58%. A coverage factor of 2 was then considered, so that an expanded relative uncertainty value of 1.16% can be assigned to the torque measurements. This means that the torque inaccuracy can be estimated in a $\pm 2\%$ range of the measured values. Of course the above assumptions are valid provided that the start-up transient is properly slowed down. In order to verify this assumption from the experimental point of view too, some direct tests were performed on the motor, after coupling it mechanically to an electromagnetic brake.

Fig. 6 shows the mechanical characteristic obtained by the proposed method and the points obtained by the direct tests in the stable region of the characteristic. The rms deviation between the

"dynamic" and "static" characteristics was estimated in 1.89 Nm, which corresponds to the 5.76% of the maximum measured torque value. Considering the inaccuracy of the electromagnetic brake, this value is in good agreement with the above estimated uncertainty.

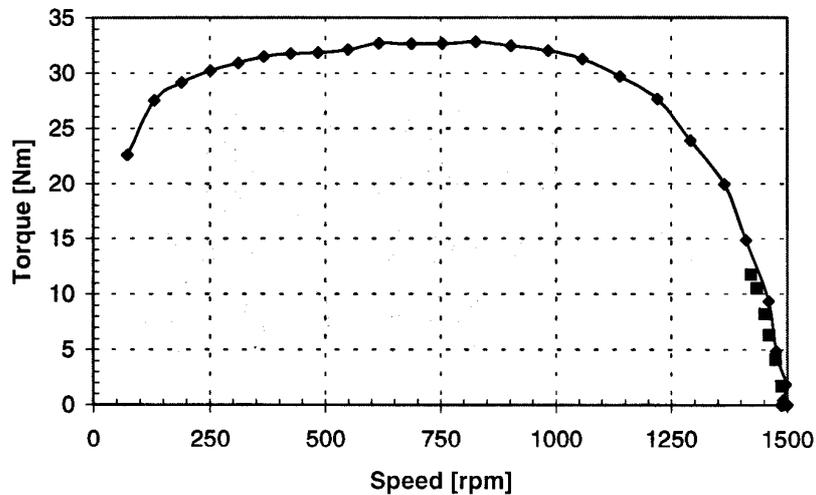


Figure 6. Measured mechanical characteristic:

- ◆ dynamic characteristic
- static characteristic

6 CONCLUSIONS

A measurement method and related equipment, based on a VI architecture, was proposed for the evaluation of the mechanical torque vs. speed characteristic of the induction motors. The method avoids the drawbacks of both the indirect and direct tests, and can be performed in an automatic way, being based on the digital processing of the signals coming from a start-up transient.

The main advantage of the proposed solution, with respect to similar solutions proposed in the past, is the capability of this method to perform an on-line measurement of the stator winding resistance, so that its values can be properly taken into account in the determination of the mechanical torque along the start-up transient.

The experimental work performed on a test motor proved the method effectiveness and proved that the method accuracy is good enough for most practical applications of motor test, especially for the final tests of mass production of low voltage, low and middle power motors.

At last, the proposed method gives the whole mechanical characteristic, including the part corresponding to non-stable motor conditions, which are not easily obtainable with direct tests.

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