

Efficiency classes of three-phase, cage-induction motors (IE-code) software

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Abstract— The Efficiency classes of three-phase, cage-induction motors (IE-code) software is presented in the paper. Software possibilities, application and generating results are explained.

Keywords- Efficiency classes; induction motors; software

I. INTRODUCTION

Using an energy-efficient motor is very important in order to save electrical energy. Three-phase induction motors of low/power (up to 7.5 kW) participate in advanced industrial countries about 26% in overall electricity consumption [1]. For this reason, the IEC was in 2007 developed the standard IEC60034–30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code) [2]. In this standard the following efficiency classes: Standard (IE1), High (IE2), Premium (IE3) and Super-Premium (IE4) are defined.

The motor producers are obligated to label on rating plates which efficiency classes a motor belongs to. In order to test the accuracy of these nameplates and to determinate classes of motors that are not marked, the Technical Faculty in Čačak has developed an appropriate measuring device and appropriate software. With it, it is possible for a very short time of effective tests, to perform more tests and to instantly get the most substantial energy characteristic: the test motor efficiency versus load.

II. DESCRIPTION OF THE MEASURING DEVICE

The measuring device consists of:

- a specially designed stand that supports the test motor and a friction brake which acts as a load
- Measuring instruments for electrical quantities: NI cDAQ-9172 (Legacy NI CompactDAQ Chassis), NIDAQ NI 9227 (4-Channel Current Input), NI9402(4 Ch LVTTTL High-Speed Digital I/O Module), NI 9225 (3-Channel, 300 Vrms Analog Input Module), 3 current transformers and speed sensor
- New software developed in LabWIEV package

The stand is constructed so that it is possible to place and load motors of various terminal measures. The stand on which the motor is placed and fixed is sliding. It can be moved both in the longitudinal and in transverse direction. Special pads also enable height adjustment.

Loading the motor is done with the friction brake which is designed so that it can be connected to motors with different terminal measures: diameter and axial height of the shaft.

For the measurement of electrical motor parameters (voltage and current of the three phases) measuring acquisition equipment of National Instruments Company was used.

CDAQ system with the specified components was used. Accuracy of the measuring instruments was tested with the instrument: Tektronix Digital Multimeter DMM4050/4040. With this instrument all instruments were calibrated. Needed accuracy that is predefined by the standard – IEC60034 2 was confirmed [3].

To measure the speed of the motor the fast NI9402 card, which measures the signal frequency, is used. The signal was obtained from the HALL sensor which is mounted near the motor shaft. On the motor shaft a permanent magnet is placed that provides signals for the sensor. By this simple and low-cost contactless solution using an encoder is avoided and also the problems associated with its installation.

III. MEASUREMENT PROCEDURE

The measurement procedure consists of multiple, interrelated steps. These are:

- 1) *Entering the basic motor parameters*: nominal voltage, current, power, speed, torque, frequency, resistance of the stator winding
- 2) *Choosing the test type*:
 - a) *Short circuit test*
 - b) *No load test*
 - c) *Eh star test*
 - d) *Efficiency test*

The order of testing is as follows [4]:

- 1) **Measuring the resistance of the stator winding**
- 2) **Motor warming-up test** that is done at full load and rated voltage, until the winding temperature become steady. The temperature of the motor is measured by a temperature sensor mounted on the motor. Thermal equilibrium is reached when the temperature of the machine does not vary by more than a gradient of 2 K per hour.

3) **Loading test** for a total of 6 load levels *in the range* of 25% to 150%, at constant voltage. From this test the average temperature of the stator windings, the line load currents, the input power and the speed of rotation *are* measured.

4) **No load test** with 6 voltage values in the range of 20% to 50% (3 measurements) and 60% to 125% (3 measurements). From the tests the following values are obtained: the line values of voltages and currents, the input power.

5) **Short-circuit test** in which the rotor is locked to prevent rotation. The test is performed to determine the parameters of the equivalent scheme.

6) **Eh-star test** to determine the additional load losses (stray-load losses). This test requires the uncoupled motor operating with unbalanced supply voltage. By the procedure described in 60034-2-1 [3] from the measured data additional load losses are obtained. The test circuit is according to Fig. 1. The supply voltage should be varied for the six test points. These points should be chosen to be approximately equally spaced between 150% and 75% of rated phase current measured in phase V (I_V). When starting the test, one should begin with the highest current and proceed in descending order to the lowest current. The losses should be expressed as a function of the square of the negative sequence current.

7) **Efficiency test**. Integrating all the data previously obtained from the tests it is possible to determine the dependence of efficiency of the motor versus output power. The obtained characteristic is compared with the characteristics defined by the standard IE60034-30. So one can determine which classes of efficiency the motor belongs to.

At the end of the tests a report is generated in which all important measured parameters and calculated values are recorded.

At any time, it is possible to choose the option monitoring to track the current values of voltages, currents, speed, torque and power of an induction motor.

IV. DEMONSTRATION OF THE SOFTWARE

Fig. 2. displays the software for collecting and processing data of each performed test.

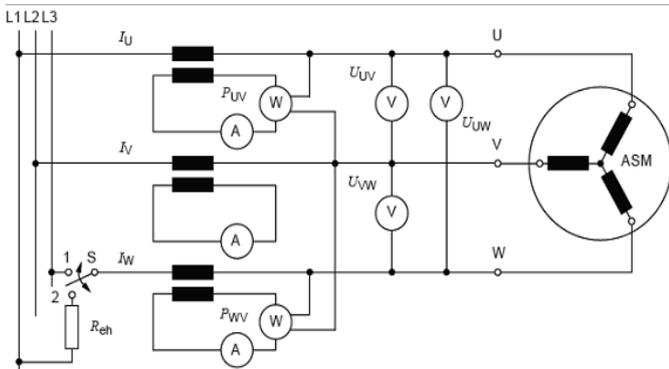


Figure 1. Eh-star test circuit

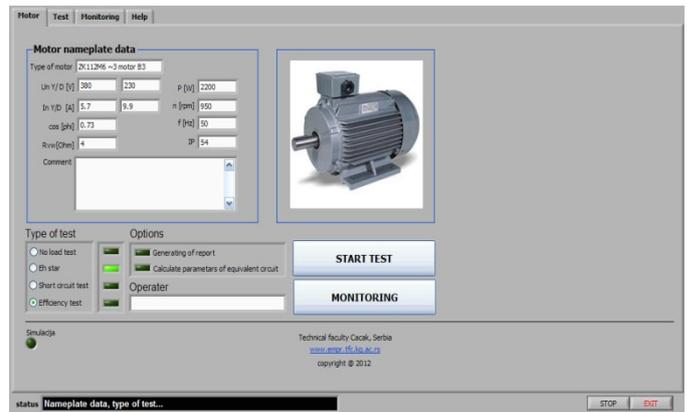


Figure 2. Initial screen display of the software

When starting the program besides entering the basic motor parameters which are described in the previous section, it is possible to select one test that is performed. At the same time there is an option to choose whether one wants report generation and parameters calculation of the equivalent scheme of the induction motor. It is also defined the option of tests performing simulation, where as the results of the measurements, previously obtained measurement data that are stored in a special database are taken. This option is designed to make this program useful in education purposes of students and for demonstration of its capabilities when the software is not connected to the measuring equipment. Monitoring option allows on-line monitoring of speed and electric parameters in any work regime.

During the performing of Short-circuit test, No load test and Eh-star test, similar screen display appears (Fig. 3).

On the screen the three line voltages and currents, the total active and reactive power that motor takes from the network and the speed of rotation can be monitored.

In the upper right corner of the window there are the reference values of the current (for Eh star test) for which the measurements should be performed. When using a three-phase autotransformer the expected values of currents are approximately achieved, one should press the **SAVE** button to save the measurements.

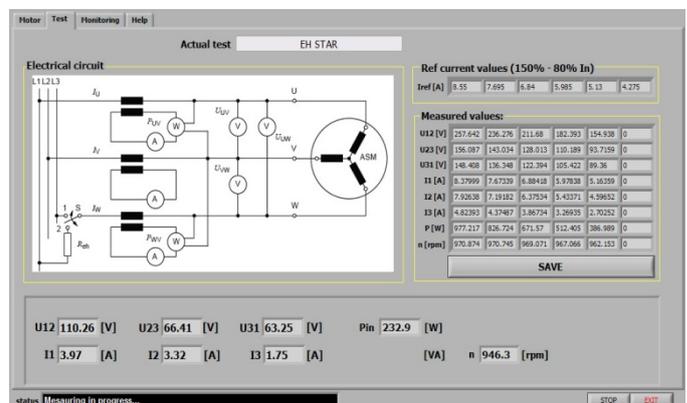


Figure 3. Screen display of Eh - star test method

Software then automatically remembers all the measured values and successively places them in the data base. After completing the test (memorizing the 6 different data sets), the testing ends. The software automatically returns to the initial screen display (Fig. 2).

When selecting Monitoring options one of the three screen displays can be chosen:

- 1) **INPUT PARAMETERS** (Fig. 4.)
- 2) **LOSSES** (Fig. 5.), and
- 3) **OUTPUT PARAMETERS** (Fig 6.)

In the **INPUT PARAMETERS** window it is possible that graphics monitor current values of line voltages and currents and the motor speed of rotation. Also, the current numerical values of these quantities, as well as their calculated mean values (terminal values) can be observed.

In the **LOSSES** window it is possible to track the values of all the losses that occur in the machine, and see how these losses change with the machine operating modes.

OUTPUT PARAMETERS window shows the two graphs in which graph of efficiency $\eta = f(P)$, and mechanical characteristic, $n = f(M)$ are immediately drawn.

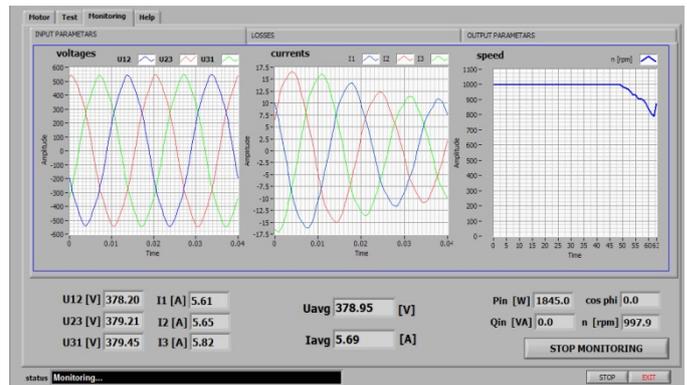


Figure 4. Screen display of INPUT PARAMETERS

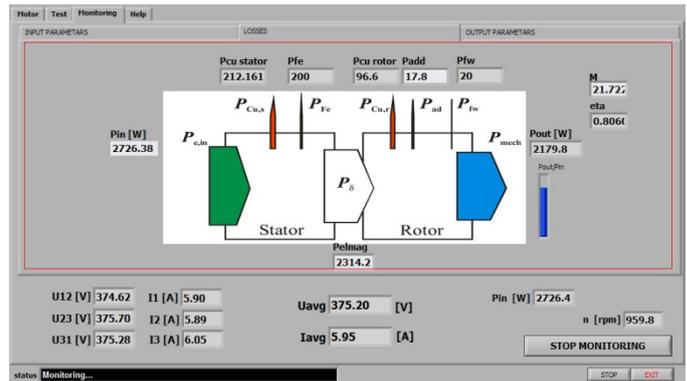


Figure 5. Screen display of LOSSES

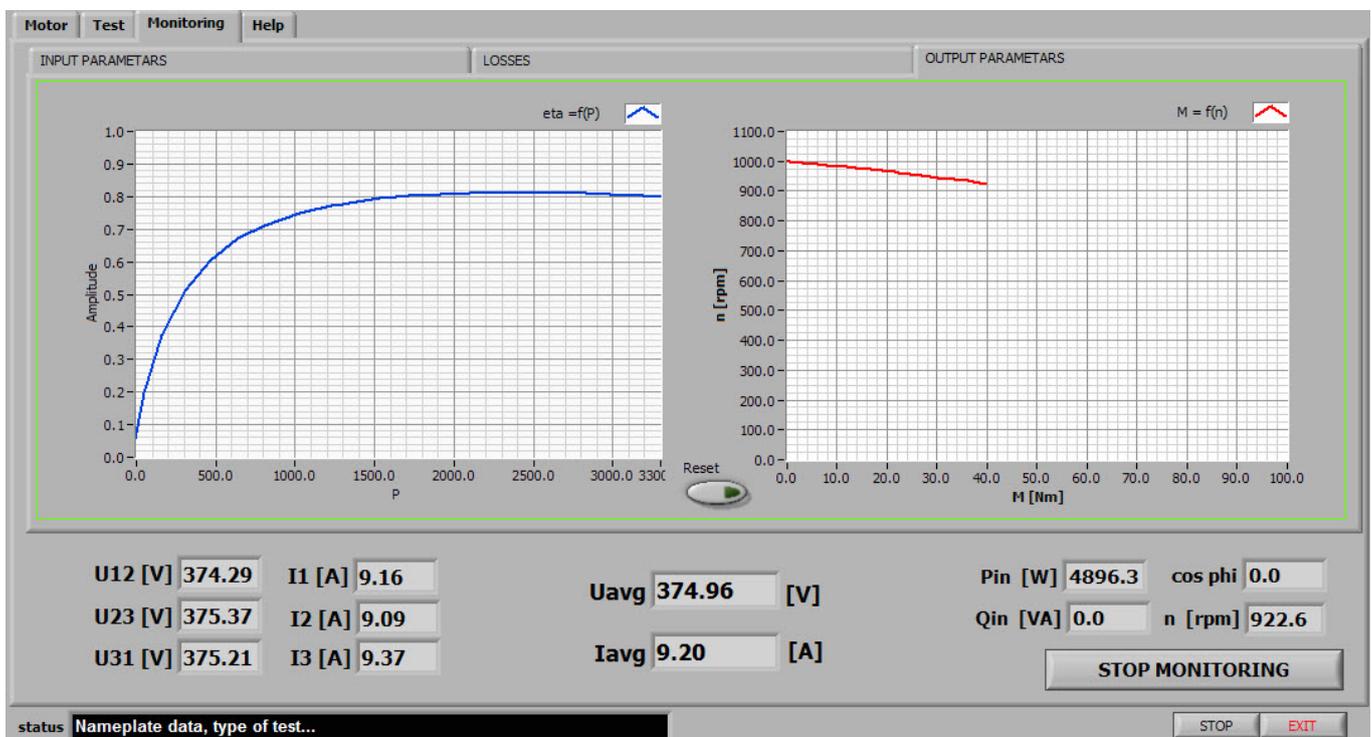


Figure 6. Screen display of OUTPUT PARAMETERS

In **Help** dialog box the basic theory of each derived test is given, so the user of the program can be introduced with the test procedure and computations which software performs.

Selecting **Generating report** option, the Word document, in which all the essential parameters of the performed tests are included, is obtained.

V. DETERMINATION OF MOTOR EFFICIENCY CLASSES

The most important information that should be obtained using the described tests is the information in which efficiency class the motor belongs to. According to IEC60034-30 standard, the formula for calculating the limiting values of Efficiency classes IE1, IE2 and IE3 is defined:

$$\eta_N = A \cdot X^3 + B \cdot X^2 + C \cdot X + D \quad (1)$$

$$X = \log_{10}\left(\frac{P_N}{1\text{kW}}\right) \quad (2)$$

where A, B, C, D are interpolation coefficients (Table I); P_N is given in kilowatts - kW.

Fig. 7 shows obtained efficiency of motors for defined range of powers along with limiting curves that define the efficiency class.

TABLE I. INTERPOLATION COEFFICIENTS

IE code	Coefficients	50 Hz up to 200 kW		
		2-pole	4-pole	6-pole
IE1	A	0.5234	0.5234	0.0786
	B	-5.0499	-5.0499	-3.5838
	C	17.4180	17.4180	17.2918
	D	74.3171	74.3171	72.2383
IE2	A	0.2972	0.0278	0.0148
	B	-3.3454	-1.9247	-2.4978
	C	13.0651	10.4395	13.2470
	D	79.077	80.9761	77.5603
IE3	A	0.3569	0.0773	0.1252
	B	-3.3076	-1.8951	-2.613
	C	11.6108	9.2984	11.9963
	D	82.2503	83.7025	80.4769

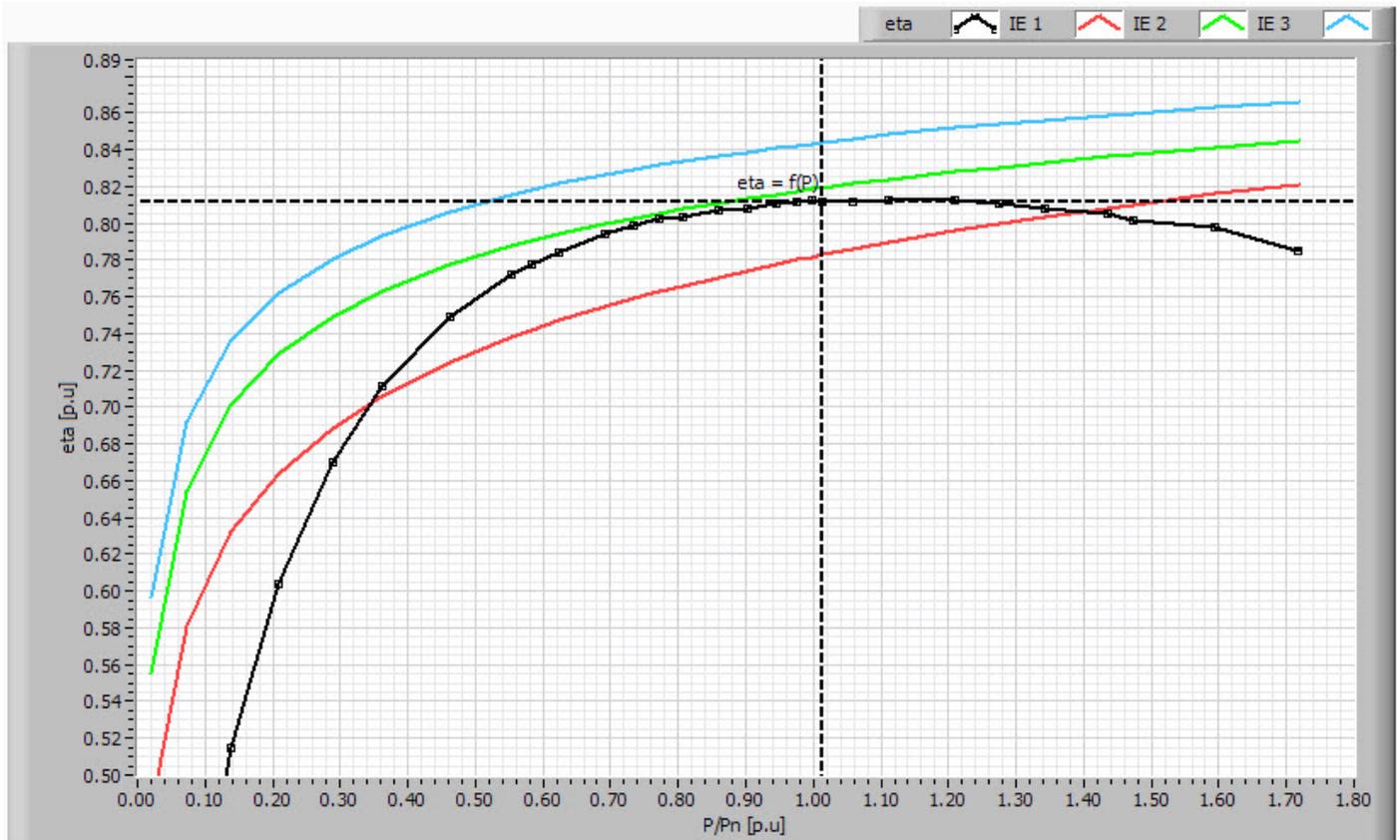


Figure 7. The motor efficiency compared to the curves of energy efficiency class boundaries

From Fig. 7 it can be seen that the testing motor is in the efficiency class IE1 for power range 0.34-1.4 P_n . Above and

below the defined power range, efficiency class is reduced. Around nominal power, efficiency is very close to class IE2.

This is a very important conclusion, because the motors in drives do not often run with the rated load but are usually under loaded. It results in that, although they are declared for one efficiency class, they effectively belong to a lower efficiency class.

The described measuring device and the software are implemented within the project TR33016 “Research, development and implementation of programs and procedures Energy efficiency of electric drives”. Project results are used by the Institute for Standardization of Serbia.

The final part of this project is designing accredited laboratory for determination of energy efficiency of asynchronous motors up to 7,5 kW. Development of the laboratory is in accordance with the standard IEC60034-2-1, which is published in Serbian as one of the results of the project.

The future development steps of measuring device would be to replace the friction brake with an electromagnetic brake, whose construction is in progress. This would ensure better control of motor load. It would be possible to control the changing of type and value of the load. Also, simulation of different operating regimes in which the test motor can run would be better accomplished. During the motor testing, a movie from which can be seen the performing procedure of described tests was made [5].

VI. CONCLUSION

This paper describes the apparatus and created software with which one can achieve basic tests with a cage-induction motor and determine its efficiency class.

The apparatus is designed for low-power motors (up to 7.5 kW). The paper describes in detail the software and the procedure of the tests performing.

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