Aspects Concerning the Speed Control of Low Power Induction Motors Used for Medical Equipment

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Abstract: - The paper deals with a technical-economic analysis of variable speed low power induction motors used in medical equipment drive systems. The study aims at developing of high performance electric drives for medical equipment, with high-speed response and exploitation even closer to the stability limit of induction motors. It appears that in the current economic and technical context, an interference is very necessary between the optimal design of the induction motor in steady state and its performance when operating at variable speed. Computer Aided Design becomes a digital lab, where prototypes are built and tested. In this case, the costs involved for experimenting are zero, and operation of the machine at variable voltages and frequencies is guaranteed. The research carried out showed that a constant torque operation, for minimal voltage and frequency, means a decrease in engine efficiency with 11.7% for the same usable power.

Key-Words: - Low power induction motors, operation at variable voltage and frequency, medical equipment.

1 Introduction

The term of “medical equipment” is comprehensive, covering virtually all of the equipment that serves the medical act. For medical devices, the driving electric motor is considered a component of precision, not an auxiliary component [10-15]. The electric motors used in medical equipment must meet the highest standards of safety, reliability and precision [24-25].

The medical equipment market includes a wide variety of practical applications: active biomedical devices for muscle testing and training for the most important joints and limbs, equipment for mobility and mobility therapy, lifting patients and beds, medical centrifuges etc.

Using induction motors to propel patient’s trolleys (carts) was analyzed in a project [15] which involved the use of a 24 V battery as a power source. Using a three-phased static converter of voltage and variable frequency, controlled by a microcomputer, a frequency between 10 and 50 Hz needed to power the asynchronous motor is obtained to achieve the necessary travel speeds.

Next, an analysis of the variable speed induction motor operation, in terms of energy and economic, was conducted [1-7]. The induction motors used in medical applications are built in a wide range of power (from a few watts to several kW) powered from three-phase networks, or through static converters.

Relative to the size and power for the usual engines, the medical market is covered by induction motors followed by synchronous motors, brushless DC motors, the synchronous motors prevailing as to the disadvantage of a higher cost.

Induction motors are widely used in the construction of medical equipment due to their robust construction, safe operation, low costs. Induction motor’s cost of sale is determined by the technological process of production in the company, by certain specific regulations, and by the dynamic evolution of the raw materials free market.

Also in the category of major concerns is the consumption minimizing of natural resources and energy used to manufacture an electric car, reducing polluting emissions, recommendations made by the European Union since 1990 [7-9], [14], [25].

Analyzing the evolution of large manufacturers of electric cars, we see that the use of computer assisted conception techniques is increasing the company’s competitiveness by reducing costs and execution deadlines, and by increasing the creative possibilities of design engineers.

Computer-aided design has the next advantages: on short-term, reducing the duration of the project - prototype - electric car cycle by increasing the productivity of the research and design teams, and for long-term, highlighting the creativity and the ability to check certain ideas through numerical simulation [10-23].

Automation and robotics in industry, medicine, household use, etc., resulted in an increase in production of low power induction motors used in drive systems for ordinary medical equipment and ancillary to medical field.

Progress made in upgrading the voltage and frequency converters used to supply low power induction motors in the medical industry, allows speed adjustment over a wide range, thus improving the overall efficiency of the system.

The paper analyzes low power induction motors used in equipment actuation for mobility and mobility therapy. To reduce the manufacturing costs of medical equipment, the standardized electric motors are commonly used. This is possible due to the large number of manufacturers offering a wide range of engines covering almost all specifications for general use.

The paper has an original character and is based on the use of advanced mathematical methods and faster computing means. An analysis of variable speed low power induction motors, used in the construction of medical equipment, is conducted [5], [17]. Improving the design quality can not ignore the conditions of severe electric sized cars with magnetic saturation consideration.

Therefore, this study completes the additional requirements that are imposed for the induction motors used to drive medical equipment.

2 Mathematical Model

For technological reasons, at low voltage and low power induction motors, the stator winding is performed of round conductor (the largest sections using multiple conductors in parallel). In this case the notch is trapezoidal (Fig. 1), and the tooth has a constant width. The rotor is shorted, with normal, oval, aluminum cage in cast construction (Fig. 2).

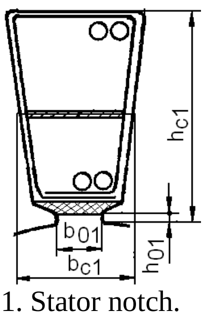


Fig. 1. Stator notch.

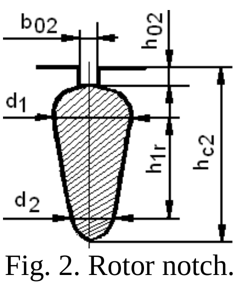


Fig. 2. Rotor notch.

At higher currents, due to the saturation of the ferromagnetic core, the reluctance is increasing on the route lines of transversal leakage flux into the notch. As a result, the leak reactances of the phase windings in the stator and rotor are reduced at the starting by connecting directly to the network.

Usually, low power induction motors have normal cage, which means that the current repression effect during startup is small. Computer aided design activity allows working with a complex mathematical model, where we use rotor parameters changed by the current discharge and magnetic saturation.

From the maximum electromagnetic torque relationship,

$$M_m = \frac{m_1 p}{2\pi f_1} \cdot \frac{U_1^2}{\pm R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}} \qquad (1)$$

at high power induction motors we can neglect the resistances and for *U/f=const.* It results a constant maximum torque [5]. At low power induction motors, and especially at low frequencies, the condition of constant maximum torque can not be true. The numerous simulations made and presented below come to confirm this and to show the quantitative differences.

3 Simulations and Results

An analysis on a concrete example of induction motor was made to see the innovations that occur when the operation takes place at U/f = const. and how these sizes change quantitatively. A three phased low power induction motor with squirrel cage used in electrical actuations was considered, with the rated data: P_N=1,1 kW – rated power; U_N=380 V – rated voltage; I_{1N}=2.50 A – rated current; n_1=1500 rot/min – rated speed; s_N=3.8% - rated slippage.

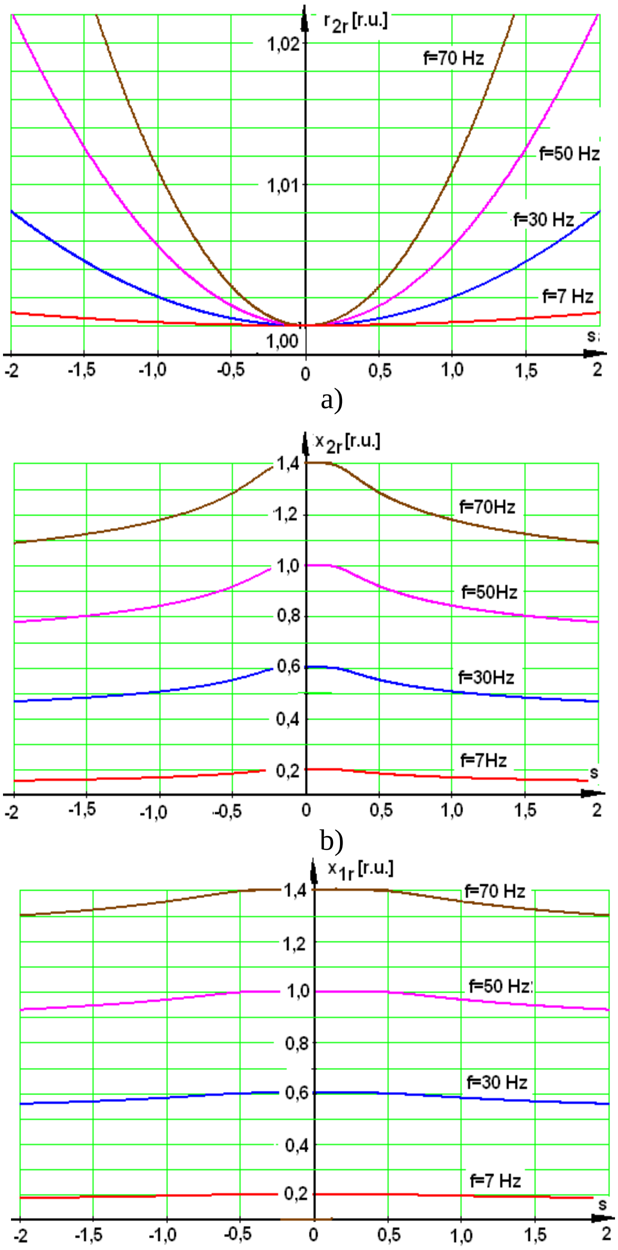
The analyzed engine's related measurements obtained by redesigning, will be considered as reference sizes (for reporting), and marked with index "m". For example: $\cos\varphi_m=0.772$; $\eta_m=0.868$; $M_{max.m}=2.42 \cdot M_N$; $M_{p.m}=1.04 \cdot M_N$; $I_{p.m}=4.75 \cdot I_N$.

The study that was done has the advantage of a precise calculation of the parameters of the machine using advanced numerical methods [14], [16], [23]. With the values of these parameters, the starting and functioning characteristics were rigorously calculated.

The analyzed engine being of low power starts by coupling to the network ($U_{1N}=380$ V and $f_{1N}=50$ Hz). Because during the start the field frequency in the rotor is variable ($f_2 = s \cdot f_1$), the rotor winding resistance changes with very little together with the slippage (Fig. 3.a, $r_{2\xi}=R_{2\xi}/R_2$ where $R_2=3.444\ \Omega$).

It is considered that, during startup, current variation follows a parabolic curve ($I_{p.m}=3.67 \cdot I_N$ la $s=1$); it results [23], [25] the influence of magnetic saturation (Fig. 3.b) on the dispersion reactances of windings, x_{1s} – reactance relative to the stator ($x_{1r}=X_{1s}/X_1$ where $X_1=10{,}47\ \Omega$) and $x_{2\xi s}$ – reactance relative to the rotor ($x_{2r}=X_{2\xi s}/X_2$ and $X_2=5.334\ \Omega$).

The fact that the rotor has a small height oval notch, means that, at startup, the effects of repression and magnetic saturation are negligible ($R_{2\xi}=1{,}0005\cdot R_2$, $X_{1s}=0{,}974\cdot X_1$, $X_{2s}=0{,}964\cdot X_2$).



a)

b)

c)

Fig. 3. Variation waveforms for the induction motor’s parameters at different frequencies: a) with the discharge of the current; b) and c) with the magnetic saturation.

Parameter’s variation at rated current and different frequencies for the analyzed induction motor can be seen in fig. 4.

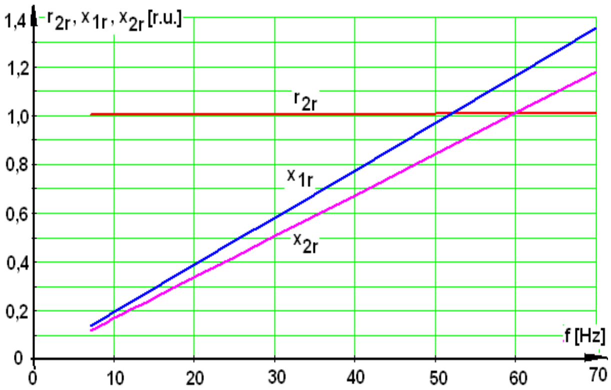


Fig. 4. Variation waveforms of the induction motor parameters at rated load and different frequencies.

Fig. 5 shows the current’s geometric curve for the analyzed induction motor, where for representation were considered the variable parameters (when discharge and magnetic saturation are considered - blue curve) and when parameters are constant (red curve). Analyzing the figure, it results that the starting inrush current is 15.1% higher compared to the situation when constant parameters are considered.

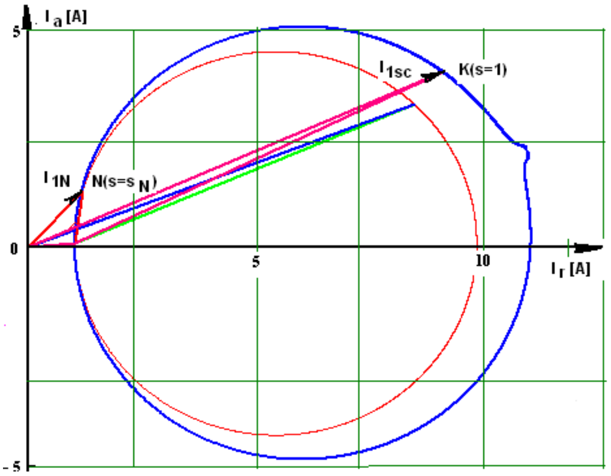
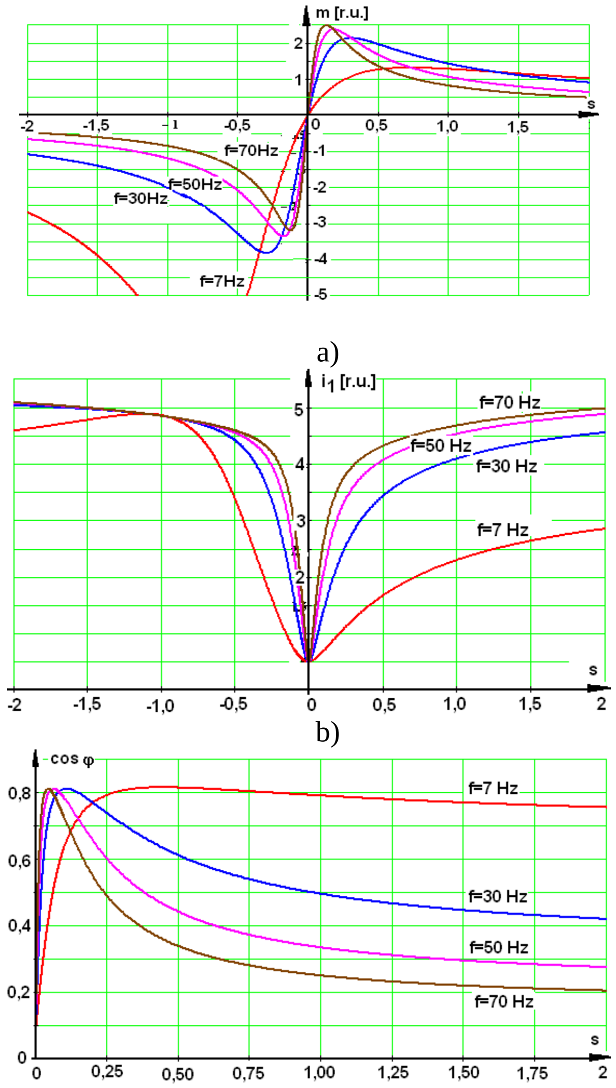


Fig. 5. Current’s diagram for the analyzed induction motor.

With a suitable software program, using the results obtained from the designing stage, some scale drawings and sections for the induction motor.

We intend the calculation, graphical representation and draw conclusions on the induction motor’s operation at low voltage and frequency.

Was taken as reference the ratio $U_1/f_1=220V/50Hz=4.4$ and a study was conducted from a power source which provides $U_1/f_1=4.4=const$. It was taked into account the operation at the shaft resisting torque variable between the limits $M=0\div M_N$, and resulted that the minimum value is $U_1/f_1=30.8V/7Hz=4.4$. In Fig. 6.a the mechanical characteristics are presented for different operating modes (motor, generator and brake), current's curves are given in Fig. 6.b and in Fig. 6.c the power factor's curves. It is observed that at startup, for lower voltages and frequencies, the current is decreasing and the starting torque increases. For the minimum value $U_1/f_1=30{,}8V/7$Hz, results $M_m=1{,}35\cdot M_N$, because in this case the stator and rotor reactances have dropped five times.



a)

b)

c)

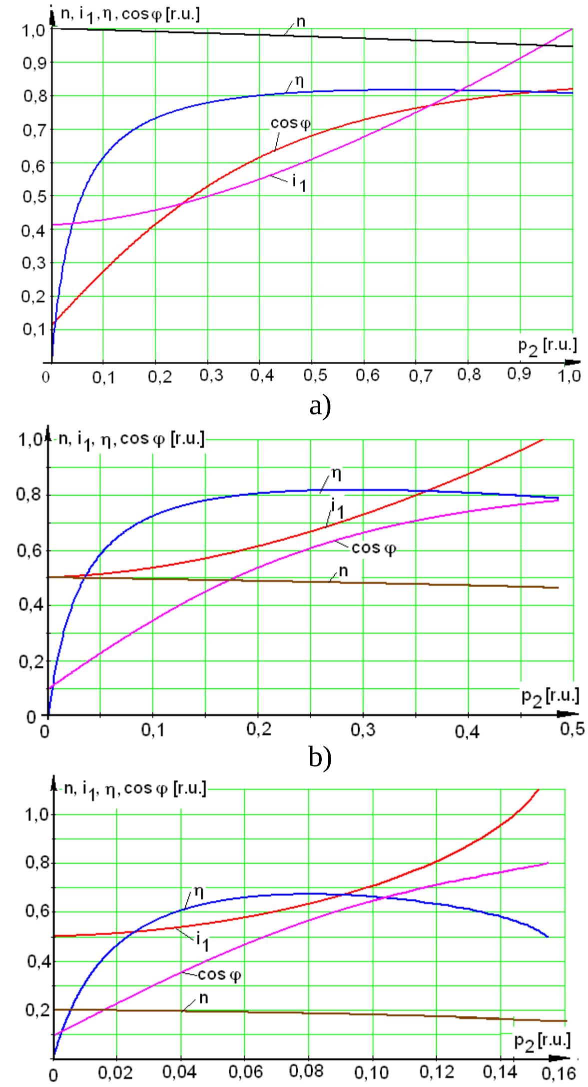
Fig. 6. Characteristics at different frequencies for the analyzed induction motor: a) torque's waveforms; b) current's waveforms; c) power factor's waveforms.

4 Operating at low Voltage and Frequency Analysis

In the following figures the operating characteristics for the analyzed induction motor are presented to highlight the advantages and disadvantages of speed setting $U_1/f_1=const.$ An analysis of the technical and economic indices was made, regarding the speed setting for low voltage and frequency, but $U_1/f_1=4{,}4=constant$. For a shaft resistant torque variable between the limits $M=0\div M_N$, the minimum possible value is $U_1/f_1=30{,}8V/7Hz=4{,}4$. In these conditions, the speed adjustment range is:

$$\gamma=\frac{n_{max}}{n_{min}}=\frac{f_{1\,max}}{f_{1\,min}}=\frac{50}{7}=7{,}14 \tag{2}$$

Fig. 7 summarizes the known operating characteristics and required in the exploitation for the designed induction motor: n – speed, i_1 – line current, η - efficiency (yield), cosφ - power factor.



a)

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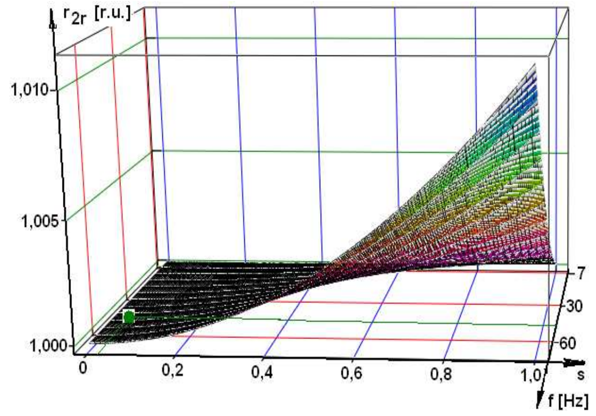
Fig. 7. Operating characteristics for the analyzed induction motor: a) for U_1/f_1=220V/50Hz=4,4; b) U_1/f_1=110V/25Hz=4,4; c) U_1/f_1=30,8V/7Hz=4,4.

The characteristics are calculated in relative units for rated voltage and frequency (fig. 7.a), at minimum voltage and frequency (fig. 7.c), respectively at an average value (fig. 7.b). It is noticed that at low voltage and frequency, the output shaft mechanical power greatly decreases ($P_2=0,16 \cdot P_{2N}$). Because of the low power induction motor's startup is made by direct coupling to the source, it is interesting to see how the current and starting torque changes or the maximum torque at various voltages and frequencies. One observed that at low voltages and frequencies, there is a pronounced decreasing in current and maximum torque and the starting torque slightly increases which is beneficial.

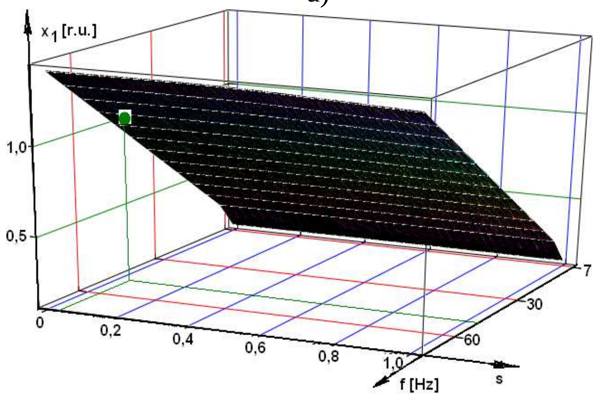
Table 1

Criterion Frequency	m_p (r.u.)	i_p (r.u.)	m_m (r.u.)	$\cos\varphi_p$	r_{2r} (r.u.)	x_{1r} (r.u.)	x_{2r} (r.u.)
f_1= 7 Hz	1,04	1,77	1,06	0,778	1,000	0,141	0,119
f_1= 25 Hz	1,49	3,81	2,05	0,522	1,0003	0,485	0,418
f_1= 50 Hz	1,02	4,48	2,39	0,349	1,0006	0,976	0,867
f_1= 70 Hz	0,84	4,58	2,48	0,278	1,0009	1,356	1,178

In Table 1 we have the concrete results of the analysis regarding the startup characteristics and parameters evolution for $U_1/f_1=4.4=const.$ at various frequencies. Note that at low frequencies there is a high starting current decrease; the maximum torque decreases to the starting torque's level, but the power factor increases.



a)



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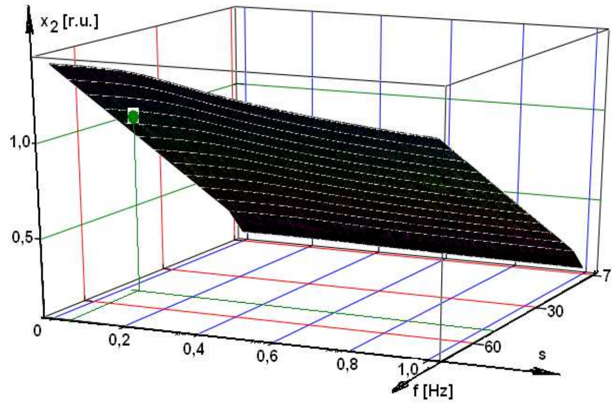

c)

Fig. 8. Specific response surfaces depending on the slippage and the frequency during startup: a) rotor's resistance; b) stator's reactance; c) rotor's reactance.

Further, an analysis of startup's specific characteristics evolution was made, considering two variables: slippage and frequency ($U_1/f_1=4,4=const.$).

The induction motor being of low power, with an oval aluminum cage, the discharge effect during the startup is very low (fig. 8.a). Stator's (fig. 8.b) and rotor's (fig. 8.c) windings reactances vary in lower limits during the startup and at low frequencies becomes negligible.

5 Conclusions

In terms of the engine's startup, the study and the data from Table 1 shows that at low frequencies and voltages the starting current decreases, the starting torque increases, justified by the power factor's increase.

In terms of energy, the operation at low speeds means an increase in energy consumption by 11.7% (for the same usable power at the shaft).

Since the speed adjustment and the energy consumption reduction in operation are current issues, the study for this type of induction motors is justified.

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