IMPORTANCE OF MODERNIZATION OF MACHINE TOOLS IN REDUCING ENERGY CONSUMPTION

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Abstract - Once Romania joins the European Union were entered into force Community regulations regarding the energy saving. One of the ways to reduce energy consumption in manufacturing is to modernize the equipment for mechanical processing. The paper aims to show some of the ways to be followed to achieve this goal, coming with theoretical arguments and demonstrate the effectiveness modernize activities through several examples of measurements done on the equipments. Are presented so the results of measurements of the energy parameters with and without CNC machines with DC and AC drives. Consider such issues as mechanical things, as well as that one concerning electric drives run or not by CNC. It is also proposes a model of economic analysis of energy efficient machine tools, taking into account the authors experience in this field.

Key words: energy efficiency, machine tools, CNC, drives

1. MODERNIZATION OF MACHINE TOOLS

Before 1990, Romania was one of the leading manufacturers of machine tools, being even in the top ten in the world. The impact of the market economy has made the production of machines for mechanical processing to stagnate. Many of these machines have been exported either as such or have been dismantled and sold for scrap, according to the economic prospects of the new owners. Companies that have survived can hardly afford the purchase of new equipments. Therefore a solution for them is to upgrade (remanufacturing) machine tools.

When an equipment is highly damaged, it modernization tends to look for remanufacturing. It is held for about 80% of the mechanical part of the machine, the remainder parts being replaced with new [2]. This can lead to a high performance machine with a considerably lower price than a new one.

Upgrading requires and a complete replacement of electrical drives. The new engines are mainly asynchronous with high performance. There are cases when the rotor asynchronous motor drive has been right from the main shaft of the machine (Figure 1).

The torque and power characteristics according to the engine speed for an 18 kW, used in the operation of the milling head for FLP upgraded equipment are shown in Figure 2.

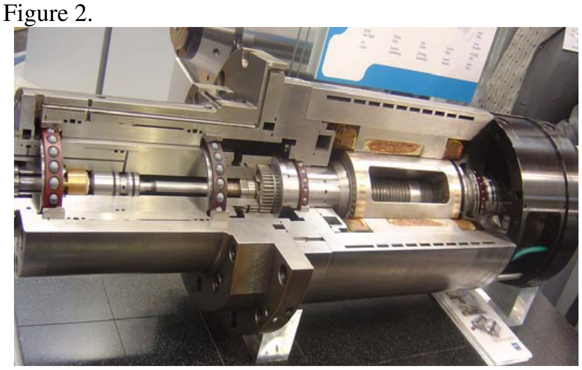

Fig. 1. Construction of a drive motor integrated in the main shaft [7]

Engine powered at 400V AC, has a rated current of 45A at a rated speed of 2810rev/min, can develop a maximum speed of 15000 rev/min, resulting a increasing productivity and smoothness appropriate processing. Because the engine positioning between the frontal and the rear of bearings prevents a shaft vibration and noise, which appearance are inevitable, because the motor rotates over 15000rev/min. As a result of high speed rotation, forced cooling is taken into account, made by rectangular slots practiced in the rotor. Other advantages may be mentioned [5]: reduced noise and vibration due to coupling to the main shaft by toothed belts, simplicity and a compact design construction.

Figure 2 shows the mechanical characteristics of the motor CySpeed , produced by Cy Tec Systems, UK Ltd.

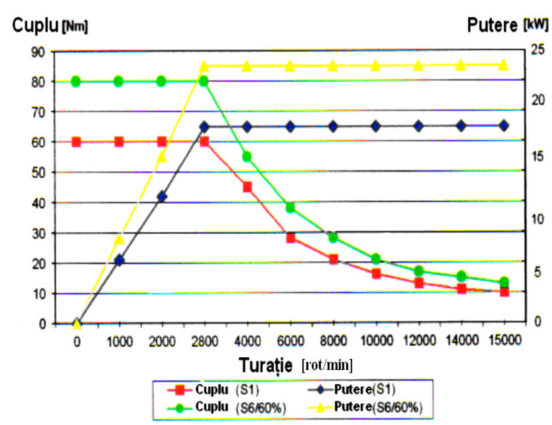

Fig. 2. CySpeed motor engine mechanical characteristics [7]

2. ENTERING NUMERICAL ORDER IN THE MODERNIZATION PROCESS OF MACHINE - TOOLS

Lately technical needs in the field of mechanical processing of materials evolved. The complexity of the machine and the work piece requires a skilled workforce and conscientious. These properties are dominated by specific human subjectivity: fatigue, inattention, lack of timeliness in critical situations, which make humans an operator not so perfect. Over time where occurred new methods which lead to the avoidance of unpleasant situations during the production process. One of these methods was process automation, with its top elements, numerical controls (CNC). These are mainly needed to increase productivity while keeping high precision. Due to the need to increase work productivity and high precision, machine tools have continuously evolved, reaching to remove human error in the execution of parts. As evidenced by the name, numerical controls (CNC) has as main element a computer with an identical structure to a PC, not very strong, but adapted to the needs of industry, meaning enhanced protection for adaptation to the environment and a corresponding reliability requirements. In addition to this CNC system also contains a connection to the peripheral unit, an external memory, an interface between the computer and the machine and a control panel (Figure 3). All this equipments (the system hardware) function according to base and applied programs (software).

The software is based on Windows NT, which is consistent with numerical control software, startup and operation of the original equipment manufacturing. Similarly, the PLC software is integrated in the base software. Interface between the computer and machine - tool ensures functions as: the effective transmission power control signals for commands of actuators, compatibility between the form in which it is sending commands to the executive actuators of the machine tool and the form in which the information is used by the computer.

The machine-tools construction has some particularities due to technical needs related to accuracy. So, the main kinematics chain, structural is similar to the classic machine-tools construction, distinguished by its flexibility of use given by variable speed drives. For asynchronous motors the staples speed is done by varying the frequency of the voltage supply with frequency converters. The kinematics chain, for high speed adjustment in steps [5], it is used a simple gear box with a few steps, with electromagnetic couplings hydraulic or hydraulic ballads.

Advance kinematics chains have the same structure as the classical machine tools. There are some structural features because they have to perform the positioning functions: point by point or delineation. Advance kinematics chain structure is also simplified by using variable speed drive motors and by removing the imprested boxes.

In them construction appeared specifically mechanical elements such as screws and guides with intermediary elements such as screw-nut mechanism which make it possible to transform the rotational movement in the translation movement.

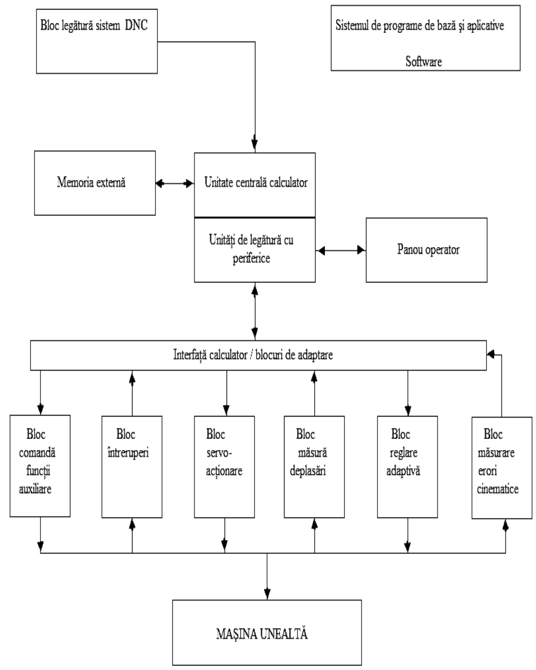

Fig. 3. Block diagram of a CNC system

Their constructive principle consists in replacing sliding friction by rolling friction, which reduces wear (friction coefficient $\mu = 0,\ 01\ .\ .\ .\ 0,\ 02$ is reduced by about 10 times in comparison with that of the conventional trapezoidal screw, with $\mu = 0,1\ ...\ 0,3$) and improves the efficiency of the mechanism [8]. In this way, it is reduces power consumption and can be used low-power actuators.

To meet the construction requirements of CNC machine tools, are used guides with intermediate elements (particularly light and medium machine tools) and hydrostatic guides (for heavy machine tools).

Because achievements in mechanical machine tools, for example by introducing at the movements axes ball screw advances were dramatically reduced friction and effective methods have been introduced to limit vibration. This resulted in reducing the masses set in motion, which results in a clear improvement of their dynamics and a considerable reduction of power at the drive engine, of shrinking to remove gear reducers.

A special contribution has CNC and in drives efficient electrical equipment, and so in the energy savings that they brings. First, it requires a well built construction machine from the mechanically point of view. It must be precise to ensure processing requirements; it must have no rubbing and big games in guides [5].

The direct consequence is a less power required to drive. Secondly, numerical controls allow selection and respect an optimal regime and splintering imprest, imposing and static voltage and frequency converters , which in turn efficiency increasingly higher, economic regime in terms of energy

After upgrading the equipment it can be adopted new solutions to lead to lower energy consumption. An energetically favorable case is the fitting machine tools with static frequency converter drives, and additional numerical controls mounted on them.

New CNC equipped machine will have a small size and high productivity. CNC machine tool requires a well constructed in terms mechanical and ensures accurate processing requirements. Secondly, numerical controls allow selection and compliance regime and an advance optimal cutting and static converters requiring voltage and frequency, which in turn efficiency increasingly higher and a setback in terms of energy. This has resulted from the measurements, where because of the company it could be compared on the same type of machines, some conventional and other types of numerical control equipment is mounted again. So boring and milling machine spindle AFP 160, not modernized, using both major shareholders and for the axis drives DC motors fed by the controlled rectifiers. They provide adjustable speed appropriate to the cutting. Another machine, same type AFP 160 has been upgraded in terms of mounting a numerical controls and replacement of electrical drives. Now the main shareholder and advances are equipped with motors powered by static frequency converter. The new drives can develop much higher speeds with very small acceleration times, in the idea of enlarging productivity.

3. CALCULATION ALGORITHM FOR ENERGY ANALYSIS OF THE MODERNIZATION

The proposed calculation algorithm is based on the fact that old equipment works with DC drives, to be replaced by motors driven by static frequency converters. Therefore, making it is made a comparative calculation of the losses occurring in these two cases.

For DC motors is done balance calculation at rated load.

From the engines catalogs are known:

- Nominal power P_n [kW],
- Nominal voltage U_n [V],
- Nominal current I_n [A],
- Resistance of the rotor circuit R_A [Ω].

Are calculated:

- Absorbed power

$$P_{AN} = U_n I_n \cdot 10^{-3} \text{ [kW]} \quad (1)$$

- Nominal loss:

$$\sum P_N = P_{AN} - P_n \quad (2)$$

- Losses in the windings:

$$P_{bN} = R_A I_n^2 \cdot 10^{-3} \text{ [kW]} \quad (3)$$

Calculation of the efficiency

It is known from the above list data

It is measured the load current I_A

Are calculated

- Losses in the rotor

$$P_b = R_A I_A^2 \cdot 10^{-3} \text{ [kW]} \quad (4)$$

- Mechanical and iron losses:

$$P_{m,f} = \sum P_N - P_{bN} \quad (5)$$

- Total looses:

$$\sum P = P_b + P_{m,f} \quad (6)$$

- Absorbed power:

$$P_A = U_A I_A \cdot 10^{-3} \text{ [kW]} \quad (7)$$

- Efficiency:

$$\eta_{cc} = \frac{P_A - \sum P}{P_A} \quad (8)$$

For motors in upgrading efficiency analysis will be considerate the energy balance of the remanufactured equipment. In this sense, it can be use an algorithm for calculation of the energy consumption for the motor drive based on their load [4]. Therefore it can be use an index based on current consumption measurements, load factor is the ratio between the current regime and the nominal regime:

$$\beta_I = \frac{I}{I_n} \quad (9)$$

For current measurement is not necessary to interrupt the operation of the machine. Following relationships are established so using pointer β_I:

$$\eta \approx \frac{\beta_I - A_\eta}{B_\eta \beta_I} \quad (10)$$

$$\cos\varphi \approx \frac{\beta_I}{A_\varphi + B_\varphi \beta_I} \quad (11)$$

Active power absorbed by the motor system is calculated by the formula:

$$P_A = \sqrt{3}\, UI\cos\varphi \cdot 10^{-3} \text{ [kW]} \quad (12)$$

Shaft power is determined by the relation:

$$P_a = \eta P_A \quad (13)$$

Active power losses in the motor:

$$\Delta P = (1 - \eta) P_A \quad (14)$$

Reactive power absorbed regime is:

$$Q_A = \frac{\sqrt{1-\cos^2\varphi}}{\cos\varphi} \cdot P_A \quad (15)$$

The coefficients A_η, B_η, A_φ, B_φ are experimental and depend on the value of nominal output, i.e. the nominal power factor.

Energy balance on the machine

Losses on engines have three components (Figure 4):

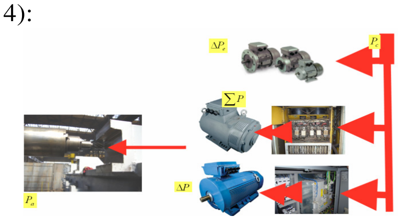

Fig. 4. Flow of energy from a mechanical processing equipment

- Equivalent auxiliary engine losses, ΔP_e, with the efficiency η_e;

- Losses in the main engine, $\sum P$, the DC motor, or ΔP for asynchronous motor;

- Losses on imprest engine, for DC engine, or for asynchronous motor

The total losses on the engine are the sum of these losses:

$$P_{tm} = \sum P + \Delta P_e \,. \qquad (16)$$

Here is such relationship:

$$P_c = P_{tm} + P_a \,, \qquad (17)$$

Where:

P_c is the power consumed by the machine;

P_{tm} is the total looses in the engines;

P_a is used for cutting the output power.

The energy consumption provides information about costs. Time t as the machine works during the day take the statement "U" sections of the production machine. Energy losses during a day are:

$$\Delta W_p = t\,P_{tm} \quad [\text{kWh}] \qquad (18)$$

Energy balance of the machine becomes:

$$W_c = W_a + \Delta W_p \,, \qquad (19)$$

where W_c is the total energy consumed by the equipment and W_a is the energy necessary for the cutting capacity.

$$W_a = P_a\,t \qquad (20)$$

This algorithm is the base of a program for fast calculation of the energy balance for the machine. Introducing evidence for machine tool considered (AFP 160) resulting balance sheet data (Figure 5).

For upgraded machines the power consumption is:

P_c=0,02+0,01+1,16 = 1,19kW,

And for the no modernized machines:

P_c=2,3kW.

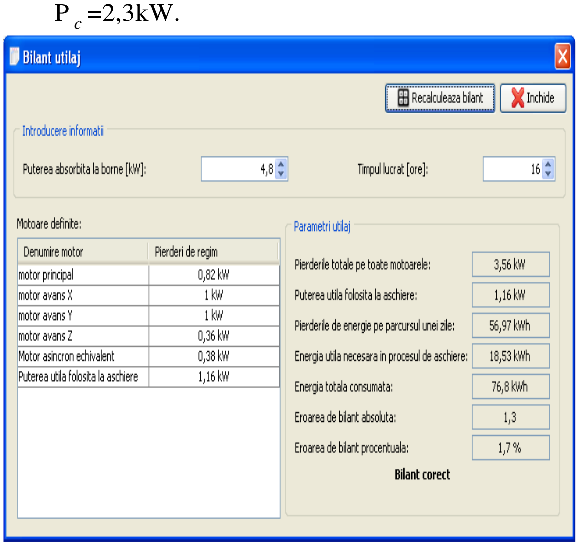

Fig. 5. Capture from the program with results calculation of the energy balance for the machine

4. COMPARATIVE MEASUREMENTS

Measurements were done on boring and milling spindle AFP160, described above, referred to as machine 1 or machine 2. Measurements were done using specialized network analyzers such acquisition and processing energy. It should be noted that the equipment was intended to perform the same kind of interests, and the same operation (boring). Comparing the results of processing chips and found similarity chip size. Measurements were done on both the main power of the machine and the AC power converters. They got that edifying results of measurements on the drive as the remaining energy can be considered approximately equal on both machines. Figures 6-10 are comparative charts derived from measurements.

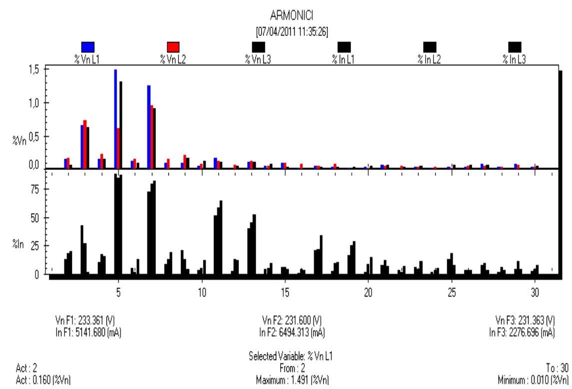

Fig. 6. Harmonics for machine 1

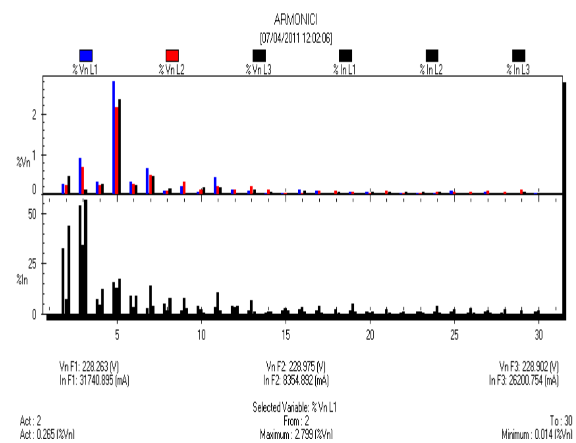

Fig. 7. Harmonics for machine 2

Parameters monitored were the actual values of the voltages and currents on the three phases, the harmonic content of the voltage or frequency spectrum for all phases of the power supply frequency, active and reactive power and energy and power factor.

It is noted especially in the case of voltage harmonics three and five a twice reduction in the case of the machine 1 (Figures 6 and 7), which shows the high torque shocks and unwanted non-upgraded machine [1]. The active power flow pursues changes evolving. Power consumption for one machine is idle and under load reaches 0.6 kW to 1.1 kW (Figure 8). Machine 2 is significantly higher active power reaching the load to 2.3 kW (Figure 9).

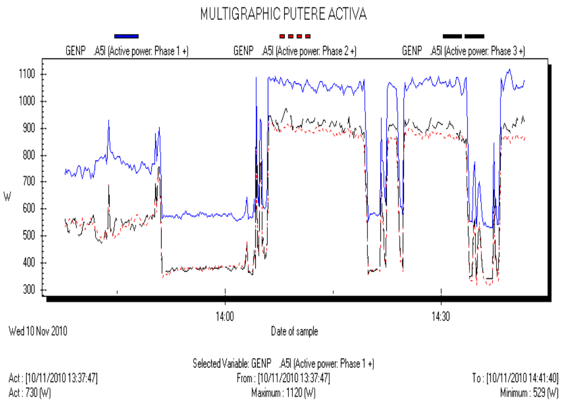

Fig. 8. Active power for machines 1

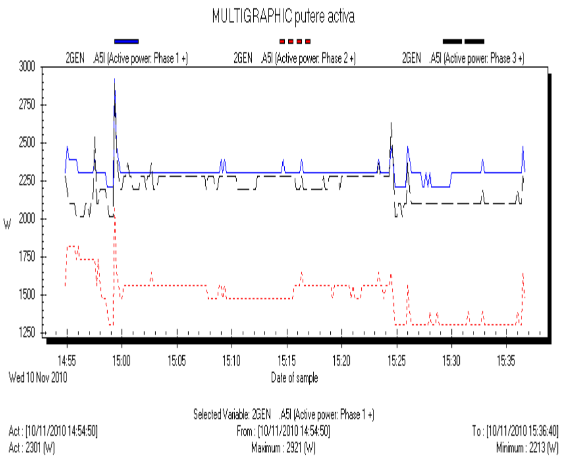

Fig. 9. Active power for machines 2

On machine 1, reactive power consumption is kept constant at 0,8 kVar (Figure 10), which indicates that it is driven mainly by auxiliary motors and almost never by CSF whose power factor tends to unit. On machines with two power ranges from 3,5 kVar reactive when the machine is working with major axis in the blank, 4,5 kVar load (Figure 11). Arguably controlled rectifier influence the reactive power growth.

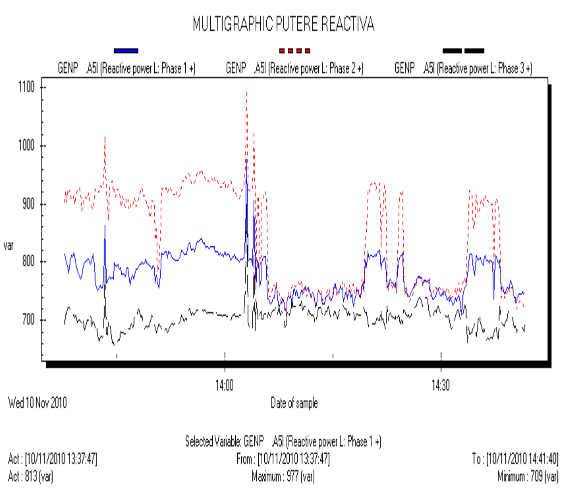

Fig. 10. Reactive power equipment 1

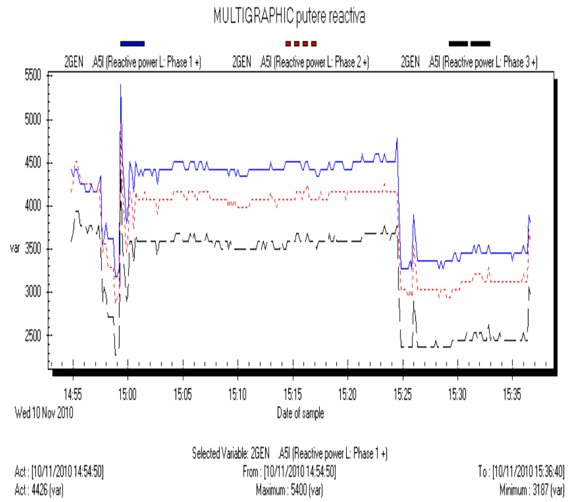

Fig. 11. Reactive power equipment 2

Are seen in the active power consumption busiest phase is about two times higher in machine 2, and if the proportion of observed reactive powers against modernized equipment.

This leads to a decrease in the power factor (see Table 1), which results in additional costs to compensate for it.

Table 1. Power factor values and the causes determining its value

Function	Machine 1	Machine 2	Main causes
the task	0,78	0,54	- Auxiliary motors
idle	0,47	0,44	- Auxiliary motors - Controlled rectifiers

5. ANALYSIS OF ECONOMIC EFFICIENCY

The benefits of the above upgraded equipment, is done due to their fitted equally numerical control that determines an optimal operation mode during processing, as well as the state of the art static inverter feeding the engine.

These benefits are made stronger out if it is an economic calculation, namely the determination of the recovery and profitability of the project. It is calculated from the relationship [3]:

- *the recovery period* with the significance of necessary time to recovery of money invested in the project and calculating by the relationship:

$$T_{rec} = \frac{C_{inv}}{P_{anual}} \text{ [Years]} \qquad (21)$$

Where:

T_{rec} is the time for recovery in year,

C_{inv} is the total cost of the investments in lei,

P_{anual} is the annual profit achieved from the application project in lei/year.

- *Profitability of the project* can be defined as the ratio of profit in each year of the period and the capital invested in the first year of the project:

$$R_{rec} = \frac{P_{anual}}{C_{inv}} \cdot 100 \quad \left[\frac{\%}{an}\right] \qquad (22)$$

From the graphs shown in Figures 7 and 8 there is a difference of about 1.4 kW for the machine 1. Considering that the machine operates only two shifts, the beneficiary has proposed a moderate annual profit of about 100 000 lei after he spent 560 000 for upgrading equipment, performing appropriate calculations, resulting indicators in Table 2.

It can be observed that there are no additional costs of maintenance because on the one hand the machine is warranted for a fairly long time, and on the other hand, modern machines have a very high reliability.

Recovery time considering that annual profit is under five considered to be acceptable, which confirms the profitability of mechanical processing equipment modernization. Modernization costs are borne entirely by the beneficiary that dropped spectacularly when accessing European funds for energy savings.

6. CONCLUSIONS

All these findings support the claim that it demonstrated superiority machinery CNC machined and fitted with variable speed drives to conventional or controlled rectifiers.

Table 2. The calculation of economic indicators

Indicator	U.M.	Result account
Economy achieved by introducing CSF	kW/hour	1,4
Annual number of hours	hours/an	3840
Annual energy savings	MWh	5,36
Energy prices	lei /MWh	311,98
Annual energy cost savings	lei/year	1677
Installation cost	lei	560 000

Digital controllers are becoming increasingly accessible to operators and engineers in designing the plant. Difficulties arise in the software developers must improve programs becoming more so as to reduce costs by reducing working time by reducing energy consumption and optimizing controls qualifying shareholders and reduce personnel costs.

Replacing old drives of machine tools with new ones, such as voltage and frequency static converters constitute a step forward in saving electricity.

Reducing consumption takes place via secondary re manufacturing and replacement of major mechanical components.

REFERENCES

[1]. Bizon, N., *Convertoare*, Editura Matrix Rom, Bucureşti, 2004

[2]. Mohora, Cristina, *Refabricarea maşinilor-unelte*, Editura AGIR, Bucureşti, 2003

[3]. Mircea,I., *Sisteme eficiente energetic pentru instalaţii cu debite reglabile*, Editura Universitaria,1999

[4]. Potlog,D.M., Mihăileanu,C. *Acţionări electrice industriale cu motoare asincrone*, Editura tehnică, Bucureşti, 1989

[5]. Prodan,D., *Maşini-uneltegrele: fabricare- refabricare*, Editura PRINTECH,Bucureşti,2008

[6]. Câmpeanu,A., Vlad, I., *Maşini electrice. Teorie ,încercări, simulări* Editura Universitaria, Craiova, 2008

[7]. www.cytecsystems-uk.com

[8]. www.hiwin.com