Energy optimization aspects by injection process technology

A Tulbure, M Ciortea, C Hutanu and V Farcas

1 Department of Science and Engineering, University “1 Decembrie 1918” of Alba Iulia, Romania
2 Electrica Transilvania Nord, Power Supply Company, Cluj Napoca, Romania

E-mail: aditulbure@uab.ro

Abstract. In the proposed paper, the authors examine the energy aspects related to the injection moulding process technology in the automotive industry. Theoretical considerations have been validated by experimental measurements on the manufacturing process, for two types of injections moulding machines, hydraulic and electric. Practical measurements have been taken with professional equipment separately on each technological operation: lamination, compression, injection and expansion. For results traceability, the following parameters were, whenever possible, maintained: cycle time, product weight and the relative time. The aim of the investigations was to carry out a professional energy audit with accurate losses identification. Base on technological diagram for each production cycle, at the end of this contribution, some measure to reduce the energy consumption were proposed.

1. Introduction. Indicators for energy performance.

In most of the manufacturing processes, the energetic efficiency and its inefficiency cannot directly be measured, but expressed using a specific performance indicator. Its value should be compared with a reference, for example, the value obtained using the worldwide best available technology.

As energy performance indicator used especially while analyzing the energy transformation process, is the energetic efficiency. This indicator is considered to be a specific, quantitative one, which can be suitably used for energy transformation, but is not adequate for final consumption ones.

The physical performance indicator, which characterizes better the energetic efficiency of a final consumption process, is the absolute energy consumption. The specific energy consumption indicator eliminates the influence of the activity volume changes, respectively the production structure.

Doing the energetic equivalence of different consumed energy forms, a physical energy performance indicator, like the equivalent specific energy consumption, $C_{se}$, can be computed with the relation (1):

$$C_{se} = \frac{(E_{REP} + b \cdot E_{EDU})}{VA}$$

were:

- $E_{REP}$ – primary energy flows
- $b > 1$ – equivalent coefficient of direct used primary energy
- $E_{EDU}$ – direct used energy flows
- $VA$ – volume of the activity.

The specific consumption of primary energy, known as energy intensity or energy content of a product, characterize the recovery level of the energy resources for a whole technological chain or a
completely manufacturing cycle. For a common comparison, in the present contribution, more experimental investigations in order to determine the specific energy consumption [kW / kg or Ws / g] for the molding - injection operation, have been made.

2. Injection moulding process technology
Regardless of the type of equipment, the injection moulding (IM) is a manufacturing process for producing components whose volume is well limited through edges and surfaces by injecting material into a mould. Injection moulding can be performed with different materials, including metals, glasses, elastomers, and most commonly polymers. Material is fed under high pressure into a heated barrel and forced into a mould cavity, resulting components with exact dimensions. The IM machine consumes energy from grid and reproduces the set high value parameters of strength-pressure-temperature. This unconventional manufacturing process [2, 3, 5] described by the chart below (figure 1), consists of three main technological steps:
1. Lamination / plasticization - run under pressure in dedicated unit
2. Compression – the raw material will be compressed during the closed nozzle regime.
3. Expansion / injection – after mixing, open the nozzle and the material expands and fills the cavities.

![Figure 1. Technological diagram (pressure-position) for one production cycle.](image1)

![Figure 2. Electric clamping unit [2].](image2)

This manufacturing technology is implemented in practice with the help of injection moulding (IM) system, which can be hydraulic or electrical.
The most stressed components of any IM facility are two massive pressure plates, one which is mobile, and a fixed one. The investigated equipment in the paper, are differentiated primarily by the design of each clamping unit.
The clamping unit in electro-motion version (EM, figure 2) contains in addition to the fixed part (chassis, frame) the movable part consisting of mobile plate (a); linear guide for mobile plate (b); leverage elbow with 5 points (c) and the electric servo-drive (d).
The clamping unit in hydraulic-motion version (HM, figure 3) contains the mobile half plate (a); linear guide for mobile plate (b); positioning cylinder for the movable plate (c) and power cylinder (d).
3. Technical considerations and energy measurements

The new hydraulic variant (H-M) is characterized by central pump with electrohydraulic control. This EH control procedure is advantageous in comparison with PQ (hydraulic variable capacity) control, because the adjustment is made direct to the source (pump) without generating under- or overpressure and does not require a special flow valve for speed control.

### Table 1. Mechanical parameters for the moulding injection process.

| Type        | Rated power [kW] | Cycle time [sec.] | Material weight [g] | Product weight [g] | Rest weight [g] | Material type |
|-------------|-----------------|-------------------|---------------------|-------------------|----------------|---------------|
| electric    | 109             | 38.2              | 35.8                | 30.9              | 4.9            | ABS           |
| hydraulic   | 95              | 28.3              | 26.7                | 23.7              | 3.0            | ABS           |

In this case the analyzer indications are proportional to the effective values of voltage, current and the cosines of the phase angle between them [1, 8], regardless of load characteristics, according to the relationship:

\[
P = \frac{1}{T} \int_0^T p \cdot dt = U_{10} \cdot I_1 \cdot \cos \varphi_{10} + U_{20} \cdot I_2 \cdot \cos \varphi_{20} + U_{30} \cdot I_3 \cdot \cos \varphi_{30}
\]

(2)

Where: \( U_{10}, I_1, \varphi_{10} \) and so on are the voltages, currents on each lines respectively the phase gaps between them.

The injection molding machine in E-motion version (109 kW total installed power) has the following energy relevant components: 41 kW servo drive, 15 kW cylinder heating system, 18 kW mold heating system, 5 kW robot arm drive and other related outlets.

The injection molding machine in H-motion version (95 kW total installed power) has in terms of energy the following relevant components: 30 kW pump motor; 15 kW cooling filtering engine, 15 kW cylinder heating system, 18 kW mold heating system, 5 kW ventilation system and other peripheral outlets.
Figure 5. Electrical power evolution by the E-motion machine (top-$P_{\text{tot}}$, down–$P_{L1}$, $P_{L2}$, $P_{L3}$).

Figure 6. Electrical power evolution by the H-motion machine (top-$P_{\text{tot}}$, down–$P_{L1}$, $P_{L2}$, $P_{L3}$).
After analyzing figure 5 and 6 we conclude that for the EM variant the electrical power achieve max. 26.89 kW range and the manufacturing cycle totaling 38.2 sec., different from HM variant where absorbed power is max. 49.81 kW and cycle time 28.3 sec.

Both machines are good balancing, with symmetrically phase currents and powers [4, 7] on each lines \( L_i \) in accordance to the measurements snapshots below (\( \Delta P < 10\% \), see figure 7 and 8):

![Figure 7. Measurements snapshot by EM machine.](image)

![Figure 8. Measurements snapshot by HM machine.](image)

Of course not all the absorbed energy is transformed into useful work, but some is converted into heat (both hydraulic oil and cooling fluid temperature increasing) and noise. It is known that oil temperature is a relevant indicator for the energy efficiency of the entire system [2, 7].

After listing the values of measurements (table 2) made on the same type of material and approximately the same sample, relevant energy statistics can result.

**Table 2.** Power measurement last sequence between 591...601 sec. for hydraulic IM machine.

| Time [s] | Power phase L1 [kW] | Time [s] | Power phase L2 [kW] | Time [s] | Power phase L3 [kW] | Time [s] | Total power [kW] |
|----------|---------------------|----------|---------------------|----------|---------------------|----------|-----------------|
| 5.91E+02 | 6.50E+03            | 5.91E+02 | 6.93E+03            | 5.91E+02 | 6.48E+03            | 5.91E+02 | 1.99E+04        |
| 5.92E+02 | 7.53E+03            | 5.92E+02 | 5.99E+03            | 5.92E+02 | 5.96E+03            | 5.92E+02 | 1.95E+04        |
| 5.93E+02 | 6.51E+03            | 5.93E+02 | 5.98E+03            | 5.93E+02 | 6.02E+03            | 5.93E+02 | 1.85E+04        |
| 5.94E+02 | 6.43E+03            | 5.94E+02 | 5.88E+03            | 5.94E+02 | 5.95E+03            | 5.94E+02 | 1.83E+04        |
| 5.95E+02 | 7.89E+03            | 5.95E+02 | 7.28E+03            | 5.95E+02 | 7.82E+03            | 5.95E+02 | 2.30E+04        |
| 5.96E+02 | 8.01E+03            | 5.96E+02 | 8.34E+03            | 5.96E+02 | 6.99E+03            | 5.96E+02 | 2.34E+04        |
| 5.97E+02 | 7.08E+03            | 5.97E+02 | 6.69E+03            | 5.97E+02 | 6.60E+03            | 5.97E+02 | 2.04E+04        |
| 5.98E+02 | 6.87E+03            | 5.98E+02 | 6.01E+03            | 5.98E+02 | 6.07E+03            | 5.98E+02 | 1.90E+04        |
| 5.99E+02 | 6.73E+03            | 5.99E+02 | 5.85E+03            | 5.99E+02 | 5.89E+03            | 5.99E+02 | 1.85E+04        |
| 6.00E+02 | 6.52E+03            | 6.00E+02 | 5.85E+03            | 6.00E+02 | 6.03E+03            | 6.00E+02 | 1.84E+04        |
| 6.01E+02 | 6.38E+03            | 6.01E+02 | 6.79E+03            | 6.01E+02 | 6.34E+03            | 6.01E+02 | 1.95E+04        |

| Time [s] | Power phase L1 [kW] | Time [s] | Power phase L2 [kW] | Time [s] | Power phase L3 [kW] | Time [s] | Total power [kW] |
|----------|---------------------|----------|---------------------|----------|---------------------|----------|-----------------|
| 7.02E+03 | 6.57E+03            | 6.48E+03 | 20.07E+03           | E/10min. | 3.345E+03       |

**Table 3.** Absolute and specific energy consumption.

| Type     | Rated power [kW] | Max.power [kW] | Avg.power [kW] | Energy / 10min. [kWs] | Energy / cycle [kWs] | Spec. energy [Ws/g] |
|----------|------------------|---------------|---------------|-----------------------|----------------------|---------------------|
| electric | 109              | 26.89         | 4.63          | 0.772                 | 0.049                | 1.585               |
| hydraulic| 95               | 49.81         | 20.07         | 3.345                 | 0.158                | 6.667               |
### Table 4. Relevant energy saving methods.

| No. | Energy saving method                                                                 | Observation                                                                 |
|-----|---------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 1e. | The MI machine selection in dependence on the production series                        | Electrical version is more economical by at least 50%.                       |
| 2e. | Local or PCC (point of common coupling) power factor correction                         | This is possible by stepwise connecting of the variable capacitor stage.     |
| 3e. | Changing the drive motors from standard to premium or EEF1 range                       | Savings up to 3% for example by the asynchronous motor with \( P = 30 \text{ kW} \) |
| 4e. | Phase symmetry / balancing between the consumer groups                                 | Checking line impedance and redistribute some single-phase consumers.        |
| 5e. | Technical and organizational measures                                                  | Compliance with maintenance program recommended by the manufacturer.        |

4. Conclusions

In order to obtain suggestive comparisons about the machine performances, the analyzed energy data were averaged to 10 minutes or summed up the manufacturing cycle.

In this way there resulted the concentrated energy data from table 3:

The modern hydraulic version of the IM machine consists of a constant pump actuator, instead of asynchronous motor in permanent operation with adjustable pump. Thus, energy efficiency is argued [2, 3] by two criteria:

- there are no control valves for speed and pressure in the decentralized drives;
- no injection (operation without load), leads to drive stopping (zero consumed energy).

The moulding injection machine in EM electric variant offers compared with hydraulic variant shorter dead times, so faster production cycles due primarily to electrical drives [6], which is capable to operate in the parallel mode. By selective control and switching of different drives, the energy consumption will be lower. In addition, the electric version is recommended by a lower acoustic pollution (also reduced dissipated energy on this form). Noise emissions are about 67 dBA / cycle compared to 73 dBA for hydraulic machine cycle.

E-motion variant provides higher power gradient (high speed worm gear) and a more stable power variation (maintaining constant speed of screw gear respectively constant material pressure on the entire length of the cylinder movement) [2, 6, 7].

The EM model is basically a "without oil" manufacturing system [9], so it does not depend on achieving the specified viscosity respectively temperature of transmission medium for the hydraulic system force. In this way the EM machine gets faster into the optimal operating point [6], and the regime is more stable even during the significant environmental parameters changes. Consequently, it is more productive. On the other hand, the power saving is more than 60% (last column from table 3).

Starting from experimental analysis, the most important energy optimization methods are shown in the table below:

References

[1] Creţu G 2015 *Intl. J. of modern manufacturing technologies* 7(2) pp 53-56
[2] **** 2014 *Engel the victory. The electric tie-bar-less*. Engel GmbH Schwertberg Austria
[3] **** 2015 *Electric/Hybrid Allrounders*. Arburg GmbH Lossburg Germany
[4] Mourão A & Co 2010 *Int. J. of Modern Manufacturing Technologies* 2(2) pp 71-76
[5] Fetecau C & Co 2010 *Int. J. of Modern Manufacturing Technologies* 2(2) pp 45-50
[6] Dimmler G & Co 2015 *Kunststoffe international* Carl Hanser Verlag Munich pp 22-25
[7] Zinckgraf S & Co 2013 *K-Berater* 7-8/ 2013 pp 14-16
[8] Sakthivel V. P. & Co 2010 *IET Electric Power Applications* 4 pp 579 – 590
[9] Wang S.& Co 2010 *2nd Intl. Conf. on Mechanical and Electronics Eng.* 1 pp V1-34 -38