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Energy-Consumption Factors of Air-Stream Moulding Machines

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Abstract

In this article, an outline of the key questions connected with the essential problems of energy-consumption of air-stream moulding machines has been presented. Research results and calculations of requisite parameters appraisable of energy-consumption of air-stream moulding machines have been supplemented also by the data analysis of offer of the moulding machines manufacturers. The attention on constructional and technological factors which are favourable for the diminution of energy-consuming of the moulding process has been paid.

Key words: Environmental protection, Energy-consumption, Air-stream moulding machines

1. Introduction

The moulding machines which compact the moulding sand by direct action of air-stream one can denominate as air-stream moulding machines. At present these machines belong to the basic equipment of the foundry plant [1]. In flask moulding most often the machines in which the moulding sand is gravitationally dosed to the flasks are used. Air-stream moulding machines have included impulse machines (air impact), impulse-squeezing machines, performing the Seiatsu process (air flow moulding machines) and vacuum assisted and squeezing moulding machines. There is also an offer of solutions bringing together the above-mentioned processes (eg. the former series of machines GFD ComPac -- Disa Georg Fisher company, at present offered by the EMI Inc.). The parting line of the air-stream process of the Seiatsu type and of impulse process is not precisely definite, nowadays it is also offered by the Künkel-Wagner company the machines about the intermediate dynamics - the solution Airpress plus [2]. Comparatively not large changes in the valve set control system of the impulse-squeezing machine can transform this machine into machine realizing the near to Seiatsu compaction process [3]. In the article the problems of energy-consumption of mentioned above variants of machines and the one of certain vacuum moulding machine [4,5]. The basic criterion of the assessment of the operation of the given moulding machine are technological effects [6]. Energy-consumption can be treated as the supplementary criterion for making the choice easy of the machine from the group of moulding machines with similar technological possibilities. This factor is all-important also from the point of view of ecologies and running costs of the machine. In the case of processes occurring in air-stream moulding machines, there also exists the relationship among operation parameters (indirectly of energy-consumption) and with the level of the noise emission.

2. Energy aspects of moulding sand compaction

The evaluation of energy demand for moulding sand compaction in different methods of the moulding is a complicated problem and gets out of varieties of realised processes [7,8,9]. Opinions on the influence of the speed of the strain growth of the moulding sand on compaction effects are diverse. According to some authors [7,10] the increasing of the speed of the strain growth of the moulding sand causes the improvement of the compaction degree (occurrences of thixotrophy phenomenon, the diminution of the viscosity of the moulding sand, the decreasing of friction etc.); according to others, [8,11] the inverse is true. Fig. 1 shows the calculation results of the moulding sand compaction process according to the rheology model described in [8]. The increasing of the speed of the stress change makes for procurances of the smaller final density and of course the increasing of the speed of density changes. Rate of the tensions growth (50 MPa/s and 5 MPa/s) (Fig.1) are the same order as rate of the pressure growth in the impulse process, as well as in the processes of Airpress and Seiatsu.

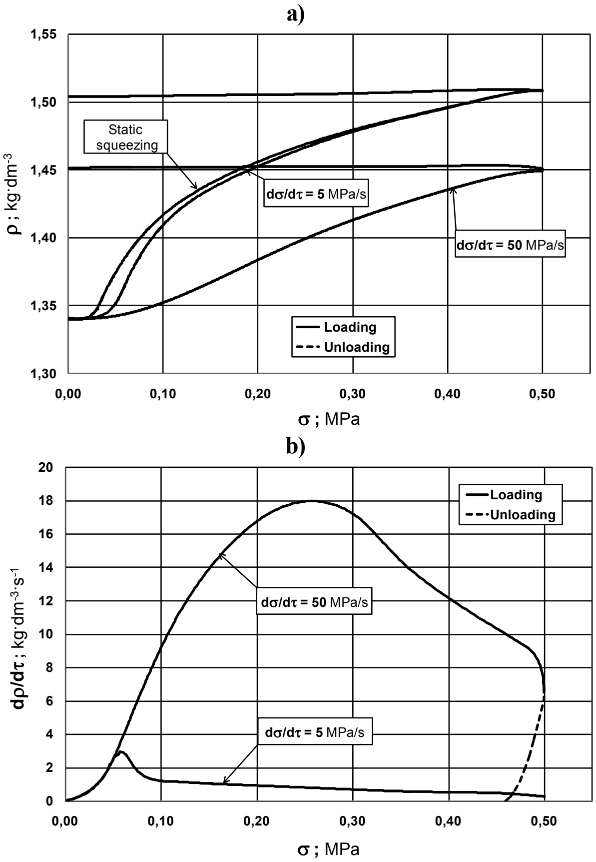

Fig. 1. Dependence between apparent density of moulding sand- ρ (a), rate of its changes- $\mathbf{d\rho/d\tau}$ (b) and compressive stress- σ during static squeezing and dynamic loading (at different stress growth rate- $\mathbf{d\sigma/d\tau}$). Data for calculation from [8]

At the unloading, within the range of analysed compressive tensions takes place the comparatively not-large elastic deformation of the moulding sand [8]. On Fig. 2 there are presented test results of the impulse moulding [3,12,13] compared with the calculations of the squeezing process according to the well-known empirical Aksjonov equations (for the static squeezing) and to the equations with the Saltykov correction coefficient [11]. The transformation of the above-mentioned equations gives:

$$\Delta\rho = \rho_k - \rho_0 = 0.682 \cdot H_0^{-0.19} \cdot (k \cdot p)^{0.25} \tag{1}$$

wherein: ρ_0 - the initial density; g/cm^3, ρ_k - the average final density; g/cm^3, H_0 - the initial height of the moulding sand layer; cm, p - squeezing pressures; MPa, k - the corrective coefficient taking into account the speed of the stress growth (at speeds of the stress growth of milliseconds order $k \approx 0{,}2$).

The acceptance of the coefficient k<1 makes for diminutions of the increase of the final density in spite the same value of squeezing pressures. Fig. 2 displays the good agreement of measurement with the calculations results (1). Results of calculations for the static squeezing (Fig. 2) confirm the opinion represented by the second group of researchers [among other 8,11]

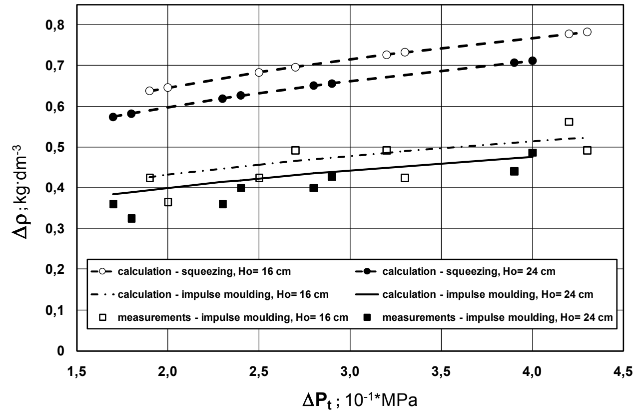

Fig. 2. Dependence between increment of mean mould density - $\Delta\rho$ and maximal overpressure value - $\Delta \mathbf{P_t}$ at impulse moulding: initial height of moulding sand layer $\mathbf{H_0}$ = 16 cm- $\rho_0 \approx 0.94$, initial height of moulding sand layer $\mathbf{H_0}$= 24 cm- $\rho_0 \approx 0.97$. Calculation acc. eq. (1) at **k**=0,2 for impulse moulding and **k**=1 for static squeezing.

The equation (1) evaluates the average value of mould density. In the impulse process, the air flow inside the moulding sand layers-thus the effective air-pressure causing compaction of the moulding sand is different from the value Δ Pt (Fig. 1) [8,12,13]. There appears the large differentiation of the density along the height of the mould. Effective pressures in the region of the pattern -plate have exceeded the value of the pressure over the upper surface of the moulding sand in the flask. The effect of the compaction in the near pattern plate region is better in the case of the enlargement of the dynamics of the compaction - what is the result of the higher kinetic energy of accelerated moulding sand layers. This phenomenon leads to the occurrence of higher values of efficient pressures in definite mould areas than the value of the maximum overpressure Δ Pt in the space over the moulding sand- consequently the better compaction have been obtained in these areas [7,8,12,14]. It is especially important with the usage of complicated patterns- the realization of such moulds by the squeezing method would then be very difficult (or even impossible). With stream-oriented methods one can perform moulds even in the case of slim pockets in pattern[1,12]. The obtainment of the profitable distribution of the compaction degree has joined, however, with enlarged energy demand.

2. Energy consumption of air-stream moulding

2.1. The impulse process

The demand of compressed air in the classical impulse process is a function of the volume of the technological space and attained in it the values of the maximal pressure. Treating the system: impulse head- technological chamber as the closed, heat-insulated system, one can count the value of the pressure- P_t, which it has achieved in the technological space after the end of the flow (and the settlement of the thermal equilibrium in the system) [13]:

$$\frac{P_t - P_a}{P_z - P_a} = \frac{\Delta P_t}{\Delta P_z} = \frac{K_v}{K_v + 1} \tag{2}$$

wherein:

V_z, V_t – volume respectively: impulse head and technological chamber,

$K_v = V_z / V_t$ – the ratio of above- volumes,

P_z, P_t, P_a – absolute pressure respectively: in impulse head (initial), in technological chamber (final) and atmospheric.

The maximal pressure in the technological chamber is a function of the initial pressure and the volume of the impulse head and the technological chamber. Fig. 3 displays the calculations results (according to eq. 2) and measurement of selected research of the process of the air flow in the prototype impulse machine [3,12,13]. Visible is the good agreement of the experiment with calculations results. Greater deviations on the first section of fitted line from the Fig. 3 can be explained with the greater influence of the error of measurement in this range (the smaller value of the pressure). Results of calculations (Fig. 3) show that enlarging of the ratio V_z/ V_t above 5 does not make for the essential enlargement of the value of the maximal pressure in the technological chamber.

In investigated systems differences among values of the maximum pressure attained in the empty technological chamber and fulfilled with the moulding sand did not exceed 5 % [3]. This results from definite proportions among the volume of the moulding sand to the entire volume of the technological chamber (embracing additionally the volume of the additional frame and occurrent usually the volume of the additional space of the expansion - dependent from the construction of the valve. On the ground values of attained pressure and the volume of the technological (with the regard of the volume the model and the specific volume of the moulding sand) one can - after bringing to normal conditions, to count the demand of the air in the cycle of the mould compaction or the unit free air demand- Zj in nm^3/the kg (referred to one kilogramme of compacted moulding sand under the given circumstances):

$$Z_j = 10 \cdot \frac{\Delta P_t \cdot (V_t - V_m)}{m_f} \tag{3}$$

where: V_t - the volume of the technological space in m^3, m_f - the mass of the moulding sand in the kg, V_m its real volume in m^3, ΔP_t - the overpressure in the technological chamber in MPa.

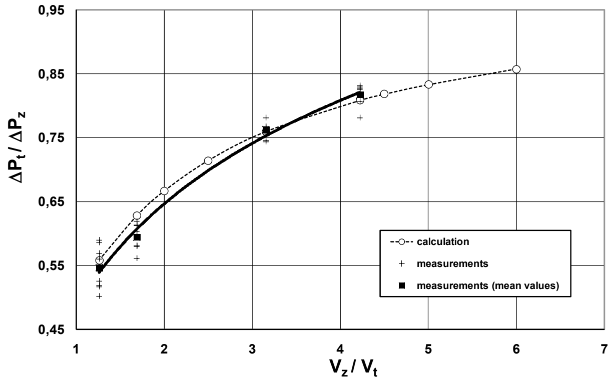

Fig. 3. Dependence between maximal overpressure ratio in technological chamber to overpressure in impulse head- $\mathbf{\Delta p_t/\Delta p_z}$ and ratio of volumes of impulse head to technological chamber volume- $\mathbf{V_z/V_t}$. Calculation acc. eq. (2).

Practically, what usually appears is a lack of tightness in the system, because one can qualify the value P_t without taking into account the presence of the moulding sand in the technological space and count the application of the air in the cycle with the certain excess. Knowing the coefficient connected with energy demand for the compression of the unit volume of the air - e (kJ/nm3), one can count specific energy consumption of air-stream moulding process- E_j (kJ/the kg):

$$E_j = Z_j \cdot e \tag{4}$$

In fig. 4 were represented the dependence of the individual demand of the air and specific energy-consumption - expressed in nm^3 on 1 kg of the moulding sand from the maximal pressure in the impulse process [3].

As it gets out of the Fig. 4 in the real impulse process Z_j and E_j are of course linear function of the pressure P_t ; relations $V_z/(V_t - V_m)$ were approximately constants. Differences in above-values reached for different heights of the moulding sand layers get out of the different initial density and other relation among the volume of the moulding box with the additional frame and the volume of the additional space. Data from graphs - Figs. 2, 4 refer the impulse compaction of the synthetic moulding sand with the bentonite. In the research, the value of the exit-pressure in the impulse head, the relation of the maximal open area of the valve to the open area of the moulding box and the relation of the volume of the impulse-head to the volume of the technological space have been changed. The change of above-parameters have caused the changes of the value of the maximal pressure attained in the technological space: from 0,27 to 0,53 MPa and the change of the dynamics of the process with expressed speed of the growth of the pressure: from 23 to 76 MPa/s [3,12].

In fig. 5 are the summary findings in the coordinates: $Z_j(E_j) = f(\sigma)$. Results represented in fig. 5 refer to the process of the impulse moulding realised in diverse circumstances (the variability of parameters), but on the same moulding machine.

The equal average values of the compaction degree can be achieved at different energy consumptions indicators. One can come to the conclusion that the operation of the same impulse-moulding machine can characterize with different values of energy-consumption.

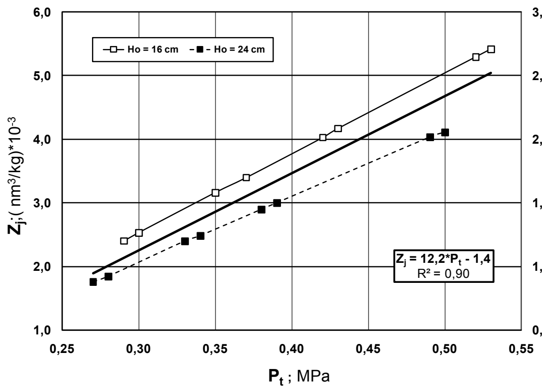

Fig. 4. Dependence between unit free air demand- $\mathbf{Z_j}$ or specific energy-consumption- $\mathbf{E_j}$ of the impulse moulding process and maximal values of absolute pressure in technological chamber- $\mathbf{P_t}$, at different values of initial height of moulding sand- $\mathbf{H_0}$. Assumed unit value- **e**=500 kJ/nm^3.

This is connected with the possible change of parameters of the machine operation or else technological parameters (eg. the change of moulding boxes , additional frame, the kind of the moulding sand etc.) . The course of the trend line shows the increasing of energy-consumption with the enlargement of the compaction degree.

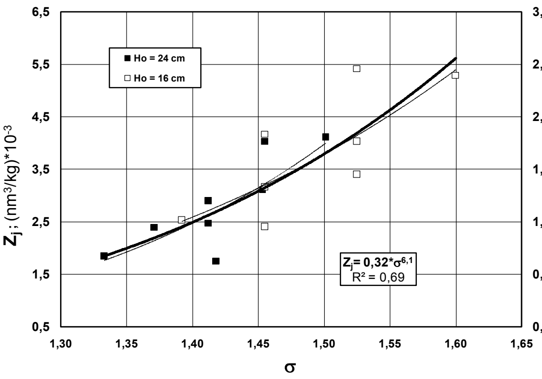

Fig. 5. Dependence between unit free air demand- $\mathbf{Z_j}$ or specific energy-consumption of the impulse moulding process- $\mathbf{E_j}$ and mean value of mould compaction degree- $\sigma = \rho_k/\rho_0$. Assumed unit value- **e**=500 kJ/nm^3

2.2. The air flow process with squeezing

The wide review of the literature concerning the air flow moulding process ($\Delta p_t/\Delta\tau$ of the order of several MPa/s) and own research permits to ascertain that represented methodics can serve also appraisable of energy-consumption of machines realizing this process. The air flow machine operation can be treated as the operation of the impulse-moulding machine with lack of tightness. What of course are the same sizes of technological chambers and attained in them values of the pressure must make for enlarged energy demand in case of the air flow process. In the process Seiatsu, the influence of the size of open area of vents in pattern plate on the phase of the increasing of pressure in technological space is, however, not large. There testify about this among other things temporary pressures courses over the moulding sand. Differences are visible in the voidance phase of the technological space- the greater value of vents openings make for the quicker voidance of the space. The groundless extension of this open time of the stream-oriented valve can make for the increasing of the application of the compressed air demand .

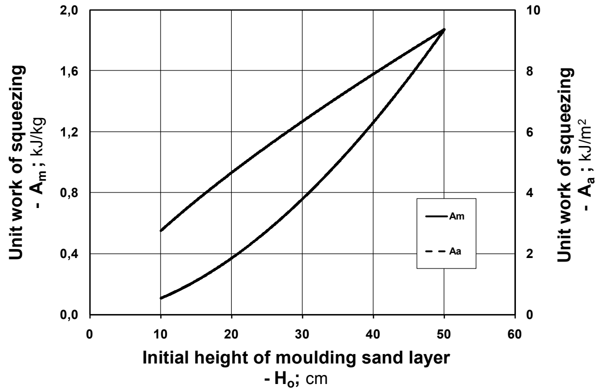

Fig. 6. Dependence between unit work of static squeezing- $\mathbf{A_m}$, $\mathbf{A_a}$ and initial height of moulding sand layer - $\mathbf{H_0}$. Aksjonov model; assumed values of apparent density of the mould : initial- ρ_0 = 1 g/cm^3 , final- ρ_k = 1,6 g/cm^3

Density distribution obtained in the air flow (Seiatsu) process has testified about this that comparatively to the impulse-process the average density of the mould the first stage of the compaction is lower. One ought to await the greater values of the specific energy-consumption factor. The profitable density distribution has joined also with enlarged energy demand. For the purpose of the achievement of the same average density level must be enlarge squeezing pressures in the second stage of the compaction; (comparatively to the impulse-process with squeezing).

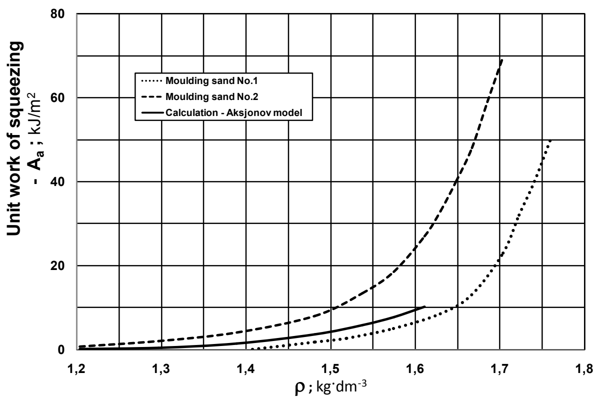

Fig. 7. Dependence between unit work of static squeezing- $\mathbf{A_a}$ and final values of apparent density of the mould- ρ_k. Data from [8]: maximal squeezing pressure- 2 MPa, mould area- 1 m^2, mass of the moulding sand- 500 kg; calculation- Aksjonov model: maximal squeezing pressure- 0,4 MPa.

The announcement only of the power of the drive is inadequate. For the purpose of the indicatory settlement of which values one can expect the graph -Fig. 6 was elaborated, picturing results of example-calculations of the individual work of the squeezing of moulding sand. It bases also on the Aksjonov model; taking into account the form of the equation (1) is self-evident the increasing of energy demand together with the increasing of density of the mould.

In Fig. 7 were compared results of calculations of the individual compaction work and data from [8]. Visible is the essential influence of the properties of the moulding sand on energy-consumption.

Energy demands connected with squeezing are considerably less than this on the realisation of the air-stream moulding process.

2.3. Vacuum assisted process

Analysed vacuum assisted moulding process has been realised in the variant without the transport of the moulding sand from the hopper to the technological space [4,5,16].

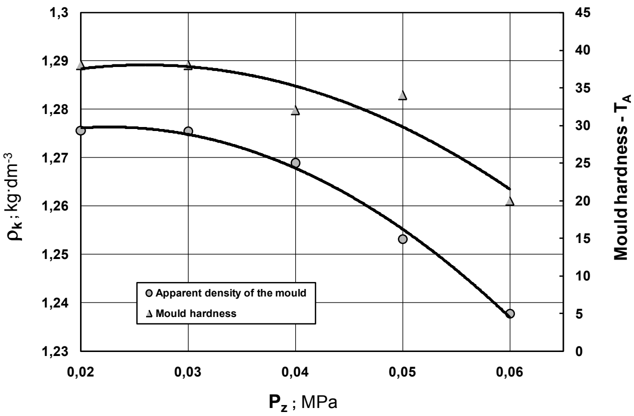

Fig. 8. Dependence between final values of apparent density of the mould- ρ_k or bottom surface hardness of the mould- T_A and initial values of absolute pressure in vacuum tank- P_z. Vacuum assisted compaction. Initial height of moulding sand layer - H_0 = 21 cm, initial value of moulding sand density- ρ_0 = 1,02 kg/dm^3.

Effects of the compaction in this method are considerably worse from those obtained in the earlier discussed air-stream processes. Its advantage is the possibility of the obtainment of the profitable density distribution in slim pattern pockets and small requirements with relation to the moulding boxes- it does not have the necessity of making a very tight connection between the technological space and the moulding sand hopper.

The calculation of energy-consumption in this method demands acquaintances: volumes of the vacuum-reservoir, the value of the initial and final pressure in vacuum-reservoir and energy demand connected with the operation of the vacuum-pump with definite efficiency. According to estimated calculations for the vacuum assisted compaction process E_j = 1,39 kJ/kg , at the pressure 0,02 MPa and the accepted value of coefficient e= 101 kJ/nm^3(tab.1). The precise evaluation of the energy demands executions of measurement during the real duty cycle of the vacuum installation. The low degree of the vacuum assisted compaction has also demanded enlarged energy for squeezing of the mould in comparison to other air-stream moulding methods.

3. The factors characterizing energy consumption of air-stream moulding machines

In source data, one can meet diverse values of factors characterizing energy-consumption of such machines. In use are different indicators; for example, the compressed air demand on one cycle of the moulding, the demand of the compressed air referred to the volume of the moulding sand, the equivalent electrical energy indispensable to the compression of the definite volume of the air referred to the kilogramme of compacted moulding sand [9]. Bringing values of above-indicator to practical in the article of the dimension of energy-consumption- Z_j m^3 /kg one receives the wide range of the free air demand: from 2,2x10^{-3} do 10x10^{-3} m^3/kg. Over a wide range situated also values of the demand of the free air given for Polish impulse-moulding machines from 0,18 to 0,75 m^3 /cycle [1]. Given coefficients for air flow moulding machines with squeezing (the Seiatsu process) are eg. 0,2 m^3 (free air)/cycle (boxes 600 x 500), or 0,7 m^3 (free air)/the cycle (boxes 1000 x 800) [1]. For the comparison the demand of the compressed air by the jolt- squeezing moulding machine FKT-65A carries out 0,85 m^3(free air)/cycle. To cited values one ought to approach with prudence. Estimated calculations prove that values from the lower range can be reached only at very low values of the maximal pressure in the technological chamber. One ought to take into account additionally the demand of the air by pneumatic accessory drives (pattern removal system, the hold-down system etc.). With relation to of the demand of the compressed air in the compaction process these are not large values. There certainly exist possibilities of the reducement of energy-consumption of impulse-machines. From the point of view of the construction of air-stream valves a main action is the assurance of the cutting off of the impulse head (the compressed air reservoir) from the technological space after the end of compaction process.

In the light of represented findings a main action is the correct selection of the volume of the impulse-head, the expansion volume and the initial operation pressure. Among technological factors influent on effects of the air-stream moulding, are the apparent density of moulding sand before the compaction process- suitable aeration of moulding sand improves the compaction level [1,10]. Using lower values of the initial-pressure one can diminish energy-consumption of the compaction process without the worsening of technological effects. Opinions on the subject of the influence of other properties of the moulding sand on impulse compaction and energy-consumption of the process are often divergent, however is not subject the discussion the influence of the kind of the moulding sand on energy-consumption of compaction process.

Impulse-machines basing on the system of the two-step air-stream process are equipped into complicated valves system. The usage of vents in pattern plate and the elongated duration of the first phase of the process cause the greater demand for compressed air. Thanks to this, however, it can obtain the improvement of the compaction degree in critical regions of the mould. The comparison of energy-consumption of air-stream machines with other types of moulding machines demands usages equivalent coefficients for energy consumption [9]. It is possible to make conversion of the demand on the compressed air on the electric energy demand. A problem is, however, acceptance of the proper value of the conversion-coefficient.

Table 1. The characterization of air-compressors (the nominal pressure 1 MPa) and vacuum-pumps (the absolute pressure 33(40) hPa)- data from [15]

Compressors (vacuum pumps)	Range of capacity- **W**; m^3/min	Range of drive power - **P**; kW	Energy factor - **P/W**; kJ/ m^3
Piston type	0,37- 3,2	3,0- 22	486-413
Rotary vane type	0,85-13,18	7,5- 90	529- 410
Screw type	0,45- 4	8,7- 55	533- 379
Vacuum pumps (with liquid ring)	0,075- 26,7	0,75- 45	600- 101

The demand for electric energy by the air-compressor is a function among other things its efficiency, the system of the control, the kind of the operation. On the base of data from folders [15] one took down the main indicators in tab. 1: the relation of the power of driving engines to the efficiency of air-compressors and vacuum-pumps. It has appeared general trend to attain of more profitable coefficients (smaller values) by the greater units [3,15]. The analysis of the literature from the range of the pneumatics shows that real values on the compression of unit value of air volume can be higher from the value of coefficients given in the table 1. Pneumatic systems possess many advantages, [17] however, the compressed air is expensive as the energy factor [18]. On the ground of current values of costs of the electrical energy one can estimate operation costs of air-stream machines. In a fuller analysis one ought to take into account, besides costs of the energy, costs of the service (repairs, the service etc.), at present with growing tendency. Example-calculations in [3] have shown significant costs connected with the exploitation of air-stream moulding machines.

4. Conclusion

Research results and the analysis of processes of the air-stream moulding have evidenced the possibility of the optimization of its course in the aspect of the diminution of energy-consumption of machines, by the proper selection of machine and process parameters. The proposed methodics of evaluation of the demand of the compressed air conditions this factor from basic constructional parameters and parameters of the operation of the moulding machine. In comparing of different air-stream moulding machines in the aspect of energy-consumption is advisable using of coefficients Z_j and E_j. Better effects in the technological aspect and energy-consumption more easily to obtain in the case of the connection of the air-stream process with squeezing. Modern control systems of machines can easily make the selection of optimal parameters of their operation (also in the aspect of energy-consumption). The regard of energy-consumption factor in the construction and the selection of operation parameters of moulding machines is also significant from the point of view of economic and ecological factors.

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