Multi-Objective Optimization of the Pneumatic Ejectors for Plastics Thin-wall Injected Parts

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In this paper a modern multi-objective optimization of the pneumatic ejectors of the plastic injection mold is presented. For this Pareto multi-objective optimization, two objective functions (volume and efficiency of the ejector) and four genes were taken into consideration and a set of twelve constraints were formulated. In solving the optimization problem we used an original two-phase evolutionary algorithm (2PhEA) inspired from the concept of “punctuated equilibrium”. 2PhEA is implemented in Cambrian v.3.2 which is in operation at the Optimal Design Centre of the Technical University of Cluj-Napoca, Romania. The study on the individuals along the obtained Pareto front reveals some important conclusions useful in the design of the pneumatic ejectors.

Keywords: optimal design, evolutionary algorithms, pneumatic ejector, injected part

Plastic part injection (area of great interest of the current days and which has seen a tremendous development in recent decades) is conditioned mainly by three factors: characteristics of injection machine, plastic material characteristics and characteristics of injection mould. In this context there have been concerns in the optimization of laminated composite parts [11-13] or parts of polymer [21], in the optimization of the manufacturing process [7], as well as in the optimization of the machines used in plastic parts processing [15 - 17]. As one can find the optimal design of the mould problem is fewly approached. In this paper, the authors propose an original variant of multi-objective optimization with evolutionary algorithms of the ejector system of injection moulds for thin-wall parts. Optimal design of the ejector system leads to a reduction of total cycle time of injection and thus an increased productivity. The mould used in the manufacture of “Bucket of 10 l” was also used in following optimization of the ejector system.

The 10 l bucket is a general purpose product made by Napochim Company originated in Cluj-Napoca, Romania. This bucket encompasses two injected parts: body of bucket and the ear. Obviously, the main component of the product is the body which is a thin-wall injected part of taper shape. More often the bucket body is made of propylene.

For this bucket body there are supposed to be known the following data:
- \( D_p \) – outer diameter of the part (core);
- \( d_p \) – inner diameter of the part (core);
- \( h \) – thickness of the injected part wall;
- \( l \) – length (height) of the injected part;
- characteristics of the injected part material (the modulus of elasticity, specific contraction, allowable bearing pressure, the coefficient of friction between the injected part and the core etc.);
parameters of the injection process (demoulding temperature, air-compressed pressure etc.).

The mould used to obtain this piece is presented in figure 1. The ejector system (necessary to eject the injected part from mould) is composed of an air valve and a double-action pneumatic ejector.

In paper [2], a mono-objective optimal design of the pneumatic ejector is presented. The objective function for this case was the ejecotor volume. The assumed goal of the optimization was to minimize as much as possible the volume occupied by the ejector in the mould volume without affecting the mould efficiency. Any space economy inside the mould volume allows, for example, a larger volume of cooling system and consequently the piece will be cooled off faster. Six variables (genes) were taken into account in this approach: five different standardized O-rings and one stainless steel pipe (the piston cylinder is made of). The optimal pneumatic ejector obtained had a volume \( V = 358146 \) mm³.

Using this result as starting point of the new research we made a step forward: the multi-objective optimal design with evolutionary algorithms of the pneumatic ejector. In the following paragraphs we will identify and propose the genes, the objective functions, and the constraints which will be aggregated in the multi-objective optimization program.

Genes of the optimization program

After a close analysis of the pneumatic ejector design (fig. 2) and having in mind the necessity of the unique description of the optimization problem we proposed 4 genes. It is worthy to note that all these genes are not simply real or integer numbers, but standardized machine elements and each of these elements encapsulates all sorts of parameters: material, dimensions, mounting and dismounting conditions etc. For example, each O-ring list

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consists of four standardized ring types, and for each type we considered the standardized diameters: 1.8, 2.65, 3.55 and 5.3 mm. For symmetry reasons, we proposed 64 types of pipes for the cylinder. The chosen genes used in solving of the optimal design problem are presented in table 1.

In comparison with the previous approach we have to mention that we reduced the number of genes since we developed an easier technique to design an ejector based only on the values of these four genes.

**Setting the objective functions**

In multi-objective optimization, it is preferably to choose objective functions with antagonist behaviour with respect to the same variables. That means that, for example, where one function reaches its desirable maximum, the other reaches its undesirable minimum (for the last function we want to capture its maximum, too). Obviously, it is a problem of compromise, and in order to obtain this settlement the authors used the well-known Pareto approach.

In this paper we set two goals since we intended to obtain an ejector (fig. 2) with the smallest possible volume and with the highest possible efficiency. Obviously these two requirements are in contradiction, since in the case of the pneumatic ejectors the efficiency increases with increasing piston diameter (and implicitly with increasing ejector volume).

The first objective function is the ejector volume and its equation is:

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>GENES OF THE OPTIMIZATION PROGRAM</td>
</tr>
<tr>
<td>Gene</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>
where:
- $d_f$ – flange diameter;
- $l_f$ – flange length;
- $d_{sh1}$ – plug shoulder diameter;
- $l_{sh1}$ – plug shoulder length;
- $d_{rd}$ – plug rod diameter;
- $l_{rd}$ – plug rod length;
- $d_c$ – cylinder outer diameter;
- $l_{so}$ – clearance through which air circulates in the return stroke

\[ l_{so} = \frac{d_{rd} - d_c}{2} \]  

(2)

- $l$ – cylinder length;
- $l_b$ – bush length;
- $d$ – piston rod diameter;
- $l$ – length of the bush hole;
- $n$ – number of ejectors.

The second objective function is the ejector efficiency:

\[ \eta = \frac{F_a - F_f}{F_a} \rightarrow \max \]  

(3)

where:
- $F_a$ – extraction force;
- $F_f$ – force of friction between the O-rings and the cylinder.

\[ F_a = \frac{\pi \cdot D^2 \cdot p_a}{4} \]  

(4)

where:
- $D$ – piston outer diameter;
- $p_a$ – air-compressed pressure.

According to [1] the equation of force of friction is:

\[ F_f = c_1 \cdot \mu \cdot p \cdot \pi \cdot D \cdot b \cdot i \]  

(5)

where:
- $c_1$ – correction factor which depends on the number of gaskets ($c_1 = 1$ for single gasket, $c_1 = 0.5$ for package of gaskets);
- $\mu$ – coefficient of friction between the O-ring and the cylinder;
- $p$ – effective pressure between gasket and the contact surface;
- $p = p_a - p_{am}$

\[ p_{am} = \text{atmospheric pressure} \ (p_{am} = 0.1 \, \text{MPa}); \]
- $b$ – O-ring contact width ($b = 1.2 \cdot d_{O-ring}$ [1]);
- $i$ – number of identical gaskets in package.

Using the above equation the friction force is given by:

\[ F_f = \mu \cdot (p_a - p_{am}) \cdot \pi \cdot D \cdot 1.2 \cdot d_{O-ring} \]  

(7)

**Constraints**

The following twelve constraints were identified and used in the optimization program:

**R1** In order to allow the reversal stroke of the ejector piston (in initial position), the piston outer diameter $D$ has to be larger than the piston rod diameter $d$ with a certain amount ($l_{so}$):

\[ g_1 = \frac{2 + d}{D} - 1 \leq 0 \]  

(8)

**R2** In order to exist a clearance through which air circulates in the return stroke, the cylinder outer diameter $d_c$ has to be larger than the plug rod diameter $d_{rd}$ with a certain amount ($l_{so}$):

\[ g_2 = \frac{2 + d_{rd}}{d_c} - 1 \leq 0 \]  

(9)

**R3** The plug rod diameter $d_{rd}$ has to be larger than the plug shoulder diameter $d_{sh1}$ with a certain amount ($l_{mm}$), enough to allow the fitting in of the O-ring IV without its damage:

\[ g_3 = \frac{2 + d_{sh1}}{d_{rd}} - 1 \leq 0 \]  

(10)

**R4** The inner diameter $D$ of the pipe has to be less than its outer diameter $d_c$:

\[ g_4 = \frac{D}{d_c} - 1 \leq 0 \]  

(11)

**R5** The difference $(d - D)$ has to be less than $2 \cdot h_c$ (double of the thickness of the pipe wall):

\[ g_5 = \frac{d - D}{2 \cdot h_c} - 1 \leq 0 \]  

(12)

**R6** The thickness of the pipe wall should be higher or equal to a minimum imposed value:

\[ g_6 = \frac{4 + d_{rd} + 2 \cdot t_i}{D} - 1 \leq 0 \]  

(13)

**R7** The thickness of the flange wall, in the fitting in zone of the O-ring III, has to be higher or equal to a minimum imposed value:

\[ g_7 = \frac{D}{d_c} - 1 \leq 0 \]  

(14)

**R8, R9** The ratio $d/d_p$ has to lie in a certain range:

\[ g_8 = \frac{d}{d_p} - 0.2 \leq 0 \]  

(15)

\[ g_9 = 0.07 - \frac{d}{d_p} \leq 0 \]  

(16)

**R10** The ejector must not damage the bottom wall of the injected part:

\[ g_{10} = \frac{\sigma_{ab}}{\sigma_{bb}} - 1 \leq 0 \]  

(17)

\[ \sigma_{bb} = \frac{4 \cdot F_y}{\pi \cdot d^2} \]  

(18)

where:
- $\sigma_{bb}$ – bearing pressure;
- $\sigma_{ab}$ – allowable bearing pressure of the material of the injected part at the demolding temperature.

**R11** The ejection length has to be a positive number:

\[ g_{11} = -l_e < 0 \]  

(19)

\[ l_e = l - l_{so} - l_{pave} - l_{spring} - l_i \]  

(20)

**R12** The ejection length has to be higher than a certain fraction of the injected part length:

\[ g_{12} = \frac{0.6 \cdot l_e}{l_i} - 1 \leq 0 \]  

(21)

**Multi-objective optimization program**

The authors of this paper conducted the evolutionary multi-objective optimization by means of the Pareto
MATERIALE PLASTICE

To the effect of constrains of an optimization problem.

Sudden and massive changes of the species) is comparable to the high level of stress in the population (which determines evolutionary optimization algorithm 25. We think that the implementing the concept of punctuated equilibrium in an present paper have a totally different point of view on many computational approaches [3, 18, 20, 22].

Beginning, the theory of punctuated equilibrium has inspired from the concept of “punctuated equilibrium”. Probably punctuated equilibrium is the best known example of evolutionary metastability [5]. From the beginning, the theory of punctuated equilibrium has inspired many computational approaches [3, 18, 20, 22].

Unlike the above-mentioned researches, the authors of the present paper have a totally different point of view on implementing the concept of punctuated equilibrium in an evolutionary optimization algorithm 25. We think that the high level of stress in the population (which determines sudden and massive changes of the species) is comparable to the effect of constrains of an optimization problem. Therefore, the main idea behind our 2PhEA algorithm is its operation in two phases. In each phase, the individual fitness is determined by another factor. In Phase 1, the individual fitness depends only on the way in which an individual is more suitable (or not) in terms of constraints. In this phase, the population “fight for survival” and there is no interest for the best individual. For this reason, the number and level of mutations is high, respectively very high. We thought this phase as some kind of “feasible individual generator”. The algorithm moves into the second phase when the number of feasible individuals of the population exceeds a preset threshold. Phase 2 is a common evolutionary algorithm (sometimes a simple genetic algorithm). Only in this second phase the Pareto front is collected.

The 2PhEA is implemented in Cambrian v.3.2 which is in operation at the Optimal Design Centre of the Technical University of Cluj-Napoca, Romania. During optimization, we used a population of 1000 individuals, and we set the cross-breeding probability 1.0 and the mutation probability 0.25 in Phase 1, and 0.8 and 0.1 respectively, in Phase 2. The best results were obtained when we used an acceptance threshold for feasible individuals of 0.4.

The input data of the optimization program are presented in table 2.

Optimization results

The optimization results are presented in table 3 and the optimal Pareto front is showed in figure 3. One can observe that there are several optimal ejector variants (all of them are good).

The first position in table 1 corresponds to an ejector with the piston diameter $D = 15$ mm and rod diameter $d = 15$ mm. The volume of this ejector is $V = 358146$ mm$^3$ (minimal volume) and its efficiency is $\eta = 78.9$ % (minimal efficiency). The last position in table corresponds at an ejector with the piston diameter $D = 45$ mm and the rod diameter $d = 15$ mm. The corresponding volume is $V = 832706$ mm$^3$ (maximal volume) and the efficiency is $\eta = 87.3$ % (maximal efficiency).

A minimal volume of pneumatic ejector will bring an economy in mould space, the saved space being used in order to obtain a better cooling system. This will decrease the cooling time and will implicitly decrease the injection cycle time and consequently, will dramatically increase productivity.

On the other hand, a maximal efficiency means a substantial decrease of friction losses that leads to the minimal energy consumption necessary to act the ejector. Unfortunately, choosing the ejector with maximum efficiency ($D = 45$ mm, $d = 15$ mm) implies an ejector volume that is unacceptable in terms of cooling system.

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### Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Denotation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large diameter of the part (core)</td>
<td>$D_p$</td>
<td>287 mm</td>
</tr>
<tr>
<td>Small diameter of the part (core)</td>
<td>$d_p$</td>
<td>205 mm</td>
</tr>
<tr>
<td>Part length</td>
<td>$l_p$</td>
<td>265 mm</td>
</tr>
<tr>
<td>Part wall thickness</td>
<td>$h$</td>
<td>2 mm</td>
</tr>
<tr>
<td>Demolding temperature</td>
<td>$T$</td>
<td>60 °C</td>
</tr>
<tr>
<td>Allowable bearing pressure of the material of the injected part at the demolding temperature</td>
<td>$\sigma_{ab}$</td>
<td>10 MPa</td>
</tr>
<tr>
<td>Air-compressed pressure</td>
<td>$p_a$</td>
<td>0.6 MPa</td>
</tr>
<tr>
<td>Coefficient of friction between the O-ring and the cylinder</td>
<td>$\mu$</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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MATERIALE PLASTICE • 47 • Nr. 1 • 2010
design (an increase in efficiency by 10% will result in a doubling of the volume of the ejector).

An acceptable solution would be to choose the nearest point to the ideal point, which here is the origin. This design solution (in fact a very good technical solution) corresponds to a pneumatic ejector with a volume $V = 539441$ mm$^3$ and an efficiency $\eta = 83.7\%$. In this case the piston diameter is $D = 35$ mm and the rod diameter is $d = 15$ mm (the solution is shadowed in table 3).

**Conclusions**

For multi-objective optimization of mould ejector system was used *Cambrian*, an original software developed in the frame of Optimal Design Centre belonging to Technical University of Cluj-Napoca, Romania. The authors of this paper have made significant contributions to designing and implementing this program.

In *Cambrian* software is implemented 2PhEA our absolutely new and original evolutionary algorithm with two phases.

The ejector efficiency is not a very important factor of influence on the ejector design.

The ejector volume varies approximately linearly with its efficiency; a maximum efficiency brings an excessive ejector volume that is unacceptable.

The solutions from Pareto front with $V > 10^6$ mm$^3$ are not included in this report because, although the efficiency increases in these cases, the ejectors are totally improper.

Multiple choices of solutions to be achieved open new perspectives for selecting other optimization criteria.

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