Innovation-Prototype. Making hydraulic and/or pneumatic plates using 3D printing technology

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Abstract. Start 3D printing allows hydraulic and/or pneumatic plates to be obtained from a single technological process without requiring further post-production operations. 3D printing with innovative materials in a rich colour range has several advantages such as: time-saving, cost is the same for any type of plate and its reported just to volume, fast and impossible realization of hydraulic and/or pneumatic links compared to traditional and high accuracy technologies.

1. Innovation-prototyping. 3D printing

The 3D printing represents a technology not as new as it may be, but which has become more and more accessible in the last decade, stimulating the innovation and increasing the efficiency in many areas, including the hydraulic and pneumatic fields, due to the designing freedom, reduced time and low costs [1].

The 3D printing – regarded as a modern manufacturing process – has a number of advantages [2]:

- design optimization;
- multiple personalization possibilities;
- rendering to a high degree of complexity;
- decrease in production time;
- cost reduction;
- material saving;
- promoting the principle of sustainability.

The 3D printing is the ideal solution for the most demanding designers and engineers; therefore, through rapid prototyping, the organizations are helped to [3]:

- improve the communication modality in terms of developing new products;
- shorten the designing cycle;
- bring high-quality products to the market faster than the competition does;
- improve the precision of the patterns;
- eliminate costly mistakes;
- bring innovation and high quality;
- optimize the collaboration between engineers, marketing and sales departments and management team, through elaborate presentations.
The application areas for 3D printing are many and various: mechanical and mechatronics engineering, engineering and management of technological systems, automation and computers, aerospace engineering, medical engineering, biotechnical systems engineering, machine building technology, electrical engineering, electronics and telecommunications, etc.

The benefits of 3D printing in engineering [4]:
- reduced costs of designing, building and marketing of a new product by verifying its shape and functionality at an early stage;
- highly efficient assessment of the ergonomics and aesthetics of the prototype;
- reducing and, often, eliminating the design changes of the manufacturing tools;
- improving the intercommunication among the members of the team, requiring a shorter time to launch a new product;
- reduced costs of machining tools by printing patterns or moulding components using 3D printed moulds.

The field of 3D printing is becoming more and more accessible, being a source of innovation similar to that of the Internet explosion.

2. Hydraulic/pneumatic blocks
The modular hydraulic/pneumatic blocks are standardized elements used for building hydraulic/pneumatic circuits with low consumption of ducts and connection elements. Constructively, they are parallelepiped-shaped.

The multiple positions in which they can be assembled have limited the number of modular board types. Typically, there is one type of board for each type of hydraulic/pneumatic device used in the control diagrams.

2.1. Role and constructive features
The hydraulic/pneumatic blocks include either embedded elements (i.e. cartridge elements) or applied elements (i.e. manifolds, valves), integrating all distribution and control elements of the hydraulic/pneumatic diagram.

The accelerated development of machine building requires the assembly of hydraulic/pneumatic equipment in a modular system.

The use of modular systems has some very important advantages:
- reduced size;
- low energy losses due to low consumption of ducts and connection elements;
- system flexibility, thanks to the possibility of modular device combinations;
- easy troubleshooting/maintenance.

The modular devices will be mounted on modular boards, enabling the building of the most diverse and complex hydraulic/pneumatic diagrams.

Figure 1. The holes of the hydraulic block [5]

Figure 2. The hydraulic block assembly[5]
2.2. Hydraulic/pneumatic calculation of hydraulic/pneumatic blocks

Hydraulic/pneumatic connecting elements having the function of transporting the working agent require a hydraulic/pneumatic calculation to determine the minimum cross-sectional area of the holes through which the working fluid circulates [6].

2.2.1. Hydraulic/pneumatic calculation. It consists of setting the required nominal diameter (DN). For calculation, the relationship can be used:

\[ d = 4.61 \frac{Q}{v} \]  \hspace{1cm} (1)

in which:

- \( Q \) - the flow of fluid flowing through the pipe, \( \left[ \frac{m}{min} \right] \);
- \( v \) - the flow velocity of the fluid in the pipeline, \( \left[ \frac{m}{s} \right] \). 

As it results from the relationship, the flow rate cannot be any size. The recommended values for these are:

\[ v = 6...7 \frac{m}{s}, \quad \text{for} \ l < 100 \cdot d \]
\[ v = 3...4 \frac{m}{s}, \quad \text{for} \ l > 100 \cdot d \]
\[ v = 1,5...2,5 \frac{m}{s}, \quad \text{for the discharge pipe} \]  \hspace{1cm} (2)

The nominal pipe diameter, established with the previous relationship, is corrected to the normalized value, since the hydraulic apparatus is designed for DN nominal values with normalized values of 6; 8; 10; 13; 20 mm.

2.2.2. Calculating the strength of the hydraulic block material. Consider the hole in the block as a pressurized case subjected to a plane tension condition. Since the tension in the transverse direction is higher, the thickness of the wall can be expressed with the relation:

\[ \sigma = \frac{p \cdot d}{2 \cdot \sigma_a} \]  \hspace{1cm} (3)

\( \sigma_a \) - is the admissible mechanical strength of the material of the pipe material. The relationship (3) is valid for the calculation of thin-walled pipes \( (16 \geq \delta d) \).

For pipelines where \( 16 < \delta d \) behavior in terms of material resistance is described by relation (4):

\[ \sigma_a = \frac{d^2 + 2\delta + 2\delta^2}{2(d - \delta)} \cdot p \]  \hspace{1cm} (4)

resulting the thickness of the pipe wall:

\[ \delta \geq \delta_{\min} = \frac{d}{2} \left( \frac{\sigma_a + p}{\sigma_a - p} - 1 \right) \]  \hspace{1cm} (5)

When designing, the pipe whose internal diameter corresponds to the required flow conditions is adopted, and then it is pre-dimensional with one of the previous relations.

2.2.3. Linear load losses - hydraulic circuits. When flowing through real piping, two types of hydraulic losses occur:
- linear hydraulic losses $h_{pd}$ (longitudinal or distributed), mathematically expressed by Darcy's formula:

$$h_{pd} = \lambda \frac{l}{d} \frac{v^2}{2g} \quad (6)$$

- local hydraulic losses $h_{pl}$, expressed by the formula of Weisbach:

$$h_{pl} = k \frac{v^2}{2g} \quad (7)$$

in which:

- $l$ - pipe length, $[m]$;
- $d$ - pipe diameter, $[m]$;
- $v$ - average fluid velocity per section, $[\frac{m}{s}]$;
- $g$ - gravitational acceleration, $[\frac{m}{s^2}]$;
- $\lambda$ - coefficient of linear hydraulic losses, $[-]$;
- $k$ - the local hydraulic losses coefficients corresponding to the different types of hydraulic resistances, $[-]$.

These coefficients $k$ of local hydraulic loss are obtained from the experiments, and depending on the change of direction, the diameter of the pipes as well as the flow direction of the fluid may have the values given in figure 3.

**Figure 3.** The value of the local pressure loss coefficient $k$, determined experimentally

The literature shows the value of the local loss coefficient $k$ for different situations and elements found in practice.

Thus, Table 1 shows these values of the local hydraulic loss coefficient $k$:
### Table 1. Values of the local hydraulic loss coefficient K - different types of elbows and joints

| Types                | Flanged | Threaded |
|----------------------|---------|----------|
| Regular 45°          | 0.2     | 0.4      |
| Regular 90°          | 0.3     | 1.5      |
| Long radius 90°      | 0.2     | 0.7      |
| Return bend 180°     | 0.2     | 1.5      |
| Line flow            | 0.2     | 0.9      |
| Branch flow          | 1       | 2        |
| Union                | 0.08    | 0.09     |

3. Hydraulic block design. Modeling flow through holes

Using PLM software packages, users can simulate the full range of processes needed to develop a new product from the initial design phase to the design, analysis, manufacturing, and maintenance phases.

The CATIA V5 benefits from a sustained pace of development, and it is practically two to three months to come up with a new revision. At present, the CATIA V5 contains over 140 robust applications covering vast areas of assisted engineering [7]. Figure 4 shows the modelling of a hydraulic block with the specification tree, visualizing the holes [8].

![Figure 4. The modeling of a hydraulic block](image_url)

Fluid mechanics equations, especially Newtonian fluid dynamics and Navier-Stokes non-stationary equations can be explained by specialized modeling and simulation software. Thus, a new branch emerged, namely CFD - Computational Fluid Dynamics, which complements the dynamics of the theoretical and experimental fluids.

This new branch of the fluid mechanics study, CFD, has a number of advantages compared to the dynamics of the experimental fluids, as follows:

- design and development time is substantially reduced;
- flow conditions that cannot be reproduced experimentally can be simulated;
- provide clear and detailed information (graphics and value);
- it is an economic method, with few material and energetic resources.
By modeling and simulation of CFD was followed by the suggestive presentation of the major energy differences of the flow of fluids through orifices processed by classical technology, respectively by the unconventional and innovative 3D printing technology.

![Figure 5. Fluid velocity field-classical mechanical processing](image1)

![Figure 6. Fluid velocity field-3D printing processing](image2)

![Figure 7. Fluid pressure field-classical mechanical processing](image3)

![Figure 8. Fluid pressure field-3D printing processing](image4)

The differences between the two solutions are presented in Figures 5, 6, 7 and 8. The speeds have much higher values for the classic solution, Figure 5, which implicitly leads to a substantial increase of the local pressure losses, Figure 8. These major differences have made us physically achieve a hydraulic block with a 3D printer.

4. **3D printing of the designed hydraulic block**

The 3D printer used uses the filament deposition technique. The printer model is Anet A6, bought as a kit and assembled. It is a printer working in Cartesian coordinates (X Y Z). The X and Y axes are driven by transmission belts, and the Z axis operates on the nut-screw principle. Technical specification is presented in Table 2 [9].

| Specification          | Technical specification |
|------------------------|-------------------------|
| model                  | A6                      |
| machine weight         | 7.6kg                   |
| gross weight           | 9.5kg                   |
| machine size           | 480x400x400mm           |
| packing size           | 450x446x215mm           |
| LCD display            | LCD12864                |
| consumable material    | ABS/PLA/HIPS/etc.       |
| material diameter      | 1.75mm                  |
| framework              | Acrylic                 |
The extruder consists of a stepper motor, a filament pushing system, a filament heating and melting chamber, a nozzle, a thermocouple and an electrical resistance. The print pad is on the Y axis and has the option to be heated for better adhesion of more sensitive materials (ABS) \[9\]. Technical parameters are presented in Table 3.

**Table 3. Technical parameters**

| Parameters                  | Value        |
|-----------------------------|--------------|
| print size                  | 220x220x250mm|
| printing speed              | 100 mm/s     |
| nozzle diameter             | 0.4 mm       |
| layer thickness             | 0.1-0.3 mm   |
| XY position accuracy        | 0.012 mm     |
| Z position accuracy         | 0.004 mm     |
| extrusion head temperature  | 260°C        |
| bed temperature             | 100°C        |

The 3D printer provides high-complexity pieces that cannot be achieved by known technology. Among the materials made available by producers, we chose the PLA (polylactic acid), which has the properties presented in Table 4.

PLA (polylactic acid) is a biopolymer, a biodegradable plastic. It is made of renewable raw materials, such as corn starch or sugar cane \[10\].

In addition to 3D printing, it is commonly used for packaging materials, plastic foils, plastic glasses and plastic water bottles.

**Table 4. Polymer properties**

| Solid PLA                  | Value        |
|----------------------------|--------------|
| print temperature          | 210-225°C    |
| raft temperature           | 190°C        |
| first layer temperature    | 200°C        |
| print base material        | MDF/Acrylic  |
| raft required              | Optional     |
| filament diameter          | 3mm          |

With the elements given in the design phase, the actual building of the hydraulic block was completed. The hydraulic block was built in the Hydraulic and Pneumatic Hydraulic Driving Laboratory of the Faculty of Engineering in Hunedoara, Figure 9.

![Figure 9. Prototyping of the designed hydraulic block](image)
5. Conclusions
The hydraulic block obtained by this process combines the technological and economic advantages of the innovative design and 3D printing process.

From a technical point of view, the following have been highlighted:
- reduce the prototyping time of the product;
- eliminating mistakes and improving product quality;
- production of compact hydraulic blocks by eliminating the inconveniences generated by classical processing;

Economical, the advantages of 3D design and printing are given by:
- cost reduction;
- material saving;
- promoting the principle of sustainability.

The 3D printing represents a technology not as new as it may be, but which has become more and more accessible in the last decade, stimulating the innovation and increasing the efficiency in many areas, including the hydraulic and pneumatic fields, due to the designing freedom, reduced time and low costs.

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