BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 70 (74), Numărul 3, 2024
Secţia
CONSTRUCŢII DE MAŞINI
DOI:10.2478/bipcm-2024-0011

MODERN TECHNOLOGIES APPLIED FOR THE MANUFACTURING OF HYDRAULIC MANIFOLDS BLOCKS

BY

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Received: November 17, 2024
Accepted for publication: December 14, 2024

Abstract. The paper provides a review of the scientific literature on modern technologies for manufacturing hydraulic blocks, focusing on additive manufacturing and laminated blocks versus conventional methods. The analysis highlights findings that show that laminated blocks can produce pressure drops lower by up to 50% compared to conventional blocks, next to weight decrease by up to 70%. Whether the additive manufacturing technology is applied, the weight can be reduced by up to 90% and the pressure drop can be lower by up to 44%, comparing to the results obtained for laminated blocks. This work examines the numerical and experimental results published last years, emphasizing the advantages and the limitations of each technology. By implementation of these two methods, more efficient design and production of hydraulic blocks can be achieved.

Keywords: additive manufacturing hydraulic manifold, laminated hydraulic block, optimization, pressure drop, weight reduction.

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1. Introduction

Last years, hydraulic block manufacturing technologies have evolved significantly, opening new opportunities for optimizing the design and the performance. Modern methods are different from traditional manufacturing techniques such as casting, forging, or extrusion, followed by material removal. They offer good flexibility of solutions and have been adopted in various industrial sectors due to the economic benefits, lower weight and technical advantages. Additive manufacturing and laminated blocks are two modern technologies to be used for manufacturing hydraulic components, but they are not yet widely implemented, as manufacturing of conventional blocks is.

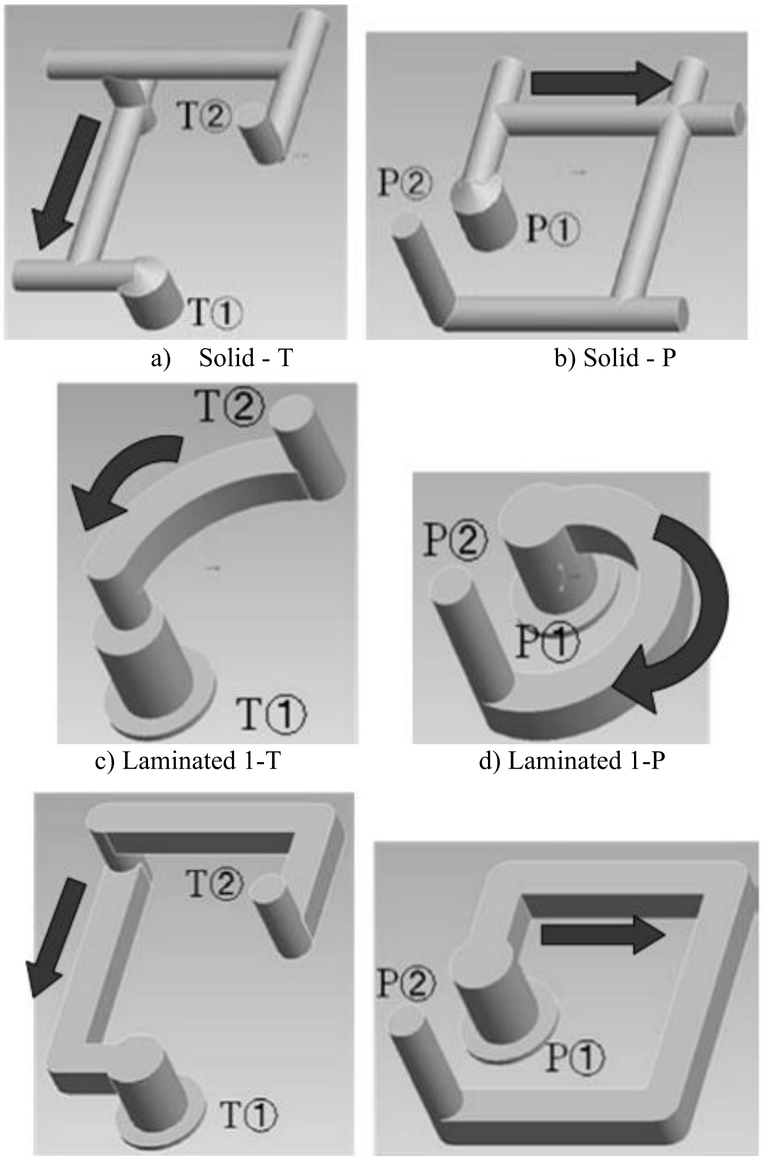
By using additive manufacturing, the engineers can develop optimized internal structures, improving the performance and the efficiency of hydraulic blocks, while paving the way for customization and innovation. The fields of application for additive manufacturing are vast, and research and development on this method have led to applications in various fields such as the medical devices, the cooling/heating systems, the hydraulic actuation systems (Zhang *et al*., 2020).

Innovative laminated blocks were proposed by patents. The patent "Hydraulic manifold system", designed by Courson Richard (Courson, 1971) and the patent "Laminated block with segment sheets connected by high-temperature soldering", designed by Krause Bernd (Bernd, 2005) are successfully implemented. Laminated blocks are made of layers of materials, each of them perforated to obtain geometries that compose the circuits within the block and after this process is done, they are assembled by brazing technologies. The challenge in assembling is to align the plates for brazing, because the perforation process for making the internal channels usually produces burrs. Another problem for the aligning process is generated by the different dimensions of the plates.

The aim of this paper is to analyze the scientific literature regarding additive manufacturing and laminated blocks technologies, applied within the manufacturing process of hydraulic blocks. The article provides a special focus on the discussion of results obtained by experimental tests and CFD analysis versus conventional technologies. Furthermore, this work aims to explore the potential for future development, offering a perspective on the impact that the two technologies could have on the hydraulic blocks production industry.

2. Analysis of research results obtained by numerical simulations and experiments

The paper "Pressure Drop of Pipe Flow in a Manifold Block" written by Osamu *et al*. (2011) presents a comparison between the configurations types Solid-T and Solid-P from a conventional block and two laminated blocks having different designs: the first has a geometry similar to the conventional block due to the smooth passages through the connections 2-T and 2-P, while the second has special geometries 1-T and 1-P (see Fig. 1).



a) Solid - T b) Solid - P

c) Laminated 1-T d) Laminated 1-P

e) Laminated 2 -T f) Laminated 2-P

Fig. 1 – The geometries studied within the paper “Pressure Drop of Pipe Flow in a Manifold Block” (Osamu *et al*., 2011).

For the conventional block presented in Fig. 1a and Fig. 1b, the diameter of the channels is 6 mm. The cross -section of channels used for the laminated blocks have a square shape with a side length of 6 mm. In the CFD analysis and the experimental tests, the working fluid is a oil with density of 870 kg/m³, the kinematic viscosity of 32 mm²/s, the temperature of 40°C and the fluid flow rate of 50 l/min.

The results indicate that both geometries can be used to reduce pressure losses. For the Solid-T configuration, the measured pressure drop is 5 MPa, while for the 1-T configuration from the Fig. 1c it is 2 MPa and for the 2-T geometry from the Fig. 1e, it is 4 MPa. For the Solid-P configuration from the Fig. 1b, the pressure drop is 4.5 MPa, and for the 1-P configuration from the Fig.1d it is ~2.3 MPa. The value of the pressure drop, obtained for the 2-P configuration presented in Fig. 1e, is 3.5 MPa (Osamu *et al*., 2011).

The paper "Laminated Manifold for Digital Hydraulics – Principles, Challenges and Benefits" written by Paloniitty *et al*. proposes a laminated block with four chambers and the conclusions recommend laminated blocks technology based on the results of structural analysis and on the endurance experimental tests (Paloniitty *et al*., 2012). The solution is presented in Fig. 2. For chamber 1, plastic deformations were observed at 280 bar. The results for chamber 2 shows that deformations were not noticed up to the pressure of 440 bar. The chamber 3 endured two tests, one up to 400 bar and the other up to 440 bar, and deformations appeared only during the second test. In chamber 4, no leaks or deformations were observed at pressure up to 1000 bar, when the test was stopped. The research proposed the design for a laminated sheet block having 8.5 kg weight, which can successfully replace the "Bosch Rexroth KSDEU" model weighing 31 kg, able to have same performance (Paloniitty *et al*., 2012).

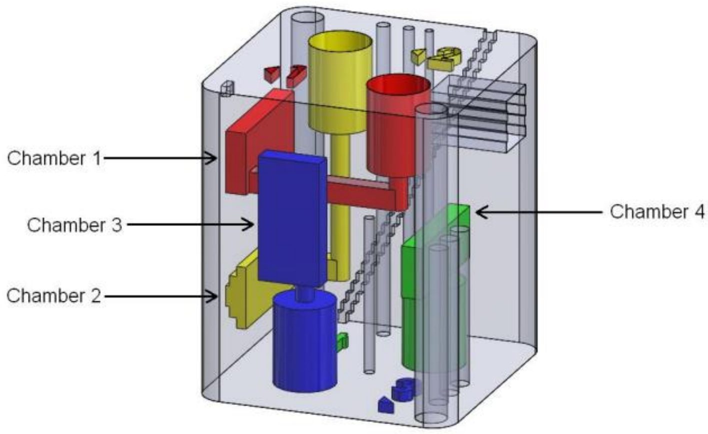


Fig. 2 – Test block used to validate the structural strength of the laminated block technology in the paper "Laminated Manifold for Digital Hydraulics – Principles, Challenges and Benefits" (Paloniitty *et al*., 2012).

The paper "Selective Laser Melted Digital Hydraulic Valve System" published by Chekurov and Lantela, compares a laminated block to a block made by using additive manufacturing technology. Within experimental tests based on different materials with similar mechanical properties, next to trials conducted at the same flow rate of 87 l/min and the same pressure of 250 bar, for both blocks. The results indicate a 44% lower pressure drop for the block made by additive manufacturing, compared to the laminated block. Chekurov and Lantela concluded that using the additive manufacturing technology made the construction of the block simpler and more efficient compared to the laminated block technology. The issue is that the additive manufacturing technology is more expensive than the laminated blocks technology for mass production (Cherukov and Lantela, 2017).

The paper "Design for additive manufacturing process for a lightweight hydraulic manifold" presents a redesign of a conventional hydraulic block weighing 16.2 kg using the additive manufacturing technology. For the redesign, Diegel and collaborators used two materials to build the studied blocks: aluminum alloy AlSi10Mg for the first case study and 316 stainless steel for the second because it is the same material as the one used for the conventional block (Diegel *et al*., 2020). The optimized design was performed using a methodology developed by Diegel *et al*., which involves removing all geometries from the 3D model, except the interfaces for components and input/output ports, modifying the model to improve hydraulic performance, and finding the optimal printing orientation to reach the lowest quantity of support material. The interfaces of the additive manufacturing blocks are positioned to optimize the fluid flow and to reduce the vortex intensity. Conclusions show that the weight decrease due to additive manufacturing technology applied for the aluminum block is 96.9% (from 16.2 kg to 0.494 kg), and for the stainless-steel block is 91.2% (from 16.2 kg to 1.4 kg). The maximum pressure for the conventional block can be 228 MPa, for the aluminum block is 53.9 MPa, and for the stainless-steel block is 98 MPa. However, the working pressure in the hydraulic system, where the conventional block is implemented is 32 MPa, meaning both blocks made by additive manufacturing technology are functionally fully able to replace the conventional block (Diegel *et al*., 2020).

The paper "Design and Qualification of an Additively Manufactured Manifold for Aircraft Landing Gears Applications" (Maurizio, 2023) presents the redesign of a hydraulic block used in the aerospace industry using additive manufacturing technologies. The AlSi10Mg material was chosen for printing the redesigned block that was used for structural and functional validation tests in accordance with SAE AS8775 (SAE-AS8775 1997) and SAE ARP1383 (SAE ARP1383 2013). The results obtained for the redesigned block, by using the finite element analysis method and the experimental tests are presented in Fig. 3. After completing the tests, the redesigned block was studied by Dye Penetrant Inspection (DPI) to detect any malformations in the threads or potential cracks in the material. During the experimental tests, no malformations, leaks, or deformations were observed. The redesigned block achieved a 40% weight reduction compared to the initial design (Maurizio, 2023).

Test	N. of Cycles	Reference
1. Proof Pressure	-	SAE AS8775 [60]
2. Endurance Cycles	5000	Legacy spectrum
3. Hydraulic Fatigue	100,000	SAE ARP183 Rev. C [61]
4. Burst Pressure	-	SAE AS8775 [60]

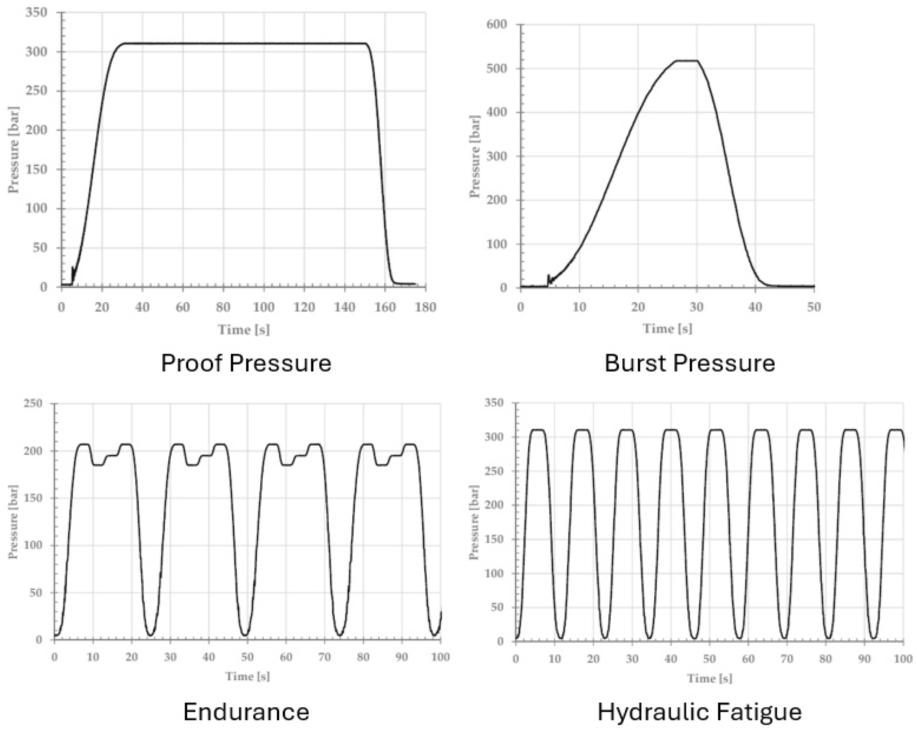


Fig. 3 – Results and type of tests performed on the redesign block (Maurizio, 2023).

The paper “Development Workflow for Manifolds and Fluid Components Based on Laser Powder Bed Fusion” presents a workflow methodology for obtaining a hydraulic block manufactured by the additive manufacturing technology. The main steps of the methodology are: the planning phase, the conceptual phase, the embodied design phase, the prototyping phase, the experimental tests and the final evaluation of the solution from a technical and economic perspective. Rolinck N. *et al*. conducted a case study where they applied the modern methodology to a hydraulic block to be used in a braking system, and the weight reduction from 8.55 kg to 2.06 kg was reached (Rolinck *et al*., 2021).

The paper "AM-Driven Design of Hydraulic Manifolds: Enhancing Fluid Flow and Reducing Weight" presents the redesign of a conventional hydraulic manifold weighing 14 kg. The main goal focus of the paper is to improve the fluid flow circulation through the hydraulic manifold channels, built by additive manufacturing technology. The diameter of the orifices is d = 10 mm, the material used for the prototype is 316L steel, similar to the material used for the conventional blocks. Before validating the CFD analysis by experimental testing, a CT (computed tomography) inspection was performed to check any deformations or defects as a consequence of the additive manufacturing, which could generate impact on the performance of the redesign block. The results of the study indicate that the redesigned block has a reduced weight of 2.6 kg, and also that the pressure drop is reduced by 31% (Zhu *et al*., 2020).

The paper *"Design of an Additively Manufactured Hydraulic Directional Spool Valve: An Industrial Case Study"* focuses on optimizing a 4/3 directional control valve using additive manufacturing technology, developed by Wandfluh AG. The results obtained for the prototype are compared to those obtained for the conventional block. Experimental trials revealed that the pressure loss is 60% lower, and the weight is halved due to the additive manufacturing technology. The authors develop a methodology based on steps to be used in the optimization process of the conventional manifold. The main requirements are imposed by the functionality, the strength, and the manufacturing process of the finished product. After defining the requirements, design solutions are identified and analyzed using CFD methodology to find out which configuration leads to the minimum pressure losses. The next step involves the validation of the spool valve assembly by integrating the components and performing detailed by using the design of functional interfaces/orifices to prepare for production (Hofmann *et al*., 2023).

The paper *"Additive Manufacturing of Hydraulic Components – Pressure Loss Comparison of Different Self-Supporting Channel Geometries"* focuses on the comparison of the pressure losses for four different configurations, presented in Fig. 4, which can be manufactured by additive manufacturing technology. The authors study each geometry for three categories of surface roughness: process roughness, roughness obtained by Hot Isostatic Pressing (HIP), and roughness obtained by Abrasive Flow Machining (AFM). The first step in the paper is the structural analysis performed by ANSYS and the studied geometries are presented in Fig. 4. The structural analysis was validated by experiments focusing on mechanical and followed by hydraulic tests. The results indicate that the triangular cross-section leads to the lowest pressure losses, whatever the category of roughness. The second-best geometry with the lowest pressure losses was the triangular cross-section, followed by the geometry specified in DIN EN ISO/ASTM 52911-1 (DIN EN ISO/ASTM 52911-1 2019) and, finally by the circular cross-section (Tappeiner *et al*., 2024).

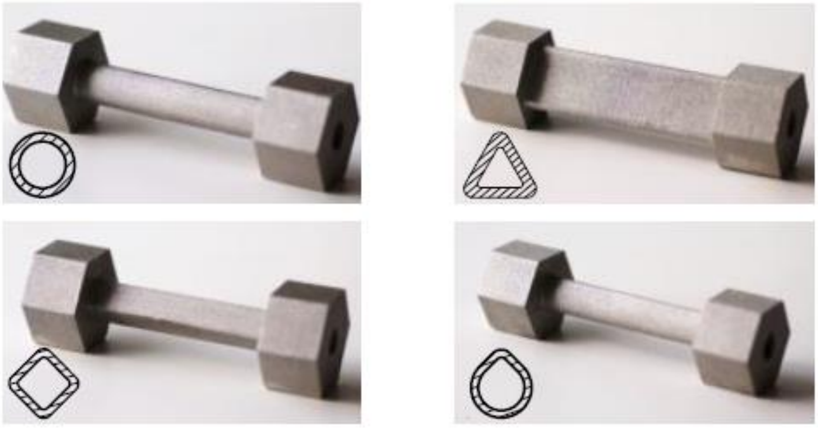


Fig. 4 - Configuration types studied within the paper ”Additive Manufacturing of Hydraulic Components – Pressure Loss Comparison of Different Self-Supporting Channel Geometries” (Tappeiner *et al*., 2024).

3. Conclusions

Studies regarding the additive manufacturing technology of hydraulic manifolds and those manufactured by laminated block technology focus on the methodologies that aim to minimize the material volume, the pressure drops, the interpretation of results obtained by numeric simulations and by experiments. The works on additive manufacturing, propose technologies such as Laser Powder Bed Fusion (LPBF) or Selective Laser Melting (SLM) for prototype production.

The main essential features that generate interest in these manufacturing methods to be used for hydraulic manifold blocks, in terms of their optimization, include:

- The design of unique channel cross-section geometries, as presented in the work of Tappeiner (Tappeiner *et al*., 2024), along with the incorporation of rounded radius at flow direction and changes of direction to minimize the vortex intensity during flow passages;
- Weight reduction in some cases by up to 90% (Diegel *et al*., 2020).

A comparison between the manufacturing methods presented in this paper and the conventional hydraulic manifold blocks can be made by highlighting the advantages and disadvantages in terms of the structural strength, the hydraulic performance, the weight reduction and the production costs.

- Structural criteria:
    - By comparing the structural aspects, it can be concluded that both modern manufacturing methods can lead to the strength level of conventional blocks. This was demonstrated by the works of Maurizio A. (Maurizio, 2023) and Paloniity *et al*.

(Paloniity *et al*., 2012). Maurizio A. did the structural validation of a redesigned hydraulic block built by using additive manufacturing. The weight was reduced by 40% compared to the conventional block, while the redesigned block withstood the prescribed loads. Paloniitty *et al*. also validated the use of laminated blocks technology, by research based on the structural analysis and endurance tests at pressures ranging from 400 to 1000 bar.

- Hydraulic performances criteria:
    - The highest efficiency can be achieved by using additive manufacturing technology, as demonstrated in the works of Osamu (Osamu *et al*., 2011) and Chekurov and Lantela (Cherukov and Lantela, 2017). Osamu *et al*. demonstrated that by using the laminated blocks technology, the pressure losses can be decreased by approximately 50% compared to conventional blocks, while Cherukov concluded that the additive manufacturing can reduce the pressure loss by 44% comparing to the laminated block technology. The explanations consist in the fact that additive manufacturing allows smoother transitions of flow through the connections, comparing to laminated blocks. The laminated blocks have the disadvantage of having nonuniform layers and limitations imposed by the perforation processes and those issues can have impact on the pressure loss.
- Weight reduction:
    - Additive manufacturing design solutions can lead to the lowest weights, as demonstrated in the work of Diegel *et al*. (Diegel *et al*., 2020), where the weight reduction by over 90% compared to conventional blocks is mentionned. Laminated sheet brazing solutions can produce weight reductions of around 70% compared to conventional blocks, as it was demonstrated by Paloniitty (Paloniitty *et al*., 2012).
- Production costs considering raw materials, process and post-processing:
    - Additive manufacturing solutions have the lowest production costs for prototyping, but in mass production, conventional blocks and laminated blocks are less expensive.

In the context of the promising results, future research could focus on:

➢ Studies on the fluid flow moving through different types of channel geometries, radius of curvature at flow direction changes, various angles, different operating conditions, research with the goal of developing design guidelines for both modern manufacturing methods analyzed in the present study;

- Exploring the use of new metal alloys and composites for both manufacturing methods. Such a study should evaluate how innovative materials can have impact on the structural strength, the durability, and the behavior at high pressure;
- Testing laminated manifolds at high-pressure and high-vibration environments. The integrity of the layer joints should be analyzed, as well as how these blocks withstand repeated load cycles;
- Comparing additive manufacturing to laminated manifolds technologies and to conventional blocks from the point of view of hydraulic performance tests, weight analyses, structural strength tests and behavior under vibration and thermal working conditions, to identify the optimal solutions;
- Developing advanced techniques and algorithms to reduce printing time without compromising structural quality, next to more efficient layering methods and faster solidification processes methodologies.

REFERENCES

Bernd Krause, *Laminated block with segment sheets connected by high-temperature soldering*, Patent US 2005/0244669, April 20, 2005.

Cherukov Sergei, Tapio Lantela, "Selective laser melted digital hydraulic valve system." *3D Printing and Additive Manufacturing*, **4**, (2017), 215-221.

Courson Richard, *Hydraulic manifold system*, Patent US 3,763,889, June 30, 1971.

DIN EN ISO/ASTM 52911-1. DIN Deutsches Institut für Normung e.V. Additive Fertigung - Konstruktion - Teil 1: Laserbasierte Pulverbettfusion von Metallen: DE_307153562, (2019).

Hofmann Urs *et al*., *Design of an additively manufactured hydraulic directional spool valve: an industrial case study*, Virtual and Physical Prototyping, 2023, 18-1.

Maurizio Arena, *Design and Qualification of an Additively Manufactured Manifold for Aircraft Landing Gears Applications*, Aerospace, **10**, (2023).

Diegel Olaf, Schutte Juan, Ferreira Arno, Chan Lun Yuk, *Design for additive manufacturing process for a lightweight hydraulic manifold*, *Additive Manufacturring*, 36, no. 101446, (2020).

Osamu Abe, Tetsuhiro Tsukiji, Takeshi Hara, Kazutoshi Yasunaga, *Pressure Drop of Pipe Flow in a Manifold Block*, JFPS International Symposium on Fluid Power, 2011.

Paloniitty Miika, Matti Karvonen, Matti Linjama, Tuomo Tiainen, *Laminated Manifold for Digital Hydraulics - Principles, Challenges and Benefits*, Proceedings of The Fifth Workshop on Digital Fluid Power, 2012, 27-42.

Rolinck Nicolas, Matthias Schmitt, Matthias Schneck, Georg Schlick, *Development Workflow for Manifolds and Fluid Components Based on Laser Powder Bed Fusion*, Applied Sciences, 2021.

SAE ARP1383, *Aerospace-Impulse Testing of Hydraulic Components*. Rev. C. SAE International, April 2013.

SAE-AS8775, *Military Specification: Hydrailc System Components, Aircraft and Missiles*, SAE International, September 1997.

Tappeiner Zita, Donners Michiel, Matthias Schmid, Katharina Schmitz, *Additive Manufacturing of Hydraulic Components - Pressure Loss Comparison of Different Self-Supporting Channel Geometries*, 14th International Fluid Power Conference, 2024.

Zhang Chao, Wang Shuai, Li Jian, Zhu Yi, Peng Tao, Yang Huayong, *Additive manufacturing of products with functional fluid channels: A review*, Additive Manufacturing, 36, no. 101490, 2020.

Zhu Yi, Shuai Wang, Chao Zhang, Huayong Yang, *Am-Driven Design of Hydraulic Manifolds: Enhancing Fluid Flow and Reducing Weight*, Technische Universität Dresden: Dresden, Germany, 2020.

UTILIZAREA TEHNOLOGIILOR MODERNE ÎN FABRICAREA BLOCURILOR HIDRAULICE

(Rezumat)

Lucrarea își propune analiza literaturii științifice privind tehnologiile moderne de fabricare a blocurilor hidraulice, concentrându-se pe fabricarea aditivă și blocurile laminate, și compararea performanţelor cu metodele convenționale. Analiza evidențiază concluziile studiilor care arată că tehnologiile bazate pe producerea de blocuri laminate pot reduce pierderile de presiune cu până la 50% și greutatea cu aproximativ 70% față de blocurile convenționale. Fabricarea aditivă permite realizarea unor geometrii interne complexe, reducând greutatea cu până la 90% și îmbunătățind performanţele hidraulice, obținându-se pierderi de presiune cu 44% mai mici decât blocurile laminate. Lucrarea sintetizează rezultate numerice și experimentale din literatura de specialitate, subliniind avantajele și limitările fiecărei tehnologii. Propunerile de cercetare viitoare ar putea conduce la proiectarea și producția mai eficientă a blocurilor hidraulice utilizând aceste două metode.