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HYDRAULIC MANIFOLD BLOCKS MANUFACTURED USING 3D PRINTING TECHNOLOGY

BY

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Abstract. This paper explores the critical aspects of designing and manufacturing hydraulic manifold blocks using advanced additive manufacturing techniques. The study focuses on how 3D printing technologies, including stereolithography (SLA), digital light processing (DLP), continuous liquid interface production (CLIP) and direct metal printing (DMP), can influence the manifold performance, the structural integrity and the fluid dynamics. The research highlights the advantages of these technologies in reducing material waste, enabling lightweight structures, and allowing for the construction of complex internal geometries that can improve the circulation of the fluid. By presenting results of Computational Fluid Dynamics (CFD) simulations, this paper demonstrates how 3D-printed manifolds can have reduced pressure losses comparing to the traditionally machined design. Resin-based materials such as epoxy, acrylate, and nanocomposites have good mechanical properties, which make them appropriate for high-pressure applications. The paper also provides information on modern technologies such as post-processing by thermal treatment and hybrid manufacturing. Future research directions regarding smart manifold integration and industrial adoption of 3D-printed hydraulic systems are discussed.

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Keywords: 3D printing, Additive Manufacturing materials, Resin, Fluid Flow Optimization, Computational Fluid Dynamics.

1. Introduction

For decades, hydraulic manifold blocks have been at the heart of fluid control systems to circulate the hydraulic oil through intricate networks of channels and valves. Traditionally, these essential components are machined from solid metal blocks by cutting processes (e.g. drilling, milling) –an expensive, time-consuming, and material-intensive process. Engineers meticulously carved out pathways to ensure precision, but with each cut, valuable material is lost as shavings, and the design limitations restricts the innovation.

The additive manufacturing technologies allow the construction of complex, internal flow channels, impossible to be made by using traditional methods. The possibility to manufacture manifold blocks using 3D printing, opens a new domain to produce lightweight, optimized and smooth components, by improving the hydraulic performance while reducing production waste (Lodhi *et al.*, 2024).

This study highlights the importance of additive manufacturing for the hydraulic manifold industry. By leveraging advanced techniques such as Stereolithography (SLA), Digital Light Processing (DLP), and Continuous Liquid Interface Production (CLIP), it became possible to increase the hydraulic efficiency. As a matter of fact, Computational Fluid Dynamics (CFD) simulations, indicate that the pressure losses are reduced and the overall system performance is increased.

- Stereolithography (SLA) is a high-precision 3D printing technology that uses a laser to trace delicate pathways in a pool of liquid resin, solidifying it layer by layer to get a detailed and intricate structure. SLA enables the construction of complex internal geometries that would be impossible to be achieved by traditional machining (Chockalingam *et al.*, 2006). Moreover, intricate internal geometries made the technology an excellent solution for hydraulic manifolds, where the performance is crucial.
- Digital Light Processing (DLP) is somehow similar to SLA, but instead of a laser, a digital projector flashes the entire layers at once, speeding up the process while maintaining small details. It works as a high-speed sculptor does, crafting complex channels that can guide the hydraulic oil with minimum turbulence and resistance.
- Continuous Liquid Interface Production (CLIP) is a new modern technology based on the elimination of unnecessary material, layer-by-layer. Using oxygen and UV light, CLIP creates parts in a

continuous, seamless flow, resulting in ultra-smooth, high-performance manifold components. It is the fastest and the most efficient of the three techniques briefly presented above, perfect for applications where both speed and precision are required.

- Direct Metal Printing (DMP) is an alternative approach, where metal powders are selectively melted layer-by-layer to produce robust, fully dense components with superior mechanical strength—ideal for high pressure hydraulic applications.

2. Comparison of classic manufacturing technology versus additive manufacturing

Figure 1 provides a visual comparison between a hydraulic manifold manufactured using traditional machining, denoted (a) and another one constructed by 3D printing, denoted (b).

- In Figure 1a) a hydraulic manifold produced by using a conventional CNC machining is presented. The result is a rigid and compact design which is very good, but traditional manufacturing can lead to significant hydraulic energy losses when the manifold is used, because of the sharp internal corners and the straight channels. These consequences are inherent to subtractive machining methods. Moreover, it is difficult to construct fluid flow-optimized geometries.
- In Figure 1b) an optimized design manifold, manufactured using 3D printing technology is presented. This approach makes the construction of complex internal geometries possible, such as curved channels, which are impossible to obtain by conventional machining. The design improvements contribute to better utilization of material, reduced weight, and enhance the overall performance, making 3D printing technology a modern option.

Although the manufacturing methods are different, the 3D-printed manifold performs the same function as the machined one, but additionally it can offer energy efficient fluid flow circulation and reduced pressure losses.

The above presented discussion underscores the potential of additive manufacturing in hydraulics, by rising an intriguing question: how much can 3D printing reshape the industry by eliminating the issues specific to traditional machining methods?

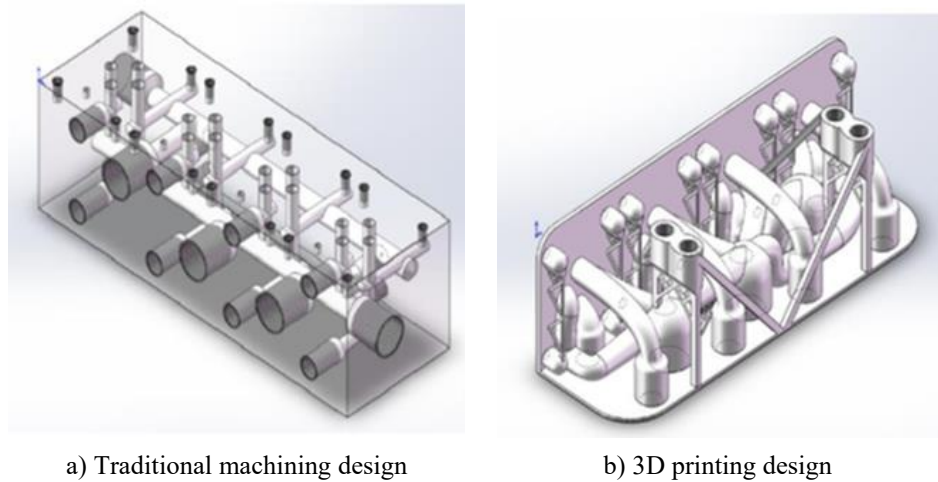


Fig. 1 – Comparison of the shape of a hydraulic manifold obtained by machine technologies versus 3D printing (Ortega *et al.*, 2019).

The CFD simulations play a crucial role in optimizing the design of hydraulic manifold. By analysing the fluid flow having in view several criteria, such as the degree of turbulence, and the pressure distribution, the designers can refine the architectures.

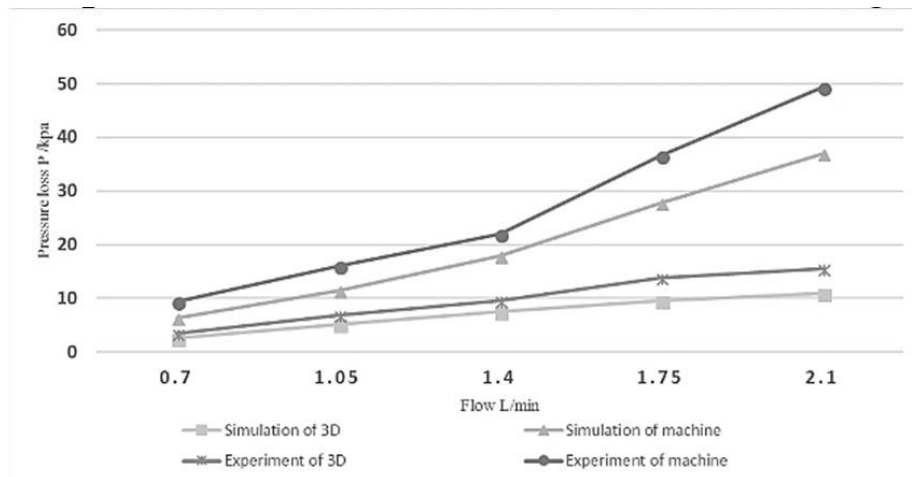


Fig. 2 – Machining versus 3D printing pressure losses (Ma *et al.*, 2018).

Figure 2 presents the results of CFD simulation concerning the pressure drop in a hydraulic manifold made by conventional technology versus the same product made by 3D printing. It may be noticed that the pressure losses are

considerably lower for the additively manufactured manifold due to the smooth walls and curved internal channels, which decrease the degree of turbulence. By consequence, the hydraulic systems made by 3D printing can provide better performance.



Fig. 3 – A manifold using stereolithography (SLA) built for medical applications (Zhang *et al.*, 2019).

Figure 3 presents an SLA-manufactured manifold designed for medical applications. This image illustrates how 3D printing can enable complex internal structures that would be impossible to be made by traditional machining. The curved internal channels indicate that additive manufacturing can create architectures having good hydraulic performance, while the structural integrity is kept.

Figure 4 illustrates the shape of intersections obtained by each technology. In the first drawing denoted (a) representing the conventional model, the abrupt transitions at intersections create turbulence, leading to high pressure losses and inefficient fluid movement. In contrast for the case-study denoted (b), representing the 3D-printed version, the intersections allow the fluid to circulate with lower degree of turbulence and lower pressure drop.

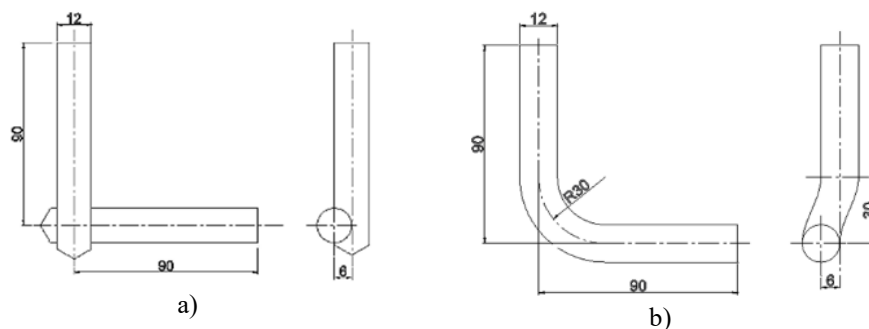


Fig. 4 – Differences between a sharp-edged transition hole and a smooth-transition optimized hole done by 3D-printing of hydraulic manifolds (Ma *et al.*, 2018).

3. Limits of the 3D printed Technology to be used for the Manufacturing of Resin Manifolds

Computational Fluid Dynamics (CFD) simulations play a crucial role in evaluating the efficiency of 3D-printed hydraulic manifolds. Biedermann et al. (2022) illustrate how channel path optimization using iterative design adjustments can significantly reduce energy losses caused by turbulence. In laser-based powder bed fusion (L-PBF) processes, they demonstrated that by maintaining a build angle above critical thresholds the structural integrity is kept and the need for additional support structures is avoided.

The simulation analysis done by using Fluent software showed that pressure losses in 3D-printed smooth transition holes were significantly lower than in conventional right-angled structures, but the selection of such solution also depends on the maximum allowable working pressure.

- **Epoxy-Based Resins** typically withstand pressures between 8-12 MPa (80-120 bar), depending on reinforcement and curing processes. (Galantucci *et al.*, 2008);
- **Acrylate Resins** were tested to withstand pressures between 5-7 MPa (50-70 bar) under controlled lab conditions. (Dizon *et al.*, 2018);
- **Nanocomposite Resins** enhanced with carbon or ceramic reinforcements, have pressure resistance of up to 20 MPa (200 bar) in experimental setups. (Dizon *et al.*, 2018).

For best performance, proper post-processing is essential. Technologies include UV curing to enhance the strength, surface finishing to improve the circulation of the fluid and reinforcement coatings to increase durability and pressure resistance.

- **UV Curing** is a process that uses ultraviolet light to polymerize photopolymer resins used in 3D printing technologies such as Stereolithography (SLA) and Digital Light Processing (DLP). This method not only accelerates the process but also enhances the mechanical properties of printed components, providing increased resistance to mechanical stress and improved durability. In hydraulic manifold production, UV curing ensures optimal adhesion between printed layers and enhances pressure resistance (Galantucci *et al.*, 2009);
- **Surface Finishing** is essential for maximizing fluid flow efficiency and reducing pressure losses in hydraulic manifolds. Techniques such as chemical polishing, mechanical sanding, and protective coatings are used to obtain smooth surfaces that does not generate turbulence zones and to improve the hydraulic performance. In 3D printing processes like DLP, smooth surfaces can be easily obtained, while additional finishing processes can further enhance the functional characteristics of the product (Dizon *et al.*, 2018);

- **Reinforcement Coatings** represent an innovative solution to be applied for the manufacturing of hydraulic manifolds, offering superior mechanical strength and enhanced pressure resistance of up to 20 MPa (200 bar), when it was tested in laboratory environmental. These materials are reinforced with carbon or ceramic particles, providing both increased rigidity and improved durability. Nanocomposite resins are perfect for high-performance applications in high-tech environments, such as the aerospace industry and industrial hydraulics (Dizon *et al.*, 2018).

The type of the resin to be selected is closely related to the domain where it will be applied, because the choice must be in line with the required mechanical performance within long-term durability condition. Several solutions are presented in the following.

- **High-Performance Resins** with improved strength and wear resistance are used in industrial and aerospace applications.
- **Flexible Resins** allows for slight deformation under pressure without cracking and are appropriate for dynamic environments.
- **Chemical-Resistant Resins** are used in applications where exposure to aggressive fluids is expected.
- **Internal Support Removal** ensures unobstructed fluid flow within complex printed geometries.
- **Layer Adhesion** covers weak points in printed parts through optimized layer bonding techniques.
- **Thermal Stability** manages heat dissipation to prevent warping during extended use.

Recent progress in additive manufacturing (AM) has significantly transformed the production of hydraulic components by enabling the creation of intricate and optimized internal geometries that conventional machining techniques cannot replicate. Notably, resin-based 3D printing has demonstrated great potential in manufacturing hydraulic manifold blocks, enhancing fluid dynamics and minimizing pressure losses (Chiriță *et al.*, 2023). The theoretical study builds upon these innovations by modelling the performance of 3D-printed hydraulic manifolds, focusing on design flexibility and performance optimization.

Additional research has shown that by incorporating additive manufacturing (AM) of hydraulic systems within modern manufacturing technologies, not only enhances design flexibility but also supports sustainability and circular economy principles. For example, Rémache *et al.* (2024) highlighted how 3D printing contributes to minimizing material waste and energy consumption while extending the overall lifespan of hydraulic systems. Their findings reinforce our methodological approach by offering a framework for evaluating the sustainable advantages of AM technologies in hydraulic drive applications.

Moreover, studies exploring Powder Bed Fusion technologies—particularly Direct Metal Printing (DMP)—have highlighted the potential for fabricating hybrid components that incorporate both solid and porous regions within a single production process (Haiati *et al.*, 2025). This capability is especially valuable for applications that demand a balance between structural integrity and optimized fluid flow. By enabling controlled porosity, these methods facilitate precise adjustments to filtration and hydraulic properties, which are essential for the performance of advanced hydraulic manifolds.

These previous findings justify the importance of the research issue, by demonstrating how cutting-edge AM techniques—whether resin-based 3D printing or metal-based processes like DMP—can overcome the constraints of conventional manufacturing. In the next paragraph, future research directions to improve the reliability, efficiency and sustainability of hydraulic systems are presented.

4. Applications and Future Prospects

Recent advancements in additive manufacturing (AM) have enabled the development of highly efficient resin-based hydraulic manifolds for the aerospace, automotive, and industrial robotics industries. The integration of smart monitoring sensors and advanced materials, such as high-performance composites, is expected to enhance durability and reliability (Beutler *et al.*, 2024). Additionally, the use of hybrid manufacturing techniques, which combine 3D-printed polymer structures with strategically reinforced metal components, is in the focus for high-pressure hydraulic systems.

Simulation-driven design automation approaches (Biedermann *et al.*, 2022) allow engineers to optimize complex hydraulic circuits, by reducing pressure losses and improving fluid dynamics performance.

3D-printed resin manifolds are recently used in several domains, as it follows.

- Aerospace - use of biodegradable polymers (e.g., PLA, PHA) in 3D printing processes such as FDM and SLS that enable the production of lightweight, high-performance components with reduced environmental impact (Asad and Schaffer, 2024);
- Automotive – reshaping the automotive sector by facilitating the fast and cost-efficient production of lightweight, customized parts. Pioneering projects like Divergent’s NODE system and Local Motors’ Strati showcase indicated how 3D-printed structures contribute to the reduction of the vehicle weight and fuel consumption while the environmental impact decreases (Ghosh *et al.*, 2020);
- Industrial Additive manufacturing, or 3D printing, is a evolving technology that enables the production of complex, high-precision components across different industries like aerospace, automotive and

healthcare. Key advantages include design flexibility, reduced material waste, and the ability to create lightweight yet durable parts. Technologies like Selective Laser Sintering (SLS) and Direct Metal Laser Sintering (DMLS) enhance structural performance, while stereolithography (SLA) offers exceptional detail and smooth finishes. As these methods advance, 3D printing is set to play a crucial role in improving efficiency, cost-effectiveness, and sustainability in industrial manufacturing of hydraulic manifolds.

5. Conclusions

The integration of additive manufacturing in the production of hydraulic manifold blocks represents a significant advancement within the fluid power systems industry. By utilizing 3D printing technologies such as SLA, DLP, and CLIP, the companies can produce high performance, lightweight, efficient manifolds that need a small quantity of material next to simpler production process.

The correct selection of the resin-based materials plays a critical role to obtain good mechanical properties and to diversify the operational capabilities of the manifold blocks. Epoxy, acrylate, and nanocomposite resins are able to offer remarkable advantages in terms of pressure resistance, flexibility, and durability. Proper post-processing techniques, including UV curing and reinforcement coatings, can enhance the strength and reliability of the components.

The manifolds constructed by 3D-printed resin technologies are appropriate to be used in multiple industries, including aerospace, automotive, and industrial hydraulics. The integration of smart monitoring systems, hybrid manufacturing approaches and sustainable innovative materials is expected to further revolutionize the industry.

By the design based on computational tools, integration of new materials and additive manufacturing techniques, the hydraulic manifolds can be significantly improved in terms of efficiency, sustainability and cost-effectiveness, paving the way for the next-generation of fluid power systems.

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BLOCURI DISTRIBUITOARE HIDRAULICE FABRICATE UTILIZÂND TEHNOLOGIA DE PRINTARE 3D

(Rezumat)

Lucrarea analizează utilizarea tehnologiei de imprimare 3D pentru fabricarea blocurilor distribuitoare hidraulice din rășini, evidențiind avantajele față de metodele tradiționale. Sunt explorate trei tehnologii principale de imprimare: SLA, DLP și CLIP, fiecare având aplicații specifice în optimizarea designului intern al manifoldurilor. Prin utilizarea simulărilor CFD, studiile de caz demonstrează o reducere a pierderilor de presiune cu 50-60% comparativ cu soluțiile convenționale.

Materialele utilizabile includ rășini epoxidice (8-12 MPa), rășini acrilice (5-7 MPa) și rășini nanocompozite (până la 20 MPa), fiecare având caracteristici mecanice diferite. Aplicațiile acestei tehnologii sunt diverse, fiind utilizabile în industria aerospațială, auto și robotică industrială. Este de așteptat ca cercetările viitoare să se concentreze pe integrarea senzorilor inteligenți, utilizarea de materiale inovative mai durabile și combinarea imprimării 3D cu elemente metalice pentru a crește rezistența și performanța blocurilor hidraulice realizate din rășini.