ADDITIVE MANUFACTURING OF HYDRAULIC MANIFOLDS - A HOLISTIC APPROACH ACROSS THE ENTIRE VALUE CHAIN

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ABSTRACT

Manifolds usually consist of metallic, rectangular base bodies into which lines are inserted by means of drilling, thus logically linking the built-on or built-in valves according to the hydraulic circuit diagram. Using additive manufacturing methods, additional degrees of freedom can be used in the design of manifolds, resulting in further benefit in hydraulic drives and their controls. The challenge is not only to understand and apply additive manufacturing technology, but also to align the entire value chain with it.

Keywords: Manifolds, Additive Manufacturing, 3D sand core printing

1. STATE OF THE ART

1.1. Manifold

A hydraulic control block (=manifold) can be described as the link between the drive unit and the consumption of a hydrostatic drive. It thus serves to control the hydraulic energy provided by the hydraulic power unit and required by the actuator to fulfil its function. The engineering of a hydraulic control system can be divided into the steps of project planning, design and manufacturing. In the project planning phase, the essential task is to design a hydraulic control system for the desired load and motion profiles of the hydraulic drives with the corresponding control elements (valves). The result is a device list that gives an overview of the required control elements and a circuit diagram that visualizes them graphically with their logical interconnection.

Figure 1: Exemplary hydraulic circuit diagram [1]

In addition, further customer requirements are taken into account, as well as the location of the connections, desired coating, etc. The requirements are implemented in the following design phase. Using 3D CAD software, for example, the desired external geometry of the manifold is created virtually and the installation geometry of the valves is applied. After the valves and connections have been loaded from the device list into or onto the installation geometry, they can be connected according to the logical connection on the hydraulic circuit diagram with straight cylindrical geometries resulting from the common manufacturing process of drilling.

In the context of the overall design, dependencies and constraints arise, for example, that the distance between the holes must not fall below a certain value. For reasons of the available installation space, the minimum wall distances and the desired direction of the hole to be drilled, auxiliary holes are often required which in turn must be provided with sealing elements.

Figure 2: Conventional design of a manifold [1]

For the basic body, which in industrial stationary hydraulics applications usually consists of a simple rectangular geometry, a metallic material such as cast iron, steel or aluminium is generally used to meet the requirements (Operating pressure, Load cycle, Installation space, Costs, ...). In the subsequent manufacturing phase, these rectangular raw materials are appropriately clamped in the cutting machines and provided with straight cylindrical bores according to the production drawing.

Figure 3: Unassembled manifold [1]

1.2. Additive Manufacturing in the context of manifolds

DIN 8580 [2] classifies additive manufacturing, which refers to the layered or elemental structure of a work piece [3], into the primary forming manufacturing processes.

Bosch Rexroth essentially uses two of the additive manufacturing processes described in [4] and [5]. In the "Selective laser melting" (SLM) process, a thin layer of a powdery metal material is applied to a base plate and locally melted by means of a laser beam, after which a solid material layer is formed by solidification. By lowering the base plate and subsequently applying a new thin layer of metal powder, this process can be repeated as often as necessary to create the desired contours and volumes of the metallic material. Depending on the application, the SLM process is suitable for smaller, more complex components with filigree structures (bore diameter 1-2mm) in the range up to 5kg. According to the current state of the art, the optimum mass of the component is approx. 0.5kg. Initial research projects in which this production technology for manifolds has been investigated indicate an application rate of up to 60 cm³/h [6].

As hydraulic control blocks, which have a complex internal structure, are usually much heavier than 5 kg and more voluminous, this production technology is only suitable for this purpose to a limited extent.

Therefore, the method of 3D sand core printing is used. First, a sand core is created by additive manufacturing, which reproduces the inner structure of the component. The sand is mixed with an activator and also applied in layers from bottom to top. The print head applies additional binder per layer in the areas relevant to the geometry. This technique allows geometries to be produced that cannot be achieved in traditional core production or only by combining several cores which then have to be laboriously installed together. Depending on the binder system used, various strengths of up to 550 N/cm² can be achieved, with which even more filigree structures can be realized [7].

The component is then finally manufactured using the common and established sand core casting process.

Figure 4: Sand core with filigree and rounded structures [1]

2. INNOVATION AND USER BENEFIT

The methods of additive manufacturing open up completely new opportunities for manifolds, as can be seen in the following picture.

Customized products
<ul style="list-style-type: none"> - Flexible production from lot size 1 - Short TTM from Month to Weeks
Energy efficiency
<ul style="list-style-type: none"> - Optimized oil flow - Reduced pressure loss (Δp) - Reduction of screw plugs / Leakage
Weight and design optimization
<ul style="list-style-type: none"> - Grid structures - Reduced part weight - Flexible internal and external geometry (e.g. oval lines)
Functional integration
<ul style="list-style-type: none"> - New or optimized functionality - Better control of mechanical properties - Improved sustainability

Figure 5: Advantages of the additive manufacturing

Due to the free design of the line cross-sections (round, oval, square, diamond-shaped, ...) and the avoidance of abrupt changes in direction of the oil flow through curved lines, the pressure losses and noise emissions can be reduced in a targeted

manner. For illustration purposes, the following figure shows the pressure loss due to a flow-optimized line routing.

Figure 6: Optimized oil flow due to curved lines. [1]

Due to the flexible internal and external geometry, manifolds can be designed more compact and lighter and almost any outer contour can be realized, thus enabling a precise application in complex installation geometries. The more flexible channel routing also makes it easier to avoid auxiliary drilling.

Basically different design and manufacturing principles have to be applied when designing a manifold which is manufactured by means of 3D sand core printing.

For example, the pressurized surfaces of the lines are no longer a metallic structure that was machined out of the solid base material, but a surface that results from the casting process. This so-called "raw cast skin" has different mechanical properties compared to the surface of the lines, which was worked from the solid material. In the case of external cast skins of cast iron components with nodular graphite (GJS), various post-treatment processes such as blasting or surface hardening are used to increase the fatigue strength or lifetime of components subjected to cyclical loads.

In most cases, these processes cannot be used for internal cast skins due to the lack of accessibility of the areas, which is why there are challenges in the lifetime assessment of such components in this context [8]. In a first approximation, however, a reduction of the life time of cyclically stressed components of approx. 20-30% can be expected. In the design of the manifold, this reduction must at least be compensated by minimizing tension gradients using the degrees of freedom through additive manufacturing of a suitable channel layout.

When designing the sand core, not only the logical connection of the valves, flow-optimized channel routing or other oil-hydraulic aspects play a role, but also technical aspects of the casting process, for example to avoid core breakage or floating of the sand core during casting or to ensure thermal stability. In the design phase of the control block, therefore, the later implementation in the subsequent casting process must always be taken into account in order to enable efficient production or to realize it at all.

The technical documentation is also different. In the past, it was common practice to purchase a rectangular raw material for which the external dimensions were sufficient. In the future, a foundry must be requested to produce a casting with a defined internal structure, for which a corresponding drawing is required in order to forecast the costs if possible.

Bearing in mind that components such as valves, filters, flanges, etc. are mounted on the surface at the outlets of the casted lines, it is clear that the manufacturing tolerances of the casting process must be compatible with the machining of the final product which must also be taken into account in the design phase.

During the final machining operation, in which the mounting surfaces or installation bores of the valves are finished, the components to be manufactured must be clamped in the working area of the processing machine. This fixes the component in a defined position in the machining area and allows the tool to reach it precisely.

The aim here is to realize the machining process with one or only a few setups, since a change of position and layer of the workpiece in the machining area causes valuable time and thus costs. In this context, the flexible external geometries of the additively manufactured manifolds represent an essential challenge for automated production. The added value and opportunities offered by additively manufactured manifolds are matched by the great challenge in the project planning phase of combining them with the customer's problem in the best possible way. This requires a detailed understanding of the customer's hydraulic problem and expert knowledge of the possibilities of additive manufacturing of manifolds.

In the preceding description of the challenges to be met in the various phases of the development of a manifold, it becomes clear that

not only the optimization and the development of competence in the individual phases is essential, but rather an interconnection of the individual process steps.

The goal must be a standardized handling process analogous to the conventional manifolds in order to provide a competitive problem solution on the market.

3. MATURITY LEVEL AND RESULT

Bosch Rexroth has pursued this goal as part of a holistic approach. The 3D sand core printing has been applied since 2012, which means that the development of competence in the application of this manufacturing technology is very advanced.

Thus the design of the sand core for the casting process could be optimized and the process times until the ready-to-use casting product could be reduced by several weeks compared to the conventional process sequence [7]. On the basis of various concept studies and further investigations, a design guideline was derived for manifolds manufactured using the 3D sand core printing process. By building up a deeper understanding of the process, an industrial application with a suitable repeatability, machine capability and quality assurance in the process is possible.

For the design phase, specifications are made which maximize the lifetime of the manifold and lead to the best possible manufacturability, for example by taking potential clamping concepts in the processing machines directly into account or necessary reference points to enable precise finishing.

These design guidelines include detailed technical specifications for screw-in holes, duct junctions and transitions, minimum wall thicknesses and specifications for the technical documentation to be prepared. This new type of manifold design thus extends the requirement profile of a design engineer.

In the project planning phase, selected sales staff is trained to ensure that, in addition to their high level of specialist knowledge of hydraulic drive technology, they are also able to provide reasonable solutions to problems using additive manufactured manifolds.

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