Additive Manufacturing for severe service valve trim

Additive Manufacturing, also known as 3D-metal printing, allows the creation of 3D-metal components using special printing machines, starting from powders and through an additive approach. This incredible technology could become a game-changer for several industrial applications, including valve (trim) design, especially for control valves used for severe service applications.

By Michele Ferrante

Severe service control valves are identified by applications. If the process parameters are challenging to the valve's ability to provide a minimum acceptable level of performance over a minimum acceptable duration, the application falls into the field of severe service.

Typical severe service applications are those on which one or more of these phenomena occur: high pressure drop (for both gas and liquid flows), cavitation (liquid), flashing (liquid), outgassing (liquid), noise generation (gas, liquid), corrosion/erosion (liquid, gas), presence of hard particles, very high or low temperatures and erosion (wet steam). All valves destined for severe service applications require a deeper understanding of all of the factors that affect their in-service performance. If one or more of the above phenomena occur, the control valve is highly stressed, and a careful design of the valve body and internals need to be reviewed and carried out.

Split pressure drop

Control valve manufacturers have developed several valve and trim designs to prevent/mitigate the aforementioned phenomena and to achieve longer service life and lower maintenance costs.

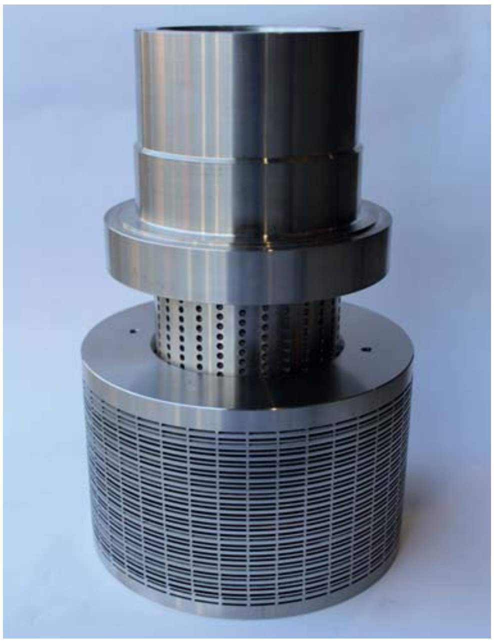
For liquid flow applications, where high-pressure drops can occur and cavitation can occur, the most common approach is to split the pressure drop in several stages, using the multistep-trims. With this concept, the velocity inside the trim is kept under control, limiting erosion phenomena, and avoiding the *vena contracta* pressure falling below the liquid-vapor pressure, generating vapor inside the flow.

Apart from multistep-trims, there are multistage-trims designed with cage and multi cage design, or with multistep cascade trims. This option is preferred where solid particles or slurry fluid are present, and a cage design may not be suitable due to clogging effects.

Noise generation

For gas applications, the typical issue is related to noise generation, and the multipath-trim is widely used the trim design splits the fluid flow into a large number of small paths to produce high frequencies noise that can be significantly reduced by the transmission loss across the pipe wall.

Multistep-trims are still effective, to split the pressure drop into multiple stages to reduce the generated acoustic power by limiting the flow regime of every single stage.



Multistep-multipath trims made by disc stacks.

Flashing and outgassing applications, as well as with multi-phase fluids, experience problems common to both gas and liquid applications, with noise, vibrations and erosion phenomena.

The use of drilled disc or fixed resistors downstream control valves trim is also widely used in severe service applications, for both gas and liquid applications, to reduce the pressure drop required to the trim and generating some counter pressure, thus reducing erosion, vibrations, noise generation on gas.

Top class solution

The top-class solution for the most demanding applications combines both the multistep and multipath trim design. State of the art multistep-multipath trims are typically manufactured employing disc stacks, where laser-cut sheets are assembled and fixed together, to obtain tortuous/meandering channel paths for fluid expansion.

Varying turns (stages) number and the shape of the channels, it is possible to design a trim suitable even for the most demanding applications. This trim typology is powerful, but at the same time requires major efforts to be produced, both in terms of engineering and manufacturing capacity. There are several components to be designed and assembled, and several mechanical technologies involved to obtain the finite component.

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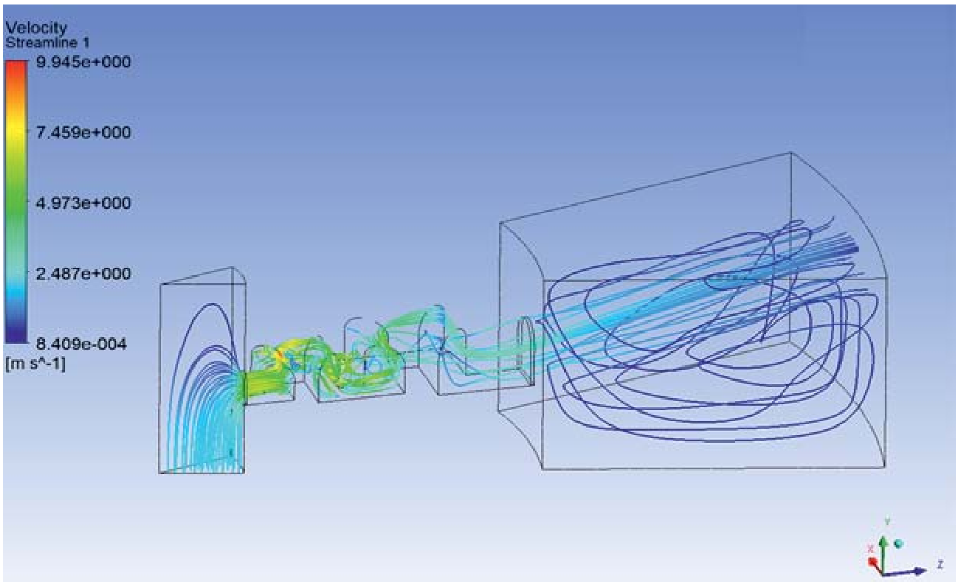
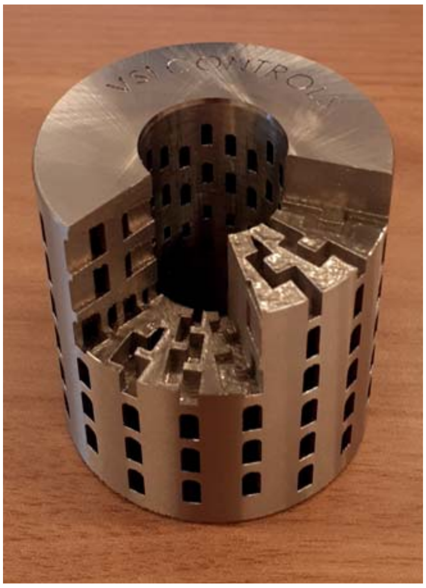


CFD analysis of a labyrinth channel.



Additive Manufacturing: channels detail.

Multistep-multipath-trims made by disc stacks have been on the market for decades. Initially, their performances were evaluated through experimental tests, on suitable test rigs. The behavior of each channel typology (in terms of length, number of curves, expansion ratios, et cetera) was thus evaluated, and translated into experimental coefficients, which allowed engineers to design new trims starting from an experimental basis.

The establishment of a large database was necessary, and the implementation of special solutions was always conditioned by the need to perform new tests. Nowadays, the widespread use of Computational Fluid Dynamics (CFD) reduces the time and effort needed to properly size a trim. The use of experimental tests is still mandatory, but no longer to get a large database of available geometries, but to validate the parameters of the CFD calculations. Once the parameters are set and the engineer has developed a sensitivity on the calculation, the validation of new geometries will be easily done.

It is precisely in the design and manufacturing of multistep-multipath trims that Additive Manufacturing exceeds the limits of the traditional technology and paves the way to new approaches in mechanical design.

AM is based upon a computerized design - a 3D CAD model of the finite component - and built up layer for layer, it is not bound by limitations in terms of design and materials which are valid for conventional technologies.

By doing so, any kind of severe service conditions can be managed by properly sizing and manufacturing trim channels.

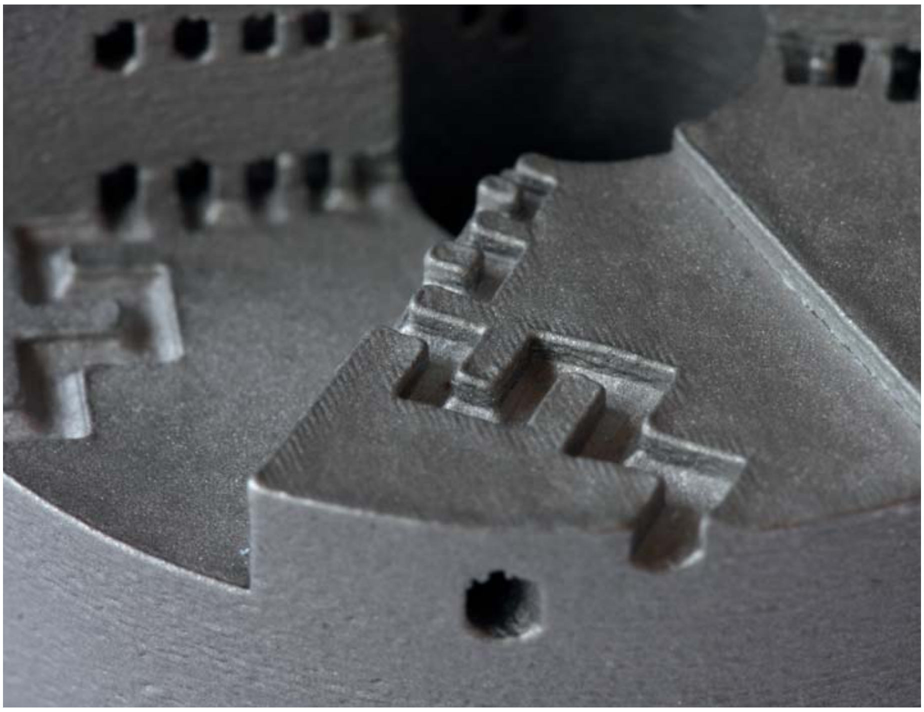
Valve rangeability, capability to manage very high and very low flow rate, is magnified since this technology allows the possibility to manufacture in the same component very small and accurate and very big flow passing areas.

Using topological optimization - a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints to minimize the weight- trim dimensions could be minimized, resulting in reduced valve and actuator size compared with traditional technology.

Design for AM

A fundamental aspect to be understood by design engineers is that AM technology requires revolutionary thinking in design: traditional limitations and conceptual approaches to design shall be demolished and reconstructed, and we shall not refer to the traditional limitations and conceptual approaches to design to exploit the maximum benefits from this technology.

To match design engineers with AM technology experts is a good way to release all the potential of this technology for trim design. This makes sense as the investments in machinery are quite high and the use of these machines will not be high in the beginning. Also, it requires extensive expertise and experience to operate AM-machines.



Additive Manufacturing: microflow channels detail.

Additive Manufacturing: trim removed from the printing machine.

Additive Manufacturing: finished trims

Choice of a suitable partner

The choice of a suitable partner for AM production is therefore important, to allow the valve manufacturer to get the most from the technology, taking advantage of the experience of the AM experts, also coming from other industrial sectors where it is widely used (aerospace, racing, military). The right partner for AM should ensure the valve manufacturer technical support for design, availability of more materials, and reduced time to market, variable between one and few weeks depending on the application. Also, the ability to transfer the know-how of the technology is important, to let the valve design engineer know the advantages and limitations of the technology, as well as the cost estimation/calculation of AM components, to free all imagination in design but keeping costs and feasibility under control.

Additive Manufacturing: laser processing of Multistep-multipath trims.

Rapid growth

Additive Manufacturing exceeds the limits of the traditional technology and paves the way for new approaches in mechanical design: extreme versatility, absence of theoretical limits to design and reduced time to market are the fundamental aspects compared to traditional technologies in the control valve industry.
Production costs and the availability of suppliers/knowledge providers are respectively declining and growing since this technology is rapidly growing. In the field of valves for severe service, the winning approach is the design sized on application: the cooperation between valve engineer and plant designers is the key to success, and the required valves need to be individually designed. In this scenario, the rapid growth of a technology that allows maximum customization, can thoroughly transform the severe service valve market.

9 steps in AM

Let us assume to have a first-hand experience in designing and manufacturing of a valve trim with Additive Manufacturing.
Schematically these are the steps that could be followed:

1. First, find the right partner for Additive Manufacturing. As discussed above it should be not only a supplier, but a technological partner suitable to develop a four-handed project with a valve manufacturer
2. Identify a suitable application: for gas or liquid, a demanding or severe service application, where a multistage trim or a special design is required
3. Define the proper alloy (austenitic, martensitic, duplex SS or superalloy), according to fluid and process conditions, and with the support of the AM partner
4. Size the trim internals, considering fluid-dynamics and acoustic phenomena (flow passing areas, number of stages for pressure reduction, fluid dynamic coefficients, etc). CFD-analysis is a powerful tool to support the design
5. Size the trim externals. Once the internals are defined, the outer shape shall be drafted, considering loads and geometric constraints
6. Design the component with a “design for additive manufacturing” approach. At this point, the AM-partner provides the bulk of added value. Topological Optimization (mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of minimizing the weight) is a powerful tool to support the design. FEA-analysis is also useful to simulate the component under service loads
7. It is necessary to consider an adequate series of tests to be performed on a prototype component:
    - Material properties (chemical composition, hardness, tensile, impact etc)
    - Cv tests (to validate the CFD analysis)
    - Strength test under operating loads (to evaluate FEM analysis)
    - Other tests (chemical resistance, high or low temperature tests, fatigue analysis, etc)
8. Test results can lead to an approval of the component and material(s) selected, or to a modification in design (with the important advantage of a short production time).
9. Once the prototype is approved, the component can be installed in a valve and field tested