Proceedings of the 6th International and 43rd National Conference on Fluid Mechanics and Fluid Power
December 15-17, 2016, MNNITA, Allahabad, U.P., India

FMFP2016–PAPER NO. 621

The EFFECT of MANUFACTURING METHOD INDUCED ROUGHNESS on SEVERE SERVICE CONTROL VALVE PERFORMANCE

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Abstract

There are a number of manufacturing methods used for the manufacture of control valve trim components, some of which are expensive processes. Current market conditions and increased competition requires manufacturers to reduce costs of these components and they are investigating new technologies such as processes using Additive Layer Manufacturing (ALM) to produce these components. These processes may require or result in variations in geometrical features and surface roughness of the produced components compared to current processes, this study quantifies the effects of the selective laser melting (SLM); a form of ALM, methods induced features on the overall valve performance of the control valve via experimental measurements of valve capacity (Cv) and the roughness of the manufactured parts.

Keywords: *ALM, Control Valve, Surface Roughness, Valve Performance, SLM*

I. INTRODUCTION

Control valves are one of the most complex flow components used in most production processes (eg Oil & Gas). They are designed to provide accurate control of one or all of the following [6];

- Fluid flow to or from a process
- Fluid level in a tank or column
- Fluid pressure up or downstream (of the valve)
- Fluid temperature up or downstream (of the valve)

Valves achieve this by constantly varying the position of a plug, against a seat, whereby further away the plug is from the seating face, the more flow can pass through the valve. Control valves come in many shapes and sizes; the style of valve depends on the process conditions that they are required to operate against. Control valves differ significantly from standard on/off isolating valves because their inherent function is to provide control over the process variables as opposed to isolation [5,6].

The valve trim is made up of a seat, the plug/stem and the cage/stack. The cage or stack is the main controlling element of a control valve. The cage controls the amount of flow passing through the control valve based on the valve opening position. The most common type of cage in a control valve is a multiple drilled hole cage. Stacks are made up from a series of stacked discs that have on their surface a complex fluid flow path typically turning the fluid through a labyrinth of right angle turns, expanding the area after each stage of pressure drop, in order to reduce the velocity of the fluid across the length of the disc [7].

Severe Service valves have undergone significant development over the past few years from their original concept designs. This development program has been fully supported by the industries requiring the specific control these products provide, however as more and more services are requiring these products and the changes to the economic climate, there is a significant drive to reduce costs for these products.

Currently, 90% of disc stack trims are manufactured using the Electron Discharge Machining (EDM) method, often known as spark eroding, the other 10% are made using traditional machining operations (i.e. milling). This manufacturing method can be quite costly, especially when increasing the number of stages or the capacity of the disc. Furthermore, EDM has relatively long lead times (of up to 10 weeks per disc), limiting the delivery times for original equipment, and also spares replacements. Preliminary investigation of the SLM method of manufacture has shown that costs could be reduced by up to 50% on a like for like disc design, combined with a significant reduction in manufacturing lead times [8]. The primary focus of this study is to critically evaluate the performance of the product following the use of SLM as the method of manufacture; focusing on the effect of the surface roughness variation from the SLM process on the Cv of the valve. There is limited information available on the impact on valve performance as a result of the variation on manufacturing method and none found where specifically SLM has been used in lieu of EDM.

II. EXPERIMENTAL FORMULATION

A 100mm control valve has been used in this study for capacity testing of two of the manufactured disc stack trims, using the flow loop set-up and water as the working fluid, in general accordance with BS EN 60534-2-3[2]. 2 Disc stacks trims were manufactured, one using EDM and one using SLM. The main objective of the test programme is to determine the Cv of the trims installed within it. The tests have been conducted at various valve opening positions i.e. fully open, 75%, 50% and 25%. The tests have been performed at three differential pressure conditions corresponding to 75% of the maximum available flow, 50% of the maximum available flow and 10% of the maximum available flow. These operating conditions are in accordance with BS EN 60534-2-3's recommendations [2].

The following data has been recorded during the tests:

- Valve Opening Position (VOP in %)
- Inlet Absolute Pressure (p1 in barg)
- Pressure Differential across the upstream and downstream pressure tapings ($\Delta p=(p1-p2)$ in barg)
- Inlet Water Temperature (T1 in °C)
- Volumetric Flow Rate (Q in m3/hr)

A. Method to find C values

The basic flow equation for non-choked, incompressible fluids is [1]

$$Q = N_1 F_R F_P C \sqrt{\frac{\Delta p}{\frac{\rho}{\rho_o}}} \qquad (1)$$

where;

- N_1 = Numerical constant that depends on the units used. N1 = 0.865 to find Cv
- F_R = Reynolds number factor. For turbulent flows its value = 1
- FP = Piping geometry factor. FP = 1 has been used in the sizing equations
- C = Flow coefficient. It can be Cv or Kv
- $\rho/\rho o$ = Relative density. For water its value = 1

Hence, this equation becomes (assuming that the flow is always within a turbulent regime.);

$$C = \frac{Q}{N_1}\sqrt{\frac{\frac{\rho}{\rho_o}}{\Delta p}} \qquad (2)$$

It has been mentioned in BS EN 60534-2-3 [2] that with the exception of valves with very small values of C, turbulent flow will always exist. It has been observed, that while conducting the experiments, that flow rates are not small enough to warrant modifications for non-turbulent flow, thus this assumption looks reasonable. Eq. (2) therefore becomes the primary sizing equation for disc stack trims. It is noteworthy at this point that Eq. (2) is valid only for:

- Newtonian fluids
- Non-vaporizing conditions

B. Method to find Cv_{Trim} values

Cv can be calculated from the experimental data directly. The values for Cv_{Trim} are calculated using the equation 3;

$$Cv_{Total} = \frac{1}{\sqrt{\left(\frac{1}{{Cv_{Trim}}^2}\right)+\left(\frac{1}{{Cv_{Valve\ Body}}^2}\right)+\left(\frac{1}{{Cv_{Seat}}^2}\right)}} \qquad (3)$$

$$\text{where, } Cv_{Valve\ Body} = K_{Body} \times \pi \times \frac{{D_{Body}}^2}{4} \qquad (4)$$

$$\text{and, } Cv_{Seat} = K_{Seat} \times \pi \times \frac{{D_{Seat}}^2}{4} \qquad (5)$$

Note that the diameters in Eqs. (4) and (5) are measured in inches. In the current study, D_{Valve} = 101.6mm and D_{Seat} = 38mm. [3,5]

C. Method to find K_{Trim}

K_{Trim} can be calculated using the following expression:

$$k_{Trim} = \frac{Cv_{Trim}}{A} \qquad (6)$$

Where A is the area available to flow within each trim. The values of A for the two trims used in the present study are both 8.46818 x $10^{-6}m^2$ per flow path

D. Surface Roughness Measurements

3D surface measurements were taken at various sections of the trims, using a Talysurf. The study includes measurement of amplitude of the surface roughness as well as reviewing the uniformity of the roughness, recording multiple surface factors including S_{dr} which is the interracial area ratio; showing the percentage increase in the area of the actual surface compared to an engineering drawing surface area (texture surface area minus cross sectional area divided by cross sectional area). This will help to further differentiate the surfaces with similar average roughness (Sa) as typically it will increase with the spatial intricacy whether Sa changes or not [4].

III. RESULTS AND DISCUSSION

The results from the capacity testing, using a flow loop setup as described in Sec. II, were recorded over a 20 second interval to ensure accuracy of the results and recorded automatically using a data logging device. Flow rates and pressure drops were recorded over the four variations in VOP and three pump drive speeds. The results were collated, converted to standard units and tabulated as shown in Table 1 to calculate the final valve Cv values. Body and seat Cv's for both valves are the same and are based on the areas as shown in Sec. IIC. The K factor used for the body was 24 (Determined previously via empirical testing) and the seat K factor is 38. Both body and Seat K factors are unaffected by changes in valve opening position so will remain constant throughout the test. (MM= Manufacturing method)

MM	VOP (%)	Q (m^3/h)	ΔP (kPa)	Cv_{Total}	Cv_{Body}	Cv_{Seat}	Cv_{Trim}	K_{Trim}
SLM	100	38.4	287	26.2	301.6	65	28.7	45.5
EDM	100	51.8	342.84	32.3	301.6	65.0	37.5	59.5

Table 1 – Collated Experimental Test Results for 2 Disc Stack trims

The full results recorded show two points regardless of manufacturing method, firstly that as the valve opening position (VOP) decreases, Cv_{Trim} decreases, while k_{Trim} increases. Also that Cv_{Trim} and k_{Trim} remains almost constant for various flow conditions but at the same valve opening position.

Values for K are not constant and actually show a minimum value at 100% of valve travel. This however can be attributed to the annular clearance between the plug and the trim. As the valve moves more open the K factor is reducing, this is because the effect of annular flow (Flow up the annular clearance between the plug and stack) is reduced when the plug is providing least resistance to fluid flow. No effect of annular area and thus annular Cv have been considered to modify values for K as due to the nature of the trim quality, exact values may not be achievable and as such only estimates for annular area could be predicted.

There is an almost 30% reduction in Cv_{Trim} for the SLM manufactured trim compared to the standard EDM showing that for a like for like design, the method of manufacture has resulted in a significant reduction in overall value of Cv_{Trim} and K_{Trim}. This would mean that in a practical application, the SLM manufactured trim would allow a reduced flow rate for the same pressure conditions compared with an EDM trim, potentially resulting in either a larger trim or larger valve, potentially increasing the overall cost of manufacture.

The trims were then sectioned appropriately and measurements were recorded for a number of surface roughness parameters, with some 3D images of surface peak analysis recorded as in Fig.1and Fig. 2

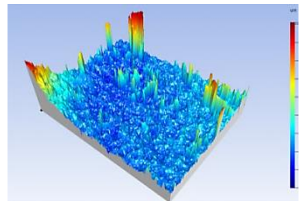

Figure 1 - EDM Trim

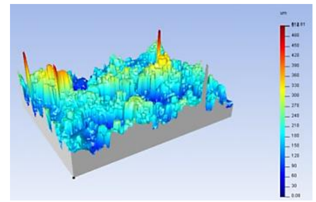

Figure 2 - SLM Trim

It can be seen in figure 2 that there is a significant increase in the roughness of the part and also in the uniformity of the surface compared to the EDM part, the maximum heights of the peaks is also significantly increased, resulting in an overall reduction in area for flow. Sdr varied from 82.4% on EDM to 229% on SLM, with Sa increasing on the SLM to 37.7microns from the 9.3microns on the EDM version – reflecting an average roughness increase of around four times.

IV. CONCLUSIONS

It is clear from the results obtained that Cv_{Trim} increases as a result of opening position, but that more importantly the manufacturing method has had significant effect on the value of Cv_{Trim} and K_{Trim} and that manufacturing a standard disc stack, normally manufactured through EDM, using SLM will result in a reduction in trim performance as a result of a significant increase in the average roughness of the part and the uniformity of this roughness. The understanding on the effects of geometrical changes are of great importance for the designers of the disc stack products and also for any designer / manufacturing engineers reviewing the potential of using an SLM method of manufacture.

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