Institution: University of Huddersfield

Unit of Assessment: UoA 12

Title of case study: Optimising the Performance of Safety Critical Industrial Valves

Period when the underpinning research was undertaken:

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof. Rakesh Mishra	Professor	2000–ongoing
Dr Taimoor Asim	Senior Research Fellow	2013–2019
Carlos Oliveira	KTP Associate	2014–2017

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

The design of valves used in challenging conditions, such as those found in the oil, gas and nuclear industries, has traditionally been based on the experience of the engineer rather than reproducible mathematical modelling. This led to unpredictable and sub-optimal performance. The inability to consistently ensure quality compliance, slowed the development of new technology.

Research at the University of Huddersfield, developed valve design methods that were responsible for reducing design lead times and manufacturing costs for an SME, Weir Valves. The resulting valves were up to 250% more accurately sized and they also out-performed competitor products. This resulted in an increase in sales of 640% and helped the company win a contract worth circa £3m.

Workshops explaining the research findings regarding multiphase valves have influenced engineer behaviour at companies such as Exxon Mobil, resulting in wide acceptance of research outcomes in the engineering practice.

2. Underpinning research

All valves (with sizes varying from a few millimetres to multiple metres), work on the same principle; where a fluid medium (which could be a liquid, gas or slurry) enters via an inlet, a piston controls its rate of flow and it exits through an outlet (see figure 1). A safety critical valve is characterized by its application in a critical infrastructure, and also by the degree of precision and manufacturing robustness to which it must be fabricated. They are designed to be used in very challenging conditions, such as those in the piping systems for nuclear power plants, or where the pressure differential across the valve is very high (for example, several thousand pascals across a valve that has a pressure-reducing element that is only 10cm long).

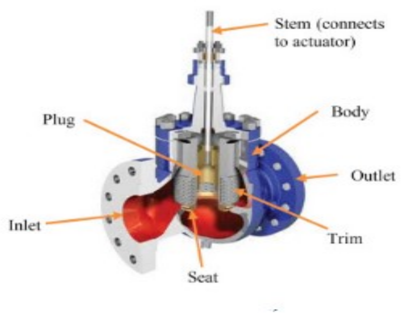

Figure 1: Valve components

In order to regulate the flow, a component called a trim is inserted within the valve in the path of the fluid. The trim consists of a series of interlocking channels, of differing diameter, geometry and interconnectivity – as the fluid flows through them, they change the pressure and flow velocity. A trim that is designed for a very high change in pressure is primarily used in very critical applications and is called a severe service trim. Trims are complex and, if not properly designed, can cause numerous problems in the valves during their operation (see figure 2). Firstly, if there are a number of flow paths that include an abrupt change in the size of the channel through which the liquid flows, they can cause the fluid pressure to drop below its critical pressure and vaporize. When the vapour enters a high-pressure part of the trim it collapses, releasing massive amounts of energy in a process known as cavitation. This can cause severe damage to the valve. Secondly, if too much energy is taken out of the fluid by the trim, then the energy requirement of the entire system may increase – this is described as the valve being inefficient. Furthermore, if the medium being transported is a slurry, the solid particles can cause erosion within the trim, seriously reducing the life of the valve. It was known that these effects existed, but there was no systematic way to accurately predict the performance of a given valve design in a specific use-case.

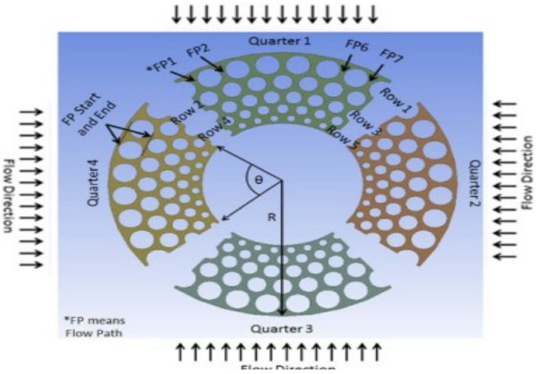

Figure 2: Cylinder arrangement in a trim disc

Although design standards for valve manufacture exist, they are empirical and focused mostly on simplified valve geometries. Before this research there was no way to mathematically model the performance of a valve relative to its trim (and other features) and valve manufacturers developed new products based on trial and error (using a valve from their "back catalogue" as the starting point for developing one for a new application). The lack of comparability between valves, and inconsistency in documented design protocols, meant the development of new design techniques in the industry had stalled.

The research described in this case study was carried out at the University of Huddersfield (UoH) by Prof. Rakesh Mishra (at UoH since 2000), Dr Taimoor Asim (Research Fellow at UoH from 2013–19) and Carlos Oliveira (KTP Associate 2014 to 2017).

The research, which was undertaken as part of a Knowledge Transfer Programme (KTP) with an SME valve manufacturer (Weir Valves) between 2014 and 2017, evolved from a previous KTP project with the same company (2011-2014) and earlier work carried out under an EPSRC Case Award with Bentley Motors in 2005 [R3]. Both of the above works involved flow mapping and design of complex geometries to enable optimum performance. Weir Valves had identified that they could generate more sales if they understood enough about the flow characteristics within their valves to explain them to their clients, and thus justify the reliability of their safety critical valves. The UoH-based research team approached the challenge in the following way.

The initial stage of the research was to map the valve design process used at Weir and investigate how effective it was in producing valves with the desired performance. This was done by measuring the flow characteristics of actual valves and then building computational models to mimic those characteristics. Next, design equations (mathematical models) were built to define how the flow within a valve was affected by all of its constituent parts and these were tested experimentally, to see whether a valve manufactured using the model behaved as predicted [R5,6]. Specifically, local flow fields were quantified and relationships between the geometrical features to be designed and the likely flow behaviour were established. By following an iterative process, it was possible to develop a modified valve design procedure that was faster and more reliable.

The process was applied in the specific case of a low shear valve [R4]. These are valves where the geometrical complexity of the trim needs to be such that there is only a small change in the physical properties of the flowing fluid. The valve had to be designed for low energy loss and required quantification of the interrelation between the geometrical complexity of the trim and the resultant local flow fields. The research characterized the link between them for the first time, by combining experimental and computational analyses. The project created a successful new product for Weir and as a result, they asked UoH to explore the much more complex case of multiphase flow applications, where they wanted to ensure minimal mixing of the phases in a mixture. A practical example is avoiding the recombination of the oil and water fractions present in partially refined crude oil.

In the second KTP, the same modelling process was used to study the behaviour of multi-phase liquids (such as slurries containing water, oil and sand) in order to predict the behaviour of the liquid through a particular valve. This resulted in a set of modified equations [R1] that could be applied in the design process.

Valves, particularly the trims, are extremely complex to manufacture and the lead time from the start of the design process to when a valve is ready to be manufactured can be several months. To speed up this process, additive manufacturing (also known as 3D printing), was being trialled across the valve sector during this period, with an expectation that it would be faster and more cost effective than traditional methods. However, valve trims provide particular challenges for the process, since the flow paths are very complex and narrow. Research [R2] studied and modelled all aspects of the manufacturing process (e.g. scanning speed, power of the laser, etc.) to derive the best balance between the limitations of the manufacturing process and the optimal specification of the valve. More recently, the sophistication of the mathematical models has meant that it is now possible to modify the flow path geometry to ensure control of the desired energy loss across each stage of the trim. This has enabled further optimization of valve performance by reducing cavitation and erosion and thus extending the life of the valve.

3. References to the research

The following outputs provide reference to the body of research and are predominantly 3* or higher, being peer-reviewed journal articles in Q1 and Q2 journals. Authors at the University of Huddersfield at the time of publication are highlighted in bold:

[R1] **D. Singh, A. Aliyu**, M. Charlton, **R. Mishra, T. Asim, A. Oliveira** (2020), Local multiphase flow characteristics of a severe-service control valve, Journal of Petroleum Science and Engineering. 195, 18 p., 107557, ISSN092-4105 https://doi.org/10.1016/j.petrol.2020.107557

[R2] **D. Singh, M. Charlton, T. Asim, R. Mishra, A. Townsend and L. Blunt** (2020), Quantification of additive manufacturing induced variations in the global and local performance characteristics of a complex multi-stage control valve trim, In: Journal of Petroleum Science and Engineering. 190, 13 p., 107053 https://doi.org/10.1016/j.petrol.2020.107053

[R3] **E Palmer, R Mishra and J. Fieldhouse** (2009), An optimization study of a multiple-row pin-vented brake disc to promote brake cooling using computational fluid dynamics. In: Proceedings of IMechE, Part D, Journal of Automobile Engineering, 223,7,865-875,11p,ISSN: 0954-4070 https://doi.org/10.1243/09544070JAUTO1053

[R4] **T. Asim, R. Mishra,** M. Charlton and **C. Oliveira** (2018) 'Improved Design of a Multi-Stage Continuous-Resistance Trim for minimum Energy Loss in Control Valves', Energy, 174, 1 May 2019, pp. 954–971, ISSN: 0360-5442 https://doi.org/10.1016/j.energy.2019.03.041

[R5] **T. Asim, R. Mishra,** M. Charlton and **C. Oliveira** (2018) 'Effects of the geometrical features of flow paths on the flow capacity of a control valve trim', Journal of Petroleum Science and Engineering, 172, pp.124-138, ISSN092-4105 https://doi.org/10.1016/j.petrol.2018.09.050

[R6] **T. Asim,** M. Charlton and **R. Mishra** (2017) 'CFD based Investigations for the Design of Severe Service Control Valves used in Energy Systems' Energy Conversion and Management, 153, pp. 288–303, ISSN 0196-8904. https://doi.org/10.1016/j.enconman.2017.10.012

4. Details of the impact

The research was carried out within a Knowledge Transfer Programme (KTP) and the findings have been exploited by the sponsoring company, Weir Valves (now part of Trillium Flow Technologies) to develop a new product, and thus increase their turnover. Lessons in the practical application of the new design approach have been shared with companies operating across the flow dynamics industry.

The impacts can be summarized under three headings:
A. Commercial benefits for Weir Valves
B. Improvements in safety-critical valve design
C. Better design practice across the critical valve industry

Commercial Benefits for Weir Valves
The research findings enabled Weir to increase their sales in a number of ways. The mathematical models [R1,4,5] applied to multiphase valve design, enabled the company to design and build valves that met the specifications of their customers more reliably. The demonstrable mathematical rigour behind the valve design, which resulted in an "astonishing improvement in size calculations" [E5] significantly increased credibility in the market and convinced customers that Weir were the partner of choice. The MD of Trillium said that their "detailed understanding of the performance of [their] valves" means "Customers now see us as knowledgeable in this area. We now use this as a sales tool" [E1].

Sales of the X-treme valve had increased by 640% by 2018, according to the KTP final report produced at the end of the project. The project was vital to the award of a £3m contract for an oil and gas industry customer in the North Sea [E5]. Sales volumes have continued to grow and the MD of Trillium stated, "The KTP was a great success [..] and has improved how competitive we are [..]. Our market share of severe service valves has increased significantly" [E1].

The new valve design method developed, also revealed that the existing design methods resulted in oversized valves for a given capacity. The UoH-developed design process increased the accuracy of the valve sizing by up to 250% [E5] which led to the creation of a smaller valve that gave the same performance envelope as a bigger valve. This gave Weir a cost advantage (because less raw materials are required) and meant they were able to reduce the price of the finished product to their customers. Confirming this, the MD of Trillium wrote that the KTP had allowed them to "be more competitive in smaller valve offerings" [E1]. Indeed, the company were able to reduce the size of all the valves, not just multiphase valves [E5]. Smaller valves provided customers with other advantages such as fewer operating issues and associated physical handling problems [E2,3].

Improvements in Safety-Critical Valve Design
The research findings resulted in a set of mathematical models [R5,6] that enabled Weir to improve the performance of their safety-critical valves, both in terms of their performance against specification and their longevity. The MD of Trillium stated that the research findings help the company to "specify valves more accurately, to select the appropriate valve and [..] choose the optimal solution [for] better operational performance" [E1]. Weir also used the models as the starting point for their valve designs. They then iteratively applied the correction factors the models indicated, which produced the optimum design more quickly.
The advantage of this approach, as opposed to the old, trial and error method based on the industry-set empirical standards, is that the performance of valves designed this way is more predictable and repeatable. This resulted in a superior finalized valve design [E1]. This approach enabled Weir to redesign and improve their X-treme valve for safety-critical applications.

The research on additive manufacturing processes [R2] enabled Weir to use this technique to produce valves to a high precision. Additive manufacturing led to a reduction in costs because it uses less material than traditional methods (it builds a structure from scratch, rather than removing metal from block) and it is less labour intensive. The X-treme valve is now manufactured using the new processes.

Better Design Practice Across the Critical Valve Industry
Weir have embedded the knowledge in their business and used it to train their engineers, which has resulted in improved understanding of the product, faster design and improved sales. UoH extensively interacted with Weir through the KTP and one-to-one meetings and explained how they combined the mathematical models with the empirical industry standards to create novel

valve designs. Weir have shared this knowledge with many businesses in the multiphase critical valve industry, including VWS Westgarth (who make water treatment plants for oil and gas installations), SBM (a service provider for the oil and gas industry based in the Netherlands) and the following firms based in the global oil capital of Houston, Texas: Wood, Worley Parsons, Exxon Mobil, Williams and Bechtel. This activity increased understanding of multiphase sizing techniques at these companies, resulting in wider incorporation.

The MD of Weir confirmed that they regularly give presentations, which are “providing the industry with more detailed knowledge of valve performance” to “leading major oil and gas contractors globally” [E1]. This has led to better awareness of the new design approach in companies such as Exxon Mobil, Equinor (a global energy company) and Worley (a service provider to the chemical industry). Feedback from a participant at one of the CPD events in 2019 indicated how they planned to change their internal processes. The Technical Director from Koso Kent Introl (an industrial valve manufacturer, formerly at Weir) said, “attending this CPD is considered [as valuable training for those working] towards attaining registered professional engineer status” [E6].

Awareness of the research findings led to interest from other flow handling companies and resulted in four further knowledge transfer partnerships with SME businesses (Koso Kent Introl (valve manufacturer), Woodcock and Wilson (centrifugal fan manufacturer), Trust Electric Heating (who make electric radiators), plus one more at Weir [E7]. The total value of these contracts to the University of Huddersfield is £955,000. It is anticipated that the total value to the businesses at the end of the KTP will be £500,000 in increased net profits and after five years will be a total of £9.65 million (based on the companies’ own calculations) [E7]. The research methodology developed when working on the first two KTP projects with Weir has been used to optimize the performance of their existing products and to develop new ones. A UoH-hosted web-based portal was launched in February 2020 and received 14,000 hits by the end of the year [E4]. All the above resulted in Hull-based Shipham Valves, one of the longest-established industrial valve manufacturers in the world, negotiating development of a KTP project.

5. Sources to corroborate the impact

[E1] Testimonial letter from MD of Trillium flow technologies formerly called Weir about the impact of the KTP.

[E2] https://fluidhandlingmag.com/news/smaller-valve-sizes-ok-for-multiphase-applications/

[E3] https://www.maintenanceandengineering.com/2018/04/06/industry-university-collaboration-improves-accuracy-of-valve-sizing/.

[E4] http://inflowsem.hud.ac.uk/ - Website used by businesses to secure online help from the UoH researchers.

[E5] KTP Final Report - Demonstrating significant benefits of the programme to the company sales and reputation.

[E6] Private email from the Technical Director, Koso Kent Introl (formally at Weir/Trillium) indicating that the approach developed by the research is now used for engineers training for professional status.

[E7] Testimonial from Knowledge Transfer Advisor, Innovate UK, on impact of the research carried out on the further funding and effects on industries in the region.