

Diaphragm Valve Design to Assist in cGMP Compliance

In recent years, diaphragm valve design has evolved and the process industries have seen the introduction of stainless steel, process fabrications, multiport divert and modular valve assemblies. Such technologies, when applied to the manufacture of weir-type valves, have been instrumental in reducing contact surfaces and hold-up volumes, resulting in higher product yields.

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The inherent need to increase product yields, product purity levels and system productivity in pharmaceutical and bioprocessing process applications, while maintaining or reducing costs, is a major challenge that confronts project and operations personnel on a daily basis. This article will discuss current technologies available for the manufacture of weir-type diaphragm valves. It will concentrate on the various body manufacturing methods, process body fabrications, multiport valve designs and modular valve assemblies that greatly reduce contact surfaces and hold-up volumes.

Materials of construction and manufacturing methods

Weir-type diaphragm valves are currently available in a variety of materials, suitable for a range of manufacturing methods. The most common material used by industry today is 316L stainless steel, but alloys such as AL6XN and Hastelloy C-22 are also available in various formats to provide increased corrosion resistance for more aggressive process applications.

Castings. Cast components are manufactured by pouring molten metal into a mould. The most common method of casting high precision parts is known as the 'lost wax method' (or 'investment cast method'). A wax impression is created for the shape required. The wax impression is dipped or sprayed with ceramic material and then fired in a kiln where the wax evaporates, leaving behind a hard ceramic shell into which molten material is poured. The cooling of molten metal may cause sub-surface porosity, which varies depending on casting techniques. The result is a product complete with flow path, bolt-holes, drain marks and body identification marks, and cast into the



Image of modular valve assembly provided by author.

required shape. Machining is therefore minimal. Ferrite content may vary considerably (5–17%, based on the use of ASTM A800 analysis techniques), depending on several variables such as wall thickness and metallurgy of the material. A ferrite content of $\leq 5\%$ may cause difficulties in the welding and polishing of the cast component.

Forgings. Forged components are produced from round stock or plate, which has been processed from an ingot. The round stock or plate is compressed between two halves of a forging tool at elevated temperatures. The result is a shape (blank), which is then machined to create the required shape. The required machining at this stage is more extensive than a casting. A ferrite content of $< 0.5\%$ based on ASTM E-562 analysis techniques is achievable.

Wrought. Wrought material is worked material such as plate or round stock. Rather than forging a shape between two halves of a tool, as above, the shape required is machined directly from wrought material. Ferrite content in wrought material may vary, depending primarily on the metallurgy of the substance used; however, the standard wrought has a ferrite content of $\leq 3\%$.

Ferrite. "Ferrite can be defined as the ferromagnetic, body-centred, microstructural constituent of iron-chromium-nickel alloys, which varies in chemical composition. It may be formed by solidification of molten metal (delta ferrite) or by transformation from austenite or sigma phase on cooling in the solid state (alpha ferrite)."¹ The formation of ferrite is a natural occurrence in stainless alloy products. Several techniques can be used to determine ferrite levels, including chemical analysis, metallographic

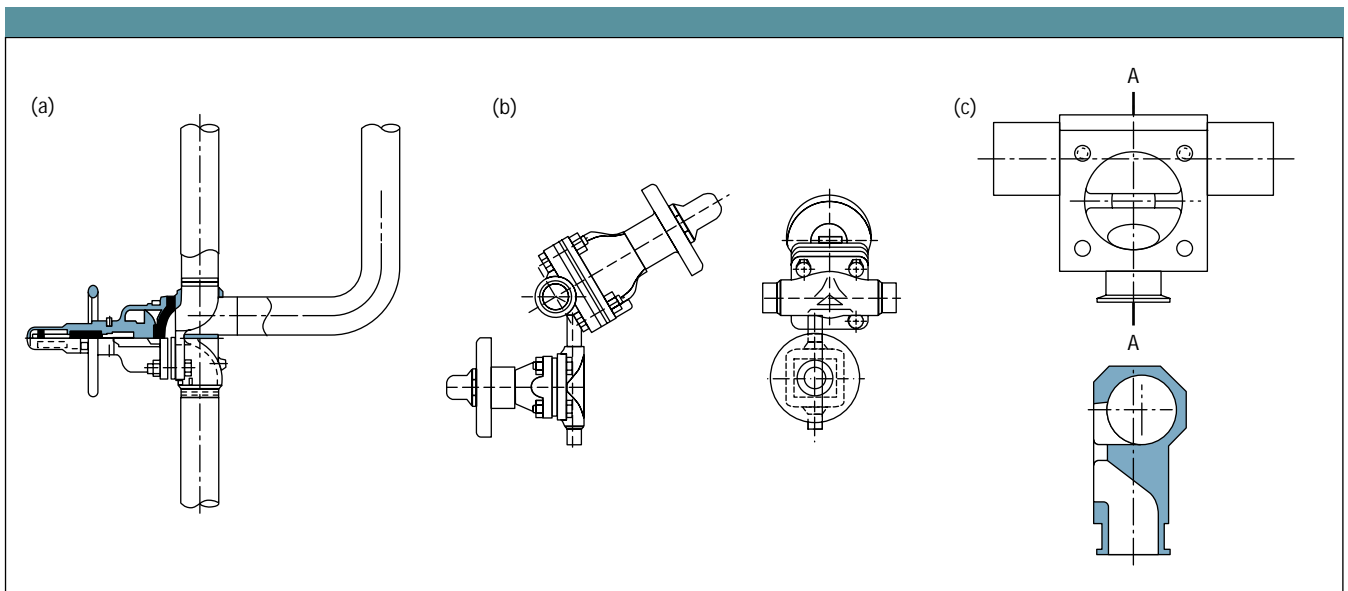


Figure 1: Diaphragm valve process fabrications: (a) point of use (GMP); (b) sterile access; and (c) block bodied tee.

examination and magnetic attraction.

In the above examples, ferrite is depleted as the material is worked — castings have the highest ferrite content, and forgings the lowest. Free delta ferrite contained in components in a process system may or may not be of concern to the end-user. The nature of the process, the utility protocols (that is, passivation, cleaning, sterilization and fabrication) and additional surface preparation of the material, such as electropolishing, will all determine the amount of free iron at the surface of the component.

The selection of process components in the pharmaceutical/bioprocessing industry, particularly in cell culture applications, demonstrates a distinct movement towards lower ferrite materials. At one time, cast bodies provided a cost benefit to the end-user, but machining techniques have since advanced to the point where forged and wrought products are as cost-effective as cast components.

Sulphur content. The sulphur content of cast and forged product may vary considerably, depending on the wrought materials. Tubing specified to ASTM A269/270 has a sulphur content of 0.005–0.017%. Cast product specified to ASTM A351 Grade CF 3M and forged product specified to ASTM A182 Grade 316L, S9, have maximum limit sulphur contents of 0.040% and 0.030%, respectively. A high differential of sulphur content in adjoining components can cause an irregular weldment. To facilitate high performance orbital weldments, valve bodies are provided with wrought tube extensions, thus reducing the frequency of reprogramming of the orbital welding machine on site.

Process fabrications. Process fabrications for

the purpose of this discussion are defined as any valve body fabrication that reduces hold-up volume and contact surfaces in a process system. The theory being that as hold-up volume and contact surfaces in a process system are reduced, product purity and yields will be enhanced. There are many possible variations to this theme, several of which are depicted in Figure 1. It is important to note that process fabrications are normally designed for specific orientations. For example, the fabrication depicted in Figure 1a would be utilized in a vertical orientation. Applications of this fabrication would include point of use (Figure 1a) or at the top of vessels, where the port adjacent to the weir would be used as the condensate

drain and/or sample port. The sterile access port fabrication (Figure 1b) is designed for horizontal installation. The valve provides access to the product stream for sampling and/or to the condensate drain, for which the valve is positioned at the correct angle for drainability into a horizontal pipeline. The third fabrication involves a point of use application (Figure 1c) where the valve is physically positioned on the piping stream. This design greatly reduces the hold-up volume and complies with the requirements of colder high purity water systems, as outlined in the US Food and Drug Administration (FDA) *Guide to Inspections of High Purity Water Systems*. Section IX (Piping) of the guide states: “The proposed LVP (large volume par-

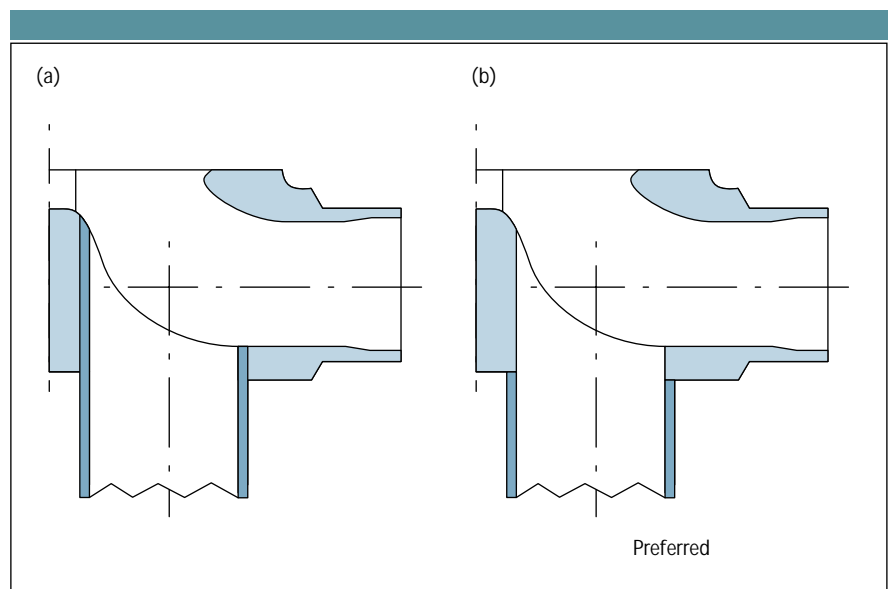


Figure 2: Fabrication technique; (b) is the preferred fabrication (see text).

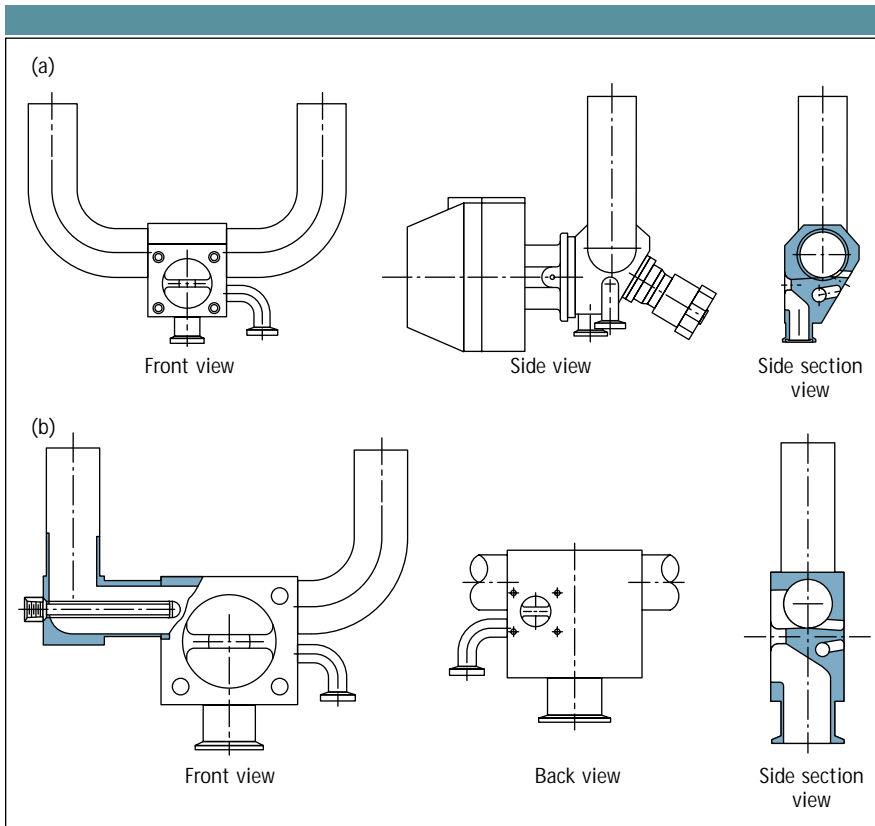


Figure 3: Block bodied tee fabrications: (a) block body tee with integral sample valve; (b) block body tee with integral sample valve and instrument port.

enteral) regulations defined deadlegs as not having an unused portion greater in length than six diameters of the unused pipe measured from the axis of the pipe in use. It should be pointed out that this was developed for hot (75–80 °C) circulating systems. With colder systems (68–75 °C), any drop or unused portion of any length of piping should be eliminated if possible, or have special sanitizing procedures.²

Although the fabrications described above demonstrate a reduction in hold-up

volume and contact surfaces, it is important to determine the method of fabrication. To help illustrate differences in fabrication technique, please refer to Figure 2, which depicts the insertion of a tube through the body directly into the waterway of the valve. This is commonly done with castings to avoid possible porosity encountered in the wall of the body. The tube is welded in the waterway of the valve and then polished. The concern arises in the integrity of the weldment. As the weld is polished, there is a real danger of

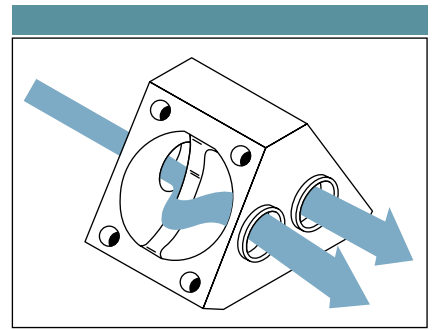


Figure 4: Two-way divert valve horizontal flow path.

depleting the weldment and exposing a crack between the outside diameter of the tube and the bore through the valve body. Cracks at the weldment can also appear during thermal cycling or if any lateral force is applied to the tube. If this occurs, product can be trapped between the outside diameter of the tube and the bore through the body creating a source of continuous contamination. In a preferred fabrication, the inside diameter aligns with the bore through a forged or wrought body (Figure 2b). The tube is then joined to the exterior of the valve body by means of a full penetration weld. The insertion of tubes through valve bodies and interior weldments as portrayed in Figure 2a should be avoided. In addition, it is recommended that forgings or wrought bodies be used instead of castings for any process fabrication.

The use of wrought bodies for point of use applications has become a preferred choice of valve body fabrications. In addition to the valve body becoming an integral part of the piping system, internal welds are eliminated and various integral ports can be machined directly on the wrought body as required. An integral sample valve and an instrument port are shown in (Figures 3a and b), respectively. The instrument port

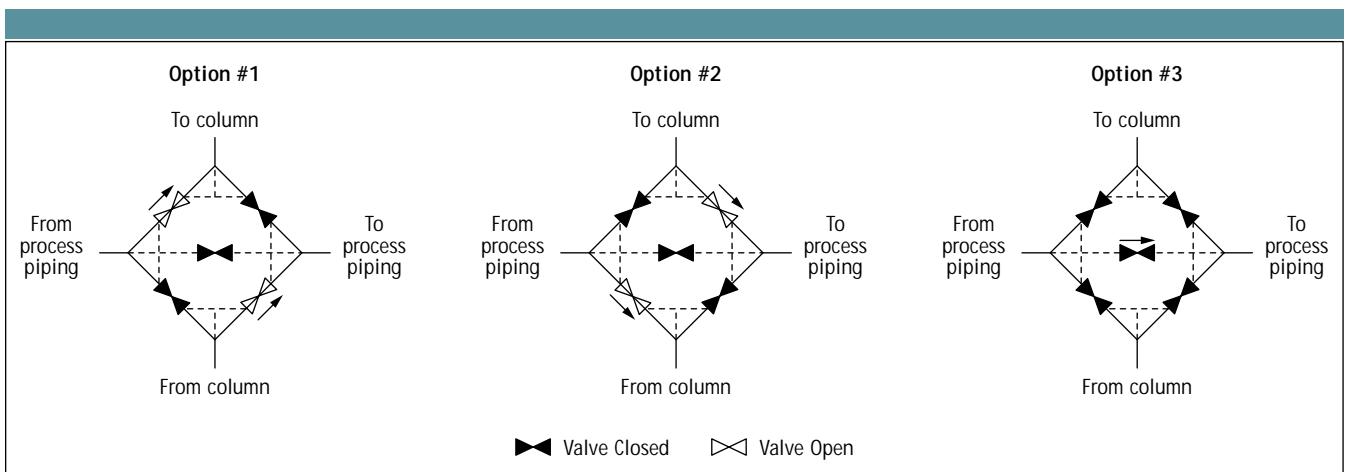


Figure 5: Chromatography valve fabrication incorporates three piping schematics into one block bodied assembly.

shown depicts the use of a thermal well, into which an RTD (resistance temperature device) can be inserted to determine temperature at the lowest point in the system, which in this case is the point of use. Although *USP 24* encourages the continuous monitoring of water quality with conductivity and TOC (total organic carbon) measuring devices, the use of sample ports strategically located throughout the piping system will greatly enhance an end-user's ability to diagnose contamination problems.³ The sample port can also be used with a portable TOC monitor.

Modular valve assemblies

Modular valve assemblies are simply the result of combining several process fabrications of standard valves into a valve module or cluster for a specific process application. The use of valve assemblies can greatly reduce the number of field weldments, the cost of installation and the time of field construction. They also provide tighter dimensional assemblies and enhance schedule, quality and operational benefits. The process of creating modular assemblies begins with identification of candidate assemblies from a piping and instrumentation diagram. To meet criteria such as maintaining 'minimum distances' between valves to minimize deadlegs and loss of product, groupings of valves are selected. Three-dimensional CAD (computer-aided design) models are then created to show orientation and locations of components. Multiple-angle images of each unique assembly are extracted from the models in the form of dimensional sketches. Approval drawings are then created from the dimensional sketches to ensure feasibility and ease of fabrication. Once approved, the assemblies are given an identification number, cross-referenced to a specific piping and instrumentation diagram, and components of the assembly are identified and given a specific tag number. Fabrication of the assembly is then accomplished.⁴

Multiport divert valves

Weir-type diaphragm valves are now readily available to provide divert and mixing capabilities through multiport designs. The multiport design concept is based on having one common port feeding several independent ports or vice versa (see Figure 4). In the first scenario, the valve would be considered a divert valve; in the second, it is a mixing valve. Benefits of the multiport design include reduction of deadlegs and contact surfaces enhancing CIP (clean-in-place) and SIP (steam-in-place) capabilities; reduction of overall welds in a process system, providing fewer areas of bacterial ingress;

and reduction of the dimensional envelope of the piping assembly, promoting ease of installation and maintenance. In addition to the straightforward multiport concept, manufacturers have also developed specialty multiport designs to provide solutions for specific process applications, such as chromatography and filtration (see Figure 5).

Summary

Because of its simplistic design, minimal contact surfaces and hold-up volume, the weir-type diaphragm valve continues to be the most utilized valve for critical process applications in the pharmaceutical/bioprocessing industries. Valve manufacturers have also been able to continually modify the valve body to meet the ever-increasing need to increase product yields and reduce costs. These two requirements, cost reduction and higher product yields, are not mutually exclusive and can be attained by implementing many of the current designs available in the market today.

References

1. ASTM A-800, 3.1.1 Ferrite (American Society For Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, USA).
2. FDA, "Guide to Inspections of High Purity Water Systems" (US Government Printing Office, 1993).
3. *USP 24-NF19*, Pharmaceutical Waters, Water Conductivity <645> and Total Organic Carbon <643> (United States Pharmacopeia, 12601 Twinbrook Parkway, Rockville, Maryland 20852, USA).
4. A. Gregory *et al.*, "Valve Assembly Use: A Case Study in Maximizing Operational Flexibility, Cost Management and Schedule Benefits," *Pharm. Eng.* **18**(6), (1998). ☺

Article Reprinted from the
©March 2000 issue of

Pharmaceutical Technology Europe

Reprint Publication number: 0396

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