

## **Dilating Disk Valve (MIL-DTL-32632) - Introducing a new high efficiency control valve which saves money, size and weight supporting mission readiness**

### **ABSTRACT**

The Dilating Disk Valve (DDV), designed and manufactured in accordance with MIL-DTL-32632, incorporates a unique, cutting-edge design which reduces the overall size, weight, noise, and energy usage when compared to a traditional globe or control valve. The rotary motion of the obturator or closure mechanism (referred to as “petals”) enables this tight shutoff, control valve throttling capability, and a full port flow path when fully open. In the fully open position, this is a full ported valve, with virtually no flow restriction, similar to a ball valve. This is accomplished using a unique linkage mechanism with a ring and pinion mechanism, which rotates the petals from the valve centerline radially outwards during actuation. The DDV internal seating mechanism is designed similar to a camera shutter, and is opened and closed using a ring and pinion gear system connected to the valve stem. When in the fully open position, the valve has very similar flow characteristics to an open pipe. The DDV can be used in both ON-OFF and throttling applications. This design allows the system designer to use a smaller size valve compared to traditional offerings, due to its increased flow capacity, and inherent low torque operational characteristics of the petals rotary motion. As a result, the valves size envelope/weight, and pumping system requirements (energy and weight), can be reduced. The ability to downsize the shipboard piping and pump sizing will result in weight, noise, and cost reductions. Given the design and inherent flow efficiency of the valve trim, the overall noise of the system can be reduced, which will improve the environment onboard ships, and reduce emitted noise, especially important in submarines. The DDV may also be used in a plug and play scenario allowing direct replacement for valves already installed and in service. The valve design also features quarter turn actuation and has low torque requirements due to its rotary motion

being perpendicular to the flow direction. This allows a smaller actuator to be used, further supporting the size, weight, and energy usage reduction benefits of the DDV.

### **INTRODUCTION**

The DDV has entered the market as a new valve technology which can reinvent how fluid systems are designed. Ship builders can use this valve technology to improve overall ship efficiency by reducing valve and actuator weight, system noise, and pumping requirements. The interlocking petal mechanism approach in the DDV allows for tight shutoff with the three interlocking petals, and the rotary motion of the petals from the centerline outward requires low actuation forces, enables precise throttling through its stroke, and provides an in-line, unobstructed flow path. The DDV was developed with the intent of enabling and supporting ship construction goals to become lighter, faster, quieter, and more energy efficient.

The DDV is designed, qualified, and manufactured to the requirements of MIL-DTL-32632. This standard was developed in 2019 to detail the requirements, and to facilitate introduction of DDV’s into the fleet. This specification requires the valve to perform with high reliability under extreme conditions. To successfully meet the requirements each valve style and size must undergo a qualification process to verify the design meets all the requirements of the specification.

The DDV design offered by Curtiss-Wright, Target Rock is available in sizes ranging from ¼ inch to 12 inches, up to Class 1500, and in all common materials used on shipboard systems. Furthermore, the DDV can be designed to fit most standard pressure classes as well as any end connection types to allow for retrofitting.

## DDV Design & Mechanism

The DDV was designed with the primary intention to be used as a control valve which, as the name suggests, is a type of valve used to control fluid flow in a system under a range of varying pressure and flow rate conditions. This differs from an On-Off type valve (such as a standard globe valve, or gate valve) which is only used in the fully open or fully closed position to allow, or isolate flow in a line. Although the DDV can be used in an On-Off application, it also includes throttling capabilities allowing the user to precisely actuate the valve into any position in between fully open and fully closed. This is accomplished using the interlocking petal mechanism.

The seating mechanism for the DDV uses a unique three petal, rotary sealing design which controls the amount of fluid flow allowed past the valve seat. When in the fully closed position, the petals are placed directly in line with the flow path and restrict the fluid from passing to the outlet port of the valve, common with most other valve types. However, what makes the DDV so unique is when in the fully open position, the seating mechanism fully retracts itself from the flow path and retreats compactly into the body cavity. Figure 1 shows the DDV in the fully closed, mid and fully open positions. In the fully closed position, shown on the left, the petals fully obstruct flow to the outlet portion of the valve. In the mid position, shown in the middle of Figure 1, the valve petals are partially obstructing the flow allowing fluid to pass. In the fully open position, as shown on the right of Figure 1, the valve petals are completely removed from the flow path. In this position, the valve has the flow characteristics of an open pipe, as there are virtually no pressure losses from the seating mechanism. This design feature is very advantageous from a system design perspective. The DDV is a smaller, lighter, and quieter valve package compared to the more traditional technologies utilized across fluid flow systems.



Figure 1: DDV Shown in The Fully Closed, Mid and Fully Open Positions

The petal seating mechanism is driven by a ring gear which mates with a pinion gear connected to the stem of the valve. For a control valve application, an actuator is mounted to the valve, via a bracket in a manner similar to other valve types. The DDV can also be operated manually with a lever. The DDV actuation is accomplished via quarter turn motion. When actuated electronically, the actuator provides the desired torque to a stem adapter coupled to the valve through a square drive, at the top of the stem. The torque is transferred from the actuator to the stem adapter to the stem which drives the ring gear via a pinion gear at the lower portion of the stem. The petals connect to the ring gear and move in and out of the flow stream based on the ring gear position. In the closed position, the three petals interlock to shut off fluid flow. The valve body and bonnet are sealed with O-rings. The stem is sealed (without packing) and has fugitive emissions certifications to API 641 and ISO 15848 AM CC3.

The petals are designed as three identical pieces which interlock to seal the valve. The petals are precision machined with male and female mating surfaces which contact each other to maintain a tight seal. The petal subassembly contains three items; the metal petal, dowel pin and petal seal. The petal main base (Item 1 in Figure 2) is typically made of stainless steel or bronze depending on the application. This component is connected to the ring gear. The secondary portion of the petal assembly called the petal seal (Item 3 in Figure 2) is currently made of a soft material and is installed into the base of the petal using a dowel pin (Item 2 in Figure 2). The petal seals can be made of various thermoplastics such as FKM, BUNA N, EPDM, PEEK or PTFE depending on the application. When the petals interlock, the petal

seal mates up with the corresponding petal base surface. This relatively soft petal seal to hard petal base metal contact arrangement allows for a tight seal as the petal seal can mate and conform to the sealing surface on the petal base.

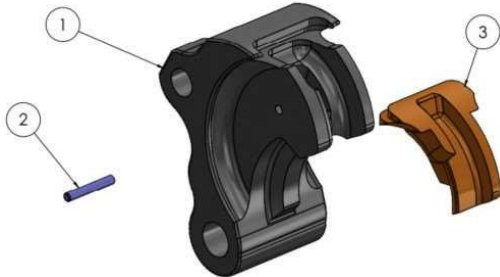


Figure 2: Exploded View of Petal Seal Assembly

The current design using a thermoplastic petal seal allows tight control valve shutoff, meeting ANSI FCI 70-2, Class IV requirements. However, this does limit the allowable operating temperature. Stainless Steel has a melting point of over 2500°F whereas a thermoplastic such as PTFE has a melting point of 620°F. Design efforts are currently underway to release a fully metal petal design in order to raise the allowable maximum operating temperature for severe service conditions. This will allow the DDV to be used in higher temperature applications such as high temperature water or steam in a reactor system of a power plant. The current military specification applicable to this valve design (MIL-DTL-32632) requires the valve be rated to a maximum design temperature of 428°F, which is achievable with the thermoplastics offered.

## DDV DESIGN TO MIL-DTL-32632

The DDV, as offered by Curtiss-Wright, Target Rock, is manufactured to meet the requirements of MIL-DTL-32632. This specification encompasses DDV's for use in naval shipboard water, oil and gas service. Like most pieces of equipment used for naval fluid handling applications, the DDV needs to operate under relatively high pressure and temperature applications with high reliability to ensure safe and effective operation in critical systems. The MIL-DTL-32632 specification contains strict requirements for the valve's material,

construction, operation, and inspection. Furthermore, MIL-DTL-32632 also outlines the qualification test program and factory acceptance test requirements the valve must fulfill to be approved for installation in shipboard applications.

The specification requires use of high-quality materials and workmanship for the valve assembly. Due to the marine environment to which this valve will be exposed, all components are required to be corrosion resistant. The metallic components of this design such as the body, cover and bonnet are typically made of an austenitic stainless steel, such as ASTM A351/A351M, grade CF3 or CF3M. Other materials including bronze and nickel-copper alloys are also offered for seawater service applications. All fasteners used in the assembly meet MIL-DTL-1222 and ASME B1.1, B18.2.1 & B18.2.2 requirements. All nonmetallic components including the pressure boundary seals, petal seals, and bushings are made of materials allowed in the specification to ensure temperature, pressure, and fluid compatibility. The structural integrity, operability, and reliability of these components, and the full assembly are verified during the qualification test program outlined in MIL-DTL-32632.

To demonstrate qualification to MIL-DTL-32632, a series of tests are required which are summarized below. Fluid flow and operational tests required include flow capacity, seat leakage and hydrostatic testing. A flow test is used to verify the valve's flow coefficient ( $C_v$ ) which is a unitless number used to quantify the valve's efficiency at allowing fluid flow. The  $C_v$  of a valve is a function of the flow rate multiplied by the square root of the specific gravity of the fluid divided by the pressure drop across the valve. The valve is set up in a test loop where it is pressurized with a known flow rate and inlet/outlet pressures. The pressure drop across the valve is measured using pressure gages and is used to calculate the  $C_v$  along with the known values of flow rate and specific gravity of the test fluid (typically water). As discussed earlier, the DDV was designed to essentially mimic the

flow characteristics of an open pipe, therefore lowering the pressure drop across the valve allowing a greater flow efficiency.

The hydrostatic test is performed to test the structural integrity of the valve as well as its ability to hold the fluid within the internal cavity. The DDV incorporates a 2-piece clamshell design to make up its pressure boundary. The body (Item 1 in Figure 3) and cover (Item 2 in Figure 3) are held together using a bolted connection. The bonnet (Item 5 in Figure 3) is bolted to the top of the body/cover and houses/guides the stem (Item 7 in Figure 3). See Figure 3 below for exploded view of the DDV assembly. The bolted connections as well as various seals and O-rings ensure zero leakage through the body, cover, bonnet, or stem.

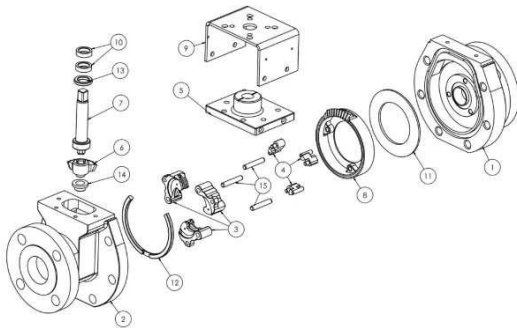


Figure 3: Exploded view of Dilating Disk Valve

Seat leakage testing is performed to measure the amount of fluid the valve allows past the seat (for the DDV, the valve seat consists of the three interlocked petal assemblies) when in the fully closed position. During this test the valve inlet is pressurized to the specified value determined by the valve pressure class. The amount of water allowed past the seat is then recorded, usually quantified in milliliters per min (ml/min). The allowable seat leakage is determined by valve size, pressure class and ANSI FCI 70-2 leakage class. The current DDV design is qualified to meet the requirements of ANSI FCI 70-2, Class IV which is the typical standard for control valve applications. When in the closed position the DDV uses the petal mechanism to seal the petals and restrict fluid flow to achieve a leakage rate below the required value. Along with the fluid tests discussed, the valve must also

undergo Shock, Vibration and Cyclic Testing to achieve MIL-DTL-32632 qualification.

MIL-DTL-32632 requires shock and vibration testing per the requirements of MIL-DTL-901 and MIL-STD-167-1. During shock testing, the test specimen is impacted with hammer blows in multiple orientations and hammer drop heights on a certified test rig to ensure structural integrity and operability before and after blows. The test is performed at an approved facility with qualified shock testing equipment. The magnitude of the blows is determined by the weight of the valve assembly plus the fixturing. For reference, the NPS 1.5 and NPS 3 DDV underwent a lightweight shock test whereas the NPS 6 DDV underwent a medium weight shock test. To successfully pass this test the valve must withstand all blows without physical damage compromising the pressure boundary integrity, or the ability of the valve to perform its intended function. Figure 4 below shows the NPS 1.5 DDV setup for a lightweight shock test. After shock testing the assembly is visually examined, and seat leakage, hydrostatic and operational tests are performed.



Figure 4: NPS 1.5 DDV in the Lightweight Shock Test Fixture per MIL-DTL-901E

Vibration testing is conducted per MIL-STD-167-1 which is the test method standard of mechanical vibrations of shipboard equipment. During the vibration test, the valve assembly must go through an exploratory vibration examination. During this phase the assembly is mounted to a vibration table, and exposed to a range of vibrational frequencies to scan for resonance frequencies. A resonance or natural



frequency of an object is discovered on the vibration table when the assembly vibrates at a higher amplitude. The higher the amplitude, the greater magnitude of force the valve will see during the resonance event. Once a resonance frequency is found the valve will be exposed to the particular frequency for a longer period (referred to as the endurance test) to ensure the assembly is able to withstand these forces without any damage or impact to operability. If a resonance frequency cannot be found the test is run at the highest frequency used during the exploratory test. This test is intended to simulate the mechanical vibrations from the environment and from internal excitation caused by unbalanced rotating components of naval shipboard equipment.

Per MIL-DTL-32632, the DDV is also required to undergo operational testing. These tests are intended to ensure the valve can operate correctly and repeatedly for the intended life of the valve. Operational testing requires the valve be exposed to the pressure, determined by the valve pressure class, across the seat and successfully cycled open and closed 20,000 times. After the cycles are completed, the valve is hydrostatically tested to ensure there is no external leakage from the pressure boundary components. During this test it is also important to inspect the valve for any signs of wear, damage, or impact to operation which could affect the valves performance.

MIL-DTL-32632 requires the valve assembly to not only perform its intended function during normal operating conditions, but also to maintain its functionality through a series of extreme tests. The qualification tests required by the specification put high stresses and fatigue on the valve to ensure when in service the valve will have high reliability and perform as expected. The valve was designed with high safety margins, and minimal parts to allow the highest performance and reliability in an affordable package. The DDV incorporates reinforced component design composed of high strength materials to ensure consistent and

precise operation even under very strenuous conditions. Even with this robust, high-performance design, the DDV still incorporates many other benefits as mentioned earlier such as reduced weight, size, energy usage, reduced fluid turbulence, noise and flow efficiency at a competitive overall cost.

## DDV FLOW EFFICIENCY

The most common method used to transport fluid from one place to another is through a pipe of a circular cross section due to its high structural integrity and flow characteristics. A circular pipe allows uninterrupted laminar flow to occur. Laminar flow is a desirable characteristic from a fluid dynamics perspective. In a laminar flow condition, particles move smoothly past each other with little or no mixing. Turbulent fluid flow is when the fluid particles start to mix through eddies and swirls. Turbulence can be caused by either higher flow velocities or obstructions in the flow path. This type of flow is not as efficient as the direction of the flow is not fully parallel to the pipe, increasing energy losses. This can be seen in Figure 5 shown below.

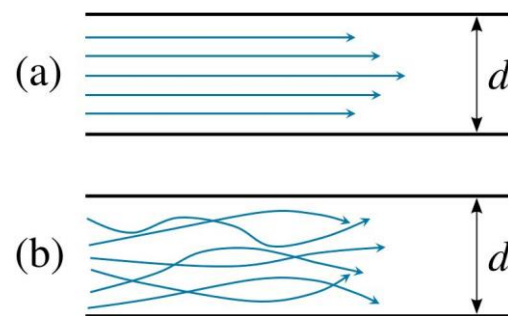


Figure 5: 2D Diagram of (a) Laminar Flow and (b) Turbulent Flow in a Closed Pipe courtesy of [simscale.com](https://www.simscale.com)

The upper portion of the diagram labeled (a) shows laminar flow within the pipe with the blue arrows representing the layers of fluid flow. These layers do not intersect allowing the flow to travel through the pipe uninterrupted requiring the least amount of energy to transport the fluid. During turbulent flow, shown in the lower portion of Figure 5 labeled (b), the flow paths intersect and contain currents normal to the flow. Since the flow forces are no longer

parallel, they will counteract each other resulting in greater energy loss.

When designing a fluid system, it is advantageous to remain in the laminar flow region as it will require the least amount of energy to push the fluid to other parts of the system. Furthermore, turbulent flow introduces the possibility of cavitation, which is the formation and collapse of vapor bubbles in the flow stream caused by changes in velocity and pressure. Cavitation has negative effects on the system as it can cause higher noise, reduce the flow efficiency, as well cause damage to the valve and other parts of the system from the collapse of vapor bubbles. Over time if not controlled, cavitation can cause pitting on the valve as well as components such as the pipe or pump, essentially decreasing the life span of these system components.

A Computational Fluid Dynamics (CFD) analysis was performed to compare DDV flow characteristics to a traditional globe valve (hereinafter simply referred to as “globe valve”), a very common valve also used in control valve applications. Globe valves use a linear motion which moves the valve stem axially to open or close the trim, thus changing the effective flow area. The DDV is a rotary motion valve with a rotating stem which opens and closes the trim from the centerline outward to change the effective flow area. The design of a globe valve has the seating mechanism directly in line with the flow path creating an obstruction when in the fully open position. This obstruction decreases the valves flow capacity, or Cv. Further, the flow through a globe valve gets redirected over, or under the valve seat. The directional changes as the fluid moves through the valve seat area further reduces the flow capacity and causes turbulence.

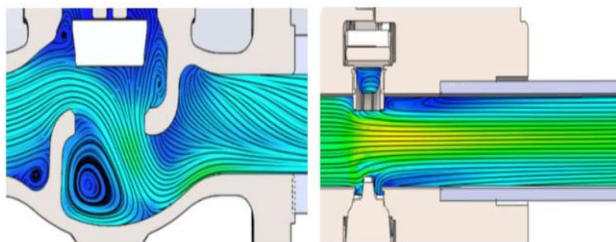


Figure 6: Typical Globe Valve (left) and DDV (right) CFD comparison

In Figure 6 displayed above, a screen shot of a CFD analysis performed on the two valve styles in the open position is shown. The darker blue & black colors indicate regions of lower velocity, and the green & yellow regions indicate a higher flow velocity. As can be seen the DDV can maintain a higher flow velocity when compared to the globe valve when the flow input is the same. Additionally, globe valves also contain vortices and dead zones with recirculation in the flow path which will further disrupt the flow. This can be seen in the circular regions in the pockets in the globe valve body. These vortices also increase the probability of cavitation. Lastly the DDV has a linear and parallel flow path much like the laminar flow in a pipe outlined in Figure 5. This increased flow efficiency is one of the main benefits the DDV has over the globe valve during valve selection for a system.

The DDV also has increased flow efficiencies when compared to other similar rotating stem valves such as a ball or butterfly valves as shown in Figure 7. These valves have similar flow characteristics to the DDV but contain obstructions in the flow path during various stages of operation. A butterfly valve flow is more laminar than a globe valve, however the seating mechanism is in the flow path even in the fully open position. This obstruction limits the valves’ ability to achieve maximum flow velocity. The vortices introduced by the disk also increase the chance of cavitation as well as erode the disk.

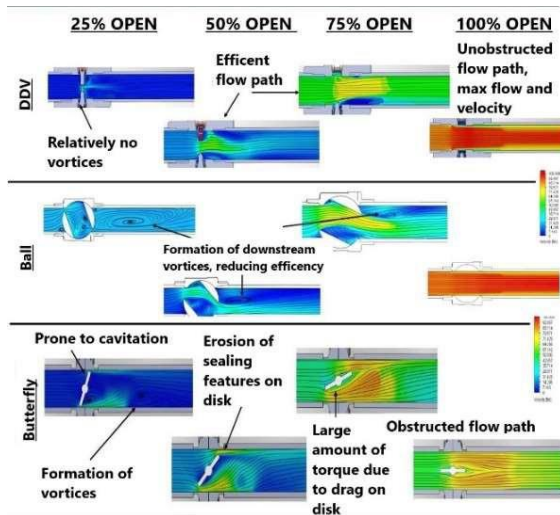


Figure 7: DDV, Ball, and Butterfly Valve CFD

A ball valve has a very similar flow path to the DDV in the fully open position, however due to the flow being redirected when hitting the side of the ball in the mid positions, it is a less efficient flow path compared to the DDV. The DDV opens directly from the pipe centerline, so the flow is not being redirected and is mostly travelling parallel to the piping system, reducing turbulence. This can be seen in the CFD analyses shown in Figure 7. The blue and green regions represent a lower velocity whereas yellow and red colors represent a higher velocity.

The flow characteristics of the DDV are superior compared to other common valves used today. This flow efficiency not only increases the effectiveness of the valve but also translates to many other benefits such as weight, size and noise reductions as well as reduced energy usage.

## DDV SIZE AND WEIGHT BENEFITS

Due to the compact design of the DDV internals as well as the increased flow efficiency, the DDV can offer significant size and weight benefits when compared to other valves of the same size. For example, like a gate valve the DDV has low flow restrictions in the fully open position. However, a gate valve requires a large bonnet on top of the body for the gate disk to occupy when in the open position. The DDV has a three-piece interlocking disk which is rotated directly into the body cavity and therefore does not need a large bonnet to house the disk. This smaller bonnet reduces the overall space envelope of the valve assembly as well as the weight. This makes the DDV a more versatile choice from an overall system design and layout perspective. The DDV also offers significant weight and size savings when compared to a globe valve of the same nominal pipe size.

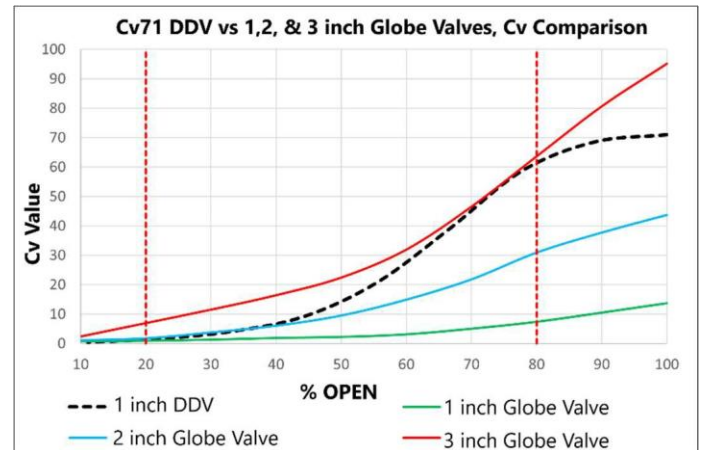


Figure 8: Cv Comparison of 1-Inch DDV vs 1,2,3-inch standard globe valves

Figure 8, shown above, displays a graph comparing the Cv values of a 1-inch DDV and 1 inch through 3-inch globe valves at various open positions. The 1-inch DDV's Cv value is greater than the 1- and 2-inch globe valves in all positions. It would take a 3-inch globe valve to achieve a similar maximum flow capacity as a 1-Inch DDV. However, a 3-inch body is much larger and adds size as well as weight to the overall assembly.

Valve Size	Dilating Disk Valve (lbs)	Standard Globe Valve (lbs)	Rotary Globe Valve (lbs)
1 inch	47	78	62
2 inch	70	135	74
3 inch	86	215	172
4 inch	137	264	213
6 inch	169	472	402
8 inch	487	1154	467
10 inch	575	1876	N/A
12 inch	659	2066	N/A

Figure 9: Weight Comparison of DDV's and globe valves in various sizes

Figure 9, shown above, displays the weights of various sizes of DDV's compared to weights of

standard globe valves. In all sizes, the DDV has the lowest weight by a significant margin. This is once again due to the compact design and low torque requirements this valve offers. The overall weight savings becomes more pronounced as the valve sizes become larger. The decreased overall valve and actuator package size can be seen in Figure 10 below. Despite the significant size difference, the DDV delivers an equivalent flow capacity (Cv) to the globe valve shown. The DDV is a direct replacement for the standard globe valve shown, offering the same end-to-end and raised face flange dimensions.



Figure 10: Two ANSI pressure class 150, 4" valves side by side. DDV shown left and Globe valve shown right.

The DDV not only offers a weight and size reduction for the valve itself, but also features a low torque quarter turn design allowing the use of a less powerful and smaller actuator. A standard globe valve requires the valve disc to open against the differential pressure forces exerted by the fluid due to the disc traveling in line with the seated disk. This requires a larger force to open the valve and consequently a more powerful actuator. Since the DDV petals operate perpendicular to the flow path, rather than in-line like the standard globe valve, it does not have to overcome this differential pressure force during the opening sequence. This results in a less powerful and smaller, lighter actuator required to operate the valve. An example of this can be seen in Figure 10. The 4-inch DDV shown features a light and compact electric

actuator to operate whereas the 4-inch globe valve requires a larger actuator to overcome the pressure forces.

## DDV NOISE REDUCTION

For many naval applications, noise is a major concern. Stealth ships and submarines in the fleet deploy technology in an attempt to remain undetected by adversaries. In addition, noise produced by the operating equipment onboard the ship can also impact sailors hearing and ability to communicate effectively. The DDV can help support achieving noise reduction goals to reduce detectability and improve the environmental conditions for the sailors. The primary reason for achieving low noise is due to the DDV's rotary petal motion, and unobstructed flow path, reducing turbulence induced noise.

Testing performed on a 1" DDV by Curtiss-Wright, Target Rock demonstrated noise levels ranging from 79 – 87 dB during flow loop testing with water, at inlet pressures ranging from 600 to 1800 psig. This is a result of the advantages discussed in the DDV Flow Analysis section of this white paper.

## ENERGY & COST REDUCTION

Reducing equipment weight or power requirements can help make a ship lighter/more agile, require less energy to operate, and free up space for other equipment needed to support the mission. Ultimately, the DDV can play a key role in supporting initiatives to reduce the weight and power consumption of ships.

To quantify how the DDV can reduce the power consumption, research was conducted in a flow loop to obtain data. Flow testing using a water flow loop was performed to quantify the energy savings of a DDV compared to an Eccentric Plug Rotary Globe Control Valve.

The outputs from the variable frequency drive user interface were measured to determine the motor output horsepower, pump output gallons per minute (GPM), and kilowatts per horsepower (kW/hp). The total energy consumption was multiplied by a typical monetary rate of dollars per kilowatt hour



(\$/kWh) to come up with an annual energy consumption cost. A common flow rate was used through both valves for this comparison

The test system had the capability to allow flow through both test lines at once, and one test line only. For this energy savings analysis, each test line was operated standalone, with flow only being applied to the valve under investigation.

A more efficient control valve will allow the pump to operate at a lower horsepower level to supply a given flow rate, thus reducing the amount of energy required to operate the pump. The data presented in Figure 11 shows the DDV requires 54% less energy to achieve the flow rate specified in the test when compared to the globe valve. It is noted the cost data calculation assumes 24 hours a day operation for 300 days in a year.

Valve Used	VFD Setting (Hz)	Motor Output HP	Pump Output GPM	kW/hp	\$/kWh	Cost per Year (\$)
Dilating Disk Valve	24	4.38	90.7	0.69	\$0.186	\$4,072
Rotary Globe Control Valve	32	9.48	86.4	0.69	\$0.186	\$8,813

Figure 11: Cost and Energy Savings Data Collected from Research Test Loop

This example shows, over the course of one year, DDV costs and power required to operate are 54% less than a Rotary Globe Control Valve. Based on these results, there are significant energy and cost savings which can be realized on shipboard applications if traditional high loss globe valves are replaced with the more fluid efficient DDV design.

**Conclusion**

As discussed throughout this white paper, the DDV is a disruptive valve technology which solves some of the major drawbacks of traditional valves. By using the rotary, interlocking petal operating concept, the DDV does not share common drawbacks of traditional valve technologies, such as high actuation forces, noise/cavitation, and large

weight/envelope/powering requirements. Due to these factors, the DDV is an excellent choice for improving the characteristics of traditional fluid flow systems used onboard ships. The DDV can be retrofitted into existing systems, or can be designed to be integrated into new systems being developed.

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Bachelor of Science Degree in Naval Architecture & Marine Engineering from the University of Michigan. Master of Engineering Management from Old Dominion University

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He received his BSME from Lafayette College in 2010, his Masters in Mechanical Engineering from Stony Brook University in 2014, and is currently pursuing an MBA at Hofstra University.

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