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Need for an industry standard for ESD valves from engineering and safety point of view

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Key words

ESD valves (Emergency Shutdown Valve), SIS (Safety Instrumented System), SIF (Safety Instrumented Function), Test Interval (TI), Maximum shut off Differential Pressure (Max. shut off DP), CAPEX (Capital Expenditure), Partial stroking, PFDavg (Probability of Failure on Demand), Dynamic Torque, Torque Safety Margin, PHA (Process Hazard Analysis), HAZOP (HAzard and OPerability study), FMEDA (Failure Mode Effect and Diagnostics Analysis)

Abstract

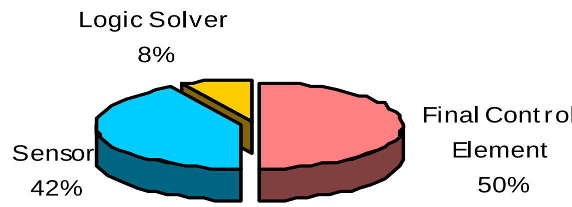
Since the Piper Alpha disaster in the North Sea, design of ESD valves has been given top priority and remains to be of great concern for plant safety management. Constant improvements have been made to ensure the integrity of the ESD valves. Essentially, ESD valves should perform their duty (usually closure of valves) under plant demand condition. To meet the production bottom-line, these valves are required to remain open for months, even years, which leads to build up or corrosion in the valve internals. Final control element is the weakest link in the SIS. It contributes 50% of total PFDavg for a SIF. To meet the desired 'Availability' figure for ESD valves, different tools have been devised. Partial Valve Stroke Test, Valve – Actuator signature curve, Testing Intervals (TI) are buzzwords in the industry. However, there is no industry standard for ESD valves which covers both engineering and safety aspects together. Design aspects of ESD valves and associated actuators vary from operator to operator and sometimes from one asset to another for the same operator. This article is an attempt to address the need for a common industry standard for ESD valves.

Introduction

Selection of maximum shut off DP for ESD valve torque calculation and associated actuator sizing sometimes become subject for debate during the design stage. Too much conservative value leads to 'oversized' actuator and increased CAPEX.

Furthermore, there is not a standard guideline for the selection of the valve safety factor amongst the valve/actuator manufacturer (service factor) and actuator-valve torque safety margin. Many valve manufacturers utilize their own safety contingency in addition to the user's specification.

As per the study, final control element contributes 50% to the SIS failure. Special care should be given while designing the ESD valves. However, ESD valves should not be oversized.



Statistical Failure Data

With the introduction of SIS, "Partial Stroke", valve/actuator signature facilities, questions may be raised whether high design contingency is still required to cater the life time torque requirement. Essentially, all put together, elevates the CAPEX.

This paper addresses the following:

- Basis of maximum DP selection from process application and recommendation for a suitable maximum DP for SIS application
- Cost analysis at different shut off DP & different actuator-valve torque safety margin
- Type of actuator mechanism to be fitted with the valve
- Dynamic torque specifications
- Valve opening & closing time -design and safety concern
- Safety valve on the actuator supply line - weakest link in actuator circuit
- Partial stroke testing , Valve-Actuator signature curve, Test Interval (TI)
- Valve-Actuator assembly PFDavg and SIL levels
- ESD valve leakage, fire test specification
- Miscellaneous design issues

Basis of maximum DP selection from process application and recommendation for a suitable maximum DP for SIS application

Sizing of an ESD valve actuator becomes a very easy task for an actuator manufacturer if all the necessary information is made available from the valve manufacturer. Valve torque is a function of maximum shut off DP. There is no standard guideline for deriving the maximum differential pressure for actuator sizing. In practice, philosophy varies from operator to operator, from one asset to another for a particular operator, and widely varies from one design consultant to another. Essentially, this happens because of lack of proper analysis during the design stage. In many instances, ESD valve engineers tend to take conservative values instead of analyzing individual cases. Proper PHA can lead to optimum selection of maximum DP.

In general, the philosophies listed below are being followed for sizing DP

- Maximum DP under operational conditions
- Maximum DP at the upstream failure conditions
- Design Pressure of the line
- Cold Flange rating of the line

It has been common practice for some of the operators or design contractors to follow only one philosophy for all the on/off valves (ESD valves and On-Off valves for general service) irrespective of the service and application which leads over design of actuators.

Line Design Pressure as sizing maximum DP

In absence of proper analysis, line design pressure is considered as standard sizing criteria, despite the large margin between safety valve set point and the design pressure. Some of the operators prefer to adopt this philosophy for all valves for service interchangeability. With same line design pressure and flange rating, these valves can be interchanged for service purposes. For example, valve for a production well can be interchanged with an injection well, whenever required. Or, the same valve can be utilized to other assets in similar applications. However, some applications demand design pressure as the sizing DP because of the process requirement where safety valve set pressure is close to the design pressure.

Cold Flange Rating Pressure as sizing maximum DP

Some operators prefer that all valve torque calculations should be done based on the cold flange rating pressure service interchangeability reasons. With this assumption, design contractors tend to specify the torque requirement for all the ESD valves and associated actuator based on the cold flange rating. This type of trivial specification will increase the CAPEX. It is also possible that during the design stage, both operator and design contractor have looked into the possibility of how many valves might be interchangeable. Interchangeability of valves between different assets may not be cost effective. Dismantling and transportation costs may be higher than a new valve, although other factors should be considered such as emergency and delivery conditions. It must be stated that there is no available data from any operator on how many valves have been interchanged from one asset to another during their sites operations history.

Case Study for Maximum DP Selection – Process HAZOP approach

Sizing DP for valve and actuator is not generally taken into discussion during conventional process HAZOP because this is purely a design related issue. However, a simplified safety analysis may justify the selection of the maximum DP.

Let us analyze a simple case study:

Consider the separator inlet node of a wellhead. In this example, the original production well is being utilized as gas lift well by installing a new ESD valve. Here, normal operating pressure is much less than the well shut in pressure and design pressure.

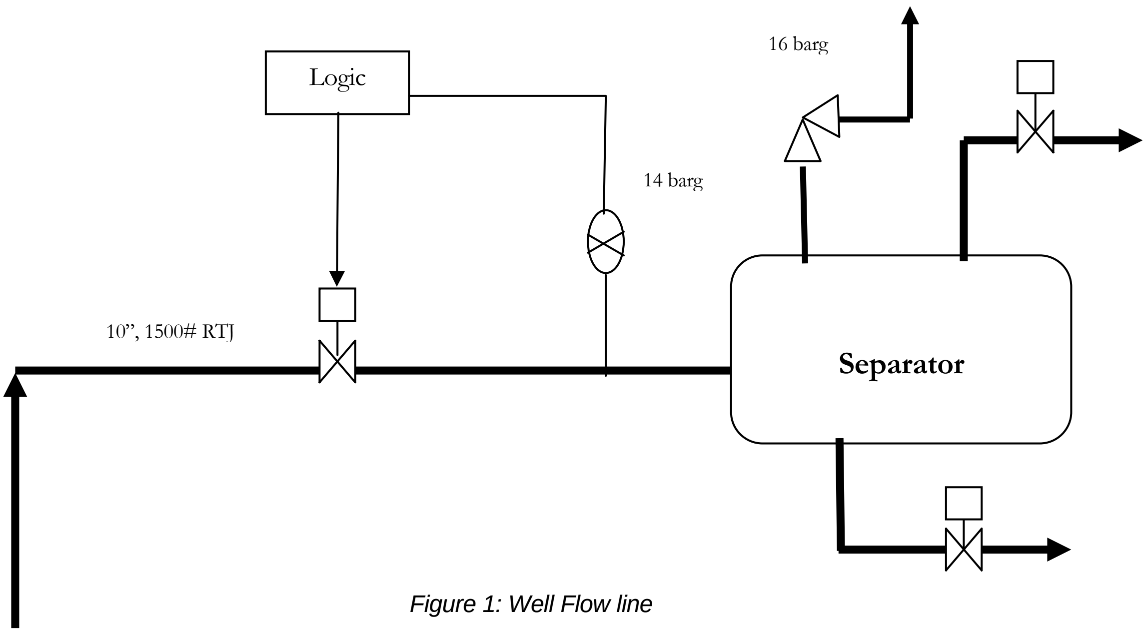


Figure 1: Well Flow line

Line Size: 10",
Line Rating: ANSI 1500# RTJ
Maximum operating pressure: 10 barg
High Pressure Alarm setting: 14 barg
Safety valve setting: 18 barg.
Well shut in pressure: 176 barg.
Line / Vessel Design Pressure: 228 barg.
Cold Flange rating pressure (@ 1500#): 259 barg
Minimum Air Supply Pressure: 5 barg
Maximum Air Supply Pressure : 10.5 barg

Line design pressure was considered as sizing DP (228 barg) for valve torque calculation.
To justify the basis, consider one upset condition (High Pressure on the well flow line) for which ESD valve is required to be closed.
Assume that pressure in the flow line suddenly started building up and approaching well shut in pressure of 176 barg.

Following Cases may arise while ***closing*** the valve:

CASE 1

1. Pressure transmitter will sense the pressure at 14 barg, SIS (PT,SOV) works properly, and closes ESD valve.
2. ESD valve does not experience well shut in pressure 176 barg during closing. Eventually, it will experience the well shut in pressure of 176 barg after closing.

Safety Evaluation: 1st layer of protection works properly. No need for a second layer of protection (safety valve) to respond.

CASE 2

1. Pressure transmitter fails to respond (poor availability) at 14 barg, or logic solver fails to respond, or solenoid valve fails to operate, or ESD valve stuck open i.e. valve fails to close at 14 barg.
2. Pressure safety valve pops at 18 barg (assuming pressure safety valve is properly sized and proof test interval maintained) and release the pressure at 18 barg with desired flow capacity.
3. ESD valve does not experience well shut in pressure of 176 barg and will not close because of one of the causes mentioned in point no. 1.

Safety Evaluation: First layer of protection (SIS) fails to respond. Second layer of protection works properly, ESD valve will not close and pressure is relieved through the safety valve.

CASE 3

1. Valve fails to close at 14 barg because of faulty SIS.
2. Safety valve fails to open (Poor maintenance, Proof Test interval is not maintained) at 18 barg.
3. ESD valve sees well shut in pressure of 176 barg and will not close because of one of the causes mentioned in point no.1.

Safety Evaluation: First layer of protection (SIS fails) and second layer of protection (Safety Valve) fail to respond.

So, it is apparent that valve will not experience well shut in pressure while closing if SIS and safety valve work properly. Also, for any spurious trip, valve will tend to close in its maximum operating pressure of 10 barg.

In the opening sequence, ESD valve experiences the well shut in pressure. However, as per the operation philosophy for most of the plant, ESD valve is opened after depressurizing the line.

Some ESD valves are fitted with by-passes and are therefore not required to open against full differential pressure. Gas pipelines, for example, are pressurized downstream before opening the valve so the valve opens against a minimal differential pressure.

Depressurize the line through small size bypass valve with double block & bleed and spectacle blind. The valve may be automatic or manual. Size the small valve for the well shut in pressure and size the main valve at the pressure right above the pressure transmitter setting or right above the safety valve setting. This leads to lower the size of the actuator and reduce the cost for main valve. Bypass line is having shortcoming of inadvertently being left open at bypass mode after depressurization. To correct this problem, a plant operational manual and safety check list should clearly highlight these issues.

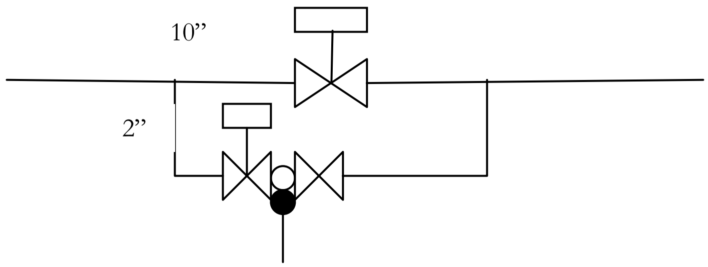


Figure 2: ESD valve Bypass

One of the operator's specifications calls for "ESD valve shall be sized based on the Cold Flange rating pressure" (ANSI 900#) for the following process condition. Project design basis demands all the ESD valves are to be designed based on Cold Flange rating pressure.

Line size: 22"
Maximum Operating Pressure: 21 barg
Safety valve set point: 25 barg
Line design pressure: 109 barg
Cold Flange rating pressure: 159 barg

If the difference between HIGH pressure set point of the pressure and well shut in pressure is not too high, then DP maximum should be selected based on the safety valve setting which may be close to the design pressure of the line. But this cannot be the case for all the ESD valves. Each application should be analyzed to determine the maximum DP for sizing.

Valve Safety Factor and Actuator-Valve Torque Safety Margin (Ref 1)

Apart from the differential pressure, valve torque is also a function of application ie: fluid handled, type of seat material used etc. Different valve manufacturers utilize different valve safety factors for torque calculation. No guideline or published data is available for determining the safety factor. Too much conservative values shall lead to 'over sizing'. Valve safety factor should be identified during design stage. Valve manufacturers should not add extra contingencies.

Essentially, these safety margins are considered, keeping in mind that the valve should operate smoothly throughout the lifespan irrespective of process condition.

Actuator sizing depends on the various valve torque values and minimum supply pressure, Actuator-Valve torque safety factor margin. Actuator- Valve safety margin is considered to cater the life time torque requirement. Plant operation demands ESD valves maintain status quo position (fully open condition) for long periods of time which leads to dirt accumulation and corrosion of the internals.

Incidentally, many end users impart the same safety margin for all On/Off valves irrespective of application. Three different applications for safety margin can be defined for the oil and gas industry. They are General Duty (150 % Safety margin), Protective Duty (200% safety margin) and Special Duty like Riser Valves (250% safety margin). Some operator goes up to 300 % safety margin.

For lower size valves e.g. 50 mm NB, it can be difficult and sometimes impossible to source the stem to take care of 200 % or 250 % torque requirement because of the limitations in the physical size or valve design. For these cases, higher size valve e.g. 80 mm NB may be used in 50 mm NB line to adequately match the torque figures.

Space limitation and structural load are one of the most significant concerns in offshore platforms, particularly for the wellhead platforms. Unjustified safety margin will not only increase the size & cost of the assembly but also lead to exceptionally large size actuator and add extra load on the platform structure.

With high torque safety margin, actuator maximum torque output may exceed the valve MAST (Maximum Allowable Stem Torque) for which higher sized model (higher strength) may be required or extra protection may be achieved by placing a safety valve on the actuator supply line.

Valve Torque Calculation

Let us calculate valve torque figures for the gas lift flow line process. Torque calculation is performed using the online tools from Cameron Valve.

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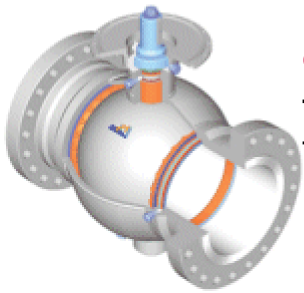


Cameron Valve Torque Calculator

To size power actuators for Cameron Ball Valves based on torque data.

ONLINE TOOLS

Input	**Valve 1**	**Valve 2**	**Valve 3**
End Connections (Nominal) ins:	10 ins.	10 ins.	10 ins.
Pressure Class:	1500	1500	1500
Operating Pressure (psig):	2552	3306	3705
Safety Factor:	1.5	1.5	1.5
Minimum Temperature (deg F):	32.0	32.0	32.0
Rotating Seats: [check for yes]	☑	☑	☑
Output			
Break Torque (in-lbs)	73814	90553	99411
Tare (running) Torque (in-lbs)	17160	17160	17160
Seat Rotation Torque (in-lbs)	23760	23760	23760
Re-seat Torque (in-lbs)	55361	67915	74558
Max Recommended Stem Torque (in-lbs)	169750	169750	169750
	Clear	Clear	Clear
	☑	☑	☑

Figure 3 : Valve Torque figure, Source : Cameron Valve

Based on the above torque figures, a comparative study of the sizing difference at various pressure and safety margin was performed for Scotch Yoke actuator as given below:

Option (a) 1.5x safety factor

Item	Valve	Valve Working D.P (barg)	Operating time open/close	Price Each
1a	10” x 1500#	176	5-10/<2s	€ X
2a	10” x 1500#	228	5-10/<2s	€ (X+2000)
3a	10” x 1500#	255	5-10/<2s	€ (X+2500)

Option (b) 2.0x safety factor

Item	Valve	Valve Working D.P (barg)	Operating time open/close	Price Each
1b	10” x 1500#	176	5-10/<2s	€ (X+2500)
2b	10” x 1500#	228	5-10/<3s	€ (X+4000)
3b	10” x 1500#	255	5-10/<3s	€(X+4500)

Option © 2.5x safety factor

Item	Valve	Valve Working D.P (barg)	Operating time open/close	Price Each
1c	10” x 1500#	176	5-10/<3s	€ (X+4000)
2c	10” x 1500#	228	5-10/<3s	€ (X+4500)
3c	10” x 1500#	255	5-10/<3s	€(X+5500)

This data indicates that there will be an approximate difference of €2500 to €3000 per valve. If the plant is having 50 ESD valves and all are to be sized based on Flange Rating pressure total additional cost will be €3000* 50= € 150000. In addition, every operator would like to go for partial stroke facilities which will lead to further cost.

Type of actuator to be fitted with valve

Rack and Pinion (RP) **versus** Scotch Yoke (SY)

Use of Scotch and Yoke actuator has been the de facto practice for most of the operators in the oil and gas industry. Primarily, the concept has evolved because of large torque requirement of the big size ESD valves and the material of construction of the actuator suitable for installation in offshore environments. Historically, enclosures of SY actuators are made of carbon steel or ductile iron, and in general, RP actuators come with aluminum enclosure. Use of aluminum in an offshore atmosphere is not recommended for obvious reasons - the corrosion effect. However, RPs are now available with Cast Iron body.

If both, maximum torque & material of enclosure, meet the criteria, RP can be used instead of SY actuator. For example, for lower size of ESD valves with low torque requirement, RP actuator may be a compact and cost effective solution.

Typical maximum output torque from commercially available RP actuator is 40 lb.in and that for SY is 60 lb.in. Not all the ESD valves require the so much large torque value!

In general, manufacturers state that Scotch Yoke transmission mechanism is 30% more efficient than Rack & Pinion of comparable size. If that concludes SY to be the cost effective and efficient solution over RP if other parameters remain the same, then why does Rack & Pinion technology exist in the industry.

Essentially, torque output is not the sole determining factor for type of actuator selection. For lower size, there must be some trade off to select the suitable mechanism. For lower size valves, RP might be cost effective if other conditions are the same.
In principle, RP actuator produces a linear torque characteristic whereas SY actuator produces non linear (sagging) characteristics.

There are some misconceptions in the relative torque concepts of RP and SY mechanism [Ref 4]. The myth is that SY actuator produces more toque than any other mechanism. Torque output of actuator shall meet the valve torque requirement. Also, torque output for particular actuator mechanism depends on the cylinder type i.e. Single Acting or Double acting. For SY double acting cylinder, torque at the end of the travels (break torque and reseat torque) is greater than the torque output at the mid travel (running torque) whereas for RP actuator torque output is constant throughout the travel. For single acting actuator reseat torque may be less than the mid travel torque, same is also applicable for RP.

SY torque output may be the replica of the valve torque requirement i.e. SY can produce higher torque whenever required at the end of the travel.

Following points shall be taken care during selection of type of mechanism:

- What is the torque requirement of the valve?
- What is the material of construction philosophy of enclosure?
- Relative cost!

Single Acting (SA) **versus** Double acting (SA)

In general, pneumatically operated spring return actuators are used for ESD valves. However, this option produces actuators of the largest size for a given torque requirement. Double acting actuators are relatively cheaper, lighter and more compact than spring return actuators. However, when a comparison is made between spring return and double acting actuator, need for a backup supply reservoir and more complex controls for the double acting actuator are required to be taken into account. Standby pneumatic supplies should be available with sufficient capacity for three strokes of the valve.
The philosophy differs from operator to operator. However, there is no obvious guideline for selecting particular action.

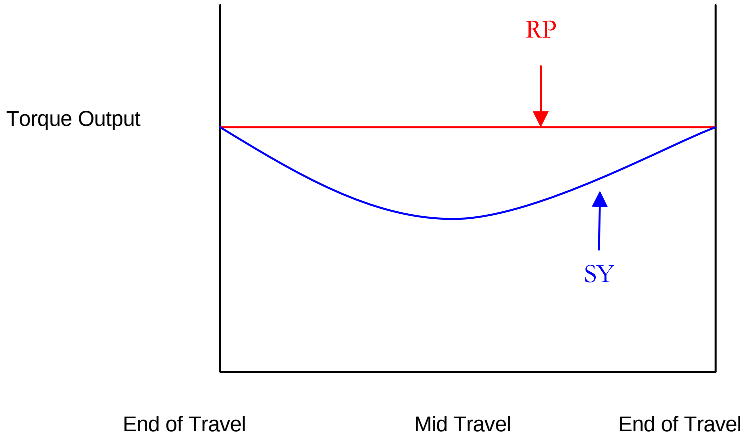


Figure 4: DA actuator torque curve

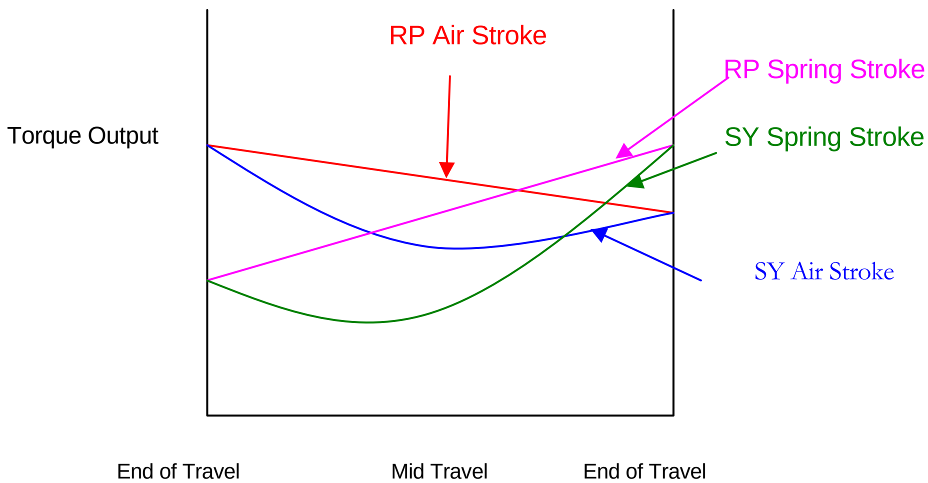
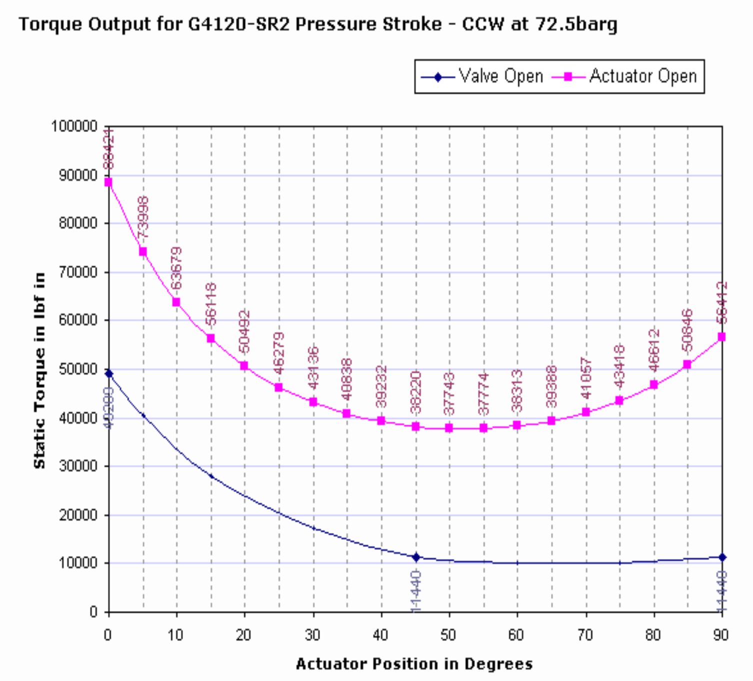


Figure 4: SA actuator torque curve



Typical Torque Curve , Source – Bettis

Dynamic Torque Specification [Ref 1, 6]

One of the famous guide words during HAZOP review is "High Flow". It is assumed that in the event of major pipe line rupture sudden "High Flow" happens. However, this phenomenon is rarely taken into the design consideration of the valve. This situation may cause very high pressure drop across the valve. This pressure drop condition is rarely analyzed and considered for sizing the valve-actuator assembly. This will lead to high localized velocities and complex dynamic forces being generated inside the valve and on the valve 'closing member'. Because of this dynamic condition, sonic flow, swirl/jetty effects, cavitations, flashing or combinations of all these are likely to occur. The resultant force on the valve stem may change suddenly. This may enhance the valve to close or oppose the valve to close. ESD valves on riser lines and export pipeline for an asset needs more attention.

The most important and crucial concern is whether the magnitude of these torque are within the sizing capacity of the installed actuator. This is crucial as the fitted actuator should be able to perform under the run away or worst case condition.

In general, the following points may be debaed with regard to dynamic operation of ESD valves and associated actuator sizing:

1. How will the torque characteristics for the valve be affected because of this complex scenario?
2. How is the valve opening / closing direction? Will this scenario oppose or enhance the opening /closing of valves.
3. How the closing / opening speed will be affected because of dynamic effect?
4. Will forces generated out of this effect reach the mechanical threshold value?
5. How the forces vary with size of the valve?
6. What is the effect of the type of fluid and fluid conditions e.g. multiphase flow, density, viscosity, etc.
7. How will the seat / seal material be affected due to this ?

As per the available data, Kalsi Engineering, Inc, USA [Ref 6] performed the test, "Dynamic Torque model for quarter turn air operated valves." Dynamic torque characteristics for ball valve under the test are shown in the report. A representative curve is shown in Fig 5. From the result, it is evident that dynamic torque characteristics widely differ from the static torque characteristics. This might give indication to the operators, manufacturer, and design contractor to conceive the dynamic torque requirement for ESD valves.

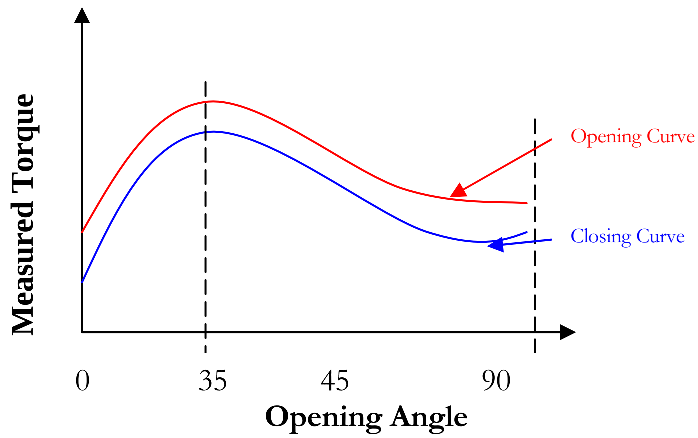


Fig 5: Dynamic Torque Characteristics for Ball valve , Source : Kalsi Engineering Inc.

ESD valve closing / opening time- design & safety concerns [Ref 1]

Fast closure is desired for all ESD valves on demand condition to avoid run away condition.
However, valve closing / opening time have significant impact on the valve design, accessories, reliability & associated piping. Maximum stroking time selected should be based on process requirement, not on what may be achieved by a particular valve or actuator.

Rapid closing/ opening may damage the valve internals, and valve reliability will be affected. To meet the valve closing time, reliability of the piping should not be compromised.

Rapid closing/opening may create surge or transients on the associated pipeline. Impact of rapid closing/ opening should be taken into account during the design phase with consideration of piping geometry / operating details for each installation. Surge effects are all too often overlooked when valves selections are made. Surge analysis should be performed for the associated pipeline. Small pipeline may be much more susceptible to damage than large pipeline due to surge effect.

Many research papers and case studies have been done on the surge effects for fast closing of the valve. In short, analysis indicates that the time in seconds to close a valve must be greater than twice the length of the upstream pipe (point of reflection of the surge wave). The more rigid the pipe, the slower the valve must close because elasticity of the pipe which affect how the pressure energy (converted from fluid kinetic energy) will be absorbed.
Further, each valve manufacturer should perform Finite Element Analysis, CFD analysis on the valve to ensure valve integrity at the desired closing / opening time. Each manufacture should also demonstrate the closing / opening time during factory acceptance testing.

As a standard practice, speed of closure is considered as 1 sec per inch of valve nominal bore size. One of the operator specified that 22" ball valve shall be closed within 5 secs and shall have adjustable opening time between 5-30 secs. This leads to highly non standard pneumatic accessories and high volume of air.

For gas pipelines the effect of low temperatures on pipeline rupture due to Joule-Thompson effects on the required valve closure torque shall be taken into account for actuator sizing.

In general, opening speed is not required to be fast for ESD valves; in fact sometimes it is desired to be slow opening. Fast opening of valve can cause as much damage as fast closing. Size of the actuator size may go high to meet the necessary closing / opening forces.

Fast closing depends how fast air is dumped out from the cylinder. Suitable Quick Exhaust Valve (QEV) shall be utilized to achieve this. However, sourcing QEV for desired flow coefficient (Cv) becomes difficult for meeting the closing time. Every actuator manufacture would like to see some standard guideline for the optimum speed of operation of the valve.

Fast opening of the valve depends on how fast the air is supplied to the actuator against the spring force. Essentially, it depends on the flow coefficient (Cv value) of the pilot valves, solenoid valves and Air Filter Regulator. To meet the fast opening huge volume of air needs to be supplied to the actuator within a short time which may lead to highly non standard accessories and may have to run 1" NB to 1.5" NB pipes to the actuator and may requires a small size compressor to cater the volume requirement !

Actuator circuit dynamic response is required to be studied thoroughly because of fast operation of the actuators. In principle, manufacturer shall ensure that there should not be any deviation from the published torque figures or spring rate.
Speed control mechanism, where necessary to avoid surge from the valve closing too quickly, speed control facilities shall be included in the actuator.

The question is whether 'Reliability' figure for the identical ESD valves with widely different operation time are same! In general parlance, this is design related issue. However, identical valves with widely different operation time can not be assigned with same 'failure rate'. FMEDA (Failure Mode Effect and Diagnostic Analysis) should take speed of operation a failure mode for valve failure. Failure due to the excessive speed may lead to some "Dangerous Failure" damaging the seat, seal of the valve, valve stem, even actuators. Expecting field failure data for this failure mode may be too adventurous. Obviously, this failure mode may not be generalized for all applications and stress factors due to this failure mode should be tailored to specific applications.

Safety valve on the actuator supply line, weakest link in the actuator circuit!

To offer competitive price, all actuator manufacturer tries to reduce the size of actuator. One way to do the same by limiting the mechanical strength of the actuator which can be achieved by placing a safety valve on the supply line & not allowing maximum supply pressure to actuator.
Sometimes, with the selected model of actuator, torque value at the maximum supply pressure may exceed the valve MAST for which safety valve is required .Set point shall be less than the vale MAST. Actuator torque values are always calculated at the minimum available supply pressure which generally the low trip set pressure of the supply air. This is required to avoid the valve to go its designed Fail Safe mode in the event of pressure fluctuation. At the same time, actuator should withstand the maximum supply pressure with or without the Air Filter Regulator.
In principle, AFR is not required for ESD valves if quality of air is ensured ,actuator torque is calculated at minimum supply pressure (for torque calculation) & maximum supply pressure for (mechanical strength). Some operator avoids using AFR. However, in general, AFR is widely used on the supply circuit of the actuator. If the actuator is not designed to withstand the maximum

supply pressure, a safety valve is required to be installed on the supply line. Safety set pressure should be below the MAWP of the actuator. In some cases, AFRs are fitted with integral pressure relief devices.
Generally, these pressure safety valves go unnoticed during design stage. Actuator manufacturers never provide the sizing calculation of thesmall safety valves, assuming that it's merely a tubing component, similar to thermal relief on the hydraulic line. These valves never come in operator / maintenance log books as they are not conventional safety valves and there is no Test Interval (TI) defined for them. If the outlet of the valve is clogged due to dirt accumulation, pressure in the actuator circuit may go beyond the acceptable limit, and can cause a major accident.
While performing safety analysis of the circuit, the following causes should be considered:

- Occurrence of maximum line pressure
- Air Filter Regulator Failure
- Safety valve failure.

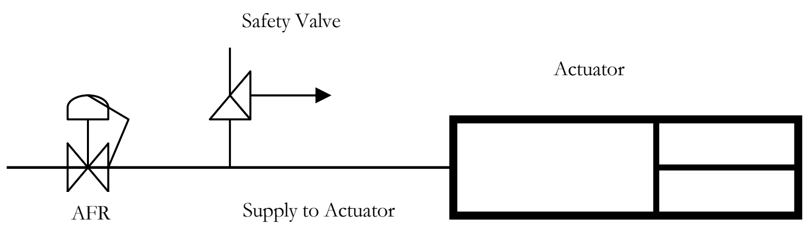


Figure 4: Simplified actuator circuit indicating safety valve

Although the simultaneous occurrence of all causes are a remote possibility, during FMEDA analysis of the actuator, the same should be addressed.

Partial Stroke, Valve-Actuator signature Curve and Test interval

Partial Stroke Test facilities have become the health prescription for the ESD valves for all the operators. Intention of the partial stroke test is to check ESD valve is mechanically healthy enough to close under actual process demand. With partial stroking facilities, PFD value and SIL level increases. [Ref 5]

Valve and actuator "Torque signature" can be traced from its birth. Birth "Torque signature" should be recorded during the factory testing of the valve. The same should be re-checked during commissioning to identify any damage during transpiration and installation. With the "Torque Signature" curve, torque variation can be traced throughout the life cycle which may help to assign or predict partial / full stroke of the valves or to replace the valve. It is to be noted that many operator still utilizes the complex local partial stroke facility with local pneumatic test panels even with the introduction of simple remote partial stroke facilities which can be achieved from control room. Apart from expensive manpower requirements during test, there is a drawback of this method. During the test, ESD valves are not available for shutdown and the valve may be inadvertently left open at it's mechanical condition (10% close).

Partial stroke may identify the failure modes that are related to:

- Speed of operation valve
- Valve sticking due to dirt accumulation
- Packing leakage

- Pneumatic Circuit Leakage through fittings
- Spring K factor change due to scragging effect
- Requirement of bypass redundant valve can be ruled out after PVST.

The prime concern is that even if the actuator is being sized with high torque contingency for life time operation , actuator may not work because of debris accumulation, inappropriate workmanship (machine tools i.e. nuts ,bolts, screws, glands ,welding rods , welding scraps are found frequently during maintenance) during flushing at the time of commissioning. Even with high torque contingency, valve –actuator assembly may not respond under demand conditions because of these problems, in reality. The point then is whether we need so much torque contingency even after the Partial Stroke Facilities or Torque Signature Curve. Also, during pigging operation, substantial debris may be collected at the seat ends and may damage the seat which may alter the torque values. Moreover, it has to be ensured that during pigging operation, the valve should be fully open. Partial opening /closing of the valve may completely damage the seat/seal integrity of the valve and directly affect the reliability.

Leakage and fire safe testing

Several standards / codes are available in the industry for leakage tests and fire safe tests. There are variations in the requirements in different standards. In general, leakage tests are done at ambient conditions, however API 6A specifies leakage test shall be performed at two extreme temperature points of fluid. Some of the operators define their own leakage standards.
For valve seat leakage testing API 508, ISO 5208 is being followed. It has to be noted that leakage specification stated in ANSI/FCI 70.2 applies to control valves only.
For Fire Safe Test the following standards are in practice:

API 607 for soft seated valve
API 6FA for API 6A & API 6D valves.
BS 6755 Part 2.

A fire safe valve must be operable even if it is fire damaged. The fire safe should eliminate heat distortion of the valve body and operating mechanism caused by thermal stresses and associated piping stress during a fire. Some increase in torque should be expected and extra contingency should be considered for actuator sizing. However, dynamics of valve and actuator needs much study in the event of fire. There appears to be little information available about the dynamics of valve /actuator in the Fire Case.

Additionally, some operators insist on installing Fusible Plug (Temperature Sensitive Device, API 14C recommendation!) on actuator supply lines for riser shutdown valves. In the event of fire, the fusible plug shall melt and cause the valve to go to its Fail Safe position.

While performing the FMEDA for valve-actuator assembly, failure of the fusible plug should be given special attention. Fusible plug is a mechanical device and susceptible to spurious trip.

Miscellaneous design issues

Valve material selection also varies from operator to operator, asset to asset. Essentially, it depends on the type of fluid handled. For most of the offshore applications, valve material shall meet NACE MR-01-75 guideline. Some of the operator's material specification includes some special material and testing requirement on & above the NACE MR-01-75 for which valve manufacturers face difficulty to meet the specification. Sometime, this creates a big impact in project schedule /delivery schedule to meet special material specification. Sometimes, manufacturers decline to quote because of special requirements. Most certainly, every manufacturer would like to see a common guideline of materials in the industry.

There are wide varieties of seat and seal material being used in the industry. Some operators use their own proprietary seat /seat material. Both soft and metal seats are equally used. Each type has its advantages and disadvantages depending upon the fluid handled. Basically, there are two types of soft seat/seal materials; Elastomer and Thermoplastic. Elastomer seat/seal are Nitrile Rubber, Viton A, Viton B, Viton GF, Viton GLT, Viton AED. Thermoplastic seat/seal are Teflon, KEL-F,PEEK,Nylon. In general ,soft seated Ball valve is restricted to temperature 150 deg C. Selecting the of type of seat is influenced by several factors e.g. differential pressure ,type of fluid, valve design type , price and/or delivery. For high differential pressure applications, metal seats are generally used. Soft seals are susceptible to blowout/extrusion under high pressure /high flow conditions. Metal seat valves require more torque than soft seated valves for a given differential pressure and actuator size shall be different. Valve manufacturers would like a common guideline for seat and seal material. Now, Fire Safe valves are available with double seat arrangements. Primary seat sealing is provided by a soft sealing ring of different rubber types or PTFE hard sealing ring. Secondary sealing is provided by metal to metal contact of the seat to the ball.
Soft seats are more susceptible to dirt, sand particles and piping debris which results to wear and tear.
Metal seats (Tungsten Carbide, Stellite, Duplex Steel, Inconel) are more tolerant to the dirt and debris.
In general, for pigging lines, soft seats are considered to be more vulnerable to damage than metal seats/seals.
Selection of Full Bore and Reduced Bore Valves shall be based on the application. For process lines which require pigging, full bore Trunnion mounted ball valves or gate valves shall be used. Reduced Bore valves may be used on services where the developed pressure across the valve is acceptable. Utility line on/off valves or Bypass valves for ESD valve may reduce bore. Reduced bore isolation valves may often be advantageous because of low CAPEX. For Full Bore valve, Bore Diameter is equal to the Line ID, Cv value is greater than Reduced Bore, Bigger Actuator is required, valve weight is greater, larger space and higher cost. Hence, there should be the trade-off between Pressure Drop vs Cost for increased actuator size, weight, space.

From the above, it is evident that valve failure data is a cause of concern for proper reliability analysis.

Valve- Actuator assembly PFDavg and SIL levels

Average Probability of Failure on Demand (PFDavg) is calculated as:

$$PFD_{avg} = (1/TI)\int_0^{TI} P_f(t)\, dt$$
$$= (1/TI)\int_0^{TI} (1 - e^{-\lambda t})\, dt$$

P_f (t) is the probability of failure at any time. It depends on the failure rate of components and the "Test Interval". Assigning a PFD_{avg} value to Valve-Actuator is always a subjective issue. In general, it does not include any design contingency or design defects.

Essentially, failure rate of any Actuator- Valve assembly should be assigned based on the following:

- Type of service whether it is clean or dirty
- Type of valve and Actuator
- Type of accessories
- Testing Interval of Valve
- Speed of Closure of the Valve!

The following design related issues should be taken into consideration during FMEDA analysis:

- "Whether or not failure data is dependent on the different torque contingencies?" Actuator designed with 300% torque contingency will deliver torque at longer span of life than actuator with 150% contingency if same kind of external "Stress" factor is applied.

- When it comes to the safety analysis & failure data issue, the question comes whether Failure Data will be same for two different Actuator-Valve assembly , one with RP actuator & other with SY, keeping all the ancillaries same?

- Use of more complex control circuit and associated ancillaries for DA might give different Failure data when FMEDA analysis is performed on both SA and DA actuator with same valve.

- "How the Actuator – Valve Failure Data is affected by rapid closing / opening of the valve?"

- Whether safety valve failure is considered one of the modes of failure in FMEDA analysis.

- Whether failure of the fusible plug installed in the actuator circuit is considered one of the modes of failure in FMEDA analysis.

- Whether failure data for Trunnion mounted ball valve and Floating ball valve is identical.

- Whether failure data for soft seated and metal seated valves are identical.

- How "Beta Model" related to common cause failure can be applied to mechanical devices like actuator-valve!

Source of failure data

Some case studies on ESD valve actuator assembly indicates that valves themselves are more reliable than that of the actuator and associated control systems. [Ref 1] As per the study, it has been experienced that solenoid valves, relays and other accessories of the valve including fluid leakage leads to non-operation of ESD valves. Some other study indicates that 50.78% valve failure is due to material deterioration of valve internals. So there are variations in the available failure data. However, it may happen that data has not been collected or interpreted in a similar way.

To get good failure data, actual field data is required. This is a challenging task. Culture should be developed to encourage all the operators and manufacturers to publish failure data.
Without good failure data, the whole purpose of probabilistic calculation will be defeated[Ref3]. Also, every field data should be validated with the manufacturer's claim data.

Therefore, for more effective PFDavg evaluation, good failure data should be made available. There should be common guidelines for FMEDA analysis for all ESD valves to assigning the Safe Failure Fraction (SFF) and Dangerous Failure Fraction (DFF).

Some reference data bases are available with OREDA, WIB database, Exida, CCPS databases.

Conclusion

Industry has complete safety standards e.g. IEC-61508, IEC-61511, ISA-84.01 and ISA TR 84.02 to provide a common safety assessment philosophy. There must be an industry standard for ESD valves (which contributes 50% of PFDavg of SIF) specifications, taking into consideration design issues e.g. basis of sizing DP, torque margin for valve and actuator, speed of operation etc. and safety issues e.g. failure rate, Test Interval together. This will certainly reduce the overall CAPEX of any installation and make life comfortable for everyone in the industry.

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