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Design of Relief Valves/Devices/Systems for Cryogenic Apparatuses and Installations

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CERN Cryogenic Safety - HSE Seminar
21-22 September 2016

Agenda

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1) Introduction – narrow down of the topic
2) Warm seated safety valves/devices, boundary conditions
3) Warm seated magnetic safety device; an alternative to spring dependent safety valve
4) Cold seated safety valves/devices, boundary conditions, considerations
5) Cold seated quench relief valve (QRV) - the case of CERN-LHC
6) Active triggered safety relief systems
7) Component's sizing by use of k_v-value formulas
8) Conclusion

Introduction – narrow down of the topic

- Spring related pressure relief valves/devices, mounted at ambient temperature, are state of the art to protect pressure vessels including cryogenic pressure vessels.
- Experiences in cryogenics shows limitations regarding set pressure variety, unauthorized increase of set pressure, seat is not tight etc.
- Therefore, sometimes for new experiments or specific boundary conditions new designs for pressure relief valve, relief devices or relief systems may requested.
- Design and function of such pressure relief valves, devices or systems will be shown and discussed also considering its limitations regarding applications of pressure vessel rules.

Introduction – narrow down of the topic

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Further considerations:

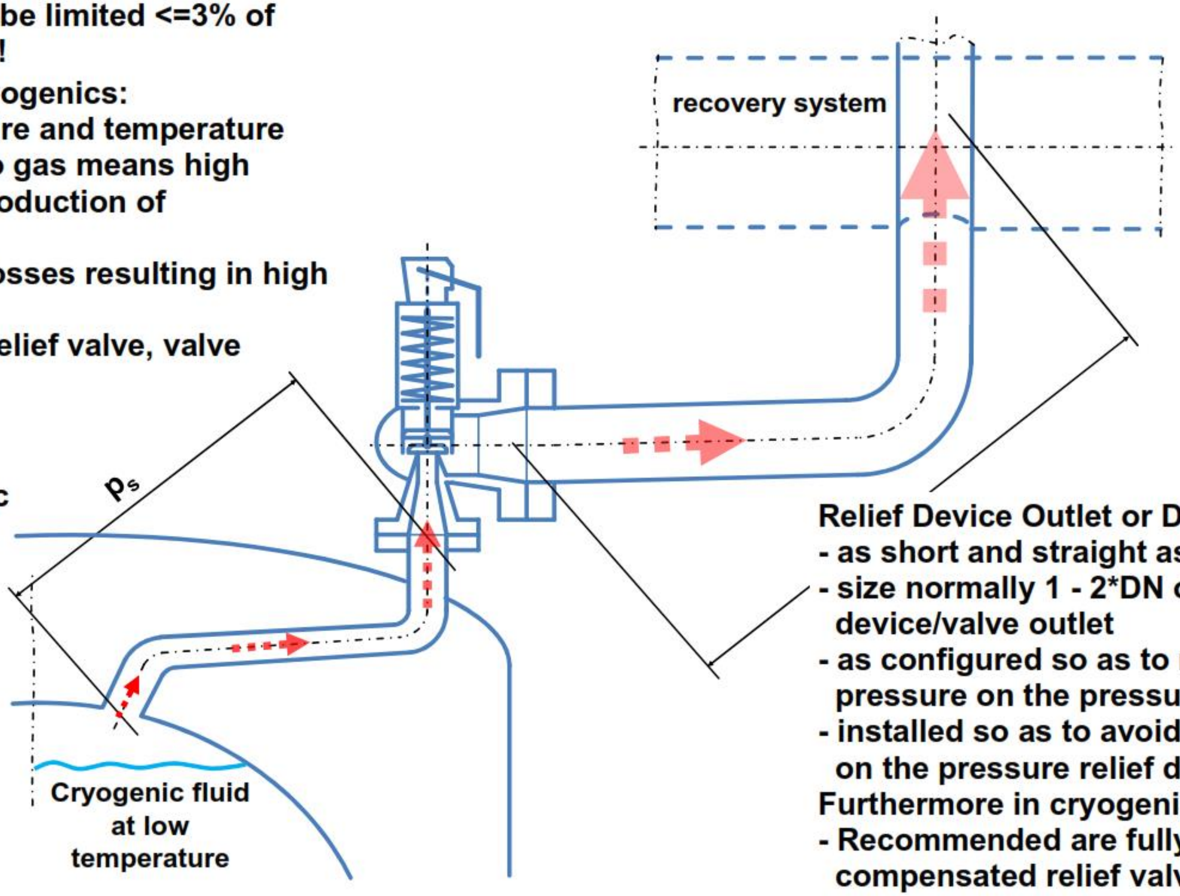
- **The inlet connection line from the cold to a relief valve/device at the warm ambient introduce severe problems regarding cryogenic service.**
- **Alternatively and parallel to cold or warm bursts disc at a rated higher set pressure, a spring related relief valve with cold seating may be used.**
- **There are also warm seated pressure relief devices available which are based on set pressure adjustment by permanent magnetic forces.**
- **Pressure vessel rules allows also active triggered relief system with a fast acting cryogenic shut-off valve. Components used for such "smart" relief design should fulfil similar requests qualified for use in SIL 3 or SIL 4 applications.**

Warm seated safety valves/devices, boundary conditions

Relief Device Inlet Piping:
Pressure losses p_s should be limited <=3% of safety valve's set pressure!

However to consider in cryogenics:
==> High change of pressure and temperature
==> Phase change liquid to gas means high change of density, introduction of 2-phase flow
==> Increase of pressure losses resulting in high flow instabilities!
==> High risk of failing of relief valve, valve chattering etc.

Furthermore:
==> Additional heat load
==> Risk of thermoacoustic oscillations



Relief Device Outlet or Discharge Piping:
- **as short and straight as possible**
- **size normally 1 - 2*DN of relief device/valve outlet**
- **as configured so as to not cause back pressure on the pressure relief device**
- **installed so as to avoid undue stresses on the pressure relief device**

Furthermore in cryogenics:
- **Recommended are fully pressure compensated relief valves**
- **Condensation of air, O_2 enrichment**
- **Icing with risk of outlet blocking**

Warm seated safety valves/devices

Advantages:

- **Certified standard relief valves/devices!**
- **Possible to have seat tightness by use of burst disc**
- **Setting force device at ambient temperature**
  However may be affected due to cooling down in case of purging ==> increasing of set pressure may appear!

Disadvantages:

- **Inlet piping from cold to warm!**
- **Standard valve, not tailored to actual service conditions**
- **Standard relief valves has no qualified seat tightness**

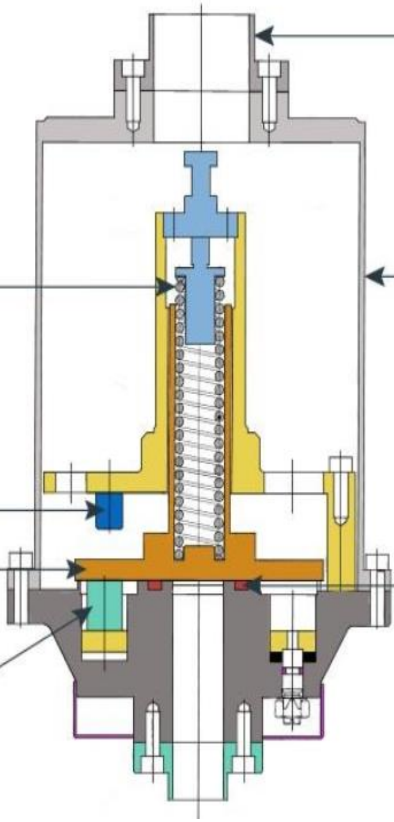
Warm seated magnetic safety device – developed by CEA

The magnetic safety device may be an alternative to spring safety valves:

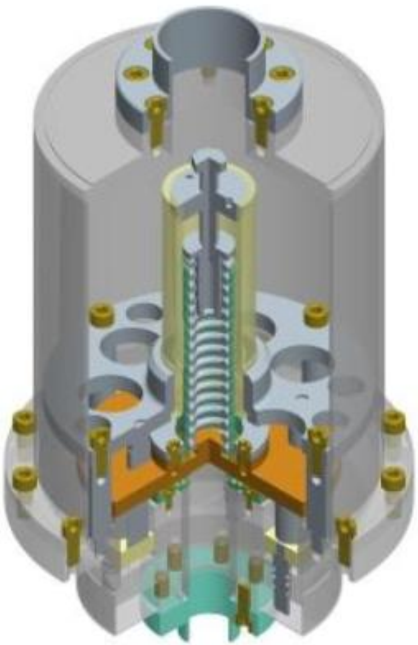
- **For low relief pressure**
- **Digital opening characteristic i.e. fully open after triggering**
- **Setting accuracy +/- 5%**
- **Repeatability +/- 1%**
- **Good seat tightness**

Concept

The Magnetic Safety Device (DMS) has especially been designed to protect containers and pressure skells against overpressures, suitable for compressed fluids at ambient temperature or during cryogenic discharge.



Warm seated magnetic safety device

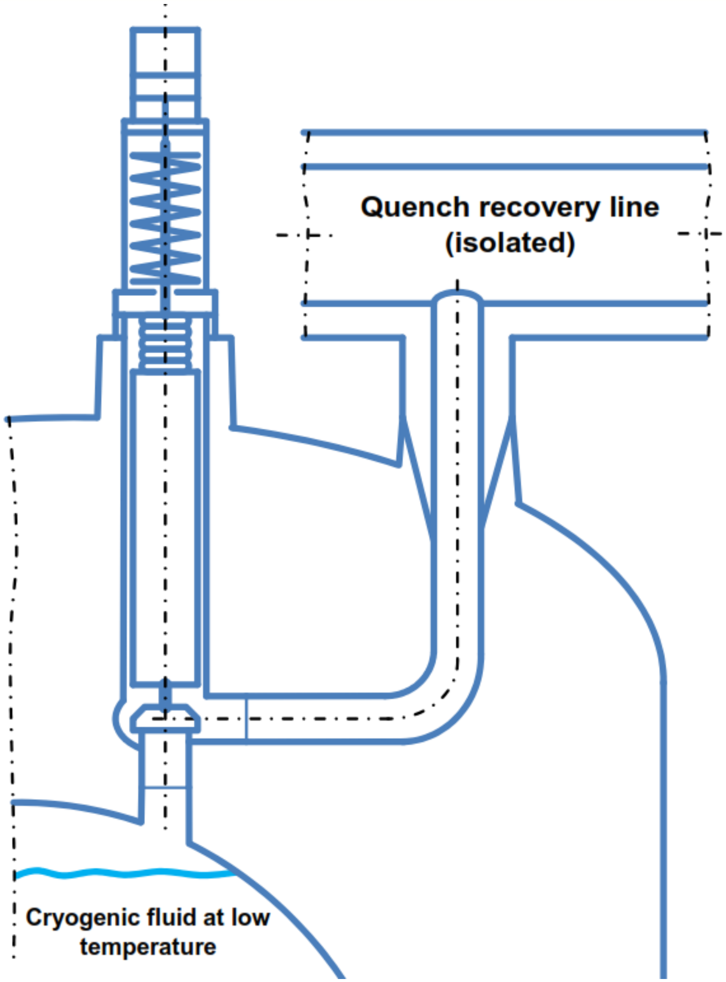


Advantages :

- Adjustable opening pressure with good accuracy
- Testability of the setting pressure
- Operating pressure very closed to opening pressure
- Full open system since beginning of setting pressure overpass
- Closing pressure adjustable
- Safety of pressure shell is insured as soon as the device is closed again

Developped by the CEA (French Committee for Atomic Energy) for its own needs, VELAN has industrialized a range of Magnetic Safety Device (DMS) from DN 10 to 150 and for pressures up to 25 bar.

Cold seated safety valves/devices, boundary conditions, considerations



Design considerations:

- Valve should have low heat load
- Fully compensated regarding back pressure change
- Spring rate adjusted to the set pressure – no chattering!
- Seat design to resist high set pressure
- Rated seat tightness at cold
- Size calculation by case testing and using of k_v-formulas for valve size calculation

Cold seated safety valves/devices

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Advantages:

- **Short inlet connection line, low pressure drop**
- **Seat tightness at the cold temperature**
- **Tailored to the application, may include further service like shut-off for by pass cooling etc.**
- **Spring or setting force device at ambient temperature, independent against cryogenic service temperature**

Disadvantages:

- **High set pressure to get force for seat tightness at cold**
- **Tailored to the application – no standard, no certification standard, individual case certification, high price, …**
- **Development and testing, application assessment**

Cold seated quench relief valve (QRV) - the case of CERN-LHC

Valve function

To protect against over-pressure the superfluid helium enclosures of superconducting magnet resulting from resitive transitions (Quench) as well as some of the cryogenic lines (QRL).

400 valves have been provided along the 27km of **LHC** circumference to ensure protection of the magnets against overpressure.

CERN Specification & Challenges

Superfluid helium service (Temperature 1.9K)
Set pressure : 17 bar (full open pressure 20 bar)
Remote control actuation (on/off function)
Flow coefficient : Kv 30
No risk of icing or jamming when operating
Downstream pressure do not affect the set pressure
Very low heal inleak
Resistant to radiations

Further manufacturers: Toko Valex Co. Ltd., JP; WEKA AG, CH

Cold seated quench relief valve (QRV) - the case of CERN-LHC

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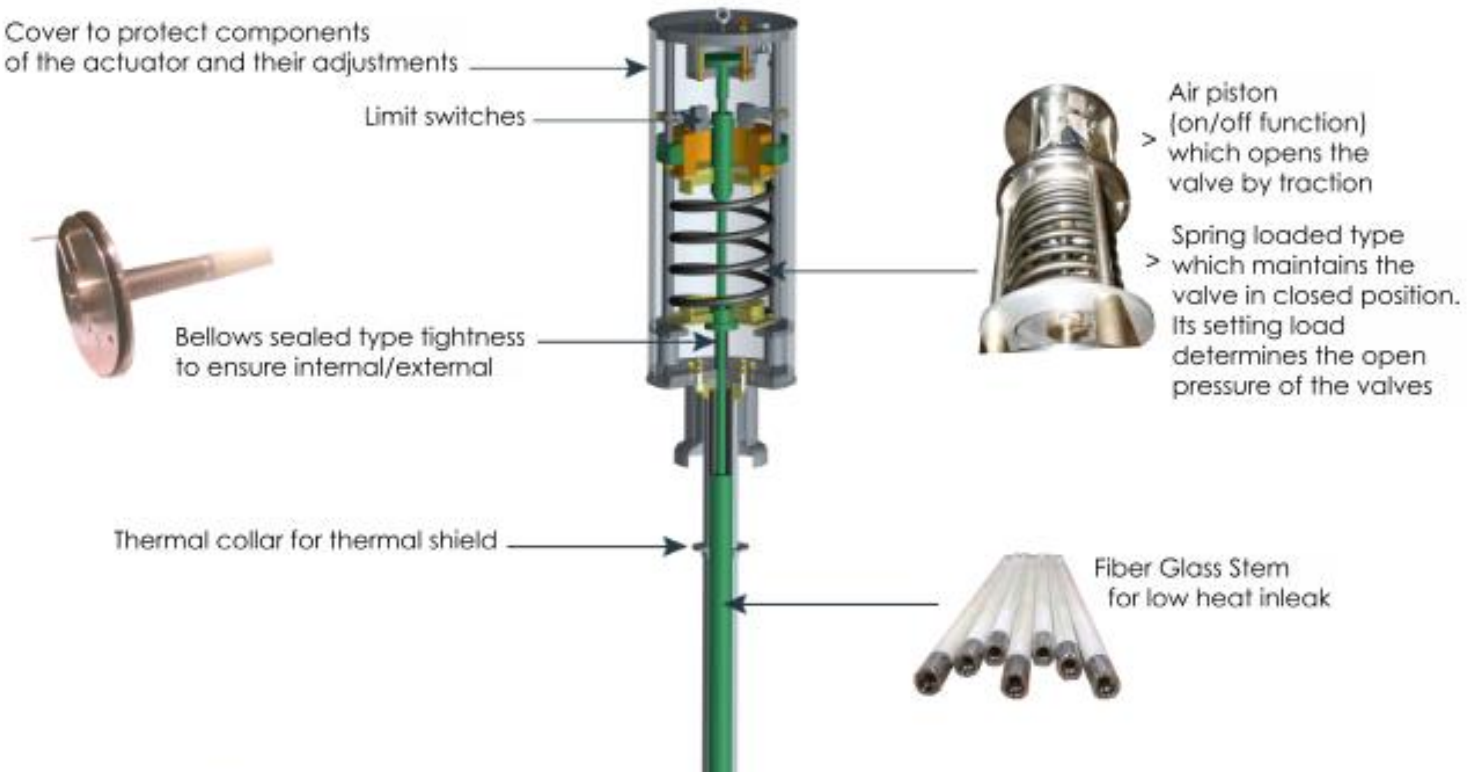


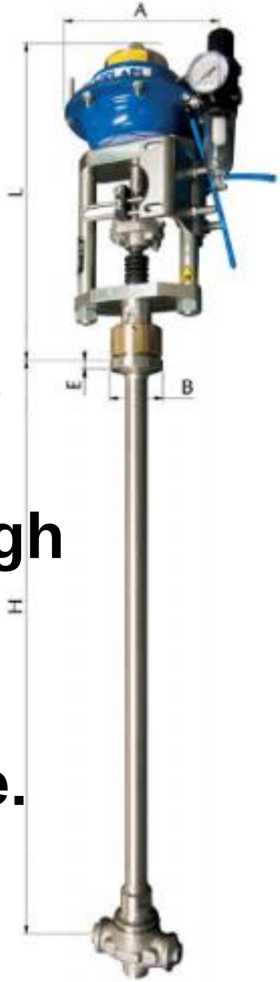
/	QV valves	SVC valves	SVE valves
Pressure set	17 – 20 bar	20 – 22 bar	22 – 24 bar
Service temperature	1.8 K	~4K	~ 50K
On/off action	YES	NO	NO
Limit switches	2 (NO – NC)	1 (NC)	1 (NC)
Thermal collar	YES	NO	NO
Bellows sealed	2	1	1
Test actuator	NO	YES	YES

Active triggered safety relief systems - with a fast acting cryogenic valve

- Pressure vessel rules allows to choice for an active triggered relief system e. g. with a fast opening or fast closing cryogenic shut-off valve

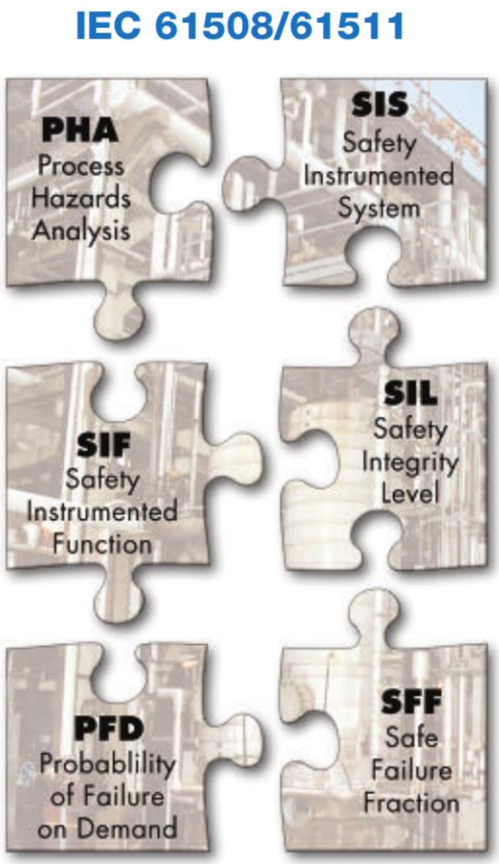
To consider for such components and devices:

- Excessive FMED-Analysis (Failures Modes, Effects and Diagnostic Analysis) including qualification tests at service conditions to achieve requested high availability and reliability for certification to applications in SIL 3 /4 level may apply.
- "Proven in use" qualification may also be possible.
- Measurements to freeze the qualified component's design has to be implemented!



Active triggered safety relief systems - with a fast acting cryogenic valve

- **Instrumented safety system designed and built in accordance with the IEC 61508 and IEC 61511 standards. These refer to safety functions (SF) and Safety Instrumented Systems (SIS) to protect equipment, personnel and environment.**
- **Increased availability of components and use of reliability data allows to implement a HIPPS safety loop (High Integrity Process Pressure System).**
- **When a HIPPS is implemented, the system controls are so thorough and reliable that there is no need to vent, or use a relief valve!**



Active triggered safety relief systems - with a fast acting cryogenic valve

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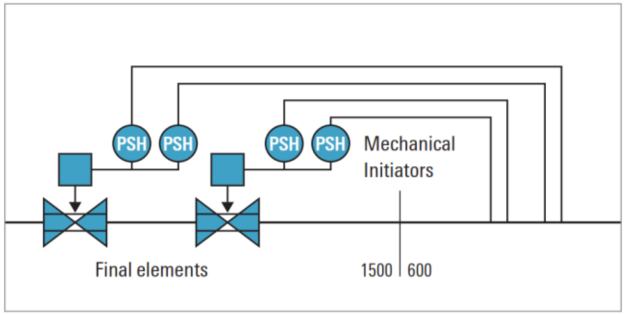
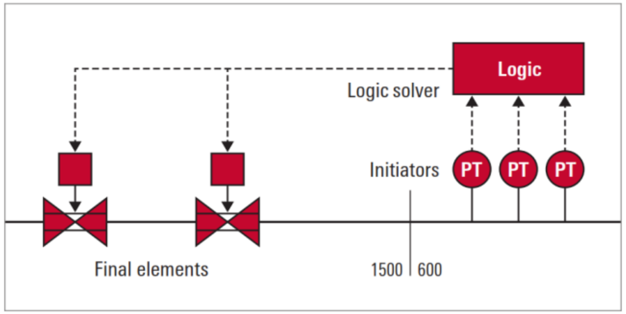
In this context to note:

- Spring pressure relief valves are considered as mechanical devices, suitable for use in environment up to SIL 2, with single redundancy up to SIL 3 environment possible
- There are burst disc available for applications in SIL 3 environment
- Also there are already shut-off and control valves available for use in SIL 3 / SIL 4 environment
- HIPPS requesting component’s assessment to qualify for SIL 3 / SIL 4 environment



Mechanical HIPPS safety loop

CAMERON
A Schlumberger Company



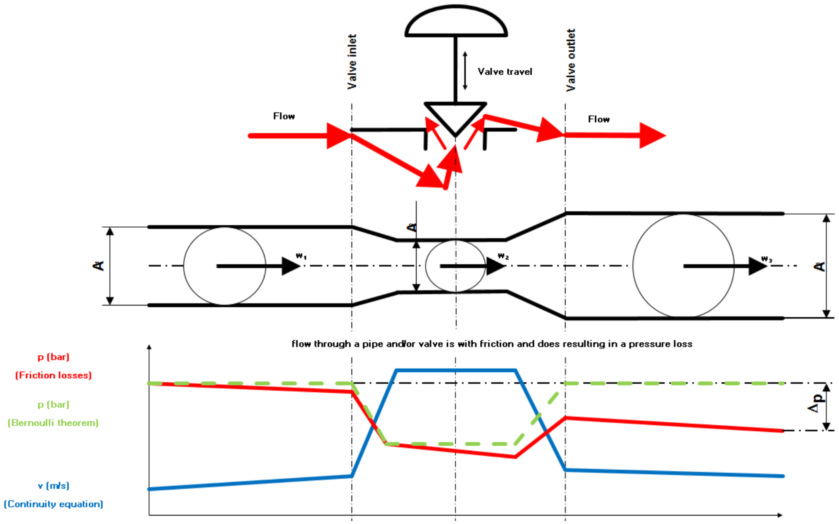
Electronic HIPPS safety loop

Component's sizing by use of k_v-value formulas

- Sizing of relief valve is specified in the relevant rules and standard by using of specific, type approved factors
- However for design a non standard safety valve, device or system it is recommended to made size calculation based the standardized IEC formulas and guidelines for valve sizing by using of k_v or C_v
- Also for 2-phase flow conditions practically proven guidelines are available and published
- It may be necessary to execute model tests to specify for the applicable flow conditions – iterations may needed!
- Between the resulting k_v- or C_v-value and the effective free flow area clear physical law based relation is given!

Component's sizing by use of k_v-value formulas

Valve sizing: Continuity Equation – Bernoulli Theorem / Energy Equation



Blue line = change in velocity due to the continuity equation.

Green line = change in pressure of an ideal loss-free flow

Red line = Change of pressure in the real flow.

Relation between K_V / C_V and free flow area resp. diameter of flow aperture:

For a rough fast verification of valve K_V / C_V calculation following formulas for free flow area and orifice bore may be helpful:

$$A_{(mm^2)} \approx 20 * K_V \quad \text{respective} \quad A_{(in^2)} \approx 2,65 * E^{-2} * C_V$$

$$D_{(mm)} \approx 5 * \sqrt{K_V} \quad \text{respective} \quad D_{(in)} \approx 1,85 * E^{-1} * \sqrt{C_V}$$

Conclusion

- **Spring related pressure relief valves to protect cryogenic pressure vessels does not always achieve requested functionality**
- **Alternative design with magnetic warm seated relief device, cold seated relief valves or active triggered relieve systems were introduced**
- **Such components or systems are tailored to the specified applications and needs sometimes new designs, assessments and testing**
- **For sizing components IEC k_v-formulas and practical guidelines may be use and be helpful**
  Note: k_v-formulas may also be helpful in the vice-versa sense to estimate mass flow, considering valve free flow area at given travel!

Thank you for your attention!

Questions? Remarks?

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