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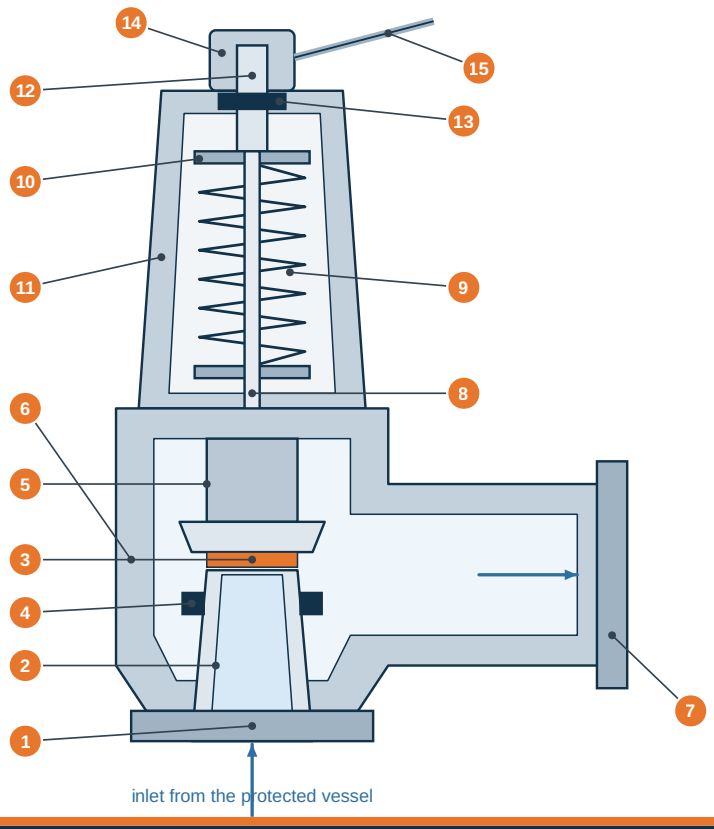
# Safety Valves, Control Valves and Flare Made Simple

## A field guide to control valves, relief valves, flares and knockout drums

Cv and Kv · characteristics · cavitation and choked flow · relief scenarios · gas, steam, liquid and two-phase relief · orifice letters · inlet and outlet piping · rupture discs · flare headers · radiation · knockout drums · testing · troubleshooting

**Conventional spring-loaded safety relief valve**

Cutaway — our own drawing; parts numbered as on Picture page 5




**FREE SAMPLER — Chapters 1 to 3**

Edition 1.0 · November 2026

**Safety Valves, Control Valves and Flare Made Simple**
A field guide to control valves, relief valves, flares and knockout drums
Edition 1.0 · November 2026 — free sampler

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Written in our own words from published engineering sources, listed in the Sources appendix. All diagrams, picture pages and charts are original PlantCalcKit artwork; every number in the worked examples was calculated with the same methods as the PlantCalcKit Excel toolkits named in each chapter. Equations based on design codes are aligned with the publicly documented methods; the book is not a reproduction of any code or standard.

**Safety first.** Relief valves, rupture discs and flare systems protect people and equipment. This guide is for training, understanding and checking. It does not replace the applicable design codes and standards, the valve maker's certified data, a certified relief system study, or your plant's procedures and management-of-change process. Example costs, where given, are illustrative.

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GUIDE

# How to use this book

This book explains control valves, pressure safety valves, flare systems and knockout drums in plain words. You do not need to be an expert. If you can read a pressure gauge and follow a recipe, you can follow this book.

## Who it is for

- **Plant operators** who line up, watch and report on valves every shift.
- **Junior engineers** who must size, check or troubleshoot a valve, a relief case or a flare header.
- **Senior engineers** who want a quick refresher before a review, a hazard study or a turnaround.

## How the book is built

The book has five parts. You can read them in order or jump to the part you need.

| Part | What you learn | Chapters |
|---|---|---|
| A | What the valves do, their parts and how they move | 1 to 3 |
| B | How to size and check a control valve | 4 to 8 |
| C | How to size and check a pressure safety valve | 9 to 16 |
| D | How flare headers, flare stacks and knockout drums work | 17 to 19 |
| E | Maintenance, testing and troubleshooting stories | 20 |

At the back you will find quiz and exercise answers, a glossary, an FAQ, printable checklists, quick-reference tables, an equation summary and the list of published sources we used.

## Our example unit

To keep things real, we follow **one example unit** through the whole book. It is made up, but every number in it was calculated, not guessed. Picture page 1 in Chapter 1 shows the unit.

- **FV-101** — a hot-water flow control valve after pump P-101, feeding heater E-101 (water at 60 °C (140 °F), 20 to 120 m³/h (88 to 528 US gpm)).
- **PV-102** and **TV-103** — the same valve body used on a hot gas letdown and on a steam line, so you can compare liquid, gas and steam.
- **V-201** — a light hydrocarbon drum protected by **PSV-201**, set at 10 bar g (145 psig), with six relief cases.
- **PSV-202** and **PSV-203** — a steam valve and a liquid valve with the same case table.
- **The flare system** — a four-segment flare header, knockout drum **V-301** and flare stack **F-301**.
- **V-401** — a vertical suction scrubber in front of compressor **K-401**.

These are the same example cases used in the matching PlantCalcKit Excel toolkits, so you can open a toolkit and see the same answers.

## The boxes you will see

- **Field check** — what to look at on the plant, and what to report.

- **Engineer's calculation corner** — a calculation with its inputs, formula, steps and the answer.
- **Worked example** — the running example, worked step by step.
- **Watch out** — a common mistake or a safety point.
- **From the field** — a short troubleshooting story. The stories are composites, written to teach; no real plant is described.
- **Try it** — exercises for you. Answers are in Appendix A.
- **Try it with PlantCalcKit** — QR codes to the free online calculators and the Excel toolkit that does that calculation.
- **Quick quiz** — five questions at the end of each chapter. Answers are in Appendix A.

## Units

We use SI units first, with US units in brackets: 10 bar g (145 psig). "bar a" means absolute pressure; "bar g" means gauge pressure, read on a normal gauge. Absolute = gauge + atmospheric pressure (1.013 bar at sea level). Mixing them up is the most common error in valve sizing, so we always write the "a" or "g". Appendix E has a conversion table.

WATCH OUT

### Read this before you use any number in this book

Control valves and relief systems are safety-critical. This book teaches you to **understand and check** a design. It is not a design code, and it does not replace a certified relief study, the valve maker's certified data, or your plant's procedures. The section "Know the limits" on the next pages says this in more detail.

FREE TOOLS

# Free calculators and Excel toolkits

Every calculation in this book can be repeated with a free PlantCalcKit online calculator, and the full multi-case version lives in a PlantCalcKit Excel toolkit. Scan a code with your phone camera to open the page.

## Free online calculators

The calculators run in your browser. They are free, with or without an account.

TRY IT WITH PLANTCALCKIT

### Free calculators used in this book

Each chapter's tool box names the calculator that matches the chapter. All calculators: **plantcalckit.com/tools/**

**Free calculator: control valve Cv for liquids**
plantcalckit.com/tools/control-valve-cv/

**Free calculator: control valve Cv for gas and steam**
plantcalckit.com/tools/gas-control-valve-cv/

**Free calculator: relief valve (PSV) sizing**
plantcalckit.com/tools/psv-sizing/

**Free calculator: fire case relief load**
plantcalckit.com/tools/fire-case-relief-load/

**Free calculator: two-phase separator sizing**
plantcalckit.com/tools/separator-sizing/

**Free calculator: pipe pressure drop**
plantcalckit.com/tools/pipe-pressure-drop/

## Excel toolkits

The toolkits do the full job for your own plant: several cases side by side, every unit system, visible formulas, built-in input checks and a print-ready report. The book chapters line up with the toolkits like this:

| Excel toolkit | Book chapters | What the toolkit does for those chapters |
|---|---|---|
| Control Valve Sizing | 4 to 8 | Required Cv or Kv for up to six cases (liquid, gas, steam), cavitation, choking and flashing checks, percent open, valve size check, rangeability, noise-risk flag |
| Pressure Safety Valve Sizing | 9 to 12, 14 | Gas, steam and liquid relief for up to six cases, required area, orifice D to T, rated capacity check, overpressure what-if |
| Flare System Load and Hydraulic Evaluation | 15, 17, 18 | Header Mach numbers, back pressure at each relief valve, radiation distance, tip velocity, purge rate and knockout drum liquid |
| Gas-Liquid Separator and Knockout Drum Sizing | 19 | Droplet settling, Souders-Brown velocity, diameter and length, hold-up and surge volume, nozzles, existing-vessel check, load cases |

TRY IT WITH PLANTCALCKIT

### The four Excel toolkits that match this book

The toolkit pages show what each workbook does, a preview of the layout and the price. The example cases in this book are the toolkits' own example cases.

**Excel toolkit: Control Valve Sizing**
plantcalckit.com/shop/control-valve-sizing-excel/

**Excel toolkit: Pressure Safety Valve Sizing**
plantcalckit.com/shop/pressure-safety-valve-sizing-excel/

**Excel toolkit: Flare System Load and Hydraulic Evaluation**
plantcalckit.com/shop/flare-system-load-and-hydraulic-evaluation-excel/

**Excel toolkit: Gas-Liquid Separator and Knockout Drum Sizing**
plantcalckit.com/shop/gas-liquid-separator-and-knockout-drum-sizing-excel/

SAFETY NOTE

# Know the limits of this book

Relief valves, rupture discs and flares are the last line of defence before a vessel bursts or a cloud of gas escapes. That is why we say clearly, in plain words, what this book can and cannot do.

## What this book does

- It explains **why** each valve and device is there and **how** it works.
- It shows the **published methods** that engineers use, in our own words, with worked examples that you can repeat.
- It teaches you to **check** a datasheet, a sizing sheet or a field installation, and to ask good questions.

## What this book does not do

- It is **not a design code**. Relief devices must be designed, selected and installed to the pressure vessel code and the standards that apply where you work. The methods in this book are aligned with the publicly documented methods (for example the API 520, API 521 and IEC 60534-2-1 methods), but they are not a copy of those documents and they are not a certified calculation.
- It does **not replace the valve maker's certified data**. Real discharge coefficients, rated capacities, recovery factors and back-pressure corrections come from the maker's certified tests.
- It does **not replace a relief system study**. Choosing which scenarios apply, and how big each relief load is, needs a team review, the process data and your plant's hazard studies.
- It does **not change your plant's rules**. Lock-out, isolation, car seals, permits and management of change come first, always.

## Plain-words rules

1. Never remove, gag, block or reset a relief device without an approved procedure.
2. Never change a set pressure, a spring, an orifice or a rupture disc type "to stop a problem" without a management-of-change review.
3. If a number in this book disagrees with your certified datasheet, the datasheet wins — and the difference is worth asking about.
4. If you find a relief valve that is isolated, leaking, chattering or missing its tag, report it the same shift.

GOOD TO KNOW

### Where the constants come from

Some constants in this book come from published standards that we could not quote word for word (for example the coefficients in the relief valve equations). We name the source next to each one. The relief valve coefficients follow API 520 Part I, 7th edition (2000), and the flare radiation and flame length items follow API 521, 4th edition (1997) — the editions they were checked against. Later editions may differ: before you use them in a real design, check them against the edition you work to.

PART A — VALVES IN THE PLANT

CHAPTER 1

# Why plants need control valves, safety valves and flares

Every process plant moves fluids under pressure. Control valves keep flows, pressures and levels where we want them. When control is lost, safety valves open to stop the pressure from rising too far, and the flare system takes the released gas to a safe place.

## 1.1 Three jobs, three kinds of device

A process plant is a set of pipes and vessels that hold liquids and gases under pressure. Three kinds of device look after that pressure:

- A **control valve** works all day, every day. It opens and closes a little at a time to hold a flow, a pressure, a level or a temperature at its set point. It is a "throttling" device: it adds just enough resistance to the flow.
- A **pressure safety valve** (PSV, also called a relief valve or safety relief valve) sleeps almost all its life. It stays shut until the pressure in the equipment reaches its set pressure. Then it opens by itself — no power, no air, no signal — and lets fluid out until the pressure falls again.
- A **flare system** collects what the safety valves (and some vents and blowdown valves) let out. It separates any liquid in a **knockout drum** and burns the gas at a safe height and distance in a **flare stack**.

The control valve is the first line of defence. The safety valve is the last. The flare makes sure that the last line of defence does not create a new hazard.

## 1.2 Layers of protection

Engineers think in **layers**. Each layer stops most of the problems that get past the layer before it.

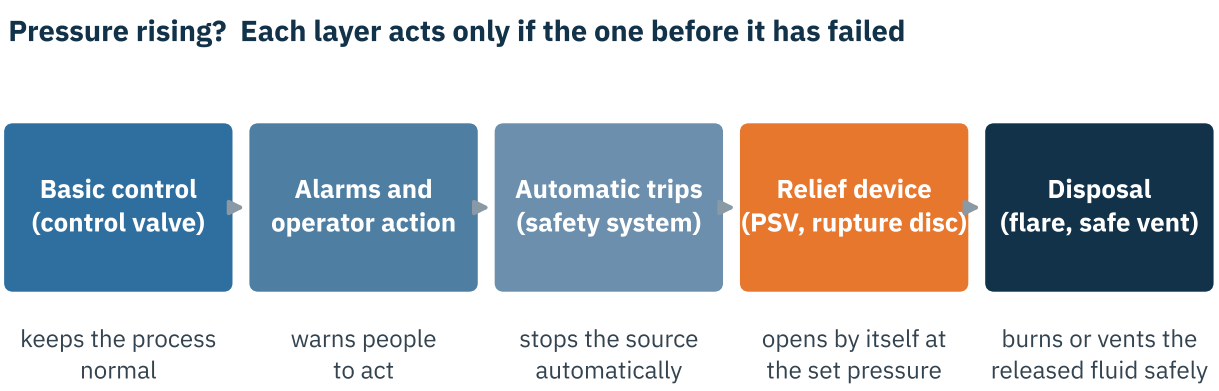



**Figure 1.1** — Layers of protection around a pressure vessel. A control valve keeps the process normal; alarms and trips act when control is lost; the safety valve is the last mechanical layer; the flare system handles the released fluid.

1. **Basic control** — the control valve and its controller keep the process normal.
2. **Alarms and operator action** — when a pressure or level runs high, an alarm sounds and the operator acts.
3. **Automatic trips** — a separate safety system closes a feed valve or stops a pump.
4. **Relief devices** — the PSV or rupture disc opens when everything else has failed.
5. **Disposal** — the flare system or a safe vent takes the released fluid away.

A good design never asks one layer to do everything. A relief valve that lifts every week is a sign that the layers above it are not working.

## 1.3 Why pressure is dangerous

A pressure vessel is designed for a **maximum allowable working pressure** (MAWP). Above it, the walls are stressed more than the design allows. Pressure vessel codes allow a short rise above the MAWP during a relief event — the **accumulation** — but only a little: about 10 % for most cases and 21 % for an external fire. Beyond that, flanges leak, gaskets blow and, in the worst case, the vessel ruptures.

Pressure can rise for many reasons: an outlet valve closed by mistake, cooling water lost, a control valve stuck wide open, a fire around the vessel, a tube burst in an exchanger, or a blocked-in pipe full of liquid that warms up in the sun. Chapter 10 walks through these **relief scenarios** one by one.

## 1.4 Why control valves matter for safety too

It is easy to think of a control valve as a production device only. But:

- A control valve that **fails wide open** can send more gas into a vessel than its safety valve can release. That "control valve failure" case often sets the size of the PSV.
- A control valve that **cavitates** can erode itself and the pipe downstream until it leaks.
- A control valve that is **too big** hunts and cycles. That shakes pipes, wears packing and upsets the process.

So a sound control valve design is the first step of a sound relief design.

## 1.5 Our example unit

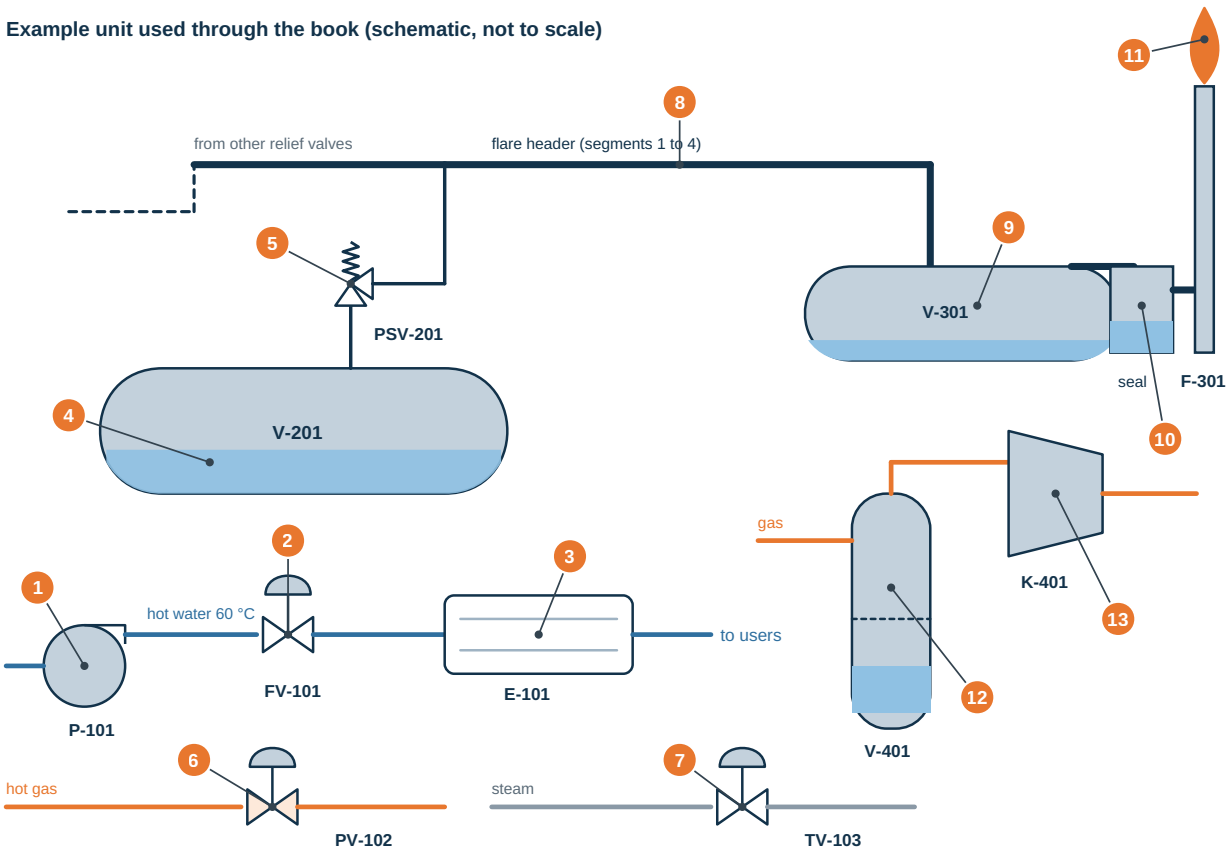
We follow one made-up unit through the whole book. Picture page 1 shows it. Hot water from pump **P-101** passes through control valve **FV-101** to heater **E-101**. A light hydrocarbon (molar mass about 44 kg/kmol, similar to propane) is held in drum **V-201**, protected by **PSV-201** set at 10 bar g (145 psig). The relief valves of the unit discharge into a flare header, through knockout drum **V-301**, to flare stack **F-301**. A compressor **K-401** takes gas from suction scrubber **V-401**.

PICTURE PAGE 1

# The example unit

The running examples of the book: one hot-water loop, a gas and a steam valve, a protected drum, the flare system and a compressor scrubber.

**Example unit used through the book (schematic, not to scale)**




| No. | Part | What it does |
|---|---|---|
| 1 | **P-101 pump** | Pumps hot water at 60 °C (140 °F) around the loop. |
| 2 | **FV-101 flow control valve** | DN100 globe valve, equal-percentage trim, rated Kv 160 (Chapters 2 to 8). |
| 3 | **E-101 heater** | Receives the controlled water flow; loss of flow can damage it. |
| 4 | **V-201 drum** | Holds a light hydrocarbon (molar mass about 44); MAWP 10 bar g. |
| 5 | **PSV-201 relief valve** | Set at 10 bar g; six relief cases; orifice L (Chapters 9 to 16). |
| 6 | **PV-102 gas letdown valve** | Same valve body on hot gas, for comparing gas sizing (Chapter 7). |
| 7 | **TV-103 steam valve** | Same valve body on steam at 200 °C (Chapter 7). |
| 8 | **Flare header** | Four segments from 750 to 1,200 mm collecting the relief valves (Chapter 17). |
| 9 | **V-301 knockout drum** | Separates liquid from the relieved gas (Chapter 19). |
| 10 | **Seal drum** | Liquid seal that keeps air out of the header. |
| 11 | **F-301 flare stack** | 100 m elevated flare with pilots (Chapter 18). |
| 12 | **V-401 suction scrubber** | Vertical separator with a mesh pad ahead of the compressor (Chapter 19). |
| 13 | **K-401 compressor** | Must not receive liquid droplets. |

## 1.6 Who does what

| Task | Usually done by | Where this book helps |
|---|---|---|
| Choose relief scenarios and loads | Process engineer with a review team | Chapter 10 |
| Size the PSV and select the orifice | Process engineer, checked by the maker | Chapters 11 to 14 |
| Check inlet and outlet piping | Process and piping engineers | Chapter 15 |
| Size the flare header and knockout drum | Process engineer | Chapters 17 to 19 |
| Size the control valve | Process or instrument engineer, checked by the maker | Chapters 4 to 8 |
| Test and repair valves | Maintenance and inspection teams | Chapter 20 |
| Watch valves every shift | Operators | Field checks in every chapter |

FIELD CHECK

### What to look at on your first walk-round

- **Control valves**: is the travel indicator steady, or does it move up and down all the time? Is the valve nearly shut (below about 10 %) or nearly fully open (above about 90 %)?
- **Safety valves**: is each valve tagged with its set pressure? Are the block valves under and after it locked or sealed open? Is there a hiss, frost or a wet spot at the outlet?
- **Flare**: is the flame steady and smokeless? Is the knockout drum level normal?

Report anything odd to the shift supervisor. Use your plant's alarm and action limits; this book does not set them.

## 1.7 Words to know

- **Set pressure** — the pressure at which a safety valve starts to open.
- **Relief load** — the flow the safety valve must pass in a given scenario.
- **Back pressure** — the pressure at the outlet of the safety valve.
- **Cv or Kv** — the flow coefficient of a control valve: how much water it passes at a set pressure drop.
- **Flare header** — the large pipe that collects the discharges of many relief valves.

Appendix B has the full glossary.

TRY IT WITH PLANTCALCKIT

### Start here

Open the free control valve and PSV calculators and press "Load the example" to see the kind of answers this book explains. The **Control Valve Sizing** and **Pressure Safety Valve Sizing** Excel toolkits do the full multi-case job for the example unit in this book.

**Free calculator: control valve Cv for liquids**
plantcalckit.com/tools/control-valve-cv/

**Free calculator: relief valve (PSV) sizing**
plantcalckit.com/tools/psv-sizing/

**Excel toolkit: Control Valve Sizing**
plantcalckit.com/shop/control-valve-sizing-excel/

**Excel toolkit: Pressure Safety Valve Sizing**
plantcalckit.com/shop/pressure-safety-valve-sizing-excel/

**QUICK QUIZ 1**

1. Which device works all day, and which one sleeps until it is needed?
2. What powers a spring-loaded safety valve when it opens?
3. Why can a control valve that fails wide open decide the size of a safety valve?
4. What does the knockout drum in a flare system do?
5. A relief valve on a drum lifts every week. What does that tell you about the layers above it?

CHAPTER 2

# Valve basics — parts, types and flow

A control valve is a variable restriction in a pipe. To understand any valve you need three ideas — its parts, its type, and the simple rule that the flow through it grows with the square root of the pressure drop.

## 2.1 The parts of a control valve

Every control valve has two halves:

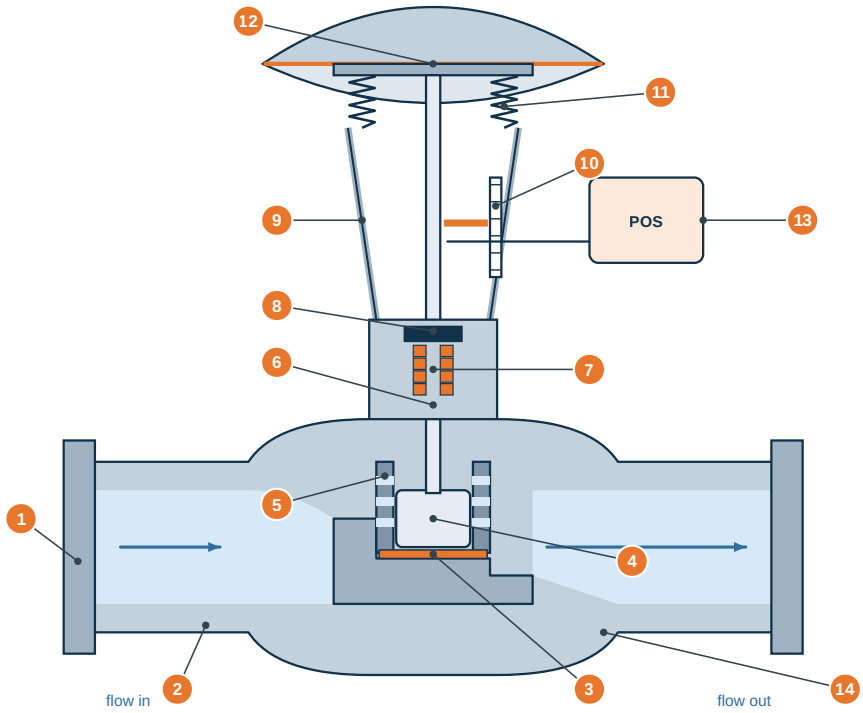
- The **valve body assembly** — the pressure-holding body, the **trim** (plug, seat, cage or disc, and stem), the **bonnet** and the **packing** that seals the stem.
- The **actuator** — the "muscle" that moves the stem, usually a diaphragm or piston driven by instrument air, with a **positioner** that makes sure the valve goes where the controller asks (Chapter 3).

Picture page 2 shows a globe valve cut in half, with its main parts numbered.

PICTURE PAGE 2

# Globe control valve — cutaway

A cage-guided globe valve with a spring-and-diaphragm actuator (generic design, our own drawing).




| No. | Part | What it does |
|---|---|---|
| 1 | **Inlet flange** | Bolts the valve into the pipe; its rating must match the line. |
| 2 | **Body** | Pressure-holding casting; the flow path turns twice through it. |
| 3 | **Seat ring** | Hard ring the plug closes on; sets shut-off tightness. |
| 4 | **Plug** | Moves up and down to vary the flow area; its shape sets the characteristic. |
| 5 | **Cage** | Guides the plug; the size and shape of its windows set flow and characteristic. |
| 6 | **Bonnet** | Closes the top of the body and carries the packing. |
| 7 | **Packing** | Rings that seal around the moving stem; too tight makes the valve stick. |
| 8 | **Gland flange** | Compresses the packing to the maker's torque. |
| 9 | **Yoke** | Frame joining actuator and body. |
| 10 | **Travel indicator** | Pointer and scale showing the valve opening. |
| 11 | **Actuator spring** | Drives the valve to its fail position when air is lost. |
| 12 | **Diaphragm** | Air pressure on it moves the stem against the spring. |
| 13 | **Positioner** | Compares the signal with the stem position and adjusts the air. |
| 14 | **Outlet** | Where pressure recovers; cavitation damage often appears here. |

The **trim** is the heart of the valve. It decides how much flow passes at each opening, how much pressure the fluid recovers after the narrowest point, and how well the valve resists cavitation and noise. Two valves with the same body can behave very differently with different trims.

## 2.2 Linear-motion and rotary valves

Control valves come in two families:

| Family | Examples | How the closure member moves | Typical uses |
|---|---|---|---|
| Linear (sliding stem) | Globe, angle, cage-guided | Plug moves up and down in a straight line | Most clean liquid, gas and steam services; high pressure drop; good control at low flow |
| Rotary | Ball, segmented ball, butterfly, eccentric plug | Disc or ball turns a quarter turn (90°) | Large lines, low pressure drop, slurries and fibrous fluids, lower cost per size |

Picture page 3, at the end of section 2.4, shows the two common rotary valves.

A globe valve has a tortuous path: the flow turns twice and squeezes through the gap between the plug and the seat. That costs pressure but gives fine, stable control. A butterfly or ball valve has a straighter path. It passes much more flow for its size, but the jet leaving the narrowest point is fast and the pressure **recovers** strongly downstream. As you will see in Chapter 6, strong recovery makes a valve more likely to cavitate.

## 2.3 What sets the flow through a valve

Think of a garden hose with your thumb over the end. Press harder — the gap is smaller — and the flow falls. Open the tap more — more pressure — and the flow rises. A valve works the same way, and for a liquid the rule is simple:

$$\text{Flow} = K_v \times \sqrt{(\Delta p \div \text{relative density})}$$

- **Kv** is the valve's **flow coefficient** at its present opening, in m³/h of water at 1 bar pressure drop.
- **Δp** is the pressure drop across the valve, in bar.
- **Relative density** is the liquid density divided by the density of water (about 999 kg/m³).

Double the pressure drop and the flow only rises by √2, about 41 %. To double the flow you need four times the pressure drop. This **square-root law** is behind almost everything in the next six chapters.

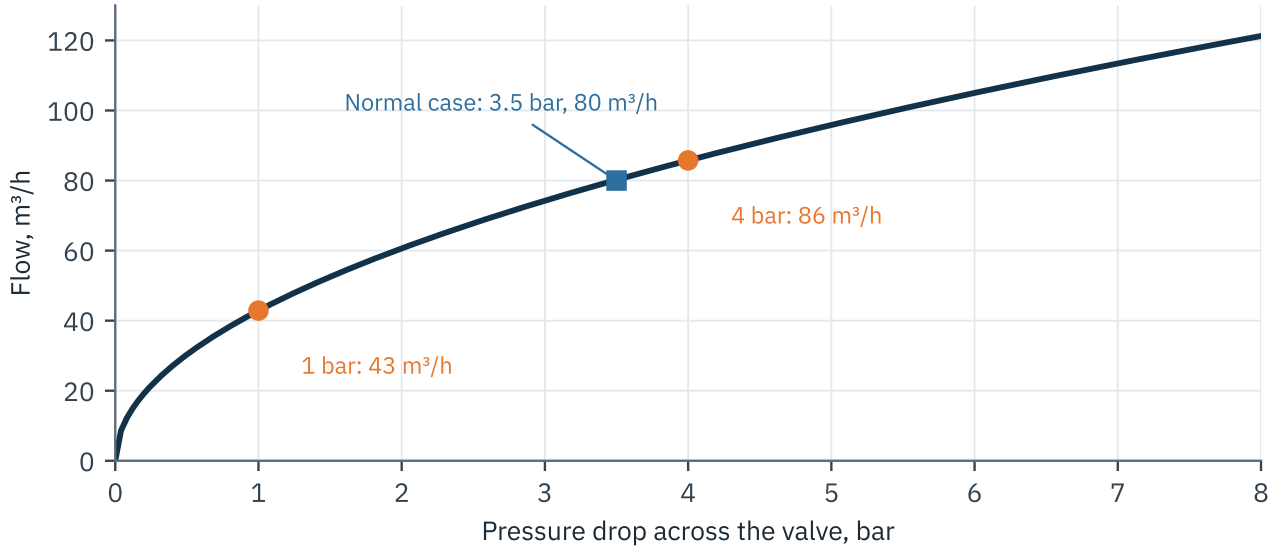



**Figure 2.1** — Flow against pressure drop for FV-101 at its normal opening (Kv 42.54). Flow grows with the square root of the pressure drop, so four times the drop gives only twice the flow.

The US unit is **Cv**: US gallons per minute of water at 60 °F with 1 psi of pressure drop. Because the units differ, **Cv = 1.156 × Kv** and **Kv = 0.8650 × Cv**. Always check which one a datasheet uses — a 16 % difference is easy to miss.

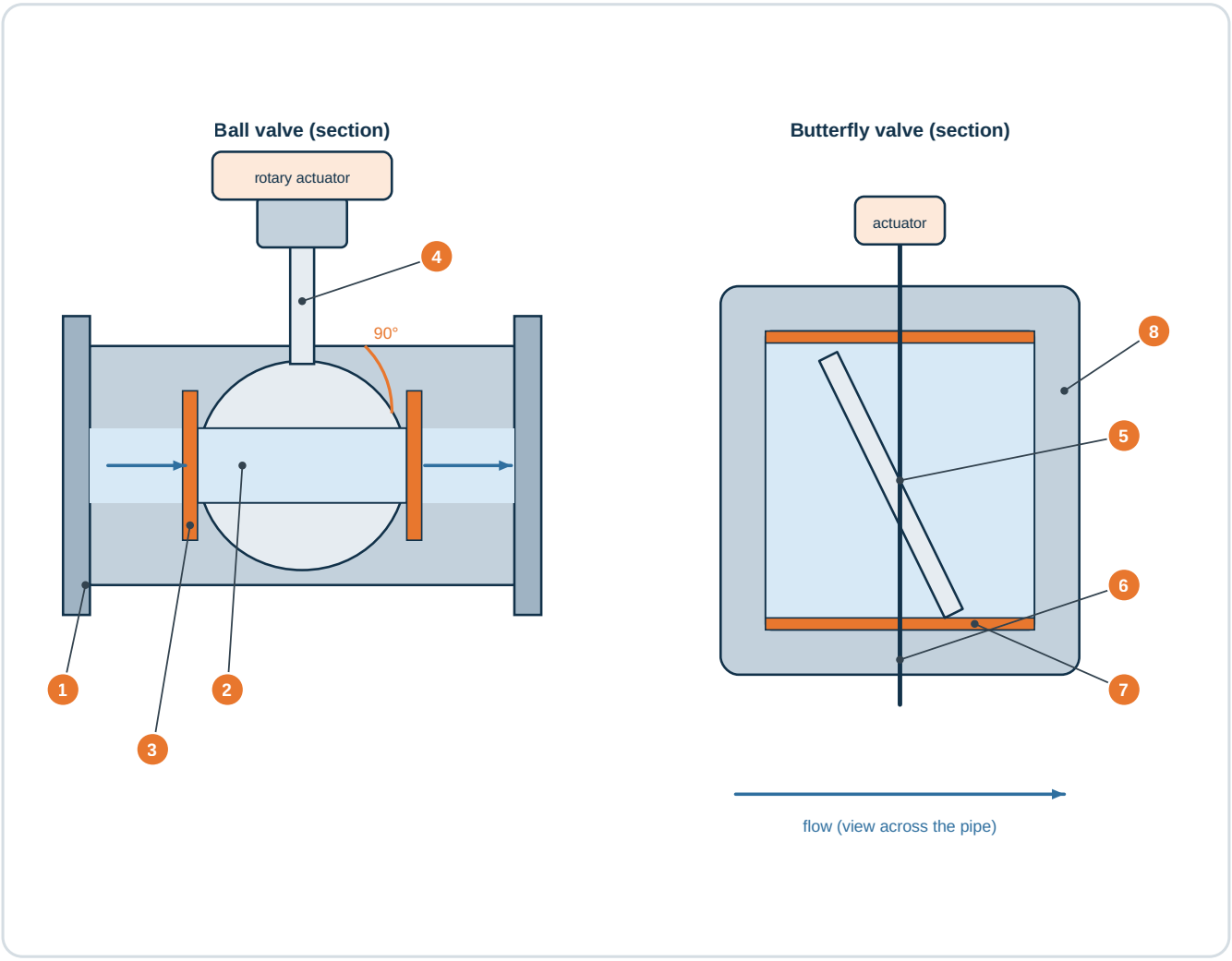
## 2.4 Rated Kv and valve size

Each valve has a **rated Kv** (or Cv): the flow coefficient at 100 % travel. The rated value grows with the valve size, roughly with the square of the diameter, but it also depends on the trim. A DN100 (4 in) globe valve may have a full-size trim with a rated Kv of about 160, or a reduced trim with a much smaller value. The valve table in our example (Chapter 8) uses six generic sizes from DN25 to DN150; real values always come from the maker's catalogue.

PICTURE PAGE 3

# Rotary control valves — ball and butterfly

Quarter-turn valves pass more flow for their size than globe valves but recover more pressure (lower FL), so they cavitate and choke sooner.




| No. | Part | What it does |
|---|---|---|
| 1 | **Body and end flanges** | Hold pressure; often the same face-to-face length as the line valves. |
| 2 | **Ball with bore** | Turns a quarter turn; a segmented (V-notch) ball gives better control. |
| 3 | **Ball seats** | Seal against the ball; soft seats give tight shut-off but limit temperature. |
| 4 | **Shaft (stem)** | Transmits the rotary actuator's torque; sealed by packing. |
| 5 | **Disc** | Turns in the flow; best control between about 20° and 60–70° open. |
| 6 | **Shaft** | Passes through the disc; carries the torque from the actuator. |
| 7 | **Seat or liner** | Seals around the disc edge; high-performance designs use offset discs. |
| 8 | **Wafer body** | Clamped between pipe flanges; short and light. |

## 2.5 Other things the valve must do

A control valve is chosen for more than flow:

- **Shut-off class.** Most control valves are not tight shut-off valves. Seat leakage classes (Class II to Class VI in the common standards) tell you how much leakage is allowed when the valve is shut. If you need tight shut-off, say so, or add an isolation valve.
- **Pressure and temperature rating.** The body and flanges must be rated for the worst pressure and temperature, including upset conditions.
- **Materials.** Trim materials must resist erosion, cavitation and corrosion.
- **Fail position.** What should the valve do if air or power is lost? Chapter 3 covers this.
- **Noise.** Gas valves with a high pressure drop can be very loud (Chapter 8).

ENGINEER'S CALCULATION CORNER

### Kv of FV-101 at the normal case — a first estimate

**Inputs.** Normal flow 80 m³/h (352 US gpm) of hot water at 60 °C (140 °F); inlet 8.5 bar a, outlet 5.0 bar a, so Δp = 3.5 bar (50.8 psi). Water density at 60 °C and 8.5 bar a: 983.5 kg/m³ (IAPWS-IF97), so relative density = 983.5 ÷ 999.1 = 0.9844.

**Formula.** Kv = Q × √(relative density ÷ Δp).

**Steps.** √(0.9844 ÷ 3.5) = 0.5303; Kv = 80 × 0.5303 = **42.43**.

**Answer.** Kv ≈ 42.43 (Cv ≈ 49.1). The full method in Chapter 4 adds a small correction for the pipe reducers and gives Kv 42.54. The simple rule is within 0.3 %.

FIELD CHECK

### Reading a valve on the plant

- Find the **tag plate**: tag number, size, rating, trim, rated Cv or Kv, fail position.
- Read the **travel indicator** on the yoke: 0 % is shut, 100 % is fully open.
- Compare the travel with the controller output on the control-room screen. A big difference means a sticking valve or a positioner problem (Chapter 3).
- Listen. A rattle like gravel in the pipe can mean cavitation (Chapter 6).

TRY IT 2.1

A valve passes 50 m³/h of water with 2 bar of pressure drop. What flow would it pass at the same opening with 8 bar of pressure drop? (Use the square-root law.)

TRY IT 2.2

A datasheet says Cv = 100. What is the Kv?

TRY IT WITH PLANTCALCKIT

### Calculate a liquid Kv

The free **control valve Cv for liquids** calculator does the first-estimate calculation above, with the choked-flow check. In the **Control Valve Sizing** Excel toolkit this is the "Required Cv or Kv per case" topic.

**Free calculator: control valve Cv for liquids**
plantcalckit.com/tools/control-valve-cv/

**Excel toolkit: Control Valve Sizing**
plantcalckit.com/shop/control-valve-sizing-excel/

QUICK QUIZ 2

1. Name the two halves of a control valve.
2. Which family of valves — linear or rotary — usually gives stronger pressure recovery?
3. If the pressure drop across a valve is four times larger, what happens to the flow?
4. Which is larger for the same valve, its Cv or its Kv?
5. Why is "tight shut-off" not something you can assume for a control valve?

CHAPTER 3

# Actuators, positioners and fail-safe action

The controller decides how far a valve should open. The actuator supplies the force, the positioner makes sure the valve really gets there, and the fail position decides what happens when the air or the signal is lost.

## 3.1 The signal chain

A modern control loop works like this:

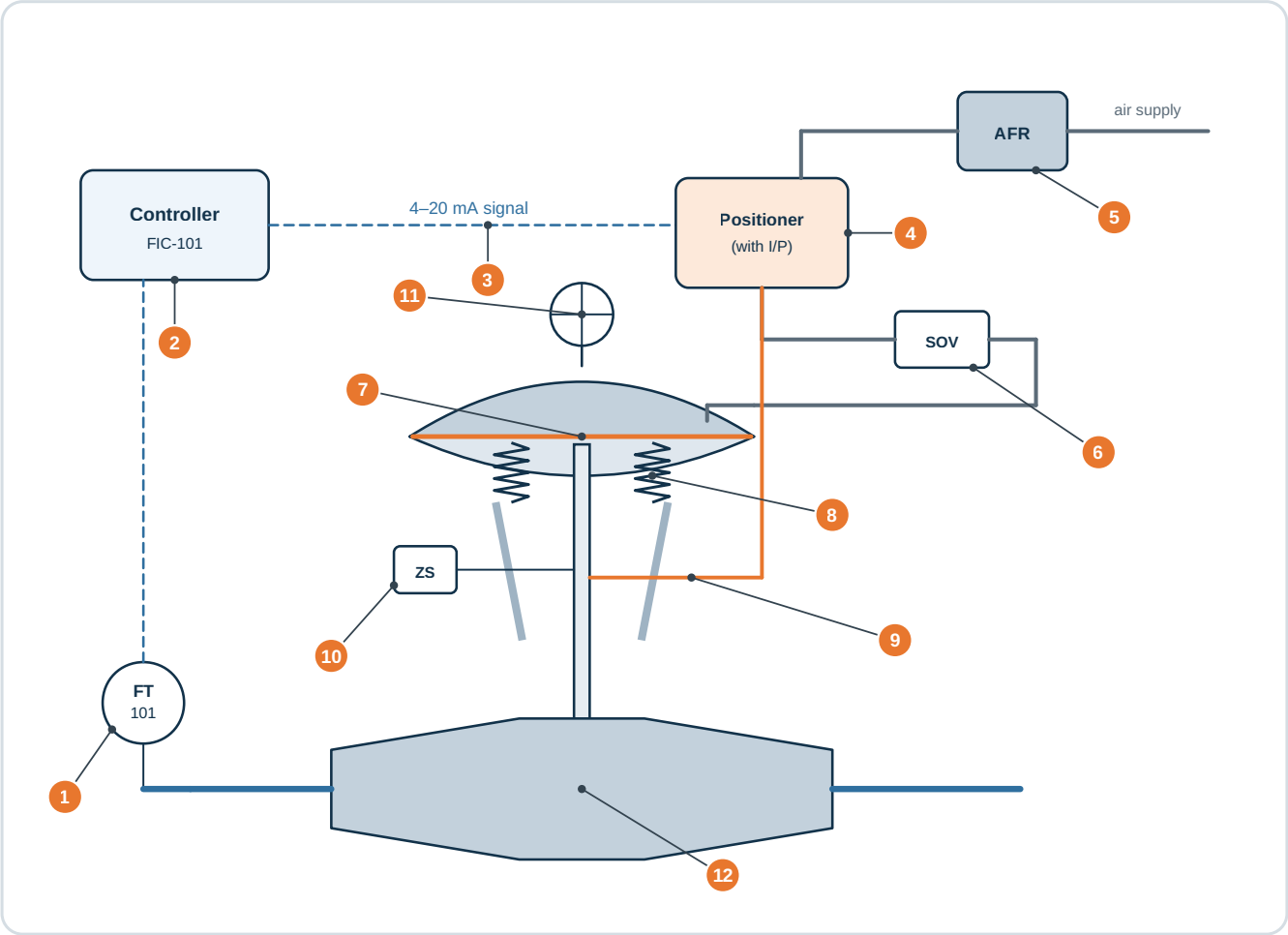
1. A **transmitter** measures the flow, pressure, level or temperature.
2. The **controller** compares it with the set point and calculates an output, 0 to 100 %.
3. The output travels as a **4–20 mA** current (or a digital signal) to the valve.
4. The **positioner** converts that signal into air pressure on the actuator and checks the stem position through a **feedback linkage**.
5. The **actuator** moves the stem until the valve travel matches the signal.

Older plants may still send a pneumatic signal of 0.2 to 1.0 bar g (3 to 15 psig) straight to the actuator. The idea is the same: a "live zero" (4 mA or 0.2 bar g) lets the system tell a zero signal from a broken wire or a lost air supply.

PICTURE PAGE 4

# Actuator, positioner and the control loop

The signal chain from the flow transmitter to the valve plug, with the accessories that decide how the valve fails.




| No. | Part | What it does |
|---|---|---|
| 1 | **Flow transmitter** | Measures the flow and sends it to the controller. |
| 2 | **Controller** | Compares the flow with the set point and sets the valve output, 0–100 %. |
| 3 | **4–20 mA signal** | Live-zero signal: 4 mA is 0 %, 20 mA is 100 %. |
| 4 | **Positioner with I/P** | Turns the signal into actuator air and corrects the stem position. |
| 5 | **Air filter regulator** | Clean, dry air at the pressure on the actuator nameplate. |
| 6 | **Solenoid valve** | On a trip it vents the actuator so the spring drives the valve to its fail position. |
| 7 | **Diaphragm** | Air pressure on it creates the stem force. |
| 8 | **Springs** | Return the valve to its fail position (fail closed or fail open). |
| 9 | **Feedback arm** | Tells the positioner where the stem really is. |
| 10 | **Limit switch** | Confirms open or closed to the control system. |
| 11 | **Handwheel** | Manual operation; must be disengaged for automatic control. |
| 12 | **Valve body** | The controlled restriction in the pipe. |

## 3.2 Actuator types

| Type | How it works | Good points | Watch points |
|---|---|---|---|
| Spring-and-diaphragm | Air pushes a rubber diaphragm against a spring | Simple, reliable, fails safe by the spring | Limited force; large size for high pressure drops |
| Pneumatic piston | Air pushes a piston, with or without a spring | High force and stroke speed | Needs clean air; seals wear |
| Electric | Motor and gearbox | No air needed | Fail position needs a battery or spring module; slower |
| Electro-hydraulic | Oil pressure from a local pump | Very high force, fast and precise | Complex; oil leaks |

The actuator must be strong enough to close the valve against the **largest pressure difference** it will ever see — usually at shut-off, when the full upstream pressure acts on the plug with nothing downstream. An actuator that is too weak lets the valve "blow open" or fail to seat. Actuator sizing is the maker's job, but you should give the maker the right shut-off pressure.

## 3.3 Fail position

What should the valve do if the air supply or the signal is lost? The answer comes from the hazard review, not from habit.

- **Fail closed (FC)** — the spring shuts the valve. Also called **air-to-open**. Used where flow must stop on a failure, for example the fuel gas valve to a furnace.
- **Fail open (FO)** — the spring opens the valve. Also called **air-to-close**. Used where flow must continue, for example cooling water to an exchanger or the spillback of a compressor.
- **Fail last / fail locked (FL)** — the valve stays where it is. Needs a lock-up relay or a double-acting piston.

For our example: **FV-101** feeds hot water to heater E-101. If the heater can be damaged by losing water flow, the valve should fail open. The **fuel gas valve** to a fired heater, in contrast, must fail closed.

WATCH OUT

**The fail position shapes the relief load**

A fail-open valve on a gas inlet to a drum means that on air failure the drum receives the **full flow** the wide-open valve can pass. That flow may become a relief case for the drum's PSV (Chapter 10). Always check the relief study when a fail position is changed.

## 3.4 The positioner and valve response

Friction in the packing, unbalanced forces on the plug and the flowing fluid all push the stem away from where it should be. The positioner fights these forces. Without one, a valve may move in jumps — **stick-slip** — and the loop will cycle.

Two words describe a valve's response:

- **Dead band** — the smallest change in signal that makes the stem move after a change of direction.
- **Hysteresis** — the difference between the travel going up and the travel going down for the same signal.

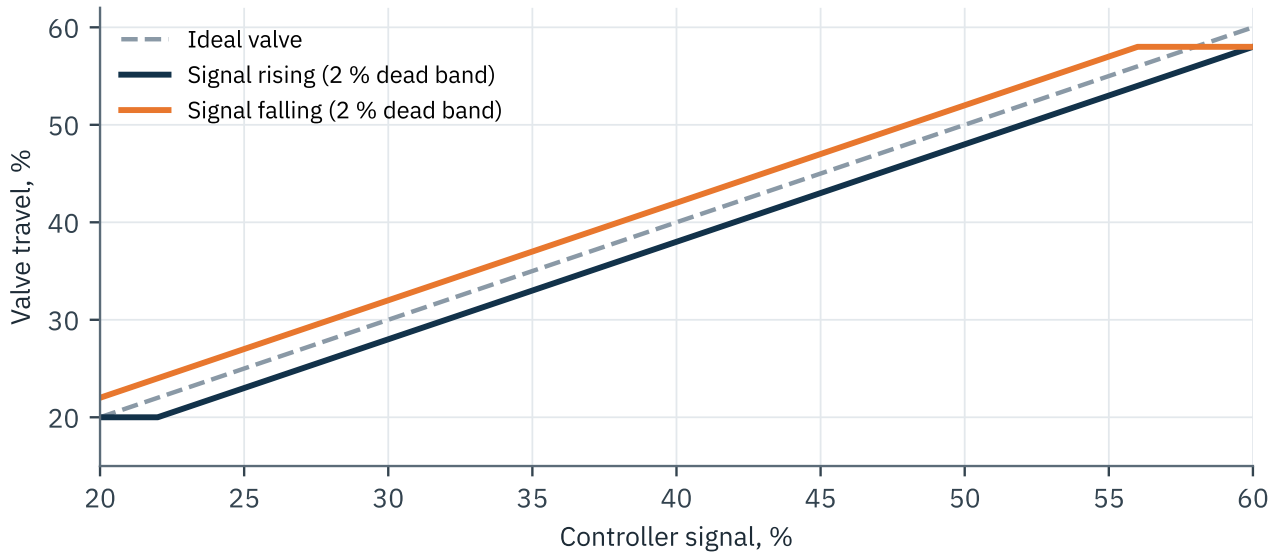



**Figure 3.1** — Valve travel against controller signal for a valve in good condition (straight line) and for a valve with a 2 % dead band (illustrative). With dead band the valve does not move until the signal has changed by the dead band after each reversal, so the loop hunts.

A **stroke test** (Chapter 20) checks these: the signal is stepped up and down in small steps (for example 1 %, 2 %, 5 %) and the travel is recorded.

## 3.5 Useful accessories

- **Air filter regulator** — clean, dry air at the right pressure for the positioner.
- **Solenoid valve** — vents the actuator to drive the valve to its fail position on a trip signal from the safety system.
- **Limit switches** — confirm open or closed to the control system.
- **Volume booster** — speeds up large actuators.
- **Handwheel** — lets an operator move the valve by hand. A handwheel left engaged can stop a valve from responding — a classic surprise during start-up.

FIELD CHECK

**Actuator and positioner walk-round**

- Air supply gauge reads the pressure on the valve's nameplate; no hissing leaks.
- Feedback linkage is tight; no loose pins or bent arms.
- Handwheel is disengaged (in its "auto" position) unless a procedure says otherwise.
- The travel indicator follows the controller output within a few per cent.
- Fail position marked on the tag (FC or FO) matches the drawing.

TRY IT 3.1

A fail-closed valve gets a 4 mA signal. What is its travel? What happens if the air supply is lost?

TRY IT 3.2

A 4–20 mA signal reads 14 mA. What controller output in per cent does that represent?

TRY IT WITH PLANTCALCKIT

### Size before you choose an actuator

Actuator force depends on the valve size and the shut-off pressure, so size the valve first with the free **control valve Cv** calculators. The **Control Valve Sizing** Excel toolkit lists every case side by side so you can pick the shut-off and maximum pressure differences to send to the maker.

**Free calculator: control valve Cv for liquids**
plantcalckit.com/tools/control-valve-cv/

**Excel toolkit: Control Valve Sizing**
plantcalckit.com/shop/control-valve-sizing-excel/

QUICK QUIZ 3

1. What does a positioner do that the actuator alone cannot?
2. Another name for "fail closed" is air-to-____.
3. Why do signals start at 4 mA instead of 0 mA?
4. Give one example of a valve that should fail open.
5. What is dead band, and what does it do to a control loop?

SOURCES

# Sources for Chapters 1 to 3

The methods in these chapters come from the published references below, described in our own words. The full book lists all sources in Appendix G.

- **IEC 60534-2-1**, *Industrial-process control valves — Flow capacity — Sizing equations for fluid flow under installed conditions* (second edition, 2011). Flow coefficient and the square-root law. Chapter 2.
- **ISA-75.01.01** (2012 edition). US counterpart of the IEC sizing method. Chapter 2.
- **IEC 60534-4** and **ANSI/FCI 70-2**, seat leakage classes. Chapter 2, named only.
- **API Standard 521**, *Pressure-relieving and Depressuring Systems* (7th edition, 2020). Causes of overpressure and layers of protection. Chapter 1.
- **ASME Boiler and Pressure Vessel Code, Section VIII, Division 1** — allowable accumulation during relief. Chapter 1.
- **Wagner, W. et al.** (2000), IAPWS-IF97 formulation for water and steam properties. Chapter 2 (water density).
- **NIST Special Publication 811**, unit conversions (Cv and Kv). Chapter 2.

The worked example is the example case of the PlantCalcKit **Control Valve Sizing** Excel toolkit.

FULL BOOK

# Enjoyed the free sampler?

The full book continues with 17 more chapters and 10 picture pages — from sizing FV-101 for all its cases to sizing PSV-201, checking its inlet and back pressure, and following its discharge through the flare header, the knockout drum and the flare stack.

## What is in the full book

- **Part B — Control valves:** Cv and Kv sizing, characteristics and rangeability, cavitation, flashing and choked flow, gas and steam valves, noise and the complete size check.
- **Part C — Pressure safety valves:** pressure words, relief scenarios and the fire case, gas, steam, liquid and two-phase sizing, orifice letters, inlet and outlet piping, rupture discs and the ten common mistakes.
- **Part D — Flares and knockout drums:** header hydraulics and back pressure, radiation, tip and purge, separator and knockout drum sizing.
- **Part E — Maintenance, testing and eight troubleshooting stories.**
- Quiz and exercise answers, glossary, FAQ, printable checklists, quick-reference tables, equation summary and sources.

TRY IT WITH PLANTCALCKIT

### Get the full book and the Excel toolkits

Find **Safety Valves, Control Valves and Flare Made Simple** and the matching **Control Valve Sizing**, **Pressure Safety Valve Sizing**, **Flare System Load and Hydraulic Evaluation** and **Gas-Liquid Separator and Knockout Drum Sizing** Excel toolkits at **plantcalckit.com/shop/**. The free calculators stay free at **plantcalckit.com/tools/**.

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**Excel toolkit: Flare System Load and Hydraulic Evaluation**
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