The modulating magnetic valves

(original product range of Staefa Control System)

Construction and principle of operation

Introduction: The valve in the HVAC control loop

Both the static and the dynamic behaviour of the valve play a major part in ensuring fast and accurate control of HVAC systems (Fig.1). The precise conversion of the control signal into a stroke movement has a significant influence on the stability and accuracy of the control loop.

This data sheet describes the technology applied (Fig. 2) and considers aspects of the valve's construction (Fig. 3) with regard to the specific demands of HVAC.

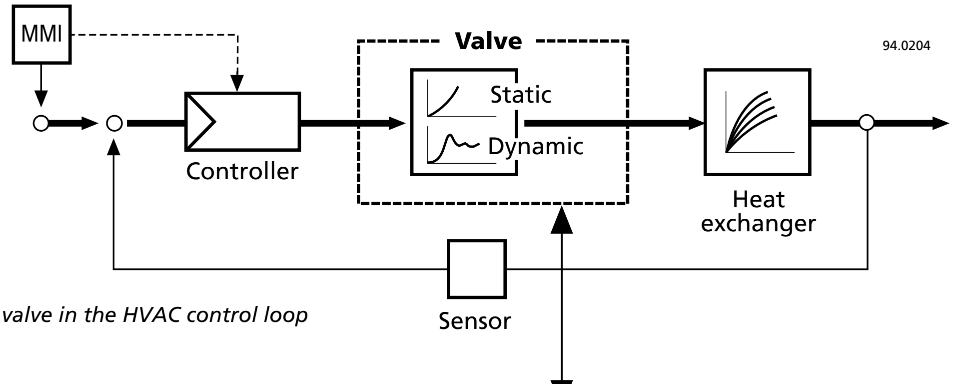


Fig. 1: The valve in the HVAC control loop

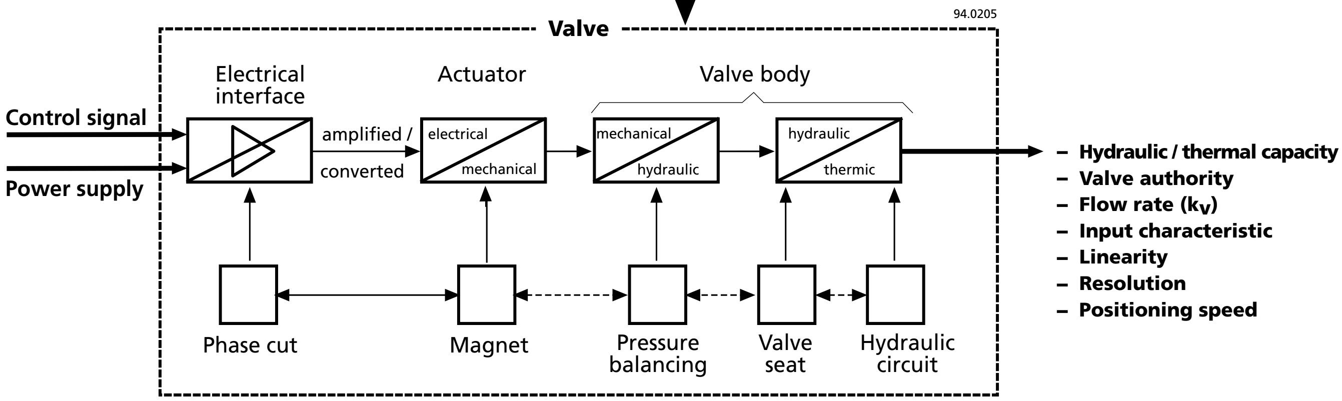


Fig. 2: The valve: An outline of the basic technology

1	Inlet port
2	Bypass
3	Outlet port
a	Magnetic coil
b	Core
c	Spring
d	Stem
e	Disc
f	Upper / lower valve seats
g	Bellows
h	Aperture for pressure balancing
i	Handwheel
k	Electrical interface

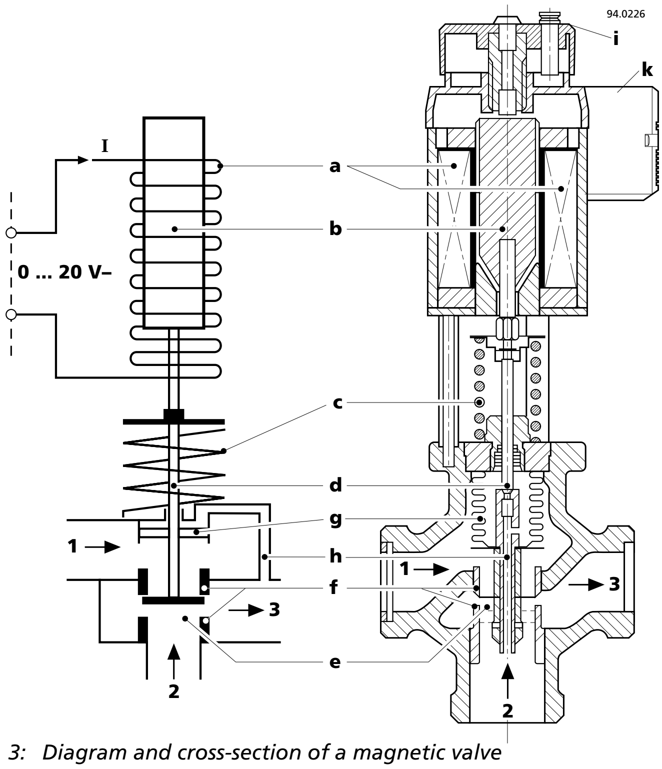


Fig. 3: Diagram and cross-section of a magnetic valve

Conversion from positioning signal to magnet voltage

The electrical interface (Fig. 3, k) is connected to an AC 24 V supply voltage and to the controller output with a DC 0 ... 10 V positioning signal for the valve. The internal phase-cut generator alters the power output of the interface in proportion to the positioning signal. The magnetic coil is connected to this phase-cut voltage (Fig. 4).

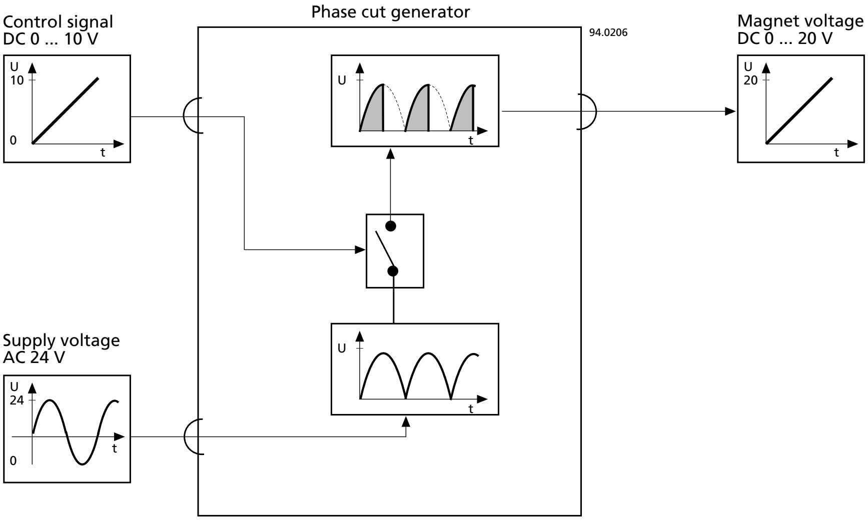


Fig. 4: Conversion of the positioning signal into a magnet voltage

Conversion from electrical to mechanical energy

a) Magnet voltage → magnetic force

In the ferromagnetic circuit, which consists of the casing (yoke) and the moving core, the voltage applied to the coil (Fig. 3) produces a magnetic field. Where the greatest magnetic resistance occurs – in the air gap – this field causes a force of attraction which becomes stronger as the voltage increases.

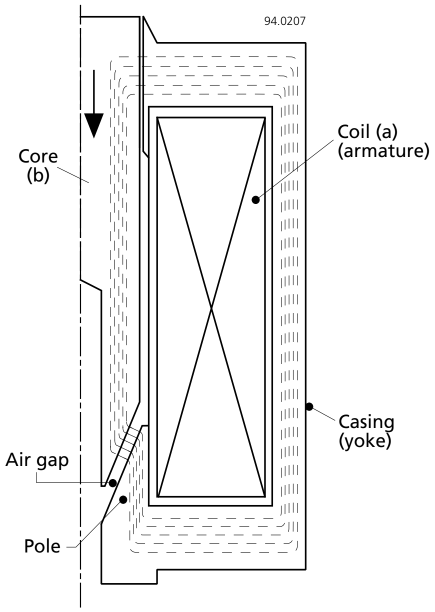


Fig. 5: The magnetic field in the ferromagnetic circuit

b) Magnetic force → counterforce → stroke

The magnetic force acts to overcome the force of a counterspring. The core now moves in the direction of the stroke until the magnetic force and that of the spring are equal. There is thus a defined stroke for each voltage signal applied.

Due to the special construction of the ferromagnetic circuit there is a linear relationship between increases in voltage and the stroke.

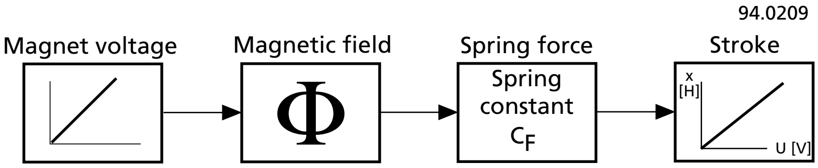


Fig. 6: Relationship between stroke (H) and voltage (U)

c) Valve control range

The full control range consists of three partial ranges:

- *Upper valve seat opening / closing range:* The closing force of the flexible disc also works here against the force of attraction. The behaviour of the valve is characterised in this range by its extremely high resolution, making very fine modulating control of fluids possible.
- *Stroke operating range:* Here, the force of attraction works only against the force of the spring.
- *Lower valve seat opening / closing range:* A reserve of force is available here, which ensures that the valve seat closes tightly.

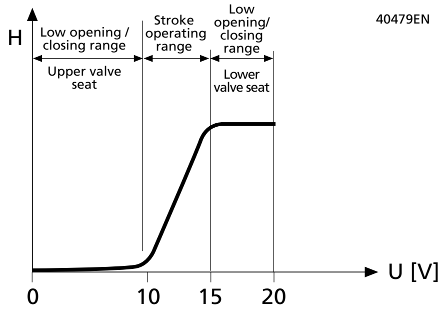


Fig. 7: Operating range of the actuator

d) Response to small signals within the stroke operating range

Within the stroke operating range, the magnetic actuator has a precisely defined hysteresis. Operating within this hysteresis, the slope changes and the stroke has a higher resolution. This feature helps to stabilise extremely difficult control loops.

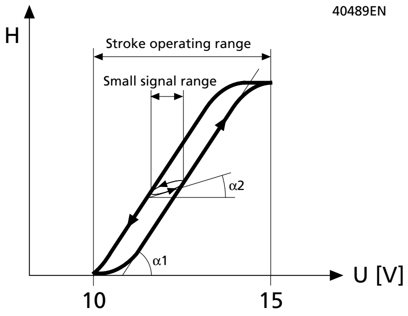


Fig. 8: Altered slope within the stroke operating range in response to small signals

e) Other influencing forces

- *Overcoming static friction*

The phase-cut voltage produces a continuous fine oscillation in the core, which overcomes any static friction between the core and the coil holder. Only sliding friction remains and there is therefore an immediate response to any change in voltage. The consequence of this is higher resolution (see Fig. 9 for an example).

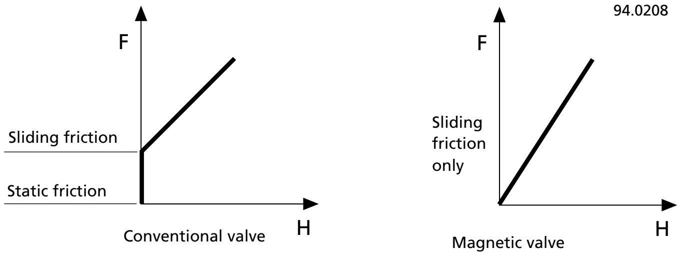


Fig. 9: Friction

- *Overcoming the pressure forces*

Differing pressures across the control path affect the magnetic force, but this potential problem can be virtually eliminated through pressure balancing. This ensures that the magnetic force is primarily used for flow control. Pressure balancing is an extremely effective solution and is achieved in practice with the aid of a bellows (Fig.10). Pressure p_2 passes through a passage in the stem into the inside of the bellows and equalises the pressure p_2 acting on the lower side of the valve disc. Pressure p_1, working on the upper side of the disc, is equalised by the pressure p_1 acting on the lower side of the bellows. This solution, within the valve itself, involves neither a special compensatory circuit nor any additional space.

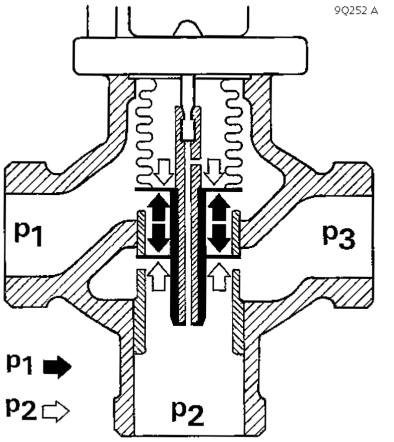


Fig. 10: Pressure balancing

Relationship between stroke and flow rate

The construction of the valve with a flexible disc as the control element means that a minimum flow is obtained immediately, as soon as the valve is “cracked” open. With an increasing positioning signal, the valve opening increases in proportion to the stroke, producing a linear increase in flow (see Fig. 11).

This flow characteristic applies both to control path 1 → 3 and to control path 2 → 3. When the valve is used for mixing, the two flows combine to give a constant flow value.

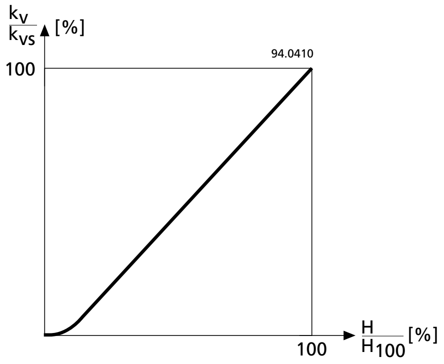


Fig. 11: Flow characteristic

Relationship between flow rate and heat quantity

When the Landis & Staefa magnetic valve is used as a simple *straight-through valve* (port 2 closed) the disc provides throttle control in response to the positioning signal from the controller.

When used as a *three-port control valve*, water from two temperature sources is mixed in a proportion determined by the positioning signal from the controller.

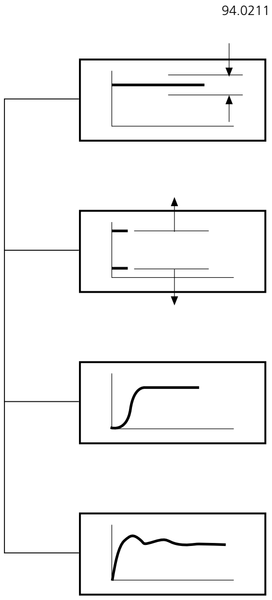
The correct hydraulic circuit and the correct installation of the valve are vital factors for control quality.

Another important criterion for the quality of a control loop is the *minimum controllable heat quantity*. The behaviour of the Landis & Staefa magnetic valve in the low opening / closing range, as described in this article, enables very small heat quantities to be controlled.

Conclusion

1) The Landis & Staefa magnetic actuator has an outstanding life expectancy, thanks to its simple construction.
2) The special behaviour of the modulating valve in the low opening range – no jump on start-up, a concave “starting curve” – ensures precise control, down to the smallest flow rates.
3) The virtually friction-free construction results in a high stroke resolution, allowing extremely accurate control of the flow rate.
4) The design characteristics of the magnetic actuator allow very quick travel through the full stroke range (1 to 2 seconds) and thus an almost immediate response to any changes in the input signal.

These special features of the Landis & Staefa magnetic valve enable even difficult HVAC control loops to be controlled.



Advantage	Main reason
Accuracy	No static friction
Wide application range	Linear stroke/voltage characteristic, high resolution in low opening range
Fast start-up response	Positioning speed
Efficient damping	Positioning speed

Fig. 12: Control characteristics

The control benefits

The quality of a control loop depends on a number of separate factors: the characteristics of the controlled system and its various elements (expressed quantitively as the 'degree of difficulty'), the controller settings and, to a large extent, the control properties of the hydraulic valve. In this context, the relevant questions are:

- *How quickly does the valve respond to a control deviation?*
- *How high is its resolution?*
- *How effectively does it control partial loads?*

The development engineers at Landis & Staefa based their work on these questions when designing the modulating magnetic valve, the product which first established the company's success. Throughout the process of continuing improvement and expansion of this market offering, the initial set of questions has remained unchanged, even in the age of widespread DDC technology in the field of HVAC controls.

Fast positioning

The simple design principle on which the magnetic actuator is based – a single moving part, the core, within a changing magnetic field – results in very fast positioning. Within the control loop, the magnetic valve is a virtually delay-free element. This has the following consequences:

- Fast elimination of interference variables
- The valve responds immediately to setpoint adjustments.
- The degree of difficulty $S_v = T_u : T_g$ of the control loop is reduced significantly : from 0.48 to 0.36 (i.e. 25 %) for example, as shown by comparative measurements in systems with magnetic and conventional valves (see Fig. 13).

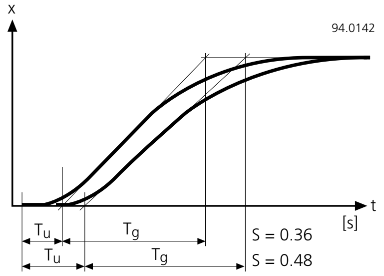


Fig. 13: Effect of positioning speed on degree of difficulty

A reduced degree of difficulty, however, also means that the admissible loop gain can be increased. The number of lag inducing elements in the controlled system can be reduced by one (see Fig. 14).

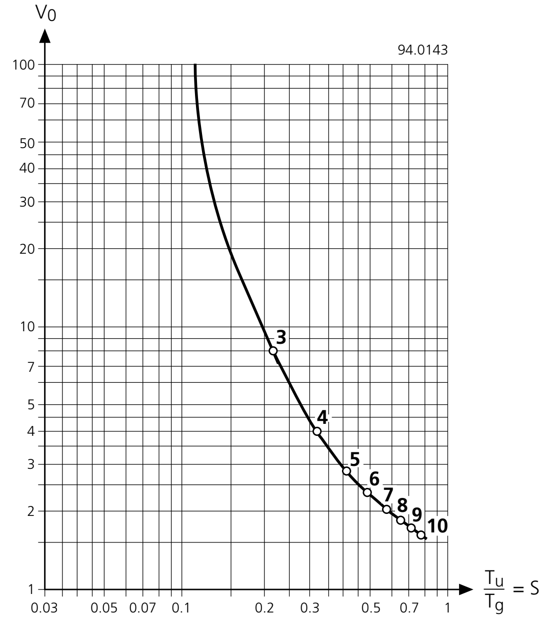


Fig. 14: Admissible loop gain V_o

High resolution

The fast, sensitive response of the magnetic actuator and the short stroke of the valve disc combine to give a valve with a high resolution. Even the smallest control deviations result in a change in the stroke and hence a change in the flow rate.
The valve controls the flow accurately across the full stroke, even at the point where the valve characteristic (K_v as a function of the stroke) is relatively steep. The average resolution ($\Delta H : H_{100}$, *where H = stroke)* of the standard Landis & Staefa disc valves is 1 : 200.

The ideal valve characteristic for control of partial loads

Figures 15, 16 and 17 show the most common types of valve characteristic in the field of HVAC controls. Figures 18 and 19 are examples of characteristic curves measured with Landis & Staefa valves across the entire stroke, and Fig. 20 depicts the curve in the low opening range (0 … 10 % stroke).
This shows the following:

- A typical feature of the Landis & Staefa valve is the flatness of the curve in the low opening range near the zero point. This is the area where the curve differs significantly from the normal linear response. The curve is concave, and there is *no jump on start-up.* The valve is *optimised in the low opening range* resulting in "drop-by-drop" control.
- In the curve in Fig. 20, the slope tolerance, as defined in the VDI/VDE guidelines, is exceeded at the point where kv = 4 %. However, these tolerances are not relevant for the Landis & Staefa valves, because as stated above, the flow is still fully controllable even where the curve is this steep. In the case of the Landis & Staefa valves, the leakage rate k_{vo} corresponds to the relevant (critical) limit value k_{vr} as defined in the VDI/ VDE guidelines.

The k_{vr} value is normally used to calculate the *rangeability, S* of a valve:

$$S = k_{vs} : k_{vr}$$

Conventional valves have a rangeability of between 50 and 100. Since Landis & Staefa valves are not subject to a maximum slope tolerance in the normal sense, there is no corresponding kvr. Hence, S would need to be calculated, using k_{vo}, giving the theoretical rangeability of the valve. With a leakage rate $k_{vo} = 0.05\ \%\ k_{vs}$, the rangeability is 1 : 0.0005 = 2000. The ability of the Landis & Staefa valve to control the flow rate in the low opening range is thus so good, that the concept of rangeability as a criterion of quality is irrelevant. The VDI/DE guidelines were written with conventional valves in mind, and do not take account of the *Landis & Staefa magnetic* valve.

Theoretical valve characteristics

The linear curve (see Fig. 15) is based on the following equation:

$$k_v = k_{vo} + n_{lin} \cdot H$$

where H = Stroke [mm]
k_v = Specific flow rate [m³/h]
k_{vo} = Flow rate where H = 0
(Jump on start-up)
n_{lin} = Steepness of curve

$$(= 1 - \frac{k_{vo}}{k_{vs}})$$

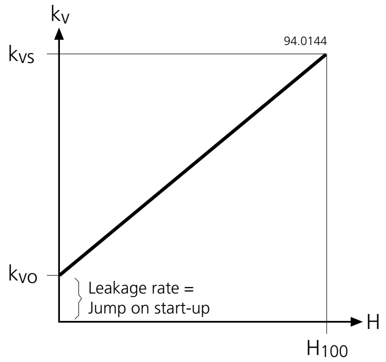


Fig. 15: Linear curve

The equation for the equal percentage (exponential) curve (Fig. 16) is:

$$k_v = k_{vo} \bullet e^{n_{gl} \bullet \frac{H}{H_{100}}}$$

The slope is not constant here, but changes with H, in accordance with the same exponential law.

The value n_{gl} determines how steeply the curve rises. For any given valve, it is a constant.

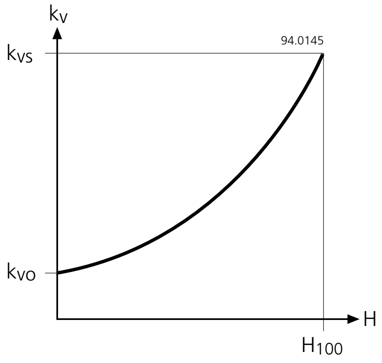


Fig. 16: Equal percentage curve (theoretical)

Actual curve of a conventional valve

In practice, the (theoretical) equal percentage curve falls away in the lowest opening range, generally producing a concave characteristic. At the point where the tangent exceeds the slope tolerance for the first time, k_v is equal to k_{vr}.

This value is used to define the rangeability of the valve:

$$Sv = \frac{k_{vs}}{k_{vr}}$$

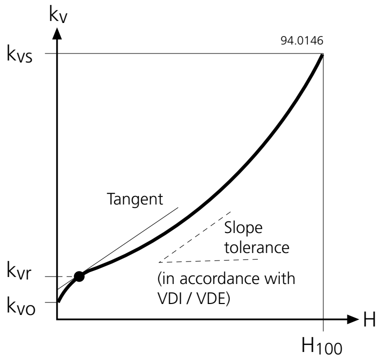


Fig. 17: Curve in practice (principle)

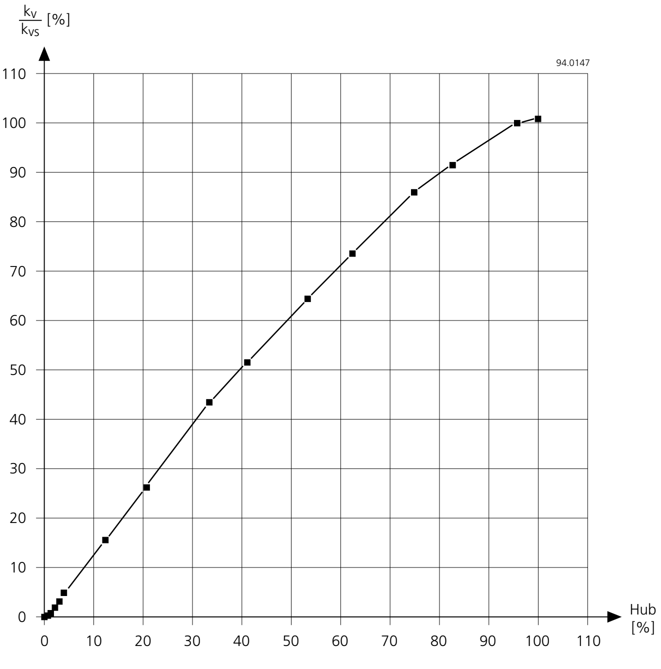


Fig. 18: M3P20F valve characteristic

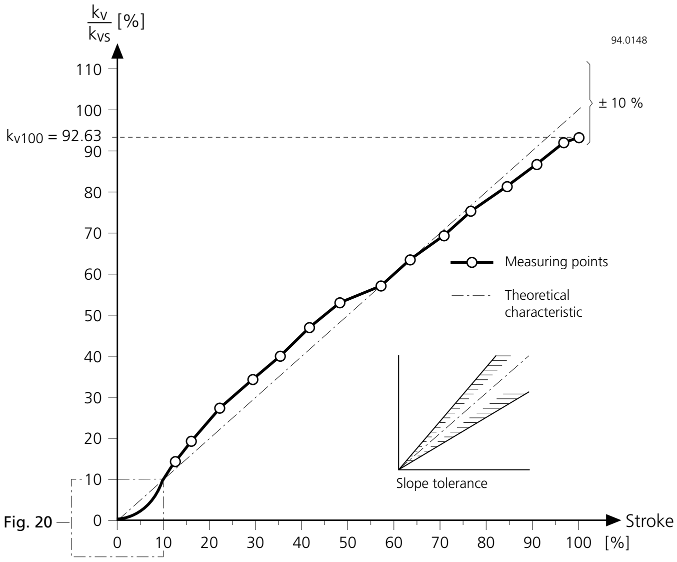


Fig. 19: M3P25F valve characteristic (across full stroke)

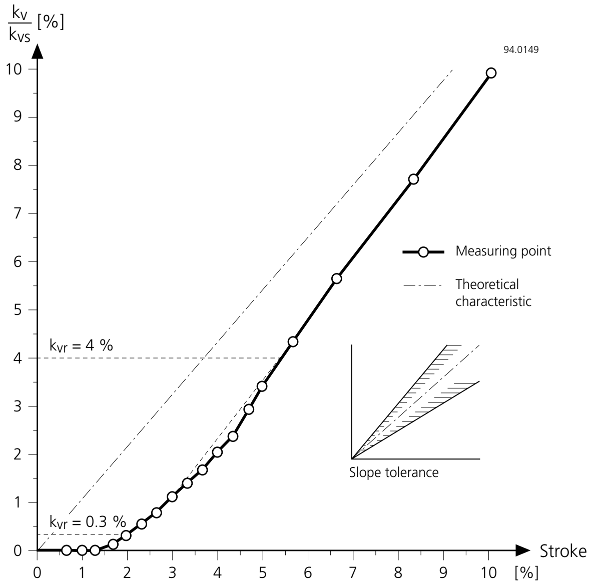


Fig. 20: M3P25F valve characteristic (low opening range)

The practical benefits: an even smaller minimum controllable heat quantity

In HVAC control engineering, hydraulic valves are normally used in conjunction with a heat exchanger. The valves control the flow of cold or hot water. The heat exchanger generally has a steep characteristic in the partial load range (see Fig. 21). Thus, even with low rates of flow, a relatively large amount of thermal energy is transferred to the air. If the valve responds with a "jump" on start-up, the minimum controllable heat quantity is significantly greater. This is not at all desirable in control terms, because it can cause the system to hunt. What is essentially a modulating form of control will become on/off control *at* this point.

A diagram (Fig. 21) is used to determine the minimum controllable heat quantity. For this purpose, two key values are required: the a-value (design characteristic) of the heat exchanger (i.e. the relationship between the difference in water temperature and the differential between the water inlet and air outlet temperature) and the *valve authority* p_v (= relationship between the pressure differential at the valve and the overall pressure differential in the variable-volume section of the hydraulic circuit).

Typical values are: $a = 0.5$ and $P_v = 0.5$. We can now compare a Landis & Staefa valve with a conventional valve on the basis of these values:

– Conventional valve: $S_v = 50$
– Landis & Staefa valve: $S_v = 200$

For the Landis & Staefa valve, the resolution should be inserted here, as it is lower than the rangeability of the valve body. (In the case of the conventional valve, the influence of the actuator has already been taken into account).

The following values can now be extracted from the diagram:

– Conventional valve: Q_{min} = 5.8 % Q_N

– Landis & Staefa valve: Q_{min} = 1.4 % Q_N

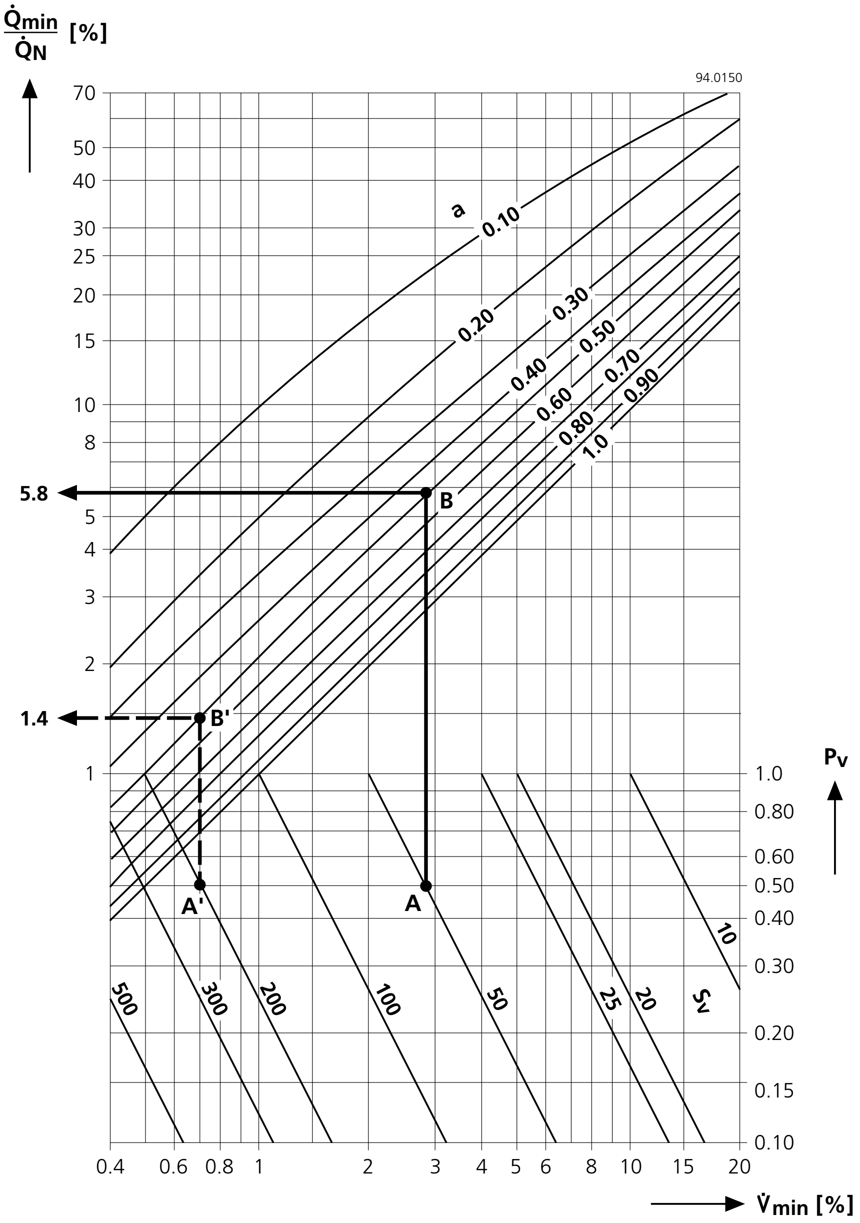


Fig. 21: Determining the minimum controllable heat quantity $\dot{Q}_{min}$ from valve authority P_V, rangeability S_v and the "a-value"(design characteristic – from "Regeltechnik", Impulsprogramm Haustechnik)

Conclusion

The modulating magnetic valves, with their outstanding control features and robust construction, minimal maintenance requirements and long service-life are ideal wherever very accurate control of temperature or humidity is required. The valves were developed for HVAC systems, but their field of application extends to industrial process control.

Certainly, the valve alone cannot optimise the control loop, but it plays the maximum possible part in achieving this aim.

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