

The modern API-Safety Valve Series, Designed in Accordance with the Latest Trends

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Summary

At the development of the new series of API- Safety Relief Valves extensive investigations of the fluid-flow were done with modern measurement technology for the recording of the function, the discharge capacity and the flow force. A new method of „Flowforce - Characteristic - Measurement“ gives the possibility of an extensive review of the quality of the shape of all parts in the flowing area and the information of possible parts-optimizing. Due to the high productive power of the Bopp & Reuther test facility it was possible to do the verifications of the required characteristics for a larger field of pressure and size much larger than needed for an ASME - certification.

In addition to these measurements special flow calculations give the knowledge about local fluid dynamics and therefore the possibility to optimize with high accuracy the parts in the flowing area. The result is the new series of API - Safety Relief Valves with ASME- and TÜV certification which gives a lot of advantages for the users.

Introduction

The so-called „API-Safety Valve“ is the most widespread all over the world. API means „American Petroleum Institute“ and it points to the fact that this safety valve standardization originates in petrochemistry, however, in the meantime it has been adopted by many other industrial branches.

The standard API 526 [1] defines design characteristics of safety valves such that the safety valves of different manufacturers are interchangeable. The planning engineer can define the safety valves already in the planning phase independent of the manufacturer and can include them bindingly into his system.

In order to permit this the API 526 defines the following design characteristics:

- the blow-off capacity for gases/steams which are assigned to the safety valves according to the seat letter symbol (from D to T),
- the connecting dimensions (side lengths) depending on the inlet and outlet flanges of the given nominal diameters (f. i. 4 x 6 inches or 100 x 150 mm) and the required pressure rating (f. i. ANSI 300 x 150),
- the maximum set pressure referring to the nominal pressure rating of the inlet flange depending on the selected material and the maximum operating temperature.

The observance of this standard is not checked or confirmed by any approval but is only documented by the manufacturer-indication „designed acc. API 526“.

The Manufacturer's Approval

The most required approval for manufacturing the API-Safety Valve is the approval according to ASME (American Society of Mechanical Engineers). The approval according to ASME Section VIII [2] is valid for pressure vessels and every safety valve is then marked with the so-called „UV-Stamp“ (UV = Unfired Vessel).

This approval confirms the manufacturer's qualification with regard to the quality requirements according to ASME VIII.

The Product Approval or Product Certification

The function and the flow quantity of the safety valve-series are proved with air, saturated steam and water in accordance with the requirements of ASME VIII in the course of a product approval. These tests are carried out on behalf of ASME by the National Board (NB) in Columbus/Ohio in the USA. The results are published for every safety valve in the so-called „Red Book“ with the title „Pressure Relief Device Certifications“. This document gives information which safety valves are certified with which pressure range and for which flow quantities, f. i. according to the requirements of ASME VIII or of the size of the current nozzle diameter d_0 and the allowed discharge coefficient K_d , respectively.

There are only very few manufacturers world-wide who cover the performance range of the API 526 with their safety valve program, have the approval according to ASME VIII and are certified in accordance with NB and may identify every API-Safety-Valve with the UV-Stamp and the indication NB on the nameplate.

After the Bopp & Reuther API 526 safety-valve-series Si 81/83/84 (figure 1) was approved in this manner in 1995 the same series was also TÜV - type test approved with the type test approval mark BKZ 1006 [3].

This TÜV-approval permits the utilization of this safety valve according to API-Standard also in systems where a TÜV-approval is required.

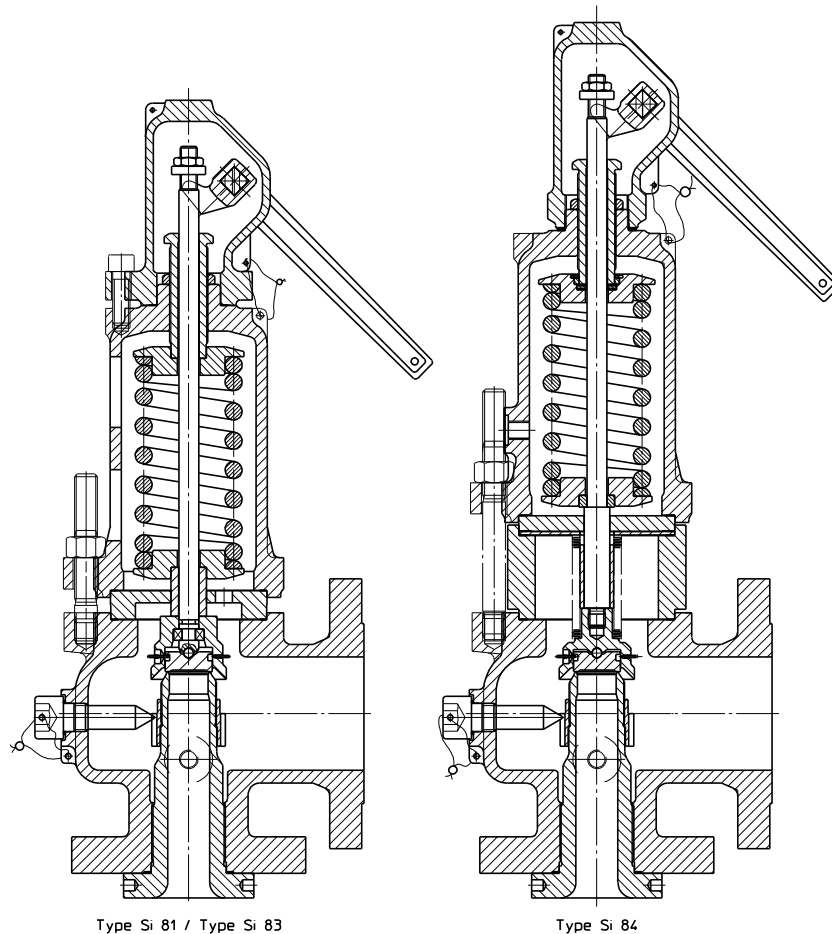


Figure 1: API-Safety-Valve without and with bellow

Object of the Development

In order to be able to obtain the above mentioned approvals quickly and reliably and to achieve high product safety and reliability, specific objectives were defined for the development of these safety valves and the modern methods of simultaneous engineering were utilized systematically.

In case of selection of the construction **with** one blow down ring these safety valves are classified according to ASME VIII with the following functional requirements (percentage referring to the set overpressure):

Gases/steams:	open	+ 10 % (min 0.2 bar)
	close	- 5 % during approval test (min 0.2 bar) - 7 % during series fabrication
Liquids:	open	+ 10 % (min 0.2 bar)
	close	no requirement

For the TÜV-Approval there is no classification as to design with or without blow down ring. The function requirements to be fulfilled according to regulation AD-A2 [4] are the following:

Gases/steams:	open	+ 10 % (min 0.1 bar)
	close	- 10 % (min 0.3 bar)
Liquids:	open	+ 10 % (min 0.1 bar)
	close	- 20 % (min 0.6 bar)

One specification for the development of these safety valves was to develop an optimized, uniform inlet nozzle giving optimal flowforce diagrams for gases/steams as well as for liquids, so that when utilizing suitable springs all function requirements for gases, steams and liquids can be fulfilled.

Hereby, this series of safety valves is also suitable for utilization of 2-phase flow even if there is no regulation yet, defining the procedure and particularly the design as to flow capacity in such cases.

Furthermore, the valve disk shall always be in its stable position at the lift stop in case of full opening. This minimum lift was determined such that f. i. during all tests incl. set pressure 1 bar (subcritical pressure ratio) the certified discharge factor could be $k_d = 0,85 \pm 5\%$ for gases/steams. The seat diameters do in the nozzle actually applied were then defined such that the discharge capacity specified according to API 526 for gases/steams is obtained, i. e. the following equation is fulfilled:

$$A_{API} * 0,975 = A_{tats.} * 0,944 * 0,9 = A_{tats.} * 0,85$$

In this equation A_{API} equals the seat area defined in API 526 for a seat letter symbol and 0,975 the corresponding theoretical flow coefficient with which the selection of the safety valve of this standard has to be made in accordance with API 520 Part I Appendix C.

For liquids the requirements should be fulfilled with the same valve program, i. e. without modification of the nozzle at the disc for ASME- and TÜV-Approval. This means that the closing pressure difference must always be smaller than 20% and the blow off capacity is then relatively high. It is not defined according to API 526.

To anticipate the result:

In fact the following discharge coefficients were certified during the NB certifications:

Gases/steams: $K_d = 0,86 = 0,955 * 0,9$

Liquids: $K_d = 0,675 = 0,75 * 0,9$

Thereby, the discharge capacity required for gases/steams according to API is safely obtained with a reserve of 1%.

For liquids the same valves show very great discharge capacities at 10% increase in pressure. Thereby, as the test record of the NB-tests proved, the closing pressure differences for liquids were always within 20%. Although this requirement was not given, it was fulfilled as well anticipating the requirements of the subsequent TÜV-Approval.



Figure 2: Bopp & Reuther large-scale test facility for pressure values up to 320 bar and a total volume of 20 m³

Fulfilment of the Development

The function opening and closing of a spring-loaded safety valve follows from the interaction of flowforce and spring force. In the certification tests the result of the correct combination flowforce/spring force is only checked with individual test valves, the size and set pressure of which being also limited by the capacity of the test laboratory. As to the approval of the whole series according to API 526 it is the manufacturer's responsibility how to guarantee safe function even for valves of great size and/or in case of high pressure.

Starting from this situation Bopp & Reuther has built one of the most modern test facilities of this kind all over the world as the solution to this responsible task (figure^o2). The installation permits tests with air and water and is characterized by its wide pressure range - until 320 bar - as well as by the high flow capacity - until 200 t/h in case of air and until 500 m³/h for water.

The test valves for steam were checked on this test facility in the same way with air. The subsequent verification during the tests in America with saturated steam confirmed our measuring results with regard to flow and function, i. e. steam is also covered as compressible medium.

This large-scale test facility has been described with all its possibilities in [5].

Before looking for a suitable spring in order to solve the task opening and closing within given limits there is the task of developing a flow geometry which is able to furnish optimal flowforce gradients.

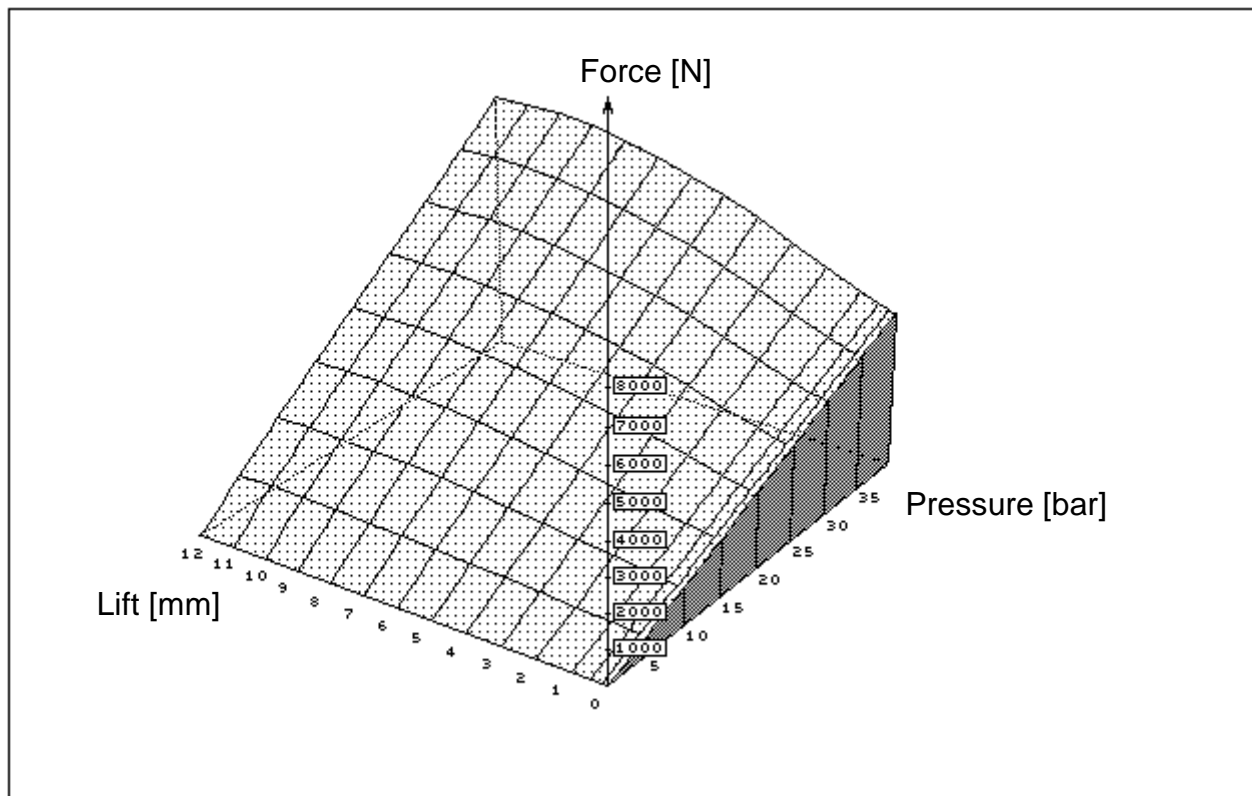


Figure 3: Flowforce characteristic of a safety valve

For this purpose Bopp & Reuther developed the method of "**flowforce-characteristic-measurement**" [6]. This method permits the evaluation of the quality of the flowforce performance gradients over a large pressure range (figure 3). Local discontinuities which usually remain undiscovered in case of individual function tests, if a test is not by accident carried out within the hazardous pressure range, are immediately discovered with this method.

Together with the "flowforce-characteristic-measurement" the flow behaviour of the safety valve is detected with a nozzle installed in front of the test specimen.

If the individual form of a flowforce-characteristic, determined by continuity and linearity of the force gradients, gives a positive characterization of the functional behaviour to be expected with suitable springs and if at the same time the flow coefficient is high enough and is constant enough under the required pressure conditions from 1 bar onwards in order to meet the $\pm 5\%$ requirement, only then coordinations of flowforce and spring force are evaluated from the flowforce characteristic for desired function values opening/closing (figure 4).

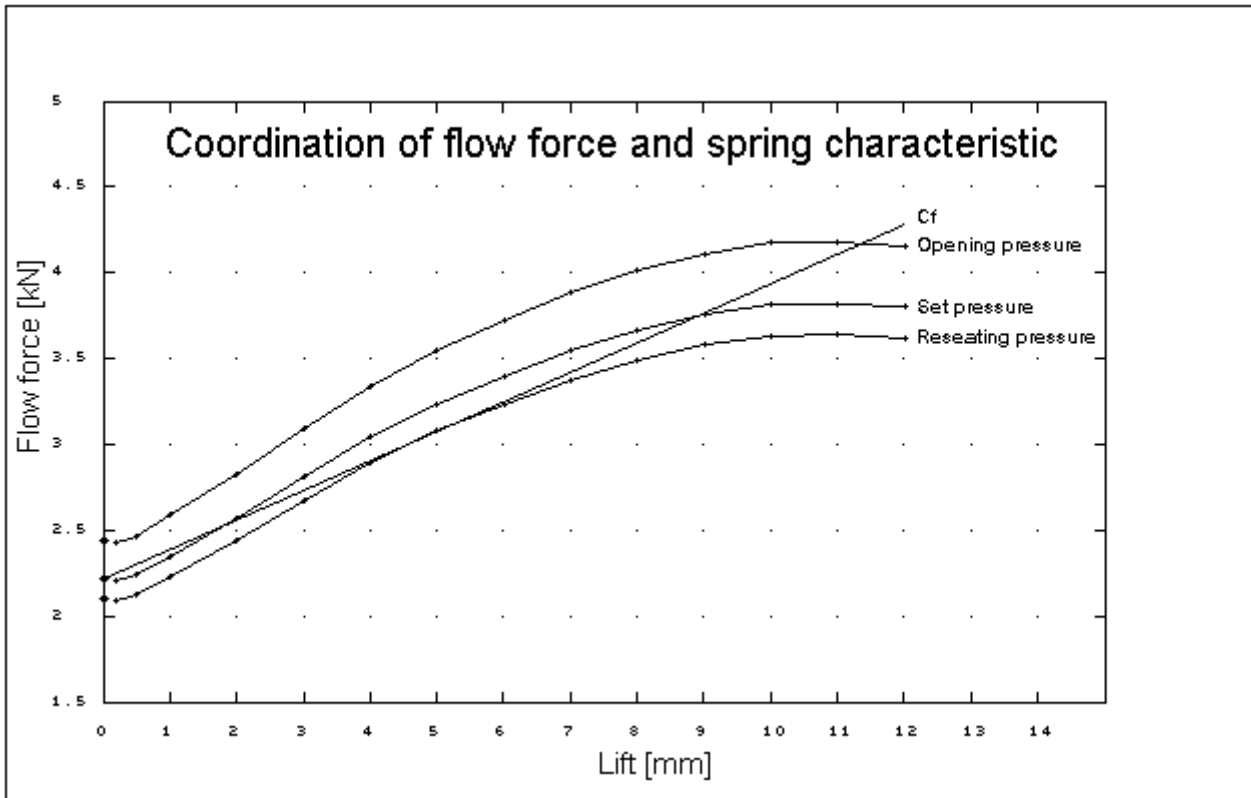


Figure 4: Coordination of flowforce and spring force for a desired function

Another evaluation results in the searched "**Spring law**" of a safety valve with the parameter closing pressure difference (figure 5).

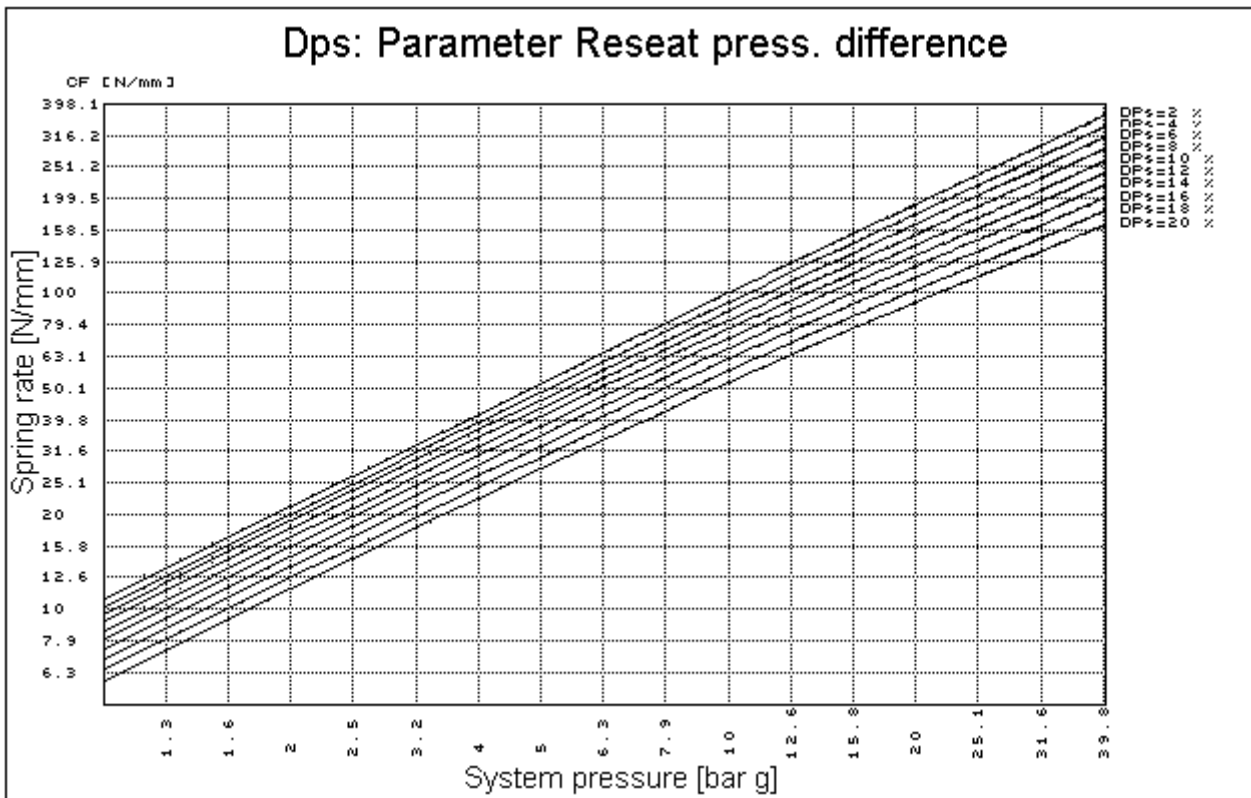


Figure 5: Spring law of a safety valve for desired closing pressures (determined from flowforce characteristic)

Only then "real" functional tests in order to confirm the actual spring adjusting ranges for a safety valve depending on the medium (gases/steams or liquids, respectively) and for the design with / without bellow are carried out. Typical results of functional measurements with spring-loaded safety valves are shown in figure 6 and figure 7.

This optimization process was carried out for a uniform flow geometry for gases/steams and liquids. Hereby, the parameter "position of the blow down ring" was not utilized. I. e. for the basic development of the optimized part in the flowing area the blow down ring is not important because it is always maintained in deep position. Actually, the manufacturing costs for the blow down ring could be saved but because of the ASME VIII - classification "with blow down ring" this is impossible. The advantage for the user, however, is that in the plant no optimization will become necessary for positioning the blow down ring.

An essential role in this optimization process was played by numerical calculations of the flow field in the safety valve with a CFD-program system according to the Finite-Volume-Method. The calculations were carried out for 3-dimensional compressible and non-compressible flow. The procedure was carefully checked by means of flow shapes known from the literature. Finally, these calculations were confirmed very well by comparison with experiments with compressible supercritical flow at a plane valve model [7].

Funktionsmessung mit Luft

DN 80 x K x 100 Si 8303

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Ansprechüberdruck : P = 30,1 bar
 Öffnungsüberdruck: Pc = 31,4 bar = 4,32 %
 Schließüberdruck : Ps = 28,1 bar = 6,65 %

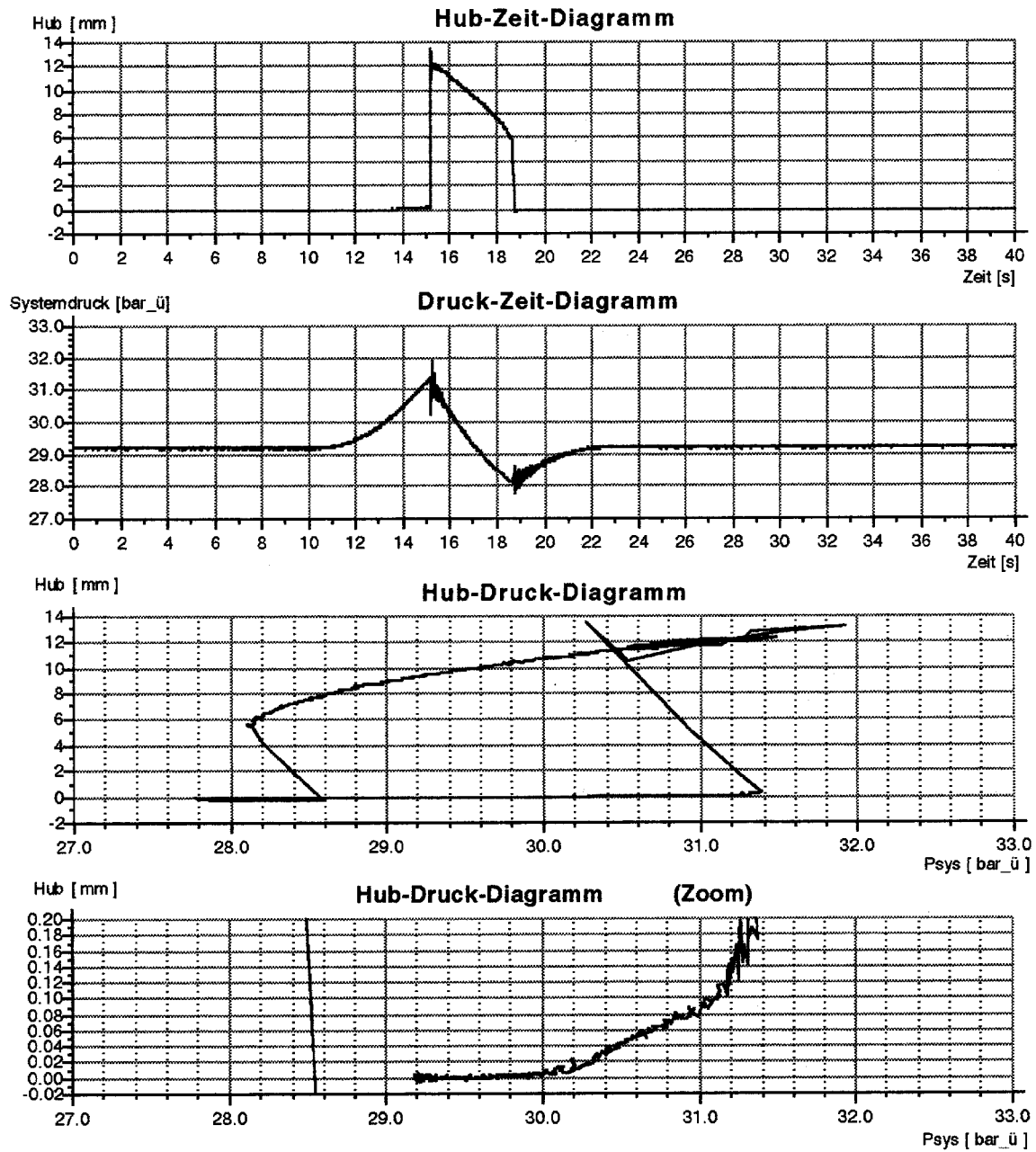


Figure 6: Result of a functional measurement with air / DN 80 x 100 30 bar

Performance Measurement with Air

DN 100 x N x 150 Si 8401

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Set Pressure : P = 4,95 bar
 Opening Pressure : P_c = 5,445 bar = 10 %
 Reseating Pressure : P_s = 4,62 bar = 6,7 %

Alfa_w= 0,87

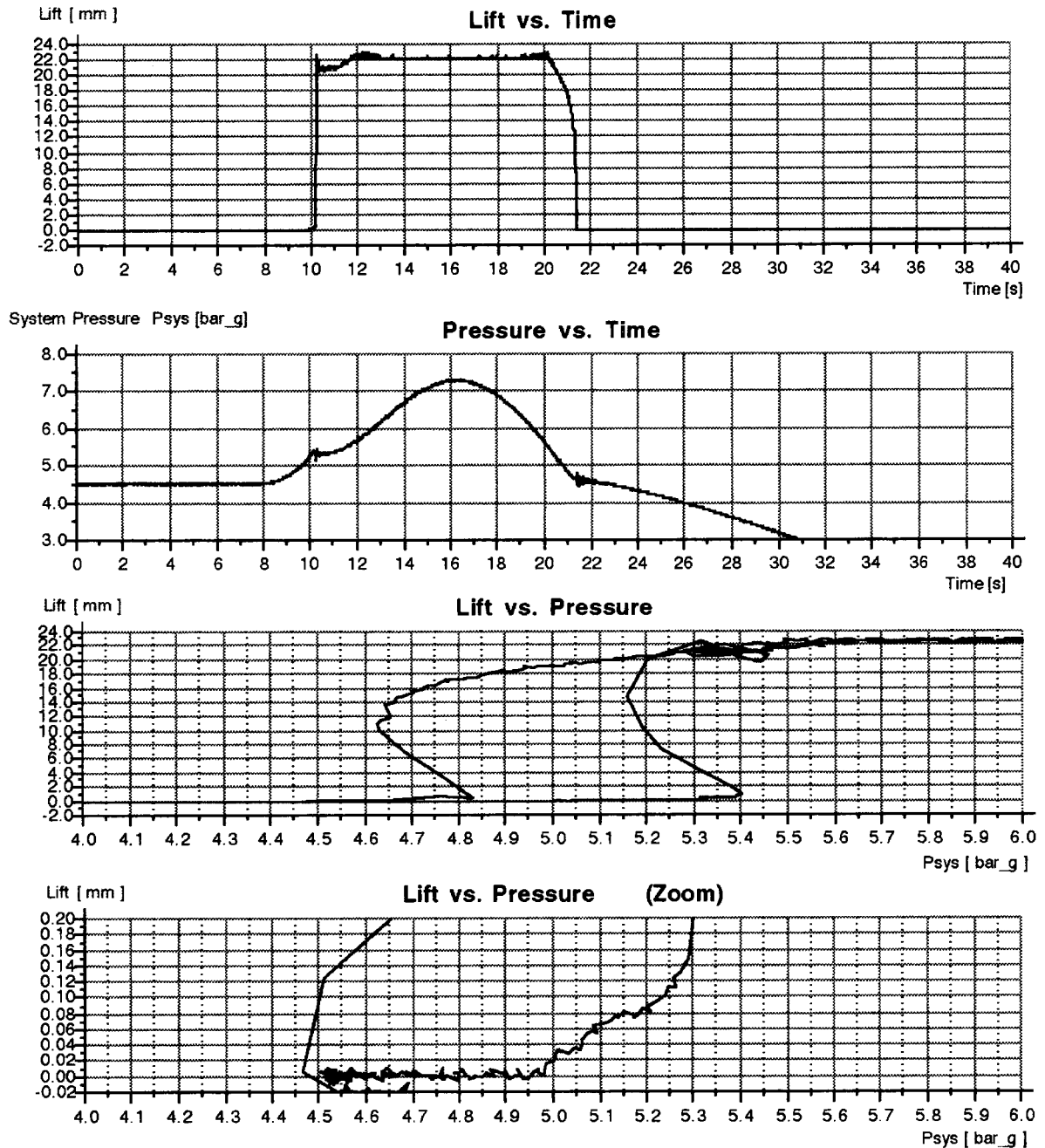


Figure 7: Result of a functional measurement with air / DN 100 x 150 5 bar

The calculation results of the spatial flow in the safety valve can be given in sections as Mach number distribution (figure 8) or as pressure distribution (figure 9).

Figure 8 shows a detail of the compressible supercritical flow between the valve seat and the shape of disk and lifting bell. In the narrowest flow cross section between the seat and the disk there is the strongly curved "sound line" with the Mach number $Ma = 1$. It is followed by a distinctive ultrasonics area with Mach numbers until $Ma = 3.3$. When arriving at the lifting bell the flow deviation leads to a sloped compression wave behind which the Mach number falls to approximately $Ma = 1.7$. At the outer lifting bell edge a "ring-shaped" Prandtl-Meyer-Expansion occurs with a new acceleration to ultrasonics with $Ma = 2.2$.

Such flow shapes have strong influence on the pressure distribution at the disk and the lifting bell (figure 9) and, thus, on the resulting flowforce. The integration of the pressure distribution at the disk and the lifting bell according to figure 9 result in the flowforce acting at the spindle which could always be compared to the measurements on the test facility. It was thus possible to determine effects of geometrical variants for the desired optimization process and to make statements as to reasons for certain measured results (remark: because of the better resolution the colour scale from red to blue indicates the pressure from 5 bar to 0.2 bar. In the area of acceleration between the seat and the disk the isobars 10, 15, 20, 25 and 30 were entered into the red colour range!)

In addition to the calculations of stability according to ASME and AD/TRD, which were required for the approvals, finite-elements-calculations were carried out. In this connection figure 10 shows the cross linkage of an API-Safety-Valve body. Regular stress distributions could be realized so that higher stresses are only present at the flanges in the area of the force introduction through the connecting screws. The situation at the flanges, however, is prescribed by the standards.

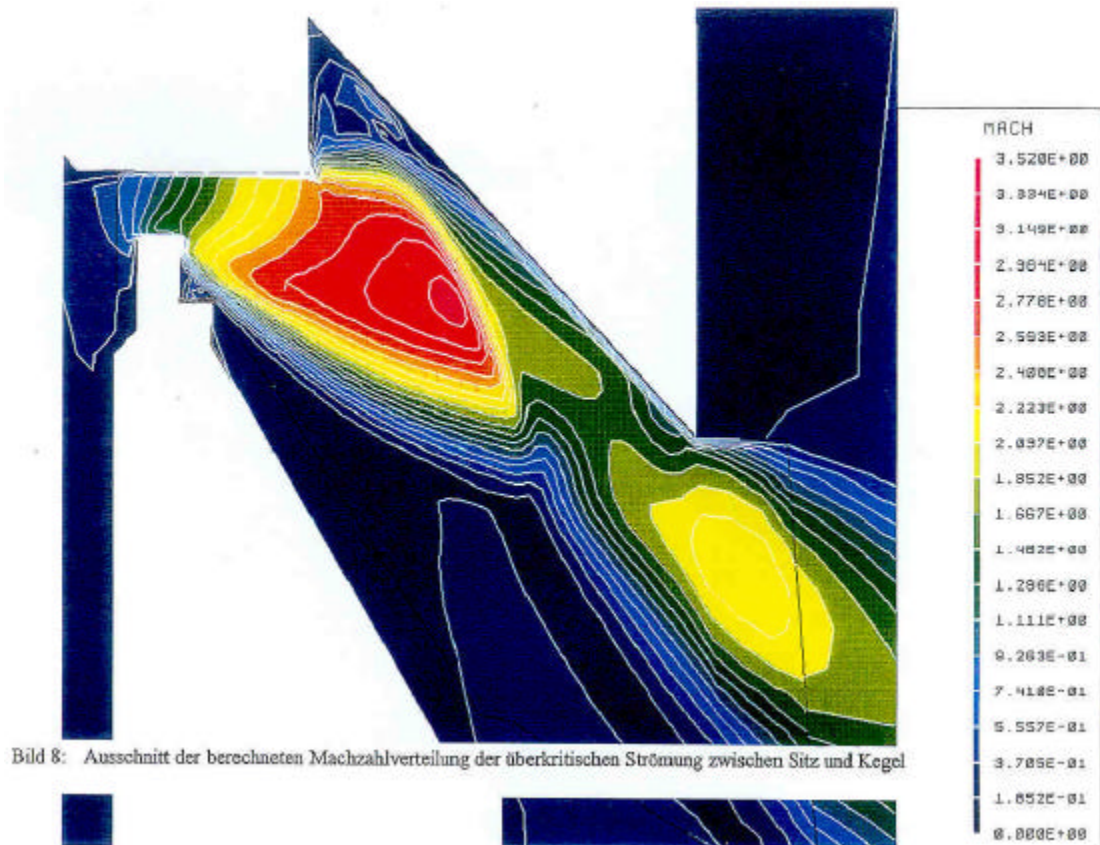


Figure 8: Detail of the compressible supercritical flow between the valve seat and the shape of disk and lifting bell (see following page)

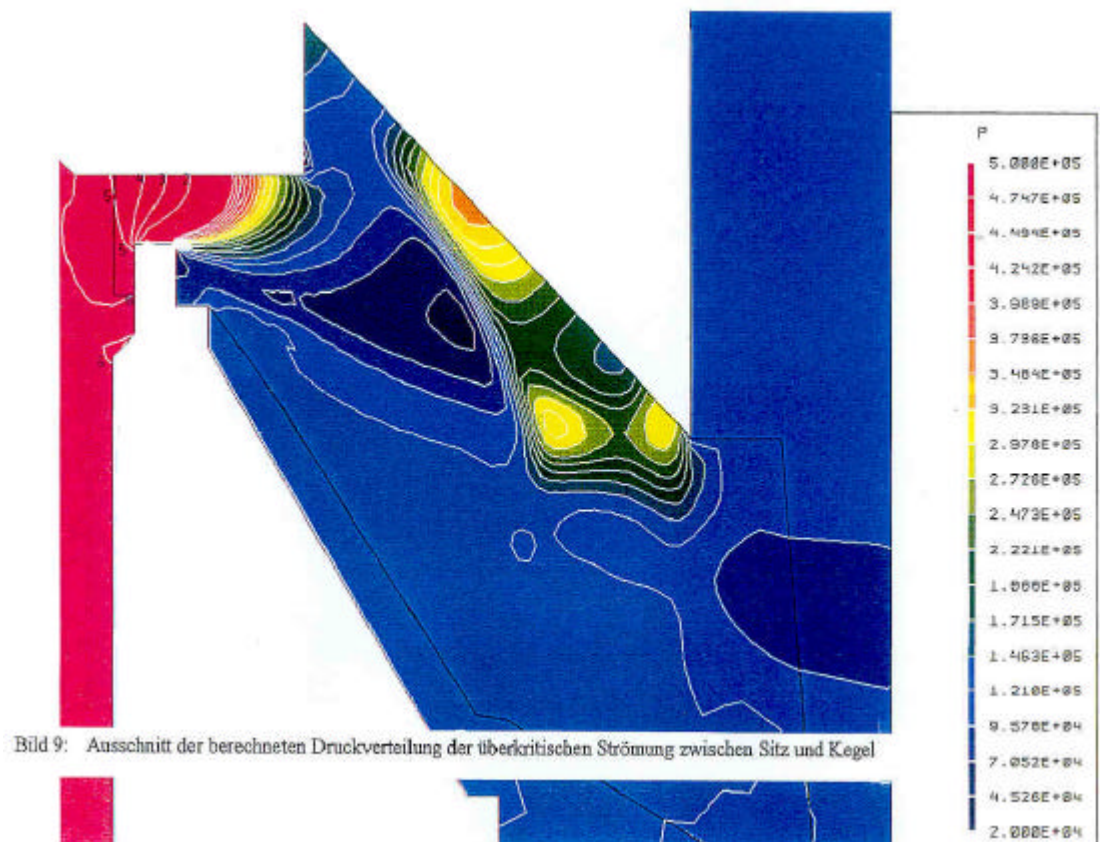


Figure 9: Detail of the pressure distribution between the valve seat and the shape of disk and lifting bell (see following page)

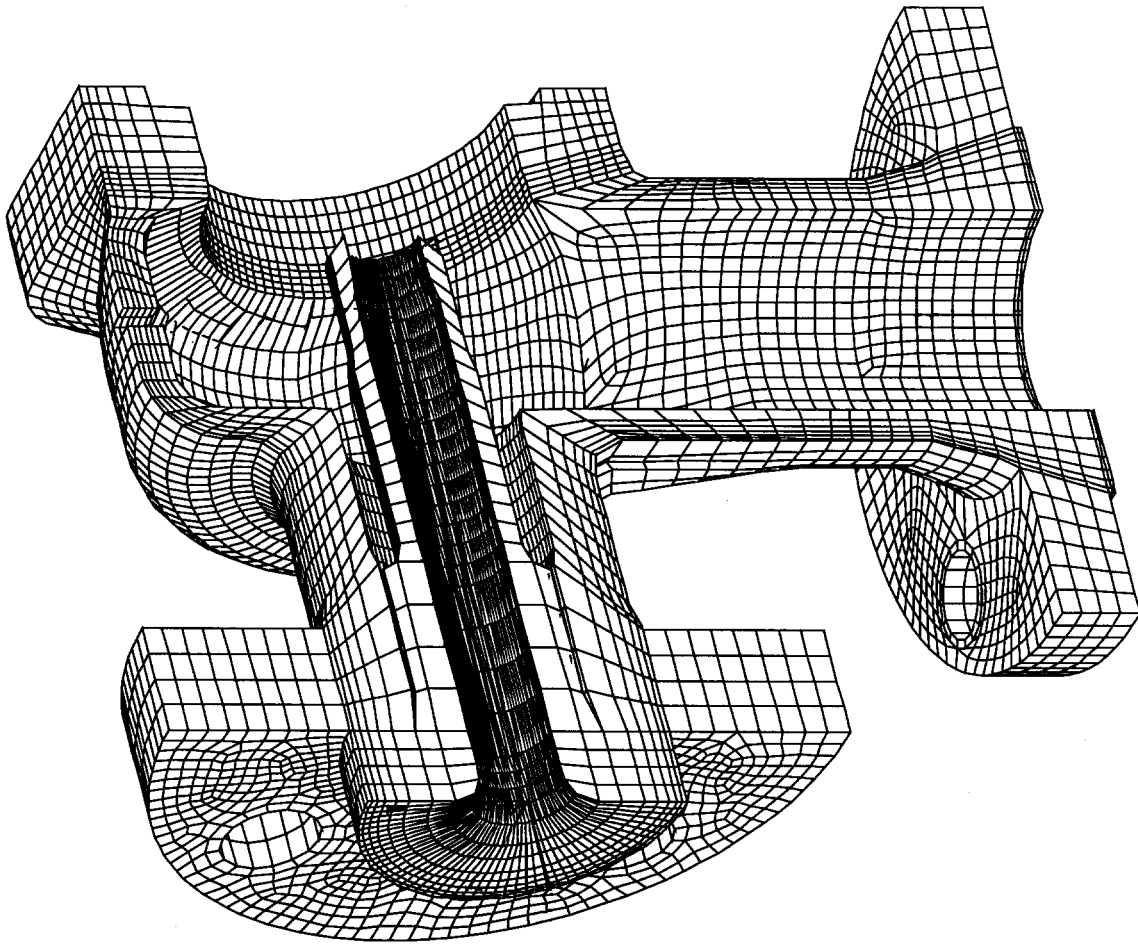


Figure 10: Cross linkage of the API-Safety Valve body for the FEM-calculation

Special design

Because of the good flow characteristics a special valve could be derived from this series (figure 11) which permits a stable proportional opening in the size 50 x 80 for 100 bar hot water 265 °C. During an actual perturbation [8] there were plant conditions during which the standard safety valve fluttered and caused the breakdown of a pipe.

Extensive tests at Bopp & Reuther and in the Wyle Laboratorium in Alabama, USA under installation conditions in the plant and under operating conditions with evaporating hot steam showed that this special design does very well under all test conditions and operates stably and reliably.

Figure 12 shows the proportional opening of the valve within the pressure increase of only 10% over the set overpressure of 100.6 bar. It becomes quite evident how the valve follows the pressure increase during the lift course. If the system pressure falls to 106 bar after having reached 107 bar the valve lift remains constant and only increases when the pressure continues to increase. This high functional stability is also the result of the effect of the installed vibration damper. During the tests with hot water in Alabama a partial evaporation, the so-called "Flashing" additionally occurred during the release.

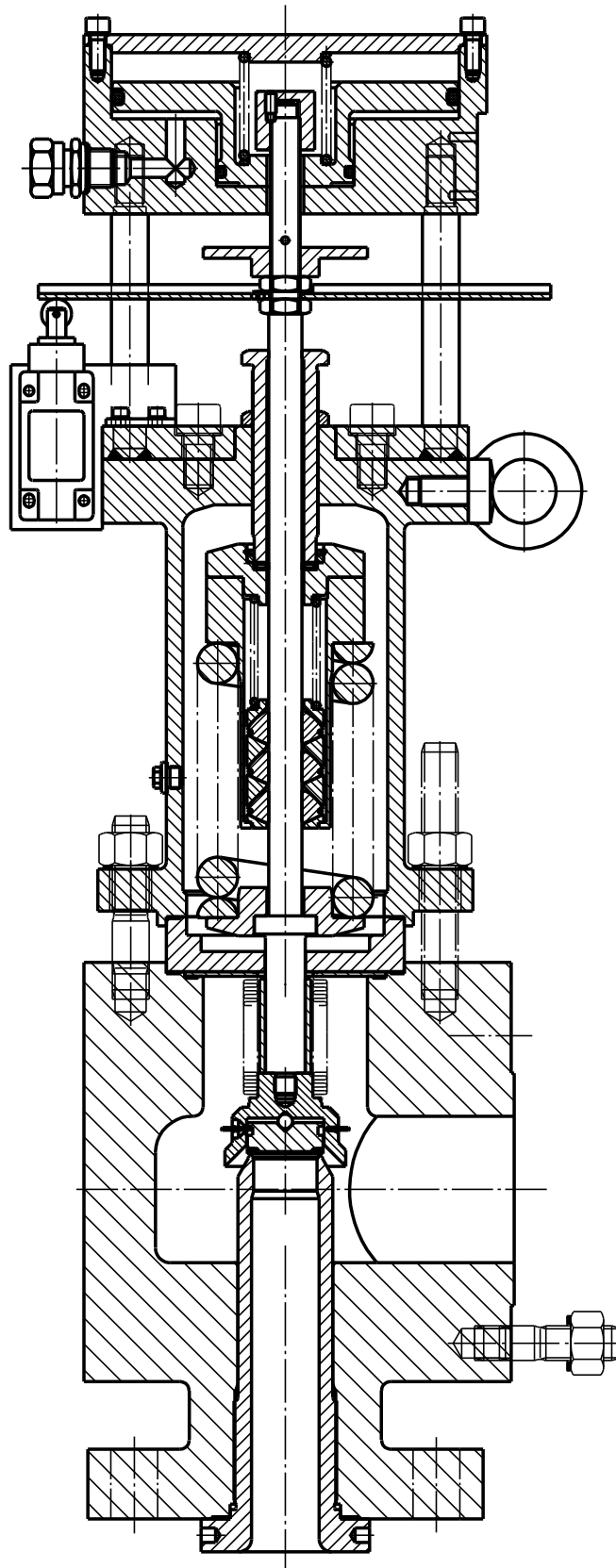


Figure 11: Proportional-safety valve DN 50 x 80 for 100 bar hot water

Performance Measurement with Water

DN 50 x J x 80 Proportional Safety Valve

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Set Pressure : $P = 100,6$ bar
 Opening Pressure : $P_c = 110,6$ bar = 10%
 Reseating Pressure : $P_s = 89$ bar = 11,5 %

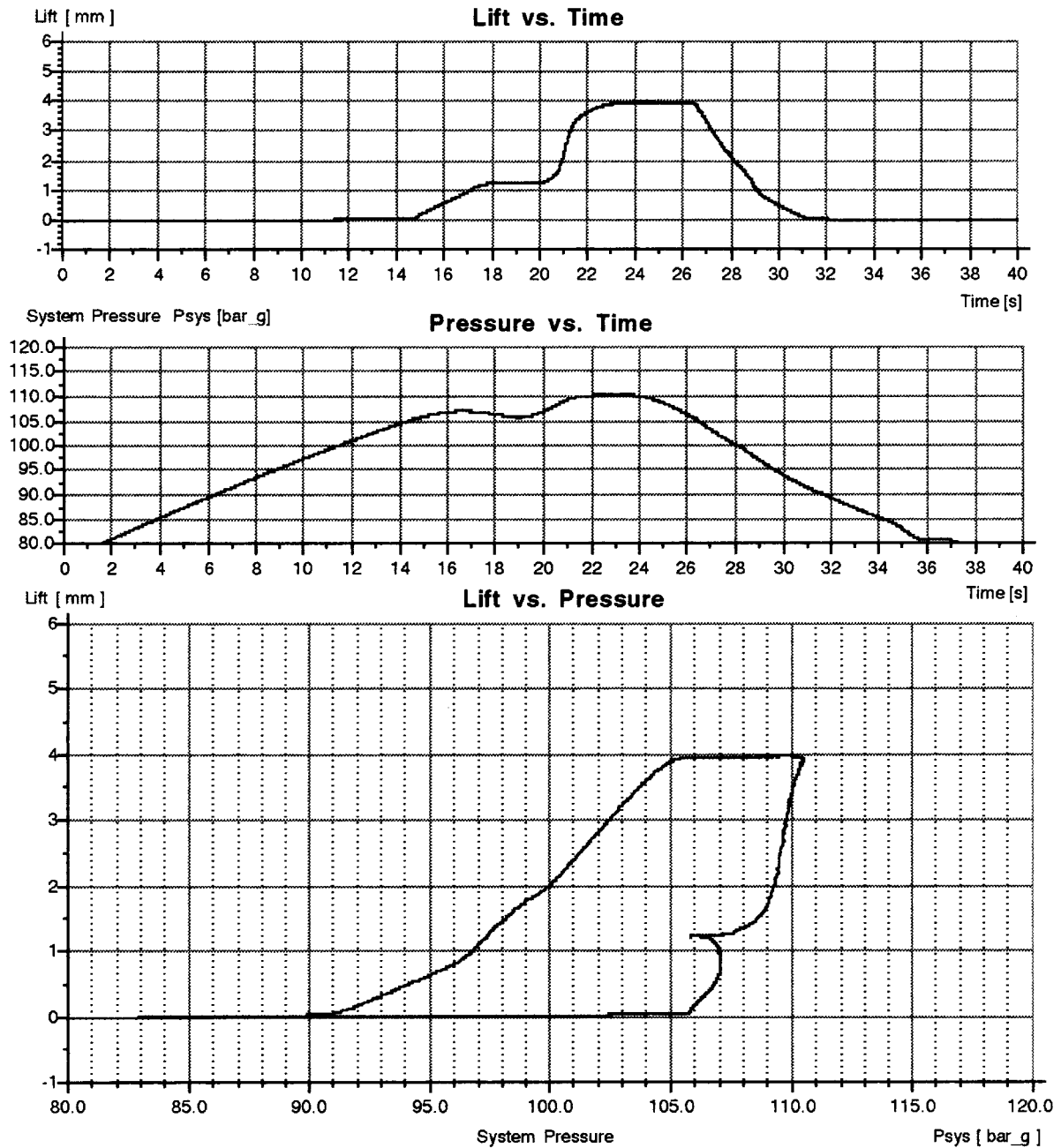


Figure 12: Functional measurement at the proportional-safety valve DN 50 x 80 with 100 bar water on the Bopp & Reuther-test facility

Summary of the Essential Characteristics

The essential characteristics of the Bopp & Reuther API-Safety Valves are:

- conformity with all specifications of API 526
- approvals according to ASME with NB-Certification and approval by TÜV
- optimized equal flow geometry for gases/ steams and liquids without adjusting the blow down ring
- therefore destined for 2-phase - flows
- high-positioned full nozzle pipe so that after the deviation at the lifting bell the flow has the body volume at its disposal for undisturbed discharge flow
- full opening (pop action) to the lift stop, i. e. stable final position
- the bellow is outside the main flow
- the bellow is balanced with the seat cross section under consideration of the production tolerances and therefore compensates the back pressure, i. e. consideration of the plant back pressure is not necessary during valve adjustment
- for lapping the disk can be easily dismounted from the lifting bell
- the springs are subject to high special quality requirements

Literature:

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