AALBORG UNIVERSITY
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Internal model control used for feed water valve located at waste incinurator

7 semester

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STUDENT REPORT
AALBORG UNIVERSITY

Preface

This report is written to document the design of a controller for a feed water valve located at a waste incinerator, and is written as the 7^{th} semester diploma project in connection to the energy engineering studies of Aalborg university Esbjerg. The purpose of this project is to meet the requirements of the university by showing the knowledge and methods learned through the time studying at the university.

Aalborg Universitet, May 5, 2023

Instructions for reading

This report has been written using Overleaf, where each chapter has it's own number and are afterwards divided into section. For references the method of the Institute of Electrical and Electronics Engineers (IEEE) has been used. The bibliography has been made with Mendeley, and BibTex. All citations has been numbered and are stated throughout the report, either in the beginning of a section/chapter, or in the middle of the text. Citations for figures are noted in the caption of said figure.

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Abstract

In this report the behavior of the feed water valve located in the system of a waste incinerator located in the city of Esbjerg, has been analysed. The work done in this report has the goal of lowering the wear and tear of the valve, while still keep inside the boundaries of low and high level alarms of the separator tank which are provided with liquid from the feed water valve. Considering the waste incinerator operators demands to the system, a controller has been designed for the feed water valve. The new controller is designed by the internal model control method, with a goal of smooth valve control, this controller has then been compared to the original system controller.

Resumé

I denne raport er opførslen af fødevands ventilen der befinder sig på en afflandsforbrænding i Esbjerg, blevet analyseret. Målet med arbejdet udført i denne raport er at nedsætte slitagen på fødevands ventilen, alt imens niveauet for lav og høj alarmerne for overbeholderen der er forsynet med væske fra fødevands ventilen, overholdes. I betragtning af operatøren af affaldsforbrændnignens krav til systemet er en ny regulering af systemet blevet designet til fødevandsventilen. Den nye regulering er designet ved hjælp af internal model control metoden, med det formål at opnå en mere jævn ventil regulering, denne regulering er så blevet sammenlignet med den originale system regulering.

Contents

1 Introduction

A waste incinerator is used to deliver district heating and electricity to around 25.000 households in the danish city of Esbjerg. The facility is build up as a steam cycle with co-generation. The control scheme of the system is maintaining the level in a water and steam condensate tank by regulating a level control valve and pump on the tank inlet. The controller aggressively track the level setpoint deviation, causing the level control valve, also known as the feed water valve, to continually adjust positioning resulting in increased equipment wear out. Strict level tracking is not necessary since the condensate level of the tank needs only to be within a tolerated range and not on the exact setpoint.

1.1 Problem statement

This has led to the following problem statement:

How is it possible to make a control design for the valve and separator system which ensures the condensate level of the separator tank remains inside the desired range and at the same time make the valve control less sensitive.

To find a solution for this problem statement the system and its components will be presented and analysed in chapter 2. Data given by the waste insinuator plant will be presented in chapter 3. Using the information gathered in the analysis of the system, and the data from the plant, the system will be modelled mathematically in chapter 4, this model will be linearized and used to obtain transfer functions which are analysed in chapter 5. The original control of the system is presented in chapter 6.2 together with the theory of the control design method used to reach the desired system response. This method is then utilized in chapter 7 where the results are also analysed.

2 System Analysis

The waste incinerator is driven like a steam cycle, as seen in Figure 2.1, and produces both electricity and district heating. The feed water system begins at point 1-2 by raising the pressure through a pump, after which the water enters the economizers to be heated up in points 2-3, before entering the separator tank at point 3-4 to be heated up before moving to the super heaters. [1] The super heaters and the turbine will not be described since this is out of scope for the problem. All information about the components of the system is found in the data sheets which are listed in appendix E.

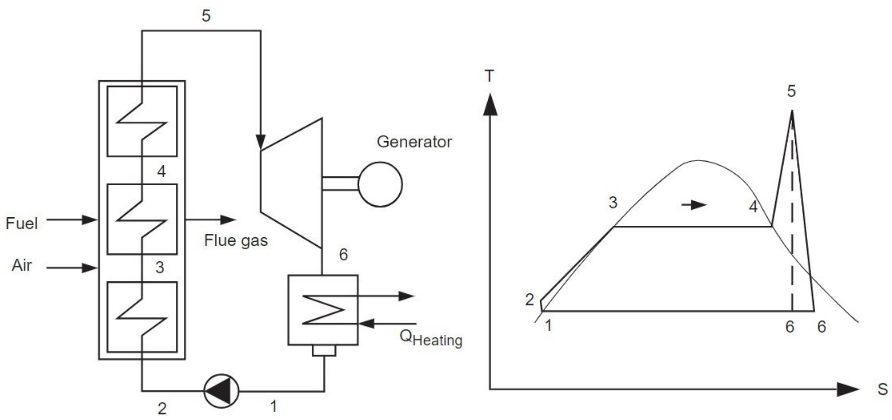

Figure 2.1: Basic principle of a steam cycle including co-generation. [1]

In Figure 2.2 the feed water system of the waste incinerator is shown. Here the system is simplified by only showing the relevant parts of the system.

- Feed water pumps
- Control valve
- Three way valve
- Economizers
- Separator tank
- DP Level transmitter

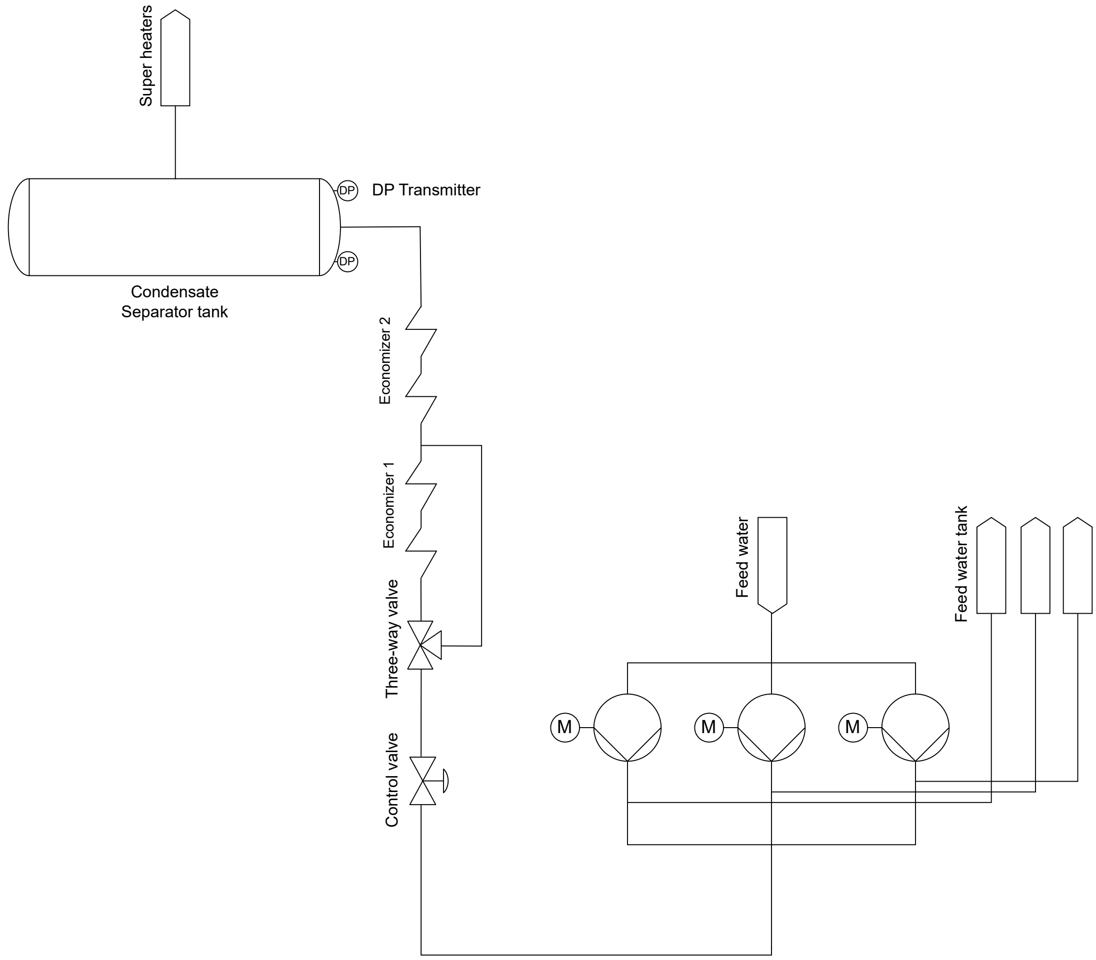

Figure 2.2: Feed water system at the waste incinerator

2.1 Pump

At the system inlet are three pumps delivering the feed water from the feed water tank to the condensate tank. These are horizontal ring-section pumps, model HGM 4/5, driven by a motor with a frequency converter. The pumps have a capacity of 125 $\frac{m^3}{h}$ each and operate in the speed range 1800 $\frac{1}{min}$ to 3600 $\frac{1}{min}$.
The pump manufacturer has provided the pump curve seen in Appendix C, together with the power curve. At the current control scheme the pump is set to provide a constant pressure of 74 bar to the system and therefore does not operate at the best efficiency point for the pump at all times. There is installed three pumps in the system, but when the facility is in operation only one of the pumps are running, with the two remaining pumps functioning as spare pumps. If the main pump malfunctions and one of the spare pumps malfunctions, the entire system is shut down.

To model the pump the model from Yang and Børsting [2] has been used, this model has the following equations for pump head and power.

$$
\begin{aligned}
H(\omega, Q_{out}) &= a_0\omega^2 + a_1\omega Q_{out} + a_2 Q_{out}^2 \\
P(\omega, Q_{out}) &= p_0\omega^3 + p_1\omega^2 Q_{out} + p_2\omega Q_{out}^2 + p_3 Q_{out}^3
\end{aligned} \tag{2.1}
$$

And considering the affinity law which states.

$$
\frac{Q_1}{Q_2} = \frac{\omega_1}{\omega_2} \qquad \frac{H_1}{H_2} = \frac{\omega_1^2}{\omega_2^2} \qquad \frac{P_1}{P_2} = \frac{\omega_1^3}{\omega_2^3} \tag{2.2}
$$

A derived version of this function can be used to model he pump disturbance in chapter 4

2.2 Control Valve

The first valve the feed water goes through is the control valve. The control valve is a feed water control valve series 300.05 DN 125 from HORA, which is a z-type globe valve. The globe valve restricts flow by moving its disc into the seat. This blocks the fluid so that it can not flow through the valve. [3] The control valve is send signals about the water level in the separator tank, and is given signals from the system whenever the water level deviates from the desired level. The control valve operates in the range of 10% to 95% opening. The control valve is an equal percentage valve, which means the plug of the valve are shaped differently from the linear and the quick opening valves[4], as seen in figure 2.3.

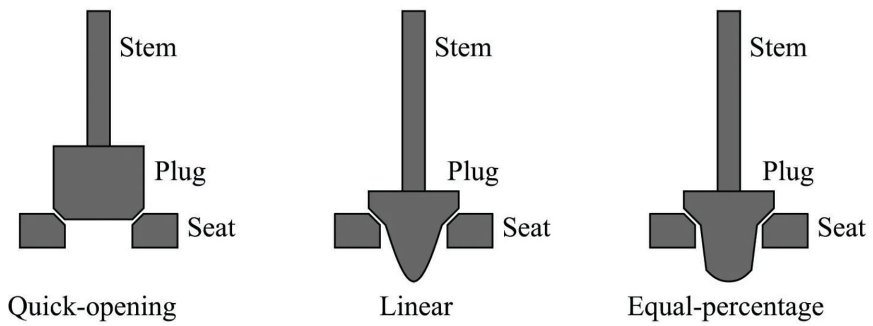

Figure 2.3: Different plugs for quick-opening, linear and equal-percentage valves. [4]

The variation in plug design results in different valve flow characteristics as seen in figure 2.4.

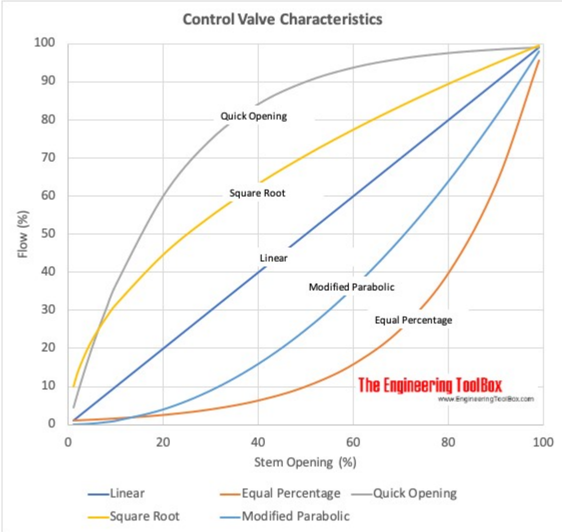

Figure 2.4: Control valve characteristics for different valve types. [5]

Since the feed water valve is an equal percentage valve the flow characteristic for the valve is an exponential function described in [6] as:

$$f(x) = R^{x-1} \tag{2.3}$$

Where x is the valve opening and R is a value stated in the data sheet. For the feed water valve the value is $R = 40$.
The flow across the valve is determined by the equation described in [6] as.

$$Q_{in} = C_v f(x) \sqrt{\frac{\Delta P}{SG}} \tag{2.4}$$

Where C_v is the orifice coefficient, an imperial unit that express how many gallons can pass the orifice per minute at a 1 bar pressure loss. To get the metric counter part K_v the value of C_v has to be multiplied by 0,862. ΔP is the pressure drop over the valve, and SG is the specific gravity which is 0,99756. With this, the flow equation becomes

$$Q_{in} = K_v \cdot 40^{x-1} \sqrt{\frac{\Delta P}{0,99756}} \quad \left[\frac{m^3}{h}\right] \tag{2.5}$$

Q_{in} is the flow across the valve. The valve will be modelled in chapter 4. After the control valve the water continues to the three-way valve.

2.3 Three-way valve

The three way valve is also a valve from HORA, but is a three-way distribution valve series 300.06 DN 150, Which is diverging the feed water either into the first economizers or around the first economizer and into the second economizer. The three-way valve is controlled by the temperature signal of the flu gasses right before the inlet of the separator tank. If the temperature of the flu gasses reaches 183 °C the three-way valve will redirect the water. Since the data shows that the opening of the 3 way valve on average lies between 9,5% and 10,5 % the three way valve will be modelled as a minor loss of the system, as described in Appendix A.

2.4 Economizers

Knowledge is from [1]. The economizers are used to preheat the feed water with convective heat transfer surfaces. This helps to extract more heat from the flue gasses. The economizers are of the non condensing type. The economizers will be modelled as minor losses of the system, as described in Appendix A.

2.5 Separation Tank

After going through the economizers the feed water enters the water-steam separator tank. This tank operates at 271 °C and can produce up to 90 tons of steam per hour. The tank consist of a demister which is used to improve the removal of water droplets in the vapor steam. In the top of the tank a mesh is added to trap the vapor at the top close to the outlet going to the super heaters.
An outlet is placed in the bottom of the tank for down comers, which is all the water that has been separated from the vapor steam. The tank has a operation pressure of 54 bar. An illustration of the tank is seen in figure 2.5

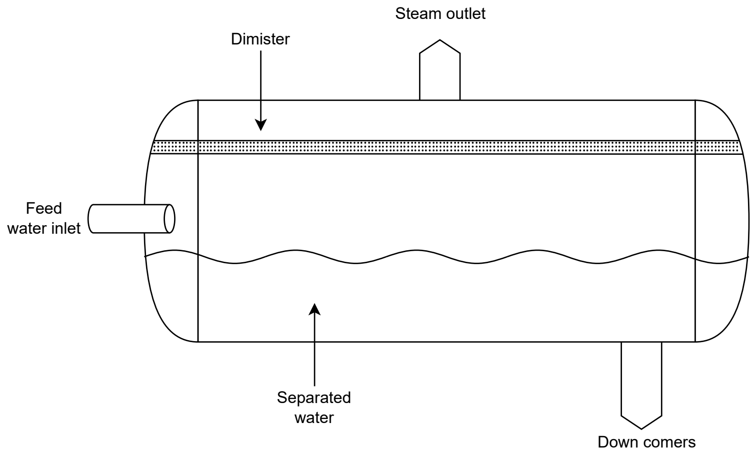

Figure 2.5: Illustration of the steam drum.

A linear function can be derived to describe the volume of the tank as a function of the level of the condensate [7]. The calculations can be seen in appendix B For this separator tank it becomes:

$$A(h) = 14,658h \tag{2.6}$$

Volume change inside the separator relates to the flow.

$$\frac{dA}{dt} = 14,658\frac{dh(t)}{dt} = Q_{in}(t) - Q_{out}(t) \tag{2.7}$$

The liquid height of the tank against the volume of the tank has been plotted in figure 2.6.

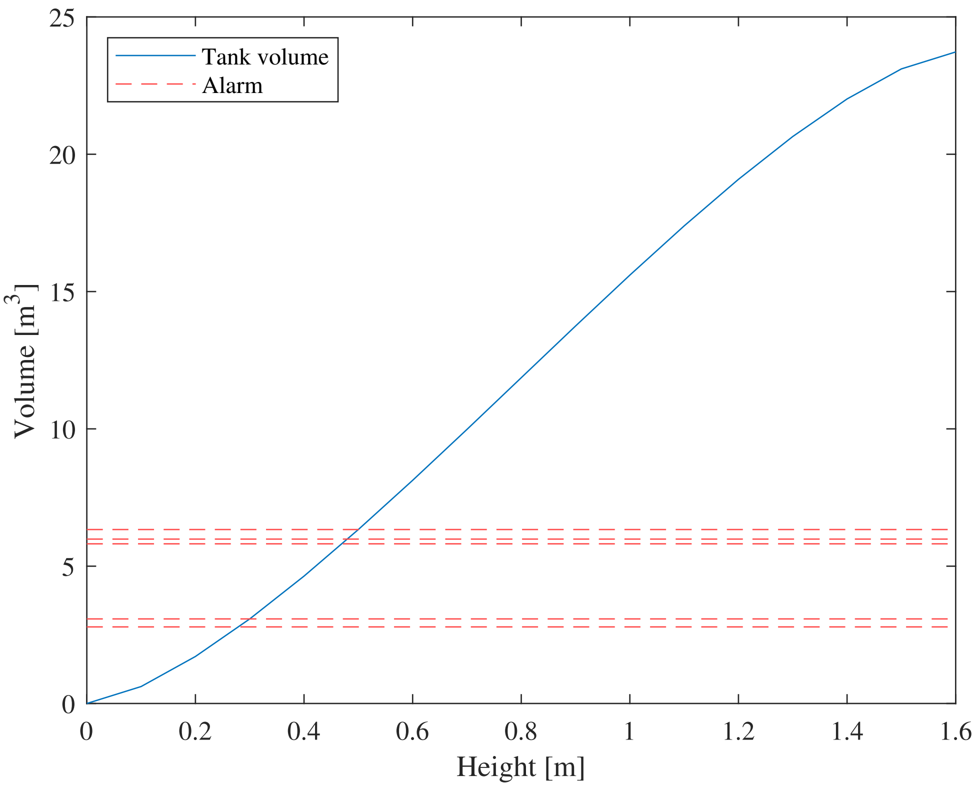

Figure 2.6: Volume as a function of height

2.6 Level transmitter

To measure the liquid level of the tank a differential pressure transmitter is used. This is a continuous type of level measurement, within a specific range. The liquid level is measured by having a reference point to take measurements, this is referred to as the high pressure side, this reference point is at the lower end of the vessel but never at the bottom. This is to avoid that the vessel become completely drained. The second measurement is on the low pressure side, this is connected above the expected maximum level of the liquid.

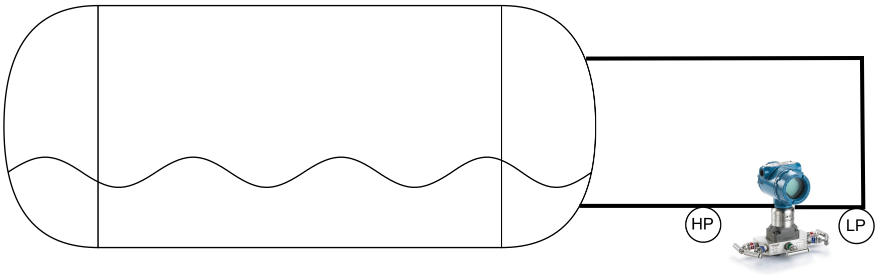

Figure 2.7: Placement of the pressure transmitter on the separator tank.

The pressure transmitter of the system is a DP transmitter ABB Multi Vison 2010TD, which uses an overload diaphragm, an internal absolute pressure sensor and a silicon differential pressure sensor.Which s placed on the tank as seen in figure 2.7.
The level sensor has 5 level alarms which turns on if the water level of the tank crosses a certain level. These alarms are measured away from the setpoint.

- -120mm away from setpoint - Low alarm 2
- -100mm away from setpoint - Low alarm 1
- 70mm away from setpoint - High alarm 1
- 80mm away from set point - High alarm 2
- 100mm away from setpoint - High alarm 3

The setpoint inside the tank is at $\approx 40cm$. To calculate the liquid level the following equation can be used [8].

$$P = \frac{\rho g h}{100.000} \tag{2.8}$$

Where P is the differential pressure range in Bar, ρ is the density of water in $\frac{kg}{m^3}$, g is the gravity in $\frac{m}{s^2}$ and h is the water level in m.

2.7 Actuator

The feed water valve is actuated by via a pneumatic diaphragm actuator.

3 Data Analysis

Two data sets has been provided by the waste incinerator operator. These data sets measure the pump speed in percent, the feed water valve opening in percent, the three way valve opening in percent, and the height divergence from the set point in the separator tank in mm. In data set 1 the measurements has been running for 6 minutes with 5 second sampling. Whereas data set 2 has been measured for 3 hours with measurements every 5 minutes.
Because the data has different measurement frequency they also look different. Data set 1 has been used for the modelling of the system and data set 2 will be used for verification of the model.
Also the pressures of the system has been collected as constants, these are:

$$\begin{aligned} P_1 &= 1,3bar \\ P_2 &= 74bar \\ P_3 &= 54bar + P_{loss} \\ P_4 &= 54bar \\ P_5 &= 54bar \end{aligned} \tag{3.1}$$

Because of limited data it has been assumed that $P_4 = P_5$ and with the modelling of the three way valve and the economizers as minor losses $P_3 = 54bar + P_{loss}$, the placement of the different pressures can be seen in figure 4.1.

3.1 Data set 1

In Figures 3.1, 3.2 and 3.3 data set 1 can be seen plotted. The data for the three-way valve has not been plotted since these data will not be of use.
In Figure 3.1 the liquid deviation from the set point has been plotted, where the setpoint is set to be 0 and the deviation from the set point is in mm. As seen the liquid level does not reach a critical point at any time, and are far from all alarm points. Especially far from the high alarm points.

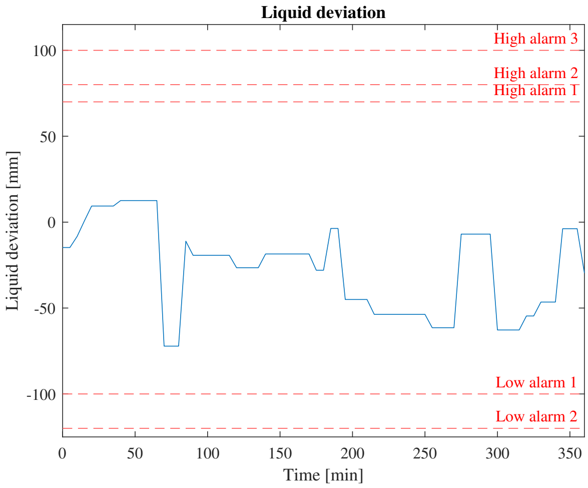

Figure 3.1: Plotted data over the liquid level in the separator tank.

In figure 3.2 the pump speed is plotted in percentage. As seen the pump operation is very rough, since it operates at either almost off, or near max operation speed. The pump is currently controlled to maintaining a system pressure of $74bar$ from the pump and to the feed water valve.

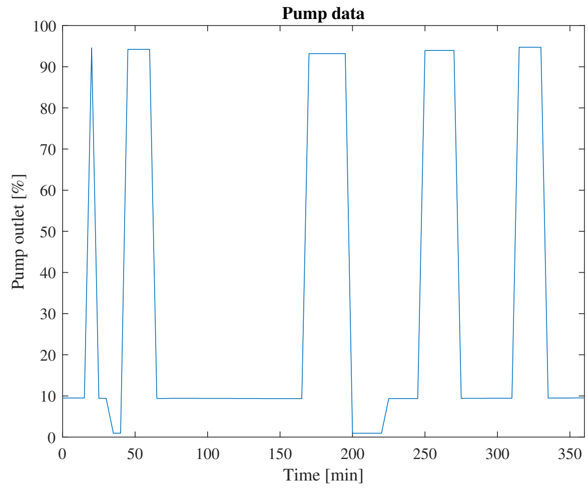

Figure 3.2: Plotted data over the pump work.

In figure 3.3 the feed water valve opening is plotted in percentage. Like the pump the operation of the valve is very rough, and the valve operates mostly between 10% and 90% opening. The feed water valve is controlled according to the liquid level of the separator tank.

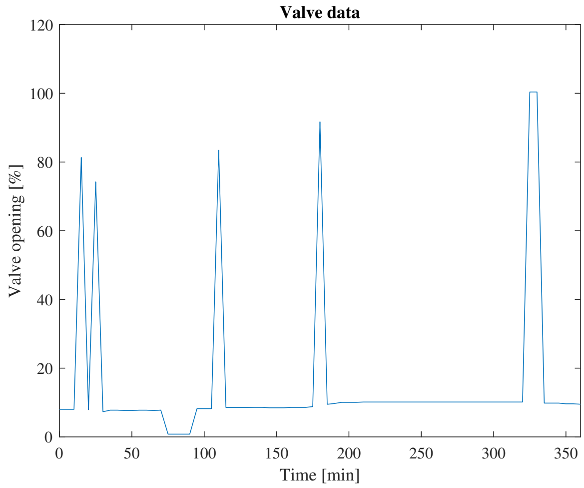

Figure 3.3: Plotted data over the valve opening.

3.2 Data set 2

The plots for data set 2 is not presented here but can be seen in appendix D.

4 Modelling

To simulate the system a model has to be developed. In this chapter three models will be made describing the pump, feed water valve and the separator tank. These models are based on [2], [6] and [7].
In figure 4.1 the different pressures location in the system can be seen.

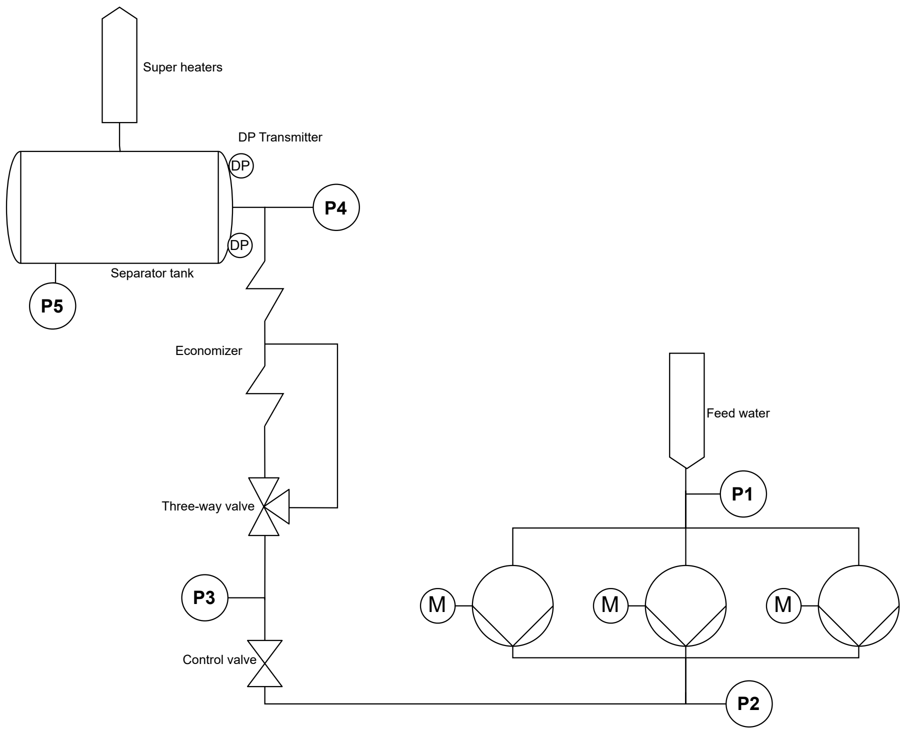

Figure 4.1: Illustration of the system and the different pressures of the system.

4.1 Separator model

For the model of the separator tank the focus points are: Flow out of the tank, liquid level of the tank, and flow in. In [7] a relation between the flow in and out of the tank, the cross section area of the tank, and the liquid height has been described when assuming constant density. 4.1

$$A\frac{dh(t)}{d(t)} = Q_{in}(t) + Q_{out}(t) \tag{4.1}$$

This equation is the foundation of the model for the entire system. The flow out of the separator tank is not controllable, the flow out of the system consist of the vapor which leaves the separator at a constant flow rate, but it also consist of the down comers of the system which is at an unknown quantity. Therefor only the flow into the tank can be affected by the control. There will be made two models which are combined to represent the flow in to the separator tank this is the feed water valve, and the pump.

4.2 Feed water valve

The equation used for the system is equation 2.4 which has been described in chapter 2

$$Q_{in} = K_v f(x) \sqrt{\frac{\Delta P}{SG}} \tag{4.2}$$

Where ΔP is defined as.

$$\Delta P = P_2 - P_3 + \frac{\rho h g}{100000} \tag{4.3}$$

And $f(x)$ is the valve flow characteristic of the equal percentage valve.

$$f(x) = R^{x-1} \tag{4.4}$$

Where R is a constant for the valve, found in the data sheet. The function for the valve characteristics become

$$f(x) = 40^{x-1} \tag{4.5}$$

The valve characteristics has been plotted in figure 4.2.

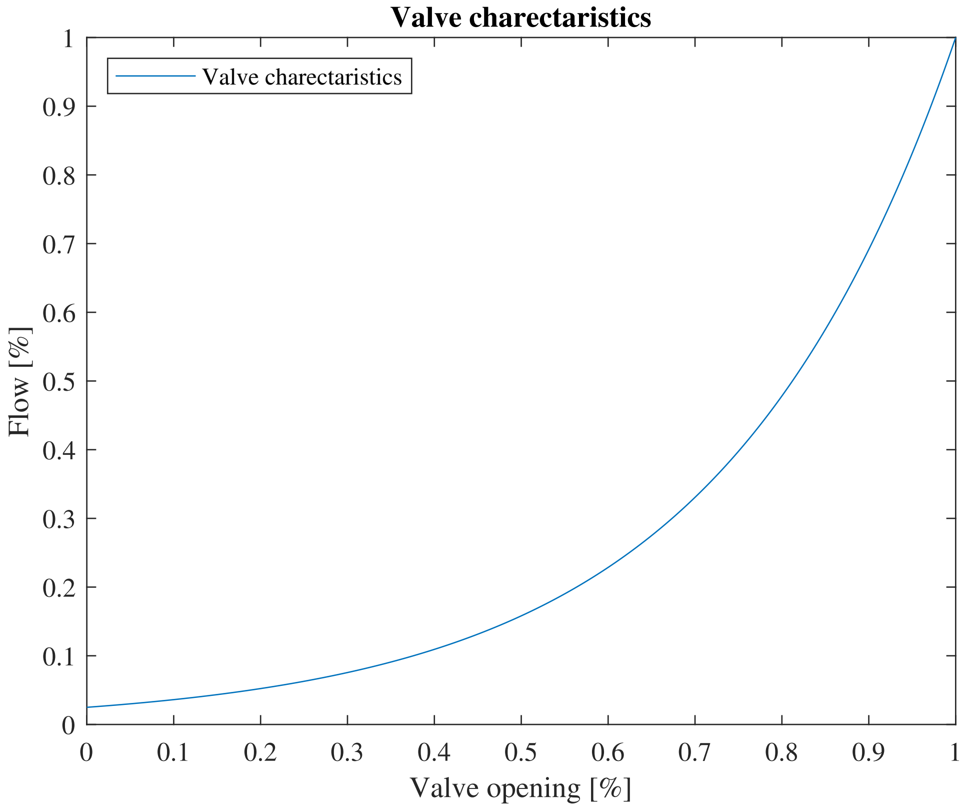

Figure 4.2: Valve characteristics for the control valve in the system

4.2.1 Pump simulation

For the simulation of the pump a equation is derived from equation 2.1. When the first order of the equation describing head of the pump is used to describe the flow. The flow equation then become.

$$Q_{in} = a_p \Delta P_p + a_\omega \omega \tag{4.6}$$

Which is from [2]. In this equation the pressure is described as.

$$\Delta P_p = P_2 - P_1 \tag{4.7}$$

Before being able to use expression 4.6 the parameters a_p and a_ω has to be calculated. To do this a guess is made by doing a linear regression on the pump data, while keeping either ΔP_p or ω constant. Since ΔP_p in this case is a constant because no more data is known this is the term that will be put constant, the guess for the parameter a_ω is found with.

$$Q_{in} = a\omega + b \tag{4.8}$$

Where the relation of the parameter a_p and b is.

$$b = a_p \Delta P_p \tag{4.9}$$

With the regression the parameters of the linear regression become.

$$\begin{aligned} a &= 0,2162m^3 \\ b &= 31,713\frac{m^3}{hr} \end{aligned} \tag{4.10}$$

And with ΔP_p being 72,7 bar the initial guess for the parameters become.

$$\begin{aligned} a_p &= 0,4362\frac{m^3}{s \cdot bar} \\ a_\omega &= 0,2162m^3 \end{aligned} \tag{4.11}$$

Now the pump function can be plotted using the newfound parameters and data set 1.

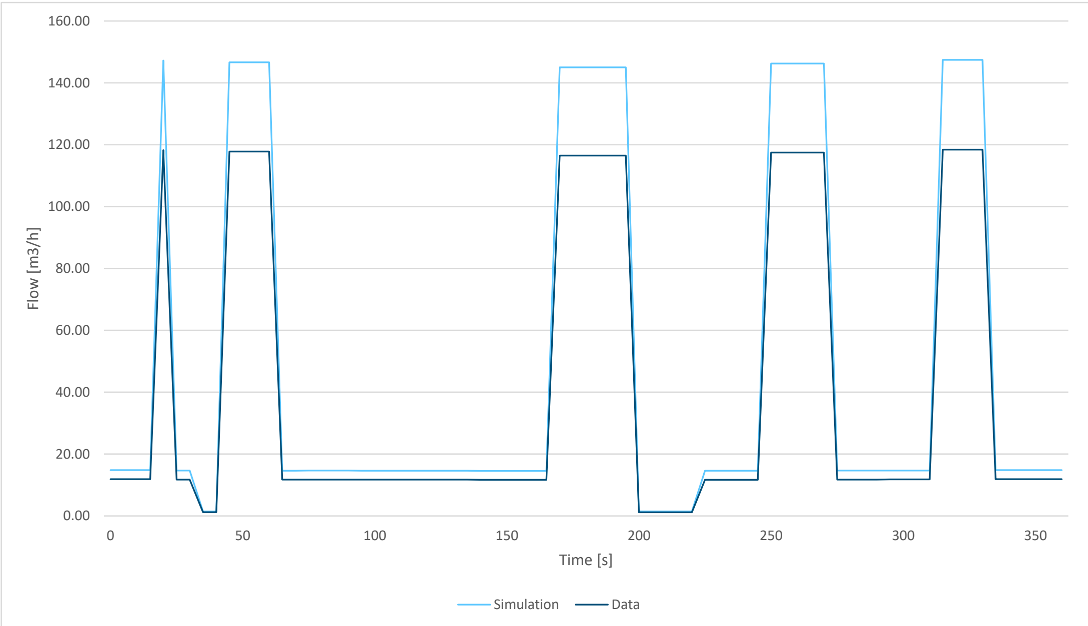

Figure 4.3: First flow equation plotted using data set 1.

In figure 4.3 the newfound function has been plotted using data set 1. The function follows the original data very well but the amplitude of the function is noticeably higher than the amplitude of the original data. Because of this a correction factor should be added to the function Therefor a correction factor is introduced.

$$Q_{in} = a_p \Delta P_p + a_\omega \omega + a_c \Delta P_p \omega \tag{4.12}$$

a_c is determined so that the simulation fits the data points better. This is when a_c is.

$$a_c = -1,15 \cdot 10^{-4} \tag{4.13}$$

When this correction factor is added the simulation and data can be seen in figure 4.4

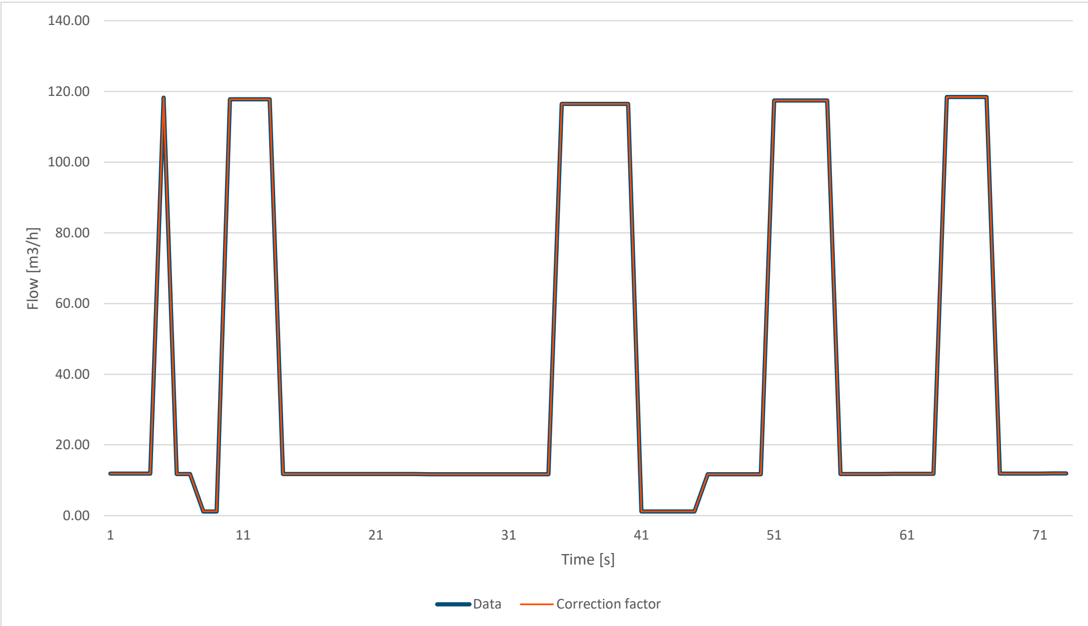

Figure 4.4: Simulation and data plotted in the same plot, showing very little deviation.

4.3 Linearization

For the linearization three equilibrium points is needed. These are the valve opening, the liquid level and the pump speed. The liquid level is chosen to be $0,4m$ since this is the setpoint for the tank and therefor the point where the system need to operate. For the equation describing the valve opening a exponential term is part of the equation. This term is firstly linearized before setting the system in equilibrium. The linearization is plottet in figure 4.5.

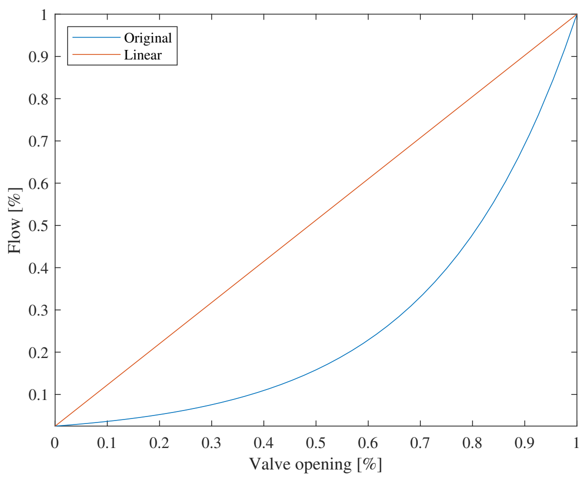

Figure 4.5: The nonlinear and the linear valve characteristics plotted besides each other.

The new expression for the valve characteristics become.

$$f(x) = 0,975x + 0,025 \tag{4.14}$$

So the equation to find the equilibrium point become.

$$0 = k_v \cdot 0,975x + 0,025\sqrt{\frac{P_2 - \frac{\rho h g}{100000} + P_3}{SG}} \tag{4.15}$$

This gives a valve opening of.

$$x_0 = 0,001 \tag{4.16}$$

Lastly the equilibrium for the pump speed will be chosen. Since the pump operates roughly at 10% and 90% of the maximum speed, a pump speed in the middle is chosen, this is.

$$\omega_0 = 2700RPM \tag{4.17}$$

The rest of the parameters used for the linerization is

$$\begin{aligned} P_1 &= 1,3bar \\ P_2 &= 74bar \\ P_3 &= 59bar \\ a_p &= 0,4362 \\ a_\omega &= 0,2162 \\ a_c &= -1,15 \cdot 10^{-4} \end{aligned}$$

Assuming that the flow in and out of the tank is equal in size the Taylor approximation [9] can be used on the system.

$$g(x) \approx f(a) + f'(a)(x-a) + f''(a)\frac{(x-a)^2}{2!} + ... + f^n(a)\frac{(x-a)^n}{n!} \tag{4.18}$$

This expression can be reduced to be linear

$$f(x) \approx f(a) + f'(a)(x-a) \tag{4.19}$$

First the valve equation is linearized by inserting equation 4.2 into equation 4.1 and afterwards linearizing it. This become.

$$V\frac{d(h_0 + h(t))}{dt} \approx f(Q_{out0}, x_0) + f'(Q_{out0}, x_0)Q_{out}(t) + f'_x(Q_{out0}, x_0)x(t) \tag{4.20}$$

And when the equation is written out.

$$14,658\frac{d}{dt}h(t) = Q_{out}(t) - 1,2771x(t) \tag{4.21}$$

$$\hat{Q}_{in_{valve}} = 1,2771x(t) \tag{4.22}$$

The same is now done for the pump simulation. So equation 4.12 is put into equation 4.1, to get the expression.

$$V\frac{d(h_0+h(t))}{dt} \approx g(h_0,Q_{out0},\omega_0)+g'(h_0,Q_{out0},\omega_0)h(t)+g'_{Q_{out}}(h_0,Q_{out0},\omega_0)Q_{out}(t)+g'_{\omega}(h_0,Q_{out0},\omega_0)\omega(t) \tag{4.23}$$

$$14,658\frac{d}{dt}h(t) = Q_{out}(t) - 0,039109h(t) - 0,207835\omega(t) \tag{4.24}$$

$$\hat{Q}_{in_{pump}} = 0,039109h(t) + 0,207835\omega(t) \tag{4.25}$$

Finally equation 4.22 and equation 4.25 can be combined to the final linearized model.

$$14,658\frac{d}{dt}h(t) = Q_{out}(t) - (0,039109h(t) + 0,207835\omega(t) + 1,2771x(t)) \tag{4.26}$$

5 Model Analysis

By using equation 4.26 three transfer functions can be developed for the system. All three transfer functions are important to simulate the system response, and they all represent an individual input into the system.
after the transfer functions has been developed they can be analysed before they are used in the simulation.

5.1 Laplace transformation

Using the Laplace transformation on equation 4.26 the following term is developed.

$$14,658 \cdot 3600 sH(s) = Q_{out}(s) - (0,039109H(s) + 0,2078\omega(s) + 1,2771X(s)) \tag{5.1}$$

With equation 5.1 three transfer functions of first order can be developed. The transfer functions are all a part to get the final output which is the separator liquid height. There are three different inputs, which are the three factors that determine the separator liquid height.
The first transfer function is made with the valve opening as input, and is a part of the flow into the separator tank which is described by two transfer functions. The transfer function is.

$$\frac{H(s)}{x(s)} = G_1(s) = \frac{0.000233}{s + 2.373 \cdot 10^{-8}} \tag{5.2}$$

The second transfer function is also describing part of the flow into the tank, this is the pump speed, which will be used as a disturbance in the system for the controller to overcome. The pump speed has the transfer function.

$$\frac{H(s)}{\omega(s)} = G_2(s) = \frac{-1,969 \cdot 10^{-6}}{s + 3,706 \cdot 10^{-7}} \tag{5.3}$$

The last transfer function is the one describing the outlet flow of the separator tank. This is also going to be used as a disturbance of the system,

$$\frac{H(s)}{Q_{out}(s)} = G_3(s) = \frac{9,475 \cdot 10^{-6}}{s + 3,706 \cdot 10^{-7}} \tag{5.4}$$

5.2 Analysis of Transfer function

In figure 5.1 a visual representation is made for the three transfer functions describing the same output.

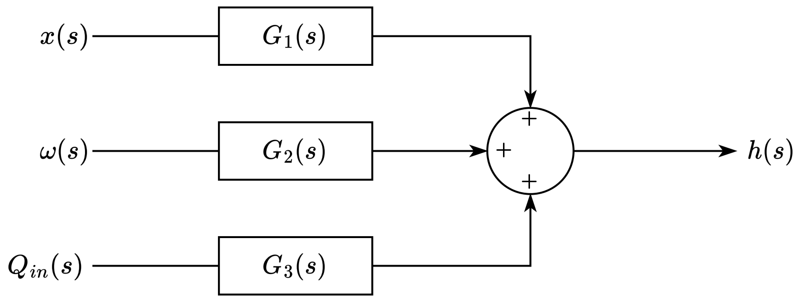

Figure 5.1: Block diagram of the transfer functions

None of the developed transfer functions have any zeros, but they all have one pole placed at $-3,7060 \cdot 10^{-7}$. This means that the system is stable.

In figure 5.2 the model of the liquid height of the tank has been plotted against the data received from the facility. The model do deviate slightly, most noticeably is the tendency for the model to move upwards the longer the simulation continues, this might be due to the disturbance from the pump, which is not controlled.

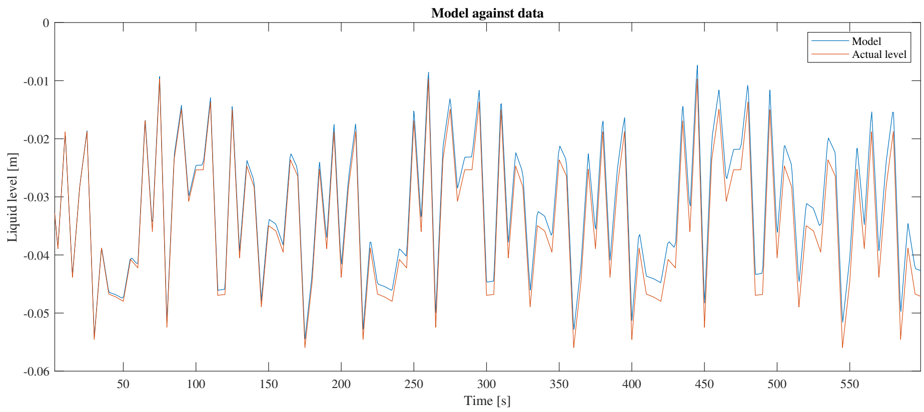

Figure 5.2: Linerized model compared to the liquid level data.

5.3 Simulation

The system has been simulated in both open loop and closed loop, without any control. In figure 5.3 the response of the system is seen. The blue graph shows the reference point which is at 0,4 m, and is the liquid level of the vapor separator tank. The red graph is the open loop response, this shows the system being unstable and continue to raise the liquid level. The yellow graph is the closed loop response. Here only a feedback has been added to the system, which makes the system stable, but the settling time of the system is very high, and is approximately 1600 seconds or 26 minutes.

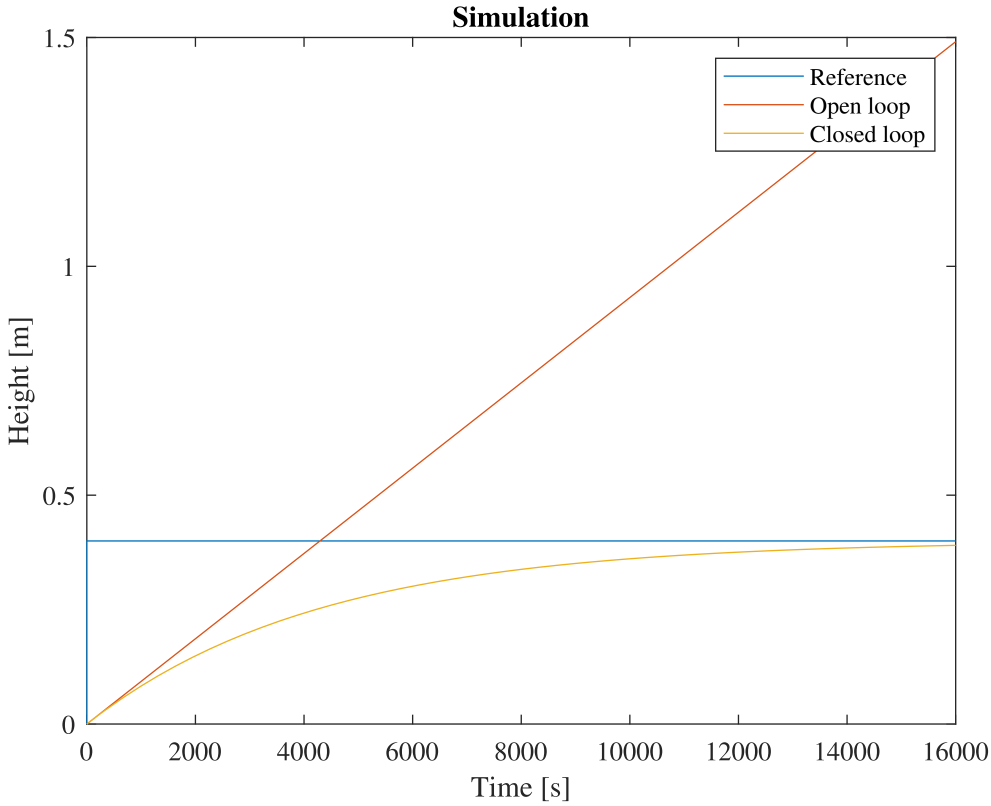

Figure 5.3: Simulation model against the reference in open loop and with feedback.

6 Control design

The main goal of the control design is to keep the water level of the separator tank between the set levels, before reaching the HH or LL alarms of the system.
Second the goal is to make a less sensitive feed water valve controller and make the control more smooth in operation, in contrast to the very aggressive control of the system that is implemented at the moment.

6.1 Existing control

For the existing controller a PI controller is used. This consist of

$$C = K_p + \frac{K_i}{s} \tag{6.1}$$

Here the controller is

$$C = \frac{429,2s + 396,5}{s} \tag{6.2}$$

In figure 6.1 the system is shown with the original controller.

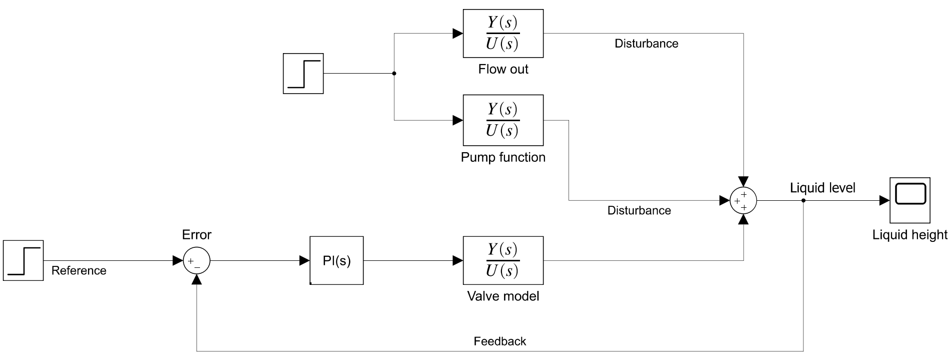

Figure 6.1: The block diagram of the system using the original PI controller on the feed water valve.

Figure 6.2 shows the system plotted using a step input and with the feed water valve PI controller.

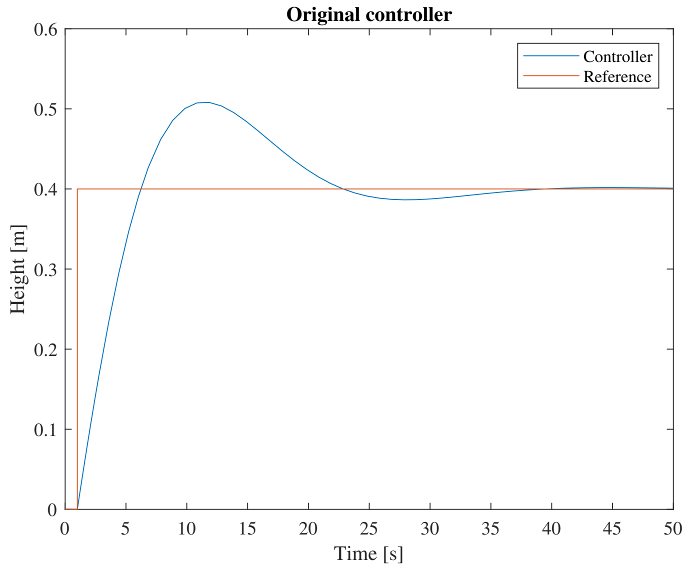

Figure 6.2: Response from the original controller at the facility.

The system has an overshoot which is acceptable since it is inside of the alarms and therefore close enough to the desired setpoint. Looking at the pole-zero map in figure 6.3, 3 of the system poles are placed in the left half plane while one pole is placed at 0, which means the system is marginally stable.

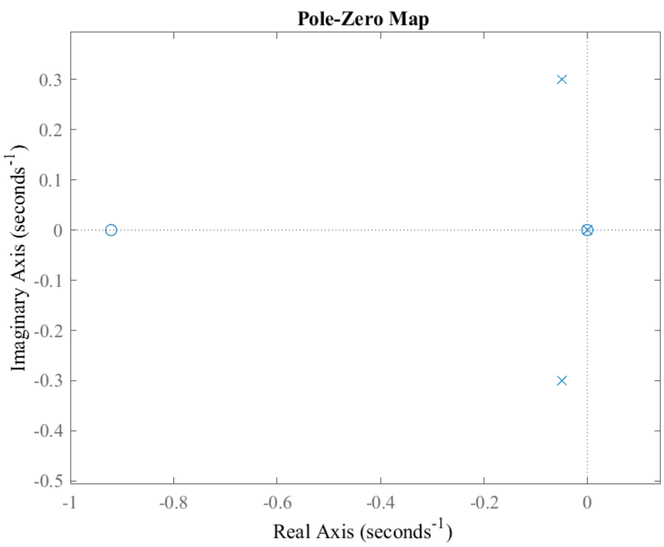

Figure 6.3: Pole-zero map for the original controller

6.2 Internal model control

This section is based on knowledge from [10] and [11]
The internal model control or IMC is a strategy used to design a controller for a system using a model of the system.

6.2.1 Theory of IMC

The strategy start with the system structure in figure 6.4, where a controller $q(s)$ is shown together with a plant $g_p(s)$ a model of the plant $\tilde{g}(s)$, these are the blocks of the system and are all affected by the system input $r(s)$.

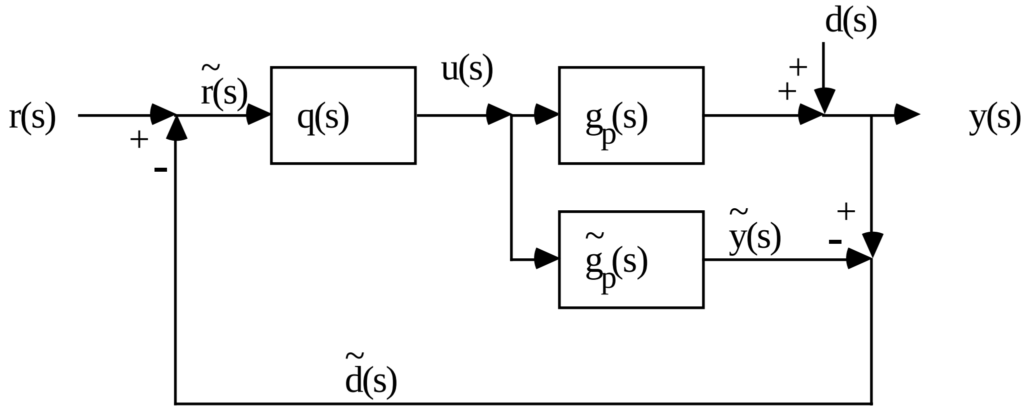

Figure 6.4: Structure of IMC [10]

An unknown disturbance is added to the system, this is $d(s)$, the output of the system $y(s)$ is compared to the model output $\tilde{y}(s)$ to get the feedback $\tilde{d}(s)$. This will be.

$$\tilde{d}(s) = [g_p(s) - \tilde{g}_p(s)]u(s) + d(s) \tag{6.3}$$

$\tilde{y}(s)$ is used to improve control of the system since this is seen as the missing part of the model $\tilde{g}_p(s)$. This is true when the unknown disturbance $d(s)$ is considered equal to $\tilde{d}(s)$ and so the model and the system are equal so $g_p(s) = \tilde{g}_p(s)$. With this feedback the control signal becomes.

$$u(s) = [r(s) - \tilde{d}(s)]q(s) = r(s) - [g_p(s) - \tilde{g}_p(s)]u(s) - d(s)q(s) \tag{6.4}$$

Which is.

$$u(s) = \frac{[r(s) - d(s)]q(s)}{1 + [g_p(s) - \tilde{g}_p(s)]q(s)} \tag{6.5}$$

And since the output of the system can be written as $y(s) = g_P(s)u(s) + d(s)$ The transfer function for the closed loop system become.

$$y(s) = \frac{[r(s) - d(s)]q(s)g_p(s)}{1 + [g_p(s) - \tilde{g}_p(s)]q(s)} + d(s) \tag{6.6}$$

With this expression of the closd loop system perfect setpoint tracking and disturbance rejection can be realized if $q(s) = \tilde{g}_p(s)^{-1}$ and if $g_p(s) = \tilde{g}_p(s)$.

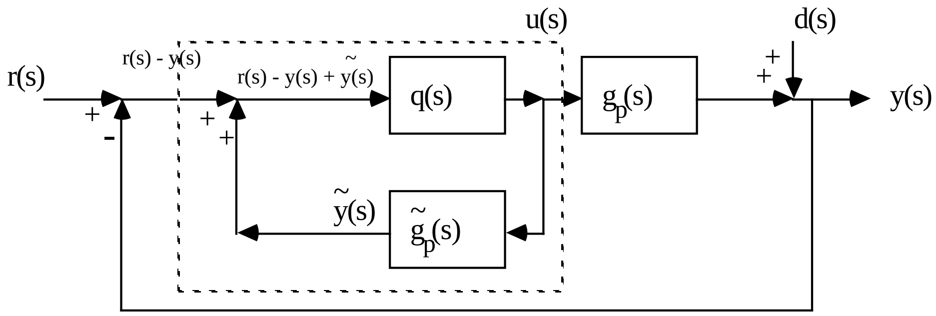

Figure 6.5: Rearranged IMC structure with inside loop [10]

6.2.2 Controller design using IMC

The model of the plant $\tilde{g}(s)$ will for a first order system be.

$$\tilde{g}(s) = \frac{k_p}{\tau_p s + 1} \tag{6.7}$$

To determine the transfer function for the controller the model is used together with a filter to get.

$$q(s) = \tilde{q}(s) f(s) \tag{6.8}$$

Here $\tilde{q}(s)$ is the inverse of $\tilde{g}(s)$, and is therefor expressed as.

$$\tilde{g}(s)^{-1} = \frac{\tau_p s + 1}{k_p} \qquad and \qquad f(s) = \frac{1}{\lambda s + 1} \tag{6.9}$$

In the end the end the expression for $q(s)$ becomes.

$$q(s) = \frac{\tau_p s + 1}{k_p(\lambda s + 1)} \tag{6.10}$$

Now the standard feedback controller can be derived with the expression.

$$q_{IMC}(s) = \frac{q(s)}{1 - \tilde{g}_p(s) q(s)} \tag{6.11}$$

Inserting equation 6.7 and 6.10 the expression for $q_{IMC}(s)$ is found.

$$q_{IMC}(s) = \frac{\tau_p s + 1}{k_p \lambda s} \tag{6.12}$$

Knowing that a PI controller has the transfer function.

$$q_{IMC}(s) = k_c \frac{\tau_I s + 1}{\tau_I s} \tag{6.13}$$

Equation 6.12 can be rearranged to find the parameters k_c and τ_I. This is done by multiplying τ_p/τ_p with equation 6.12. Thereby getting.

$$q_{IMC}(s) = \left(\frac{\tau_p}{k_p \lambda}\right) \frac{\tau_p s + 1}{\tau_p s} \tag{6.14}$$

Equating the term the parameters can be found.

$$k_c = \frac{\tau_p}{k_p \lambda} \qquad and \qquad \tau_I = \tau_p \tag{6.15}$$

With k_p and τ_p known there is only one tuning parameter left, this is the IMC filter factor λ.
With the controller designed the closed loop transfer function becomes.

$$y(s) = \frac{q_{IMC}(s)g_p(s)r(s) + [1 - q_{IMC}(s)\tilde{g}_p(s)]d(s)}{1 + [g_p(s) - \tilde{g}(s)]q_{IMC}(s)} \tag{6.16}$$

7 Simulation

Using the method described in section 6.2, a controller ha been designed for the feed water valve, with the pump output and the flow out of the tank as disturbances. Using equation 6.14 the controller is designed with the transfer function 5.1 to be.

$$g_{IMC}(s) = \frac{4291.85s + 1}{\lambda s} \tag{7.1}$$

In figure 7.1 the block diagram of the system is shown with the controller. Here the filter coefficient λ is unknown and described as l in the controller block. The disturbance consist of the pump flow and the flow out of the vapor separator tank.

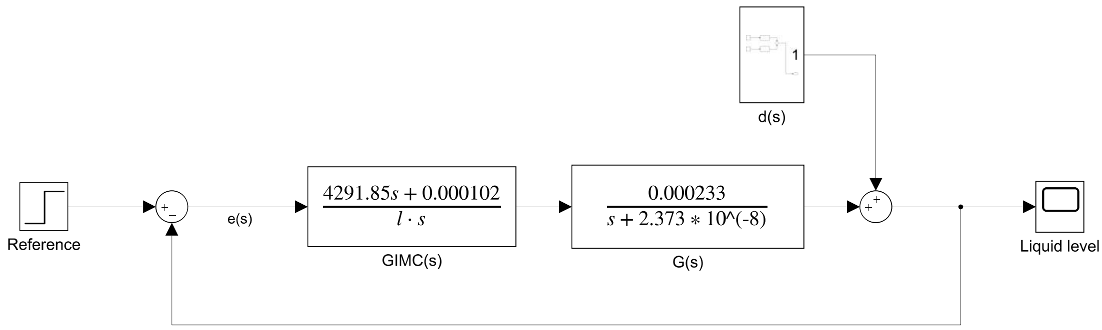

Figure 7.1: The block diagram with the IMC designed controller implemented.

7.1 Analysis

Starting of with an initial guess for the filter coefficient λ to be $\frac{\tau_p}{2}$, see figure 7.3. This gives a stable system which also has a lower settling time than the system with only feedback. The system is still far from perfectly controlled. Therefor the filter coefficient is tuned.

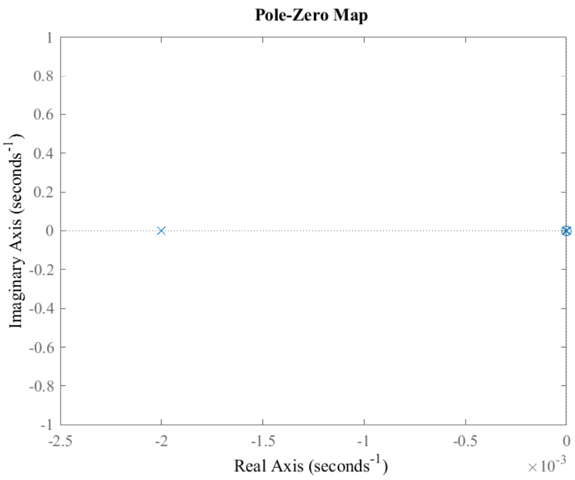

Figure 7.2: Pole zero map for the IMC designed controller.

In figure 7.2 the pole zero map for the closed loop transfer functon of the system and the controller is shown. The closed loop IMC system has both a pole and a zero in 0, which makes the system marginally stable. No poles or zeros are located in the right half plane.

7.2 Simulation

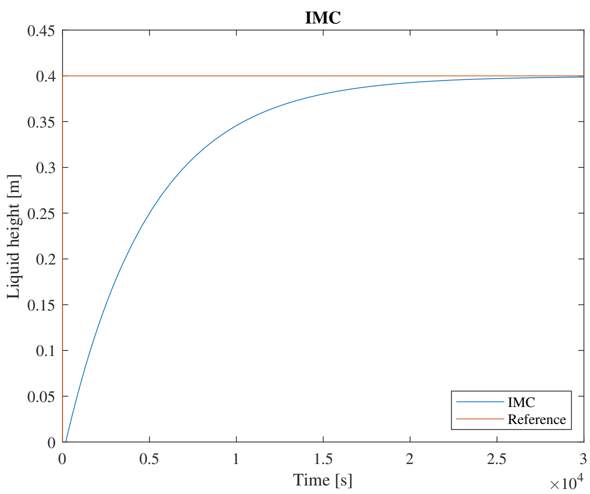

Figure 7.3: The step response using the initial λ value.

In figure 7.3 the step response of the system is shown when the initial filter value is $\lambda = 4909$. The system settles slightly above the setpoint and it the settling time is very large at 20000 seconds. The λ value is tuned to match the criteria of the system better. Using $\lambda = 500$ it is possible to keep the valve output smooth and have a slightly faster system than with the initial value.

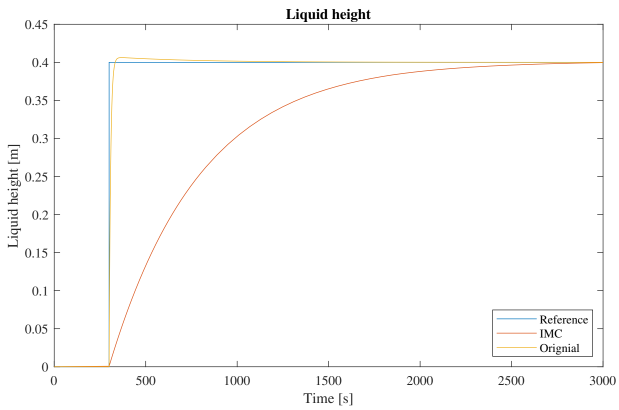

Figure 7.4: Response of the system after the filter coefficient has been tuned.

In figure 7.4 the step response is shown when $\lambda = 500$, and this response is plotted against the step response of the original controller. The IMC designed controller is now faster than the initial guess and settles at the setpoint after 2700 seconds. The original PI controller is still much faster, but since a fast response is not the main objective the obtained response time is acceptable for the IMC designed controller.

A new disturbance is now added to the system in the form of varying liquid level, this disturbance is from data set 2, and has been repeated to get a disturbance for a longer period of time. The disturbance has been plotted in fig. 7.5.

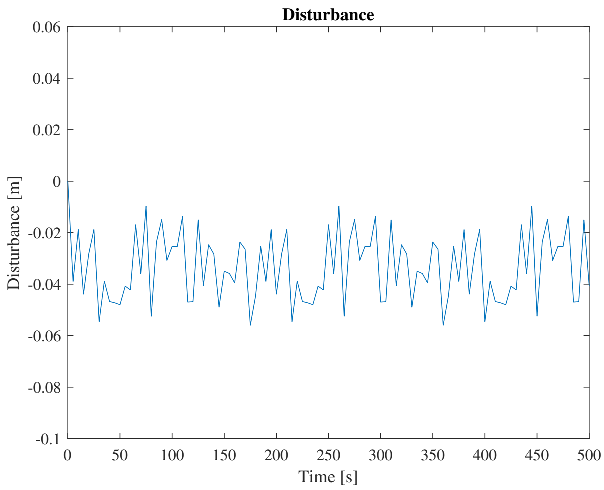

Figure 7.5: Level disturbance added to the system.

Now the IMC designed controller can be compared to the original controller when there is actual disturbance to respond to.

In figure 7.6 the valve opening is plotted for the original controller and for the IMC designed controller. The original PI controller is very aggressive compared to the IMC designed controller. These openings of the feed water valve is not realistic in real life since the valve is only able to open 100% which on the plot would be 1 on the y axis. This is a problem for both controllers, and therefor a saturation block should be added when looking at the nonlinear system.

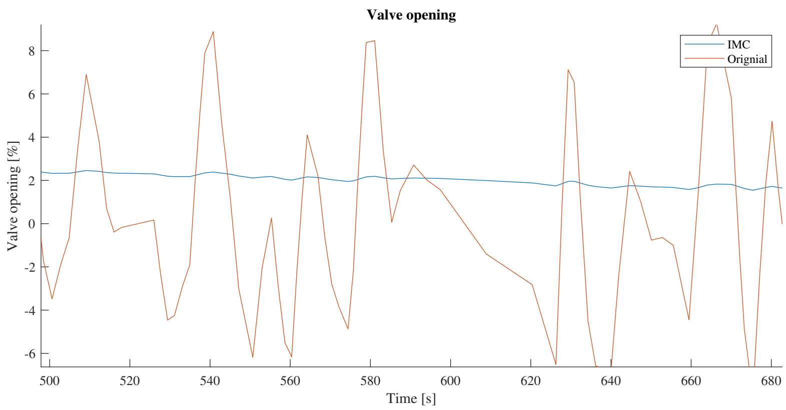

Figure 7.6: Valve opening of IMC and original controller

In figure 7.7 the liquid height is plotted for both the original and the IMC designed controller. Since the IMC designed controller had less valve opening varying the amplitude of the liquid height is also larger than that of the original controller. This is not a problem though since the liquid height stays inside of the boundaries of the alarms in the separator tank.

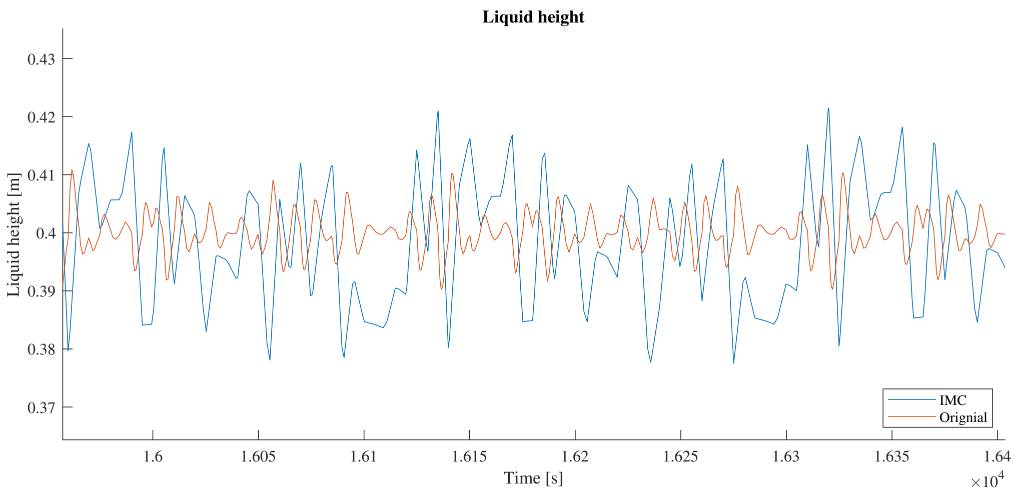

Figure 7.7: Liquid height with IMC controller and with original controller

In figure 7.8 a step response is made at 300 seconds for both controllers, and at the same time the disturbance of the liquid height is also added. Again the IMC controller is slower than the original controller, and has a bigger amplitude, but for the purpose of the valve control desired for the system this response is acceptable.

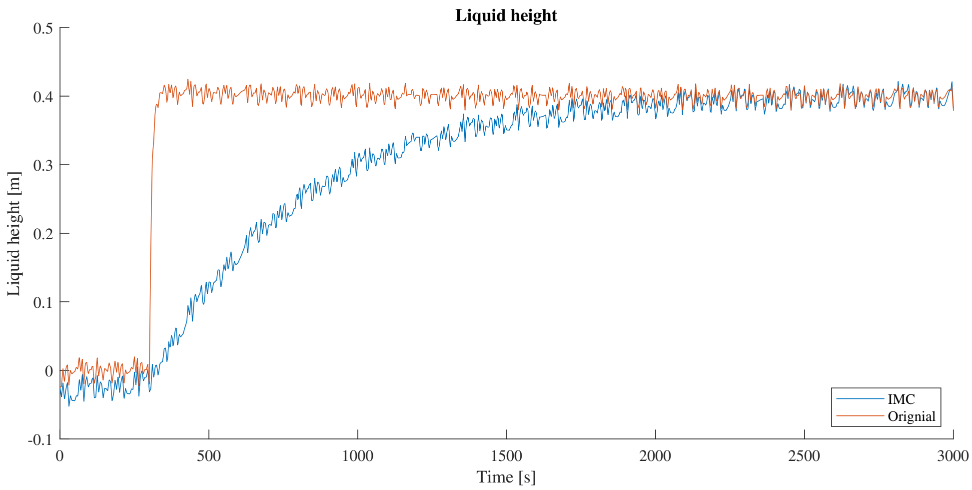

Figure 7.8: IMC designed controller plotted with the original controller, both with added disturbance and step input.

Lastly the controller has been added to the nonlinear model of the system. In figure 7.9 the liquid height of the system is seen when a step is added at 100 seconds together with the level disturbance from fig 7.5. A saturation block was added after the controller to get a realistic response where the valve maximally opens 100%. Because of the disturbance the liquid level for the IMC designed controller is below zero. After the step input at 100 seconds there is only very little disturbance in the output, but the liquid level for the IMC designed controller never reaches the setpoint of 0,4 m. However it does stay inside of the low alarm set point of 100 mm. Compared to figure 7.8 the nonlinear system respond immediately, and is just as fast as the original controller.

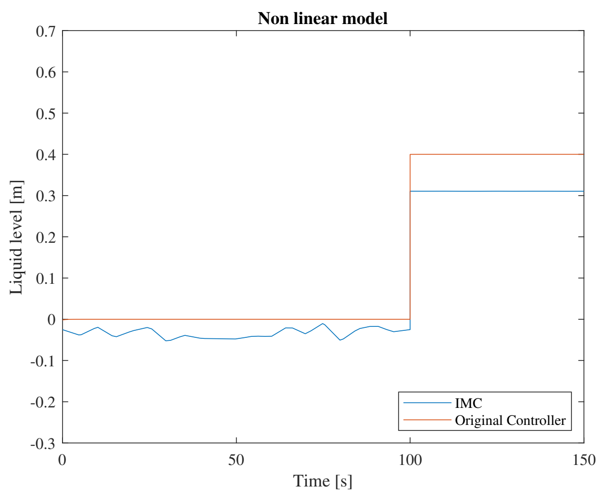

Figure 7.9: IMC designed controller and original controller used on the nonlinear model.

In figure 7.10 the valve opening is shown when a step response is used on the nonlinear system. Here the IMC designed controller start out in a undesired manner of fluctuating a lot compared to the original controller. After the step input, both controllers behave alike, and stays within acceptable valve opening.

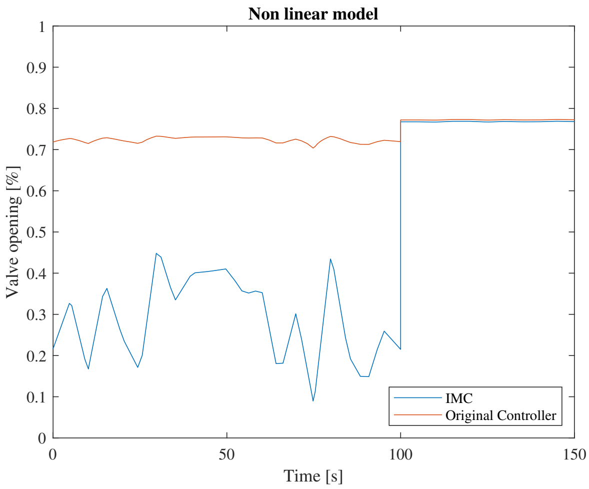

Figure 7.10: Valve opening for the IMC designed controller and the original controller.

Even though the system stays inside the desired boundaries the output of the nonlinear model is not desirable, since it seems that the original controller performs better than the IMC designed controller.

8 Discussion

The problem examined in this report was the aggressive control implemented on the feed water valve of a waste incinerator. As the waste incinerator is running in the current state this problem was not of critical nature, but rather it was a proposal to improve the possible life of the feed water valve. To find a solution to this problem a model was made to describe the systems, pump, feed water valve and separator tank.

System model
With limited data concerning the system some data has been assumed to make the three models. This makes the models slightly incorrect when describing the system.
However the models has been made and linearized to get three transfer functions with three different input but the same output, which means that put together this would give the desired output, the liquid level of the separator tank. To get the desired liquid level in the tank the input flow and the output flow should be of the same size wich are not the case when the three transfer functions are added, there are still a tendency for the liquid level to keep rising when a step is added to the three transfer functions, which makes the model incorrect.

IMC designed controller
The IMC method has been used to design a controller that would have the ability to make the valve input more smooth, to relive the feed water valve if even just a little. This method was used because of it's robustness and because there is only one tuning parameter, making the tuning process of the controller easier.
The controller was only designed for the transfer function describing the valve since the output of the tank it not controllable, and control of the pump is not in the scope of this project.
Using the controller on the linear model with the initial guess for a filter constant λ showed a system which where very slow, and used around 30.000 seconds to settle after a step input. The filter coefficient was then tuned to the value of 500, which made the system much faster and settling after only 3000 seconds. Not only where the system faster but the valve had a very desired smooth behavior, which where the goal of the controller. Together with the liquid level of the tank being inside the alarm set points, the controller seemed very promising.

Nonlinear system
Using the new designed controller on the nonlinear system showed a non desired output, the liquid level might have been inside of the alarm boundaries, however the valve behavior showed a much faster system when implemented on the nonlinear system and also showed a very aggressive valve behavior before a step input was implemented. This could be expected knowing from the start that the model was not very accurate because of assumed data values and because of the response of the three transfer functions added. The fact that the exponential term of the valve characteristics had to be linearized before finding a operation point could also have an impact on the model accuracy.

Future work
For future work, the model describing the system should be improved since the controller designed showed promising results when used on the linear models.
Also working with control of the pump in the system would be interesting, the pump of the system is controlled by the pressure of between the pump and the feed water valve, and the pump is at the moment working at 10 % capacity or 90 % capacity. By implementing control of the pump the control of the pump and valve could be coordinated to make the system more energy efficient, while also making wear and tear minor for both components.

9 Conclusion

The major goal of this report was to design a controller which would make the behavior of the valve more smooth. This was done my making a model of the system and with this model designing a controller for the system using the IMC method. The controller designed showed promising results after tuning the filter coefficient to be 500. The valve behavior plotted where smooth and the liquid level of the separator tank where inside the desired level.
However the use of the controller on the nonlinear model showed results which where not desired, with a very fluctuating valve opening.

Concluding that the IMC method is a suiting method to solve the problem of this report, however the model developed to describe the system as a linear model has not been good enough or close enough to the actual system to give the correct results. Therefor the model shall me remade before making a new attempt at a IMC designed controller.

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A Appendix

Based on knowledge from [12].
The minor losses of the system are defined by the equivalent length, which is calculated by.

$$l_{eq} = \zeta \frac{D}{f} \tag{A.1}$$

This is the bends, the three way valve and the economizers of the system. Here ζ is the minor loss coefficient, which is a set value for different components in the system. This equivalent length can then be added to the total length of the system when calculating the major losses with equation.

$$h_L = f \frac{L + L_{eq}}{D} \cdot \frac{V^2}{2g} \tag{A.2}$$

To calculated both the minor losses and the major losses the friction factor f has to be known. The friction factor is based upon the Reynolds number of the system. The Reynolds number determine if the fluid in the system is laminar, transitional or turbulent, and is found with the equation:

$$Re = \frac{\rho v D}{\mu} \tag{A.3}$$

Here ρ is the density of the fluid, v is the velocity of the fluid and μ is the dynamic viscosity of the fluid.
In this case the flow is turbulent, which means that to determine the friction factor the Colebrook-White equation is used.

$$\frac{1}{\sqrt{f}} \approx -2log\left(\frac{\epsilon}{3,7D} + \frac{2,51}{Re\sqrt{f}}\right) \tag{A.4}$$

Where ϵ is the material roughness, here the value for stainless steel is used which is 0.002mm. When the friction factor is calculated the minor and major losses of the system can be found, and then the dynamic loss coefficient k_{loss} can be determined.

B Volume calculations

To determine the volume characteristics the theory of circle segments are used. Written with knowledge from [13].

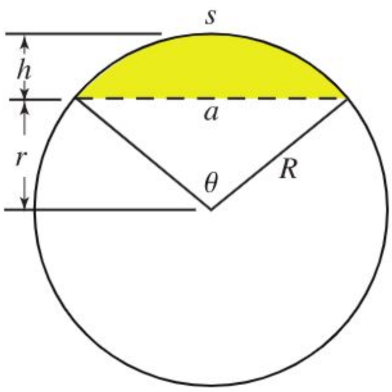

Figure B.1: Visual representation of the circle segment [13]

First the length of r is.

$$\begin{aligned} r &= Rcos(\frac{1}{2}\phi) \\ &= \frac{1}{2}a \cdot cot(\frac{1}{2}\phi) \\ &= \frac{1}{2}\sqrt{4R^2 - a^2} \end{aligned} \tag{B.1}$$

And the arc length a is.

$$\begin{aligned} a &= 2Rsin(\frac{1}{2}\phi) \\ &= 2rtan(\frac{1}{2}\phi) \\ &= 2\sqrt{R^2 - r^2} \\ &= 2\sqrt{h(2R - h)} \end{aligned} \tag{B.2}$$

The angle ϕ has the relation.

$$\begin{aligned} \phi &= \frac{s}{R} \\ &= 2cos^{-1}\frac{r}{R} \\ &= 2tan^{-1}\frac{a}{2r} \\ &= 2sin^{-1}(\frac{a}{2R}) \end{aligned} \tag{B.3}$$

To get the desired area a simple equation is set up.

$$A = A_{circularsector} - A_{triangle} \tag{B.4}$$

This is the entire area of the wedge where the yellow part is located, from this area the area of the triangle below the desired area is subtracted. Using the earlier equations we get.

$$\begin{aligned} A &= \frac{1}{2}R^2(\phi - sin(\phi)) \\ &= \frac{1}{2}(Rs - ar) \\ &= R^2cos^{-1}(\frac{r}{R}) - r\sqrt{R^2 - r^2} \\ &= R^2cos^{-1}\left(\frac{R-h}{R}\right)(R-h)\sqrt{2R-h-h^2} \end{aligned} \tag{B.5}$$

To get the volume of the tank, the length is multiplied on the equation to get.

$$V = R^2cos^{-1}\left(\frac{R-h}{R}\right)(R-h)\sqrt{2R-h-h^2}L \tag{B.6}$$

Using equation B.6 the volume of the tank can be shown as a function of the liquid height. Using the data for the tank..

$$R = 0,8m \qquad L = 11,8m \tag{B.7}$$

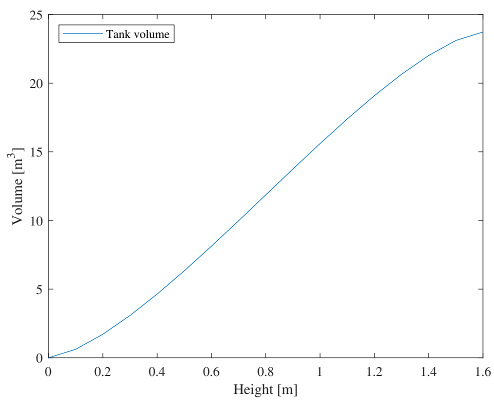

Figure B.2: The plot of volume vs height of the liquid of the tank.

C Pump curve

Type / size	Speed [1/min]	Temperature [°C]	Density [kg/dm3]
HGM 4/5 7.1 S 6.2 N	3600	140	0.926

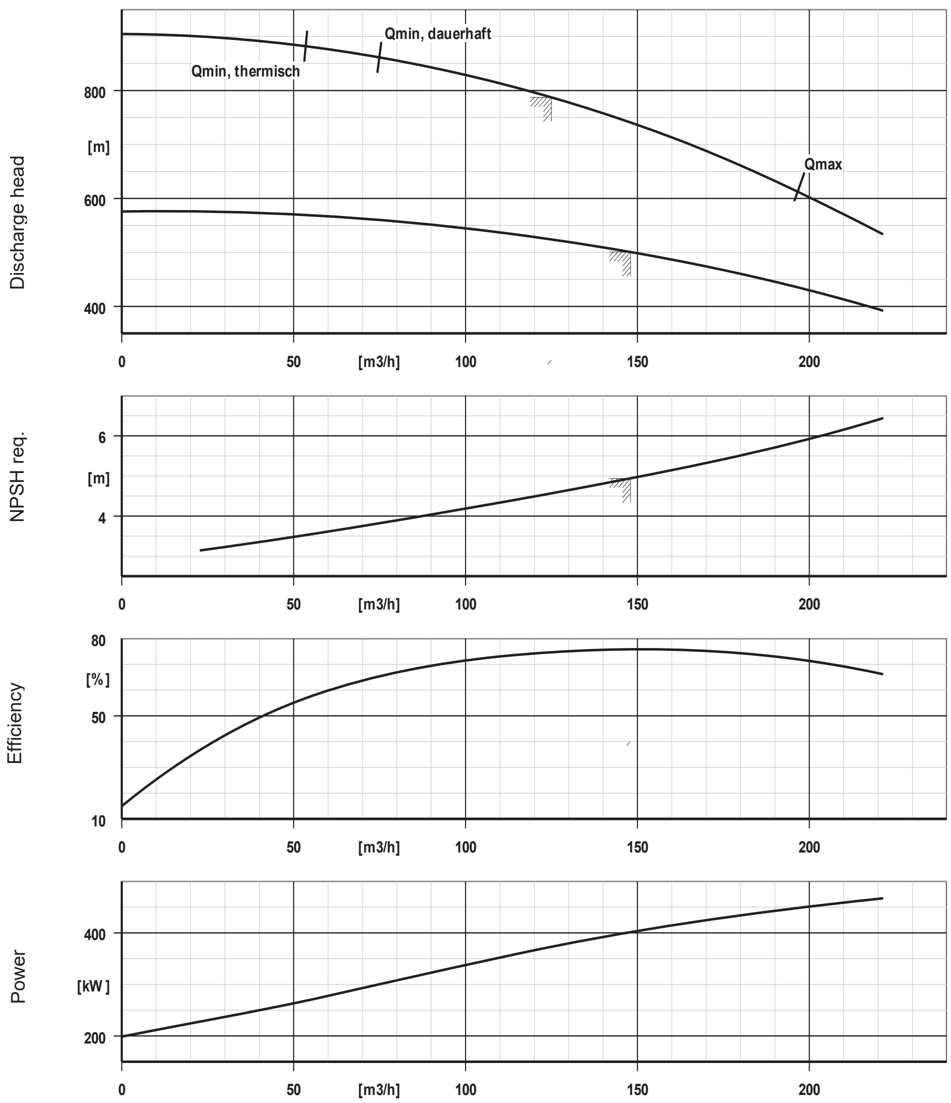

Figure C.1: Pump curve and power curve for the system pump

D Data set 2

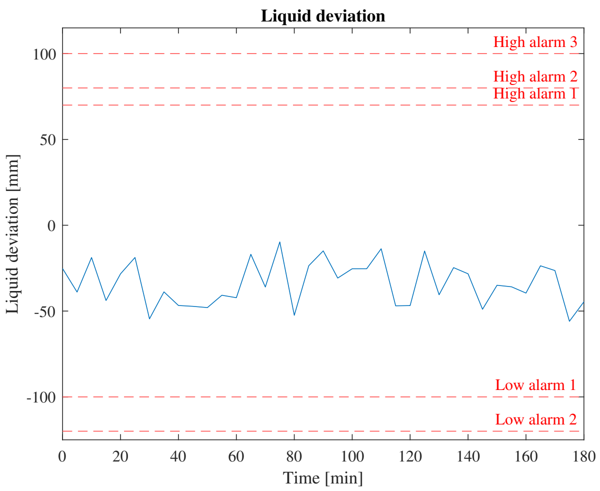

Figure D.1: Liquid level of the separator tank.

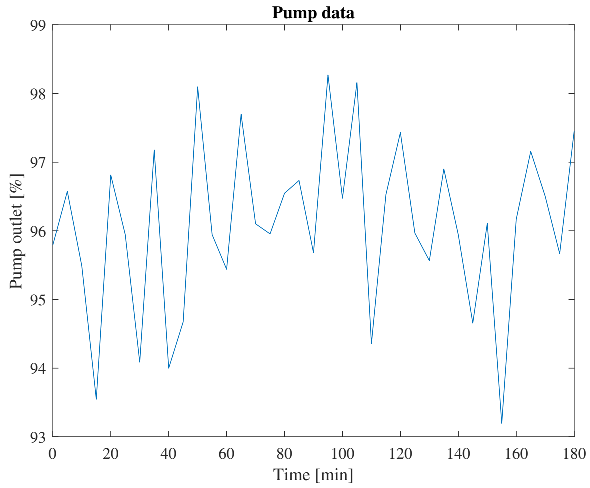

Figure D.2: Pump work presented in %.

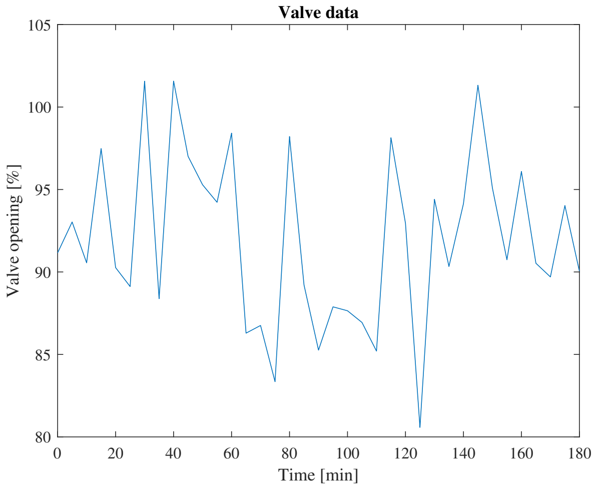

Figure D.3: Valve opening in %.

E Data sheets

- 3.0 HORA Fødevandsventil DN 125
- 4.0 HORA 3-vejs-ventil DN 150 LAB51AA301
- Operating data HGM 4-5 (rev 2)
- Multi vision, digital transmitter 2010TD

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REGELARMATUREN
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List of documents

Numbering	3
Item No.	3
Tag No.	LAB 50 AA 301

Contents

Feedwater Control Valve Series 300.05
DN 125

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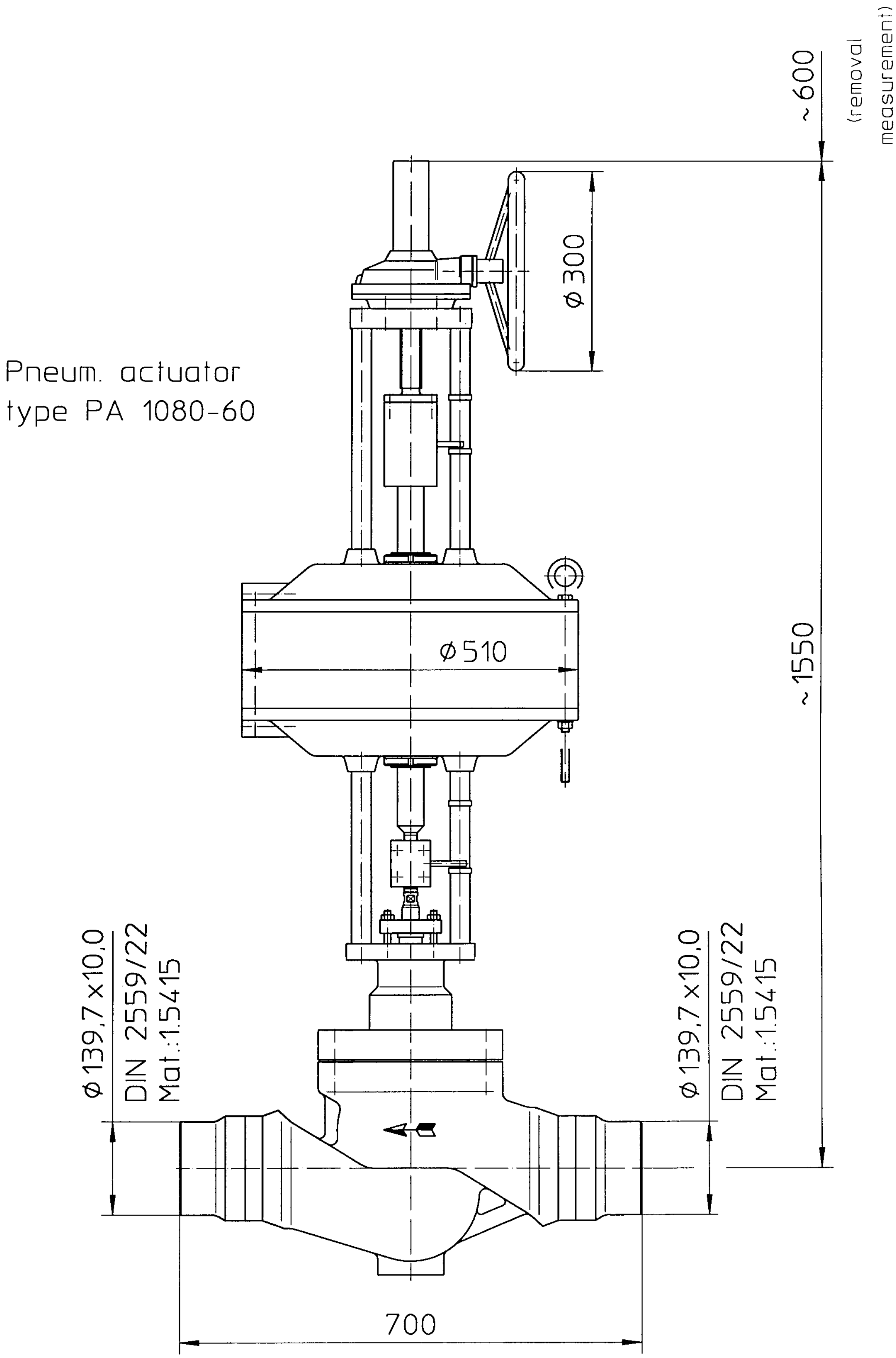
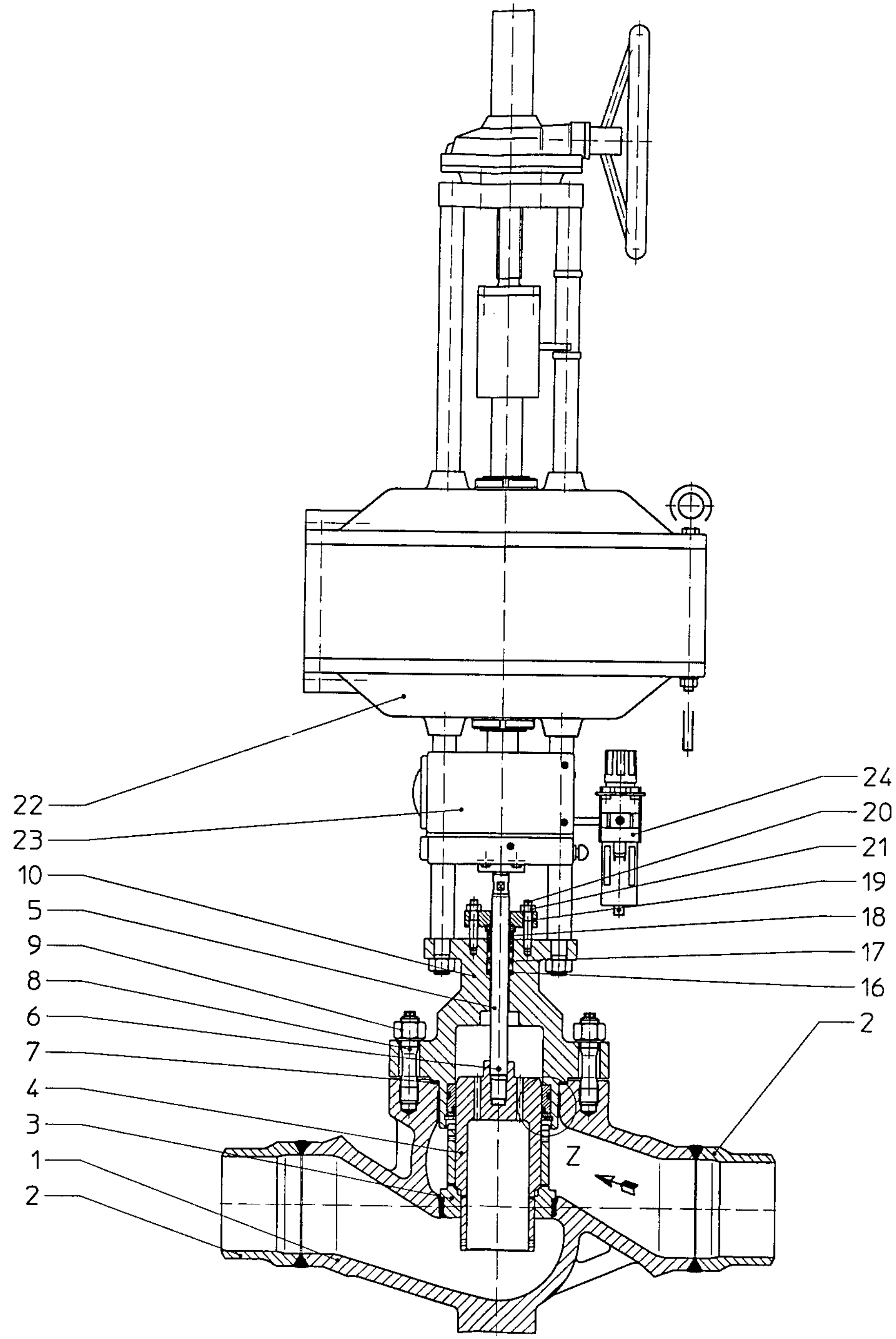
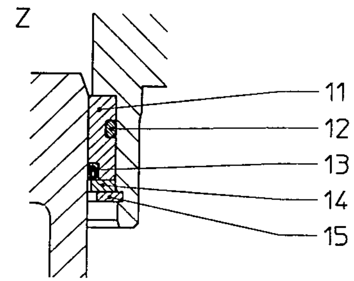


Pos. : 3	Weight ~ 260 kg			Drawing No
Mark : LAB 50 AA 301	2002	Date	Name	
Plant: Völund-Esbjerg Kraft Värme	Drawn	09.01.	Whitear	E-62809/GB
	Proofed	09.01.	Wol.	





Pos.	Designation	Mat. Spec.	Sp. Parts
1	Body	1 [illegible]619	
2	Buttweld end	[illegible]15	
3	Seal ring w. sieve	1 [illegible]122	X
4	Plug	1.4057	X
5	Valve stem	1.4122	X
6	Cylindrical pin	niro	X
7	Gasket	1.4541/Gr.	X
8	Expansion bolt	1.7709	
9	Hexagon nut	1.7709	
10	Bonnet	1.0460	
11	Guide bush.	1.4057	
12	O-ring	EPDM	X
13	Turcon-variseal-ring	T24S	X
14	Support ring	1.4571	
15	Retaining ring	St chrom	
16	Ring	1.4122	
17	Stem packing	gr./K80S	X
18	Stuffing box	1.4057	
19	Flange	1.7380	
20	Stud bolt	1.7709	
21	Hexagon nut	1.7258	
22	Actuator	PA 1080	
23	I/P-Positioner	---	
24	Filter Regulator	---	

Pos. : 3

Mark : LAB 50 AA 301

Plant : Völund - Esbjerg Kraft Värme

Index	Change No	Date	Name	Microf.	Index	Change No	Date	Name	Microf.
2002									

	Date	Name	
Drawn	09.01.	Whitear	HORA REGELARMATUREN Excellence is our standard — Holter Regelarmaturen, 33758 Schloß Holte-Stukenbrock
Proofed	09.01.	Wol.	
Norm-Pr.			

Scale: -

Feedwater Control Valve
DN 125 Series 300.05
Actuator PA 1080-60

Drawing-No: C-25749/GB

Replacement for

Replace off

Control Valve - Base Characteristic

Characteristic: equal percent

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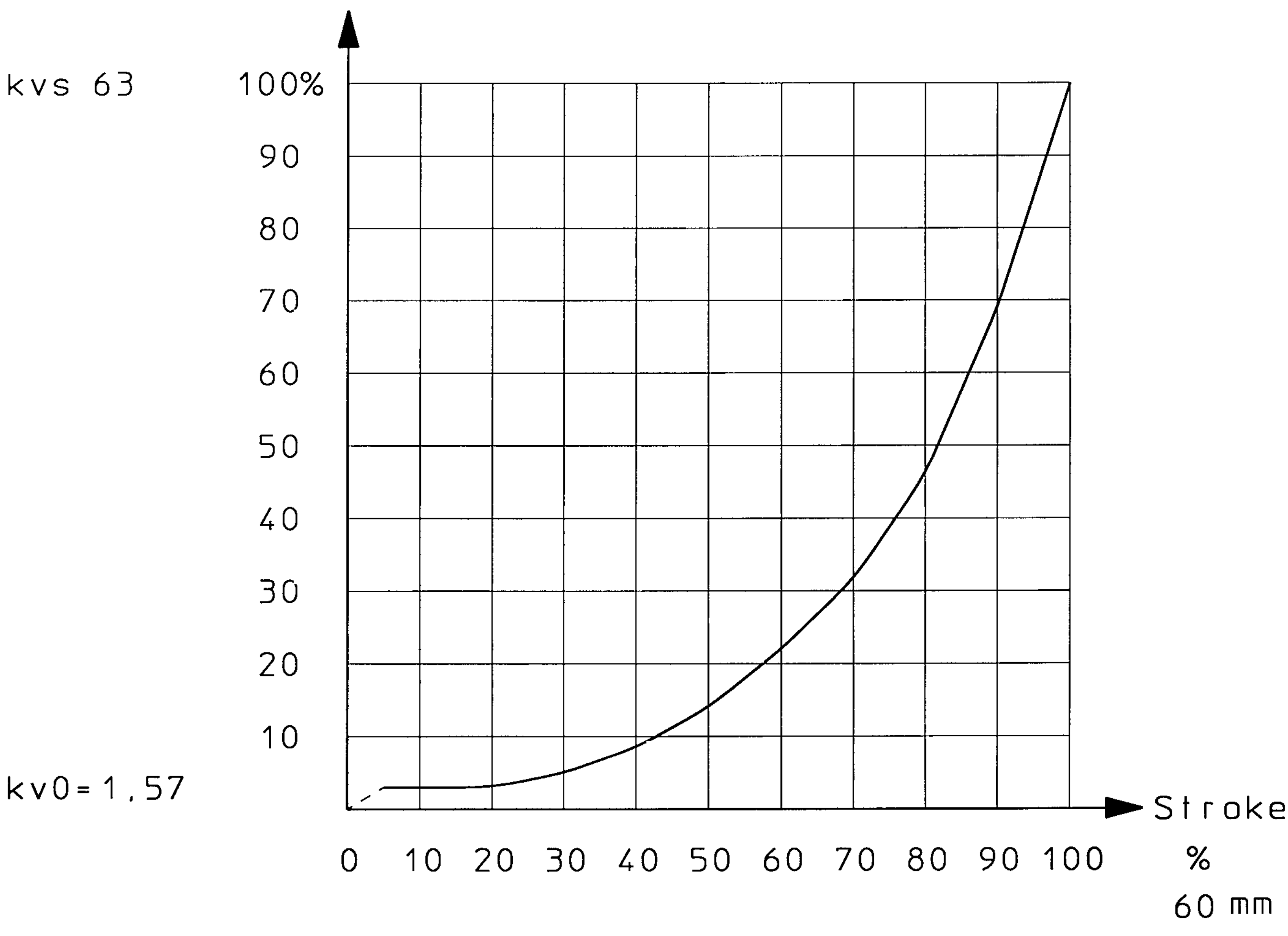
Theoretical proportion = $\frac{Kvs}{Kv0} = \frac{63}{1{,}57} = 40:1$



Definition of KV-rate according to VDI/VDE 2173

The meaning of the KV-rate is the rate of flow from water at 5 till 30°C (ϱ = 1000kg/m^3), which pass the valve with a pressure drop of 1 bar at the momentary stroke.

Pos. : 3				Drawing No.
Mark : LAB 50 AA 301	2002	Date	Name	KB-01211383-03/GB
Plant: Völund-Esbjerg Kraft Värme	Drawn	09.01.	Whitear	
	Proofed	09.01.	Wol.	

KKS nr. LAB50AA301

Tegningsnr. C-25749/GB

Pos 3

Del	Stk		DKK/stk
3	1	Iskruet sæde med hulkurv	21.945,-
4-6	1	Hulkegle med spindel	22.470,-
7	1	Spiraltætning	546,-
12	1	O-ring	199,-
13	1	Turcon Variseal ring	1.995,-
17	1	Spindeltætning komplet	1.103,-

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List of documents

Numbering	4
Item No.	4
Tag No.	LAB 51 AA 301

Contents

Three-way Distribution Valve Series 300.06
DN 150

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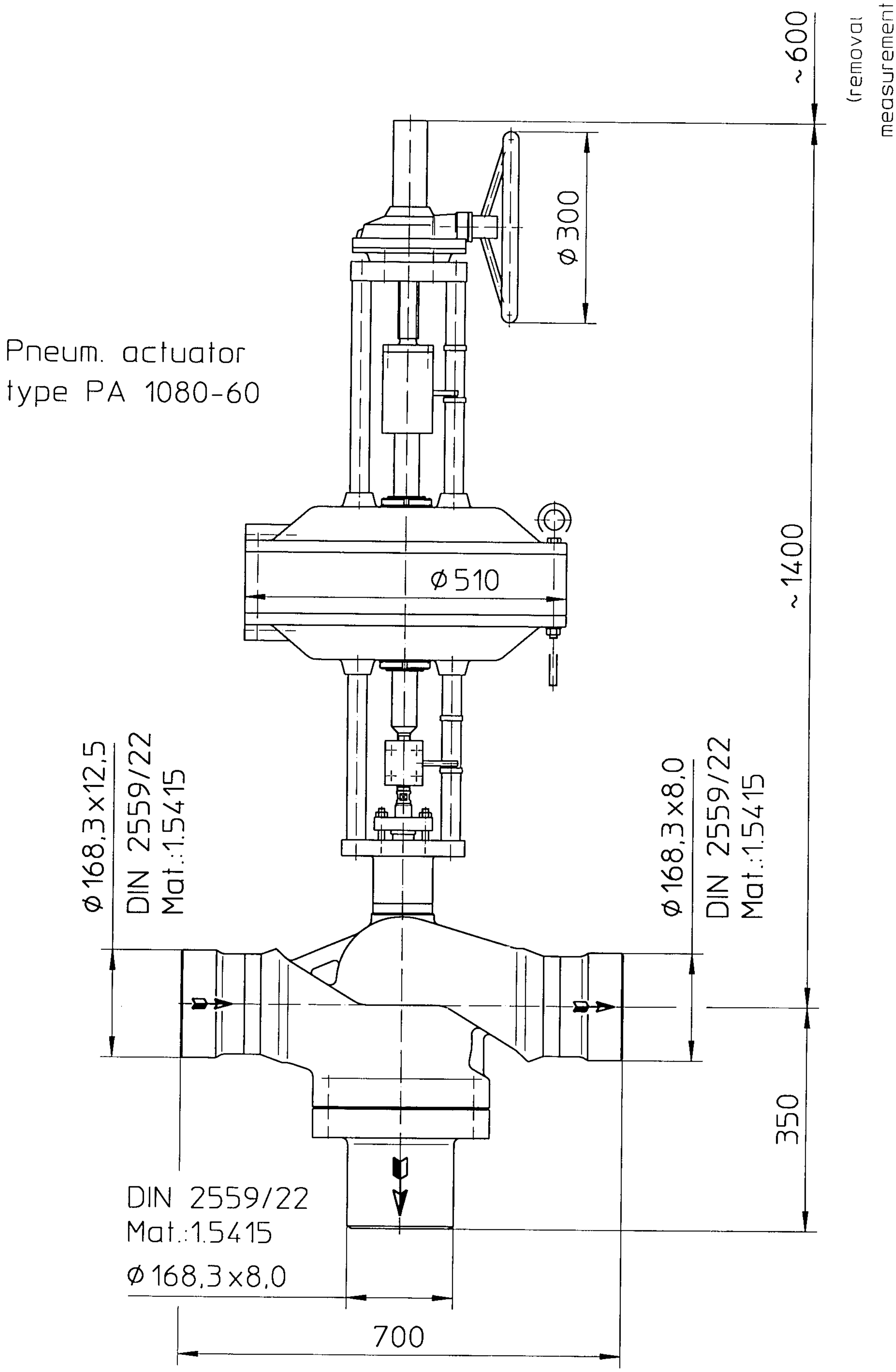
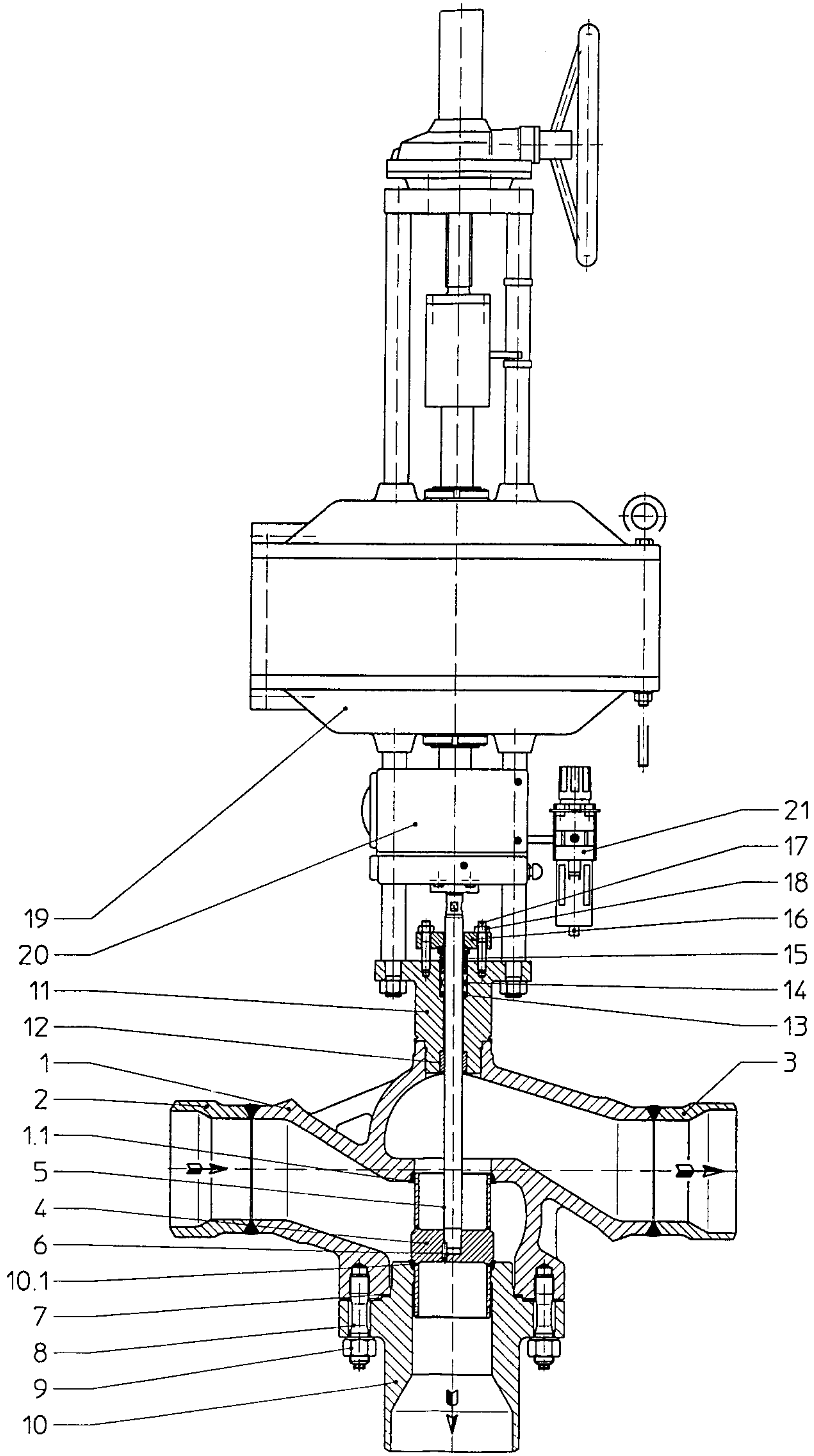


Pos. : 4	Weight ~ 270 kg			Drawing No.
Mark : LAB 51 AA 301	2002	Date	Name	
Plant: Völund-Esbjerg Kraft Värme	Drawn	11.01.	Whitear	E-62816/GB
	Proofed	11.01.	Wol.	



Pos.	Designation		Mat. Spec.	Sp Parts
1	Body		1 [illegible]19	
1.1	Seal ring		F[illegible] SKWAM	
2	Buttweld end		1.5415	
3	Buttweld end		1.5415	
4	Plug		1.4057	X
5	Valve stem		1.4122	X
6	Cylindrical pin		niro	X
7	Gasket		1.4541/Gr.	X
8	Expansion bolt		1.7709	
9	Hexagon nut		1.7709	
10	Connection		1.5415	X
10.1	Seal ring		FOX SKWAM	
11	Bonnet		1.0460	
12	Guide bush		1.4057	
13	Ring		1.4122	
14	Stem packing		gr./K80S	X
15	Stuffing box		1.4057	
16	Flange		1.7380	
17	Stud bolt		1.7709	
18	Hexagon nut		1.7258	
19	Actuator		PA 1080	
20	I/P-Positioner		---	
21	Filter Regulator		---	

Pos. : 4

Mark : LAB 51 AA 301

Plant: Völund - Esbjerg Kraft Värme

Index	Change No		Date	Name	Microf	Index	Change No	Date	Name	Microf
2002	Date	Name								
Drawn	11.01.	Whitear	HORA Regelarmaturen – Excellence is our standard			Holter Regelarmaturen				
Proofed	11.01.	Wol.				33758 Schloß Holte-Stukenbrock				
Norm-Pr.										

Scale		Drawing-No
-	Three-way Distribution Valve DN 125 Series 300.06 Actuator PA 1080-60	C-25751/GB
		Replacement for
		Replace off

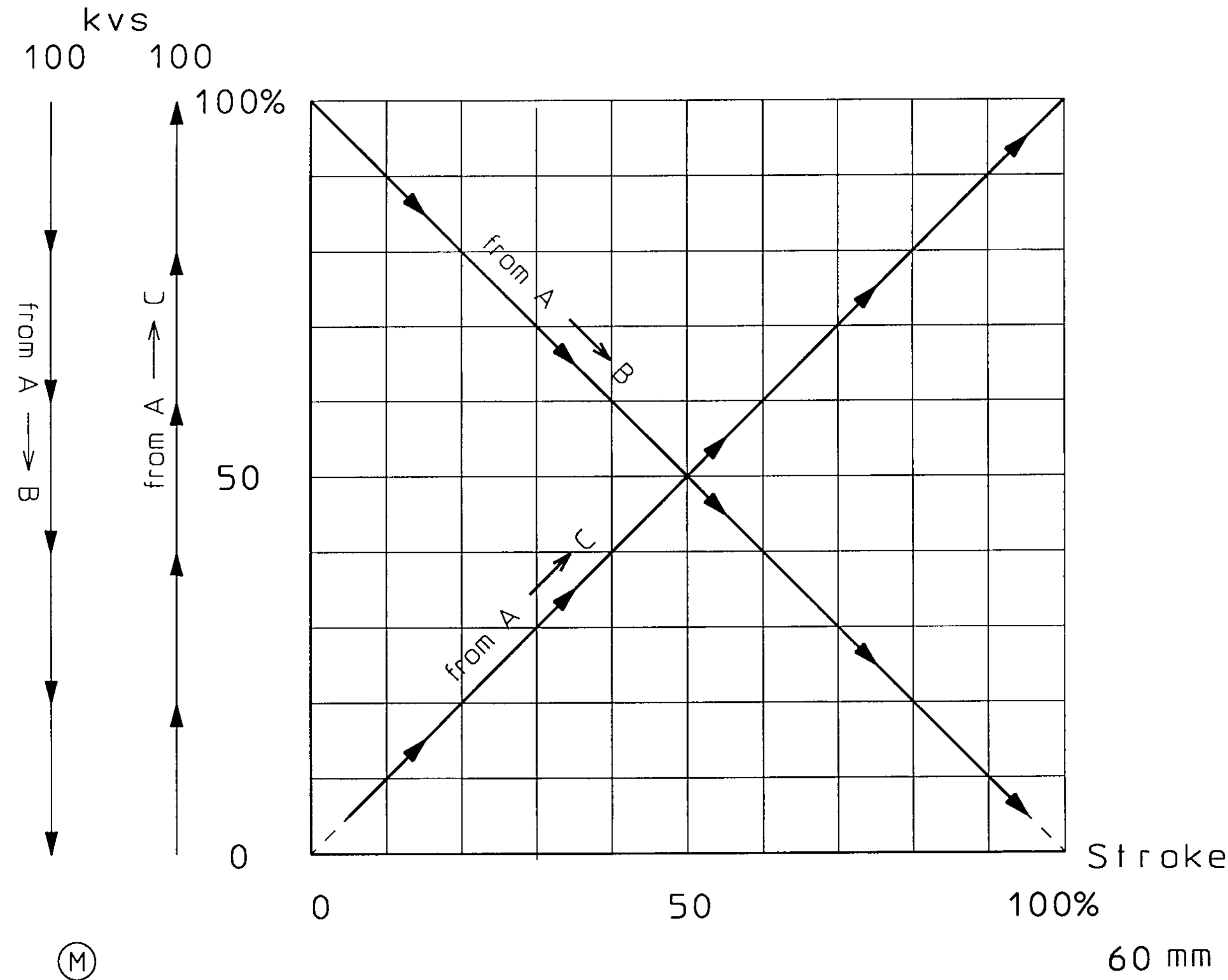
Three-way Distribution Valve - Base Characteristic

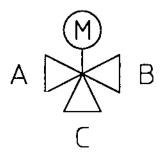
Characteristic: linear

HORA REGELARMATUREN
Excellence is our standard

Theoretical proportion AB--->A $= \frac{Kvs}{Kv0} = \frac{100}{2,5} =$ 40:1

Theoretical proportion AB--->B $= \frac{Kvs}{Kv0} = \frac{100}{2,5} =$ 40:1





Definition of KV-rate according to VDI/VDE 2173

The meaning of the KV-rate is the rate of flow from water at 5 till 30°C (ϱ = 1000kg/m^3), which pass the valve with a pressure drop of 1 bar at the momentary stroke.

Pos. : 4				Drawing No.
Mark : LAB 51 AA 301	2002	Date	Name	KB-01211383-04/GB
Plant: Völund-Esbjerg Kraft Värme	Drawn	15.01.	Whitear	
	Proofed	15.01.	Wol.	

KKS nr. LAB51AA301

Tegningsnr. C-25747/GB

Pos 4

Del	Stk		DKK/stk
4-6	1	3-vejs kegle med spindel	21.735,-
7	1	Spiraltætning	546,-
14	1	Spindeltætning komplet	1.103,-
		For aktuator type PA 1080	
	1	Membran	1.943,-
	2	Spindeltætning komplet	1.785,-

Inquiry / PO. No.	L90 Esbierg	Page No.	1
Customer	Gronbech & Soenner A/S	Date	
Code name	L90 Esbierg		
KSB reference No.	4003011122-05	Pump.	HGM 4/5
Dept. / In charge	TSS Eng.PP FT Manuel Di Bella	Product No.	

Pump size/Stages: HGM 4/5 Pump type: Horizontal ring-section pump
Drive: Motor with frequency converter

Application/Medium handled: Boiler feed water
Conditioning AF Alkaline composition with salt-free water
pH value at 25°C >9.0 O2 contents mg/l <= 0.02

Operating Data (tapping closed)

Operating point	Unit	Guarantee point Design point to ISO 9906 / 2B	Qmin, thermal
Operating temperature	°C	140	140
Density	kg/dm3	0.926	0.926
Pressure in inlet vessel	bara	3.614	
NPSH available	m	10	
	bar	0.908	
NPSH required at Qs **)	m	4.939	
	bar	0.448	
Pressure at suction nozzle	bar g	3.522	
Mass flow rate at disch. nozzle	t/h	115.72	
Capacity	m3/h	125	53.51
Overall head	m	810.73	892.24
	bar	73.61	81.01
Pump discharge pressure	bar g	77.13	
Efficiency *)	%	73.28	
Pump input power	kW	352.07	
Pump speed	1/min	~3600	~3600

Direction of rotation clockwise as viewed from the driven end

Operating Data in Case of Tapping

Operating point	Unit	Design point
Total disch. Pressure	bar	75
Total power	kW	372.78
Total efficiency	%	74.73

Stages		1. - 4.	5. - 6.
Flow rate	m3/h	148	125
Flow rate at tapping	m3/h	23	
Discharge head	m	500.84	787.36
	bar	45.47	71.48
Tapping pressure	bar g	48.99	
Shut-off pressure	bar g	56.21	85.64
Efficiency *)	%	74.45	74.41
Pump input power	kW	253.28	119.5

ADDITIONAL DATA

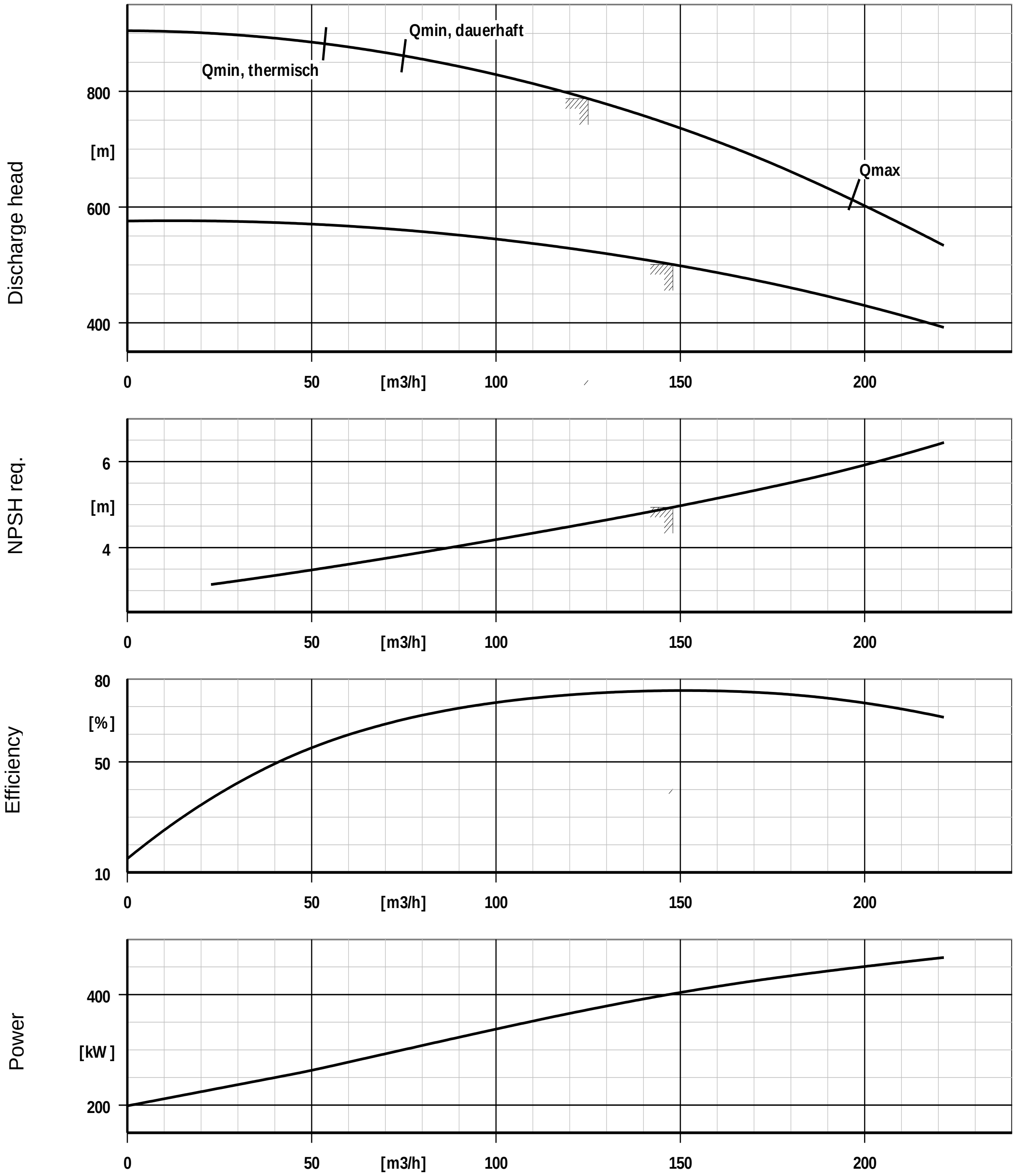
Pump discharge pressure at Q = 0, cold water 36001/min		Pump discharge nozzle	Tapping nozzle 1
	bar g (+/- 3%)	88.56	56.82

Permissible minimum operating speed 1800 1/min

*) Efficiency improvement acc. to Karassik
**) without strainer loss

Inquiry / PO. No.	L90 Esbierg	Page No.	2
Customer	Gronbech & Soenner A/S	Date	
Code name	L90 Esbierg		
KSB reference No.	4003011122-05	Pump.	HGM 4/5
Dept. / In charge	TSS Eng.PP FT Manuel Di Bella	Product No.	

Type / size	Speed [1/min]	Temperature [°C]	Density [kg/dm3]
HGM 4/5 7.1 S 6.2 N	3600	140	0.926



Code name	Item No.	Date

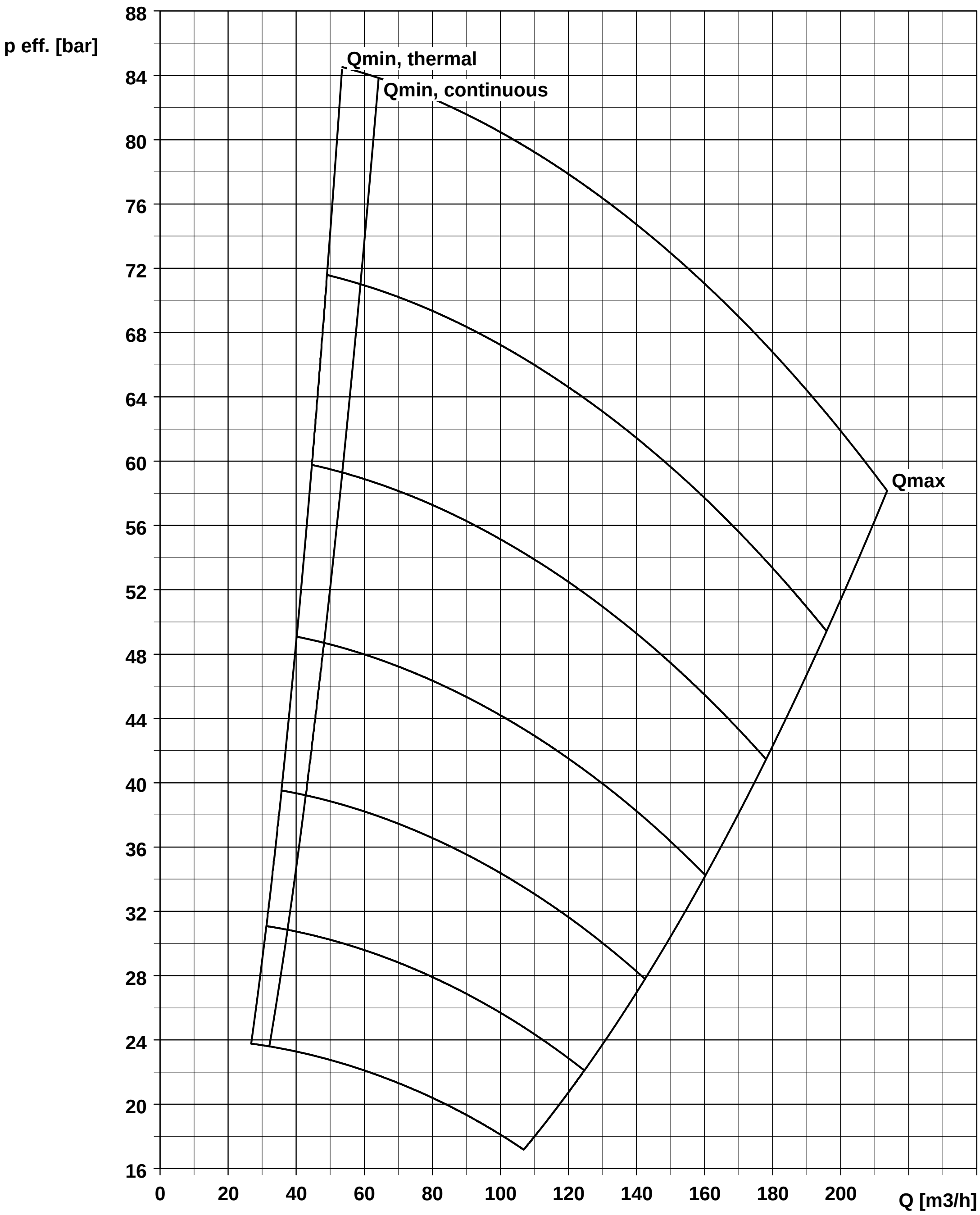
Code name	Item No.	Date	
L90 Esbierg		4.4.2017	
Project No.		Hydraulic	
4003011122		HGM 4/5 7.1 S 6.2 N	
Type - size		Temperature [C]	Density [kg/m3]
HGM 4/5		140	925.8

Operating range diagram

Closed tapping

Speeds

1: 3600 [1/min]
2: 3300 [1/min]
3: 3000 [1/min]
4: 2700 [1/min]
5: 2400 [1/min]
6: 2100 [1/min]
7: 1800 [1/min]



Minimum permissible speed 1800 [1/min]

Pump Design

Nozzle	Design	DN	Class	Drilled acc to	Position [°] *)
Inlet	Flange	6 in	300	ANSI B 16.5 RF	vertically upwards
Outlet	Flange	4 in	600	ANSI B 16.5 RF	vertically upwards
Tapping	Flange	2 in	600	ANSI B 16.5 RF	60.0

*) clockwise viewed from the driven end (0° = top)

Shaft Seal	Manufacturer	Type	Material	Cooling
GLRD	BURGMANN	KB065-	AQ1EGG	Air cooled

Axial thrust balancing Hydraulically by means of Disc

Bearing	Design	Lubrication	Cooling
Radial	Plain bearing	By medium	No
Thrust	-	-	-

Pump Feet Arrangement Foot

Accessories

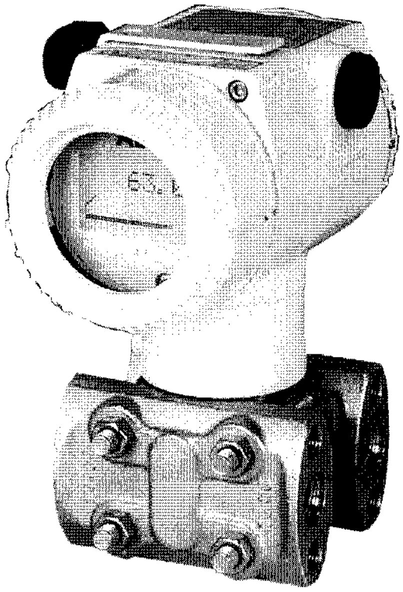
Balancing water pipe return to the first stage
Instrumentation acc. to list of measuring points
Intake elbow - ANSI
Baseplate for pump and motor (with foundation bolts)
Wiring & Terminal Box

Multi Vision™
Digital Transmitter

2010TD for Differential Pressure, Flow Rate, and Level
2010TA for Absolute Pressure

Instructions

42/15-712-7 EN



Contents

1 Safety

General safety precautions and health protection
To ensure safe operation of the 2010TA / 2010TD Transmitters, the following instructions have to be observed:

☞ **Please read these instructions / operating manual carefully prior to assembly and commissioning!**
For reasons of clarity the instructions do not contain all details on all types of product and do therefore not take into account every conceivable case of assembly, operation or maintenance.
If you want further information or if special problems arise which are not treated in detail in the instructions, please ask the manufacturer for the necessary information.
Moreover we would like to point out that the content of these instructions is neither part of nor provided for changing a previous or existing agreement, promise or legal relationship. All obligations of ABB Automation Products GmbH result from the respective sales contract which also comprises the complete and solely valid warranty clauses. Such contractual warranty clauses will neither be limited nor extended by the content of these instructions.

☞ **Observe warning signs at packaging etc.!**

☞ **For assembly, electrical connection, commissioning and maintenance of the transmitter, only qualified and authorized specialists are to be employed.**
Qualified specialists are persons who are experienced in the assembly, electrical connection, commissioning and operation of the transmitter or similar devices holding the necessary qualifications for their job, e.g.:

- Training or instruction and / or authorization to operate and maintain devices / systems according to the safety engineering standard for electric circuits, high pressures and aggressive media.
- Training or instruction according to the safety engineering standard regarding maintenance and use of adequate safety systems.

⚠ For the sake of your own safety we draw your attention to the fact that for the electrical connection, only sufficiently isolated tools acc. to DIN EN 60 900 may be used.

- Furthermore the pertinent safety regulations concerning the construction and operation of electrical installations, e.g. the rule regarding technical working material §3 (safety rule for instruments), have to be observed.
- The pertinent standards, e.g. DIN 31 000 / VDE 1000.
- The regulations and recommendations relating to explosion protection if explosion-proof transmitters are to be installed.
- The device can be operated with high pressure and aggressive media.

⚠ Serious injury and / or considerable material damage can therefore be caused when this device is handled incorrectly.

- The regulations, standards, recommendations and rules mentioned in these instructions are valid in Germany. When using the transmitter in other countries, the pertinent national rules have to be observed.

Correct usage
The 2010TD Transmitter measures differential pressure, flow rate or level; the 2010TA Transmitter measures absolute pressure of gases, vapors and liquids. The measuring ranges are graduated from 10 mbar to 100 bar for the 2010TD resp. from 400 mbar abs. to 20 bar abs. for the 2010TA, each for the nominal pressure stages PN 160, PN 250 and PN 400. The transmitter can be overloaded on one side up to the relevant nominal pressure.

2 Transport and Storage

After unpacking the transmitter, check the device for transport damage. Check the packing material for accessories.
During intermediate storage / transport, store and transport the transmitter in the original packaging only. See section 10 "Technical Data" for permissible ambient conditions regarding storage and transport. The storage time is indefinite, however, the warranty conditions stipulated in the order confirmation of the supplier are valid.

3 General Description

The digital 2010TD / 2010TA Transmitters are communicating field devices with microprocessor-controlled electronic in multi-sensor technology.
For bi-directional communication, an FSK signal according to the HART® protocol or Bailey FSK protocol is overlaid to transmitters with 4 ... 20 mA output signal whereas, in case of fully digital transmitters, communication is effected via the fieldbus protocols PROFIBUS-PA or FOUNDATION Fieldbus, depending on the model.
The communication software SMART VISION allows PC-based configuration, scanning and testing of transmitters according to the respective protocol. Communication is also possible by means of a handheld terminal provided that the transmitters are working according to the HART® or Bailey FSK protocol.
For "local" operation, a control unit is optionally available which can also be retrofitted.
The control unit consists of two keys for the adjustment of zero and span and a write protect key. In conjunction with an installed LCD indicator, a complete external configuration and parameter setting of the transmitter is possible via the "local control unit", irrespective of the selected communication protocol.
As standard, the amplifier housing has a coat of varnish resistant to aggressive atmosphere; the process connection is made of stainless steel or Hastelloy C. The housing cover and the push button unit can be sealed.
The relevant transmitter data, such as transmitter type, communication, wetted parts material (O-ring, separating diaphragm or measuring diaphragm), measuring range, min. span, operating voltage, output signal, adjusted span and serial number (F.-No.) are to be found on the type plate. **In case of inquiries, please always indicate this number which is valid worldwide!**
For explosion-proof transmitters, the explosion protection type is described on a separate plate.
Another separate plate in front of the "local" control unit shows the functions of the three control elements by means of readily comprehensible symbols.
Additionally, a tie-on plate indicating the tag number may be attached (optional).

Principle of operation and construction
The transmitter has a modular design and consists of the pressure sensor module with an integrated electronic matching unit and an amplifier with control unit.
The completely welded sensor module is a twin-chamber system with an integral overload diaphragm, an internal absolute pressure sensor and a silicon differential pressure sensor. The absolute pressure sensor, which is only exposed to the pressure at the high pressure side (⊕), acts as a reference value to compensate for the static pressure. The differential pressure sensor is connected via a capillary tube to the negative side / the reference vacuum of the sensor module. The applied differential pressure (dp) / absolute pressure (pabs) is transferred via the separating diaphragm and the fill fluid to the diaphragms of the silicon differential pressure sensor.
A minimal deflection of the silicon diaphragm changes the output voltage of the pick-up system. This output voltage, proportional to the pressure, is converted by the matching unit and the amplifier into an electrical signal.
Depending on the model, the transmitter is connected to the process by means of oval flanges with fixing threads according to DIN 19213 (M10 / M12) or 7/16 - 20 UNF, 1/4-18 NPT female thread or remote seal.
The transmitter operates with a 2-wire system. The same wires are used for the operating voltage (depending on the transmitter, see section 10 "Technical Data") and the output signal (4...20 mA or digital). The electrical connection is made via cable entry or plug.

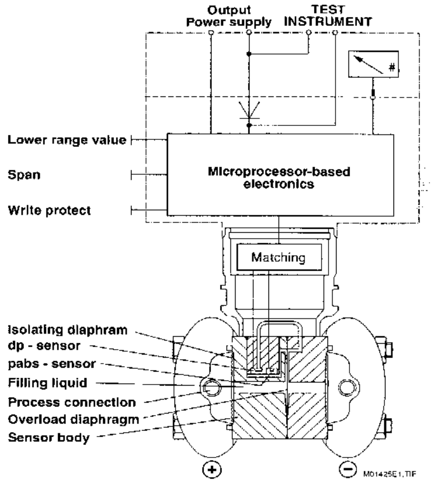


Figure 1. Transmitter 2010TD for differential pressure

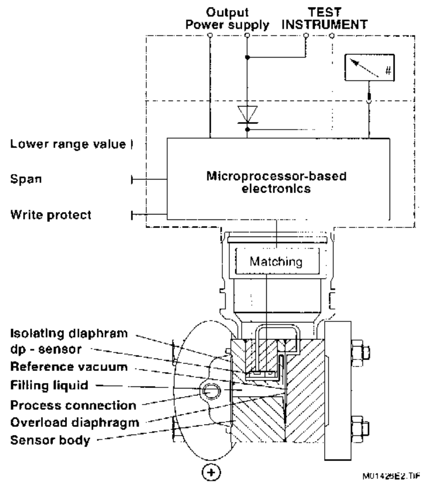


Figure 2. Transmitter 2010TA for absolute pressure

In case of HART® / Bailey FSK devices, the output signal 4...20 mA can be measured at the "TEST" sockets without interrupting the signal circuit (not applicable in case of fieldbus devices!).
A fixing possibility is provided for a stainless steel tie-on plate indicating the tag number.
Lower range value and upper range value can be set by means of "local" keys (optional, can be retrofitted) and, if required, the keys can be interlocked with the write protect switch.
The transmitter may be equipped with an LCD indicator which can be read from the front (optional, can be retrofitted).
In conjunction with the LCD indicator, an external parameter setting and configuration of the most important transmitter function / data is possible via the "local" control unit (see section 7 "Operation").

Documentation
Supplementary documentation:
Instructions 42/15-710 EN
For device construction, detailed operation, assembly examples.

4 Mounting

General

Before mounting the transmitter, check whether the model meets the measurement and safety requirements of the measuring point, e.g. with regard to materials, pressure rating, temperature, explosion protection and operating voltage. The relevant recommendations, regulations, standards and the rules for prevention of accidents must also be observed! (e.g. VDE / VDI 3512, DIN 19210, VBG, Elex V, etc.)

Measurement accuracy is largely dependent upon correct installation of the transmitter and the related measurement piping(s). The measuring set-up should be screened as much as possible from critical ambient conditions such as major temperature variations, vibration and shock. If unfavorable ambient conditions cannot be avoided owing to reasons related to building structure, measuring requirements or other reasons, this may influence the measurement quality! (see section 10 "Technical Data").

If remote seals with capillary tubes are attached to the transmitter, see also the Instructions 42/15-813 EN.

Transmitter

The transmitter can be connected directly onto the shut-off valve. There is also a mounting bracket for wall or pipe mounting (2" pipe) available as an accessory.

Preferably in such a position that the process flange axes are vertical (horizontal with barrel-type amplifier housing) so as to avoid zero shifts.

If the transmitter were installed inclined, the hydrostatic pressure of the filling fluid would exert pressure on the sensing dia-phragm and thus cause a zero shift! A zero point correction would then be necessary.

Various versions are available for connecting the measuring lines, and these are shown in detail on the dimensional diagram. Unconnected process connections on the measuring mechanism must be sealed with the enclosed blanking plugs (1/4-18 NPT).

For this purpose use your officially approved sealant.

Please refer to section 11 "Dimensional Diagrams" for possible mounting with bracket.

Measuring piping

The following points must be observed for correct installation:

- Keep the measurement piping as short as possible and avoid sharp bends.
- Lay the measurement pipings so that no deposits can accumulate. Gradients should not be less than 8 %.
- Measurement pipings should be blown through with compressed air or, better still, flushed through with the measuring medium before connecting to the measuring element.
- If the medium is a liquid/vapour the filling liquid must be at the same level in both pipes. If using separating liquids, both pipes must be filled to the same height (2010TD).
- Keep both pipes at the same temperature whenever possible (2010TD).
- Completely bleed measuring pipings if the medium is a liquid.
- Lay the process piping so that gas bubbles, when measuring liquids, or condensate when measuring gases, can flow back into the process piping.
- Ensure that the process piping is correctly connected (+ HP and – LP side on measuring mechanism, seals, ...).
- Take care of the tightness of the connection.
- Lay the process piping so that blow-outs do not occur via the transmitter!

5 Electrical connection

The relevant guidelines must be observed during the electrical installation!

Since the transmitter has no switch-off elements, overcurrent protection devices or mains disconnection possibilities must be provided on the system side. (Overvoltage protection at option)

Check that the existing operating voltage corresponds to that indicated on the type plate. For power supply and output signal, the same lines are used. **Consult the enclosed connection diagram!** Depending on the supplied model, the electrical connection is made via cable entry 1/2-14 NPT or M 20 x 1.5 or via plug Han 8 U. The screw terminals are suitable for wire cross-sections up to 2.5 mm^2.

Caution: For transmitters of category 3 regarding the application in "Zone 2" the cable gland has to be provided by the customer. For this purpose there is a thread of size M 20 x 1.5 in the electronic housing. The cable gland must comply with the protection type "Increased Safety EEx e" according to the directions 94/9/EG (ATEX). Furthermore, the conditions stated in the type test certificate of the cable gland have to be observed!

Note: If the type of protection "Flameproof enclosure" (EEx d) applies to the transmitter, the enclosure cover has to be locked by means of the attachment screw (Fig. 9).

We would like to point out here that after intervals of several weeks an increased force is required to screw off the housing. This effect is not caused by the thread but only due to the gasket type.

Electrical connection in the cable connection compartment

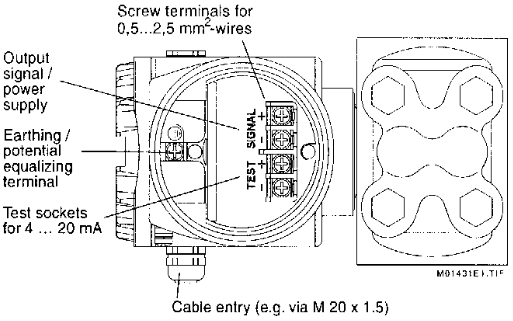


Figure 3. Cable connection compartment

Electrical connection with plug

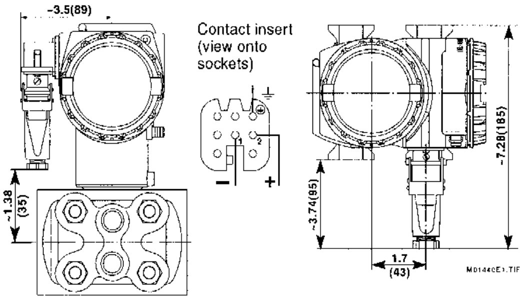


Figure 4. Plug connection

Mounting of the socket connector

The socket connector for the cable connection is enclosed with the transmitter for the plug version.

Installation (see Fig. 5):

The contact sockets (2) are crimped or soldered onto the cable ends (wire cross-section 0.75...1 mm^2) from which 1.5...2 cm of the sheath and about 8 mm of the insulation has been removed and inserted from the rear into the contact insert (1). The screwed gland (5), thrust ring (7), sealing ring (4) and grommet housing (3) must be pushed onto the cable in the specified order prior to installation (the sealing ring (4) may have to be adapted to the cable diameter first).

Attention:

Check the connecting points again before pressing the sockets all the way into the contact insert. Incorrectly installed sockets can only be removed again with a special removal tool (item no.: 0949 813).

A connection terminal is available for grounding (PE) on the transmitter exterior and also in the plug. Both terminals are electrically interconnected.

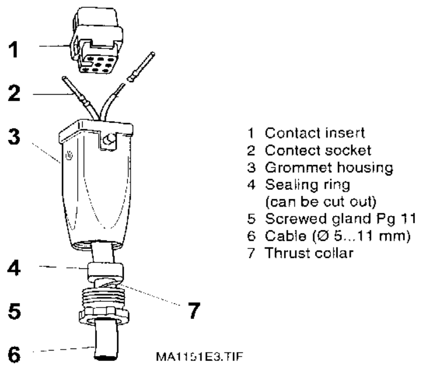


Figure 5. Mounting of the socket connector

Protective conductor / grounding

The transmitter operates within the specified accuracy with common mode voltages between the signal lines and the housing up to 250 V.

On principle the power supply of the transmitter with an output voltage of max. 60 VDC has to be effected from a voltage source which is safely separated from mains. In order to fulfill the requirements of the low-voltage guidelines and the relevant EN 61010 rules for the installation of electrical components, the housing must be provided with a protective circuit (e.g. grounding, protective conductor) if voltages of >60 VDC could occur.

Set-up of the signal circuit / communication circuit for transmitters with 4...20 mA output signal (HART® / Bailey FSK protocol)

The transmitter can be operated via a modem by means of a PC or laptop. The modem can be connected in parallel to the transmitter at any place in the signal circuit. Communication between transmitter and modem is made via AC signals which are overlaid to the analog 4...20 mA output signal. This modulation is effected without averaging and therefore, it does not influence the measuring signal.

Communication between transmitter and PC or laptop is only possible if the signal circuit is set up as shown in Fig. 6. The resistance between the connecting point of the FSK modem and the power supply must be at least 250 ohm including the internal resistance of the supply unit. If this value is not reached with the normal installation, an additional resistance must be used.

The additional resistance has already been installed by the manufacturer in the supply units TZN 128 and TZN 129. In the "FSK bus" mode, the TZN 128 allows to communicate directly via the supply unit.

For power supply, either supply units, batteries or power packs can be used which must be designed to ensure that the operating voltage UB of the transmitter is always between 10.5 and 45 V DC (for LCD indicator 14 ... 45 V DC).

The max. current of 20... 22.5 mA which may occur by overranging according to the respective parameter setting, must be taken into account. The minimum value for US results from this. If further signal receivers (e.g. indicators) are connected into the signal circuit, their resistance must also be taken into account.

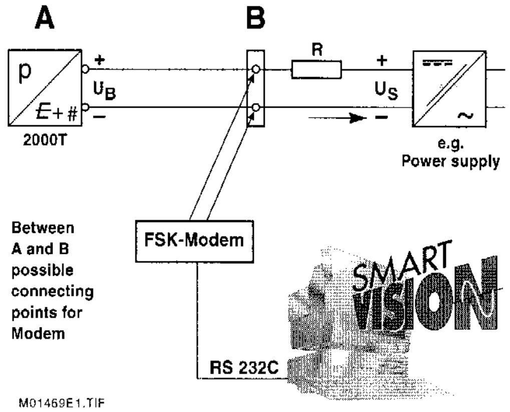


Figure 6. Communication mode: "point-to-point"

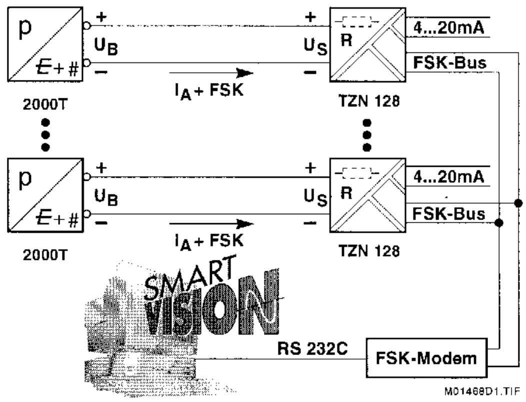


Figure 7. Communication mode: "FSK bus"

Notes on connecting cable

To allow communication between transmitter and PC/laptop, cabling must meet the following requirements:

It is recommended to use shielded and twisted pair lines.

The minimum wire diameter should be:

- 0.51 mm for lines up to 1500 m
- 0.81 mm for lines longer than 1500 m

The maximum line length is limited to:

- 3000 m for twin-core cable
- 1500 m for multicore cable

The actually possible line length of the electric circuit depends on the total capacitance and joint resistance; it can be estimated according to the following formula:

$$L = \frac{65 \times 10^6}{R \times C} - \frac{C_f + 10000}{C}$$

L = Line length in m
R = Joint resistance in
C = Line capacitance in pF
Cf = Capacitance of the devices existing within the circuit

The shield should be grounded on one side only.

Laying together with other electric circuits (with inductive load, etc.) and the proximity of large electrical installations should be avoided.

Max. permissible residual ripple of the supply voltage during communication:

7 Vss at 50 Hz ≤ f ≤ 100 Hz
1 Vss at 100 Hz < f ≤ 200 Hz
0.2 Vss at 200 Hz < f ≤ 300 Hz

Notes on PROFIBUS-PA transmitters
Fieldbus transmitters are provided for the connection to segment couplers DP/PA. The permissible terminal voltage ranges from 10.2... 32 V DC. Current consumption is 14 mA (at average transmission).
A shielded cable is recommended. Contacting of the shield is effected in the metal screwing. The transmitter must be grounded.
The transient behavior corresponds to the draft DIN IEC 65C / 155 / CDV dated June 1996. When operating with an Ex-segment coupler according to DIN EN 61 158-2 October 1994, the max. number of devices may be reduced by a time-dependent current limitation.
The output signal of the transmitter is transferred digitally according to IEC 61158-2. For PROFIBUS-PA, the communication protocol corresponds to Version 3.0, Class B, Ident-No.: 04C2 HEX (EN 50 170).
During cyclic data traffic, the OUT variable is transmitted. It is composed of the output value and 1 byte status information. The output value is transmitted with 4 bytes as IEEE-754 Floating-Point-Type.
Further notes on PROFIBUS-PA, e.g. with respect to the "Ident Number", are given in the "Additional Instructions 42/15-712-Z0.20", the data sheet "Installation Suggestions 10/63-0.40" as well as under the Internet address http://www.profibus.com.

Notes on explosion protection
For the installation (electrical connection, grounding / potential equalization, etc) of explosion-proof transmitters, the national statutory orders, DIN/VDE rules, guidelines for explosion protection and the explosion proofness test certificate of the device have to be observed. The certified explosion proofness of the transmitter is indicated on the type plate.

Transmitters of the type of protection "Intrinsically safe EEx i" according to the directions 94 / 9 / EG (ATEX):
- Install only intrinsically safe devices within the transmitter signal circuit.
- The signal circuit may be interrupted even when the transmitter is in operation (e.g. disconnect and connect signal lines).
- The housing may be opened during operation.
- Transmitters with and without remote seal of the protection type "Intrinsically Safe EEx i" may be installed directly at Zone 0 if the power supply is effected via an intrinsically safe circuit EEx ia or EEx ib.
- Test circuit (terminals "TEST +/-"): in protection type Intrinsically Safe only for connection to passive intrinsically safe circuits. The category, the explosion class as well as the max. values Uo, Io and Po of the intrinsically safe test circuit are determined by the connected intrinsically safe signal circuit. The rules for interconnection have to be observed!

Transmitters of category 3 for the application in "Zone 2" according to the directions 94 / 9 / EG (ATEX):
- The transmitter has to be connected via the approved cable gland (protection type "Increased Safety EEx e" according to ATEX).
- It is not permitted to open the housing during operation (operating voltage switched on)!

Transmitters of the type of protection "flameproof enclosure EEx d" according to the directions 94 / 9 / EG (ATEX):
- It is not permitted to open the housing during operation (operating voltage switched on)!
- The following set-up instructions have to be observed:

1. The transmitter has to be connected via suitable cable and line entries or piping systems which meet the requirements according to EN 50 018:1994, Section 13.1and/or 13.2 and for which a separate test certificate is available!
2. Unused openings of the housing have to be closed according to EN 50 018:1994, Section 11.9!
3. Cable and line entries as well as blanking plugs which do not correspond to the points 1. and 2. must not be used!

- To align the transmitter (torsion by max. 360°) at the measuring point, the rotatable housing can be loosened at the shaft between sensor and housing:
  - Release the attachment screw by max. 1 rotation.
  - Align the housing.
  - Retighten the attachment screw!
- Before switching on the operating voltage:
  - Close the housing.
  - Secure enclosure cover by turning the attachment screw (hexagon socket screw) to the left.
  - Protect housing from torsion by turning the attachment screw (stud) to the right.
- Enclosure cover, electronic housing and sensor may only be replaced by approved components!

Type test certificate / Conformity statement
For transmitters in explosion-proof design the EC type test certificate and/or the conformity statement have to be considered as part of these operating instructions.

6 Commissioning

After installing the transmitter, it is placed into operation by switching on the operating voltage.

- Check the following before switching on the operating voltage:
  - Process connections.
  - Electrical connections.
  - That the measurement piping and measuring chamber of the transmitter are completely filled with the medium.

- Subsequently it is placed into operation.
  The shut-off valves should be operated in the following sequence (basic setting: all valves closed):
  with 2010TD:
  1. Open the shut-off valves on the pressure tap connections - if present.
  2. Open the pressure equalisation valve of the manifold.
  3. Open the positive shut-off valve.
  4. Close the pressure equalisation valve.
  5. Open the negative shut-off valve.

  with 2010TA:
  1. Open the shut-off valve on the pressure tap connection - if present.
  2. Open the shut-off valve of the manifold.

- Proceed in the reverse order when taking the unit out of operation.

Regarding the 2010TA for absolute pressure with a measuring range of 400 mbar abs. it has to be observed that during transportation and storage the sensor has been overloaded by the atmospheric pressure for a long time. Due to this, a starting time of approx. 30 min. is necessary after commissioning until the sensor is stabilized so that the specified accuracy is kept.
If, in case of transmitters of the type of protection "Intrinsically safe", a current meter is connected to the test sockets or a modem is connected in parallel when an explosion hazard is existing, the

sums of the capacitance and inductance of all circuits including transmitter (see type plate) must be equal to or smaller than the permissible capacitance and inductance of the intrinsically safe signal circuit (see type plate of the supply unit). Only passive or explosion-proof test devices or indicators may be connected.
If the output signal is slow to stabilize, a high damping time constant has probably been set in the transmitter.

Notes on transmitters with 4...20 mA output signal (HART® / Bailey FSK protocol)
If the applied pressure is within the values indicated on the type plate, the output current ranges between 4 and 20 mA. If the applied pressure exceeds the calibrated range, the output current is between 3.5 mA and 4 mA in case of underranging or between 20 mA and 22.5 mA (according to the respective parameter setting) in case of overranging; standard setting: 3.8 mA / 20.5 mA.
In order to prevent errors in the lower flow ranges (2010TD) it is possible, via the communication tool SMART VISION, to adjust the "Zero suppressor" and/or the lin./sq. rt. transition point. Should no values have been given then the factory set values will be: 5% for the lin./sq. rt. transition point and 6% for the "Zero suppressor" of the maximum flow, i.e. the 2010TD operates only with the "Zero suppressor".
A current of < 4 mA or > 20 mA may also indicate that the microprocessor has detected an internal error; standard setting: 21 mA. Via the communication tool SMART VISION, an exact diagnosis of the error can be performed. A short-time interruption of power supply results in an initialization of the electronic (restart of the program).

Write protection
Write protection prevents an illegal overwriting of the configuration data. If write protection is activated, the function of the keys 0 % and 100 % is disabled. However, it is still possible to read out the configuration data by means of SMART VISION (or another comparable communication tool).
If necessary, the control unit can be leaded.
Write protection is activated as follows (see also symbolism on the plate):
1. First, fully press down the switch with an appropriate screw driver.
2. Then turn the switch clockwise by 90 °∠.
For deactivation the switch has to be pushed down a little and turned counterclockwise by 90 °∠.

Sensor misalignment / zero correction
During the installation of the transmitter, zero shifts (e.g. slightly inclined installed position, uneven liquid columns in the differential pressure lines, additional remote seals etc.) caused by mounting may occur which have to be corrected.
Note: The transmitter must have reached its operating temperature (approx. 5 min after switch-on if the transmitter has already assumed ambient temperature) in order to be able to carry out the zero check. The correction has to be made at dp = 0 / pabs = 0 !
There are two possibilities (point 1A or 1B) to perform the **4...20 mA-output signal** correction directly at the transmitter (control unit is available):
1A. Apply pressure at lower range value (4 mA) – from the process or from a pressure pick-off. The pressure must be stable and applied with high accuracy << 0.05% (observe adjusted damping). Press the 0 % key at the transmitter – output signal is adjusted to 4 mA. The span remains unchanged.
Subsequent to the last actuation of the 0% key, the non-volatile storing of the lower range value adjusted in this way is effected after < 25s for HART and/or
< 110s for PROFIBUS-PA and/or
< 15s for FOUNDATION Fieldbus
1B. In conjunction with an installed LCD indicator, call up the menu item "SHIFTZERO" via the keys "M" and "+". Corrections are made by pressing the key "M" (see also section 7 "Operation").
2. Subsequently put the transmitter into the operating state.
The above procedure acc. to "1A" has no influence on the display of the physical differential pressure, but instead corrects the analogue output signal. Therefore, a difference may occur between the analogue output signal and the display of the physical differential pressure on the digital display or the SMART VISION communication tool. In order to avoid this difference, the necessary zero-point shift must be carried out using the SMART VISION (menu path **Configure_Differential Pressure Measurement_Process Variable** (Oblique Sensor)).
However, then a zero-point shift must not have been carried out with the 0% key beforehand.

Rotate housing with regard to the sensor
The electronic housing can be rotated through 360°∠ and can be fixed in any position. A stop prevents the housing from being turned too far.
To this effect, the fixing screw at the housing shaft (hexagon socket screw SW 2.5mm, see section 11 "Dimensional Diagrams") must be released and hand-tightened after the position has been reached.

Assembly / disassembly of push button unit (Figure 8)
- Loosen the screw of the protective cap and turn it aside.
- Push the lock completely out of the push button unit, e.g. by means of a suitable screw driver.
- Remove the uncovered square nut from the push button unit.
- Loosen the fixing screw of the push button unit by a Torx screw driver (size T10) and pull the latter out of the electronic housing.
- If necessary, insert a spacer and tighten it by the attached screw.

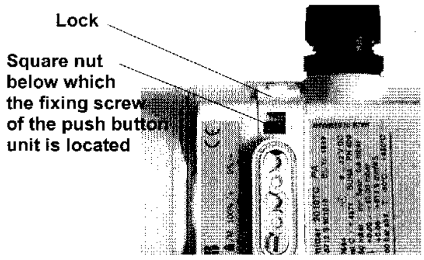


Figure 8. Push button unit - disassembly / assembly

Mount LCD indicator
- Unscrew enclosure cover of the electronic compartment (see figure 8) (if necessary, observe section "Secure enclosure cover for EEx d").

- Plug LCD indicator.
  Depending on the mounting position of the transmitter, the LCD indicator can be slipped on in four different positions; in this way turns by ± 90° or ± 180° are possible.
  Note: If the LCD indicator is backlit (option), there is a three-core cable with plug on the back of the indicator.
  Connect this plug with the three-pole plug strip in the electronic compartment (see Fig. 8) before slipping on the indicator.
  If there is a jumper on the 3-pole plug strip (in case of fieldbus transmitters no jumper is existing), it has to be removed and plugged into the "socket for jumper".

- Fasten LCD indicator with both screws.

- Hand-screw the enclosure cover (if necessary, observe section "Secure enclosure cover for EEx d").

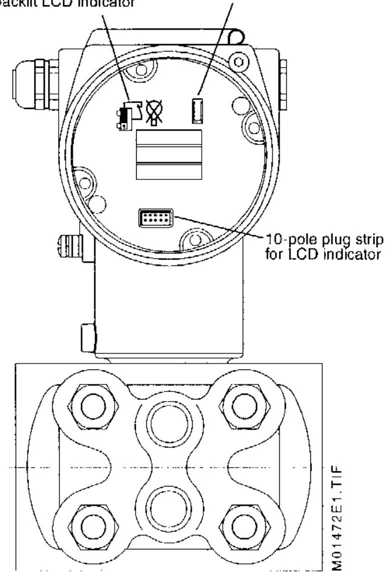


Figure 9. Electronic compartment – LCD indicator mounting

Secure enclosure cover for EEx d
On the top right of the electronic housing front, there is an attachment screw (hexagon socket screw, SW 3mm).

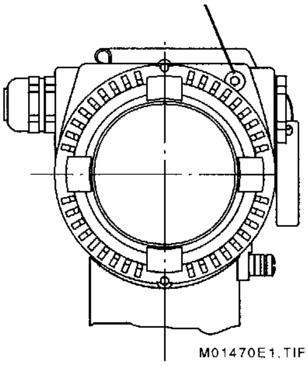


Figure 10. Secure enclosure cover

- Turn enclosure cover hand-tight into the housing.
- Secure enclosure cover by turning the attachment screw to the left. In doing so the screw must be unscrewed to the stop of the screw head at the housing cover.

7 Operation

⚠ There is no protection against electric shock when the housing covers are open. Do not touch live parts.

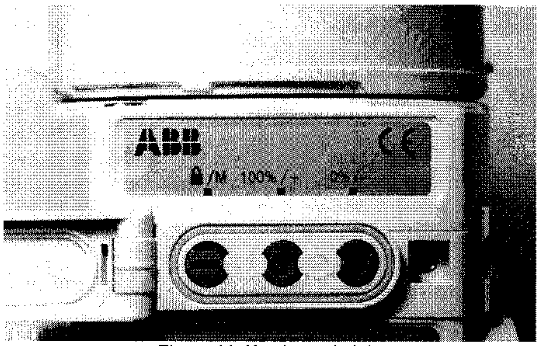


Figure 11. Key legend plate

Operation with
"local keys" (at the device) without LCD indicator
The retrofit / optional control unit comprises 2 keys for external adjustment of lower range value (0 %) and upper range value (100 %) and a write protect switch. There are no physical connections through the housing for the keys and the switch.

Calibration
Lower range value and span may be adjusted directly at the transmitter via keys.
The transmitter has been calibrated by the manufacturer according to the order data. The set values for lower range and upper range are indicated on the type plate.

Generally the following applies:
The 1st pressure value (e.g. 0 mbar) is always assigned to the 4 mA signal and the 2nd pressure value (e.g. 400 mbar) always to the 20 mA signal.

To readjust the transmitter, apply the pressure for the lower and upper range value to the sensor. Make sure that the measuring limits are not exceeded.
Pressure reducing stations with adjustable pressure and comparative displays can be used as sensors. When connecting, take care to avoid residual liquids (with gaseous test media) or air bubbles (with liquid test media) in the piping since they can cause errors.
The pressure reducing station should have an accuracy of at least 3 times better than the transmitter to be tested.
It is advisable (adjusted time constant is known!) to set the damping to zero (via key plus LCD indicator or SMART VISION).

Regarding the 2010TA for absolute pressure with a measuring range of 400 mbar abs. it has to be observed that during transportation and storage the sensor has been overloaded by the atmospheric pressure for a long time. Due to this, a starting time of approx. 30 min. is necessary after commissioning until the sensor is stabilized so that the specified accuracy is kept.

Sequence of steps:
1. Apply pressure for lower range value and wait approx. 30 s until it has stabilized.
2. Press key 0 % - output current is set to 4 mA.
3. Apply pressure for upper range value and wait approx. 30 s until it has stabilized.
4. Press key 100 % - output current is set to 20 mA.

5. If necessary, reset damping to the initial value.
6. Document new settings.

10 s after the last actuation of the 0 % or 100 % keys, the respective parameter is stored in a failsafe way.

This procedure of adjustment only changes the **4...20 mA** current signal. The representation of the physical process pressure on the digital display or by means of a communication tool, e.g. SMART VISION, is not changed. To avoid this difference, a correction can be made via the communication tool SMART VISION and its menu path **Calibrate_Differential Pressure Measurement_Adjust Input.**

After such a correction, the calibration of the device must be checked.

Operation with
"local keys" (at the device) with LCD indicator

In conjunction with an LCD indicator, the transmitter can be configured with the keys (- / + / M) as follows:

(Note: Indications in ( ) designate the menu item, they are shown in the 1st and 2nd line of the indicator.)

- Exit the menu (EXIT)
- View selected measured and calculated values (VIEW)
- Lower range value with applied pressure (GET 0%)
- Upper range value with applied pressure (GET 100%)
- Lower range value without applied pressure (SET 0%)
- Upper range value without applied pressure (SET 100%)
- Correct zero drift (e.g. oblique sensor) (SHIFTZERO)
- Parallel shift (OFFSET SHIFT)
- Scaling output variable – initial value (OUT 0%)
- Scaling output variable – final value (OUT 100%)
- Damping (DAMPING)
- Output current in case of an error (ALARM CURRENT); only available for 4...20 mA devices with HART® or Bailey FSK protocol
- Displayed value (DISPLAY)
- Pressure unit (UNIT)
- Temperature unit (UNIT) of internal temperature sensor
- Characteristic (FUNCTION) and the
- Fieldbus address (ADDRESS); only available for devices with PROFIBUS-PA or FOUNDATION Fieldbus protocol.

In the following, some of the a.m. menu items are described in detail.

Notes on "Parallel shift (OFFSET SHIFT)"

This function performs a parallel shift of the characteristic so that it runs through a specified point. Thus, the output signal of several measuring devices which measure the same process variable, can be brought to the same value without carrying out calibration with applied pressure.

On certain conditions, the function may be performed at any point of the characteristic:

- Process variable within the adjusted measuring range
- Transmitter with linear transfer function

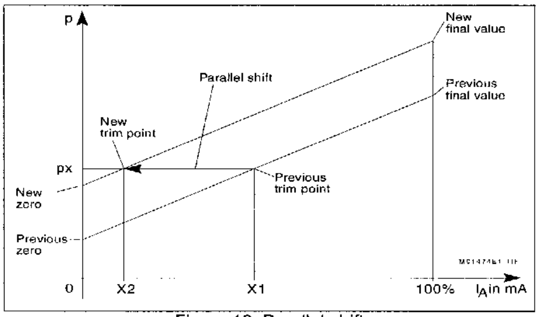


Figure 12. Parallel shift

Comments on Fig. 12:

By entering a percent value, an offset shift of the measuring range is carried out.

The transmitter displays with applied pressure px the standardized output value x1 in percent. However, for the present application, the value x2 should be displayed. Now the value x2 is set via local operation. The transmitter calculates the new zero and the new final value and then assumes these new settings.

Notes on "Damping (DAMPING)"

A fluctuating output signal of the transmitter, caused by the process, can be electrically smoothed (damped).

The additional time constants is adjustable between 0 sec. and 60 sec. in stepwise of 0.001s.

The damping set in this way does not affect the digitally indicated value in physical units, only the derivatives such as analogue output current, free process variable, input signal for controller etc.

Notes on "Characteristic (FUNCTION)"

In this menu option you can select the functions: linear and freely programmable. The "individuel values of the freely programmable characteristic" cannot be changed here. A Hand-Held-Terminal or the communication tool SMART VISION has to be used for changes.

Notes on "Fieldbus address (ADDRESS)"

Under this path, the fieldbus-slave-address may be changed. Enter a figure between 0 and 126 for the selected transmitter.

Remark: Generally, the manufacturer assigns the address 126 to all new devices! The transmitters should get different addresses in order to allow the addressing of a specific device. If, e.g., the device data are loaded via the communication tool SMART VISION after the address has been changed, the connection set-up is executed again, and possibly an error message appears. Acknowledge this with "Repeat", then the data will be loaded without any problem.

Measured value display

- **The LCD indicator**

2-line, 7-character, 19-segment alphanumeric display with additional bar chart display. Optionally the indicator is available with back illumination.

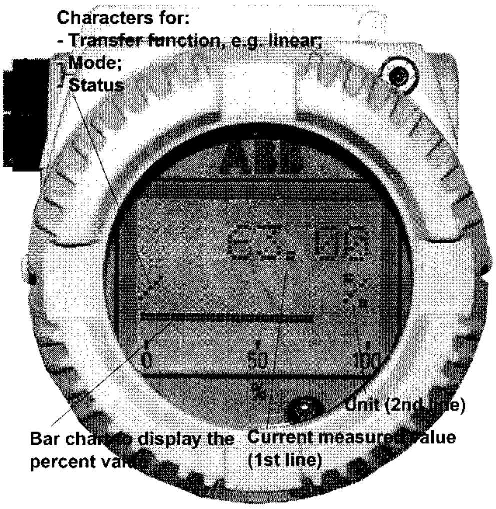


Figure 13. LCD indicator (optional)

- **Display of the physical value**

At the first position of the first line, the sign is displayed. The following six positions show the amount of the measured value. The comma is placed in such a way that the maximum value can be displayed with these six positions. Die place of the comma is not changed. A comma at the sixth position is not displayed. Thus it is possible to display max. +/-999999. If this value is exceeded Overflow is indicated. In the second line, the unit is displayed with the last five positions.
The first position shows the following characters, if necessary, one after the other. Display changes every second.

Display for	Character	Comment
Transfer function	⌐, √ or ⁄	Always one of these characters appears.
Write protection	⊡	Only if write protection has been set.
Cyclic communication	...	Only in case of PROFIBUS-PA
Status available (e.g.measuring range infringement or hardware error)	⚠	Only if a status is available.
Code of displayed value	1 . . . 9	See menu Display (see structure tree)
Transmitter is busy	⌛	This character overwrites other characters.

Table 1: Legend

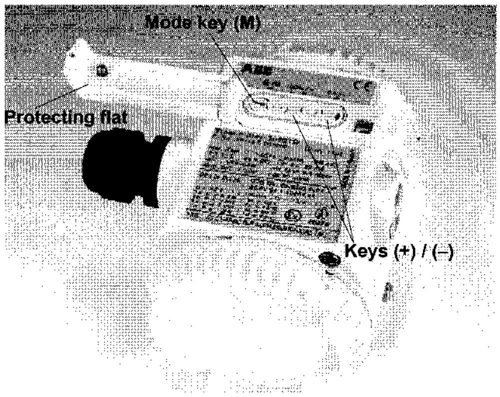


Figure 14. Control elements (optional)

Display of the percent value

	Display on LCD indicator
1st line	Percent value, limits: -25% to 125%, 2 decimal places
2nd line	1st position: Transfer function (Table 1) 2nd position: Write protection (Table 1) 7th position: %
Bar chart	2% steps - from -2% to +10%, no hysteresis

Table 2: Percent value display on LCD indicator

Program control

To make the keys accessible, release the screw and turn the protection cap aside (see Figure 13). With the mode key "M", you can start menu-controlled programming. To call the next menu item, press the key "+". You will return via the key "- ". Submenu items / selection lists are activated via the mode key "M". A numerical value can only be changed via the keys "+" and " - ". It must be taken into account that the key "+" changes the value (each keystroke increases the value by 1), whereas the position of the value to be changed is reached via the key " - ". Acknowledge changes with the mode key "M"; the subsequent OK acknowledgement (via the key "M", "+" or "-") writes the new value into the failsafe storage. An adjusting process can be aborted by pressing simultaneously the keys "+" and "-". From any main menu item, you can return to the menu item "EXIT" by simultaneously pressing the "+" and "-" keys. When the adjustment has been finished, quit the program via the menu item "EXIT". By means of the following structure tree, you will get an overview of the selection / programming possibilities.

Start with "mode key" (M)

- EXIT
- VIEW (temporary presentation of display values 1 up to 9)
  - Output signal in physical unit (2010TD: current measured value of the differential pressure or the derived measured value such as flow / level and / or 2020TG: current measured value of the gauge pressure or the derived variable such as level and / or 2010TA / 2020 TA: current measured value of the absolute pressure and / or. 2010TC: current measured value of the differential pressure in each case with user-specific-unit); correspond to the "OUT" variable in case of PROFIBUS-PA 1
  - Percent value of the output signal 2
  - Current (not for fieldbus transmitters) 3
  - Mass flow / standard volume flow (only for 2010TC) 4
  - Operating volume flow (only for 2010TC) 5
  - Static pressure (only with differential-pressure transmitters) 6
  - Process temperature (only with 2010TC, displays the temperature of the Pt100) 7
  - Pressure / differential pressure 8
  - Sensor temperature 9
- GET 0% } Adjustment with applied pressure
- GET 100%
- SET 0% } Adjustment without applied pressure
- SET 100%
- SHIFT ZERO — Sensor misalignment / zero correction
- OFFSET SHIFT — Parallel shift
- OUT 0% } Adjustment of output variable
- OUT 100%
- DAMPING
- ALARM CURRENT (not for fieldbus transmitters)
  - HIGH ALARM
  - LOW ALARM
  - LAST VALUE
- DISPLAY
  - Output signal in physical unit (2010TD: current measured value of the differential pressure or the derived measured value such as flow / level and / or 2020TG: current measured value of the gauge pressure or the derived variable such as level and / or 2010TA / 2020 TA: current measured value of the absolute pressure and / or. 2010TC: current measured value of the differential pressure in each case with user-specific-unit); correspond to the "OUT" variable in case of PROFIBUS-PA 1
  - Percent value of the output signal 2
  - Current (not for fieldbus transmitters) 3
  - Mass flow / standard volume flow (only for 2010TC) 4
  - Operating volume flow (only for 2010TC) 5
- UNIT
  - p / dp
    - Pa
    - GPa
    - MPa
    - KPa
    - mPa
    - uPa
    - HPa
    - bar
    - mbar
    - Torr
    - Atm
    - psi
    - g/cm2
    - Kg/cm2
    - in H2O
    - mm H2O
    - ft H2O
    - in HG
    - mm HG
  - OUT
    - "Selection list" with units (for the output variable, e.g.: kg/h, m)
- FUNCTION
  - Linear
  - Square root
  - Custom (Activation / deactivation of a freely programmable characteristic)
- ADDRESS (only for fieldbus transmitters)

1 = Code of the display value (2nd line, left)

M01466E3.TIF

Figure 15. Structure tree

Operation with PC / laptop or handheld terminal
To configure the transmitter via PC / laptop, the software SMART VISION is required. Please refer to the software description for operating instructions.

Communication protocol:	PROFIBUS-PA® or Foundation Fieldbus® or HART® or Bailey FSK
Hardware:	for HART® and Bailey FSK: FSK modem for PC / notebook
Handheld Terminal:	STT 04 or HHT 275

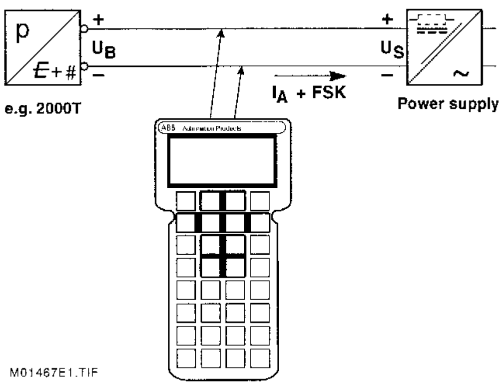


Figure 16. Communication set-up via STT04

Configuration of the flow measurement with SMART VISION
If the transmitter has been configured at the manufacturer's work for the measuring point according to the specifications given in the questionnaire you do not have to do anything else than to assemble the transmitter as specified (perhaps correct the sensor misalignment - refer to command **Configure_Differential Pressure Measurement_Process Variable** (Oblique Sensor)). After switch on the measuring point is ready for operation. If the transmitter is equipped with an LCD indicator, the current differential pressure (default adjustment) is displayed immediately.
However, it you want to make changes e.g. concerning the configuration of the mass flow measurement, you need a communication tool, e.g. SMART VISION. By means of this tool the device can be configured completely. It supports the HART Protocol as well as the fieldbus protocols "PROFIBUS-PA and FOUNDATION Fieldbus" and is operable on a PC / Notebook and/or in an automation system.
The necessary operating steps for the installation of SMART VISION are described in the installation instructions delivered with the software. The parameters can be adjusted via the path **Configure_Differential Pressure Measurement or Configure_Static Pressure Measurement.**
The program offers the possibility to configure, to set parameters, to interrogate and to test the devices. Furthermore an OFF-line configuration can be carried out via an internal data management. Every parameter setting and configuration is subjected to a plausibility check.
The <F1> key provides extensive context-sensitive help at every stage throughout the complete program.
Attention: Immediately after the delivery of the transmitters and/or before changing the configuration we recommend to save the existing configuration data on a data medium using the command **File_Save**.

Operation via SMART VISION®
System requirements
- SMART VISION®
  SMART VISION® as from Version 4.00.31
  When installing the DTM (Device Type Manager), SMART VISION® is updated to Version 4.00.43.
- Operating systems
  • Windows NT 4.0
  • Internet Explorer as from Version 5.0

Note:
The DTM is started by means of the right mouse button or via the menu item "Device" with "Edit". After a "Connection setup", first the data of the 2010TD/TA should be loaded completely. Changed data are underlined and displayed in blue. These data are transmitted to the device via "Store data in the device".
After the data have been saved in the transmitter, their nonvolatile storage is effected automatically. To do this, power supply to the transmitter must be continued for 2 minutes. If this is not observed, the previous data will become active again during the next operation. In case of software versions < 0.20 (< 20 for HART), storage will only be effected after disconnection.
For Profibus devices, the disconnection of "Local operation" only becomes effective in case of cyclic communication. If write protection is set by means of the DTM, the setting of the 2010TD/TA can no more changed via the control keys.
For Profibus devices, the slave address must be indicated correctly in the project tree of SMART VISION®. Communication name and description are automatically updated when loading the device data.
The most important calibration / parameterization possibilities under SMART VISION® are shortly described in the following. You will find further notes on the menu items in the context-sensitive help. Before carrying out any setting, please ensure that write protection has neither been activated on the transmitter itself (key) or via SMART VISION®(menu path **Configuration_Basic Parameters _General _Local Operation)**.

- **Adjust damping**
  Menu path:
  Configuration_Differential Pressure Measurement_Output
  The required value has to be entered in the field "Output parameters" in the line "Damping".
- **Correct oblique sensor**
  Menu path:
  Configuration_Differential Pressure Measureent_Process Variable
  Actuate the button <Balance> in the field "Oblique sensorment". Balancing is immediately effected with nonvolatile storage in the transmitter.
- **Adjust lower and upper range value**
  Menu path:
  Configuration_Differential Pressure Measurement_Process Variable
  In the field "Scaling", the adjustment is possible in two ways:
  - **Value input:** The required value / values has / have to be entered in the input fields "Lower range value" and / or "Upper range value".

  or
  - **Process pressure acceptance:** For the adjustment, the lower range value and the upper range value are preset as pressure at the sensor. Make sure that the measuring limits are not exceeded. Pressure reducing stations with adjustable pressure and comparative displays can be used as sensors. When connecting, take care to avoid residual liquids (with gaseous test media) or air bubbles (with liquid test media) in the piping since they can cause errors. The pressure reducing station should have an accuracy of at least 3 times better than the transmitter to be tested.

8 Maintenance

The transmitter is maintenance-free.
It is sufficient to check the output signal – depending on the operating conditions - at regular intervals according to section 7 "Operation".
If deposits in the sensor are to be expected, the sensor should also be cleaned at regular intervals – depending on the operating conditions. Cleaning should preferably be carried out in the workshop.
If remote seals are attached to the sensor, they must not be dismounted!
Replace defective transmitters/units according to the "Spare Parts Data Sheet".

Dismantling / fitting the process flanges
If remote seals are fitted do **not** dismantle the flanges!

1. Undo the process flange screws diagonally opposite each other (13mm Allen key for hexagon screw).
2. Carefully remove the flanges so as not to damage the isolating diaphragms.
3. Using a **soft** brush and a suitable solvent thoroughly clean the isolating diaphragms and, if necessary, the process flanges. Do not use sharp or pointed tools.
4. Renew the process flange O-rings (Spare Parts Data Sheet 15-9.01 EN).
5. Fit the process flanges onto the measuring cell. Take care not to damage the isolating diaphragms.
   NOTE: The flange faces of the both process flanges must be in one plane and at right angles to the electronic enclosure.
6. Check that the process flange screw thread moves easily: Tighten the nut by hand as far as the screw head.
   If this is **NOT** possible, use **new** screws and nuts (Spare Parts Data Sheet 15-9.01 EN).
7. Lubricate the screw threads and contact faces of the screwed joint with, for instance "Anti-Seize AS 040 P" (Supplier: P.W. Weidling & Sohn GmbH & Co.KG, An der Kleimannbrücke 49, D 48157 Münster).
   With cleanliness stages, the corresponding regulations must be observed, e.g. DIN 25410!
8. **For 2010TD with measuring ranges ≥ 60 mbar and 2010TA**
   First tighten the diagonally opposite process flange screws and resp. or nuts with the joining torque M_F = 10 Nm (1.0 kpm) by means of a torque wrench.
   Then tighten fully by continuing to turn each diagonally opposite screw and/or nut through the tightening angle α_A = 180°, divided into **two** steps of 90° each.
9. **For 2010TD with measuring range 10 mbar**
   Tighten the process flange screws alternately in two steps and diagonally opposite by means of a torque wrench.
   Tightening torque MA = 10 Nm (1.0 kpm).
10. Check for leaks.
    Apply pressure with max. 1.3 x SWP for the **2010TD** / max. 1.0 x SWP for the **2010TA** where the pressure in case of 2010TD has to be applied simultaneously to both sides of the sensor.
11. Check the lower range value and the upper range value in accordance with Section 7 "Operation".

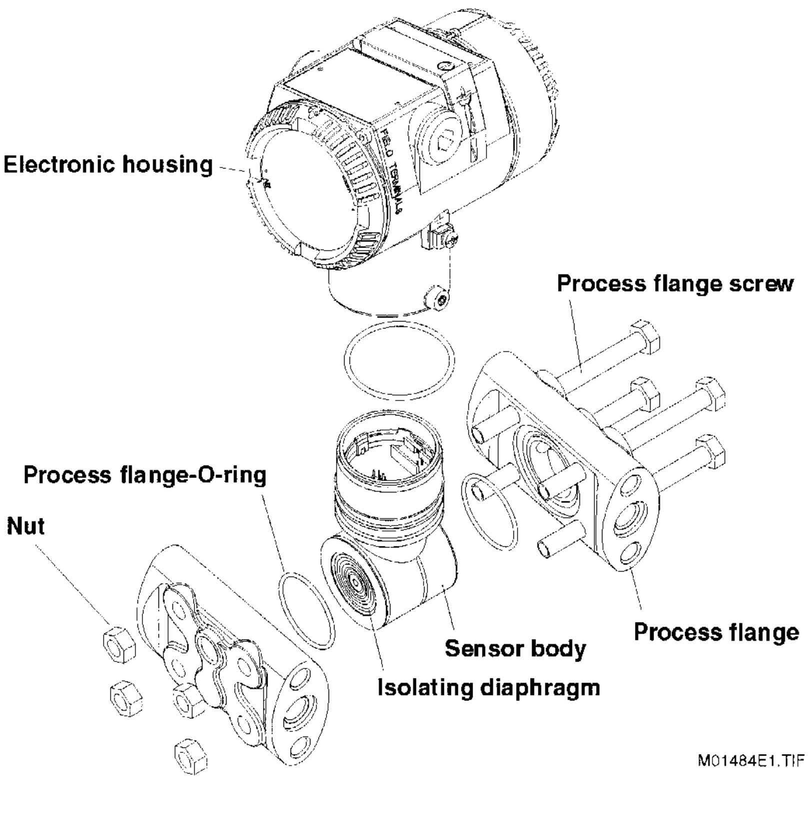


Figure 17. Exploded view

9 Repairs

Attention: Explosion-proof transmitters may only be repaired by the manufacturer, or they must be certified by an acknowledged expert after the repair has been carried out!
Observe the pertinent safety regulations before, during and after commissioning.
Disassemble the transmitter only to such extent as necessary for cleaning, checking, repairing and replacing the defective parts.
Observe section 8 "Maintenance"!
Sensor as well as sensor with attached remote seal can only be repaired by the manufacturer.
If the electronic housing has to be detached from the sensor / the measuring cell, the electronic unit must be removed from the electronic housing before in order to prevent a damage to the electronic unit. For this purpose, first of all the housing cover has to be screwed off (attachment screw!, refer to figure 10), then remove a possibly existing LCD indicator from the electronic unit (loosen 2 screws), unscrew the two captive screws of the electronic unit and remove same carefully from the electronic housing. Detach the two plugs from the electronic unit (both plugs have got a mechanical reverse battery protection and the smaller one additionally a mechanical interlock: seize the plug on the front side between thumb and forefinger and press the lock towards the plug, then pull off the plug from the socket). Put the electronic unit on a suitable pad. Unscrew the electronic housing from the sensor / the measuring cell.

Return

Defective transmitters/units are to be sent to the repair department, if possible stating the fault and its cause.
Note: When ordering spare parts or instruments, please quote the serial number (F.-No.) of the original transmitter.

Address:

ABB Automation Systems GmbH
Department SWM
Schillerstraße 72
D-32425 Minden

10 Technical Data

Measured value

2010TD: Differential pressure, Absolute pressure
2010TA: Absolute pressure

Measuring range (upper and lower range values)

Lower range value (continuously adjustable)
2010TD: - 100% to + 100% of the URL
2010TA: 0% and + 100% of the URL

Upper range value (continuously adjustable)
Up to 100% of the URL

Spans

dp-sensor: The adjusted span must not be lower than the minimum range (recommendation for square root function: at least 10% of the range).
Measuring ranges

Code	min.	max.	SWP
A	50 Pa / 0.5 mbar	1 kPa / 10 mbar	6
B	200 Pa / 2 mbar	6 kPa / 60 mbar	160...410
C	400 Pa / 4 mbar	40 kPa / 400 mbar	160...410
D	2.5 kPa / 25 mbar	250 kPa / 2.5 bar	160...410
E	20 kPa / 0.2 bar	2 MPa / 20 bar	160...410
G	100 kPa / 1 bar	10 MPa / 100 bar	160...410
L	400 Pa / 4 mbar abs.	40 kPa / 400 mbar abs.	160
M	2.5 kPa / 25 mbar abs.	250 kPa / 2.5 bar abs.	160
N	20 kPa / 0.2 bar abs.	2 MPa / 20 bar abs.	160

Code	min.	max.	SWP (psi)
A	0.2 $inchH_2O$	4 $inchH_2O$	90
B	0.8 $inchH_2O$	24 $inchH_2O$	2300...6000
C	1.6 $inchH_2O$	160 $inchH_2O$	2300...6000
D	10 $inchH_2O$	1000 $inchH_2O$)	2300...6000
E	80 $inchH_2O$	290 psi	2300...6000
G	400 $inchH_2O$	1450 psi	2300...6000
L	1.6 $inchH_2O$ abs.	160 $inchH_2O$ abs.	2300
M	10 $inchH_2O$ abs.	1000 $inchH_2O$ abs.	2300
N	80 $inchH_2O$ abs.	290 psia	2300

pabs-sensor:
Measuring range
Code
1 41 MPa abs. / 410 bar abs. / 6000 psia
(0.6MPa / 6bar abs. / 90psi with 10mbar (4$inchH_2O$) range)

Output signal

Transmitters with 4...20mA

Signal:	analogue 4 ... 20 mA
Output signal limits:	Imin = 3.5 mA, Imax = 22.5 mA (configurable).
Standard setting:	Imin = 3.8 mA, Imax = 20.5 mA

Alarm current

Min. alarm current:	configurable from 3.5 mA to 4 mA, standard setting: 3.6 mA
Max. alarm current:	configurable from 20 mA to 22.5 mA, standard setting: 21 mA
Standard setting:	max. alarm current

Load
Transmitters with 4...20 mA

$$R \leq \frac{Us - 10,5V}{I_{max}} \text{ in kOhm}$$

Imax = 20 ... 22.5 mA (configurable)
Us = supply voltage
min. power supplyy: 10.5 VDC, 14 VDC with backlit LCD-indicator
min. load for digital communications > 250 Ohm

Field Bus transmitters

Signal:	digital
Transmission technique:	acc. to IEC 61158-2
Power supply:	10.2 VDC ... 32 V DC
Base current:	14 mA
Transmission rate:	31.25 kbits/s
PROFIBUS-PA:	Version 3.0, Profile B for pressure transmitters; Ident No.: 04C2 HEX
Foundation Fieldbus:	FF-890 / 891 ans FF-902 / 903

Characteristic

Linear, square root, freely programmable with 20 reference points, $x^{3/2}$ - and $x^{5/2}$ - output function

Accuracy

Reference conditions

to DIN IEC 770

Temperature:	20 °C (68 °F)
Relative humidity:	65 %
Atmospheric pressure:	1013mbar (1013 hPa, 14.7 psia)

additional conditions:
Separating diaphragm material “Hastelloy C“ [1], filll fluid “silicone oil” and „linear output“
All specifications are limits and relate to the output range or calibrated range. The influences marked * relate to the measuring range (URL) and are to be multiplied by the turn down factor (ratio range (URL) / calibrated span). The turn down factor should be kept to a minimum.

Conformity

• for 2010TD and 2010TA, **dp-sensor**:
terminal based, including hysteresis and the dead band [2]

linear	square root
0.075%	0.15%

Optional [2] (Order code: 5C9)

linear	square root
0.05%	0.1%

for 2010TD, **pabs-sensor**:
0.8 bar, with pabs-sensor 6 bar: 12 mbar
(321 in.H2O, with pabs-sensor 90 psi: 4,82 in.H2O)

Hysteresis [2]

linear	square root
0.05%	0.1%

Reproducibility
0.01 %

Warm-up time
< 15 s

Rise time
The time behaviour of this transmitter is composed of the rise time of the sensor and an adjustable integration time constant of the A/D converter. A high time constant results into a high resolution, e.g. required for a high span ratio, and at the same time into a higher rise time for the output signal. A low time constant means a lower resolution, but a shorter rise time and thus a faster reaction time of the transmitter. In case of the default integration time constant the values shown in the table below result.

range	linear				square root	freely programmable function
	turn down factor					
	< 1 : 10	> 1 : 10 up to ≤ 1 : 20	> 1 : 20 up to ≤ 1 : 40	> 1: 40		
10mbar (4in.H_2O)	~ 2.0 s	~ 2.2 s	~ 2.6 s	~ 3.1 s	~ 2.6 s	~ 2.2 s
60mbar (25in.H_2O)	~ 0.8 s	~ 1.0 s	~ 1.4 s	~ 1.9 s	~ 1.4 s	~ 1.0 s
>400mbar (160in.H_2O)	~ 0.3 s	~ 0.5 s	~ 0.9 s	~ 1.4 s	~ 0.9 s	~ 0.5 s

additional adjustable time constant 0...60s

The effect appearing at the output for non-linear output (e.g. square root function) depends on the function and is to be calculated accordingly.

Long-term drift
* 0.05% per 12 months

Effect of position
* on zero approx. 3.5 mbar(1.4 in.H_2O) x sin ∠° (∠° = angular deviation indegrees from the nominal mounting position)

Ambient temperature effect (dp-sensor)
Thermal change (-40°C ... +80°C)[3)4)] / (-104 °F ... +176 °F)[3)4)]
* on zero 0.1 %
  on span 0.1 %

Temperature coefficient (-40°C...+80°C)[3)4)] / (-104°F...+176°F)[3)4)]
* on zero 0.04 % per 10°C (50 °F)
  on span 0.04 % per 10°C (50 °F)

Ambient temperature effect (pabs-sensor (2010TD))
Thermal change (-40°C ... +80°C)[3)4)] / (-104 °F ... +176 °F)[3)4)]
* on zero 0.4 bar (160 in.H_2O)
  6 mbar with 6 bar pabs-sensor
  (2.4 in.H_2O with 90 psi-sensor)

Thermal change (-20°C ... +60°C)[3)4)] / (-68°F...+140°F)[3)4)]
* on span 2 bar (803 in.H_2O)
  30 mbar with 6 bar pabs-sensor
  (12 in.H_2O with 90 psi-sensor)

Thermal change (-40°C ... +80°C)[3)4)] / (-104°F...+176°F)[3)4)]
* on span 3 bar (1204 in.H_2O)
  45 mbar with 6 bar pabs-sensor
  (18 in.H_2O with 90 psi-sensor)

Static pressure effect

Messbereich	10 mbar (4 in.H2O)	≥ 60 mbar (≥ 24 in.H2O)	100 bar (1450 psi)
* on zero	0.05% /1 bar	0.05% / 100bar	0.1%/100bar
on span	0.05% /1 bar	0.05% / 100bar	0.1%/100bar

Effect of electro-magnetic interference
* 0.05%

1) with Tantalum, Monel or Gold Plated Isolating Diaphragm, the factor 1.5 is to be taken into account with static pressure and ambient temperature effect with conformity

2) additionally with turn-down factor > 1:10

$$\pm(0.005 \times \frac{\text{measuring range}}{\text{adjusted span}} - 0.05)\%$$

3) with range 10mbar / 100 bar: -20 °C ... +60 °C (4 in.H_2O / 1450 psi: (-68°F...+140°F)

4) with carbon fluoride filling liquid: -20°C ... +80°C (-68°F ... +176°F)

Ambient conditions

Ambient temperature
-40 °C ... +85 °C (with O-ring Viton: -20 °C ... +85 °C)
(-104°F ... +185°F) (with O-ring Viton: -68°F ... +185°F),
Observe approvals for explosion-protected transmitters.

Storage temperature / transport temperature
-50 °C ... +85 °C, with LCD-indicator -40 °C ... +85 °C
(-122°F ... +185°F, with LCD-indicator -104°F ... +185°F)

Humidity
Relative humidity: ≤ 95% annual average
Condensation, icing: admissible

Protection class
IP 67 acc. to EN 60 529 (=NEMA Standard Type 6);
with Han 8U plug: IP 65 (=NEMA Standard Type 4X)

Protective varnish
epoxy resin, greywhite, RAL 9002

Shock resistant
Acceleration: 50g
Duration: 11ms

Vibration resistance
2g up to 1000 Hz, with amplifier housing made of "stainless steel" are valid restricted values (on request)

Electromagnetic compatibility (EMC)
to EN 50 082-2
Definition: Class 3
Radio suppression (EN 55 011): Limit class B
Fulfills NAMUR recommendation.

Process conditions

Temperature limits
-50 °C ... + 120 °C (-122°F ... +248°F), at process connection to +400 °C (752 °F) in conjunction with remote seals.
with gasket:
• O-rings Viton (fluorocaoutchouc (FPM))-20 °C ... +120 °C (-68°F ... +248°F)

Pressure limits
2010TD: Static pressure limits: from 3.5 kPa abs. (14 in.H_2O abs.) to the nominal pressure (SWP),
proof pressure up to 1.5-times the nominal pressure simultaleously on both sides of the transmitter admissible.
2010TA: Static pressure limits: from full vacuum up to the nominal pressure (SWP),
proof pressures up to 1.0-times the nominal pressure admissible.

Overload limit
One-sided overload up to the rated pressure.

Weight
3.5 kg

Material

Sensor body:	316 L stainless steel
Isolating diaphragm(s):	Hastelloy / 316 L stainless steel (1.4435) / Tantalum / Monel /gold plated
Process flange:	316 Ti stainless steel (1.4404) * / Hastelloy C * / Monel * / PVDF
Nuts and bolts:	stainless steel (A4) *
Plugs:	as process flange material
Fill fluid:	Silicone oil / carbon fluoride
O-rings:	the whole ranges: • Viton(FPM) (green) • Perbunan (NBR) (black) • EPDM * (black) furthermore: • ranges ≥ 60 mbar (≥ 24 in.H_2O) PTFE * , color: white max. permissible SWP ≤ 250bar (≤ 3600 psi) min. permissible operating temperature -20°C (-68°F) • range 10 mbar (4 inchH_2O) : FEP-sheathed silicone, color: grey
Amplifier housing / Housing cover:	aluminium with epoxy resin coat / stainless steel

* in compliance with NACE MR0175 Class II

Process connection

Flange with fixing thread 7/16-20 UNF and 1/4-18 NPT female thread on both sides or
flange connection to DIN 19 213 with thread M 10 for 6 bar (90psi) and 160 bar (2300psi) or M 12 for 250 bar (3600psi) and 410 bar (6000psi) and 1/4-18 NPT female thread on both sides.

Electrical connections

Two female threads 1/2-14 NPT or M 20 x 1.5 or one plug Han 8 U. Screw terminals for wire cross-sections up to 2.5 mm^2.

Auxiliary energy

Transmitters with 4...20mA

Power supply: 10.5 ... 45 VDC (14 ... 45 VDC with backlit indicator), inverse polarity protection, explosion-protected transmitters, observe the approvals.

Harmonic distortion: Maximal permissible voltage ripple of the power supply during the communication:

7 Vpp at 50Hz ≤ f ≤ 100Hz
1 Vpp at 100Hz < f ≤ 200Hz
0.2 Vpp at 200Hz < f ≤ 300Hz

Field Bus Transmitters

Power supply: 10.2 ... 32 VDC, inverse polarity protection, explosion-protected transmitters, observe the approvals.

Pollution degree

2 according to EN 61 010-1 (ANSI / ISA 82.01)

Overvoltage category

II according to EN 61 010-1 (ANSI / ISA 82.01)

Certificates and Approvals

Observe mounting conditions according to EN 60079-10; 1996ff!

Transmitters of the type of protection "Intrinsically safe EEx ia" according to the directions 94 / 9 / EG (ATEX)

- Transmitter with 4...20 mA output signal
  Marking (DIN EN 50 014): II 1/2 G EEx ia IIC T6
  EC-Type-Examination Certificate: ZELM 01 ATEX 0064

  Supply and signal circuit type of protection Intrinsic Safety EEx ib IIB / IIC resp. EEx ia IIB / IIC for connection to supply units with maximum values:
  II 1/2 G EEx ia IIC T4 ... T6,
  for Temperature class T4:
  Ui = 30 V
  Ii = 200 mA
  Pi = 0,8 W for T4 with Ta = (-40...+85)°C / (-104...+185)°F
  Pi = 1,0 W for T4 with Ta = (-40...+70)°C / (-104...+158)°F

  for Temperature class T5, T6:
  Ui = 30 V
  Ii = 25 mA
  Pi = 0,5 W for T6 with Ta = (-40...+40)°C / (-104...+104)°F
  Pi = 0,75W for T5 with Ta = (-40...+40)°C/(-104... +104)°F

  effective internal capacitance Ci ≤ 10 nF
  effective internal inductivity Li ≈ 0

  Permissible ambient temperature range in dependence on temperature class:

Temperature class	Ambient temperature minimum	Ambient temperature maximum
T4	-40 °C -104 °F	+85 °C +185 °F
T5	-40 °C -104 °F	+40 °C +104 °F
T6	-40°C -104 °F	+40 °C +104 °F

- Field Bus transmitters (PROFIBUS / Foundation Fieldbus)
  Marking (DIN EN 50 014): II 1/2 G EEx ia IIB/IIC T6
  EC-Type-Examination Certificate: ZELM 01 ATEX 0063

  Supply and signal circuit type of protection Intrinsic Safety EEx ib IIB / IIC resp. EEx ia IIB / IIC for connection to FISCO supply units with rectangular or trapezoidal characteristics with maximum values:
  II 1/2G EEx ia respectively ib IIC T4...T6 Ui = 17.5 V
  Ii = 360 mA
  Pi = 2.52 W

  II 1/2G EEx ia respectively ib IIB T4...T6 Ui = 17.5 V
  Ii = 380 mA
  Pi = 5.32 W

  resp. for connection to supply unit or barrier with linear characteristics maximum values:
  II 1/2G EEx ia respectively ib IIC T4...T6 Ui = 24 V
  Ii = 250 mA
  Pi = 1.2 W
  effective internal inductance Li ≤ 10 µH,
  effective internal capacitance Ci ≈ 0

Permissible ambient temperature range in dependence on temperature class:

Temperature class	Ambient temperature minimum	Ambient temperature maximum
T4	-40 °C -104 °F	+85 °C +185 °F
T5	-40 °C -104 °F	+40 °C +104 °F
T6	-40°C -104 °F	+40 °C +104 °F

Transmitters of the type of protection "flameproof enclosure EEx d" according to the directions 94 / 9 / EG (ATEX)

Marking (DIN EN 50 014): II 1/2 G EEx d IIC T6
EC-Type-Examination Certificate: PTB 00 ATEX 1018
Ambient temperature range: -40 °C ... 75°C (-104°F ... 167°F)

Transmitters of category 3 for the application in "Zone 2" according to the directions 94 / 9 / EG (ATEX)

Marking (DIN EN 50 014): II 3 G EEx nL IIC T6
EC-Type-Examination Certificate: ZELM 01 ATEX 3059
Operating conditions:
Supply and signal circuit (terminals signal + / -): U ≤ 55 V
U ≤ 22.5 mA
Ambient temperature range:
Temperature class T4: Ta= -40 °C ... 85 °C (-104°F ... 185°F)
Temperature class T5, T6: Ta= -40 °C ... 40 °C (-104°F ... 104°F)

Factory Mutual (FM) (pending)

Intrinsically safe,
Explosion-Proof: Class I, Division 1, Groups A, B, C, D
Class II/III, Division 1, Groups E, F, G
Degree of protection: NEMA Type 4X (Indoor or outdoor)

Canadian Standard (CSA) (pending)

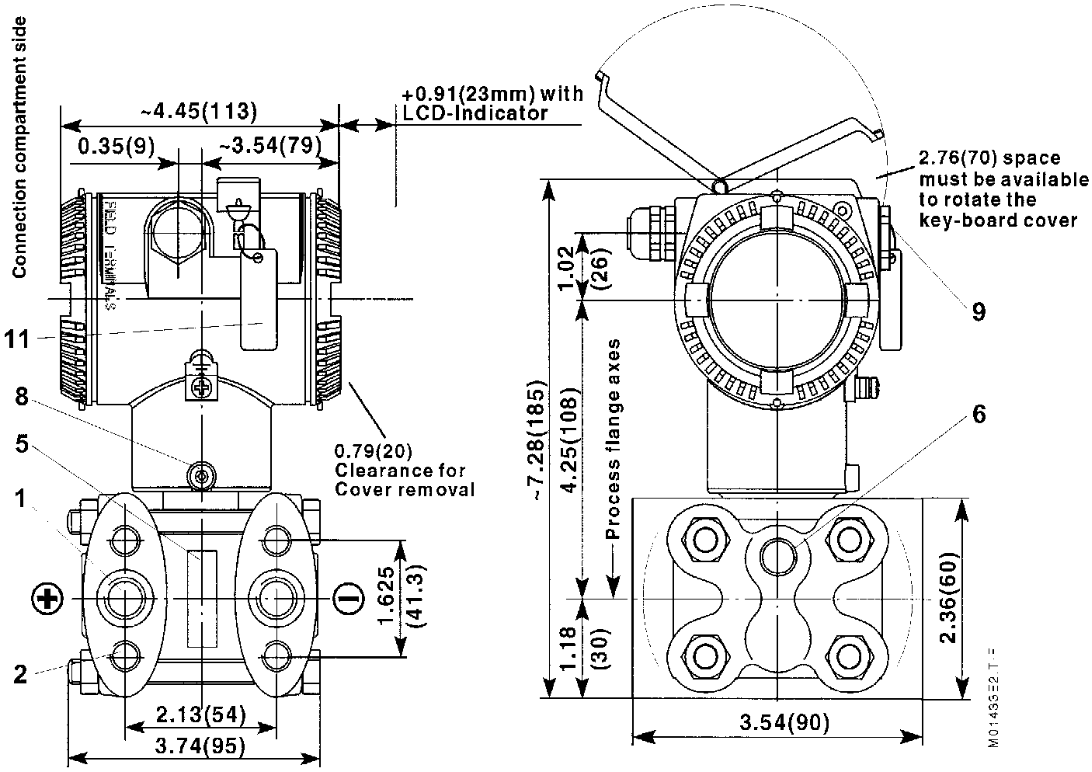
Intrinsically safe,
Explosion-Proof: Class I, Division 1, Groups A, B, C, D
Class II, Division 1, Groups E, F, G
Class III
Degree of protection: NEMA Type 4X (Indoor or outdoor)

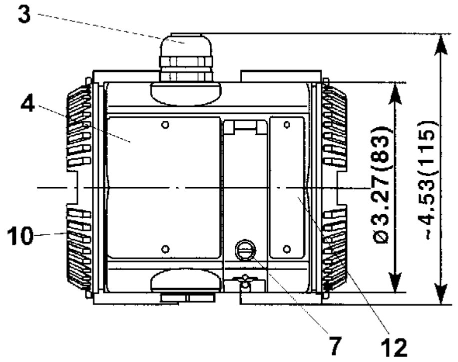
Overflill protection for non-inflammable and inflammable, toxic liquids

Approval: Z-65.11-271

11 Dimensional Diagrams

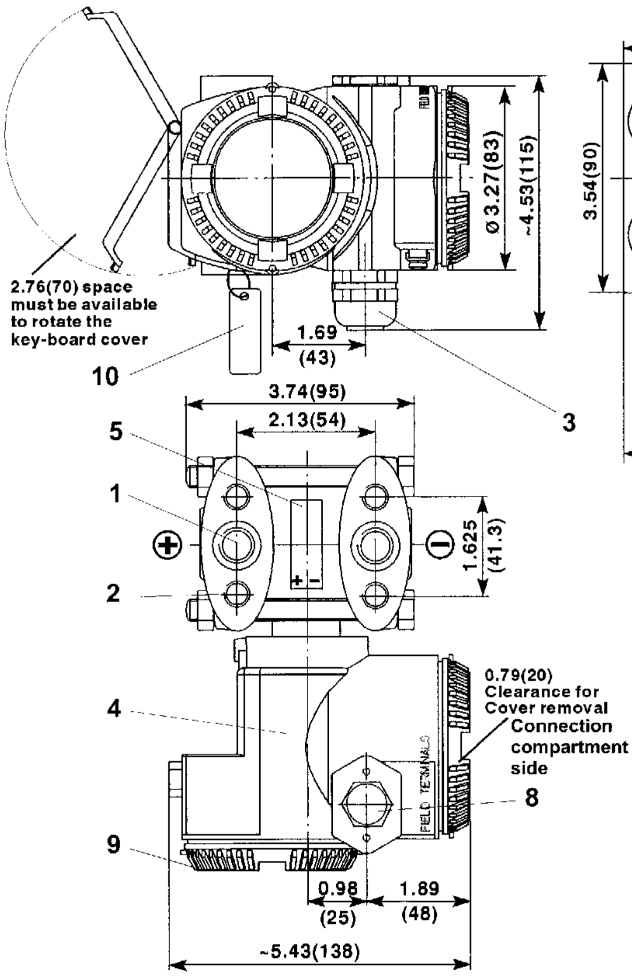
Transmitter with barrel-type amplifier housing
Errors and omissions excepted. All dimensions in millimeters.

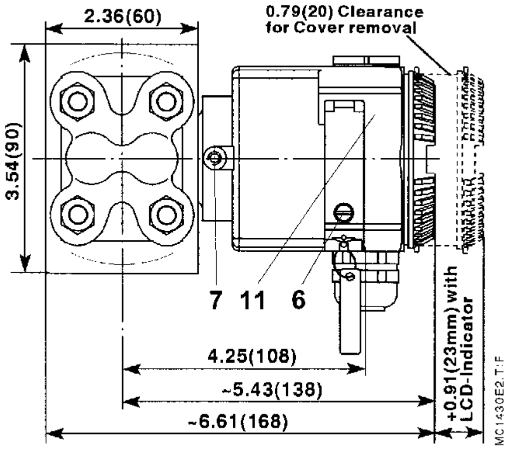




1 1/4-18 NPT female thread
for process connection or sealing plug.
2010TD: no female thread on the LP-side (-).
2 Thread for fixing screws: 7/16-20 UNF, 16mm deep. Minimum screw-in length is 12mm, however 15mm with PN400. With a flange according to DIN 19 213: M 10 with PN 6 and PN 160 bar, M 12 with PN 250 and PN 410 bar, minimum screw-in length according to DIN 19 213.
3 Electrical connections:
M20 x 1.5 cable gland on both sides or
1/2-14 NPT female threads on both sides or
one plug Han 8U.
4 Type plate.
5 Measuring mechanism plate.
6 Threaded side-mounted entry 1/4-18 NPT for drain / vent valves.
2010TD: no threads on the HP-side (+).
7 Captive screw for key unit cover.
8 Housing rotation stop screw.
9 Blind plug.
10 Enclosure cover.
11 Tie-on plate, e.g. for tag number (optional).
12 Plate, also with key legend.

Transmitter with DIN-type amplifier housing
Errors and omissions excepted. All dimensions in millimeters.



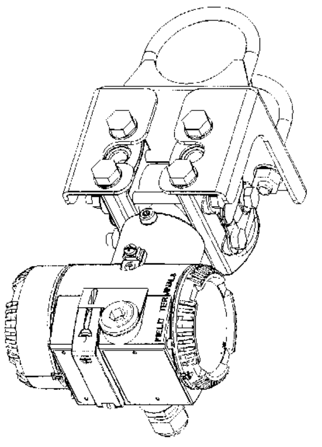


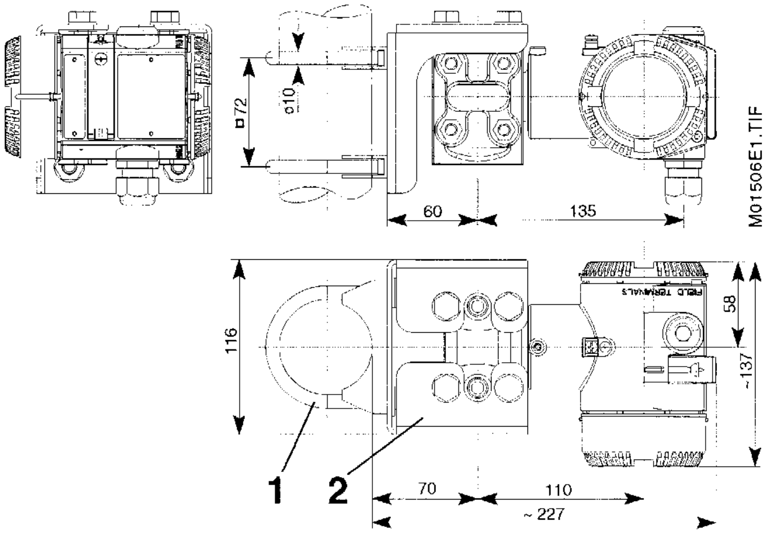
1 1/4-18 NPT female thread for process connection or sealing plug.
2 Thread for fixing screws: 7/16-20 UNF, 16mm deep. Minimum screw-in length is 12mm, however 15mm with PN400. With a flange according to DIN 19 213: M 10 with PN 6 and PN 160 bar, M 12 with PN 250 and PN 410 bar, minimum screw-in length according to DIN 19 213.
3 Electrical connections: M20 x 1.5 cable gland on both sides or 1/2-14 NPT female threads on both sides or one plug Han 8U.
4 Type plate.
5 Measuring mechanism plate.
6 Captive screw for key unit cover.
7 Housing rotation stop screw.
8 Blind plug.
9 Enclosure cover.
10 Tie-on plate, e.g. for tag number (optional).
11 Plate, also with key legend.

Possible mounting with bracket (optional,Code 142/144) for barrel-type electronic housing

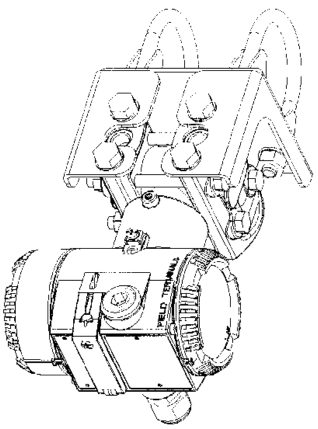
Errors and omissions excepted. All dimensions in millimeters.

Vertical pipe mounting

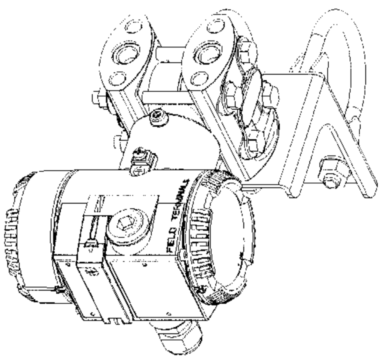




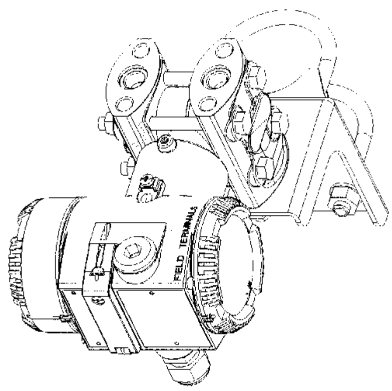
Horizontal pipe mounting



Horizontal pipe mounting
and transmitter above the
mounting bracket



Vertical pipe mounting
and transmitter above the
mounting bracket



1 U-bolts for pipe mounting. Pipe: 2" (internal-Ø).
  Permissible pipe-Ø: 53 ... 64mm.
  Rearrange the brackets for horizontal pipe mounting.
2 Brackets, hole-Ø: 11mm.

ABB

EG-KONFORMITÄTSERKLÄRUNG
EC DECLARATION OF CONFORMITY
ATTESTATION DE CONFORMITE C.E.

Hersteller: *Manufacturer / Fabricant:*	**ABB Automation Products GmbH** **Minden**
Anschrift: *Address / Adresse:*	**Schillerstraße 72** **D-32425 Minden**
Produktbezeichnung: *Product name:* *Désignation du produit:*	**Messumformer Multi Vision – 2010TA, 2010TC, 2010TD, 2020TA, 2020TG** *Transmitter Multi Vision –2010TA, 2010TC, 2010TD, 2020TA, 2020TG* *Transmetteur Multi Vision – 2010TA, 2010TC, 2010TD, 2020TA, 2020TG*

Das Produkt stimmt mit den Vorschriften folgender Europäischer Richtlinien überein:
This product meets the requirements of the following European directives:
Les produits répondent aux exigences des Directives C.E. suivantes:

89/336/EWG *89/336/EEC* *89/336/C.E.E.*	**EMV-Richtlinie *** *Electromagnetic Compatibility Directive ** *Directives concemant la compatibilité électromagnétique **
73/23/EWG *73/23/EEC* *73/23/C.E.E.*	**Niederspannungsrichtlinie *** *EC-Low-Voltage Directive ** *Directives concemant la basse tension **
97/23/EG *97/23/EEC* *89/336/C.E.E.*	**Druckgeräterichtlinie** *Pressure Instruments Directive* *Directives concemant les appareils soumis à pression*

Für Geräte in Ex-Ausführung gemäß Kennzeichnung auf Typschild gilt zusätzlich:
For products in Ex design according to identification on nameplate the following is additionally applicable:
Pour des produits en exécution Ex selon marque sur plaque signalétique le suivant est aussi applicable:

94/9/EG *94/9/EEC* *94/9/C.E.E.*	**ATEX-Richtlinie** *ATEX Directive* *ATEX Directive*

*** einschließlich Änderungen und deutscher Umsetzung durch das EMVG und Gerätesicherheitsgesetz**
** including alterations and German realization by the EMC law and the instruments safety law*
** y compris les modifications et la réalisation allemande par la loi cocemant la compatibilité électromagnétique et la sécurité d'appareils*

Die Übereinstimmung mit den Vorschriften dieser Richtlinien wird nachgewiesen durch die vollständige Einhaltung folgender Normen:
Conformity with the requirements of these Directives is proven by complete adherence to the following standards:
La conformité avec les exigences de ces directives est prouvée par l'observation complète des normes suivantes:

EN 50 081-1 / EN 50 082-2 / EN 61 010-1
Ex: EN 50 014 / EN 50 284 / EN 50 018 / EN 50 020

20.11.2000		i.V.
Datum *Date* *Date*	**Dieter Friedemann** Standortleitung *Division manager* *Responsable de la division*	**Friedrich Kipp** Qualitätsmanagement *Quality management* *Assurance de la qualité*

ABB Automation Products

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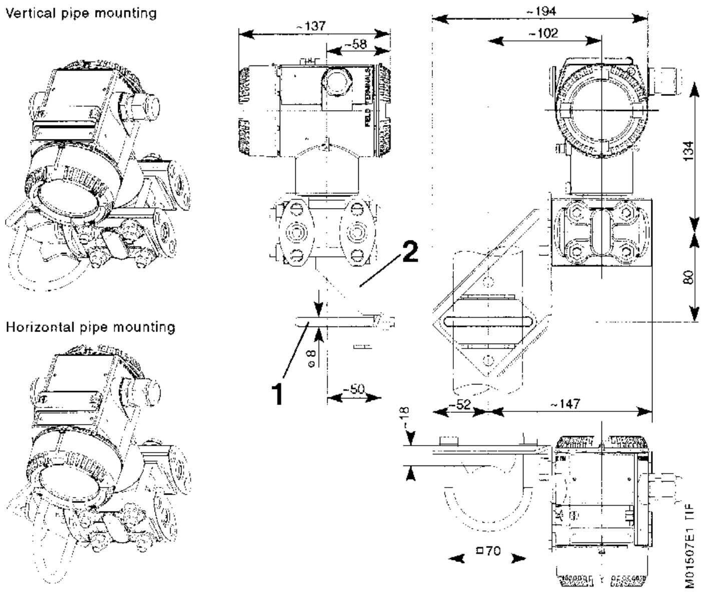
F 6016 AL

Possible mounting with bracket (optional,Code 14E/14F) for barrel-type electronic housing

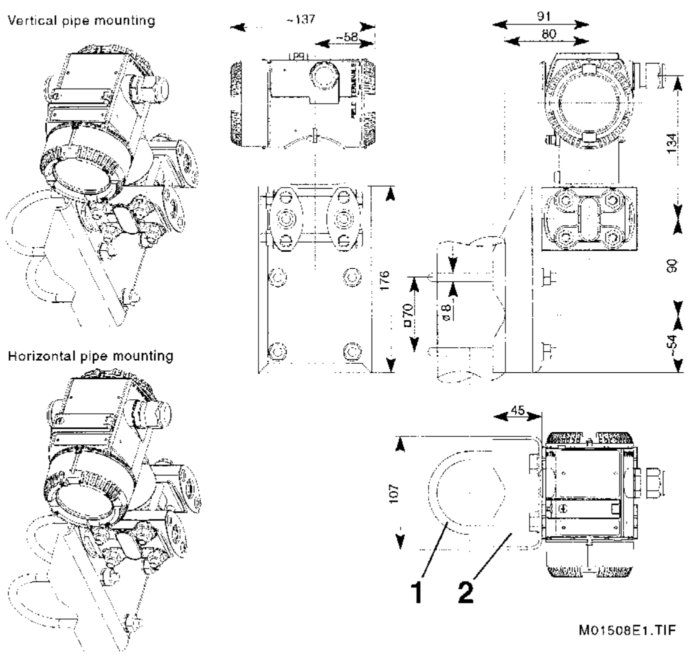
Errors and omissions excepted. All dimensions in millimeters.



1 U-bolts for pipe mounting. Pipe: 2" (internal-Ø). Permissible pipe-Ø: 53 ... 64mm. Rearrange the brackets for horizontal pipe mounting.
2 Brackets, hole-Ø: 9mm.

Possible mounting with bracket (optional,Code 14D) for barrel-type electronic housing

Errors and omissions excepted. All dimensions in millimeters.



1 U-bolts for pipe mounting. Pipe: 2" (internal-Ø). Permissible pipe-Ø: 53 ... 64mm. Rearrange the brackets for horizontal pipe mounting.
2 Brackets, hole-Ø: ~10mm.