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Äspö Hard Rock Laboratory

Äspö Pillar Stability Experiment

Description of the displacement and temperature monitoring system

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September 2005

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Abstract

This report is a detailed description of the system that was installed to measure the pillar behaviour during the Äspö Pillar Stability Experiment – APSE. The geometry of the experiment area is shown in Figure 1.

Temperature, displacement, confinement pressure and heater power were the main parameters that were logged. Two different types of Linear Variable Differential Transformer (LVDT) sensors were used to measure the displacement, one short range sensor with very high accuracy and one wide range sensor with less accuracy. This was necessary in order to acquire sufficient data in both the initial elastical phase of the pillar response as well as during spalling.

A steel frame was installed in the open hole to hold the sensors in position during the experiment. Both the frame and the sensors were thus subject to the elevated temperatures in the hole. The thermal effects on both the steel construction as well as the sensors must therefore be taken into consideration during the data analysis.

All sensors were connected to a data logger, which sampled and stored data continuously. The data was then filtered in order to remove data that were sampled during disturbed time intervals, i.e. during maintenance in the open hole. Calculations were also made to show the total relative changes in measured values during the experiment, this will significantly ease the data analysis. Both original raw data and the calculated data channels are stored in the SKB's database SICADA.

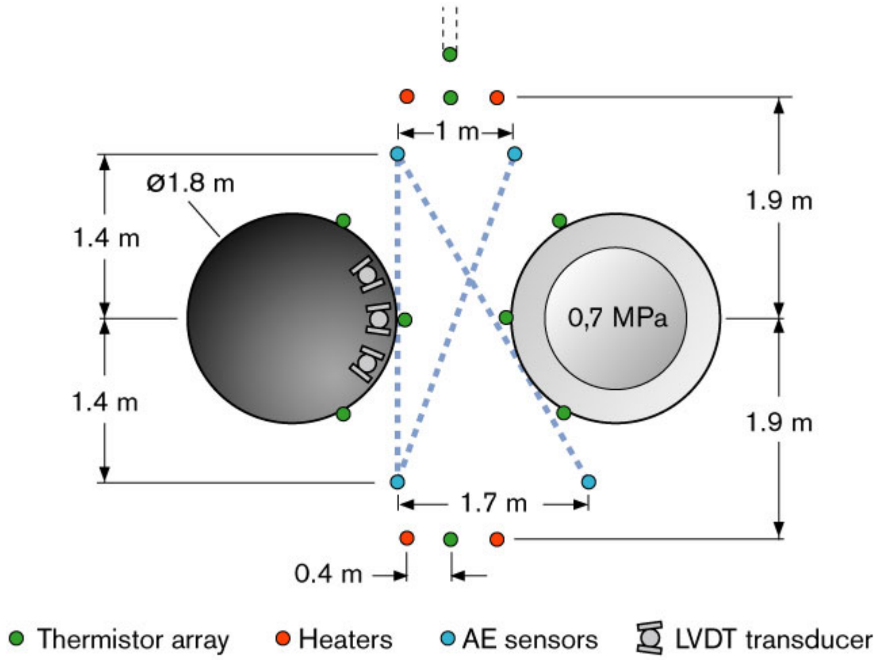


***Figure 1** The experiment geometry seen from above. The open hole to the left is illustrated with the pipe construction and LVDT sensors, to the right is the confined hole. The temperature, heater and acoustic emission (AE) holes are also marked in the figure.*

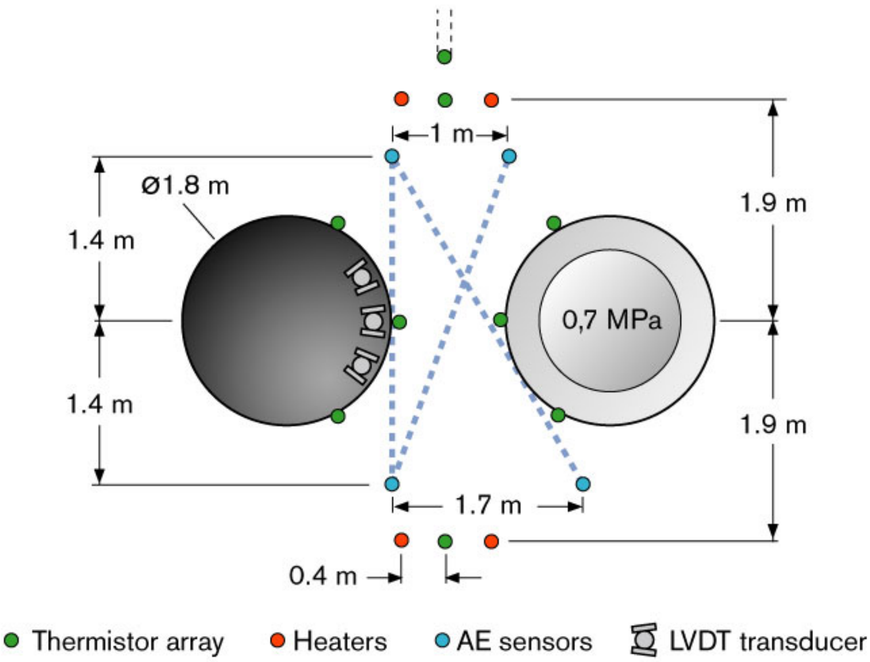
Sammanfattning

Denna rapport är en detaljerad beskrivning av det mätsystem som installerades för att övervaka experimentförloppet under Äspö Pillar Stability Experiment – APSE. Experimentareans geometri redovisas i Figure 1.

Parametrarna som mättes och lagrades var temperatur, deformationer samt mothållstryck. Två olika givare användes för att på ett bra sätt kunna mäta pelarväggens deformation, en mycket exakt Linear Variable Differential Transformer (LVDT) givare med kort mätområde och en LVDT givare med något mindre noggrannhet men i gengäld större mätområde. Detta var nödvändigt för att både kunna mäta mycket små rörelser under den elastika pelarväggens deformation samt de större rörelserna som uppstod då brottlasten uppnåtts och spjälkning sker.

LVDT givarna monterades på en stålkonstruktion i det öppna hålet. Den höjda temperaturen i det öppna hålet påverkade både givarna och stålkonstruktionen under experimentet och därför måste de termiska effekterna i både givare och stålkonstruktion inkluderas i dataanalysen för att erhålla ett korrekt resultat.

Samtliga givare var anslutna till en datalogger, vilken samplade data kontinuerligt under försökets gång. Efter avslutade mätningar filtrerades och behandlades data för att ta bort mätvärden från störda tidsintervall, underhållsarbeten etc. Beräkningar gjordes också för att kunna visa totala relativa förändringar i mätvärdena vilket avsevärt förenklar dataanalysen. Både originalvärdena samt de behandlade datavärdena lagras i SKB:s databas SICADA.



Figur 2 *Planvy av experimentgeometrin. I det öppna hålet till vänster illustreras LVDT givarna och stålkonstruktionen de är monterade på, hålet till höger i figuren är det som var trycksatt. Lägena i horisontalplanet för värmarna, temperaturgivarna och det akustiska systemet är också de markerade i figuren.*

Contents

1 Introduction

The full scale rock mechanics experiment at the SKB Äspö facility was a study of pillar stability, the main objectives were summarized in Andersson 2003 as:

- Demonstrate the capability to predict spalling in a fractured rock mass.
- Demonstrate the effect of backfill (confining pressure) on the rock mass response.
- Comparison of 2D and 3D mechanical and thermal prediction capabilities.

The experiment was conducted for about 110 days. During this time the pillar between two boreholes was heated. The heat caused the rock to expand resulting in thermal stress in the pillar. This lead to spalling of the borehole wall. The geometry of the experiment area is shown in Figure 1-1.

A detailed presentation of the experiment can be found in Andersson (2004).

In order to accurately analyze the experiment it was necessary to be able to measure the temperature, pre and post spalling displacement and record the acoustic emission of the pillar. This document describes the techniques that were used for these measurements. The acoustic emission measurement system is not described in this report, but can be found in SKB report R-05-09.

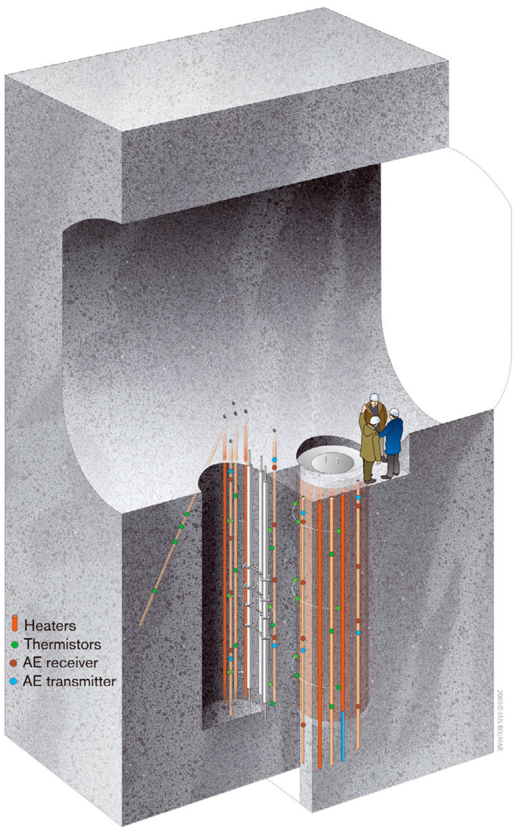


Figure 1-1 *The experiment area in the TASQ tunnel.*

2 Sensor descriptions

During the experiment several different parameters were measured at a number of positions to achieve a good data set of the pillar behaviour. The pillar displacement was closely monitored as well as the rock mass temperature. Confinement pressure was logged and the heater power documented. All data were stored for post experiment analysis.

The sensors that were used to monitor the experiment were of three main types. LVDT type sensors were used to measure rock displacement, the temperature was measured with thermocouples and finally a pressure sensor measured the confinement pressure.

To be able to measure small movements with accuracy as well as larger movements, two types of LVDT displacement sensors were used. One LVDT sensor with short range and one with wider range, though less accurate. The reason for this was to be able to measure small movements with high accuracy in the elastic phase of the experiment and larger displacements during the spalling process.

A system that was used during the experiment though not described in detail in this report is the Acoustic Emission (AE) system. The AE-system monitors the rock mass by listening for acoustic events. The system uses a large number of acoustic transducers that are placed at the outer boundaries of the pillar. When an acoustic event occurs these transducers register a "hit". A precise location of the event can then be calculated by using the small differences in arrival time between the transducers that registered the event and the velocity of sound in the rock mass. To determine the sound velocity and to calibrate the system small loudspeakers at known positions were used to create "artificial events". A detailed description of the AE system is found in "**Haycox J.R, W.S. Pettitt, and R.P. Young** *Äspö Pillar Stability Experiment. Acoustic Emission and Ultrasonic Monitoring*. SKB report R-05-09.".

2.1 Temperature sensors

The temperature of the experiment area was monitored using a large number of thermocouples. The sensor positions were spatially distributed to ensure a good reading of the temperature throughout the experiment volume. The locations of the sensors are shown in chapter 3.1. Corrosion resistant, type K thermocouples, manufactured by Pentronic were used because the sensors would be subject to heat and saltwater. The shielding material of the sensors is cupronickel, which is extremely corrosion resistant. The sensors are also waterproof.

The temperature readings in the data logging equipment are based on the difference in temperature between the sensor tip and a reference point - the position where the sensor is connected to the logging equipment (the cold junction). Prior heating of the rock mass the temperature in the rock was almost exactly the same as the surrounding air temperature which made the temperature difference between the sensor tip and the cold junction very small. Consequently an exact temperature reading was hard to accomplish at this stage of the experiment. Temperature readings should therefore not be taken as an exact absolute value but rather as a relative value, a value of the temperature increase. The relative accuracy of the readings, i.e. the difference between two consecutive samples during heating, was very good, but when looking at one sample alone the accuracy of the absolute value is about 1ºC.

The sensors were calibrated at both 0ºC and 100ºC to ensure correct readings.

The calibration sheets of the thermocouples are found in Appendix A. Additional information can also be found on the manufacturer's website, www.pentronic.se.

2.2 LVDT sensors

The Linear Variable Differential Transformer (LVDT) sensors used during the APSE experiment are extremely sensitive devices which measure displacement magnetically. The use of magnetic transfer instead of mechanical alternatives gives a friction free device providing practically infinite resolution with no hysteresis. Since there is no physical contact inside the sensor that generates the measuring result there is no wear on the sensor, hence it has a very high degree of robustness.

The LVDT can be made waterproof to suit a number of different conditions, like the one in the Äspö borehole where the high relative humidity otherwise could lead to a problem with the electrical equipment. The LVDT sensors can also be calibrated for high temperatures.

The construction of these LVDT sensors actually allows sensors with wide range and high accuracy at the same time. The theoretical infinite resolution of the sensor makes changes in the output signal possible even for the smallest movements. In practice however the external equipment will limit the resolution. The output from a sensor with wider range will change less with a small movement than the narrower range sensor, given that the outputs are the same, i.e. 4 – 20 mA. Therefore it is easier to detect small changes with a narrow range LVDT than with a wide range, despite the theoretical infinite accuracy of the sensors. Consequently, to achieve both high accuracy and wide range measurements at the same time, two types of sensors are required at each measuring position.

For these reasons two types of LVDT sensors have been used during the experiment, one short range sensor with high accuracy, and one sensor with wider range but somewhat less accurate. This setup with two sensor types allows tracking of both small deformations prior spalling as well as larger displacements during and after spalling. In this section the sensors and their characteristics are presented.

2.2.1 Short range LVDT

The short range LVDT sensors were Schaevitz GCD-121-250, Figure 2-1. The sensor has a measuring range of 12.7 mm. The tip of the sensors is spring loaded to ensure contact with the rock wall at all times. The sensors deliver an output of ±10 V (+ 10 volt when fully compressed). The resolution of the sensor is according to the data sheet 40 Volts per inch. If the output is measured using two decimals the actual resolution of the sensor is 0.00635 mm. Each sensor was shielded in a RocTest casing to protect if from water and dirt, Figure 2-2.

The sensors were powered via a "PULS ML30.106" power adapter. Sensor power input is ±15 V DC.

Additional information about the sensor and the sensor casing is found in Appendix B, or at the manufacturers' web pages, www.schaevitz.com and www.roctest.com.

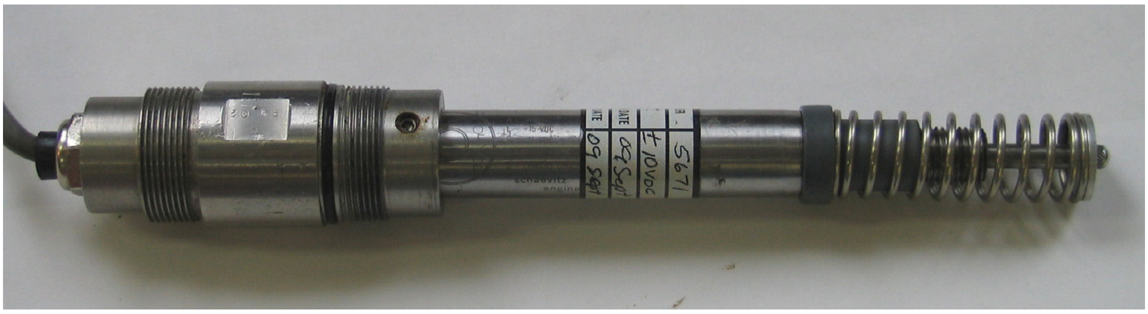


Figure 2-1 *The short range LVDT sensor without its casing.*

Figure 2-2 *The short range sensor mounted in the casing that protects it from dirt and water.*

Curve fit parameters

To calculate and convert the voltage output to engineering values (mm) curve fit functions were applied. The function is unique for each sensor and derived during calibration of the sensors. The calibration was conducted by the owners of the sensors – Atomic Energy of Canada Limited (AECL). The complete calibration sheet can be found in Appendix B.

The functions are in the form $x = \frac{y - b}{m}$, where x is the displacement [mm], y is the sensor output [V], b and m are the sensor unique parameters. Appendix B gives the b and m values for the sensors used.

The sensors have a temperature dependent drift. A temperature calibration of the measured value can be calculated from a function that is unique for each sensor. The temperature calibration is included in Appendix B. Because the temperature increase in the monitored hole was less than 10°C the temperature related corrections were small. The maximum error difference in the measured displacement due to temperature increase in the sensor is 0.03 mm.

2.2.2 Wide range LVDT

The "Geometrik Miniextensometer" is used as a wide range LVDT during the experiment, Figure 2-3. The sensor itself is waterproof and does not require any protective housing.

Measuring range of the Geometrik sensor is 40 mm. The tip of the sensors is spring loaded, just as the short range sensor, to ensure contact with the rock wall at all times. Output of the Geometrik sensor is 4 – 20 mA (4 mA when fully compressed). Accuracy of the sensor is 0.025 mm which is considerably less than the short range sensor.

The sensors are powered via a "PULS ML30.100" power adapter. Sensor power input is 24 V DC.

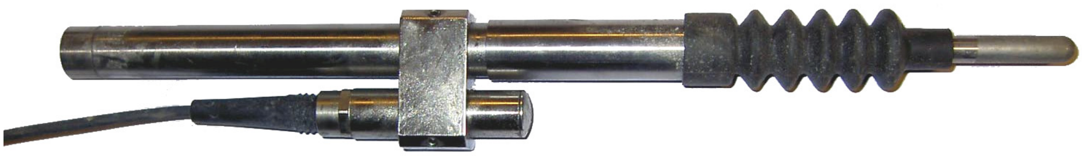


Figure 2-3 *The wide range LVDT sensor. The sensor has a range of 40 mm and the sensor output is 4-20 mA.*

Curve fit parameters

The wide range sensors also have curve fit functions to convert the output signal to a displacement. Each sensor has its unique function derived by the manufacturer during calibration. The function for the Geometrik sensor is a polynomial of the fourth degree. The formula for sensor number one is for example:

$$X = -33.933744 + 4.3830415 \times y - 0.2771088 \times y^2 + 0.0164305 \times y^3 - 0.0003441 \times y^4$$

Where X is the resulting displacement [mm] and y is the sensor output [mA]. The complete calibration sheet including all curve fit formulas is found in Appendix C.

The Geometrik sensors also have temperature dependent calibration functions. These functions are also included in the calibration document that is found in Appendix C.

The required correction was also small due to the small temperature change in the hole. The method that is used to calculate the temperature drift is shown below.

$$\delta_{\mathrm{Xt}} = 0.0015 \times (t - 20) \; [mm], \; 20°C \le t \le 50°C$$
$$\delta_{\mathrm{Xt}} = 0.04492 + (x \times 0.00111) \times (t - 50) \; [mm], \; 50°C < t \le 80°C$$
$$t = 21 \Rightarrow$$
$$\delta_{Xt} = 0.0015 \times (21 - 20) = 0.0015\,mm$$

The calibration functions above describe the drift for the wide range sensor with sensor ID 2. Calibration was done with 20°C as a reference point. The sensors have calibration functions all the way up to 80°C as the original temperature increase was calculated to about 55°C, but because the temperature did not reach that high only the first temperature interval is used. As the example above shows, the temperature drift is only 0.0015 mm per degree change in the open hole temperature for sensor number two. The other sensors used have a temperature dependent drift between 0.001 and 0.01 mm per degree Celsius.

2.3 Pressure sensor

The pressure sensor was mounted directly on the confinement pressure top plate and used to monitor the confinement pressure. The gauge a Druck PTX7515, is an absolute pressure gauge with maximum pressure 1.5 MPa. The gauge was connected to the same power supply as the Geometrik LVDT's and delivered an output signal in volts. Appendix D contains more information about the pressure sensor used. No temperature correction was applied on the pressure measurements.

2.4 Heater power

The electric power fed to the heaters was also monitored during the experiment. The power was controlled via a number of thyristors. From these thyristors a control signal was taken and logged. Burst mode was used on the thyristors to avoid signal disturbances. Detailed information about the thyristors is found in Appendix E.

3 Measurement positions

In this chapter the measurement positions are presented.

3.1 Thermocouple positions

The temperature of the rock mass is measured at a total of 28 positions. Nine sensors were mounted in an array pattern in each of the large holes, DQ0063G01 and DQ006G01, and the remaining 10 sensors were placed in the designated heat measuring boreholes surrounding the large holes. The horizontal layout of the thermocouple sensors is shown in Figure 3-1 and the vertical layout in Figure 3-2. A table that identifies each sensor and specifies the exact positions is found in Appendix A.

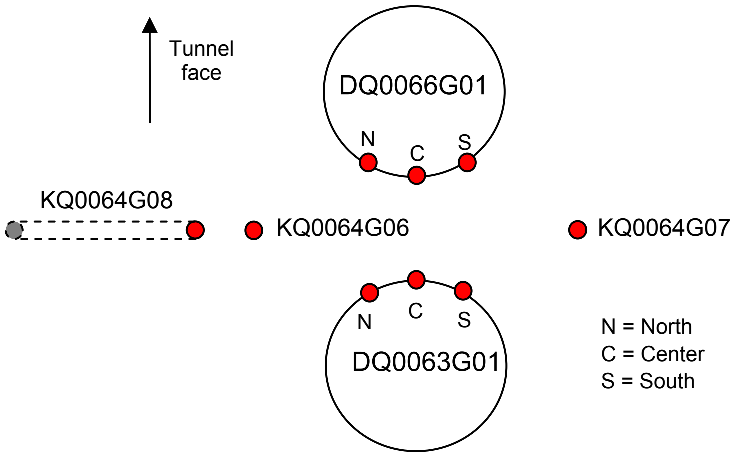


Figure 3-1 *The positions where the thermocouples are placed. The N, C, S markings are used to separate the positions within the same hole. Several sensors are placed below each of the marked positions.*

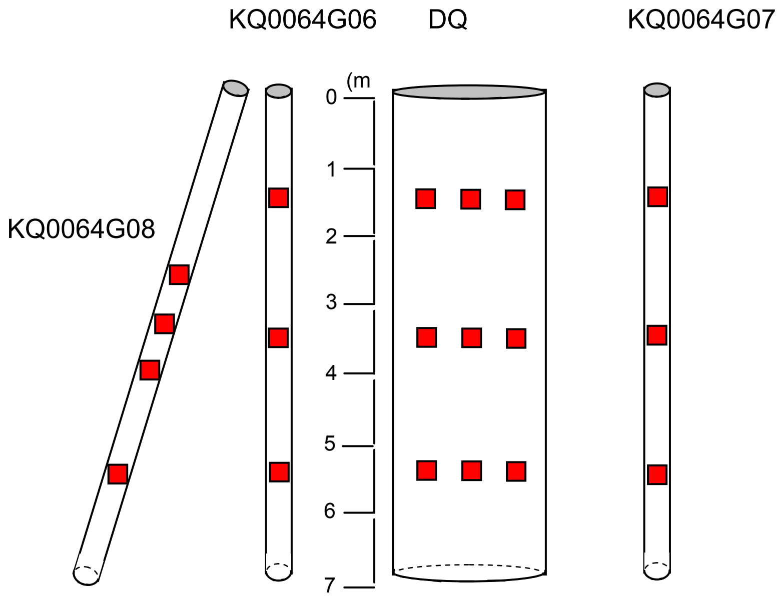


***Figure 3-2** The vertical layout of the thermocouples in the boreholes. Since the layout in the large holes are identical, only one of the two holes is shown. The sensors were positioned at 1.5, 3.5 and 5.5 meter down the holes. The exception is the KQ0064G08 hole, far left in the figure, in which the sensors measured the temperature at 2.75, 3.25, 3.75 and 5.5 meters. All depths are given relative the tunnel floor at -446.07 metre level.*

The depth of the thermocouple sensors were 1.5, 3.5 and 5.5 metres down in all holes except from KQ0064G08 where the sensors were positioned at 2.75, 3.25, 3.75 and 5.5 meters depth. The depths are all given relative the tunnel floor at -446.07 metres.

Two thermocouples were also used inside the open, DQ0063G01, to measure the air temperature at two and four metres depth. During installation of additional power supplies to the heaters, one of these thermocouples was removed to free a measuring channel on the data logging equipment (the channel was needed to monitor heater power from the added thyristor). The remaining sensor was the one located at four meters depth.

3.2 LVDT positions

The deformation of the pillar was measured against the borehole wall in the open hole, DQ0063G01. At first the number of measuring positions was set to twelve, but during the experiment the number was increased to 24. All positions are marked in Figure 3-3. Note that four of the positions were never used, but the notation with 24 sensor positions was kept to ease the position identification.

The measurement positions are divided into four levels, thus six sensor positions on each level. The levels used are 2.5, 3, 3.5 and 4 meters below the tunnel floor. The horizontal distance between the sensors is 15 cm. The total span of the horizontal measurement is consequently 75 cm. The original levels for the monitoring were set to 0.5 and 1.5 meters below the tunnel floor, but because the spalling of the pillar was initiated during drilling, the levels were adjusted in order to be able to measure the elastic phase of the pillar expansion.

Use of two sensors (Chapter 2) at each measurement location means that the positions measured are not exactly the same for the two sensor types. The vertical difference between each set of two sensors is approximately 8 cm.

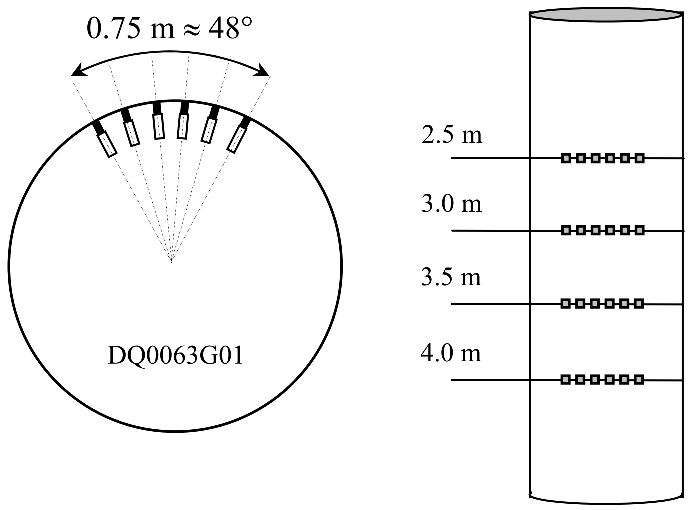


Figure 3-3 *To the right all potential LVDT sensor positions are displayed. Note that all positions were not used at the same time. The positions are marked as grey squares on the right image, the depths below the tunnel floor are also displayed. On the left the sensors are drawn from above to illustrate their radial positioning.*

Since additional short range LVDT sensors were installed during the experiment and some sensors were moved the LVDT positions at different times are showed in two figures below. Figure 3-4 shows the positions of the short range LVDT and Figure 3-5 shows the positions of the wide range sensors. In each figure, the images on the left are the initial planned arrangement, the centre image were the arrangement implemented on 2004 June 03, and the image on the right show the final setup adopted after 2004 June 17. In all arrangements, 12 wide range sensors were used, initially 12 short range LVDTs were used with an additional four short range LVDTs added on 2004 June 03. Figure 3-6 shows the overall LVDT setup.

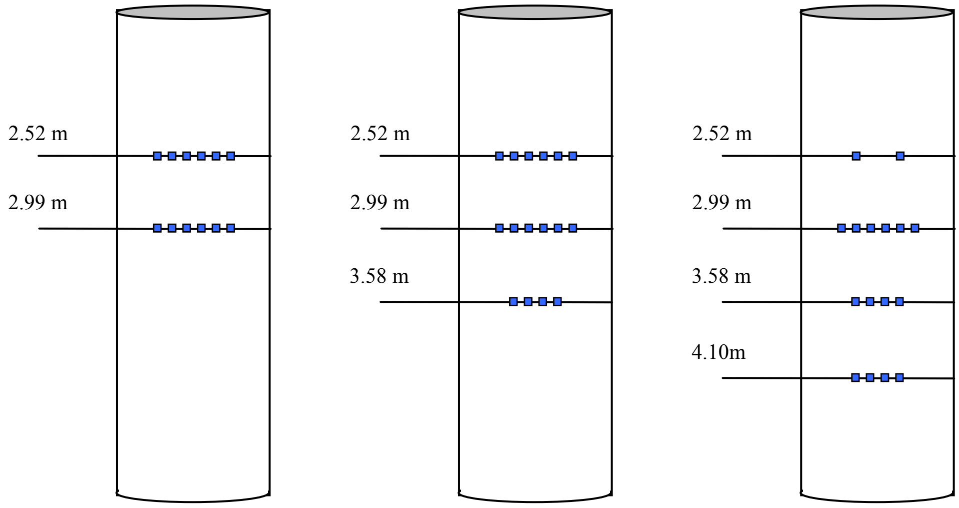


Figure 3-4 *Position map of the short range LVDT sensors in DQ00G3G01. The left setup is the original, the middle shows the setting after 2004 June 03, and the right one the setup after 2004 June 17.*

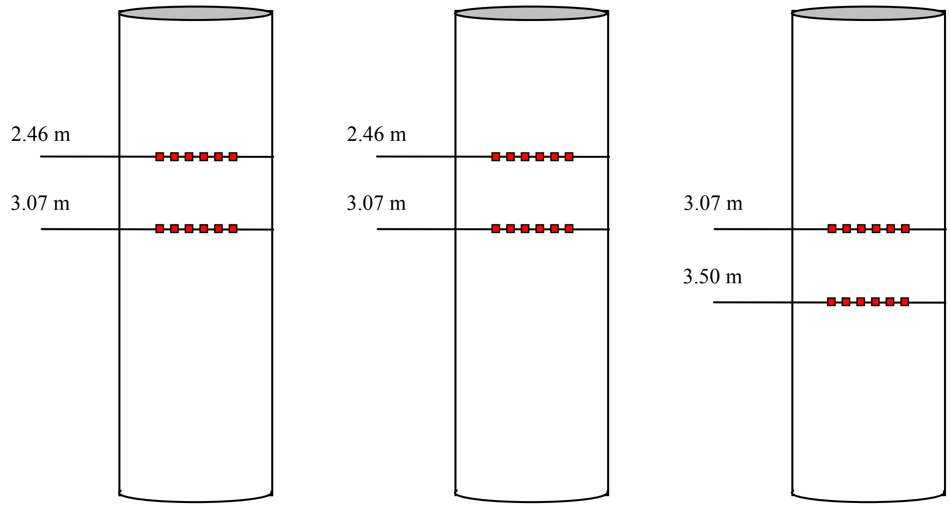


Figure 3-5 *Position map of the wide range LVDT sensors in DQ0063G01. The left setup is the original, the middle shows the setting after 2004 June 03, and the right one the setup after 2004 June 17.*

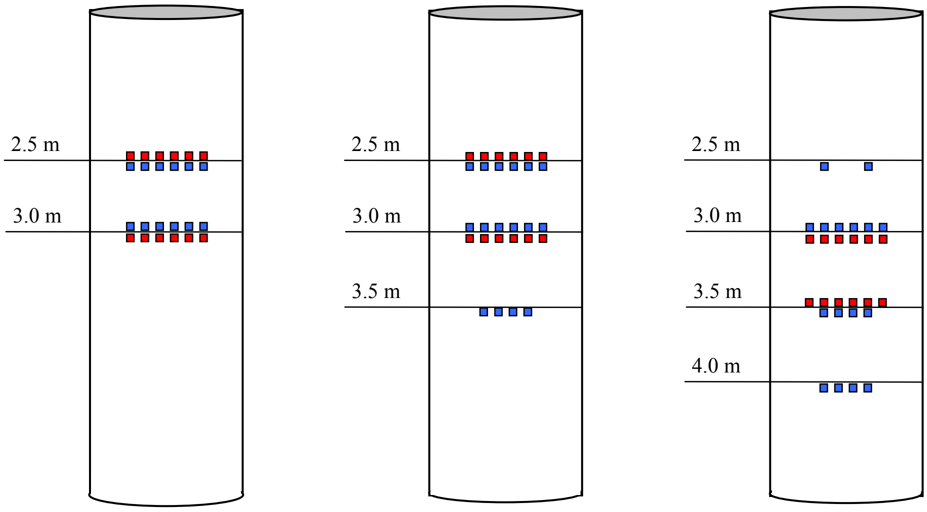


Figure 3-6 *The complete measurement position layout, both short and wide range LVDT sensors. Blue indicates a short range sensor and red a wide range sensor. The left setup is the original, the middle shows the setting after 2004 June 03, and the right one the setup after 2004 June 17.*

In Appendix B detailed information about the placement of each individual short range LVDT sensor is found, the table identifies the sensor using a unique sensor ID. The corresponding information about the wide range sensors is found in Appendix C.

4 Data logging

In this chapter the methods and equipment that were used for the data logging are described.

The data was continuously logged during the experiment. Data from each sensor was stored to the hard drive once every minute. This ensures a good amount of data for the analysis of the pillar events.

Data from all connected sensors were stored at all times, there was no filtering of data at the time of logging. The filtering of unnecessary data was done in the post experiment data analysis as required. This ensured that the original data was preserved.

4.1 Computer

A “Fuijitsu Siemens Scenic xS” computer was used to host the data logging. The computer had a 730 MHz Pentium III processor and 256 MB of ram. The operating system is Windows XP pro, version 2002, Service Pack 1.

The computer was physically placed inside a container in the TASQ tunnel during the experiment. A powerful UPS was used to ensure power and continuous data logging in case of power failures.

Remote access to the computer was given through the PcDuo (version 8.00) software.

4.2 DataScan

The main module in the data acquisition system was the DataScan 7327. The modules served as a connection point between the sensors and the computer. The module has 16 onboard channels for analog and digital measurements. The channels are relay controlled and can handle both voltage and 4-20 mA inputs. Thermocouples can also be connected to the 7327 module. To extend the measuring system, the 7327 has a local expansion bus for use with the 7027 unit and memory for configuration storing. The DataScan units were powered with the same type of supply as the Geometrik sensors, a “Puls ML30.100”. The power supply delivers DC 24-28 V, maximum load of 1.3 A.

Additional information can be found in Appendix F, or at the manufacturer’s website, www.measurementsystems.co.uk.

4.3 ScadaPro

The software used for the data logging is ScadaPro 64 v2.6.2.0. The software can handle 64 data channels. If the number of channels needs to be extended, the software can be upgraded to support more channels.

More information about the used data logging software can be found at www.measuresoft.com.

4.4 Interface converter

The DataScan equipment uses the RS232 COM port to communicate. Since the range of the serial communication cable is limited due to signal strength a “Tibbo DS100 RS232 to Ethernet” adapter has been used. This adapter allows the data logging computer to be located anywhere in the facility where the SKB LAN is present and still be in contact with the DataScan units. Further information about the Tibbo unit can be found at www.tibbo.com.

5 Sensor mounting

A support frame was built to hold the LVDTs firmly in position during the experiment. The design of the frame required it be stable but that it allows sensors to be repositioned as required. The frame was designed to minimize the effects of thermal expansion on the frame from the heating sequence. The frame components are described in this chapter.

5.1 LVDT Supporting construction

The construction that the LVDT sensors are mounted on must not at any place be connected to the pillar. Any fastening point on the pillar wall would mean that the movements of the pillar would propagate to the supporting construction and affect the measurements.

5.1.1 Pipes

The basic building blocks of the support frame were three corrosion-resistant stainless steel pipes mounted on the borehole floor and a steel frame member at the top of the borehole. This design was chosen because any attachment between the pillar and borehole wall would affect the recorded measurements. The pipes were mounted using threaded steel rods and screw nuts, Figure 5-1.

Figure 5-1 *The left image shows two of the three mounted pipes. The right image shows how the pipes are fastened to the floor in the open hole.*

The outer diameter of the pipes was 80 mm and the thickness of the steel was 2 mm. Since the pipes are only 6 meters long when delivered they were spliced to get the total length of 6.5 meters.

Pipe positioning

The positions of the pipes are chosen to get measurements within the interesting area of the pillar – the pillar centre. The pipes were placed 30 cm apart.

The layout of the pipes is shown in Figure 5-2. The distance between the pipes and the borehole wall was roughly 10 cm. This enabled the sensors to be close enough to the wall without the risk that the pipes might hinder the dilatation of the chips formed during spalling.

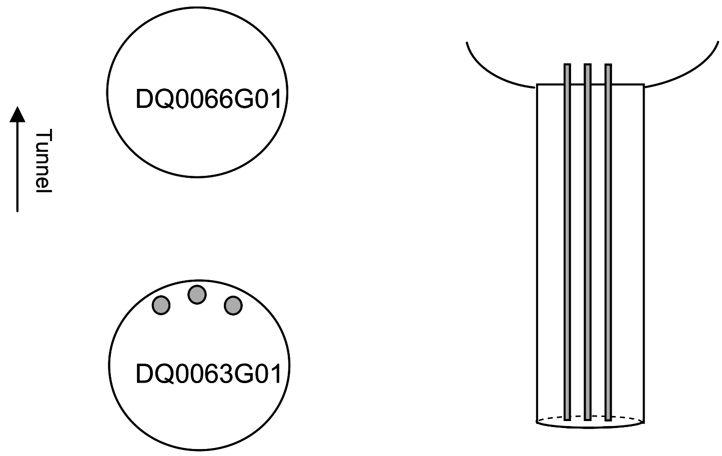


Figure 5-2 *Pipe Arrangement, in plan and section view.*

Thermal expansion

The temperature increase will cause thermal expansion of all the material used. The thermal expansion of the pipes is both axial and radial and can easily be calculated.

During the experiment the temperature increased approximately 10°C in the open hole, the calculation below shows the axial pipe expansion.

$\Delta L = L \times \alpha \times \Delta T$

$\mathrm{L} = 6500 \text{ mm}$

$\alpha = 16.5 \cdot 10^{-6}$

$\Delta T = 10\,°C$

$\Delta L = 6500 \times 16.5 \cdot 10^{-6} \times 10 \approx 1.07 \ mm$

where ΔL is the thermal expansion, L is the original length of the pipe, α is the thermal elasticity constant for steel and ΔT is the temperature increase. If the pipes are restrained in the axial direction, the temperature rise will cause stress in the material. If excessive, this stress could cause the pipes to buckle, which must be prevented, as uncontrolled movements will endanger the measurements and their interpretation. The solution is addressed in 5.1.2.

The radial thermal expansion is calculated using the same formula as above, the difference is the L value, which is now the thickness of the pipe.

$$\Delta L = L \times \alpha \times \Delta T$$
$$L = 2\ mm \quad (Pipe\ thickness)$$
$$\alpha = 16.5 \cdot 10^{-6}$$
$$\Delta T = 10°C$$
$$\Delta L = 2 \times 16.5 \cdot 10^{-6} \times 10 = 0.00033\ mm$$

Because the thermal expansion is small the amount of stress will also be small and the influence on the measurements due to the radial expansion of the pipes can therefore be neglected.

5.1.2 Stabilising crossbars for horisontal pipe support

The geometry of the pipes, 6.5 meters long and comparatively thin, made the stability an issue. Only a small force was needed to deflect the pipes. Since the displacement measurements expected are small and the instruments are capable of recording very small displacements even small deflections of the pipes in any direction would have a significant impact on the recorded measurements. For this reason any vibration or deflection of the pipes had to be prevented.

There were a number of factors anticipated that could lead to pipe vibration or deflection. Obvious reasons are accidental contact with the pipes, the force applied on the pipes from the spring loaded sensors and rock pieces falling down during spalling and hitting the construction. To test the stability a pipe was mounted vertically at the tunnel entrance. The pipe was clearly not able to provide the needed stability by itself and the need for additional support was established. This was accomplished using three crossbars, one above the borehole securing the pipe ends, Figure 5-3, and two crossbars placed at two levels behind the pipes inside the open hole, Figure 5-4.

The frame design required that the pipes only be supported in horizontal direction, it must not interfere with the pipes ability to expand upwards as the temperature rises. This is to prevent unnecessary stress, which could lead to pipe buckling, as described earlier.

All crossbars were standard HEB bars (HEB-100), the bars are not stainless steel but were painted to prevent rust.

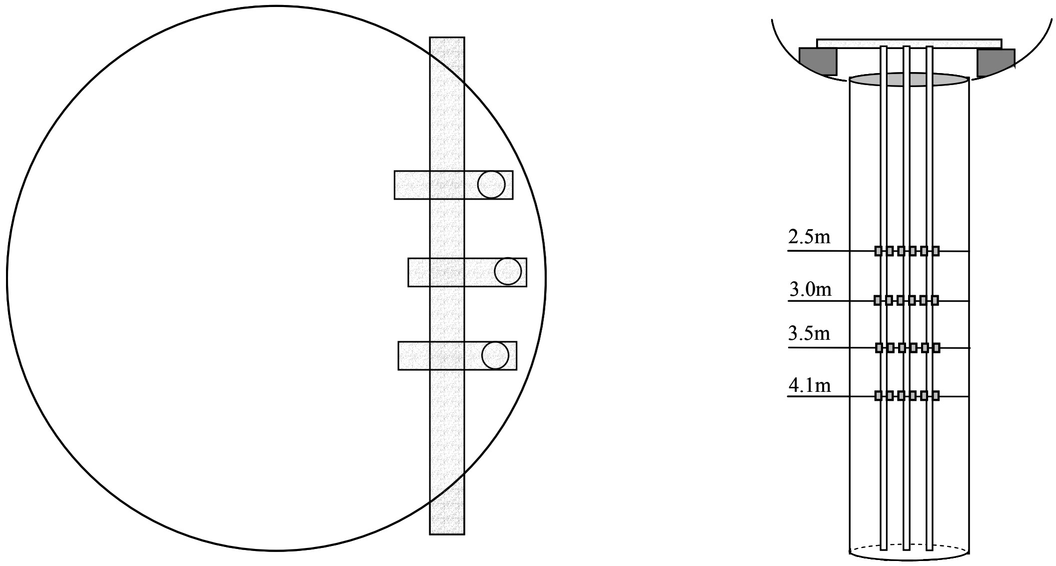


Figure 5-3 *Arrangement of the top crossbar used to stabilise the pipes in plan and section views. To the right the sensor levels with specified depths are also shown.*

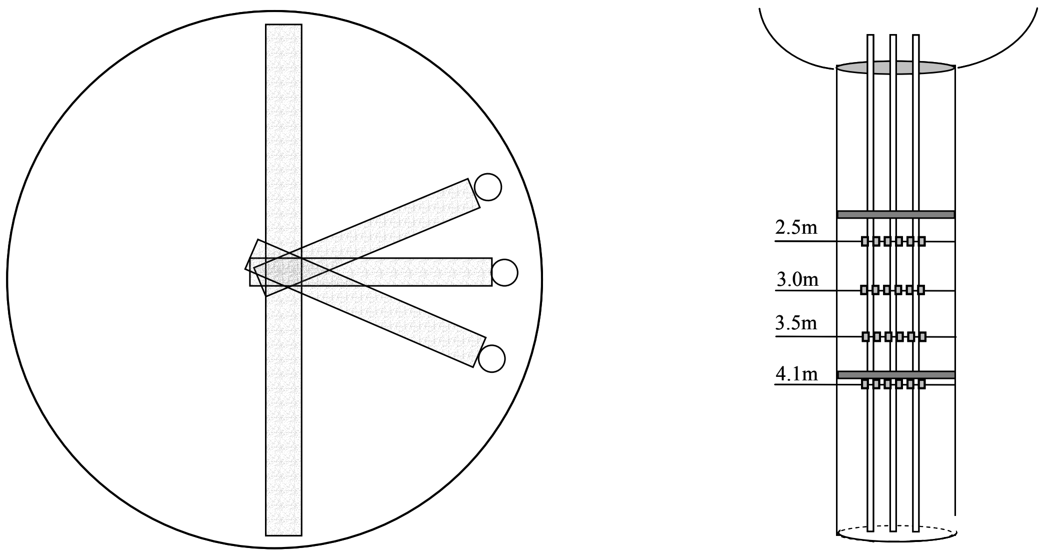


Figure 5-4 *Arrangement of the mid hole crossbars used to stabilise the pipes in plan and section views. To the right the sensor levels with specified depths are also shown.*

Top crossbar

The main task for the crossbar above the hole is to hold the pipes firmly in position. The bar is securely fastened in concrete foundations on the sides of the hole, Figure 5-5. Six bolts were used on each side of the crossbar to fasten it to the foundation.

Figure 5-5 *The top crossbar fastening. Six bolts are used on both sides to secure the crossbar.*

Three steel plates, one for each pipe, were welded to the crossbar. Each plate had a hole with a "plastic pipe coupling", Figure 5-6 and Figure 5-7. At the top of each pipe a solid steel pole was attached, this pole was put trough the pipe coupling. The coupling was then tightened, making the pipe unable to move horizontally but allowing vertical movements – i.e. allowing thermal expansion of the pipes.

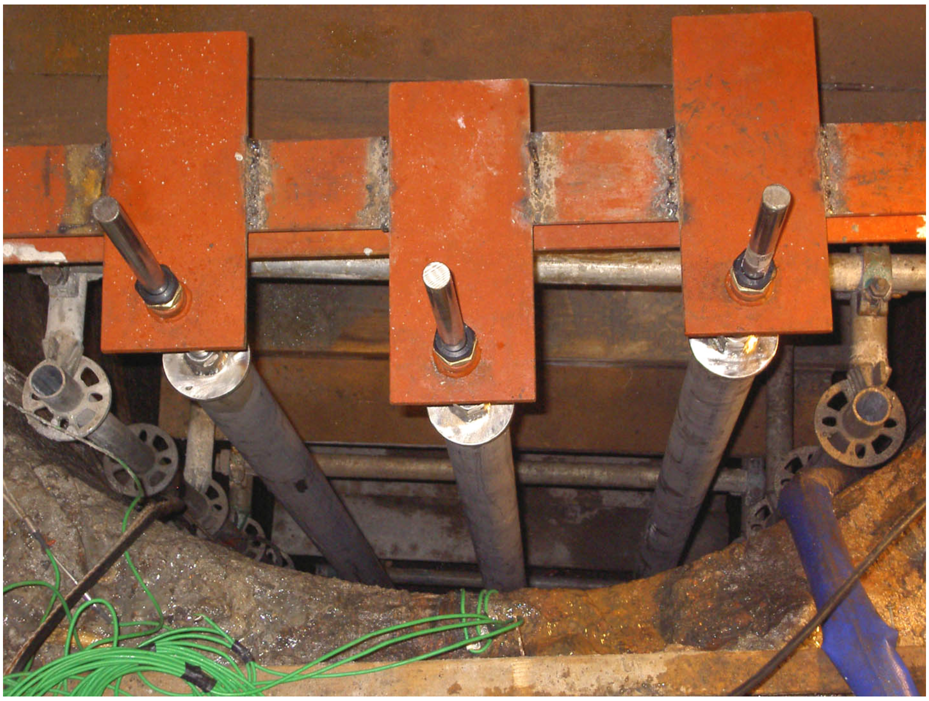


Figure 5-6 *The plates on the top crossbar. The image shows the complete setup with the pipes in place.*

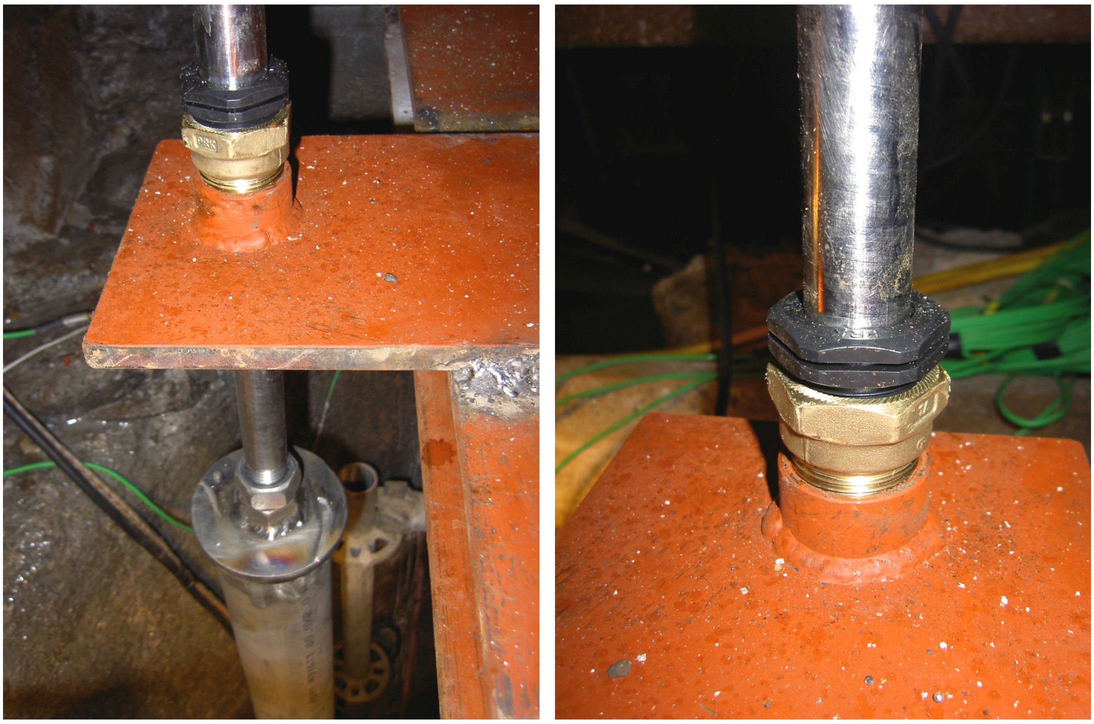


Figure 5-7 *Close-up's on one single plate with the coupling holding the pipe.*

Mid hole crossbars

The mid hole crossbars were placed two and four meters below the tunnel floor.
To minimize alterations of the crossbars position due to hole wall movements the bars are placed at the "center" of the hole, parallel to the major principal stress direction, Figure 5-8.

To allow the crossbars to expand with the temperature increase a special holding construction was used. The end of each crossbar was placed in a short U-bars that was bolted to the hole wall. The crossbar was then pressed to one side of the U-bar using bolts. The construction held the crossbars firmly in all directions but did not interfere with the crossbars ability to expand in its axial direction. The calculated length expansion of the bar is limited to 0.09 mm ($\Delta T = 10$). Even if the bar was clamped at both ends the bar would not buckle from its thermal stress. But since the possibility of hole wall movements is also present, though unlikely, extra precaution was taken to avoid deformation of the crossbars during the experiment.

The placement of the crossbars required extra carbon steel plates to reach the pipes. These plates were welded to the crossbars, the alignment of the plates were radial in the hole, Figure 5-8. At the pipe end of the plates a clamp attaches the pipe to the plate firmly anchoring the pipes in the horizontal direction. The radial arrangement of the plates allowed for easier calculation of the thermal expansion plates and their effects on the deflection of the pipes. The calculated deflection of the pipes from the plate expansion can then be subtracted from the LVDT measurements.

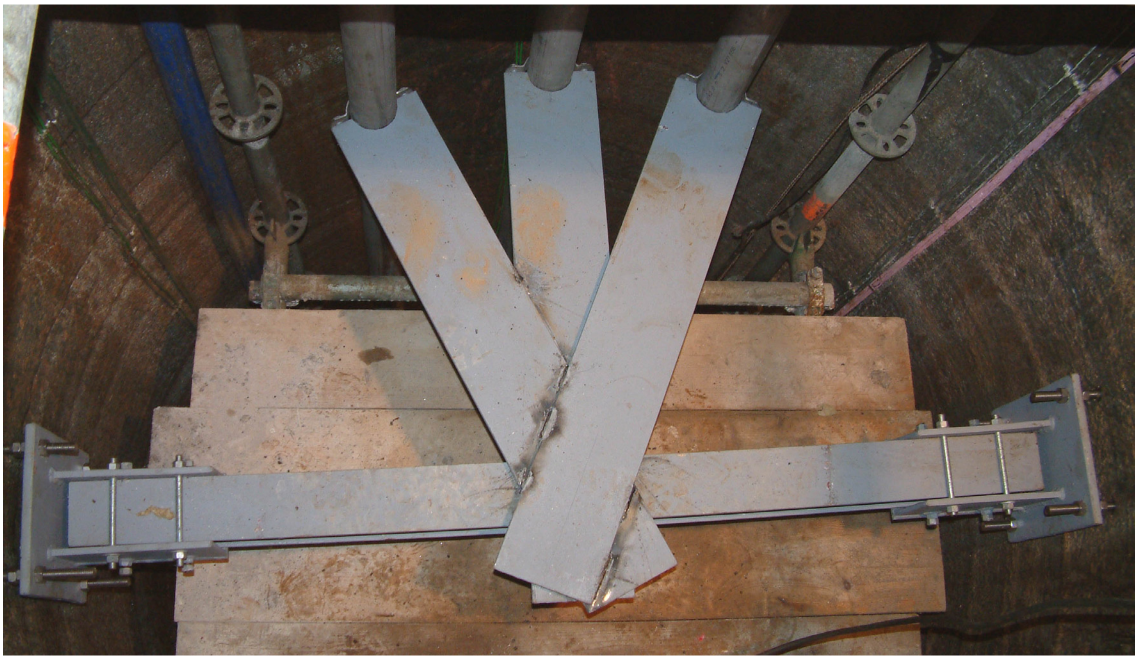


Figure 5-8 *The top mid-hole crossbar with attached plates that holds the pipes.*

Also the stabilizing plates were made of ordinary steel and painted to prevent rust.

5.2 Sensor fastening device

To hold the sensors firmly in position a sensor fastening device was constructed, Figure 5-9. The device was clamped around the pipe. The device allowed each sensor to be individually adjusted in both horizontal position and angle and also possible to move the device up or down the pipe in order to find a suitable measuring position. Each device can hold up to four sensors if necessary, but the design was primarily made with two sensors in consideration. If more than two sensors are mounted on each device the adjustment of a sensor will affect the positioning of the sensor sharing its position. For that reason only two sensors were mounted on each device during the experiment. Blueprints of the device are found in Appendix G.

The device was made of stainless steel and the small amount of material in the construction kept the thermal expansion to a minimum. Calculations shows that the worst case thermal expansion is limited to 0.007 mm.

The ability to alter the sensor positions during the experiment was important both for the ability to correctly mount the sensors but also to be able to move or remove them in order to not prevent further spalling or damage to the sensors when they have reached the end of their measuring range.

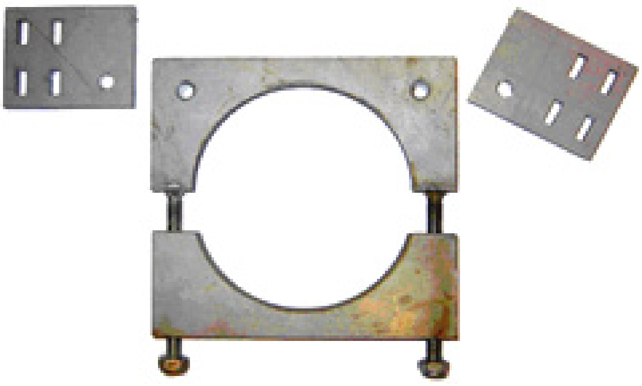


Figure 5-9 *The sensor fastening device. The device can be moved up and down the pipe in order to find a good measuring position before it is securely fastened to the pipe. The sensors can also be individually adjusted sideways. The device can hold up to four sensors.*

5.2.1 Clamps

The sensors were attached to the device using steel “hose clamps”. The clamps are put through the rectangular holes in the small plates shown in Figure 5-9 and tightened around the sensor, Figure 5-10. If the sensor needs to be adjusted the clamp is loosened somewhat and tightened again when the adjustment is done.

Figure 5-10 *The original clamp construction. As seen in the image both sensor types are secured using the method.*

There was concern that the hose clamps would be unable to firmly hold the Schaevitz LVDTs firmly in place due to their stiff springs and position of the clamps near the back of the LVDT casings. A standard pipe clamp was substituted with a diameter to fit the sensors, Figure 5-11. The new clamp also allows the sensors to be adjusted in both length and angle. However, to adjust the sensor, one bolt holding the clamps must be loosened, this resulted in both the angle and lengthwise position of the sensor being affected. It was very difficult to adjust only one parameter without the other being affected.

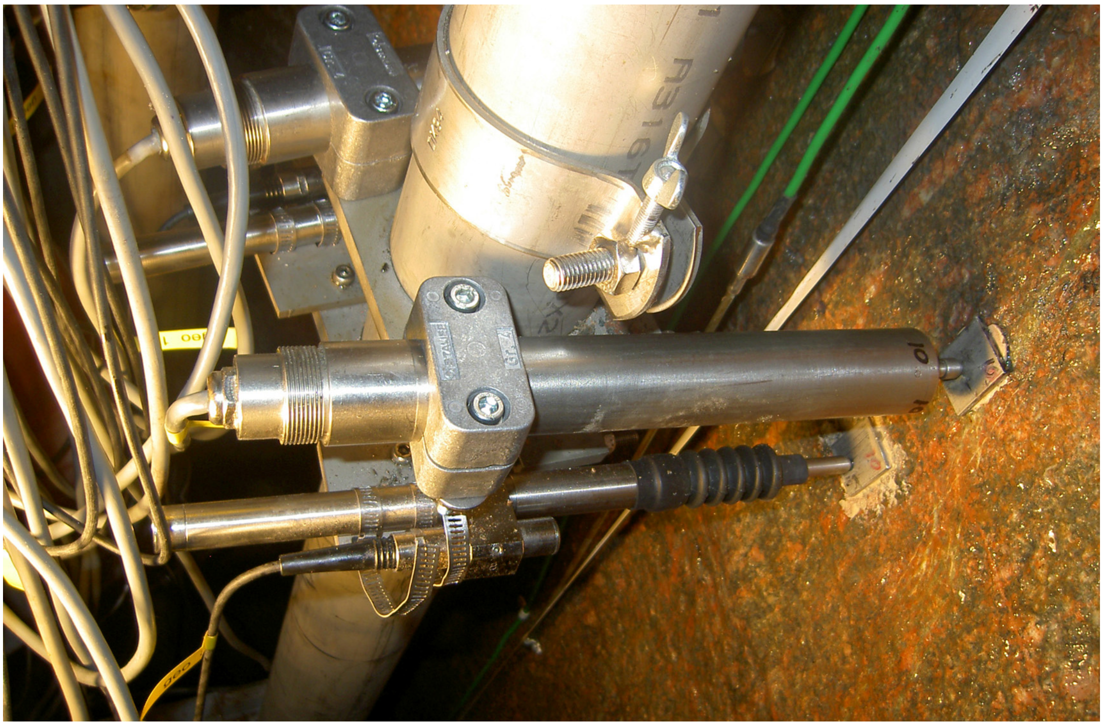


Figure 5-11 *The new clamp that was used to secure the short range sensors. As seen the wide range sensors are not fitted with the new clamp.*

Using the new clamps the measurement shows the same characteristics as the original clamp solution. It was therefore concluded that the original clamp solution was functional and the measured data acquired when the original design was in use was fully usable.

The original hose clamps were used to mount both LVDT types while the pipe clamps were only used to mount the short range LVDTs. All short range sensors that were mounted after the experiment was started were fitted with the new type of clamp. The clamps holding the short range sensors on the second row, at three meters depth, were also changed to the new type when additional sensors were installed on 2004 June 03.

5.3 Measurement plates

The pillar wall is neither completely smooth nor exactly vertical. The fact that the LVDTs vertical position will change somewhat during the pipe expansion together with the pillar roughness might also have an influence on the measurements. To prevent the borehole wall from interfering with the movement of the LVDT plungers, 24 small steel plates, 3×2.5 cm square, were glued on the pillar wall, Figure 5-12, one at the location of each LVDT. The plates served as flat surfaces to measure against. The small size of the plates were not expected to prevent spalling of the pillar.

Figure 5-12 *One of the small steel plates glued to the pillar wall. A short range LVDT is mounted and using the plate as a measuring point.*

Prior the experiment start up an effort was made to document the alignment of the small plates. This was made by raising and lowering each pipe several times using a jack. Since all sensors on the 12 first positions were mounted during this test the changes in measured value can be taken as a measure of the plates alignment, and the result can be used in post experiment analysis. A table of the results from the plate alignment is found in Appendix H. When the additional LVDT sensors were mounted midway in the experiment a decision was made not to glue additional measurement plates and measure their alignment. The main reason for this was to not endanger the displacement readings on the upper rows.

5.4 Temperature sensor mounting

Sensors inside the large holes were fastened to the borehole wall using ordinary wire clamps anchored to the rock. The tip of the sensors, where the measurement is made, was inserted into a small predrilled hole, approximately 20 mm deep. The thermocouples were grouted into these holes to couple them to the rock.

The sensors that are placed in the smaller diameter-boreholes drilled outside the pillar were lowered to the desired depth and the holes were completely filled with sand to avoid convection and to set a good coupling between the heaters and the rock.

6 Data preparation

In this chapter the steps taken to prepare the data for analysis are discussed. This included filtering the data and performing some calculations to allow use of more powerful analysis tools than the data logging software could provide.

The main steps in this process were:

* Data export from the logging software
* Data import to analysis software
* Conversion of raw data into mm values
* Data filtering
* Calculation of measurement results
* Export to software independent ASCII files

The details of each step are described below

6.1 Data export

The logging software (ScadaPro) uses a data format incompatible with other software programs. The data logged data must first be exported into an ASCII file, which can be imported by the desired analysis software.

The logging software has an export function that allows selection of desired time interval and data channels. All channels containing unformatted data were exported to ASCII files using this function. The timestamp for the data was also included in the exported files.

6.2 Data import

A more powerful data analysis tool than the logging software was required to be able to perform the needed calculations. The software used for this was the National Instruments “DIAdem 9.1” application. More information about the software is found on www.ni.com.

All channels were imported into the DIAdem software. The channels were sorted and categorised in groups, one per sensor type. The timestamp channels were included in the process and one date and time channel was included in each sensor group. These date and time channels were always included to ensure the data were shown at the correct position in time.

6.3 Conversion of raw data into mm values

Raw data from the displacement sensors were logged in volts. The data was converted to a mm value using the curve fit parameters described in chapters 2.2.1 and 2.2.2. The new channels are stored next to the original channels, no data was deleted.

6.4 Data filtering

Data filtering was the critical step in the data preparation. The filtering was conducted in order to remove data from the time intervals where the experiment area was considered disturbed. For example this can include taking photographs in the hole or mounting of additional sensors. During most of these times the AE system was shut down to avid collecting spurious data. Data is only filtered if it can be correlated with activity in or around the boreholes. The time period from which data is removed is left empty, so the filtered time periods can be clearly discerned. The filtering was performed with software developed by Acuo Engineering AB. Appendix I contains the list of time intervals that were filtered out. The filtering had to be done after the measurement data has been converted into mm values. This was because some of the functions that are used in the conversion are not linear.

To make the data curves readable after removal of data from disturbed time periods, the data following the disturbance had a correction factor applied to match the data from before the disturbance, Figure 6-1. This allowed the total displacements due to wall movement to be determined from the start of the test.

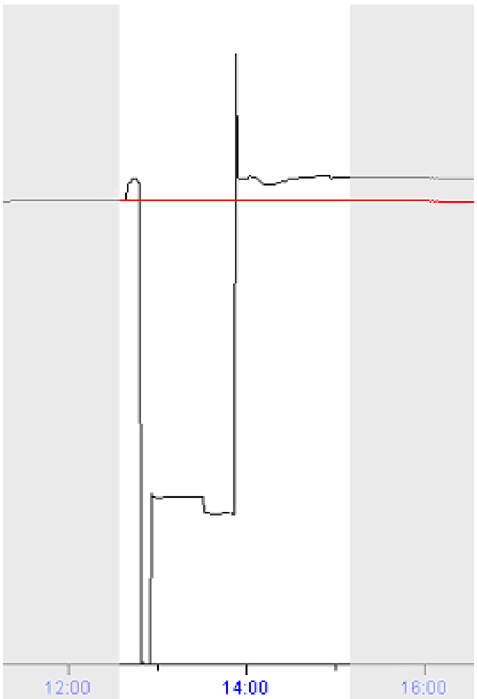


Figure 6-1 *Example of the filtering process. The white area is considered disturbed. The black line is the measured data from one sensor during the disturbed time. The red line is the resulting data after the filtering is done. As the figure shows the filtering application removes the data from the disturbed time interval and the following data is adjusted to make a seamless continuous curve. The result is a data set that shows only the effective displacements during the experiment. The plot is done by interpolating sampled data, for that reason the red line is continuous though the filtered interval.*

6.5 Calculation of measurement results

During the experiment the data was represented as an absolute volt or mm value. To quickly and easily be able to see the results separate channels were created that showed the relative measurement results of the sensors.

The new channels were created by subtracting the initial values of the sensors from subsequent readings. The date and time of 2004 May 17 at 1700 hours was set as the start point for the measurements. The system was considered stable at this point and all checks of the data logging system had been conducted.

Initial data collected prior the start time was removed for the relative measurement channels, though not removed from the original dataset. These channels were used for further analysis of the pillar response.

6.6 Export to software independent ASCII files

The DIAdem software stores the data in a non standard file format. This makes the data dependent on the DIAdem software. In order to secure that the data can be read in the future, the data was exported to a ASCII format file. The file is an ordinary text file in which the data columns are separated with a semicolon. The headers of the columns were included in the file to ensure that the channels can be identified. The ACSII file is together with the original data stored in the SICADA system.

7 Temperature effects

In the previous chapters a number of factors that can affect the measurements were discussed. It is vital to understand what happens with the different components of the measurement hardware during the experiment. All parts of the support frame (pipes, crossbars, stabilizing plates) expand, the metal of the LVDTs expand and the LVDTs experience drift in readings. Even if each of these factors is very small the total sum of the temperature effects had to be taken into consideration during the data analysis.

The method of calculating the thermal effects is shown in Appendix J. The calculations show that the total thermal effect during the entire experiment is less than 0.1 mm on the most interesting measurement positions, Table 7-1.

Table 7-1 Calculation of the total measurement error on position 9, 10, 15 and 16. A positive number indicates that the sensors have been compressed by the thermal effects. No measurement plates were used on position 15 and 16, indicated by a "-" in the table.

Measurement position	Sensor type	Plate expansion [mm]	Measurement plate alignment [mm]	Sensor drift [mm]	Total sum (mm)
9	short range	0.0468	0.0101	-0.0009	0.0560
9	wide range	0.0468	0.0000	0.0294	0.0762
10	short range	0.0468	-0.0154	-0.0053	0.0261
10	wide range	0.0468	-0.0145	0.0515	0.0838
15	short range	0.0468	-	-0.0099	0.0369
15	wide range	0.0468	-	0.0528	0.0996
16	short range	0.0468	-	-0.0045	0.0423
16	wide range	0.0468	-	0.0000	0.0468

Data analysis was divided into two sub parts, one adapted to data within a short term interval and one with a long term. In the short term interval the time windows that are analysed varies from a couple of minutes to a few days, while the long term interval was over several weeks. The need for thermal error calculation within each type was based on the accuracy demands and the temperature change during the analysed interval.

The short term analysis used to analyse the elastic behaviour of the rock required a very high degree of accuracy in the data. The temperature increase is however small during short time intervals, less than one degree Celsius. Hence the thermal effects of the system were small. The thermal error per degree raised temperature during the experiment is less than 0.01 mm (thermal error, found in Table 7-1, divided by the total temperature increase, approximately 10°C). If the analysed period of time is very small, i.e. a couple of hours, the temperature can even be said to be constant and the thermal effects can be totally neglected. The measured values are in this case very accurate.

The long term analysis was used to analyse the spalling behaviour of the pillar. During spalling far greater displacements of the pillar were observed than during the initial elastic phase. The greatest spalling movements were about 16 mm, because this is far greater than the effect of thermal expansion over the entire duration of the experiment the thermal effects were not included in the final data set.

8 Discussion

Achieving a good foundation for the pillar displacement measurements proved to be a difficult task. The demands on the sensor mounting construction was to not in any way support the pillar or be affected by its displacement. These demands together with the obvious demand for a fix position for the sensors throughout the measurement proved impossible to fulfil. The compromise was to allow small movement in the sensor position since supporting the pillar was not an option. This compromise is acceptable as the sensor position movements is held to a minimum and is possible to calculate in the post experiment analysis. Examples on calculations of this kind are found in Appendix J. The solution allows the thermal effect to be calculated at all times throughout the experiment if needed. A short discussion about the need to calculate the thermal effects is found in chapter 7, Temperature effects, where the conclusion is that in most cases the need to do these calculations is very small. This is however an issue mainly for the data analysis and is therefore not extensively discussed here.

When accessing the open hole for maintenance purposes the displacement measurements almost always showed a lot of activity, primarily due to the fact that the sensor supporting construction was affected, but also because the temperature in the hole was raised by human body temperature. The sensors did not necessarily return to the exact positions as prior the disturbance. To be able to analyse the displacements induced by the pillar stress and not by human activity these displacement readings must be removed. As described in chapter 6.4 software was written to perform this task. The list of filtered time intervals is found in Appendix I. An issue here is at what time the disturbances is said to be ended and the filtering stopped. It is clear that there has been no human activity in the hole after the logged stop time, but there might be cases in witch the system needs some time to return to the steady state. If the system shows anomalies, i.e. extended displacement readings in connection to a filtered time interval this might be the case even though effort has been made to manually go through the data.

Disturbances in temperature data reading were also observed. In the beginning of the experiment the temperature data seems to have been subject to electrical noise. The symptoms are not found in readings from other sensors types. No explanation to this phenomenon has been found. These disturbances disappeared after 2004 June 19, about half way in to the experiment. Temperature trend and magnitude were unaffected at this time which suggested that no offset error was induced by the noise. No activity was logged in connection to this date that can explain the behaviour.

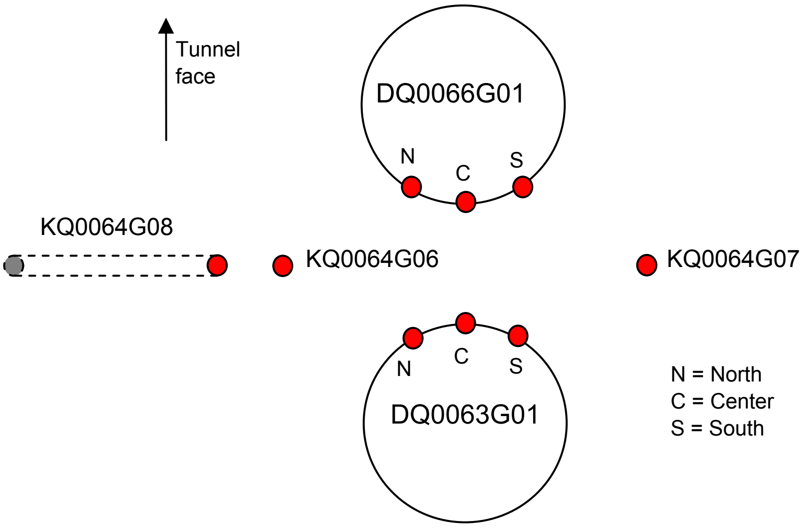
Appendix

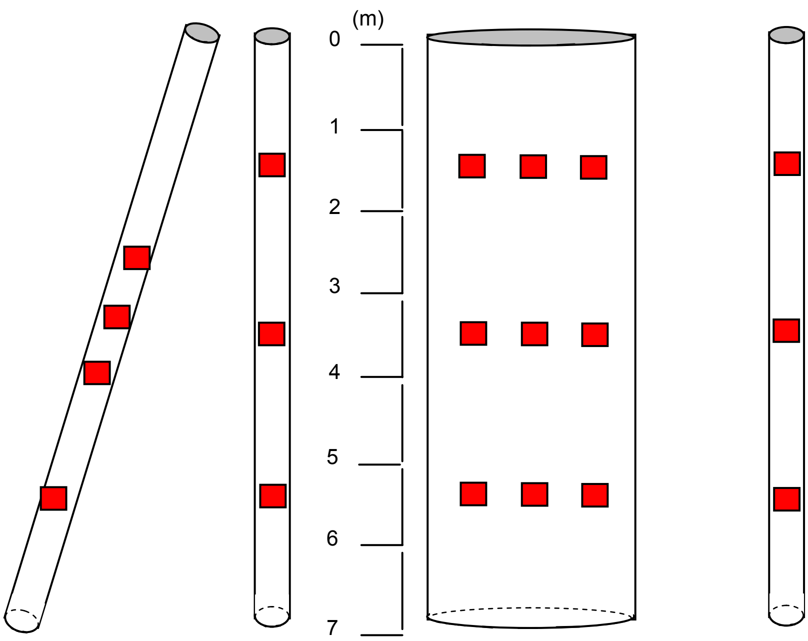
A. Pentronic thermocouples

Coordinates are ÄSPÖ96 format

Thermocouple ID	Borehole	Position	APSE sensor number	Measurement depth. (relative -446.07 m)	X	Y	Z
297422	DQ0066G01	N	1	1.5	7321.351	2127.466	-447.57
297417	DQ0066G01	N	2	3.5	7321.351	2127.466	-449.57
297411	DQ0066G01	N	3	5.5	7321.351	2127.466	-451.57
297425	DQ0066G01	S	4	1.5	7320.498	2127.679	-447.57
297424	DQ0066G01	S	5	3.5	7320.613	2127.585	-449.57
297437	DQ0066G01	S	6	5.5	7320.498	2127.679	-451.57
297428	DQ0066G01	C	7	1.5	7320.255	2128.525	-447.57
297429	DQ0066G01	C	8	3.5	7320.255	2128.525	-449.57
297436	DQ0066G01	C	9	5.5	7320.255	2128.525	-451.57
297430	DQ0063G01	N	10	1.5	7320.018	2126.085	-447.57
297432	DQ0063G01	N	11	3.5	7320.018	2126.085	-449.57
297415	DQ0063G01	N	12	5.5	7320.018	2126.085	-451.57
297426	DQ0063G01	S	13	1.5	7319.775	2126.931	-447.07
297427	DQ0063G01	S	14	3.5	7319.775	2126.931	-449.57
297416	DQ0063G01	s	15	5.5	7319.775	2126.931	-451.57
297423	DQ0063G01	C	16	1.5	7318.921	2127.144	-447.57
297421	DQ0063G01	C	17	3.5	7318.921	2127.144	-449.57
297431	DQ0063G01	C	18	5.5	7318.921	2127.144	-451.57
297413	KQ0064G06	-	19	1.5	7321.504	2125.982	-447.57
297418	KQ0064G06	-	20	3.5	7321.517	2125.962	-449.57
297435	KQ0064G06	-	21	5.5	7321.53	2125.942	-451.57
297414	KQ0064G07	-	22	1.5	7318.766	2128.641	-447.57
297420	KQ0064G07	-	23	3.5	7318.759	2128.652	-449.57
297434	KQ0064G07	-	24	5.5	7318.751	2128.663	-451.57
297412	KQ0064G08	-	25	2.75	7323.194	2124.296	-448.82
297410	KQ0064G08	-	26	3.25	7323.405	2124.087	-449.32
297433	KQ0064G08	-	27	3.75	7323.61	2123.882	-449.82
297419	KQ0064G08	-	28	5.5	7324.347	2123.15	-451.57

Borehole layout





PENTRONIC

Kund / *Customer:*	Svensk Kärnbränslehantering AB
Kundreferens / *Customer reference:*	9619
Vårt ordernummer / *Our order number:*	54296

Utcheckning av termoelement typ K / *Test of thermocouple type K*

Artikelnummer / *Article number:*	80-20000
Kontrolltemperatur / *Test temperature:*	0°C
Standard / *Standard:*	IEC 60584
Isolation / *Isolation:*	500 V DC
Nominellt värde *Nominal value:*	0,000 ± 200,000 µV
Klass / *Class:*	Oklassad

Nummer/ *Number:*	Mätvärde/ *Measured value:*	Nummer/ *Number:*	Mätvärde/ *Measured value:*	Nummer/ *Number:*	Mätvärde/ *Measured value:*
297410	-28	297411	-32	297412	-42
297413	-44	297414	-42	297415	-37
297416	-42	297417	-42	297418	-46
297419	-43	297420	-45	297421	-34
297422	-43	297423	-36	297424	-35
297425	-41	297426	-38	297427	-38
297428	-41	297429	-36	297430	-39
297431	-41	297432	-35	297433	-80
297434	-134	297435	-96	297436	-85
297437	-117				

Datum / *Date:* 03-11-18 Ansvarig för kontroll / *Responsible for control:* Kristin Gullqvist Signatur / *Signature:* ICG

Vid leveranskontrollen har använts utrustning vars prestanda och egenskaper, via Pentronics ackrediterade lab (AKL 0076), är spårbara till normaler hos riksmätplatsen.

The test was carried out using equipment whose accuracy and performance is tracable, via Pentronic's accredited laboratory (AKL0076), to National Standards at the Swedish National Testing Institute.

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Kund / *Customer:*	Svensk Kärnbränslehantering AB
Kundreferens / *Customer reference:*	9619
Vårt ordernummer / *Our order number:*	54296

Utcheckning av termoelement typ K / *Test of thermocouple type K*

Artikelnummer / *Article number:*	80-20000
Kontrolltemperatur / *Test temperature:*	100°C
Standard / *Standard:*	IEC 60584
Isolation / *Isolation:*	500 V DC
Nominellt värde *Nominal value:*	4096,000 ± 200,000 µV
Klass / *Class:*	Oklassad

Nummer/ *Number:*	Mätvärde/ *Measured value:*	Nummer/ *Number:*	Mätvärde/ *Measured value:*	Nummer/ *Number:*	Mätvärde/ *Measured value:*
297410	4068	297411	4064	297412	4054
297413	4052	297414	4054	297415	4059
297416	4054	297417	4054	297418	4050
297419	4053	297420	4051	297421	4062
297422	4053	297423	4060	297424	4061
297425	4055	297426	4058	297427	4058
297428	4055	297429	4060	297430	4057
297431	4055	297432	4061	297433	4016
297434	3962	297435	4000	297436	4011
297437	3979				

Datum / *Date:* 03-11-18 Ansvarig för kontroll / *Responsible for control:* Kristin Gullqvist Signatur / *Signature:* KG

Vid leveranskontrollen har använts utrustning vars prestanda och egenskaper, via Pentronics ackrediterade lab (AKL 0076), är spårbara till normaler hos riksmätplatsen.

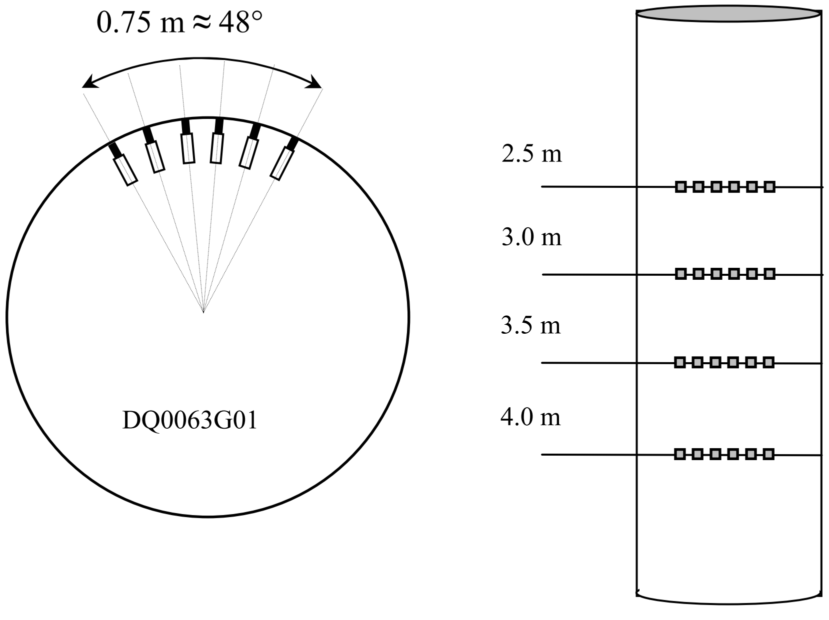
The test was carried out using equipment whose accuracy and performance is tracable, via Pentronic's accredited laboratory (AKL0076), to National Standards at the Swedish National Testing Institute.

B. Schaevitz LVDT sensor and Roctest Casing

			Coordinates are in ÄSPÖ96 format			Active time	
Sensor number:	Sensor ID	Depth (rel - 446.07) [m]	X	Y	Z	June 5th 2004	August 16th 2004
1	7192	2.52	7 320,011	2 126,484	-448,590	May 5th 2004	June 17th 2004
2	7052	2.52	7 319,942	2 126,657	-448,590	May 5th 2004	August 16th 2004
3	5606	2.52	7 319,832	2 126,817	-448,590	May 5th 2004	June 17th 2004
4	7985	2.52	7 319,696	2 126,945	-448,590	May 5th 2004	June 17th 2004
5	5654	2.52	7 319,529	2 127,044	-448,590	May 5th 2004	August 16th 2004
6	7721	2.52	7 319,352	2 127,103	-448,590	May 5th 2004	June 17th 2004
7	5962	2.99	7 320,011	2 126,484	-449,060	May 5th 2004	August 16th 2004
8	6760	2.99	7 319,942	2 126,657	-449,060	May 5th 2004	August 16th 2004
9	6210	2.99	7 319,832	2 126,817	-449,060	May 5th 2004	August 16th 2004
10	7051	2.99	7 319,696	2 126,945	-449,060	May 5th 2004	August 16th 2004
11	7999	2.99	7 319,529	2 127,044	-449,060	May 5th 2004	August 16th 2004
12	7058	2.99	7 319,352	2 127,103	-449,060	May 5th 2004	August 16th 2004
13	Not used	3.58	-	-	-	-	-
14	7065	3.58	7 319,95	2 126,65	-449,650	June 3rd 2004	August 16th 2004
15	7751	3.58	7 319,83	2 126,82	-449,650	June 3rd 2004	August 16th 2004
16	6084	3.58	7 319,70	2 126,94	-449,650	June 3rd 2004	August 16th 2004
17	7987	3.58	7 319,52	2 127,05	-449,650	June 3rd 2004	August 16th 2004
18	Not used	3.58	-	-	-	-	-
19	Not used	4.1	-	-	-	-	-
20	7192	4.1	7 319,95	2 126,65	-450,170	June 17th 2004	August 16th 2004
21	5606	4.1	7 319,83	2 126,82	-450,170	June 17th 2004	August 16th 2004
22	7985	4.1	7 319,70	2 126,94	-450,170	June 17th 2004	August 16th 2004
23	7721	4.1	7 319,52	2 127,05	-450,170	June 17th 2004	August 16th 2004
24	Not used	4.1	-	-	-	-	-
Fracture	7712	-	-	-	-	May 5th 2004	August 16th 2004
Pipe	7716	0.3	-	-	-	May 5th 2004	August 16th 2004

Sensor layout illustration

The sensor positions are numbered from left to right, top to bottom.
On the first row, located at 2.5 meters depth, sensors 1 to 6 are mounted.
On the second row, at 3.0 meters, sensors 7 to 12 are mounted.
Sensors 13 to 18 are mounted on the third row, at 3.5 meters depth.
Finally the sensors 19 to 24 are mounted on the fourth row, at 4.0 meters depth.



ASPO LVDT curve fit parameters F. Johnston, revised 25 May 2004

		Using the linear curve fit formula x=(y/m-b/m) where x=displacement (mm), y=LVDT output (vdc), b=intercept, and m=slope							
						EXAMPLE CALCULATIONS at 1.00 and -1.00 mm LVDT calibration points			
ASPO Position	ASPO datalogger channel	AECL LVDT number	AECL LVDT s/n	b	m	LVDT 1.00 mm output voltage	LVDT calculated displacement (mm)	LVDT -1.00 mm output voltage	LVDT calculated displacement (mm)
Upper array, 1	1	11	7192	-0.002864286	1.609272656	1.6172	1.0067	-1.6226	-1.0065
Upper array, 2	2	1	7052	0.007971429	1.630642969	1.6359	0.9983	-1.6366	-1.0085
Upper array, 3	3	9	5606	0.001585714	1.646521875	1.6705	1.0136	-1.6745	-1.0180
Upper array, 4	4	30	7985	0.003842857	1.599284375	1.6127	1.0060	-1.6135	-1.0113
Upper array, 5	5	14	5654	-0.008300000	1.685652344	1.6943	1.0101	-1.7072	-1.0079
Upper array, 6	6	2	7721	0.012528571	1.608131250	1.6251	1.0028	-1.6222	-1.0165
Bottom array, 7	7	13	5962	-0.005400000	1.633525781	1.6464	1.0112	-1.6498	-1.0067
Bottom array, 8	8	8	6760	0.006707143	1.625095313	1.6551	1.0143	-1.6447	-1.0162
Bottom array, 9	9	25	6210	0.000128571	1.599222656	1.6002	1.0005	-1.5958	-0.9979
Bottom array, 10	10	5	7051	0.002221429	1.643427344	1.6446	0.9994	-1.6547	-1.0082
Bottom array, 11	11	4	7999	0.016478571	1.596893750	1.6132	0.9999	-1.6061	-1.0161
Bottom array, 12	12	3	7058	0.020121429	1.637356250	1.6638	1.0039	-1.6485	-1.0191
Fracture, 13	13	15	7712	0.008635714	1.581238281	1.5815	0.9947	-1.5974	-1.0157
Pillar, 14	14	27	7716	-0.025164286	1.526448438	1.5268	1.0167	-1.5289	-0.9851
bad. do not use		7	7697	-0.021350000	1.611730469	1.6124	1.0137	-1.6231	-0.9938
spare		16	7751	0.013150000	1.622171875	1.6390	1.0023	-1.6362	-1.0168
spare		17	7065	-0.022342857	1.636882813	1.6295	1.0091	-1.6548	-0.9973
spare		19	6084	-0.010642857	1.764173438	1.7812	1.0157	-1.7833	-1.0048
spare		20	5671	0.000385714	1.643540625	1.6588	1.0090	-1.6709	-1.0169
spare		21	7987	0.019021429	1.612916406	1.6304	0.9990	-1.6223	-1.0176
spare		33	6758	0.004842857	1.630216406	1.6535	1.0113	-1.6536	-1.0173
spare		34	8006	0.004935714	1.612772656	1.6272	1.0059	-1.6187	-1.0067

ASPO LVDT CALIBRATION SHEET (Revised 25 May 2004, F Johnston)

Atomic Energy of Canada Limited
Underground Research Laboratory
Pinawa, Manitoba, Canada, R0E 1L0

phone: 204.345.8625
fax: 204.345.8868

Firm: ASPO
Address: SKB, Äspölaboratoriet
Godsmottagningen
Christer Andersson
PL 300
572 95 Figeholm
Sweden

Contact: Christer Andersson
Project Engineer Rock Mechanics
Phone: +46 491 767 848
Cellular: +46 70 59 77 848

Test Item: Schaevitz Bof-Ex Linear Variable Displacement Transducers (LVDT) water bath temperature response test
Units were clamped at a nominal voltage close to 1.0 vdc and subjected to a varying temperature test.

Test Duration: START 21-okt-03 END 11-nov-03

Test Equipment: 1. Polystat Model 1211-10 water bath s/n 404404
2. HP Model 3468A DMM s/n 2137A10328
3. Campbell CR7X Micrologger

ASPO Position number	AECL LVDT number	AECL LVDT serial number	Waterbath Temperature (deg C)				
			15	30	45	60	70
1	**11**	**7192**	1.1019	1.0901	1.0787	1.0669	1.0508
2	**1**	**7052**	1.0613	1.0560	1.0495	1.0402	1.0335
3	**9**	**5606**	1.0848	1.0501	1.0171	0.9808	0.9552
4	**30**	**7985**	0.9228	0.9006	0.8855	0.8608	0.8456
5	**14**	**5654**	0.9842	0.9684	0.9538	0.9363	0.9011
6	**2**	**7721**	1.0783	1.0671	1.0544	1.0407	1.0301
7	**13**	**5962**	1.0496	0.9933	0.9365	0.8756	0.8330
8	**8**	**6760**	0.9331	0.8940	0.8554	0.8046	0.7633
9	**25**	**6210**	0.9661	0.9622	0.9585	0.9495	0.9453
10	**5**	**7051**	1.1202	1.1009	1.0803	1.0580	1.0408
11	**4**	**7999**	0.8622	0.8505	0.8366	0.8249	0.8135
12	**3**	**7058**	1.0126	1.0091	1.0053	1.0002	0.9940
13	**15**	**7712**	0.9179	0.8980	0.8753	0.8489	0.8271
14	**27**	**7716**	1.0531	1.0425	1.0273	1.0003	0.9925
bad, do not use	**7**	**7697**	0.9445	0.9303	0.9186	0.9100	0.8972
spare	**16**	**7751**	0.9313	0.9226	0.9165	0.9062	0.8836
spare	**17**	**7065**	0.5390	0.5273	0.5124	0.4828	0.4589
spare	**19**	**6084**	1.0356	1.0276	1.0168	1.0069	0.9978
spare	**20**	**5671**	1.0340	1.0152	0.9880	0.9609	0.9403
spare	**21**	**7987**	1.0215	1.0009	0.9856	0.9708	0.9537
spare	**33**	**6758**	1.0012	0.9506	0.9043	0.8349	0.7922
spare	**34**	**8006**	1.0387	1.0332	1.0197	1.0032	0.9931

Comments: All transducers were immersed into a water bath at 5 test points ranging from 15 to 70 degress Celsius
Units were set to about 1.0 vdc and allowed to stabilize before measuring an output signal at each test point.

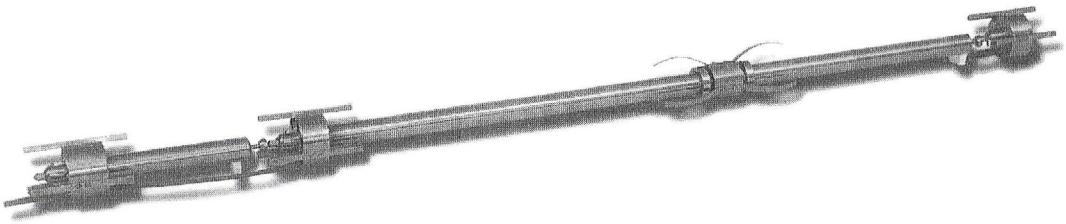
Calibration Technician:________________________________

Date: ____

phone: 204.345.8625 ext 240
fax: 204.345.8868
email: johnstof@aecl.ca

RETRIEVABLE BOREHOLE EXTENSOMETER

Model BOF-EX



APPLICATIONS

The borehole extensometer Model BOF-EX is the most significant development in the field of borehole extensometry applied to rock and concrete structures. Its unique design provides an exhaustive list of outstanding features which make the instrument applicable to a wide range of situations encountered on civil and mining engineering projects.

ACCURACY - ADAPTABILITY. Above all, the BOF-EX MPBX is characterized by its high accuracy as well as its great adaptability to widely different environmental conditions.

The BOF-EX lends itself to applications such as:

- Monitoring of underground vaults for nuclear waste disposal
- Stability assessment of internal cracks in concrete dams

and in more traditional use such as:

- Rock slope stability monitoring
- Rock displacement measurements around tunnels and shafts

DESCRIPTION

The BOF-EX is best described as a multiple-point single tube extensometer. It consists of 4 main components: the mechanical anchor, the measurement module, the extension tubing and the centralizers. An installation consists of a number of measurement modules, in series in a borehole, each one being mounted on the length of extension tubing required to span a lower and upper mechanical anchor. Displacement measurement is therefore made in the hole, in sections distributed along the borehole length.

THE MECHANICAL ANCHOR. The special design of the BOF-EX mechanical anchor allows the complete retrievability of the system. The anchor consists of a cylindrical body with three contacting shoes at 120 degrees angular spacing. Using the installation tool and rods, the anchor is screw-actuated from the collar of the hole until its shoes make contact with the borehole walls.

The anchoring capacity of the anchor is very high and the contacting shoes are designed to adjust to small deformations of the borehole while still exerting the anchoring force.

THE MEASUREMENT MODULE. The measurement module of the BOF-EX is a watertight capsule in which a spring-loaded linear displacement transducer is mounted. The moving spindle of the measurement module comes in contact with the lower anchor of each monitoring section.

THE EXTENSION TUBING. The extension tubing is made of individual lengths of flush-coupled tubes bridging the two mechanical anchors of each monitoring section.

Centralizers are mounted at regular spacing over the extension tubing to prevent their sagging.

FEATURES

- **IN-THE-HOLE WATERTIGHT MOVEMENT SENSING MODULES**
- **ADAPTS TO ANY LINEAR DISPLACEMENT TRANSDUCERS (VIBRATING WIRE, POTENTIOMETER, LVDT AND FIBER OPTIC)**
- **CAPACITY OF 10 MODULES IN SERIES IN AN "N" SIZE BOREHOLE**
- **SPECIAL MECHANICAL ANCHOR PERMITS COMPLETE RETRIEVABILITY**
- **NO PROTRUDING PART ABOVE ROCK SURFACE**
- **EXCELLENT MECHANICAL STABILITY TO BLAST VIBRATIONS**
- **ALLOWS FOR REMOTE READING AND DATALOGGING**
- **MODULAR SYSTEM EASILY AND RAPIDLY INSTALLED**
- **HIGH ACCURACY**

INSTALLATION

The BOF-EX is designed to be installed using an installation rod in an "N" size 76 mm (3 in.) borehole. It can however be easily adapted to boreholes of larger sizes. The installation procedure is simple and straightforward due to the modular design of the instrument. The BOF-EX can also be fully grouted in a borehole. In unstable poor quality rock a BOF-EX installation can be performed using telescoping plastic tubing previously grouted in the hole.

SPECIFICATIONS

Borehole diameter (standard)		76 mm		
Number of measuring modules		1 to 10		
Minimum distance between anchors with standard 38 mm range transducer		30 cm		
TRANSDUCER	**VIBRATING WIRE**	**POTENTIOMETER**	**LVDT (DC)**	**FIBER OPTIC**
Ranges	25-50-100 mm	25-50-100 mm	5-25-50-100 mm	20 mm
Accuracy	±0.25% F.S.	±0.5% F.S	±0.5% F.S.	±0.1% F.S.
Resolution	0.02% F.S.	0.01 mm	0.01 mm	0.002 mm
Operating temperature	-20 to +80°C	-20 to +80°C	-20 to +80°C	-40 to +80°C
Thermistor	3kΩ (see model TH-T)	-	-	-
Readout unit	MB-6T(L)	REP	ACCULOG-iX	FTI-10, UMI
Data acquisition system	SENSLOG	SENSLOG	SENSLOG	BUS, DMI
Cable	IRC-41	IRC-41	IRC-41	CFO-3ST

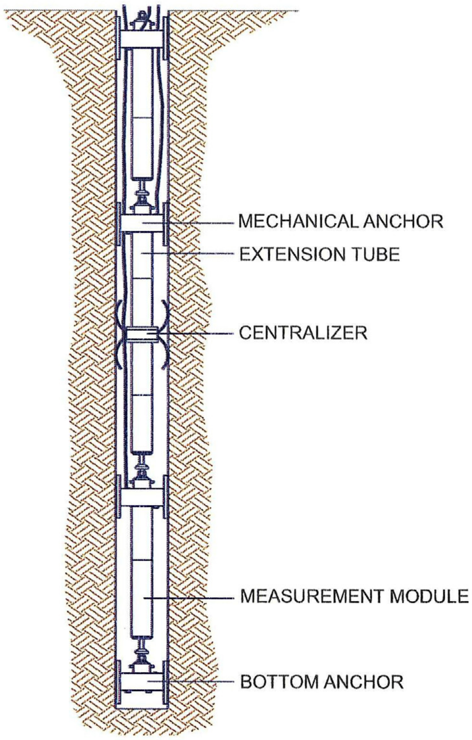
ACCESSORIES

- Installation tool
- Collar mounted fine adjustment tool for transducer positioning
- Pneumatic single or straddle packers to run injection or water tests

ORDERING INFORMATION

Please specify:

- Borehole diameter
- Number of measuring modules
- Depth of each anchor
- Range and type of transducers
- Type of material (aluminum, s/s)
- Accessories



BOF-EX IN A BOREHOLE

E5004C-040707

GCA/GCD Series Precision Gage Heads

Spring-Loaded Design for ±0.050" to ±2.00" Range Measurement

Features

- ***CE compliant (DC models)***
- ***All-welded construction***
- ***Resistant to harsh environments***
- ***MS-type connector***
- ***Electronics hermetically sealed***
- ***Calibration certificate supplied with every gage head***
- ***Compatible with all Schaevitz® signal conditioners***
- ***Special contact tips (see page 100)***

Applications

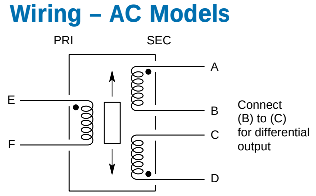
- ***In-process measurements to close loop with PLC or CNC controller***
- ***Environments requiring hermetically sealed transducers***
- ***High temperatures (300°F for AC units)***

Stainless steel construction enables the GCA/GCD Series gage head to perform in environments containing moisture, dirt and other contaminants. Electronic components are hermetically sealed for added protection against hostile conditions. These are heavy duty, long stroke units with ranges up to ±2.0" (50mm). Maximum spring force is typically 8 oz (226.8g), dependent upon probe position. The working end or probe has a removable chrome plated, hardened tool steel tip threaded to the probe with a 4-48 UNF-2A threading. Schaevitz® replacement and alternate contact tips are available (see page 100). Tips are also interchangeable with AGD dial indicator tips.

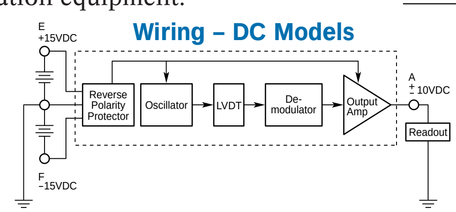
Internal construction prevents the core and shaft from rotating as they move longitudinally. Units terminating into connectors allow for easy cable replacement if damage should occur. Installation and adjustment are facilitated by external threading; locknuts are provided.

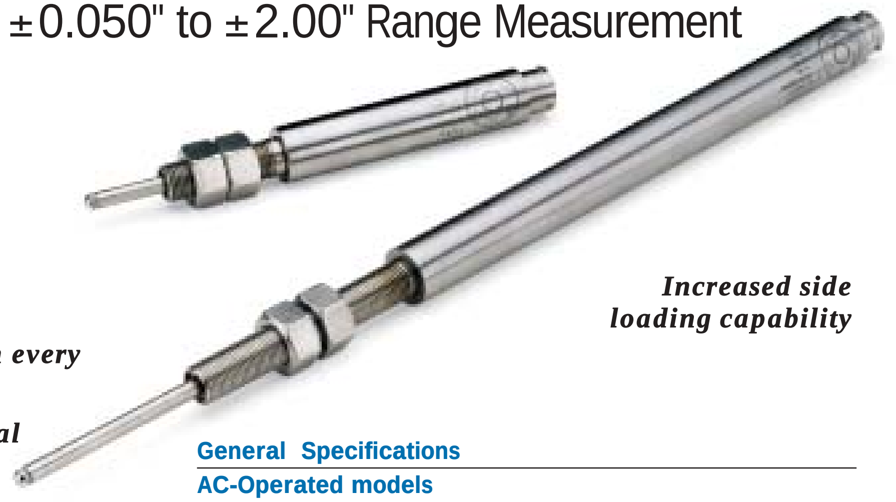
GCA/GCD Series gage heads are available in AC and DC versions. AC-operated units utilize external signal conditioning (see the Instrumentation section of this catalog); DC-operated units incorporate the core, LVDT and all necessary electronics in one housing. Use of monolithic, surface mount circuitry eliminates most of the volume, weight and cost of conventional AC excitation, amplification and demodulation equipment.

Wiring – AC Models



Wiring – DC Models





Increased side loading capability

General Specifications

AC-Operated models

Excitation	3 V rms (nom)
Frequency Range	400 Hz to 10 kHz
Null Voltage	Less than 0.5% full scale output
Linearity	±0.25% of full range output
Repeatability	0.000025" (0.0006 mm)
Operating Temperature Range	-65°F to 300°F (-55°C to 150°C)
Shock Survival	1000 *g* for 11 milliseconds
Vibration Tolerance	20 *g* up to 2 kHz
Housing Material	AISI 400 series stainless steel
Electrical Termination	6-pin connector

DC-Operated models

Excitation	± 15 VDC ±30 mA max
Null Voltage	0 VDC
Linearity	±0.25% of full range output
Repeatability	0.000025" (0.0006 mm)
Operating Temperature Range	32°F to 160°F (-0°C to 70°C)
Shock Survival	250 *g* for 11 milliseconds half sine
Vibration Tolerance	10 *g* up to 2 kHz
Housing Material	AISI 400 series stainless steel
Electrical Termination	6-pin connector

How to Order

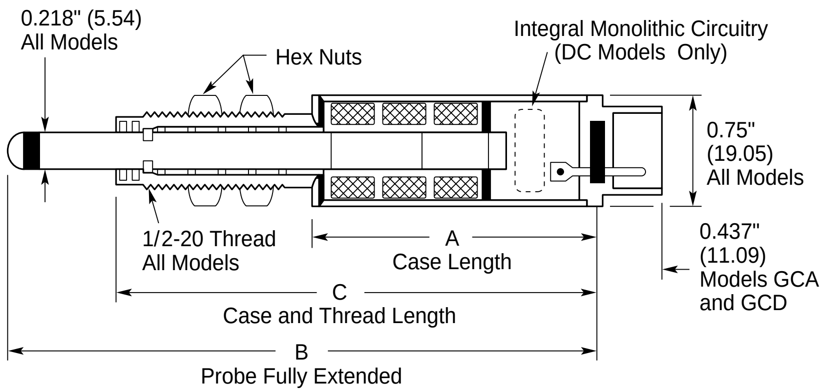
Specify the appropriate model number, followed by the desired Gaging Range suffix. For example: GCA-121-050 is AC operated with a ±0.050" range. Special contact tips are also available and can be ordered separately (see page 100).

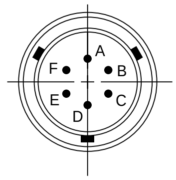
Model Number	Operation
GCA-121	AC
GCD-121	DC

Gaging Range	Description
050	±0.050" (1.27 mm)
125	±0.125" (3.17 mm)
250	±0.250" (6.35 mm)
500	±0.50" (12.7 mm)
1000	±1.00" (25.4 mm)
2000	±2.00" (50.8 mm)

GCD Series models, when correctly installed, are CE certified to comply with the EMC Directive 89/336/EEC.

Dimensions in (mm)





Models GCA and GCD MS-Type Connector Mates with PT06A-10-65 Connector

GCA Specifications @ 2.5 kHz – AC-Operated Models

Model Number	GCA-121-050	GCA-121-125	GCA-121-250	GCA-121-500	GCA-121-1000	GCA-121-2000
Gaging Range	±0.050" (±1.27mm)	±0.125" (±3.17mm)	±0.250" (±6.35mm)	±0.500" (±12.7mm)	±1.000" (±25.4mm)	±2.00" (±50.8mm)
Phase Shift	+6°	+5°	+5°	+2°	+1°	-1°
Sensitivity (mV/V/0.001")	4.2	2.4	1.6	1.1	0.84	0.34
Impedance (Ohms)						
Primary	430	1710	800	900	900	525
Secondary	950	1820	940	1150	2100	535
Pretravel (Nominal)	0.26" (6.6mm)	0.30" (7.6mm)	0.06" (1.5mm)	0.18" (4.5mm)	0.01" (0.3mm)	0.1"
Minimum Overtravel	0.15" (3.8mm)	0.15" (3.8mm)	0.15" (3.8mm)	0.20" (5.1mm)	0.10" (2.5mm)	0
Spring Load Over Gaging Range	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.2 to 8.0 oz. (91 to 227g)	3.2 to 8.0 oz. (91 to 227g)	3.2 to 8.0 oz. (91 to 227g)
Dimensions						
A (±0.01"/0.25mm)	1.90" (48.3mm)	2.75" (69.9mm)	3.61" (91.7mm)	5.29" (134.4mm)	7.55" (191.8mm)	10.89" (276.6mm)
B (±0.03"/0.76mm)	4.33" (110.0mm)	5.14" (130.6mm)	6.10" (154.9mm)	10.75" (273.1mm)	13.01" (330.5mm)	20.94" (531.9mm)
C (±0.02"/0.50mm)	3.27" (8.1mm)	4.12" (104.6mm)	4.99" (126.7mm)	8.27" (210.1mm)	10.53" (267.5mm)	16.37" (415.8mm)
Weight	2.2 oz (64g)	2.9 oz. (82g)	3.17 oz. (90g)	5.0 oz. (142g)	7.5 oz. (213g)	13 oz. (369g)

GCD Specifications – DC-Operated Models

Model Number	GCD-121-050	GCD-121-125	GCD-121-250	GCD-121-500	GCD-121-1000	GCD-121-2000
Gaging Range	±0.050" (±1.27mm)	±0.125" (±3.17mm)	±0.250" (±6.35mm)	±0.500" (±12.7mm)	±1.000" (±25.4mm)	±2.000" (±50.8mm)
Sensitivity (V/1")	200	80	40	20	10	5
Pretravel (Nominal)	0.30" (7.62mm)	0.35" (8.8mm)	0.18" (4.5mm)	0.20" (5.08mm)	0.01" (.25mm)	0.1"
Minimum Overtravel	0.39" (9.4mm)	0.14" (3.5mm)	0.03" (0.76mm)	1.00" (25.4mm)	0.10" (2.5mm)	0
Spring Load Over Gaging Range	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.2 to 8.0 oz. (91 to 227g)	3.2 to 8.0 oz. (91 to 227g)	3.2 to 8.0 oz. (91 to 227g)
Dimensions						
A (±0.01"/0.25mm)	2.66" (67.6mm)	3.50" (88.9mm)	4.37" (111.0mm)	6.06" (153.9mm)	8.31" (211.1mm)	11.48" (291.6mm)
B (±0.03"/0.76mm)	5.08" (129.0mm)	5.90" (149.9mm)	6.77" (172.0mm)	11.53" (292.9mm)	13.76" (349.5mm)	21.52" (546.6mm)
C (±0.02"/0.50mm)	4.02" (102.1mm)	4.87" (123.7mm)	5.74" (145.8mm)	9.05" (229.9mm)	11.29" (286.8mm)	16.96" (430.8mm)
Weight	2.5 oz. (71g)	3.2 oz. (93g)	3.5 oz. (100g)	5.5 oz. (156g)	8.0 oz. (227g)	14 oz. (397g)

Options and Accessories

See individual gage head model specification pages for compatibility

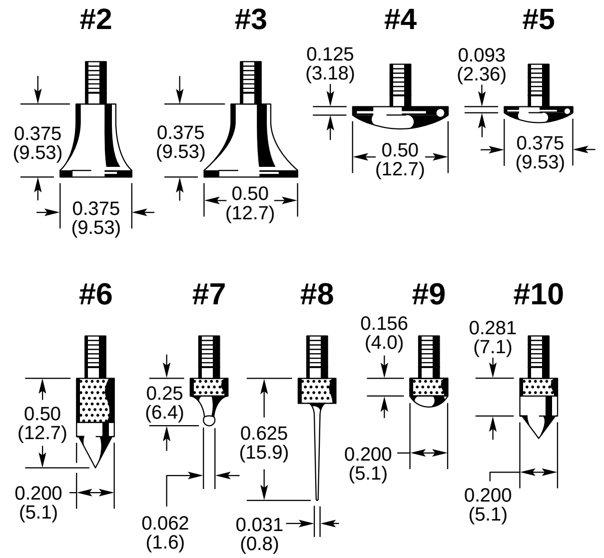
Connectors

Seven different connectors are available to simplify installation of LBB and PCA Series gaging probes, including the PCA Series Bi-directional Lever Probe. To select the proper connector, simply add the appropriate number to the end of the gage head part number. For example, by adding a 2 to a model number such as LBB375PA-020-2 allows the user to specify a standard sensitivity gage head with an Amphenol-type 126-195 connector.

Connector Part Number Suffix	Description
1	Bendix-type PTO6A-10-6P (SR)
2	Amphenol-type 126-195
3	Amphenol-type 165-13
4	DE-9 compatible with Schaevitz® ATA2001
5	Switchcraft-type 12CL5-M compatible with Schaevitz® SYS-96 Dimensional Data Acquisition System
6	LEMO-type CONN. FGG-OB-305-CNAD52
7	Switchcraft-type 05BL5-M compatible with Schaevitz® MP series LVDT readout/ controller

Special Contact Tips

Nine different Schaevitz® contact tips are available for special applications and as replacements for standard tips supplied with most gage heads. All Schaevitz® contact points are 4-48 AGD threaded. To order, select the proper contact tip number.



MS-Type Connector Cables

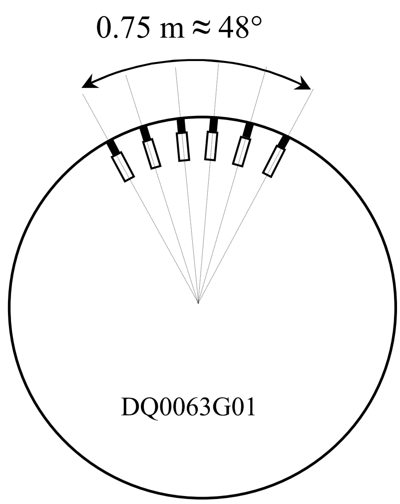
Consult factory for price and availability of adaptor cables for LVDTs and signal conditioners.

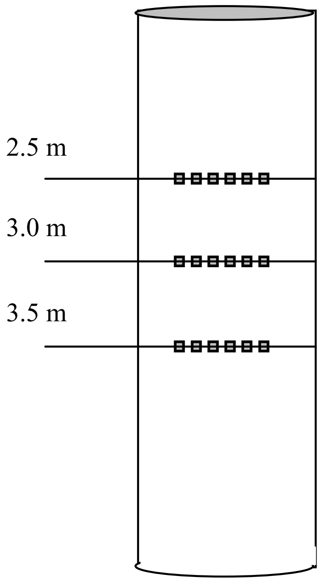
C. Geometric LVDT sensors curve fit and temp calibration sheet

			Coordinates are in ÄSPÖ96 format			Active time	
Sensor position:	Sensor ID	Depth (rel - 446.07) [m]	X	Y	Z	June 5th 2004	August 16th 2004
1	6	2.46	7 320,011	2 126,484	-448,530	May 5th 2004	June 17th 2004
2	5	2.46	7 319,942	2 126,657	-448,530	May 5th 2004	June 17th 2004
3	7	2.46	7 319,832	2 126,817	-448,530	May 5th 2004	June 17th 2004
4	1	2.46	7 319,696	2 126,945	-448,530	May 5th 2004	June 17th 2004
5	2	2.46	7 319,529	2 127,044	-448,530	May 5th 2004	June 17th 2004
6	3	2.46	7 319,352	2 127,103	-448,530	May 5th 2004	June 17th 2004
7	11	3.07	7 320,011	2 126,484	-449,140	May 5th 2004	August 16th 2004
8	10	3.07	7 319,942	2 126,657	-449,140	May 5th 2004	August 16th 2004
9	12	3.07	7 319,832	2 126,817	-449,140	May 5th 2004	August 16th 2004
10	8	3.07	7 319,696	2 126,945	-449,140	May 5th 2004	August 16th 2004
11	9	3.07	7 319,529	2 127,044	-449,140	May 5th 2004	August 16th 2004
12	4	3.07	7 319,352	2 127,103	-449,140	May 5th 2004	August 16th 2004
13	6	3.5	7 320,011	2 126,484	-449,570	June 17th 2004	August 16th 2004
14	5	3.5	7 319,942	2 126,657	-449,570	June 17th 2004	August 16th 2004
15	7	3.5	7 319,832	2 126,817	-449,570	June 17th 2004	August 16th 2004
16	1	3.5	7 319,696	2 126,945	-449,570	June 17th 2004	August 16th 2004
17	2	3.5	7 319,529	2 127,044	-449,570	June 17th 2004	August 16th 2004
18	3	3.5	7 319,352	2 127,103	-449,570	June 17th 2004	August 16th 2004

Sensor layout illustration

The sensor positions are numbered from left to right, top to bottom.
On the first row, located at 2.5 meters depth, sensors 1 to 6 are mounted.
On the second row, at 3.0 meters, depth sensors 7 to 12 are mounted.
Sensors 13 to 18 are mounted on the third row, at 3.5 meters depth.





KALIBRERINGSPROTOKOLL

Typ av givare : Lägesgivare LG-40
Nummer : **1**
Kalibreringsdatum : 2004-1-7

RESULTAT

y = -33.933744+ 4.3830415x^1 -0.2771088x^2 + 0.0164305x^3 -3.441E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	3.98	-19.93	0.07
-15.00	5.74	-15.17	-0.17
-10.00	7.86	-9.94	0.06
-5.00	9.98	-4.87	0.13
0.00	11.99	-0.01	-0.01
5.00	13.96	4.88	-0.12
10.00	15.98	9.95	-0.05
15.00	18.11	15.13	0.13
20.00	20.35	19.95	-0.05

Temperaturkompensering:
$\delta x_t = x * 0.00105 * (t - 55)$ mm, där $55° < t < 80°$ och $x = \pm 20$ mm

Typ av givare : Lägesgivare LG-40
Nummer : **2**
Kalibreringsdatum : 2004-1-7

RESULTAT

y = -31.966202+ 3.1550382x^1 -0.0993185x^2 + 0.0070936x^3 -1.819E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.22	-19.95	0.05
-15.00	6.07	-15.13	-0.13
-10.00	8.09	-9.97	0.03
-5.00	10.07	-4.89	0.11
0.00	11.98	0.03	0.03
5.00	13.88	4.91	-0.09
10.00	15.87	9.90	-0.10
15.00	18.10	15.14	0.14
20.00	20.50	19.96	-0.04

Temperaturkompensering:
$\delta x_t = 0.0015 * (t - 20)$ mm, där $20° < t < 50°$

$\delta x_t = 0{,}04492 + (x * 0.00111) * (t - 50)$ mm, där $50° < t < 80°$ och $x = \pm 20$ mm

KALIBRERINGSPROTOKOLL

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 3
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -23.054690-1.0296600x^1 + 0.4464566x^2 -0.0203809x^3 + 3.039E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.73	-19.94	0.06
-15.00	6.79	-15.20	-0.20
-10.00	8.71	-9.87	0.13
-5.00	10.39	-4.88	0.12
0.00	12.00	-0.04	-0.04
5.00	13.68	4.88	-0.12
10.00	15.53	9.97	-0.03
15.00	17.58	15.12	0.12
20.00	19.74	19.96	-0.04

Temperaturkompensering:

$\delta x_t = 0.002039 * (t - 20)$ mm, där $20° < t < 57°$

$\delta x_t = 0.07545 + (x * 0.000987) * (t - 57)$ mm, där $57° < t < 80°$ och $x = \pm 20$ mm

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 4
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -27.794087+ 0.9072592x^1 + 0.2040343x^2 -0.0082048x^3 + 8.372E-05x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.65	-19.95	0.05
-15.00	6.59	-15.14	-0.14
-10.00	8.50	-9.94	0.06
-5.00	10.28	-4.88	0.12
0.00	11.99	0.00	0.00
5.00	13.74	4.89	-0.11
10.00	15.65	9.95	-0.05
15.00	17.79	15.11	0.11
20.00	20.13	19.97	-0.03

Temperaturkompensering:

$\delta x_t = 0.002612 * (t - 20)$ mm, där $20° < t < 58°$

$\delta x_t = 0.09924 + (x * 0.001122) * (t - 58)$ mm, där $58° < t < 80°$ och $x = \pm 20$ mm

KALIBRERINGSPROTOKOLL

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 5
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -33.135313+ 3.8011831x^1 -0.1664922x^2 + 0.0086652x^3 -1.669E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.05	-19.94	0.06
-15.00	5.82	-15.14	-0.14
-10.00	7.86	-9.97	0.03
-5.00	9.95	-4.90	0.10
0.00	12.00	0.02	0.02
5.00	14.06	4.96	-0.04
10.00	16.09	9.83	-0.17
15.00	18.36	15.20	0.20
20.00	20.47	19.94	-0.06

Temperaturkompensering:

$\delta x_t = 0.00459 * (t - 20)$ mm, där $20° < t < 58°$

$\delta x_t = 0.17442 + (x * 0.00115) * (t - 58)$ mm, där $58° < t < 80°$ och $x = \pm 20$ mm

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 6
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -34.533772+ 4.6831633x^1 -0.3587960x^2 + 0.0238041x^3 -5.334E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.07	-19.96	0.04
-15.00	5.92	-15.10	-0.10
-10.00	8.02	-9.98	0.02
-5.00	10.08	-4.91	0.09
0.00	11.99	0.04	0.04
5.00	13.77	4.89	-0.11
10.00	15.57	9.90	-0.10
15.00	17.53	15.16	0.16
20.00	19.61	19.95	-0.05

Temperaturkompensering:

$\delta x_t = 0.003727 * (t - 20)$ mm, där $20° < t < 61°$

$\delta x_t = 0.15282 + (x * 0.001185) * (t - 61)$ mm, där $61° < t < 80°$ och $x = \pm 20$ mm

KALIBRERINGSPROTOKOLL

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 7
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -32.385675+ 3.3389077x^1 -0.2116605x^2 + 0.0195708x^3 -5.283E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.55	-19.96	0.04
-15.00	6.53	-15.12	-0.12
-10.00	8.53	-9.96	0.04
-5.00	10.34	-4.89	0.11
0.00	11.99	0.03	0.03
5.00	13.55	4.87	-0.13
10.00	15.17	9.90	-0.10
15.00	16.98	15.18	0.18
20.00	18.96	19.95	-0.05

Temperaturkompensering:

$\delta x_t = 0.010565 * (t - 20)$ mm, där 20° < t < 57°

$\delta x_t = 0.3909 + (x * 0.001082) * (t - 57)$ mm, där 57° < t < 80° och x = ± 20 mm

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 8
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -37.776648+ 6.2609919x^1 -0.5528958x^2 + 0.0324163x^3 -6.628E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	3.93	-19.90	0.10
-15.00	5.52	-15.23	-0.23
-10.00	7.69	-9.90	0.10
-5.00	9.91	-4.87	0.13
0.00	11.99	-0.01	-0.01
5.00	13.95	4.87	-0.13
10.00	15.90	9.94	-0.06
15.00	17.96	15.16	0.16
20.00	20.21	19.95	-0.05

Temperaturkompensering:

$\delta x_t = 0.010303 * (t - 20)$ mm, där 20° < t < 56°

$\delta x_t = 0.37091 + (x * 0.001326) * (t - 56)$ mm, där 56° < t < 80° och x = ± 20 mm

KALIBRERINGSPROTOKOLL

Typ av givare : Lägesgivare LG-40
Nummer : **9**
Kalibreringsdatum : 2004-1-7

RESULTAT

y = -28.264683+ 0.9755705x^1 + 0.1990763x^2 -0.0080817x^3 + 9.166E-05x^4

där:
y = beräknat värde [mm]
x = avläst värde

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.75	-19.96	0.04
-15.00	6.67	-15.12	-0.12
-10.00	8.54	-9.96	0.04
-5.00	10.30	-4.90	0.10
0.00	11.99	0.02	0.02
5.00	13.69	4.88	-0.12
10.00	15.53	9.96	-0.04
15.00	17.52	15.11	0.11
20.00	19.58	19.96	-0.04

Temperaturkompensering:
$\delta x_t = 0.00212 * (t - 20)$ mm, där $20° < t < 57{,}5°$

$\delta x_t = 0.07949 + (x * 0.001234) * (t - 57{,}5)$ mm, där $57{,}5° < t < 80°$ och $x = \pm 20$ mm

Typ av givare : Lägesgivare LG-40
Nummer : **10**
Kalibreringsdatum : 2004-1-7

RESULTAT

y = -30.968338+ 2.4933384x^1 + 0.0159732x^2 -3.418E-04x^3 -2.833E-05x^4

där:
y = beräknat värde [mm]
x = avläst värde

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.32	-19.94	0.06
-15.00	6.15	-15.15	-0.15
-10.00	8.12	-9.98	0.02
-5.00	10.07	-4.88	0.12
0.00	11.99	0.05	0.05
5.00	13.94	4.90	-0.10
10.00	16.06	9.89	-0.11
15.00	18.50	15.14	0.14
20.00	21.12	19.96	-0.04

Temperaturkompensering:
$\delta x_t = 0.003182 * (t - 20)$ mm, där $20° < t < 57{,}5°$

$\delta x_t = 0.11932 + (x * 0.001251) * (t - 57{,}5)$ mm, där $57{,}5° < t < 80°$ och $x = \pm 20$ mm

KALIBRERINGSPROTOKOLL

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 11
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -32.905579+ 3.8120407x^1 -0.2194133x^2 + 0.0150217x^3 -3.471E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.14	-19.92	0.08
-15.00	5.97	-15.21	-0.21
-10.00	8.12	-9.89	0.11
-5.00	10.12	-4.87	0.13
0.00	11.99	-0.02	-0.02
5.00	13.82	4.86	-0.14
10.00	15.72	9.96	-0.04
15.00	17.74	15.15	0.15
20.00	19.87	19.95	-0.05

Temperaturkompensering:

$\delta x_t = 0.008157 * (t - 20)$ mm, där $20° < t < 59,5°$

$\delta x_t = 0.32219 + (x * 0.001341) * (t - 59,5)$ mm, där $59,5° < t < 80°$ och $x = \pm 20$ mm

```
Typ av givare     : Lägesgivare LG-40
Nummer            : 12
Kalibreringsdatum : 2004-1-7

          RESULTAT

y = -35.802247+ 4.9114884x^1 -0.3386606x^2 + 0.0195857x^3 -3.967E-04x^4

där:
y = beräknat värde [mm]
x = avläst värde
```

Verkligt värde [mm]	Avläst värde	Beräknat värde [mm]	Avvikelse [mm]
-20.00	4.16	-19.94	0.06
-15.00	5.87	-15.15	-0.15
-10.00	7.94	-9.93	0.07
-5.00	10.01	-4.91	0.09
0.00	12.00	-0.01	-0.01
5.00	13.93	4.90	-0.10
10.00	15.87	9.97	-0.03
15.00	17.86	15.11	0.11
20.00	19.90	19.96	-0.04

Temperaturkompensering:

$\delta x_t = 0.005888 * (t - 20)$ mm, där $20° < t < 59,5°$

$\delta x_t = 0.23259 + (x * 0.001126) * (t - 59,5)$ mm, där $59,5° < t < 80°$ och $x = \pm 20$ mm

Druck

PTX 7500 Series

Industrial Pressure Transmitters

- Standard ranges or custom scaled
- ±0.15% accuracy
- Temperature range -40 to 100°C
- Wide range of electrical connections
- RFI protected to CE Heavy Industrial standard
- ATEX Intrinsically Safe versions available

The PTX 7500 series combines modular design with the latest advances in ASIC technology and surface mounted electronics. This provides a lightweight and cost effective solution for a range of industrial pressure measurement applications.

At the heart of the transmitter is Druck's own piezo-resistive silicon sensor. This technology is extensively qualified and proven, for example in aerospace and subsea programmes which demand the highest levels of performance and long term reliability.

The sensor features a Hastelloy isolation diaphragm and is enclosed in an electron beam welded stainless steel body. This rugged construction ensures full compatibility with a wide range of pressure media and operating conditions.

On-site trimming of the transmitter output is via non-interactive potentiometers readily located within the electrical connector. The PTX 7500 series also offers excellent RFI immunity, meeting the highest level of CE marking requirements for heavy industrial use.

PTX 7500 Series

Industrial Pressure Transmitters

Druck

STANDARD SPECIFICATIONS

Pressure Measurement

Operating Pressure Ranges
0 to 70, 100, 160, 250, 500mbar, 1, 2, 3.5, 7, 10, 20, 35, 70 bar gauge and absolute.
0 to 140, 200, 350, 700 bar sealed gauge and absolute. *Note: Any pressure unit and span can be specified between 70mbar and 700 bar F.S. including compound, offset and barometric ranges.*

Overpressure
The operating pressure range can be exceeded as below without degrading performance:
12 x for ranges up to 100mbar
8 x for 160mbar range
6 x for ranges from 250 to 500mbar
4 x for 1 and 2 bar ranges
3 x for 3.5 to 140 bar ranges (200 bar max)
2 x for 140 to 700 bar ranges

Pressure Containment
Gauge ranges:
16 x for ranges up to 100mbar
12 x for 160mbar range
8 x for ranges from 250 to to 500mbar
6 x for 1 and 2 bar ranges
4 x for 3.5 to 70 bar ranges (250 bar max.)
Absolute and Sealed Gauge ranges:
250 bar for ranges 100 mbar to 140 bar
1000 bar for ranges 200 bar to 700 bar

Pressure Media
Fluids compatible with 316L stainless steel and Hastelloy C276. (NACE compatible grades).

Supply Voltage
9 to 30V at PTX terminals. (IS units 9 to 28V).
Maximum load (Ω) = 50 x (Supply Voltage -9).

Supply Sensitivity
0.005% F.S./Volt.

Insulation Resistance
>10MΩ @ 500 Vd.c. (@ 20°C).

Surge Protection
Ranges up to 140 bar: withstands 2kV spike.
Ranges above 140 bar: withstands 1kV spike.
Spike test conforms to EN61000-4-4 and EN61000-4-5.

Output Current
4 - 20mA (2-wire) proportional for zero to full scale pressure.

Performance

Accuracy
Combined Non-linearity, Hysteresis, Repeatability.
Terminal definition: the output will not deviate from a straight line connecting zero and full scale output by more than 0.15% typical (0.3% max.).
Best Straight Line: ±0.1% F.S. typical (±0.2% max.).

Zero Offset and Span Setting
Factory set ±0.05mA. Further nominal ±5% site adjustment via non-interacting potentiometers.
N.B. Adjustment not available with PTX 7533.

Long Term Stability
At standard reference conditions the calibration will not change by more than 0.1% F.S. per year.

Operating Temperature Range
-40 to 100°C (80°C max. for PTX 7511/7533).

Temperature Effects
For ranges of 500mbar and above the output will not deviate from room temperature calibration by more than:-
0.7% F.S. typical (1% F.S. max.) over - 10° to 50°C
1.5% F.S. typical (2% F.S. max.) over - 20° to 80°C
For ranges below 500mbar, these values will increase pro-rata with span.

Time Response
1msec time constant (63% response to step change in pressure).

Start-up Time
500msec max. at power up. For pulse power applications please refer to Druck.

Physical

Pressure Connection
G$^1/_4$ female. *Optional adaptors available.*

Electrical Connection
1m integral cable (longer lengths available), 6 pin bayonet plug, DIN 43650A plug/socket or M20 female conduit entry. *For gauge ranges up to 70 bar, vented cable (P/N 192-004) required.*

Weight
200 grams nominal.

CE Conformity
EMC Emissions: EN50081-1, EN55022
EMC Immunity: EN61000-6-2: 1999
(10V/m Heavy Industrial).

OPTIONS

(A) Intrinsic Safety Approval
BAS 01 ATEX 1254.
EEx ia IIC T4 (-40°C < Tamb < 80°C).
300m max integral cable length (PTX 7511/7533).
Extra cable may be added during installation in accordance with the system certificate (Ex 99E2163).

(B) Screw-in male/male adaptors with bonded seal
G$^1/_4$ male (P/N 190-040).
$^1/_4$ NPT male (P/N 190-038).
$^7/_{16}$ UNF male to MS 33656 (P/N 190-042).
M14 x 1.5 male (P/N 190-036).
G$^1/_2$ (pressure gauge)(P/N 190-039).
All adaptors 316 stainless steel construction.

ORDERING INFORMATION

(1) Select model number:

Code	Model
PTX 75	Base Model

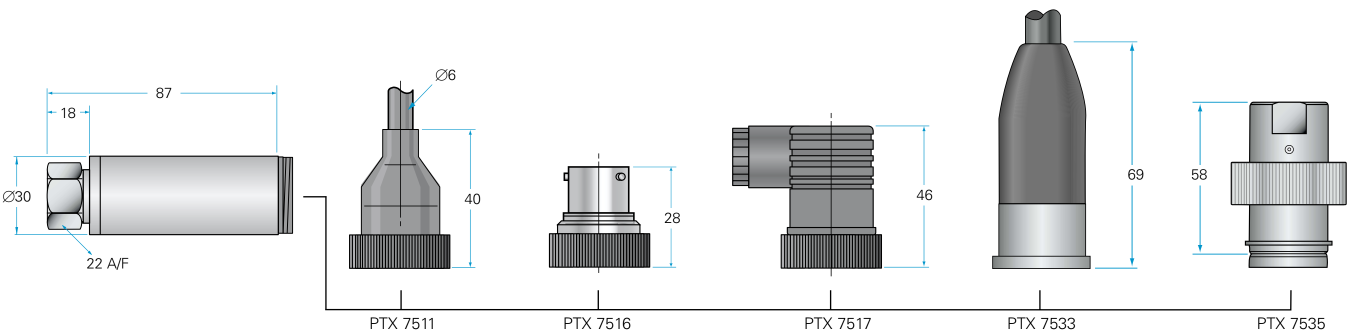
Code	Electrical Connection
11	Integral Cable (IP 65)
16	6 Pin Bayonet (IP 65)
17	DIN 43650A Plug/Socket (IP 65)
33	Integral Cable (IP 67)
35	M20 Female Conduit (IP 65)

PTX 75 11 Typical Model Number

(2) Pressure range/units required.
(3) Options (if required).

Continuing development sometimes necessitates specification changes without notice.

INSTALLATION DRAWINGS - Dimensions in mm



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UKAS CALIBRATION
0221

UKAS QUALITY MANAGEMENT
001

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Internet: www.JumoUSA.com

Thyristor unit for analogue control

mounted on rail to EN 50 022 or wall-mounted

for stock items see price list

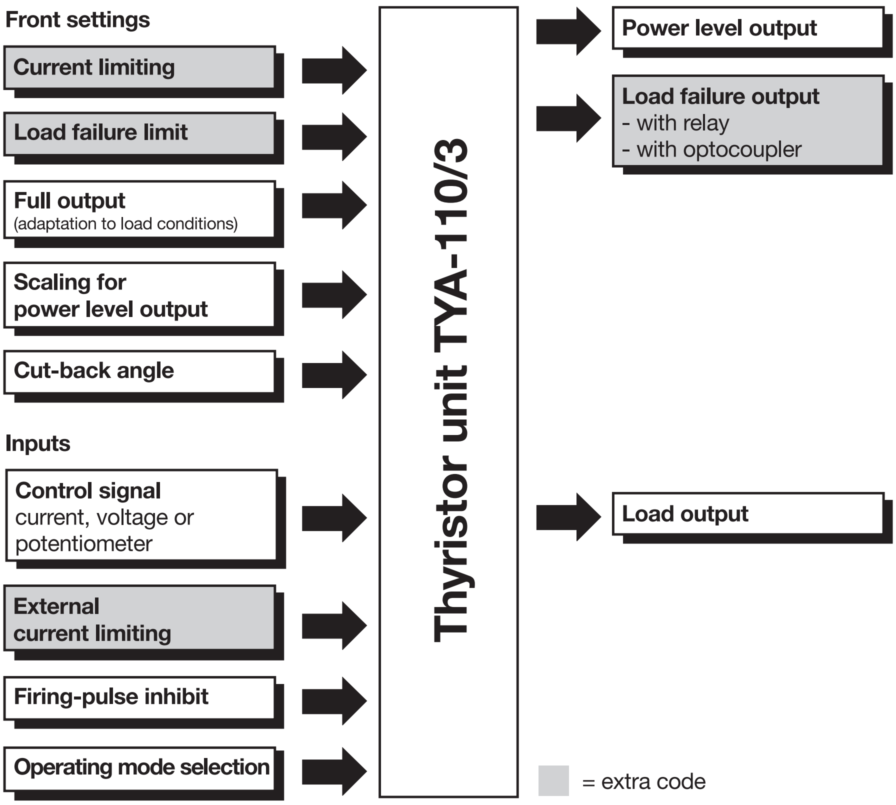
Brief description

Thyristor units are used in all applications where larger resistive and inductive loads have to be switched, for example in industrial furnaces and in plastics processing. The thyristor unit consists of two thyristors connected in inverse parallel, the isolated heat sink and the control electronics. Thyristor units up to 50A load current can either be snapped onto a 35 mm rail or wall-mounted using a mounting plate. Units from 75A load current can only be wall-mounted. Depending on the settings of the internal switches, the thyristor units operate either in phase-angle mode with adjustable current limiting, or in burst-firing mode. In burst-firing operation, the start of the first half-wave can be partly cut back to permit operation on transformer loads. A subsidiary control, which can be selected as U^2, P or I^2, ensures that fluctuations in the supply voltage do not affect the control loop during the process. The control range can be restricted by attenuating the input signal, and a base load can be set using an external potentiometer. An economy circuit can be used on multi-phase loads in burst-firing operation. In phase-angle operation, the phase angle set by the controller is approached slowly, starting from 180 degrees, in order to avoid high inrush currents (soft start). The thyristor units conform to VDE 0160 5.5.1.3 (5/88) and VDE 0106 Part 100 (3/83). The unit has to be grounded in accordance with the requirements of the local power supply authority.

Type TYA-110/3,

Type TYA-110/3, 150…250, …

Block structure



- **input for voltage, current and potentiometer**
- **input signal can be freely selected**
- **freely selectable operating mode (phase-angle/burst-firing operation)**
- **adjustable cut-back of first half-wave in burst-firing operation**
- **supply voltage monitoring**
- **input signal attenuation**
- **soft start in phase-angle operation**
- **U^2 control with adjustable process value output**
- **master-slave economy circuit**
- **firing-pulse inhibit**
- **recognition of part-load failure for economy circuit**

Technical data

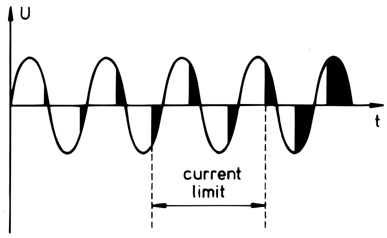
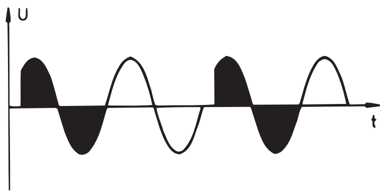
Load circuit

Nominal load voltage	24V -20%/+15% AC 45 — 63Hz 42V -20%/+15% AC 45 — 63Hz 115V -20%/+15% AC 45 — 63Hz 230V -20%/+15% AC 45 — 63Hz 265V -20%/+15% AC 45 — 63Hz 400V -20%/+15% AC 45 — 63Hz 460V -20%/+15% AC 45 — 63Hz 500V -20%/+15% AC 45 — 63Hz (control voltage = nominal load voltage)
Continuous load current I_L	25A, 50A, 75A, 100A, 150A, 250A
Load types	resistive and resistive-inductive loads (B 1.2Tesla max.)
Current limiting	in phase-angle operation, the load current can be set by a trimmer at the front within the range 10 — 100% I_N. The limitation is based on the rms value of the load current.
Fuse	super-fast semiconductor fuse
TSE circuit	RC network as standard
Power loss	1.3V x I_{load} (A) approx.
Control accuracy	supply voltage fluctuations within the tolerance range (-20%/+15%) are accurately compensated. Fluctuations 0.5% max.

Control

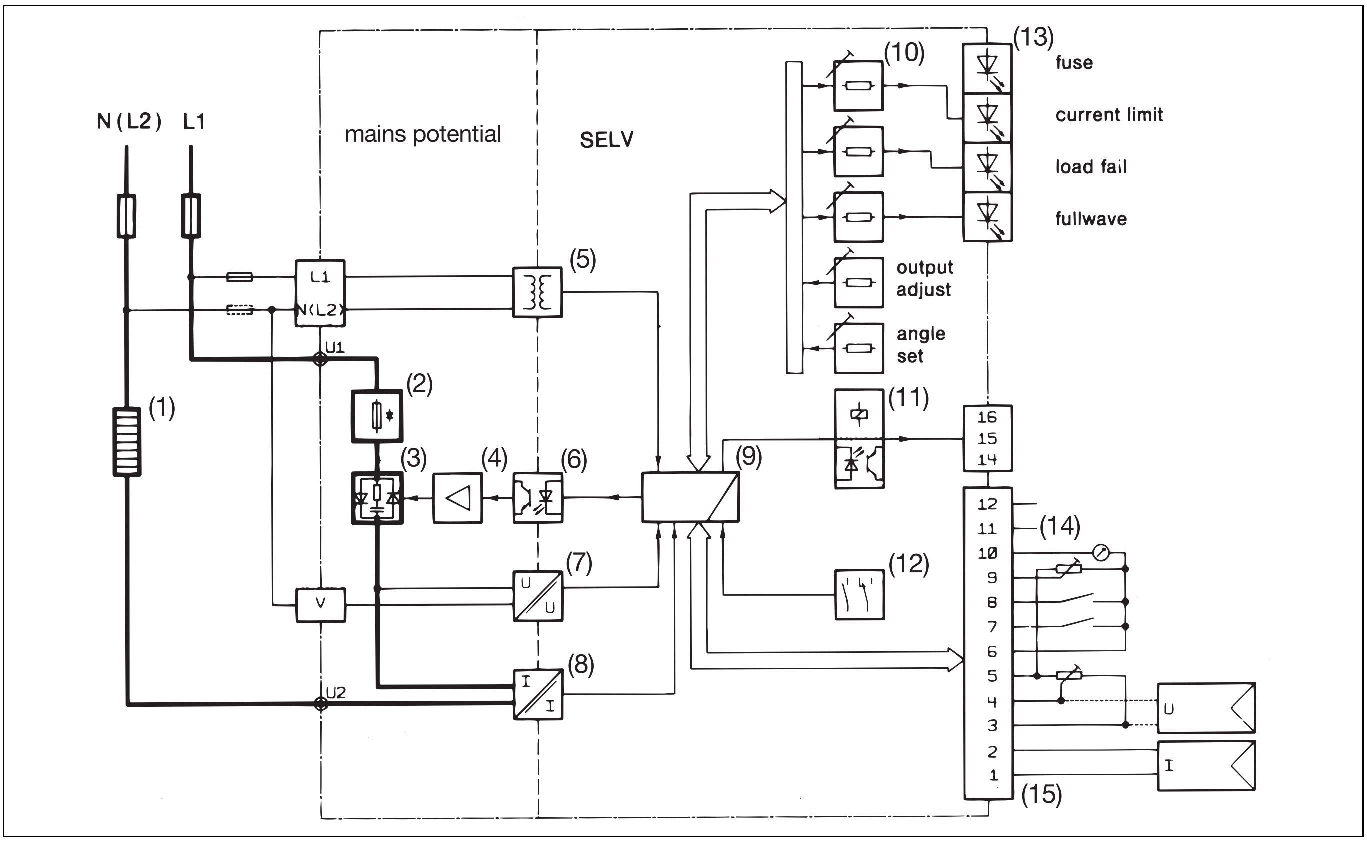
Control signal	0 (4) — 20mA $R_I = 50\ \Omega$ 0 (2) — 10V $R_I = 25k\Omega$ 0 (1) — 5V $R_I = 12k\Omega$ 0/10V (0/5V) $R_I = 12k\Omega$ 0/20mA $R_I = 50\Omega$ floating contact or manual control from an external 5 kΩ potentiometer
Input signal attenuation	adjustment range 100 — 20%

General data

Circuit variants	- single-phase operation - star circuit with accessible star point - open delta circuit - economy circuit with master-slave principle and subsidiary U^2 control in burst-firing operation - free-running economy circuit (star or delta), only with subsidiary P control in burst-firing operation
Operating modes	- phase-angle operation for resistive and transformer loads with soft start (with extra code TR, TO with current limiting)  - burst-firing operation for resistive or transformer load. 

Features	Two single-phase units can be linked into an economy circuit in burst-firing operation - free-running economy circuit for resistive loads - master-slave economy circuit for resistive and transformer loads
Subsidiary controls	U^2 control as standard. With extra code TR or TO: free choice between U^2, P, I^2 control via internal switches.
Power level output	U^2 signal as standard. With extra code TR or TO: free choice between U^2, P, or I^2 signal via internal switches, adjustable 0 — 5V to 0 — 10V. $I_{max} \approx 2$ mA.
Electrical connection	Control wiring by screw terminals for conductor cross-sections 0.2 — 2.5 mm^2. Load connections by cable lugs to DIN 46 212.
Protection	IP00 to EN 60 529, grounded heatsink
Permitted ambient temperature range	0 — 45°C Permitted current reduced by 2% for each °C increase in ambient temperature; the maximum permissible ambient temperature must not exceed 60°C.
Permitted storage temperature range	-10 to +70°C
Climatic conditions	rel. humidity 75% max. annual mean, no condensation
Cooling	by natural convection
Operating position	vertical
Operating conditions	The thyristor unit is designed as a built-in unit to: VDE 0160 5.5.1.3 (5/88) VDE 0106 Part 100 (3/83) pollution degree 2 to VDE 0110 Part 1 4.2 (1/89) overvoltage category U III to VDE 0160 5.7 (5/88)
Test voltage	to VDE 0160 Table 4 (5/88)
Creepage distance	control electronics to load circuit 10mm min. control electronics to housing 10mm min. Unit can be connected to SELV circuits. SELV = Separate Extra Low Voltage
Housing	TYA110/3, 25 (50) 110 x 195 x 152mm TYA110/3, 75 (100) 125 x 195 x 170mm TYA110/3, 150 (250) 150 x 220 x 280mm
Weight	TYA110/3, 25 (50) 2.8 kg TYA110/3, 75 (100) 3.7 kg TYA110/3, 150 8.6 kg TYA110/3 250 9.0 kg
Standard accessories	1 mounting plate for wall-mounting 1 Operating Instructions B 70.9040

Block diagram



Description of the blocks

(1) load

(2) super-fast semiconductor fuse

(3) thyristor module with RC protection circuit

(4) driver stage for thyristor module

(5) supply voltage for control electronics

(6) optocoupler

(7) voltage transformer

(8) current transformer

(9) control electronics

(10) front trimmers

(11) fault-report output via relay or optocoupler

(12) configuration switches

(13) message LED

(14) master-slave links

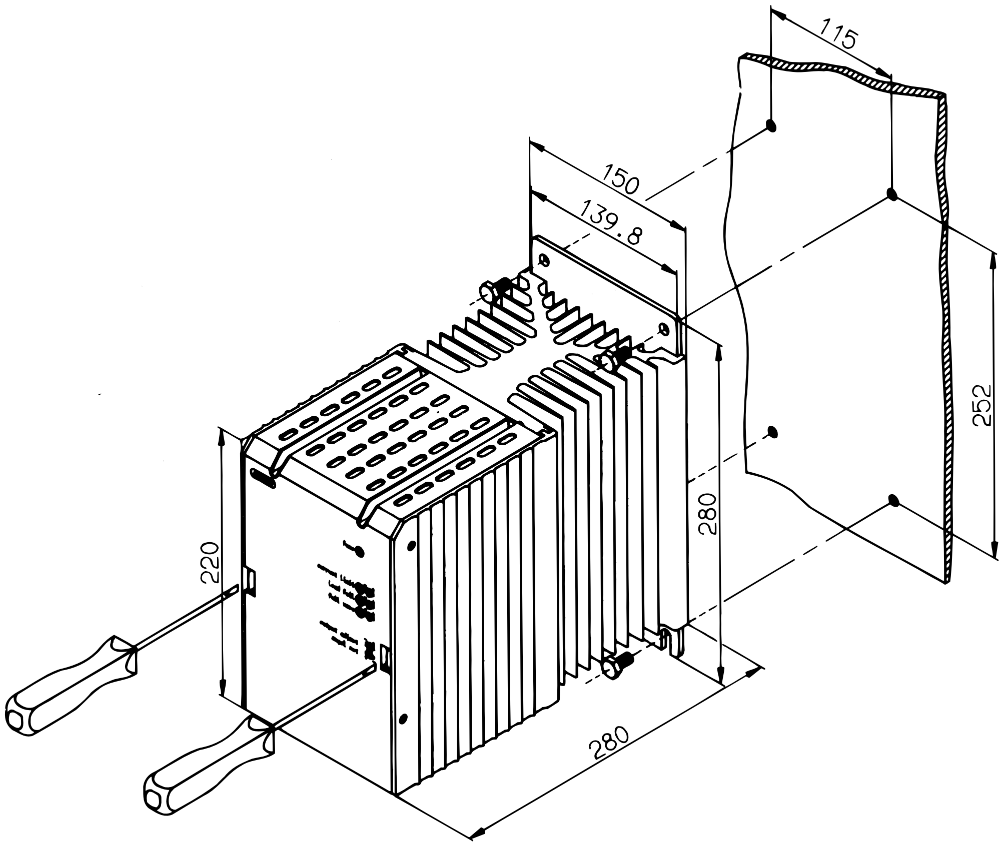
(15) output control, control inputs, power level output

Description of function

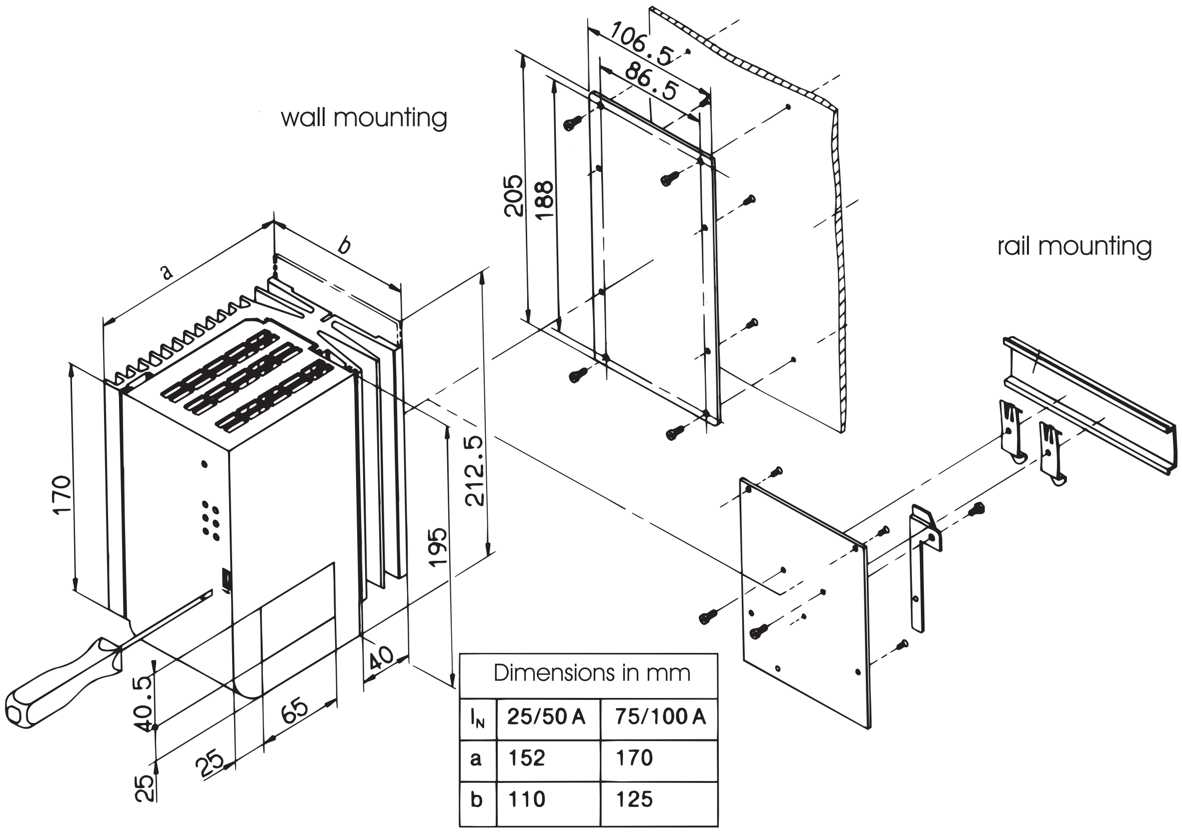
From the control electronics (9), the firing pulses for the thyristors (3) pass through an optocoupler (6). The different operating and load types can be set by internal switches (12). Load current and voltage are sensed by the transformers (7) and (8), to provide subsidiary U^2, I^2 or P control.
Numerous monitoring functions (10) or (13) and a fault-report output (11) via relay or optocoupler are available. The fault-report output indicates load and part-load failure, as well as a blown fuse. The transformer (5) provides the supply for the control electronics.

Dimensions/mounting

Wall mounting for 150/250-A thyristor unit

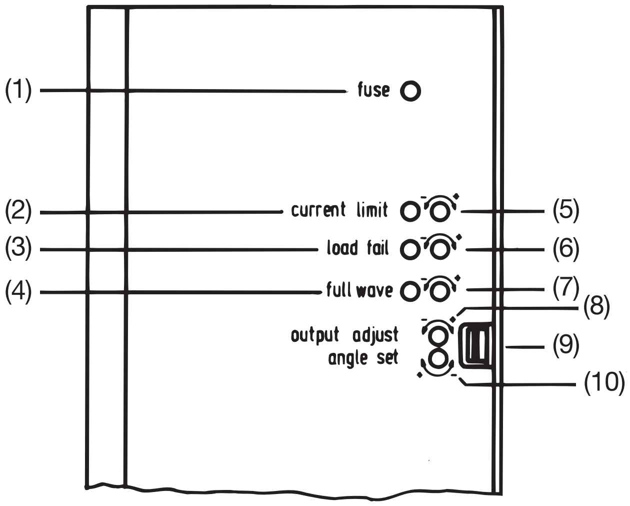


Mounting on rail to EN 50 022, or wall mounting for thyristor units up to 100 A



Dimensions in mm		
I_N	25/50 A	75/100 A
a	152	170
b	110	125

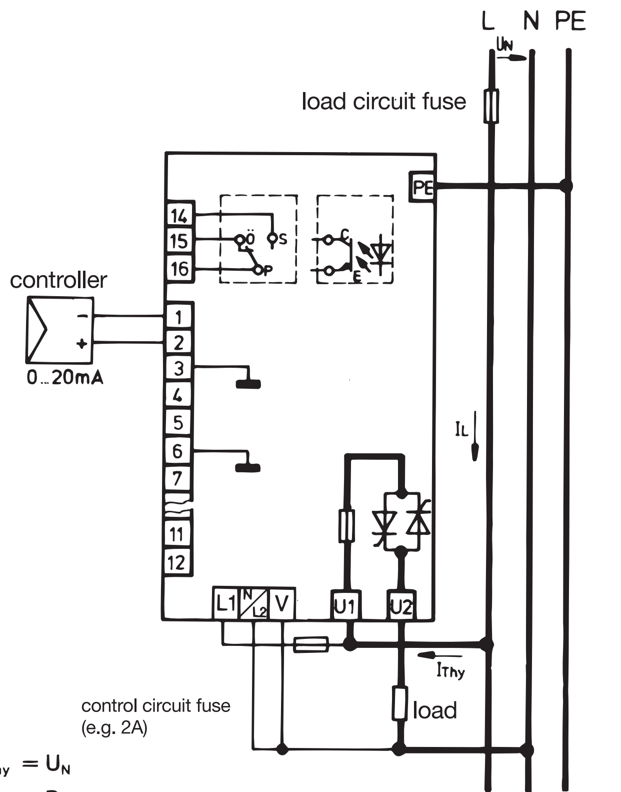
Front view



(1) indicator LED for blown semiconductor fuse
(2) current limit indication LED
(3) load failure indication LED
(4) full output indication LED
(5) current limit adjustment for phase-angle operation (with extra code TO or TR)
(6) response threshold adjustment for part-load failure indication (for extra codes TO or TR)
(7) adjustment for full output
(8) adjustment of power level signal
(9) release clip for removing the cover
(10) adjustment of the cut-back angle for first half-wave in burst-firing operation

Circuit diagrams

Single-phase operation Phase/N

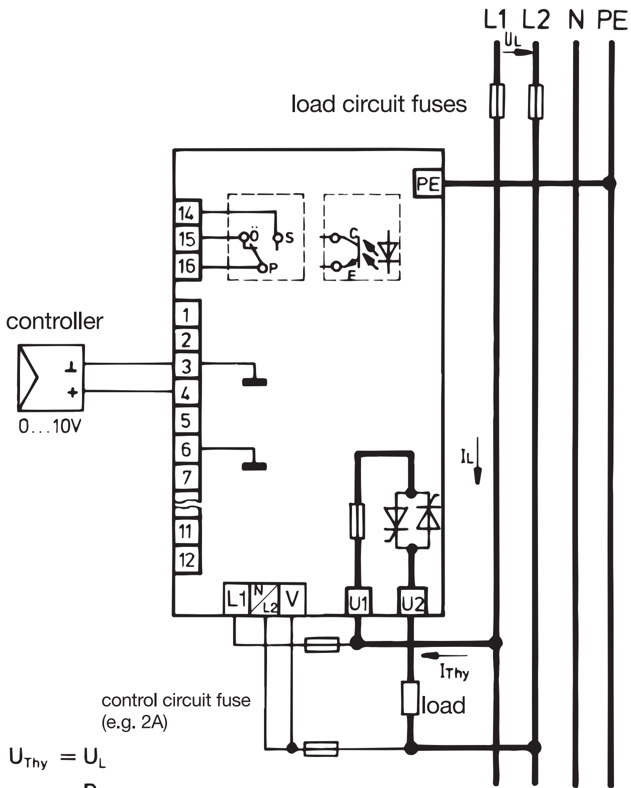


$U_{Thy} = U_N$

$I_{Thy} = \frac{P_{tot}}{U_N}$

$I_{Thy} = I_L$

Single-phase operation Phase/Phase



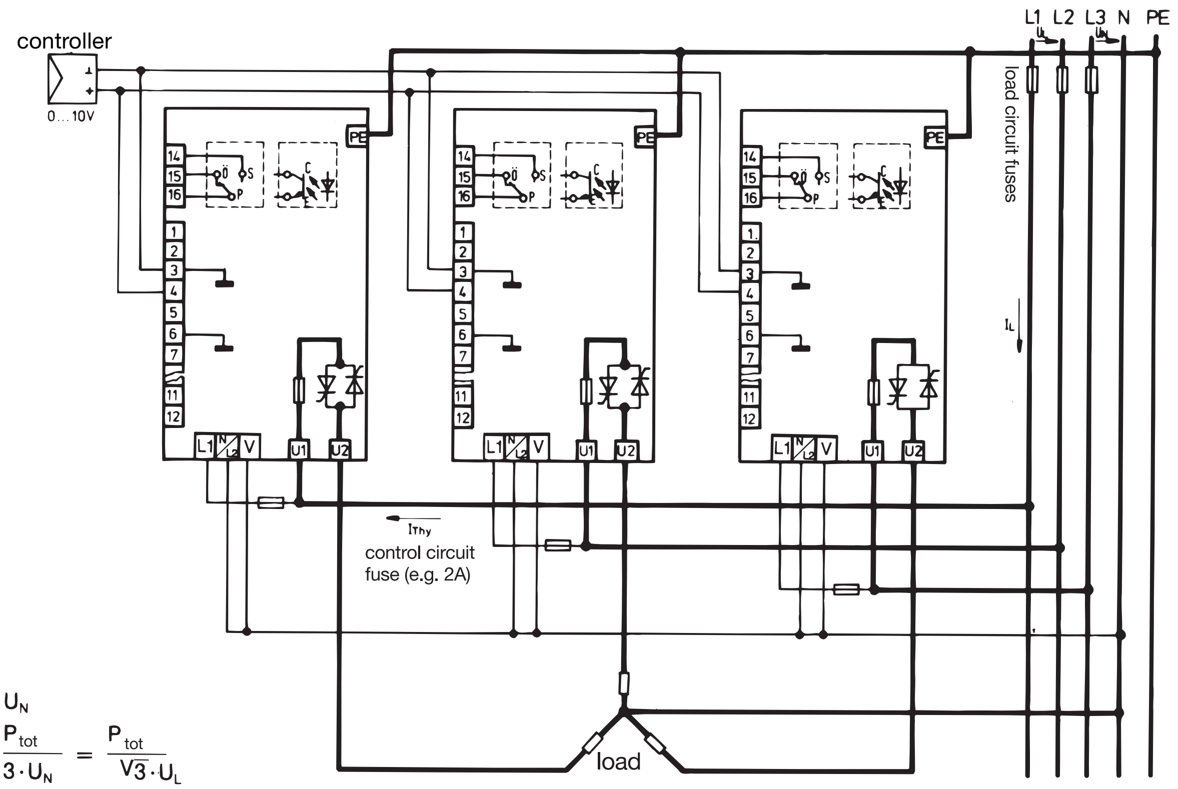
$U_{Thy} = U_L$

$I_{Thy} = \frac{P_{tot}}{U_L}$

$I_{Thy} = I_L$

Circuit diagrams

Star circuit with accessible star point (Mp)

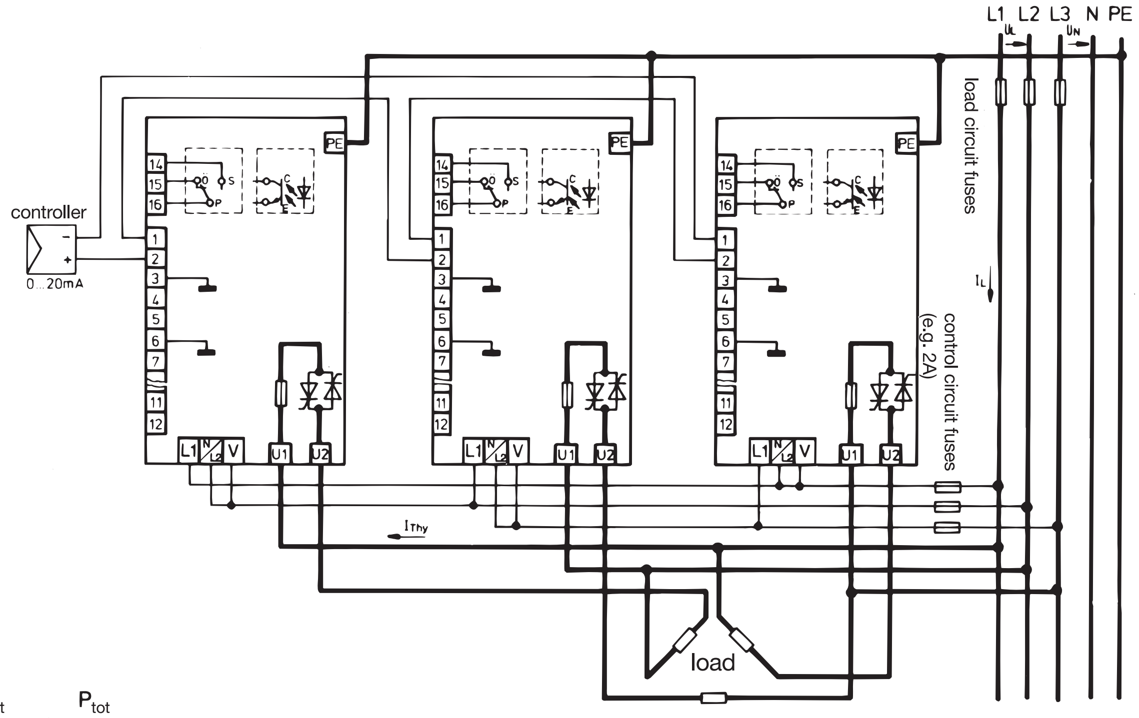


$U_{Thy} = U_N$

$I_{Thy} = \frac{P_{tot}}{3 \cdot U_N} = \frac{P_{tot}}{\sqrt{3} \cdot U_L}$

$I_{Thy} = I_L$

Open delta circuit (6-wire circuit)



$U_{Thy} = U_L$

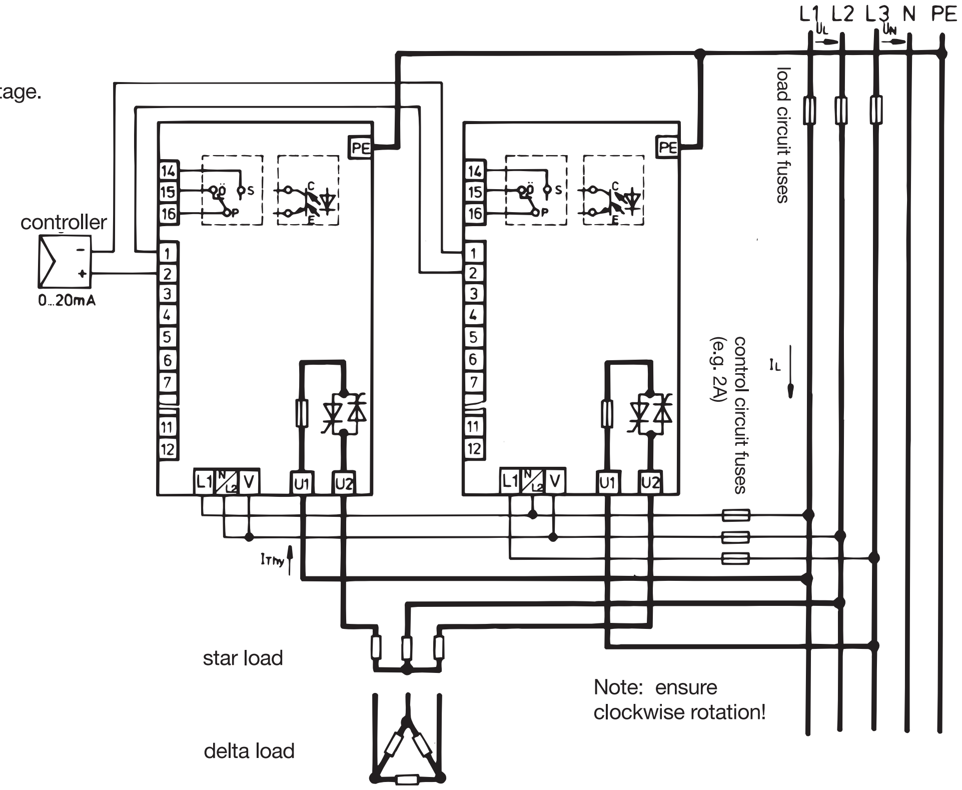
$I_{Thy} = \frac{P_{tot}}{3 \cdot U_L} = \frac{P_{tot}}{3 \cdot \sqrt{3} \cdot U_N}$

$I_{Thy} = \frac{I_L}{\sqrt{3}}$

Circuit diagrams

Free-running economy circuit with purely resistive loads, star or delta (only in burst-firing mode)

NOTE!
Ensure clockwise rotation.
The thyristor units must be
rated for the phase-phase voltage.



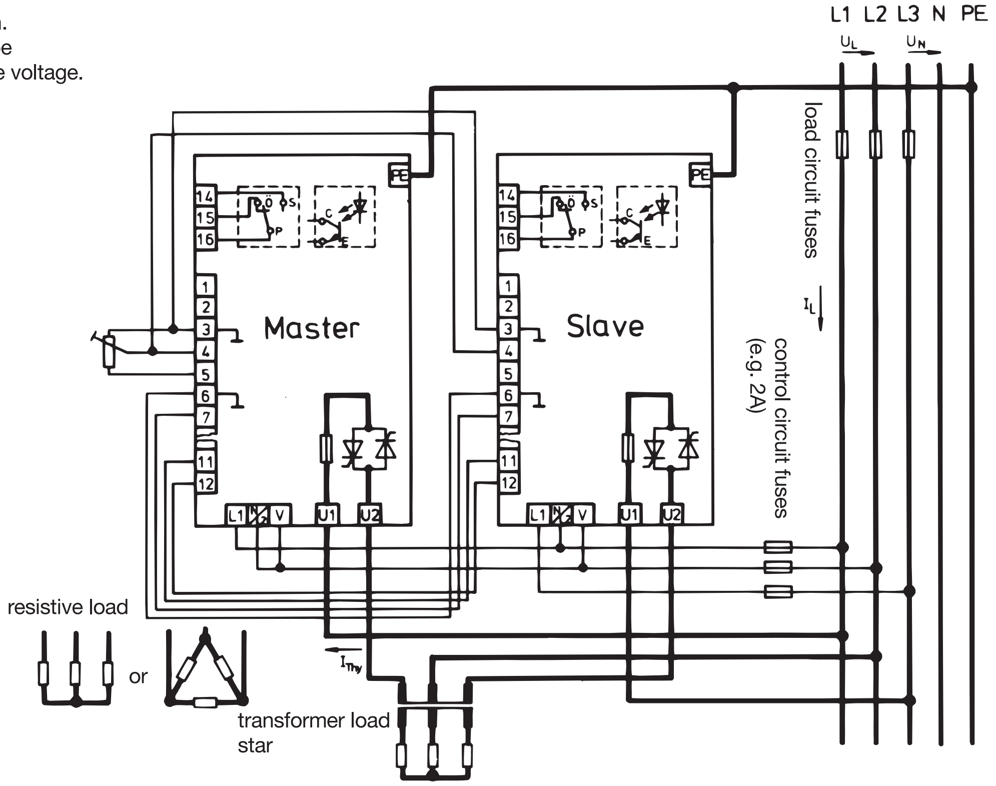
$U_{Thy} = U_L$

$$I_{Thy} = \frac{P_{tot}}{3 \cdot U_N} = \frac{P_{tot}}{\sqrt{3} \cdot U_L}$$

$I_{Thy} = I_L$

Master-slave economy circuit with resistive-inductive loads, star or delta (only for burst-firing mode)

NOTE!
Ensure clockwise rotation.
The thyristor units must be
rated for the phase-phase voltage.



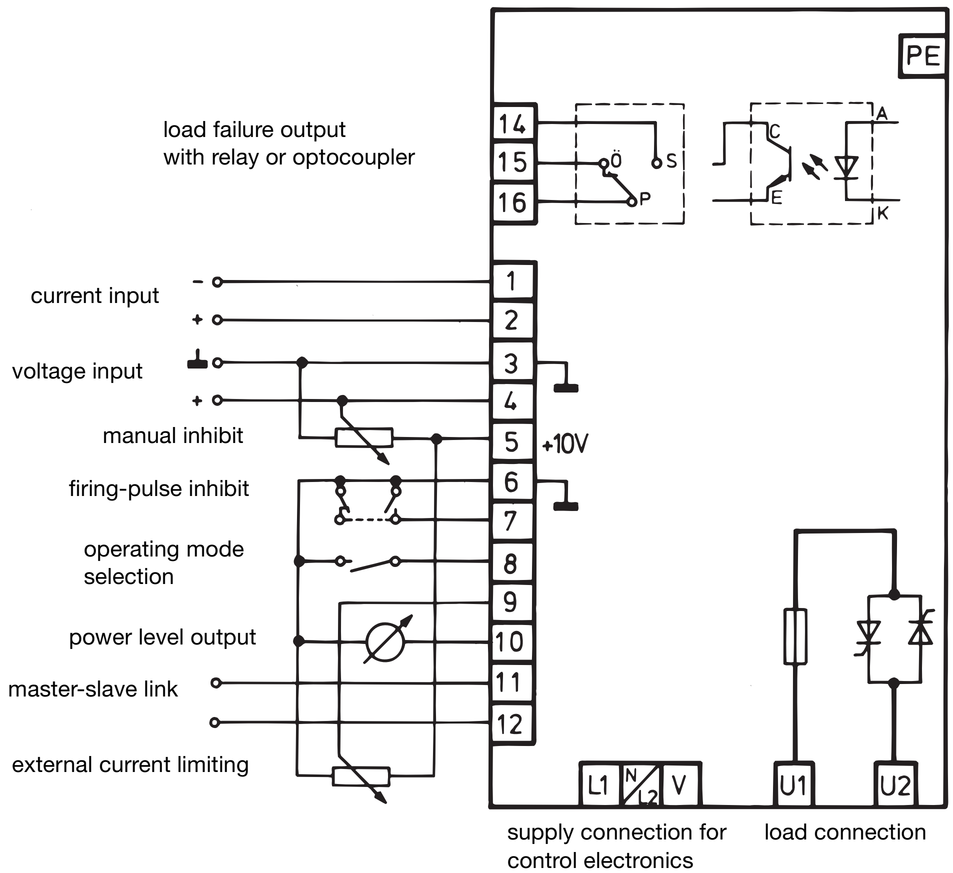
$U_{Thy} = U_L$

$$I_{Thy} = \frac{P_{tot}}{3 \cdot U_N} = \frac{P_{tot}}{\sqrt{3} \cdot U_L}$$

$I_{Thy} = I_L$

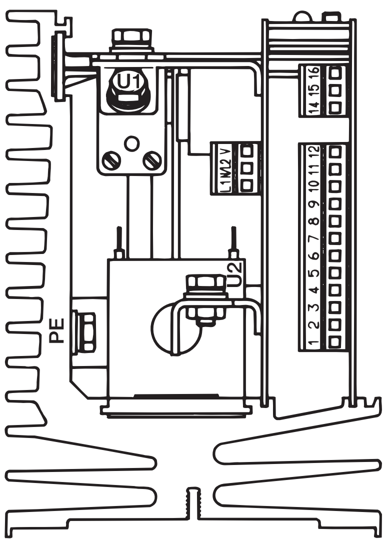
Circuit diagrams

Connection diagram

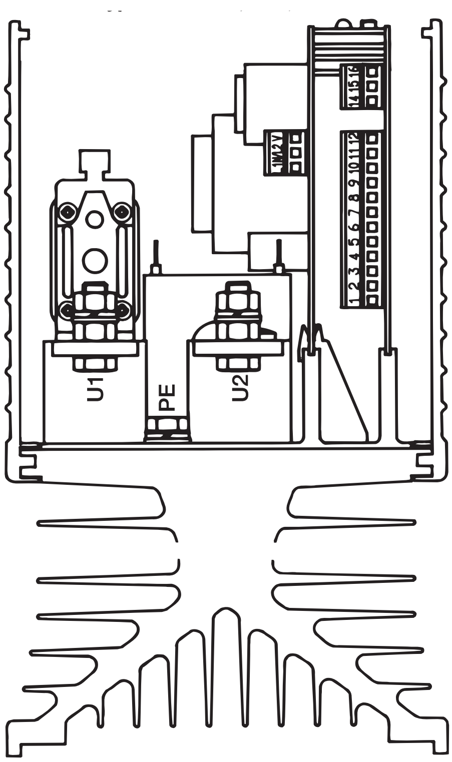


Connection diagrams

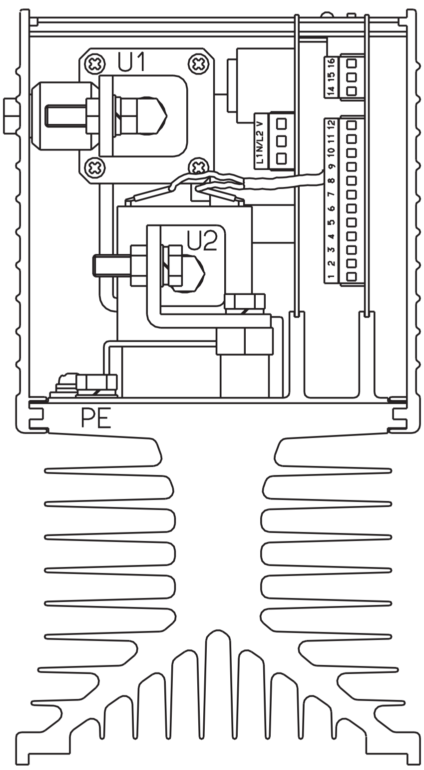
Type TYA-110/3, 025 ... 100, ...



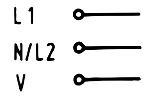
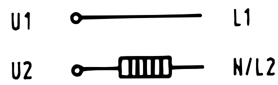
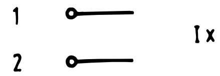
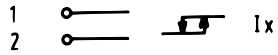
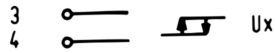
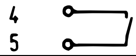
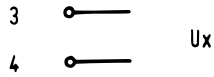
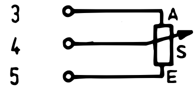
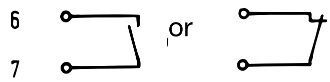
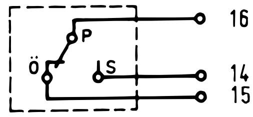
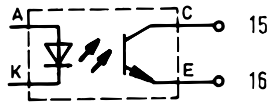
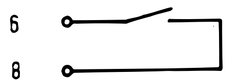
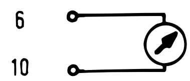
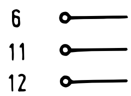
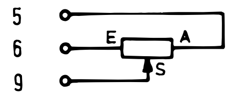
Type TYA-110/3, 150, ...



Type TYA-110/3, 250, ...



Connection diagram

Connection for		Terminals	Symbol
Supply for control electronics; link terminal V with N/L2 (except for economy circuit)		L1 N/L2 V	
Load connection		U1 U2	
Current input (differential input)		1- 2+	
Logic input	current signal	1- 2+	
	voltage signal	3⊥ 4+	
	floating contact	4+ 5 (+10V, 2mA)	
Voltage input (referred to ground)		3⊥ 4+	
External manual adjustment with 5 kΩ potentiometer (via voltage input)		3 start (⊥) 4 slider 5 end (+10V, 2mA)	
Firing-pulse inhibit (inhibit input) $I_K \approx 1\,mA$ (n.c. or n.o.)		6⊥ 7+	
Load failure output with relay rating 5A 230V AC resistive load relay de-energised on fault		14 n.o. (make) 15 n.c. (break) 16 common	
Load failure output with optocoupler $I_{Cmax.} = 2\,mA$ $U_{CEO\ max.} = 32V$		15 collector 16 emitter	
External changeover of operating mode (phase-angle or burst-firing mode)		6⊥ 8+	
Power level output 0 — 10V $I_{max} \approx 2\,mA$		6⊥ 10+	
Master-slave link for master-slave economy circuit		6⊥ 11 12	
External current limiting with 5 kΩ potentiometer		5 start (+10V, 2mA) 6 end (⊥) 9 slider	

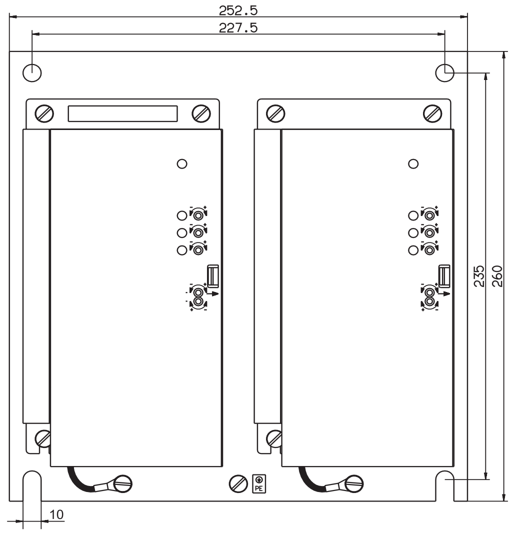
Suitable operating and control modes for different loads

Extra code TR, TO required	Operating mode	Load type Temperature coefficient of load			
		constant $R_{warm} = R_{cold}$	positive $R_{warm} > R_{cold}$	negative $R_{warm} < R_{cold}$	long-term ageing
non	phase-angle operation	X	-	-	-
yes	phase-angle operation with current limiting	-	X	X	X
no	burst-firing operation	X	-	-	-
no	burst-firing operation with initial phase-angle cut-back	X	-	-	-
yes	burst-firing operation with initial phase-angle cut-back and current limiting	-	X	X	X
	Control mode				
no	subsidiary U^2 control	X	X	-	-
yes	subsidiary I^2 control	-	-	X	-
yes	subsidiary P control	-	-	-	X

X = suitable- = not suitable

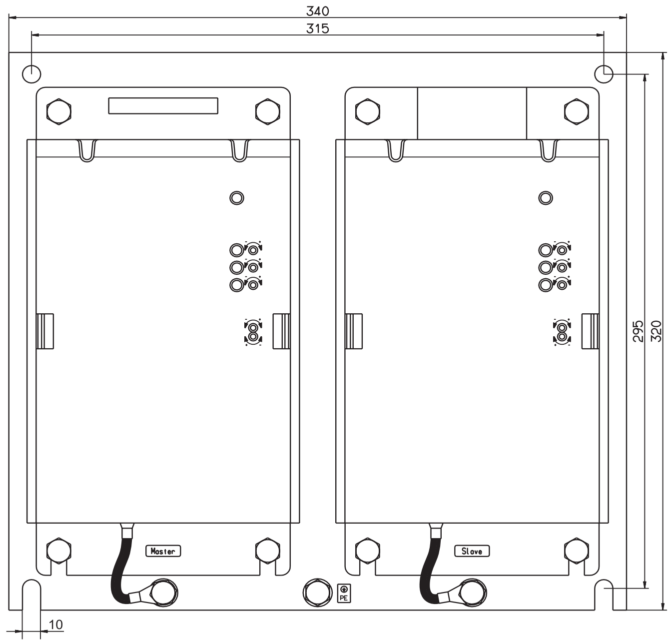
Extra code MS (master-slave circuit)

Type TYA-110/3, 025…100, …, MS…



Mounting plate thickness: 5mm
Units are wired up.

Type TYA-110/3, 150…250, …, MS…



Mounting plate thickness: 10mm
Units are wired up.

Ordering details

Type code **TYA-110/3,** [. . .] (1) , [. . .] (2) - [. .] (3) , ...*

* list extra codes in sequence, separated by commas.

(1) Load current	**025**	=	load current 25A
	050	=	load current 50A
	075	=	load current 75A
	100	=	load current 100A
	150	=	load current 150A
	250	=	load current 250A
(2) Rated load voltage	**024**	=	rated load voltage 24V
	042	=	rated load voltage 42V
	115	=	rated load voltage 115V
	230	=	rated load voltage 230V
	265	=	rated load voltage 265V
	400	=	rated load voltage 400V
	460	=	rated load voltage 460V
	500	=	rated load voltage 500V
(3) Extra codes	**TR**	=	expanded version with indication of part-load break (adjustable by trimmers) and blown fuse via a common relay contact and LED. This version also includes: - current limiting (internal, external) - rated current adjustment at $I \leq I_N/2$ - free selection of subsidiary control (U^2, P or I^2); permits free-running economy circuit with P control - power level output can be switched to U^2, P or I^2 signal
	TO	=	as TR, but message via optocoupler
	MS	=	master-slave circuit on mounting plate, prepared and ready for connection

Accessories

Assembly kit for rail mounting at 25A and 50A load current Order No. 70/00067312	
Super-fast semiconductor fuses for protecting thyristors against short-circuits (no line fuses)	
32A for I_N = 25A Order No. 70/00068009	160A for I_N = 100A Order No. 70/00081801
80A for I_N = 50A Order No. 70/00068011	350A for I_N = 150A Order No. 70/00083318
125A for I_N = 75A Order No. 70/00081800	550A for I_N = 250A Order No. 70/00371964

Datascan Reed Relay
Analog Input Module
7027

General Description

The Datascan is a series of intelligent distributed input output modules designed for real time measurement, data collection and communication. Ideal for factory industrial and scientific applications. The Datascan series includes intelligent Measurement Processors and various types of input modules for channel expansion, in all 26 modules for differing I/O requirements. The 7027 is a reed relay analog input module providing up to 200 volts isolation, and can be used with the 7010 series of measurement processor.

Main Features

- Direct Sensor connection for DC voltages, thermocouple and 4-20 mA converters
- In built Cold Junction compensation
- I6 bit measurement performance with 0.625µV sensitivity
- High Common Mode and Series Mode rejection
- Reed Relay differential inputs
- Plug in Screw terminal blocks
- Fully Isolated to 200 volts channel to channel, channel to ground.
- Channel mix and match capability
- Local measurement speed up to 40 readings/sec 1000/sec over the network
- Individual channel programming of sensor type and speed
- Digital configuration permitting mix and match of analog and digital inputs
- Compact Rugged DIN rail mounted

The **Datascan** series is designed to provide a simple reliable accurate and cost effective means of connecting plant sensors to standard computers for real time monitoring and data acquisition. The Datascan can be used universally with any type of computer as the data interface is by means of a standard serial port.

The **Datascan** series can be configured in local clusters of channels or alternatively as part of a total distributed network. Datascan can support up to 256 channels of local inputs or outputs using the units local expansion bus. Alternatively it can become part of a distributed network of up to 1000 channels spanning a distance of up to 4 Km (15000 ft).

Specification

The 7027 is a reed relay analog input expansion scanner and signal conditioning unit for the 7010. The 7027 is a 16 channel unit providing 200 volts isolation.

Model Type	No of Inputs	Sensor Types	Resolution	Input Impedance
7027	**16** (3 pole)	DC Voltage, Thermocouple, 4-20 mA	16 bits @ 40 rdgs/sec	1M ohm

The unit provides direct sensor connection for thermocouples DC voltages, 4-20 mA inputs and current. Internal cold junction compensation and linearisation provides direct measurement in degrees C and degrees F.

Sensor	Range	16 bit	14 bit	Accuracy
DC voltage	10 V	320 µV	1.28 mV	+/-0.02%rdg+0.01%range+2bit
	1.3V	40 µV	160 µV	+/-0.02%rdg+0.01%range+2bit
	150mV	5 µV	20 µV	+/-0.02%rdg+0.01%range+2bit
	20mV	0.625µV	2 .5 µV	+/-0.02%rdg+0.01%range+10µV
	Auto			

Calibration period 12 months. Calibration temperature 20°C. All quoted errors are worst case.

Temperature coeff <30 ppm / °C (CJC Error 0.5 °C)

Each channel can be individually programmed for specific sensors and measurement range.

The high performance 16 bit ADC (Analog to digital converters) offers sensitivities as high as 0.625 µV.

Channels can be mixed and matched under software control.

A facility is provided to configure analog channels as digital inputs.

The integrating technique of conversion provides very high immunity to mains borne noise.

Wide range of supporting software

Sensor Type Thermocouple	Ranges	Sensitivity (16 bit resolution)	Limits of Error
K Type	-100 to 500 °C	0.02 °C	0.4 °C
	500 to 1200 °C	0.20 °C	0.7 °C
	1200 to 1600 °C	0.20 °C	4.5 °C
J Type	-50 to 360 °C	0.02 °C	0.4 °C
	360 to 800 °C	0.20 °C	0.6 °C
N Type	-200 to -100 °C	0.10 °C	0.8 °C
	-100 to 580 °C	0.05 °C	0.6 °C
	580 to 1300 °C	0.10 °C	0.8 °C
T Type	-150 to 400 °C	0.02 °C	0.4 °C
R Type	0 to 1600 °C	0.10 °C	1.8 °C
S Type	0 to 1700 °C	0.10 °C	2.0 °C
E Type	-50 to 290 °C	0.02 °C	0.4 °C
	290 to 1000 °C	0.10 °C	0.9 °C
B Type	200 to 1600 °C	0.50 °C	4.5 °C
4-20 mA	4-20 mA		+/-0.15%

Number of 7027's per network : 64
Number of 7027's per 7010 : 8

Other Details

Overload Protection
+/- 100 V continuous

Common mode range (channel to channel)	+/- 200 V peak
Common mode range (channel to ground)	+/- 200 V peak
DC Common mode rejection	110 dB 100R unbalance
AC Common mode rejection	140 dB 100R unbalance
AC Series mode rejection	60 dB @ 50 or 60 Hz +/-0.1%

Connection to 7010 :
26 way PLEB connector

Power	Dimensions	Weight	Op temp	Humidity
200 mW typ 300 mW max	W 178 mm H 123 mm D 80 mm	1 Kg	-20 to 50°C storage -20 to 80°C	RH 90% Non-Condensing

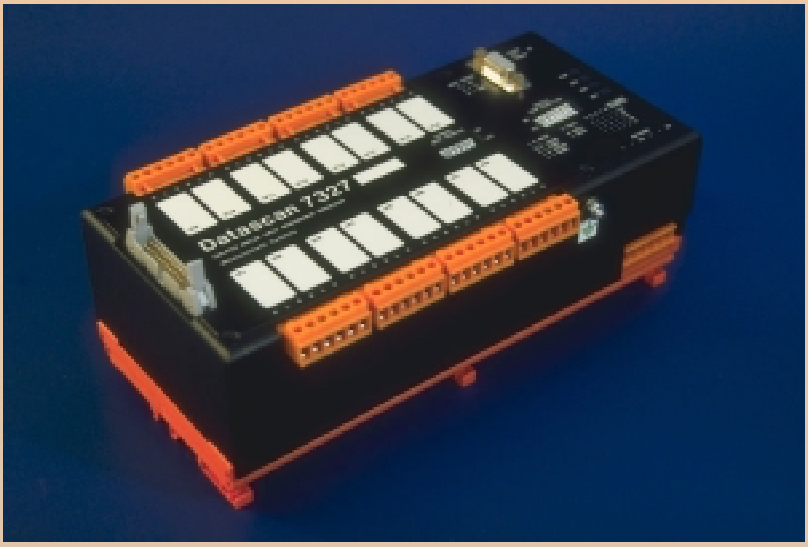
Your Local Distributor

Click Here to see our List of Distributors

Datascan Technology
7B Faraday Road
Newbury
Berkshire
RG14 2AD UK
Tele: +44 (0)1635 551222
Fax : +44 (0)1635 551677

Issue3.2 5/96

Datascan 7327
Reed Relay
Measurement Processor
Module



Main Features

- Direct Sensor connection for DC Voltages, thermocouples and 4-20mA converters
- In built Cold Junction compensation
- 16 bit measurement performance with 0.625uV sensitivity
- Reed relay differential inputs
- **Fully isolated to 200V channel to channel, channel to ground**
- 16 inputs on board expandible locally to 128 channels using 7027 modules
 (1000 over network)
- Individual channel programming of sensor type and speed
- Compact DIN Rail Mounting
- Serial Port and Network port both isolated to 500Vdc

General Description

The Datascan 7000 range is a series of intelligent, distributed input/output modules designed for Real-Time Measurement, Data Collection and communication. Ideal for factory, industrial and scientific applications, the Datascan 7300 series combine the cost saving benefits of Distributed I/O with the flexibility of local channel expansion.

The 7300 series is designed to provide simple, reliable, accurate and cost effective means of connecting plant sensors to standard computers for real time monitoring and data acquisition. The Datascan can be used universally with any type of computer as the data interface by means of a standard serial port.

The 7300 series can be used autonomously or alternatively as part of a total distributed network. Each 7300 can support up to 256 channels of local inputs or outputs using the units local expansion bus. It can also become part of a distributed network of up to 1000 channels over 1.2km. Each 7300 module incorporates a programmable 16 bit ADC, an isolated serial interface, an isolated token passing network interface, on board volatile memory for storing unit configurations and an expansion port for channel extension. The 7327 module has 16 inputs on board. The unit is packaged in a compact DIN Rail mounted carrier making it simple to install.

7327 Technical Specification

Specification	Model Type	No of Inputs	Sensor Types	Resolution	Input Impedance
The 7327 is a reed relay analog input measurement processor. The 7327 is a 16 channel unit providing 200 volts isolation.	**7327**	16 (3 pole)	DC Voltage, Thermocouple, 4-20mA	16 bits @ 40 readings/sec	1M ohm
Internal Cold Junction Compensation and linearisation provides direct	Sensor	Range	16 bit	14 bit	Accuracy
measurement in degrees C and degrees F.	DC Voltage	10V 1.3V 150mV 20mV Auto	320uV 40uV 5uV 0.625uV	1.28mV 160uV 20uV 2.5uV	+/-0.02%rdg+0.01%range+2bit +/-0.02%rdg+0.01%range+2bit +/-0.02%rdg+0.01%range+2bit +/-0.02%rdg+0.01%range+10uV

Calibration Period 12 months. Calibration temperature 20ºC. All quoted erros are worst case.
Temperature coeff <30ppm/ºC (CJC error 0.5ºC)

	Sensor Type Thermocouple	Ranges	Sensitivity 16bit resolution	Limits of Error
Each channel can be individually programmed for specific sensors and measurement range.				
The high performance 16bit ADC offers sensitivities as high as 0.625uV	**K type**	-100 to 500ºC 500 to 1200ºC 1200 to 1600ºC	0.02ºC 0.20ºC 0.20ºC	0.4ºC 0.7ºC 4.5ºC
The integrating technique of conversion provides very high immunity to mains borne noise.	**J type**	-50 to 360ºC 360 to 800ºC	0.02ºC 0.20ºC	0.4ºC 0.6ºC
A facility is provided to configure analog channels as digital inputs.	**N type**	-200 to -100ºC -100 to 580ºC 580 to 1300ºC	0.10ºC 0.05ºC 0.10ºC	0.8ºC 0.6ºC 0.8ºC
Channels can be mixed and matched under software control.	**T type**	-150 to 400ºC	0.02ºC	0.4ºC
Number of 7027's able to be plugged into 7327 module is 7.	**R type**	0 to 1600ºC	0.10ºC	1.8ºC
Software Support	**S type**	0 to 1700ºC	0.10ºC	2.0ºC
Can be used with a wide variety of standard software products available from several third party vendors.	**E type**	-50 to 290ºC 290 to 1000ºC	0.02ºC 0.10ºC	0.4ºC 0.9ºC
Other Details	**B type**	200 to 1600ºC	0.50ºC	4.5ºC
Overload Protection = +/-100V continuous	**4-20mA**	4-20mA		+/- 0.15%

RS232 Interface
Baud rates: 4800, 9600, 19k2, 38k4
Isolation : 500V

Common/Series Mode rejection
DC Common mode : 110dB
AC Common mode : 140dB
AC Series mode : 60dB @ 50 or 60Hz +/- 0.1%

Common Mode range (channel to channel) +/- 200V Peak
Common Mode range (channel to ground) +/- 200V Peak

Network	Power	Dimensions	Weight	Op Temp	Humidity
Electrical Specification : RS485 Media : Twisted Pair					
Max. Network Length : 1.2km Data Rate : 1000 results/sec Isolation : 500Vdc Total Channels per Network : 1000	24Vdc supply <2W @24V consumption	W 230mm H 123mm D 80mm	750g	-10 to 60ºC storage -20 to 80ºC	RH 90% Non-Condensing

Measurement Systems Ltd
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Fax : +44 1635 31023
e-mail : sales@msl-datascan.com
Web : www.msl-datascan.com

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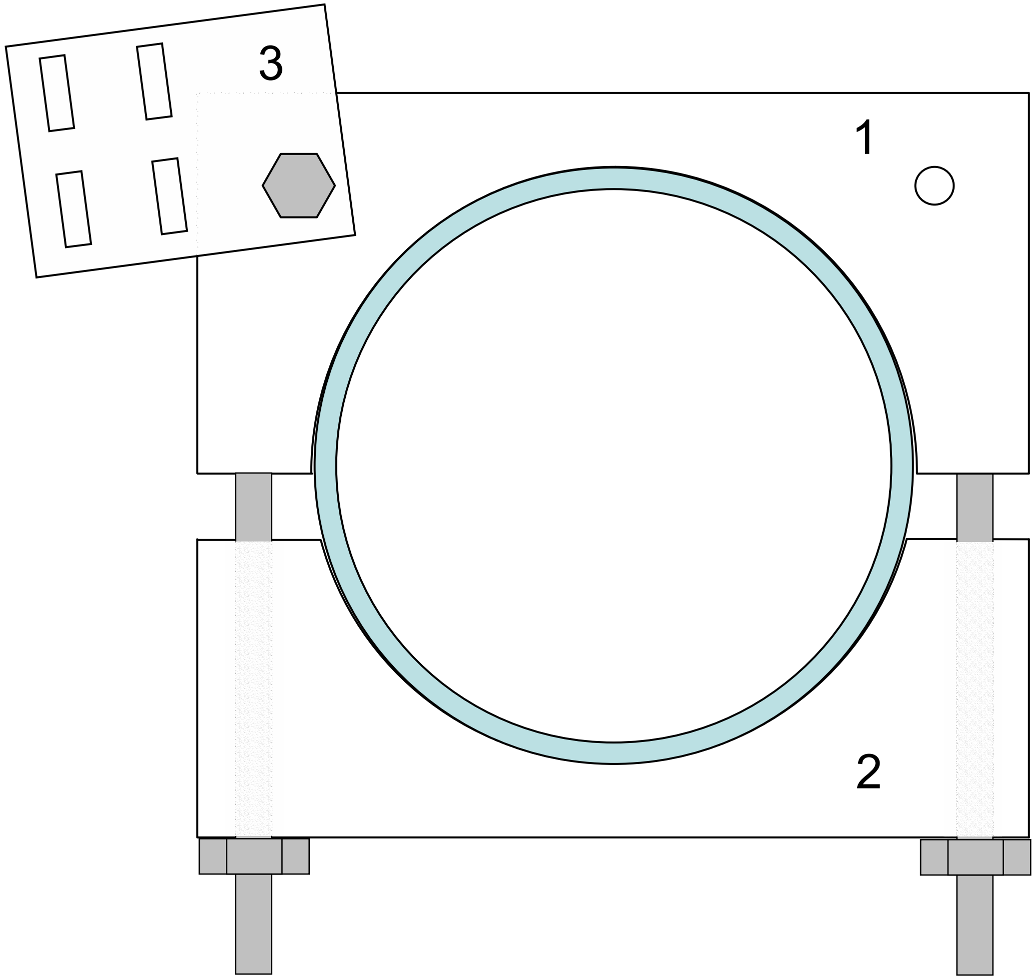
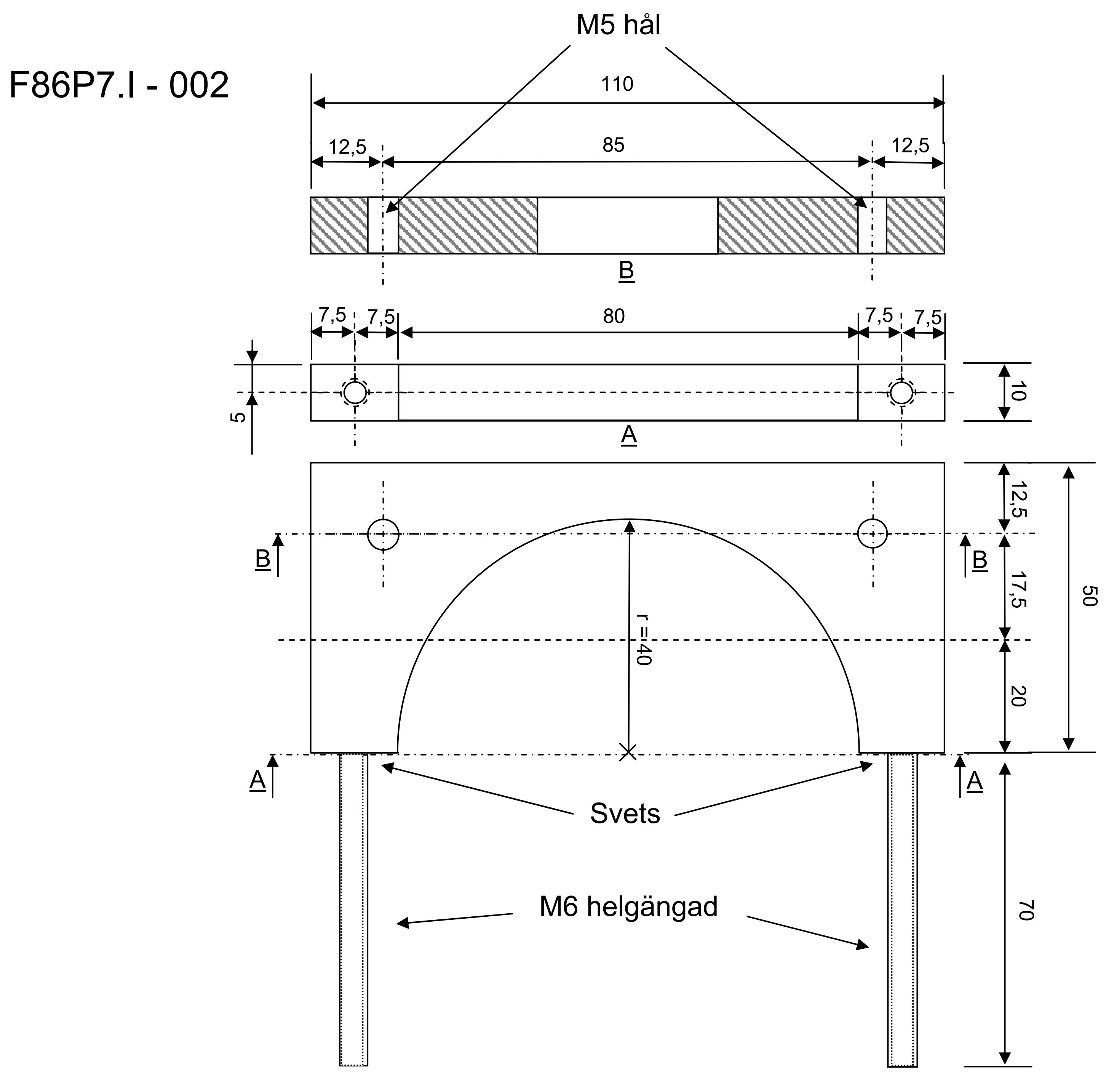
Sensorhållare

Antal:
Del 1: 12 st
Del 2: 12 st
Del 3: 30 st

Material:
Rostfritt Syrafast (SS-2343)



G. Sensor fastening device blueprints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Svets
70
M6 helgängad

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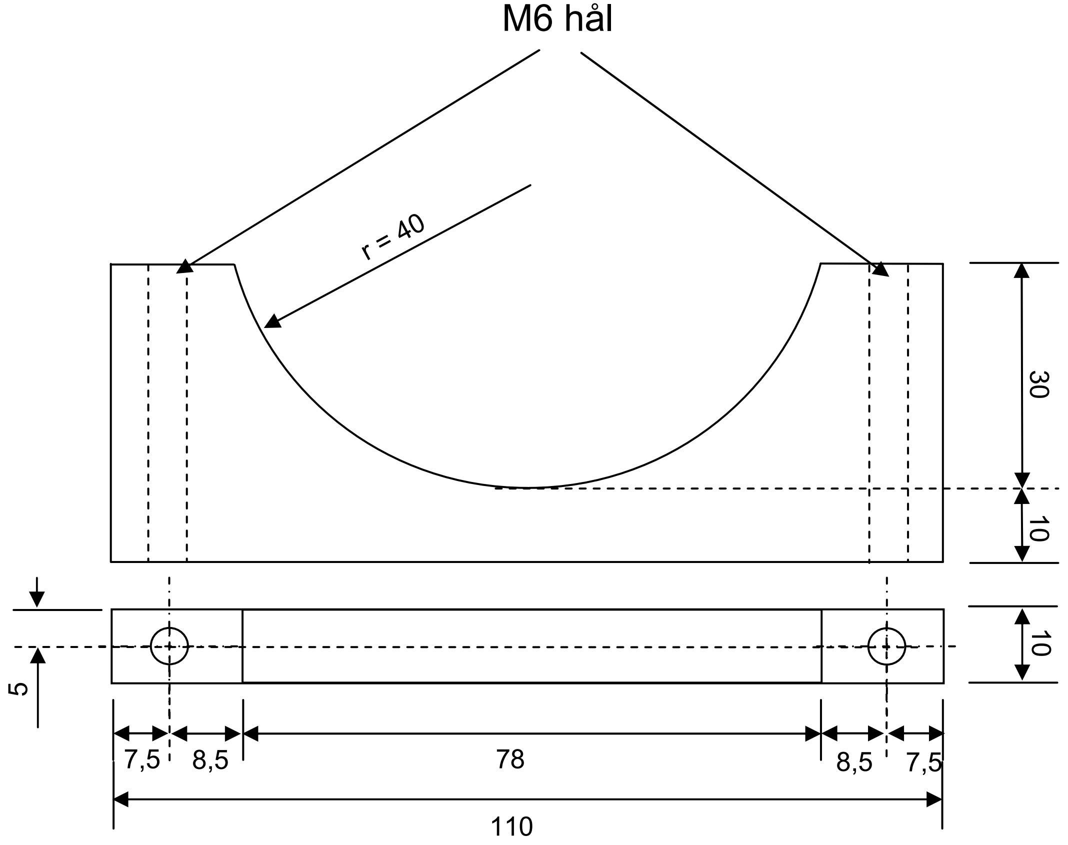

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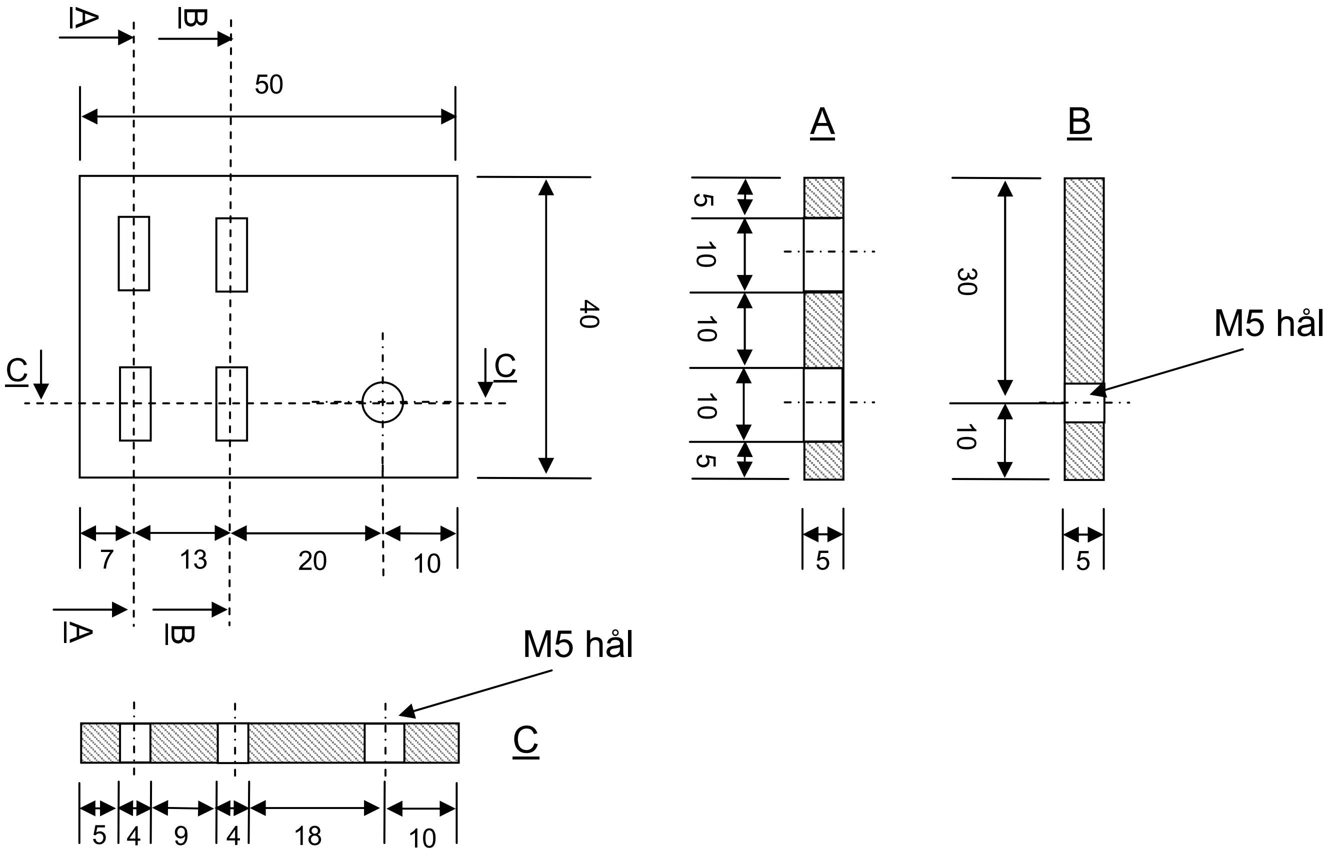
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B
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A
B
A
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M5 hål
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H. Measurement plate alignment

This list is divided into two groups. One group concerning the positions where short range LVDT sensors were mounted and one group for the wide range LVDT sensor positions.

Short range sensor positions.

The plates were mounted on sensor position 1 to 12. The plates are numbered in exactely the same way as the sensors, hence plate number 4 corresponds to short range LVDT sensor number 4.

The list shows the change in measured value on the sensors when the pipe is raised (see chapter 6.3). The value is presented as the change in measured displacement (mm) per mm the pipe is raised. A positive value indicates that the sensor has been compessed when the pipe was raised.

Position number	Displacement change [mm]/[mm raised pipe]
1	0.0025
2	0.0017
3	-0.0154
4	-0.0166
5	0.0013
6	-0.0076
7	0.027
8	0.0311
9	0.0188
10	-0.0287
11	0.0001
12	-0.01

Wide range sensor positions.

The same conditions as above applies for the plates on the wide range sensor positions. The only difference is that a compression of the sensor is here indicated by a negative change in the displacement.

Position number	Displacement change [mm]/[mm raised pipe]
1	0.069
2	0.056
3	0.055
4	0.044
5	0.052
6	0.013
7	-0.008
8	0.013
9	0.000
10	0.027
11	0.004
12	0.000

I. Filtered time intervals

Filtered time intervals

Time turn OFF	Time turn ON
2004-05-12;15:20:00	2004-05-12;16:00:00
2004-05-14;15:00:00	2004-05-14;16:20:00
2004-05-18;10:08:00	2004-05-18;11:28:00
2004-05-18;15:55:00	2004-05-18;16:35:00
2004-05-25;10:02:00	2004-05-25;11:31:00
2004-05-25;12:53:00	2004-05-25;14:42:00
2004-05-25;15:39:00	2004-05-25;17:16:00
2004-05-27;10:35:00	2004-05-27;11:30:00
2004-05-27;12:34:00	2004-05-27;15:12:00
2004-05-28;12:52:00	2004-05-28;14:11:00
2004-06-01;13:37:00	2004-06-01;15:25:00
2004-06-02;08:16:00	2004-06-02;09:30:00
2004-06-02;16:15:00	2004-06-02;17:10:00
2004-06-03;13:25:00	2004-06-03;16:30:00
2004-06-04;08:30:00	2004-06-04;09:11:00
2004-06-04;13:20:00	2004-06-04;13:37:00
2004-06-08;12:38:00	2004-06-08;13:26:00
2004-06-16;10:19:00	2004-06-16;11:21:00
2004-06-16;12:49:00	2004-06-16;14:00:00
2004-06-17;08:36:00	2004-06-17;12:00:00
2004-06-23;09:45:00	2004-06-23;11:30:00
2004-06-29;10:21:00	2004-06-29;11:30:00
2004-06-29;12:43:00	2004-06-29;14:24:00
2004-07-02;14:20:00	2004-07-02;15:20:00
2004-07-06;10:10:00	2004-07-06;11:30:00
2004-07-12;13:03:00	2004-07-11;14:45:00
2004-07-15;20:07:00	2004-07-15;20:22:00
2004-08-03;10:03:00	2004-08-03;11:11:00

J. Calculating thermal influence

If the thermal influence on the measurements is desired, it should be calculated as described below. A temperature change of five degrees is used in all examples below. Five degrees represents about half the total thermal change during the experiment.

Plate expansion.

Expansion of the stabilising plates described in chapter 5.1.2 were compressing the LVDT sensors. The amount of expansion is calculated in the same way as we have calculated all material expansion, see example below.

$$\Delta L = (T_2 - T_1) \times \alpha_{plate} \times L$$
$$T_1 = initial\ temperature\ [°C]$$
$$T_2 = final\ temperature\ [°C]$$
$$\alpha_{plate} = 11.7 \times 10^{-6}\ [°C^{-1}],\ Thermal\ expansion\ coefficient$$
$$L = 800\ [mm],\ inital\ \ plate\ length$$

According to the formula above, the expansion of the plates at five degree temperature increase was:

$$\Delta L = (T_2 - T_1) \times \alpha_{plate} \times L = (25 - 20) \times 11.7 \times 10^{-6} \times 800 = 0.0468\ mm$$

Pipe expansion

The pipe expansion calculation uses the same formula as above to calculate the plate expansion.

With adjustment for the pipe length the formula then looks like:

$$\Delta H = (T_2 - T_1) \times \alpha_{pipe} \times H$$
$$T_1 = initial\ temperature\ [°C]$$
$$T_2 = final\ temperature\ [°C]$$
$$\alpha_{pipe} = 16.5 \times 10^{-6}\ [°C^{-1}],\ Thermal\ expansion\ coefficient$$
$$H = 6500\ [mm],\ inital\ \ pipe\ length$$

The total expansion during a five degree temperature rise is then as an example calculated to

$$\Delta H = (T_2 - T_1) \times \alpha_{pipe} \times H = (25 - 20) \times 16.5 \times 10^{-6} \times 6500 = 0.53625\ mm$$

Measurement plates alignment.

To be able to calculate the effect that the alignment of the small measurement steel plates the exact vertical movement of the LVDT sensors has to be known. The total pipe expansion is calculated as described above.

When the total pipe expansion is known the movement of the LVDT sensors are calculated by dividing the total pipe expansion with the pipe length (including the steel rod holding the pipe at the bottom of the open hole) and then multiply the result with the distance between the hole floor and the desired sensor level- the pipe expands linear from the reference point. Since the measurement plates were mounted only on the upper two rows, the calculations looks like this:

First row, sensor depth = 2.5 meter (equal to 4000 mm above the hole floor):

$\Delta h_{2m} = \Delta H / 6500 \times 4000 = \Delta H \times 0.6154$, where ΔH is the total pipe expansion.

Second row, sensor depth = 3.0 meter (equal to 3500 mm above the hole floor):

$\Delta h_{.2.5m} = \Delta H / 6500 \times 3500 = \Delta H \times 0.5385$, where ΔH is the total pipe expansion.

When the LVDT movement is calculated the final step is to find the constant describing the measurement plate calibration, Appendix H. The constant is then multiplied with the recently calculated Δh and the final influence on the LVDT sensor is calculated. It is important to note the direction of the alignment, i.e. the sign on the alignment constant (further explained in the datasheet).

To illustrate the amount of error that the alignment might give, the example below calculates the effect on a wide range LVDT sensor at measurement position 1, which happens to be the one with the highest amount of influence from the small measurement plates. The example uses a 5 degree temperature increase. The calculation is done in one step to minimize truncation errors.

$$\Delta d = \frac{(T_2 - T_1) \times \alpha_{pipe} \times H \times 4000}{6500} \times 0.0686 = \frac{(25-20) \times 16.5 \times 10^{-6} \times 6000 \times 4000}{6500} \times 0.0686 \approx 0.0209\ mm$$

As seen the influence on the measurement due to misalignment of the small measuring plates is only 0.0209 mm during a five degree temperature rise.

Sensor temperature drift

Thermal effects on the sensors are calculated from the sensor specification sheets in Appendix B and C. The short range LVDTs were calibrated using a 15 degree thermal increase between the measurements. This makes the calculation of the thermal effects calculated as ΔMeasure [V] = $(V_{30}-V_{15}) / 15 \times (T_2-T_1)$, where V_{30} and V_{15} are the calibration values for the sensor found in Appendix B, T_1 and T_2 are the start and end temperature. The result must then be converted to an engineering value (mm) as described earlier. The short range LVDT sensor with most temperature drift was placed at position 7, where the drift during a 15 degree temperature increase is calculated to 0.033 mm. A five degree temperature change then corresponds to 0.011 mm change in the measured value.

Drift of the wide range LVDT sensors are calculated with 20 degrees Celsius as a reference point, the formula are on the form ΔMeasure [mm] = C × (T-20), where C is the sensor unique constant found in Appendix C. The wide range sensor with the highest amount of drift was placed at position 3 and 15 (the sensor was moved during the experiment). The calculated effect on that particular sensor during a five degree temperature rise is 0.010565 × 5 = 0.0528 mm.

It is important to note the direction of the sensor drift. The sensor drift was counteracting the stabilising plate expansion, this was the case for all LVDT sensors regardless of type. The sum of those two parts is then smaller than the separate parts by themselves.

Total thermal effects

The previous chapters have shown how to calculate the thermal effects on the separate parts of the measurement system. To get a complete understanding of the effect a figure of the total thermal expansion is needed. For that reason the measurement error is calculated for the four positions where the highest amount of activity have been observed, 9, 10, 15 and 16. The calculations are based on a temperature increase of 5 degrees. Included in the calculations are the plate expansion, the plate alignment and the sensor drift. A positive value in the table indicates a compression of the sensor, in this table this true for both sensor types.

Table 8-1 Calculation of the total measurement error on position 9, 10, 15 and 16. A positive number indicates that the sensors have been compressed by the thermal effects. No measurement plates were used on position 15 and 16, indicated by a "-" in the table.

Position	Sensor type	Plate expansion [mm]	Measurement plate alignment [mm]	Sensor drift [mm]	Total sum (mm)
9	short range	0.0468	0.0101	-0.0009	0.0560
9	wide range	0.0468	0.0000	0.0294	0.0762
10	short range	0.0468	-0.0154	-0.0053	0.0261
10	wide range	0.0468	-0.0145	0.0515	0.0838
15	short range	0.0468	-	-0.0099	0.0369
15	wide range	0.0468	-	0.0528	0.0996
16	short range	0.0468	-	-0.0045	0.0423
16	wide range	0.0468	-	0.0000	0.0468

No position suffered from more error than 0.1 mm per 5°C temperature rise.