GTS Phase VI ISC Project

Installation of Grout/Resin P/T Monitoring Packer Systems in the Boreholes PRP 16.001, PRP 16.002, PRP 16.003 and SBH 15.004

Report

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Installation of Grout/Resin P/T Monitoring Packer Systems in the Boreholes PRP 16.001, PRP 16.002, PRP 16.003 and SBH 15.004

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Table of Contents

List of Figures

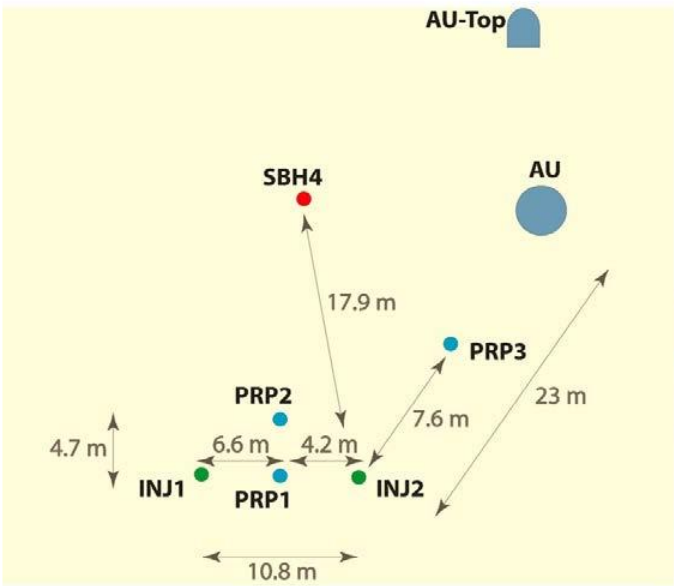
List of Tables

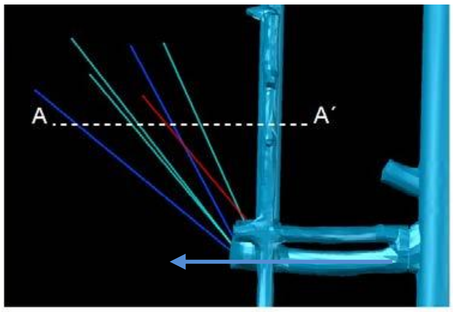
List of Appendices

1 Introduction

In October 2016, Solexperts was awarded a contract to install customised grout packer systems in the monitoring boreholes PRP 16.001, PRP 16.002, PRP 16.003 and SBH 15.004 as part of the In-situ Stimulation and Circulation (ISC) Project. The aim of the instrumentation of the monitoring boreholes is to capture the three-dimensional pressure, stress and temperature propagation behaviour which develops during water injection at high pressures into one or several shear zones for fracture network stimulation. The monitoring boreholes are located in the VE cavern at the end of the AU gallery. The geometry of the monitoring boreholes as top view and in a vertical cross-section and the specifications of concerned boreholes are given in Figure 1.

The down-hole completions are described in Chapter 2. The technical drawings are displayed in Appendix A. The field installation work is described in Chapter 3 and the corresponding photo documentation is shown in Appendix B. The details of the field activities are summarized in the logbook of Appendix C. The calibration sheets of the pressure sensors, the wiring diagrams of DAS components, and the fibre optic cable and resin data sheets are included in Appendix D.





BH Name	Length (m)	Az / Dip	Diam (mm)
INJ15001	44.66	310 / 34	146
INJ15002	44.80	332 / 44	146
PRP16001	47.91	320 / 44	131
PRP16002	44.98	322 / 32	131
PRP16003	32.33	335 / 25	131
SBH15004	23.90	320 / -5	101

Figure 1: Monitoring borehole setup and specifications (source ETHZ and Nagra)

2 Borehole instrumentation

The borehole information is given in Table 1.

Table 1: Details of the boreholes PRP 16.001, PRP 16.002, PRP 16.003 and SBH 15.004 (source ETHZ and Nagra)

Name	Diameter [mm]	Depth [m]	X	Y	Z	Azimuth [°]	Dip [°]
PRP 16.001	131	47.91	667466.510	158889.310	1732.640	320	44
PRP 16.002	131	44.98	667466.510	158889.310	1732.120	322	32
PRP 16.003	131	32.33	667468.390	158892.660	1733.100	335	25
SBH 15.004	101	23.90	667468.729	158892.774	1733.910	320	-5

The down-hole completions are mainly composed of the following elements:

- Pore pressure monitoring intervals
- Resin sections
- Hydro-mechanical packers
- Grout sections
- Fibre optic cables

The setup with the intervals separated by resin sections and with the upper section filled with grout ensures a high stability and a low compressibility of the system. Furthermore the positioning and isolation of the monitoring intervals is enhanced. The fibre optic cables for distributed temperature and strain measurements along the boreholes provide detailed views of the temporal and spatial evolution of these parameters.

The packer systems consist of the central tubing made of synthetic material and hydro-mechanical packers separating the intervals from the resin and grout sections. The diameter of the central tubing and the packers is 125 +/-3 mm. The borehole completion layouts are presented in Figures 2 to 5. The technical drawings are shown in Appendix A. The position and the length of each interval are given in Table 2. The theoretical volumes of water, resin and grout sections are summarized in Table 3.

2.1 Packer sleeves

The packer sleeves are 0.2 m long and hydro-mechanically inflated by applying water pressure to the packer piston. The inflation line has an outer diameter of 6 mm and an inner diameter of 2 mm. The inflation pressure ranges between 20 and 30 bar.

2.2 Monitoring intervals

The monitoring intervals are equipped with access ports for the flow (Q) and pressure (P) lines and for the PT1000 temperature sensors. The Q-lines are made of PEEK material and have an outer diameter of 1/4” (6.35 mm) and an inner diameter of about 4.4 mm. The P-lines are made of polyamide and have an outer diameter of 6 mm and an inner diameter of 2 mm. Table 3 shows the specification of the lines and their volumes. The positions of the line access ports and the temperature sensors are given in Table 4.

2.3 Resin sections

The resin sections are equipped with two access ports for the resin injection and extraction lines which are made of polyamide and have an outer diameter of 8 mm and an inner diameter of 6 mm. The volume of the resin intervals is shown in Table 3 and the volume of the resin injection and extraction lines is shown in Table 4. The data sheet of the used resin is shown in Figure D-9 (Appendix D).

2.4 Grout sections

In all boreholes, the borehole sections above the uppermost packer till the borehole mouth, containing the installation rods, were grouted. The installation rods are made of PVC and have an outer diameter of 60 mm. For the grout injection into PRP 16.001, PRP 16.002 and PRP 16.003, a 20 mm outer diameter and 16 mm inner diameter tube was fixed to the installation rods to fill the grout section from the bottom to the top. For the grout injection into SBH 15.004 two grouting tubes and a mechanical packer at the borehole mouth were installed to prevent grout out flow from the upwards oriented borehole (Table 1). The injection line is located after the mechanical packer at the borehole mouth and the extraction line near the hydro-mechanical packer. Both lines have an outer diameter of 12 mm and an inner diameter of 10 mm. The grout mixing ratio is shown in Table 6 of Chapter 3.

2.5 Fiber optic cables

The fibre optic cables for distributed temperature and strain measurements, one for each parameter, are continuously installed in the 3 boreholes PRP 16.001, PRP 16.002 and PRP 16.003. The cable routing layout in the 3 boreholes including the cable lengths at each borehole mouth and borehole end is shown in Figure A-5 (Appendix A). The cables are looped at the end of the system on a customised half circle seat especially designed and manufactured to ensure cable bending without the risk of breaking the fibres (Figure B-1 and B-2, Appendix B). The fibre optic cable data sheets are shown in Figure D-7 and D-8 (Appendix D). To install the fibre optic cables without the risk of damaging the cables, 2 slits were made along the packer system tubing and sleeves, one for the temperature and one for the strain cable (Figure B-3 and B-4, Appendix B), where the cables where fixed for installation (see also Chapter 3).

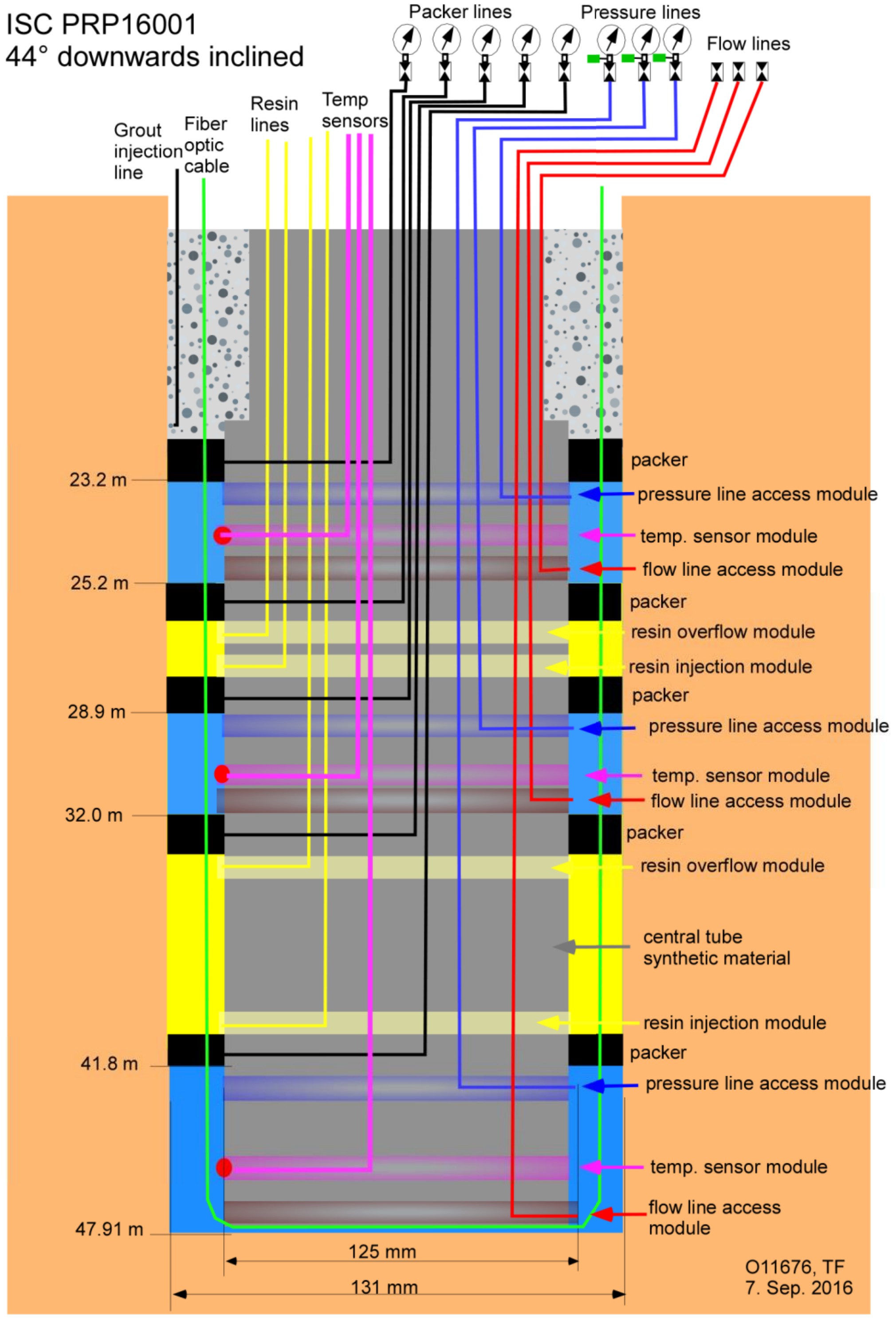


Figure 2: Schematic drawing of PRP 16.001 borehole completion

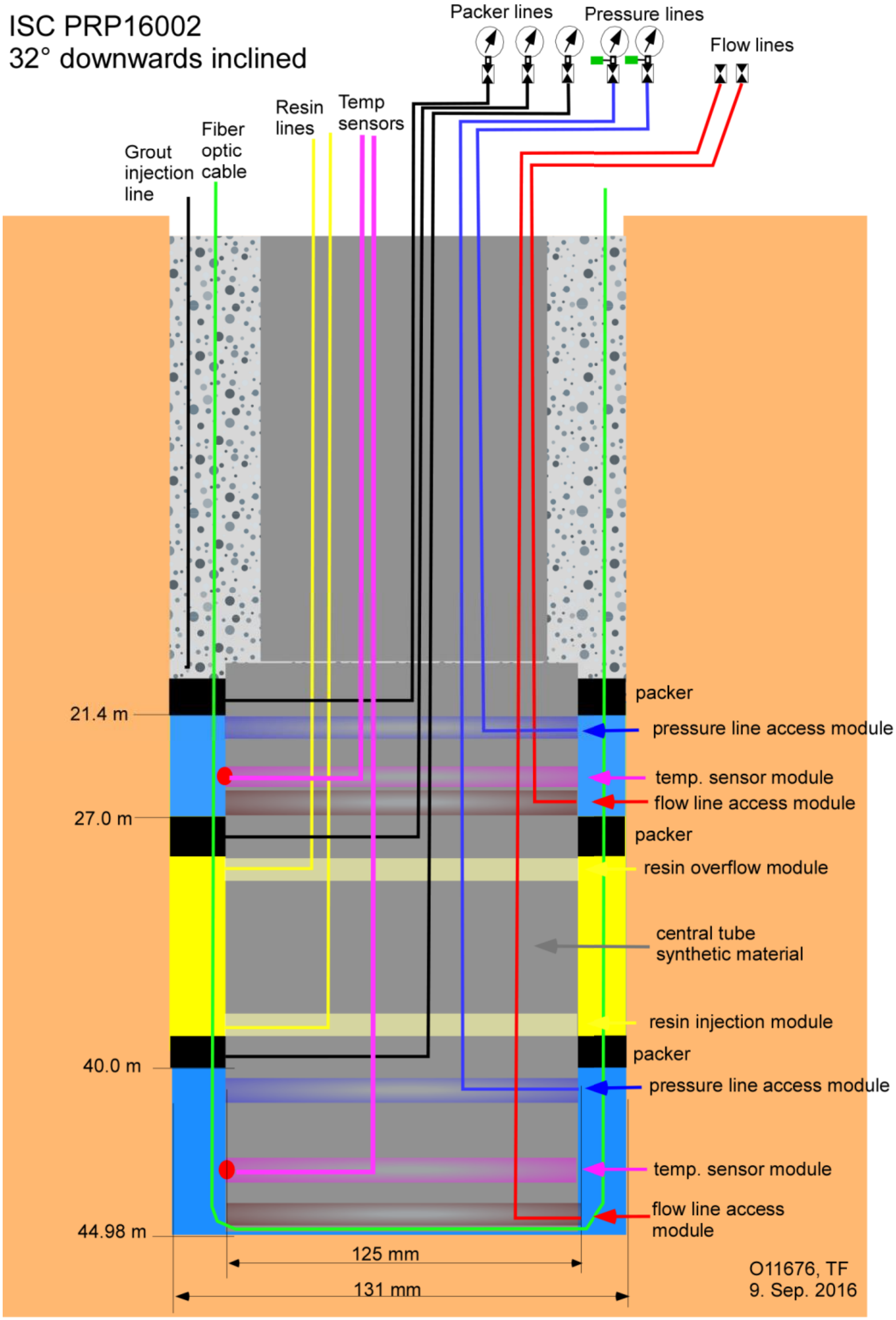


Figure 3: Schematic drawing of PRP 16.002 borehole completion

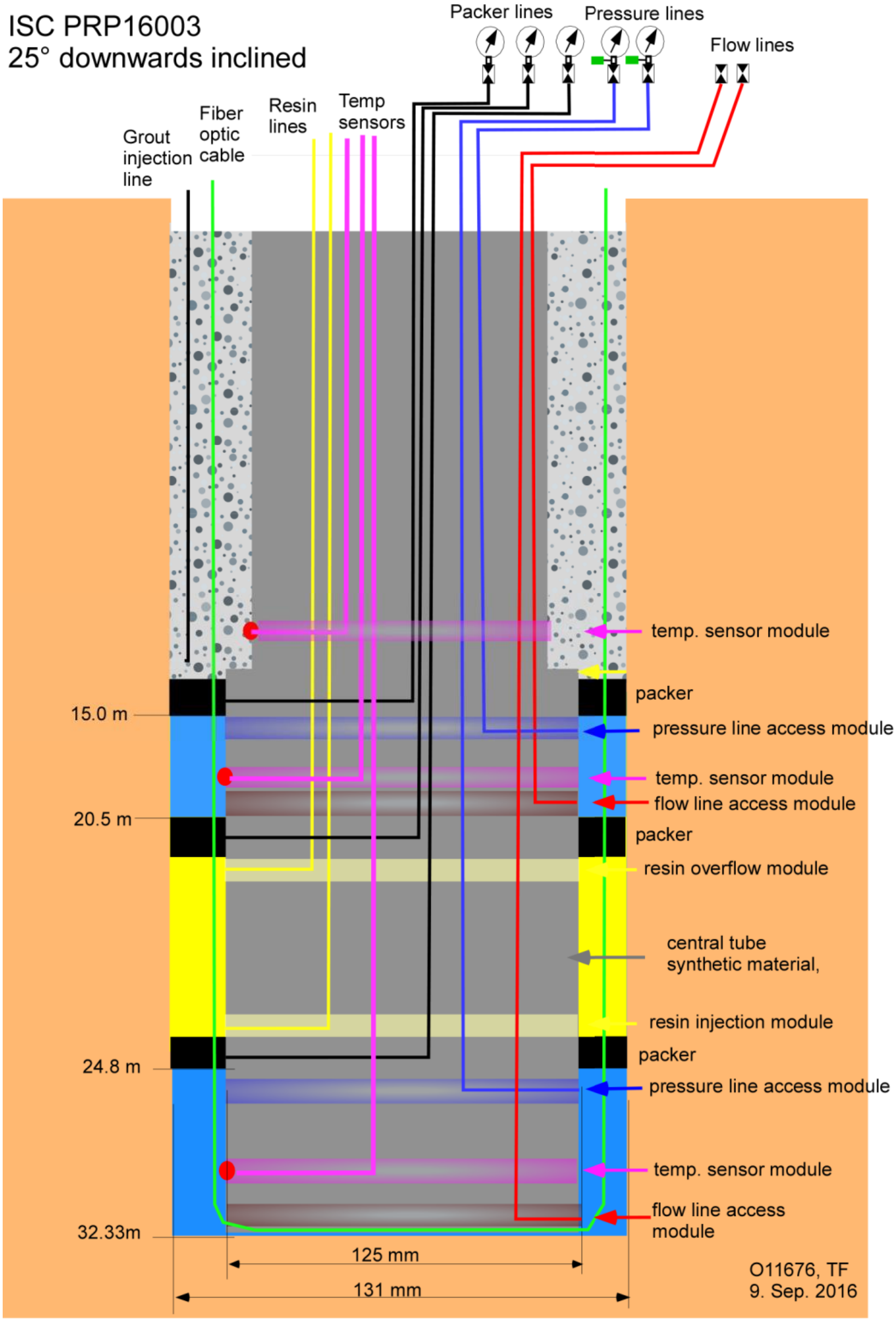


Figure 4: Schematic drawing of PRP 16.003 borehole completion

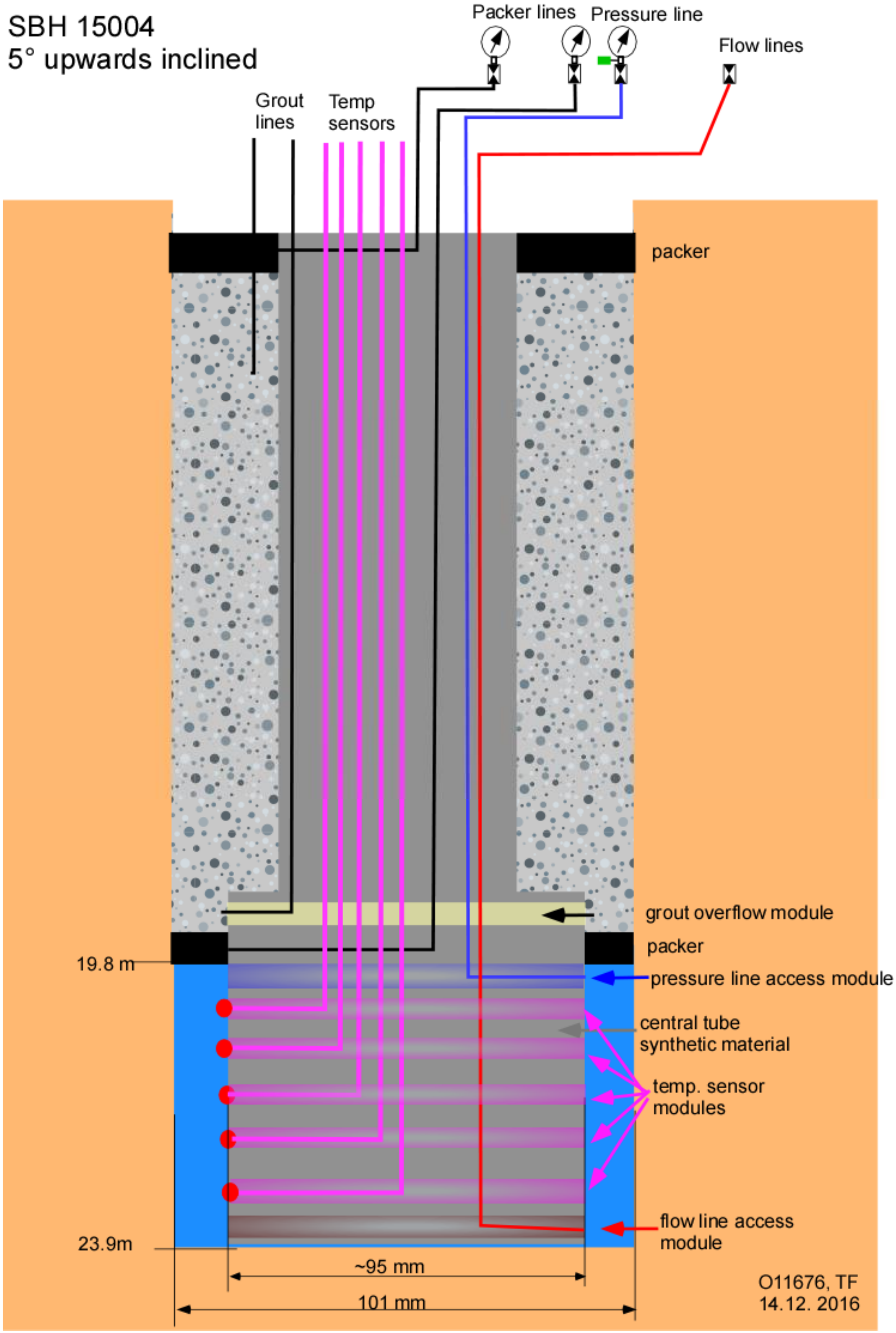


Figure 5: Schematic drawing of SBH 15.004 borehole completion

Table 2: Interval and packer positions, lengths and volumes

PRP 16.001	From [m]	To [m]	Length [m]	Approx.Volume [l]
Interval 1	41.8	47.91	6.11	7.39
Packer 1	41.6	41.8	0.20	0.24
Interval-resin-1	32.2	41.6	9.40	11.37
Packer 2	32	32.2	0.20	0.24
Interval 2	28.9	32	3.10	3.75
Packer 3	28.7	28.9	0.20	0.24
Interval-resin-2	25.4	28.7	3.30	3.99
Packer 4	25.2	25.4	0.20	0.24
Interval 3	23.2	25.2	2.00	2.42
Packer 5	23	23.2	0.20	0.24
Grout section	0	23	23.00	244.95
PRP 16.002	**From [m]**	**To [m]**	**Length [m]**	**Approx.Volume [l]**
Interval 1	40	44.98	4.98	6.03
Packer 1	39.8	40	0.20	0.24
Interval-resin-1	27.2	39.8	12.60	15.25
Packer 2	27	27.2	0.20	0.24
Interval 2	21.4	27	5.60	6.78
Packer 3	21.2	21.4	0.20	0.24
Grout section	0	21.2	21.20	225.78
PRP 16.003	**From [m]**	**To [m]**	**Length [m]**	**Approx.Volume [l]**
Interval 1	24.8	32.33	7.53	9.11
Packer 1	24.6	24.8	0.20	0.24
Interval-resin-1	20.7	24.6	3.90	4.72
Packer 2	20.5	20.7	0.20	0.24
Interval 2	15	20.5	5.50	6.66
Packer 3	14.8	15	0.20	0.24
Grout section	0	14.8	14.80	157.62
SBH 15.004	**From [m]**	**To [m]**	**Length [m]**	**Approx.Volume [l]**
Interval 1	19.8	23.9	4.10	4.96
Packer 1	19.6	19.8	0.20	0.24
Grout section	0	19.6	19.60	208.74

Table 3: Line specifications of the packer systems

ISC PRP 16001

Module	Line type	Ø OD/ID (mm)	Material	Color	Length	Vol. (ml)
GROUT INT 1	Injection	20/16	poly.	1	29.00	5830.74
PA 5	Packer	6/2	poly.	5	28.00	87.92
INT 3	Pressure	6/2	poly.	3	28.40	89.18
	Flow	1/4"/4.4	PEEK	3	29.70	451.74
PA 4	Packer	6/2	poly.	4	29.00	91.06
RES INT 2	Overflow	8/6	poly.	2	29.00	819.83
	Injection	8/6	poly.	2	34.00	961.18
PA 3	Packer	6/2	poly.	3	34.00	106.76
INT 2	Pressure	6/2	poly.	2	34.10	107.07
	Flow	1/4"/4.4	PEEK	2	36.50	555.17
PA 2	Pressure	6/2	poly.	2	38.00	119.32
RES INT 1	Overflow	8/6	poly.	1	38.00	1074.26
	Injection	8/6	poly.	1	47.00	1328.69
PA 1	Packer	6/2	poly.	1	47.00	147.58
INT 1	Pressure	6/2	poly.	1	47.00	147.58
	Flow	1/4"/4.4	PEEK	1	52.40	797.00

ISC PRP 16002

Module	Line type	Ø OD/ID (mm)	Material	Color	Length	Vol. (ml)
GROUT INT 1	Injection	20/16	poly.	1	27.00	5428.62
PA 3	Packer	6/2	poly.	3	27.00	84.78
INT 2	Pressure	6/2	poly.	2	26.60	83.52
	Flow	1/4"/4.4	PEEK	2	31.50	479.12
PA 2	Pressure	6/2	poly.	2	32.00	100.48
RES INT 1	Overflow	8/6	poly.	1	33.00	932.91
	Injection	8/6	poly.	1	45.00	1272.15
PA 1	Packer	6/2	poly.	1	45.00	141.30
INT 1	Pressure	6/2	poly.	1	45.20	141.93
	Flow	1/4"/4.4	PEEK	1	49.50	752.90

ISC PRP 16003

Module	Line type	Ø OD/ID (mm)	Material	Color	Length	Vol. (ml)
GROUT INT 1	Injection	20/16	poly.	1	20.00	4021.20
PA 3	Packer	6/2	poly.	3	20.00	62.80
INT 2	Pressure	6/2	poly.	2	20.20	63.43
	Flow	1/4"/4.4	PEEK	2	25.00	380.25
PA 2	Packer	6/2	poly.	2	26.00	81.64
RES INT 1	Overflow	8/6	poly.	1	27.00	763.29
	Injection	8/6	poly.	1	30.00	848.10
PA 1	Packer	6/2	poly.	1	30.00	94.20
INT 1	Pressure	6/2	poly.	1	30.00	94.20
	Flow	1/4"/4.4	PEEK	1	36.80	559.73

ISC SBH 15004

Module	Line type	Ø OD/ID (mm)	Material	Color	Length	Vol. (ml)
PA 2	No line,required (mechanical packer)					
GROUT INT 1	Injection	12/10	poly.	2	15.00	1178.10
	Overflow	12/10	poly.	1	30.00	2356.20
RES INT 1	Injection	8/6	poly.	1	30.00	848.10
PA 1	Packer	6/2	poly.	1	30.00	94.20
INT 1	Flow	1/4"/4.4	PEEK	1	28.80	438.05
	Pressure	6/2	poly.	1	25.00	78.50

Table 4: Line access ports and temperature sensor positions in the boreholes

Access ports and temperature sensors	Position in the borehole [m]
PRP 16.001	
Flow line access port Q-1	47.69
Temperature sensor T-1	47.74
Pressure line access port P-1	41.83
Flow line access port Q-2	31.80
Temperature sensor T-2	31.80
Pressure line access port P-2	28.93
Flow line access port Q-3	25.00
Temperature sensor T-3	25.00
Pressure line access port P-3	23.23
PRP 16.002	
Flow line access port Q-1	44.76
Temperature sensor T-1	44.81
Pressure line access port P-1	40.03
Flow line access port Q-2	26.8
Temperature sensor T-2	26.8
Pressure line access port P-2	21.43
PRP 16.003	
Flow line access port Q-1	32.11
Temperature sensor T-1	32.16
Pressure line access port P-1	24.83
Flow line access port Q-2	20.30
Temperature sensor T-2	20.30
Pressure line access port P-2	15.03
SBH 15.004	
Pressure line access port P-1	23.87
Temperature sensor T-1	23.40
Temperature sensor T-2	22.98
Temperature sensor T-3	21.50
Temperature sensor T-4	20.60
Temperature sensor T-5	19.86
Flow line access port Q-1	19.82

2.6 Data acquisition system

The layout of the data acquisition system (DAS) is shown in Figure D-6 (Appendix D). The setup of the sensors is given in Table 5. The calibration sheets of the pressure sensors are included in Figure D-1 (Appendix D). The connection of the sensors of each system to the corresponding junction box is shown in Figures D-2 to D-5 (Appendix D). The temperature sensors of the 4 systems are connected to a Solexperts SBI-A interface and to the data acquisition PC (DAS) running the Solexperts GeoMonitor II software. The PT1000 temperature sensors have a measuring range from -50 to 650 °C with a resolution of < 0.01 °C. The maximum sampling rate is 1 Hz.

Table 5: Specification of sensors and connection to DAS

Borehole	Sensor name	Sensor	Type	Unit	Range	GeoMonitor ch.	GM3-HF id.
PRP16001	PRP16001_INTT01	Temperature	PT1000	°C	-50…650	1	--
	PRP16001_INTT02	Temperature	PT1000	°C	-50…650	2	--
	PRP16001_INTT03	Temperature	PT1000	°C	-50…650	3	--
	PRP16001_INTP01	Pressure	PAA 33-X	kPa	0-100 bar	--	1
	PRP16001_INTP02	Pressure	PAA 33-X	kPa	0-100 bar	--	2
	PRP16001_INTP03	Pressure	PAA 33-X	kPa	0-100 bar	--	3
PRP16002	PRP16002_INTT01	Temperature	PT1000	°C	-50…650	4	--
	PRP16002_INTT02	Temperature	PT1000	°C	-50…650	5	--
	PRP16002_INTP01	Pressure	PAA 33-X	kPa	0-100 bar	--	4
	PRP16002_INTP02	Pressure	PAA 33-X	kPa	0-100 bar	--	5
PRP16003	PRP16003_INTT01	Temperature	PT1000	°C	-50…650	6	--
	PRP16003_INTT02	Temperature	PT1000	°C	-50…650	7	--
	PRP16003_INTT03	Temperature	PT1000	°C	-50…650	8	--
	PRP16003_INTP01	Pressure	PAA 33-X	kPa	0-100 bar	--	6
	PRP16003_INTP02	Pressure	PAA 33-X	kPa	0-100 bar	--	7
SBH15004	SBH15004_INTT01	Temperature	PT1000	°C	-50…650	9	--
	SBH15004_INTT02	Temperature	PT1000	°C	-50…650	10	--
	SBH15004_INTT03	Temperature	PT1000	°C	-50…650	11	--
	SBH15004_INTT04	Temperature	PT1000	°C	-50…650	12	--
	SBH15004_INTT05	Temperature	PT1000	°C	-50…650	13	--
	SBH15004_INTP01	Pressure	PAA 33-X	kPa	0-100 bar	--	8

The pressure sensors are connected via the Solexperts SCI-A interface to the Solexperts data acquisition PC (DAS) running the Solexperts GM^3-HF software with a maximum scan rate of 20 Hz. The SCI-A interface with 16bit ADC resolution enables a speed of 20Hz and is designed for 8 pressure sensors, but can be extended to 16 pressure sensors and 11 temperature sensors. The pressure range is 10 MPa for stimulation and characterization phases, the sensor resolution is < 1kPa at a sampling rate of 20 Hz. T

The Solexperts GM^3-HF is designed for fast data acquisition. The sampling rate is configurable and can be changed according to the requirements. A linear conversion function with offset, factor and reference can be applied to each channel (Figure 6). Data are streamed into a TDMS data file where both sensor configuration and data are stored for each test sequence. Add-ons for reading TDMS files are available in MS Excel, OpenOffice.org (Calc) and MATLAB. In addition GM^3-HF provides an export function which writes the data into an ASCII file (*.dat). The recent measurements are shown in the main program window and are graphical displayed with the possibility to set the time range (number of data points). Four channels can be displayed at one time with each channel running its own secondary axis (Figure 7). The cursor function shows the selected values at the cursor position (x,y).

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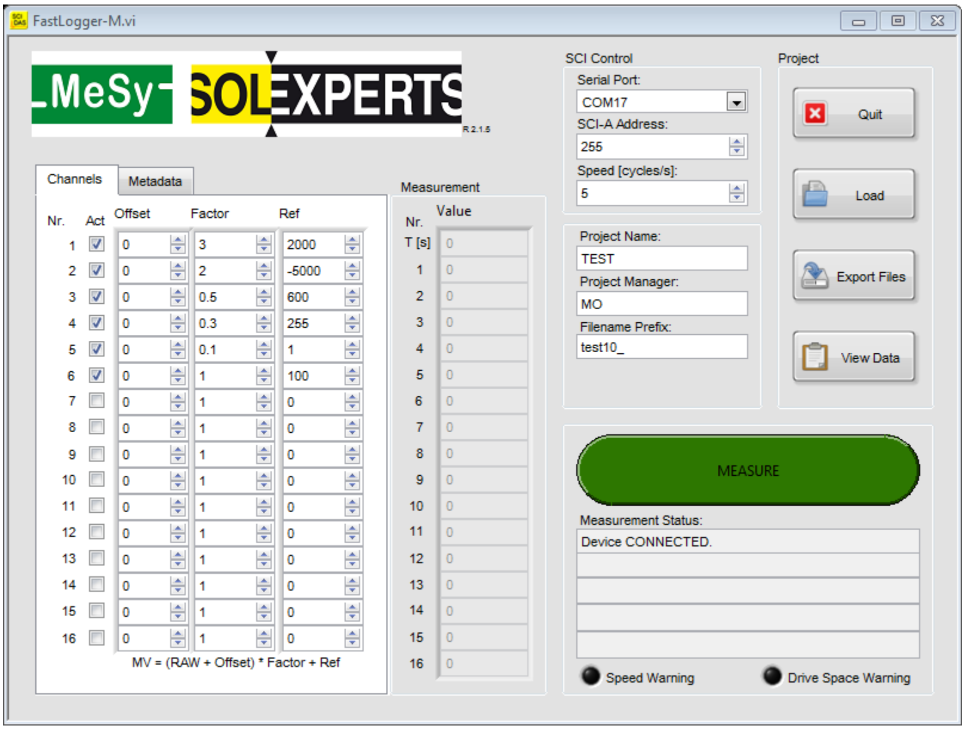


Figure 6: GM^3-HF program interface

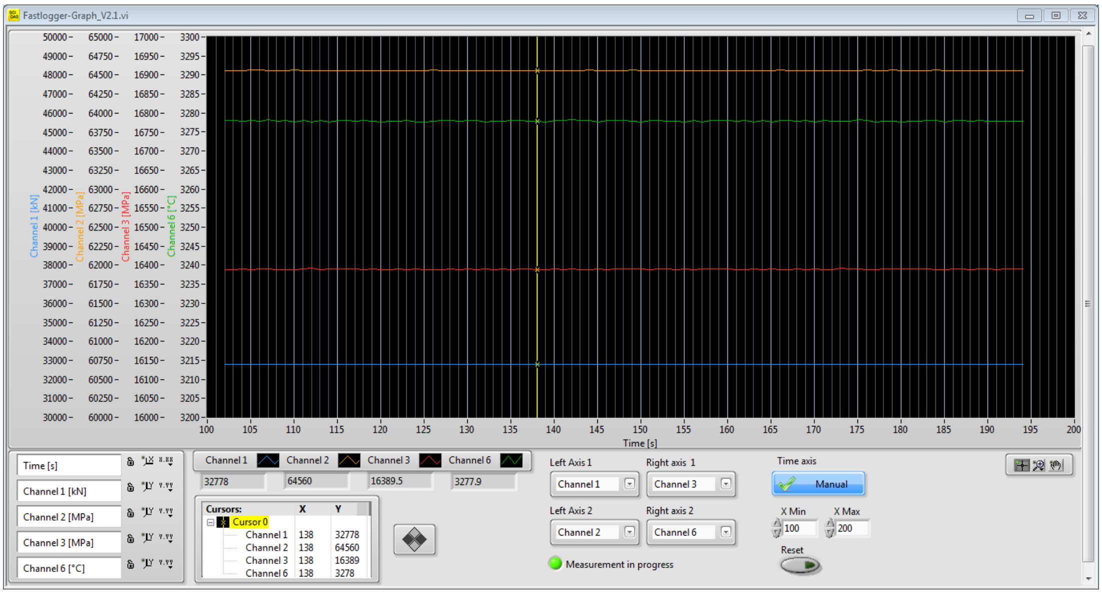


Figure 7: GM^3-HF program graphic display

The data acquisition system can be connected to the internet for remote access and data transmission. Although TDMS efficiently saves the data, files might reach considerable sizes depending on sampling rate and measuring duration.

3 Installation

Details of the installation work are given in the field activity logbook in Appendix C and the photo documentation of the installation is included in Appendix B.

On the 14th December 2016 the packer system PRP 16.001 was transported to the site and the installation was started after site preparation. The installation of PRP 16.001 was completed on the 16th December 2016 and on the same day the installation of the system PRP 16.002 was started. The installation of PRP 16.001 and PRP 16.002 systems required a manual winch and a deflection pulley which were fixed at the tunnel wall and used to push the systems inside the borehole (Figure B-5). During the installation, two clamps were fixed at each introduced system element to secure and facilitate the installation (Figure B-6). The strain fibre optic cable was put under tension during the installation to ensure reliable measurements during fracture opening and closing expected during the planned high pressure injections. The installation of PRP 16.002 was completed on the 19th December 2016. The installation of PRP 16.003 system started on the 20th December and was completed on the same day.

On the 21st December 2016, after installation of the packer system at SBH 15.004, the responsible GTC engineer spliced the fiber optic cable at cable ends and checked the signal (Figure B-9). The cables were mostly intact, only a minor signal perturbation was detected at two spots. At the same time the resin equipment including pressure tank, N_2 bottle, balance and resin mixing tool was prepared and resin was mixed (Figure B-7 and Figure B-8). Then, the resin sections of PRP 16.001 and 16.003 were successfully filled. The injected masses and the corresponding volumes are shown in Table 6. The injected mass into PRP 16.001 and 16.003 was higher than the theoretically calculated mass. This could be due to the different diameters of the central tubes and the connection part between packers and interval tubes (Chapter 2). Additionally, a part of the resin might have penetrated in the rock through fractures and fissures. On the 22nd December and during resin injection into PRP 16.002, the resin quantity was insufficient for the entire resin section. Thus, a second resin was added. Unfortunately, the combination of two resin types led to a highly viscous mass which did not fill the entire resin section. Furthermore part of the resin reached the Q-line of interval 2. To clean the line and avoid resin flow into interval 2 water from the GTS network was injected from the P-line into interval 2. The system control performed in January 2017 revealed that the Q-line was filled with resin. However, only a minor amount of resin might be in the interval and pressure measurements are fine. Hydraulic testing is still possible via the P-line.

On the 22nd December 2016, the top of the annular space of all boreholes was filled with grout according to the layouts shown in Chapter 2. The mixing ratio for the injection is given in Table 7. The grout used for SBH 15.004 was less viscous then the grout used for PRP 16.001, PRP 16.002 and PRP 16.003 as the line inner diameter was smaller.

Table 6: Resin volume and weight

Borehole resin section	Total volume 1) [L]	Theoritical mass 3) [kg]	Effective injected mass [kg]
PRP 16.001-I2	14.06	15.47	17.54
PRP 16.001-I4	6.06	6.66	8.60
PRP 16.002-I2	17.17 2)	18.89	16.20
PRP 16.003-I2	6.28	6.91	8.90

1) Total volume of the interval, packer system lines and surface injection and extraction lines. The total length of the surface lines is 10 m for PRP 16.001 and PRP 16.003
2) The length of the surface lines is 1 m for PRP 16.002
3) The mass is calculated based on the density of the resin given by the supplier

Table 7: Grout mixing ratios

Component	RPR 16.001, RPR 16.002, RPR 16.003 [%]	SBH 15.004 [%]
Cement	47	45.25
Water	38	45.25
Opalite	14	9
Bentonite	1	0.5

4 Conclusion

- Generally, the installation of the 4 systems was successful, no major problems occurred during the installation.
- A small resin volume might have penetrated the formation during resin injection through fractures and fissures.
- During hydraulic testing the Q-line of interval PRP 16.001-I2 was found to be clogged. Resin from the resin section below might have by-passed the packer through fractures and entered the Q-line of the interval. Pressure monitoring and hydraulic testing is still possible with the P-line.
- The higher resin injection pressures needed for borehole PRP 16.002 most probably caused resin flow through fractures to the Q-line of interval PRP 16.002-I2 and caused clogging of the Q-line. Pressure monitoring and hydraulic testing is still possible with the P-line.
- On the 17th January 2017, the inner tubes of the PRP 16.001, PRP 16.002 and PRP 16.003 systems were filled with grout to enhance the stability of the system parameters during the stimulation tests planned for February 2017.
- The first fibre optic measurements after installation are promising in terms of detecting pressure, stress and temperature behaviour.

6 References

Fierz, T. (2016): Pressure monitoring during the stimulation experiment at the Grimsel Test Site. Technical Note for quotation document.

Appendix A: Down-hole equipment

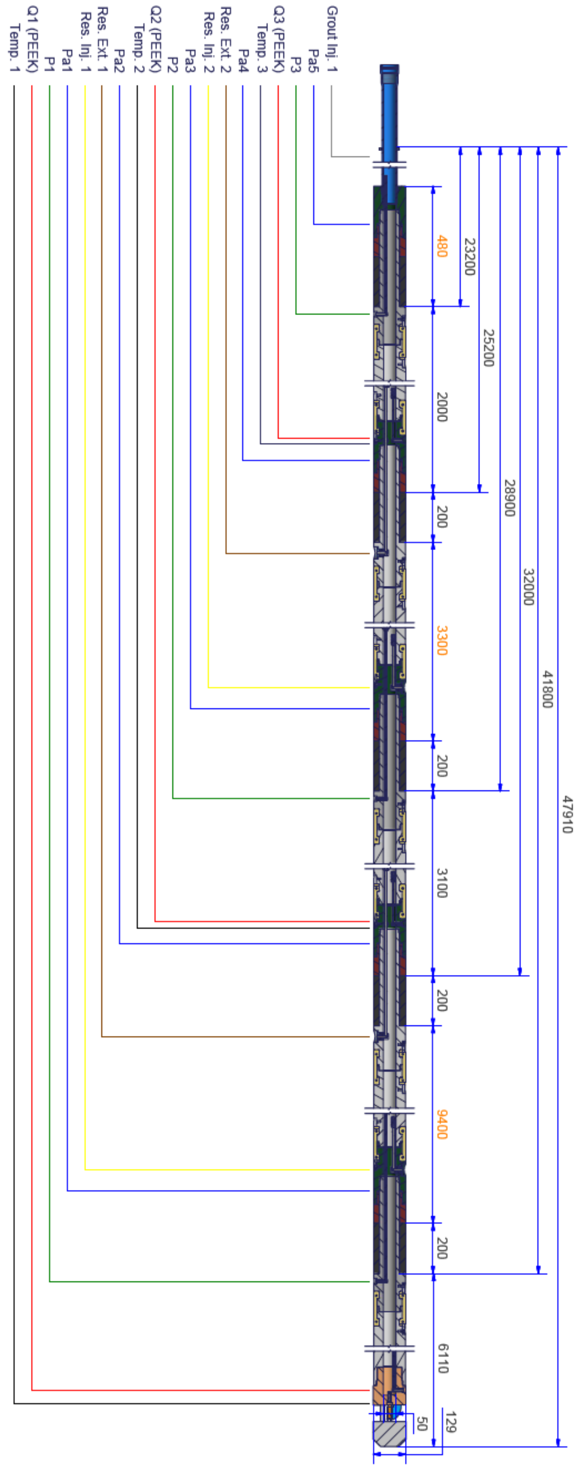


Figure A-1: Technical drawing of packer system at PRP 16.001

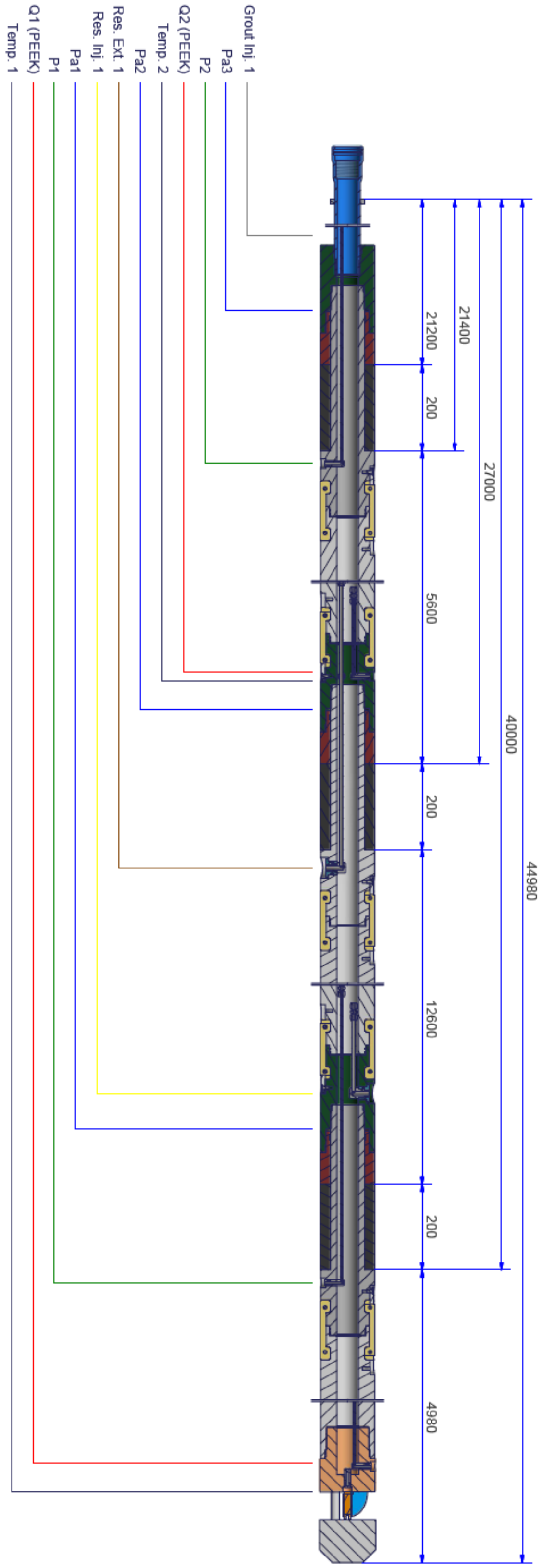


Figure A-2: Technical drawing of packer system at PRP 16.002

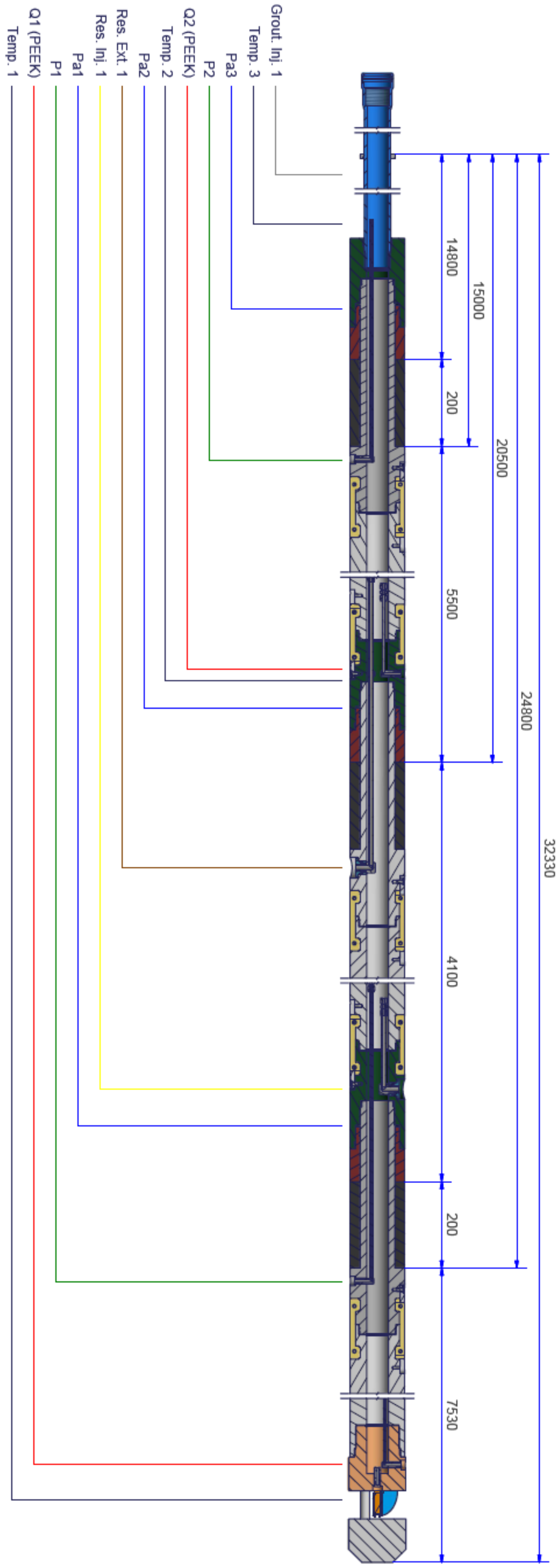


Figure A-3: Technical drawing of packer system at PRP 16.003

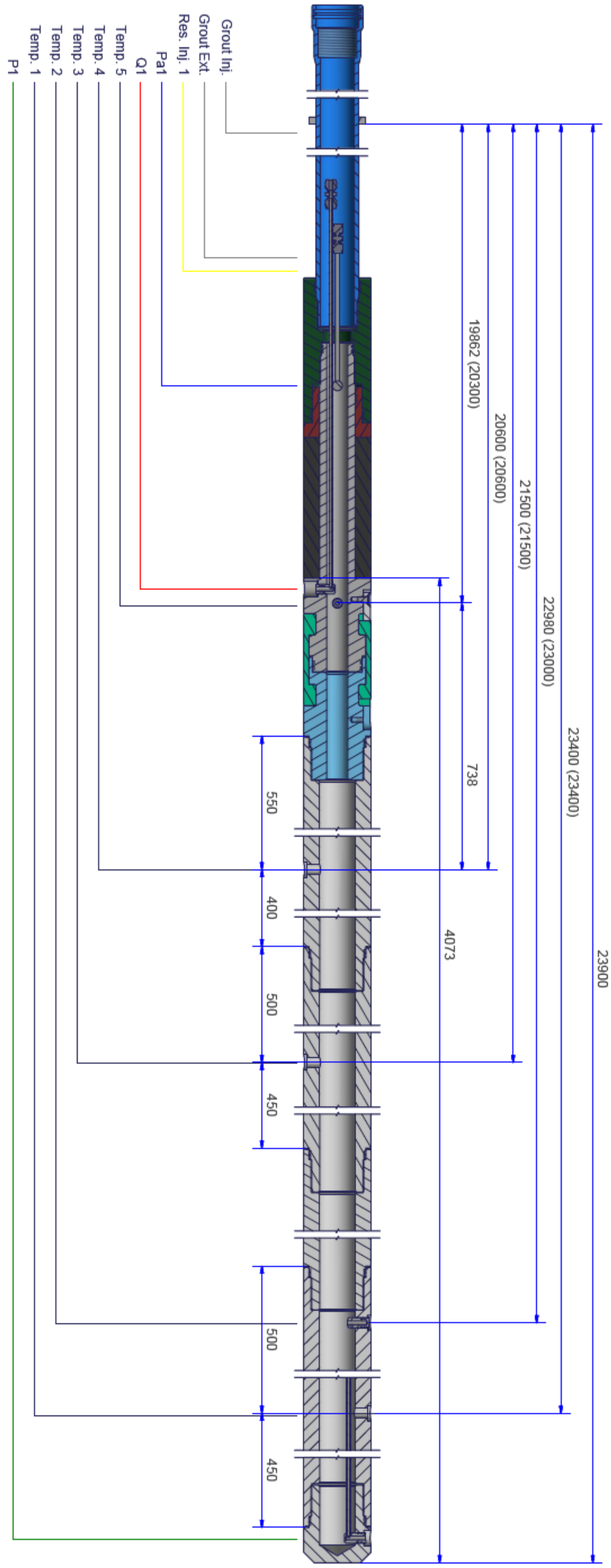


Figure A-4: Technical drawing of packer system at SBH 15.004

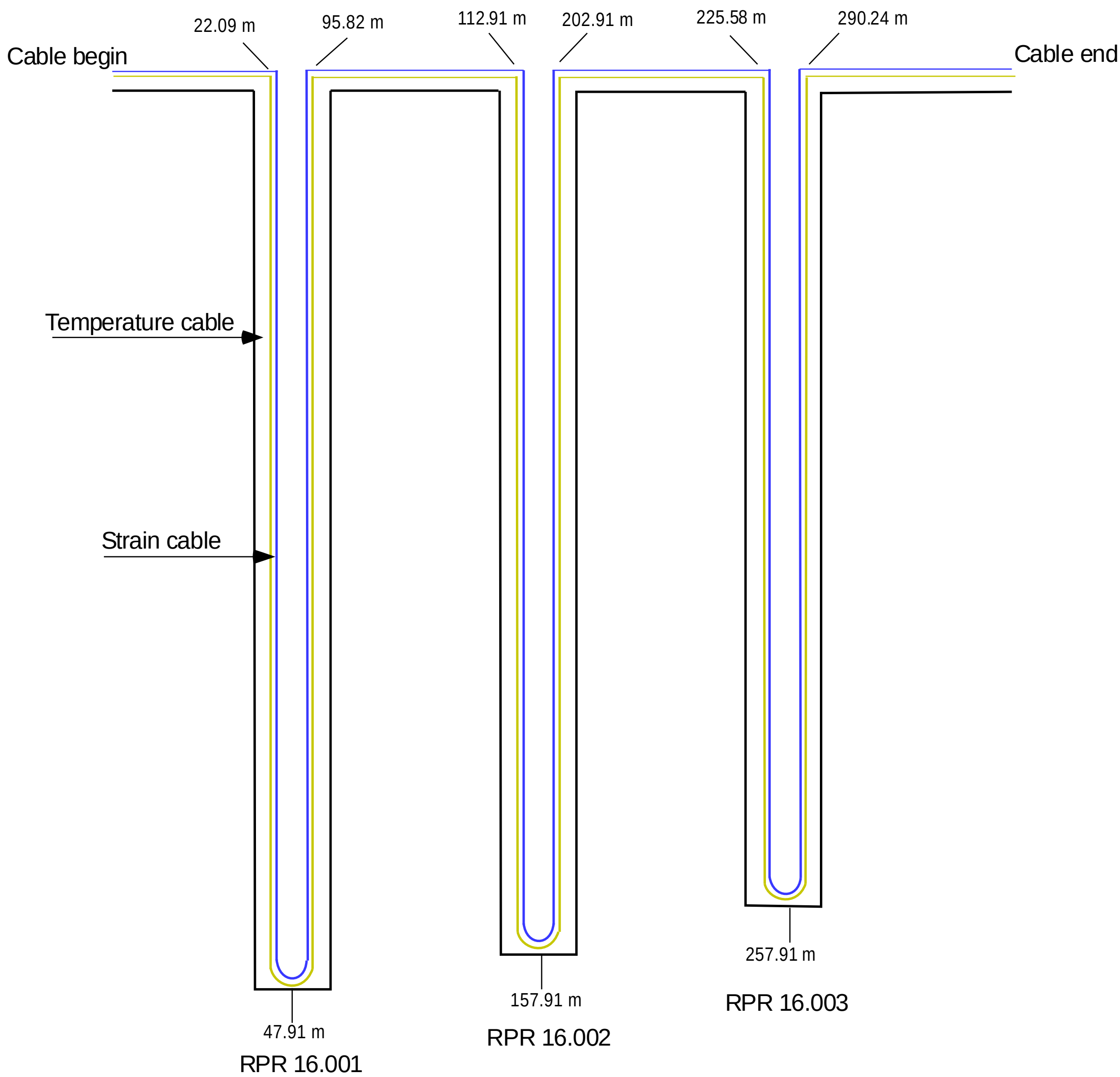


Figure A-5: Continuous routing layout of fibre optic cables in PRP 16.001, PRP 16.002 and PRP 16.003

Appendix B: Photo documentation

Figure B-1: System end and cable seat

Figure B-2: Fibre optic cables fixed at system end

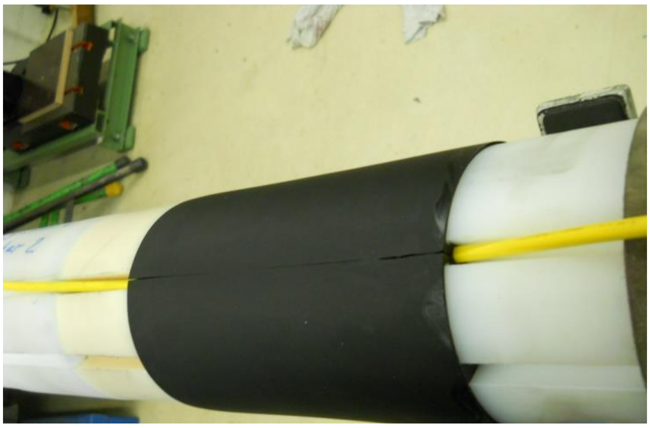


Figure B-3: Fibre optic temperature cable passed through packer sleeve

Figure B-4: Fibre optic strain cable passed through packer sleeve

Figure B-5: Installation using winch and pulley

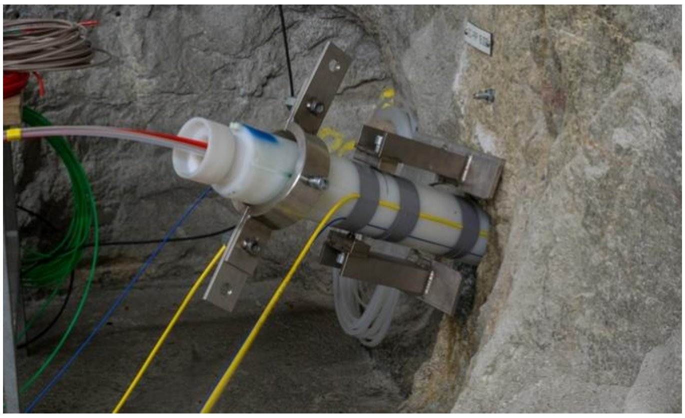


Figure B-6: Two clamps used to install and secure the system (photo: H. Fisch, Nagra)

Figure B-7: Resin injection tank and balance

Figure B-8: Resin components

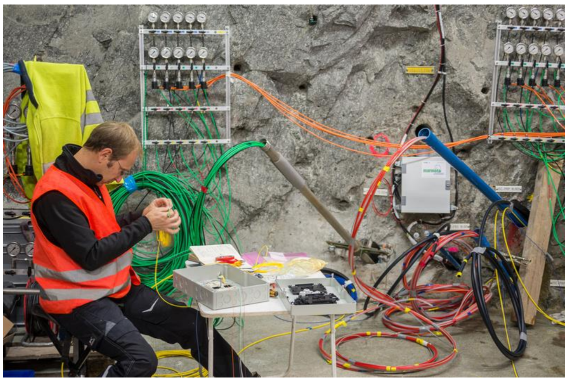


Figure B-9: Fibre optic splicing

Figure B-10: Grout mixing

Figure B-11: Line tightness check during installation of PRP 16.003 (photo H. Fisch, Nagra)

Figure B-12: Installing 2 meter long tube of PRP 16.001 system

Figure B-13: SBH 15.004 packer system

Figure B-14: PT1000 sensor installation at SBH 15.004 system (photo: H. Fisch, Nagra)

Appendix C: Field activity logbook

Date	*Time (DAS)*	*Who*	*Action*
14.12.16	08:30-18:00	KK/Bos/AJ	Prepare the site for installation at PRP 16.001 and start installation - Fix winch and pulley at the wall - Rout FO cables 20 m outside, 50 m point at bottom hole, 100 m point at hole mouth, 10 m to next borehole - Prepare the lines and the system elements - Insert PT1000 in the corresponding position and extend cable outside for the DAS - Always pull FO strain cable during installation to be able to measure strain during stimulation according to Reza Jalali and Florian Ammann (onsite)
15.12.16	08:00-13:00	KK/Bos/AJ	Continue installation PRP 16.001. To have the strain FO cable on tension at the upper part (grout section), cut small line piece to pass the FO cable through, acting as mini centralizer
16.12.16	07:00-16:00	KK/AJ/ML	Complete installation of PRP 16.001 and start installation of PRP 16.002 using same procedure as for PRP 16.001. Cable routing -> 50 m point at bottom hole, 100 m point at hole mouth and 10 to next borehole Interval 1, packer 1 and 2 meters rod installed in PRP 16.002. Complete the installation on 19.12.16
19.12.16	08:00-18:00	KK/Bos/AJ	Transport packer system PRP 16.003 and SBH 15.004 to the ISC site Transport cement and grout material to ISC site Transport resin equipment and resin to ISC site Complete installation PRP 16.002 Start installation PRP 16.003. Push the system without winch. Cable routing -> 40 m point at bottom hole, 80 m point at hole mouth and leave the rest to be connected to the corresponding DAS from ETH
20.12.16	07:00-18:00	KK/Bos/AJ	Complete installation of PRP 16.003
21.12.16	07:00-18:30	KK/Bos/AJ	Installation of SBH 15.004. Installation completed. Keep a 3rd line for possible re-injections if necessary after the holidays Prepare resin equipment and material to perform resin injection at PRP 16.001 - Inject resin in resin section 1 -> total injected weight 17.54 kg - Inject resin in resin section 2 -> total injected weight 8.6 kg Prepare resin injection for PRP 16.003 as the interval is smaller than in PRP 16.002 and will require less time - Inject resin in resin section 1 of 16.003 -> total injected weight 9 kg Axel Fabritius from GTC onsite, splice the FO cable and put the connector at the beginning of the cable. Prepare the cable end for ETH. The strain cable was not cut as it has a connector at the cable end at 400 m
22.12.16	07:00-12:30	KK	Connection of all pressure and temperature sensor to DAS
22.12.16	07:00-12:30	Bos/AJ	Grout injection in all 4 systems (AJ leaves the site at 12:30)
22.12.16	13:45-18:00	KK/Bos	Resin injection at PRP 16.002-interval 2: - Mix 6 kg Webac resin and start injection - Mix 6 kg Denepox resin and continue injection -> injection became difficult even by applying high pressure maybe due to 2 different resins. Injecting from injection line is not possible, need to inject from the extraction line

Date	Time (DAS)	Who	Action
			- Mix 6 kg Denepox resin and continue injection from the extraction line, fast injection, need to check if resin flows to water interval-> check the Q line of interval 2 to see if there is any bypass -> resin flows out -> stop resin injection and inject water at 7 bar into the extraction line of interval 2 to wash out resin and avoid blocking of the whole interval. Total injected weight 16.2 kg (KK leaves the site)
23.12.16	07:00-12:00	Bos	Check PRP 16.002-int 2 -> Q line is full of resin but interval still full of water, pressure can be monitored. Tidy up and demobilise material. Travel back to Solexperts
17.01.2017	07:00-11:30	KK/AJ	Cement injection inside the system tubes to achieve more stability as per agreement with ETH. The whole length of PRP 16.001, PRP 16.002 and PRP 16.003 systems is grouted until the top. 7.5 bags X 25 Kg used. Estimated total volume 230 L. 2 L was injected into grout interval of SBH 15.004 from the 3rd additional line.

Abbreviations:

KK: Karam Kontar
Bos: Markus Bosshard
AJ: Adem Jakupi
ML: Markus Lutz

Remark: ETH crew was onsite during the entire installation period

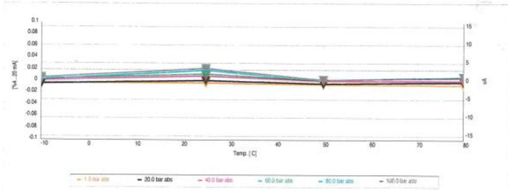
Appendix D: Calibration sheets, wiring diagrams of DAS components, fibre optic cable and resin data sheets

Prüfprotokoll
Calibration certificate / Fiche de calibration

Typ : Type / Type	PAA-33X / 100bar / 80794.5			
Serienummer : Serial no./ No. de serie :	535560			Produkt Nummer : 233305.0520 (Product no./ No. de produit :)
Messbereich : Measurement range / Etendue de mesure :	0	...	100	bar abs
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
	⊕	:	CASE	

Bemerkung :
Remark / Remarque :

Abweichung analoges Ausgangssignal
Deviation analog output signal / Deviation signal de sortie



Linearitätsfehler: Linearity error / Erreur de linearité:	-0.002	%FS(Lbfsl)	@ 25 °C
Totales Fehlerband : Accuracy(TEB)/Erreur total :	-0.006 ... 0.022 %FS	@ -10 ... 80	°C
PrüferIn : Test person / Contrôlé par: GY		Datum : Date / Date :	18.10.2016

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Prüfprotokoll
Calibration certificate / Fiche de calibration

Typ : Type / Type	PAA-33X / 100bar / 80794.5			
Serienummer : Serial no./ No. de serie :	535561			Produkt Nummer : 233305.0520 (Product no./ No. de produit :)
Messbereich : Measurement range / Etendue de mesure :	0	...	100	bar abs
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
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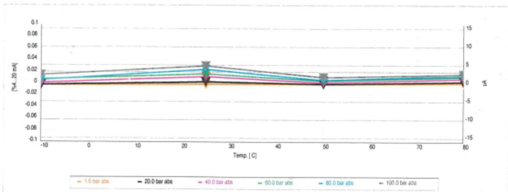
Bemerkung :
Remark / Remarque :

Abweichung analoges Ausgangssignal
Deviation analog output signal / Deviation signal de sortie



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PrüferIn : Test person / Contrôlé par: GY		Datum : Date / Date :	18.10.2016

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Prüfprotokoll
Calibration certificate / Fiche de calibration

Typ : Type / Type:	PAA-33X / 100bar / 80794.5			
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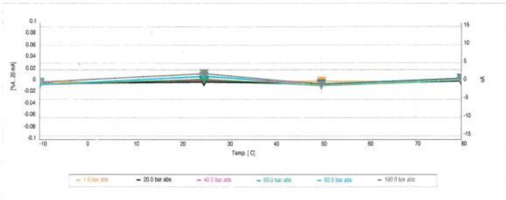
Messbereich : Measurement range / Etendue de mesure :	0	...	100	bar abs
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
	⊕	:	CASE	

Bemerkung :
Remark / Remarque :

Abweichung analoges Ausgangsignal
Deviation analog output signal / Deviation signal de sortie



Linearitätsfehler: Linearity error / Erreur de linearité:	0.002	%FS(Lbfsl)	@ 25 °C
Totales Fehlerband : Accuracy(TEB)/Erreur total :	-0.006 ... 0.013 %FS	@ -10 ... 80	°C
PrüferIn : Test person / Contrôlé par: GY		Datum : Date / Date :	18.10.2016

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Prüfprotokoll
Calibration certificate / Fiche de calibration

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Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
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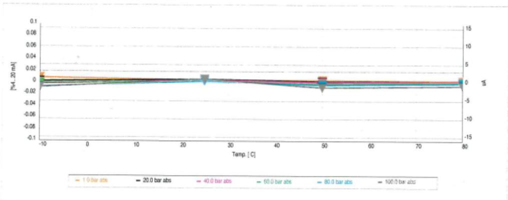
	3	:	+Vcc	
	⊕	:	CASE	

Bemerkung :
Remark / Remarque :

Abweichung analoges Ausgangsignal
Deviation analog output signal / Deviation signal de sortie



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PrüferIn : Test person / Contrôlé par: GY		Datum : Date / Date :	18.10.2016

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Prüfprotokoll
Calibration certificate / Fiche de calibration

Typ : Type / Type:	PAA-33X / 100bar / 80794.5			
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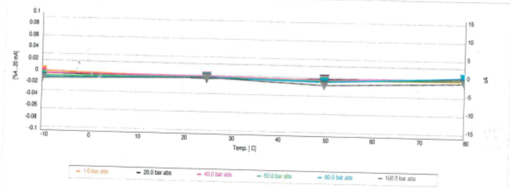
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
	⏚	:	CASE	

Bemerkung :
Remark / Remarque :

Abweichung analogs Ausgangsignal
Deviation analog output signal / Deviation signal de sortie



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PrüferIn : Test person / Contrôlé par:	GY	Datum : Date / Date :	18.10.2016

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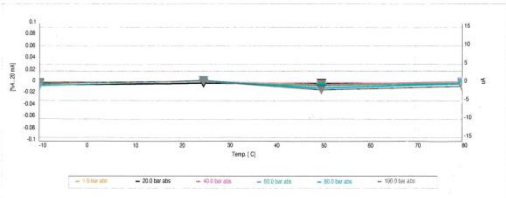
Prüfprotokoll
Calibration certificate / Fiche de calibration

Typ : Type / Type:	PAA-33X / 100bar / 80794.5			
Serienummer : Serial no./ No. de serie :	535565			Produkt Nummer : 233305.0520 Product no./ No. de produit :
Messbereich : Measurement range / Etendue de mesure :	0	...	100	bar abs
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
	⏚	:	CASE	

Bemerkung :
Remark / Remarque :

Abweichung analoges Ausgangsignal
Deviation analog output signal / Deviation signal de sortie



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Totales Fehlerband : Accuracy(TEB)/Erreur total :	-0.013 ... 0.004 %FS	@ -10 ... 80	°C
PrüferIn : Test person / Contrôlé par:	GY	Datum : Date / Date :	18.10.2016

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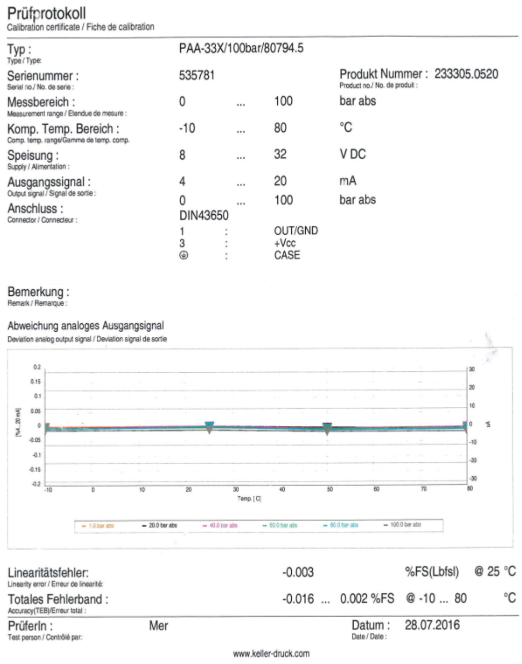

Prüfprotokoll
Calibration certificate / Fiche de calibration

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Messbereich : Measurement range / Etendue de mesure :	0	...	100	bar abs
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
	⊕	:	CASE	

Bemerkung : Remark / Remarque :

Abweichung analoges Ausgangssignal
Deviation analog output signal / Deviation signal de sortie

Linearitätsfehler: Linearity error / Erreur de linearité:	-0.003	%FS(Lbfsl)	@ 25 °C
Totales Fehlerband : Accuracy(TEB)/Erreur total :	-0.016 ... 0.002 %FS	@ -10 ... 80	°C
PrüferIn : Test person / Contrôlé par: Mer		Datum : Date / Date :	28.07.2016

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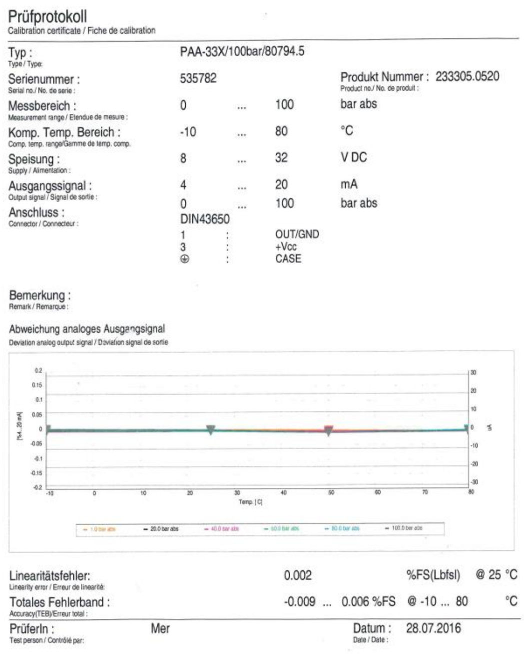

Prüfprotokoll
Calibration certificate / Fiche de calibration

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Messbereich : Measurement range / Etendue de mesure :	0	...	100	bar abs
Komp. Temp. Bereich : Comp. temp. range/Gamme de temp. comp.	-10	...	80	°C
Speisung : Supply / Alimentation :	8	...	32	V DC
Ausgangssignal : Output signal / Signal de sortie :	4	...	20	mA
	0	...	100	bar abs
Anschluss : Connector / Connecteur :	DIN43650			
	1	:	OUT/GND	
	3	:	+Vcc	
	⊕	:	CASE	

Bemerkung : Remark / Remarque :

Abweichung analoges Ausgangssignal
Deviation analog output signal / Deviation signal de sortie

Linearitätsfehler: Linearity error / Erreur de linearité:	0.002	%FS(Lbfsl)	@ 25 °C
Totales Fehlerband : Accuracy(TEB)/Erreur total :	-0.009 ... 0.006 %FS	@ -10 ... 80	°C
PrüferIn : Test person / Contrôlé par: Mer		Datum : Date / Date :	28.07.2016

Figure D-1: Pressure sensor calibration sheets

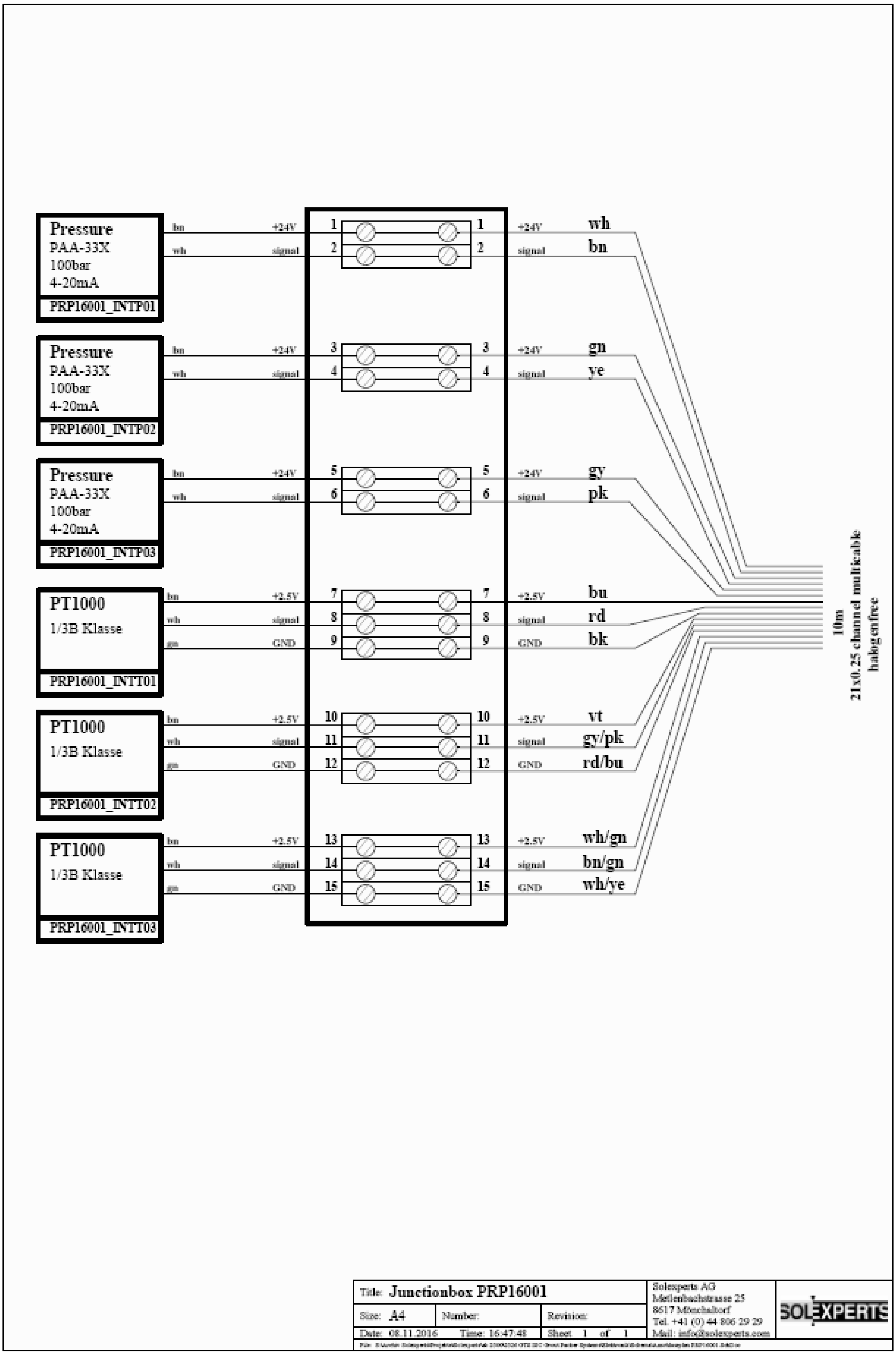


Figure D-2: Wiring diagram of junction box for PRP 16.001 sensors

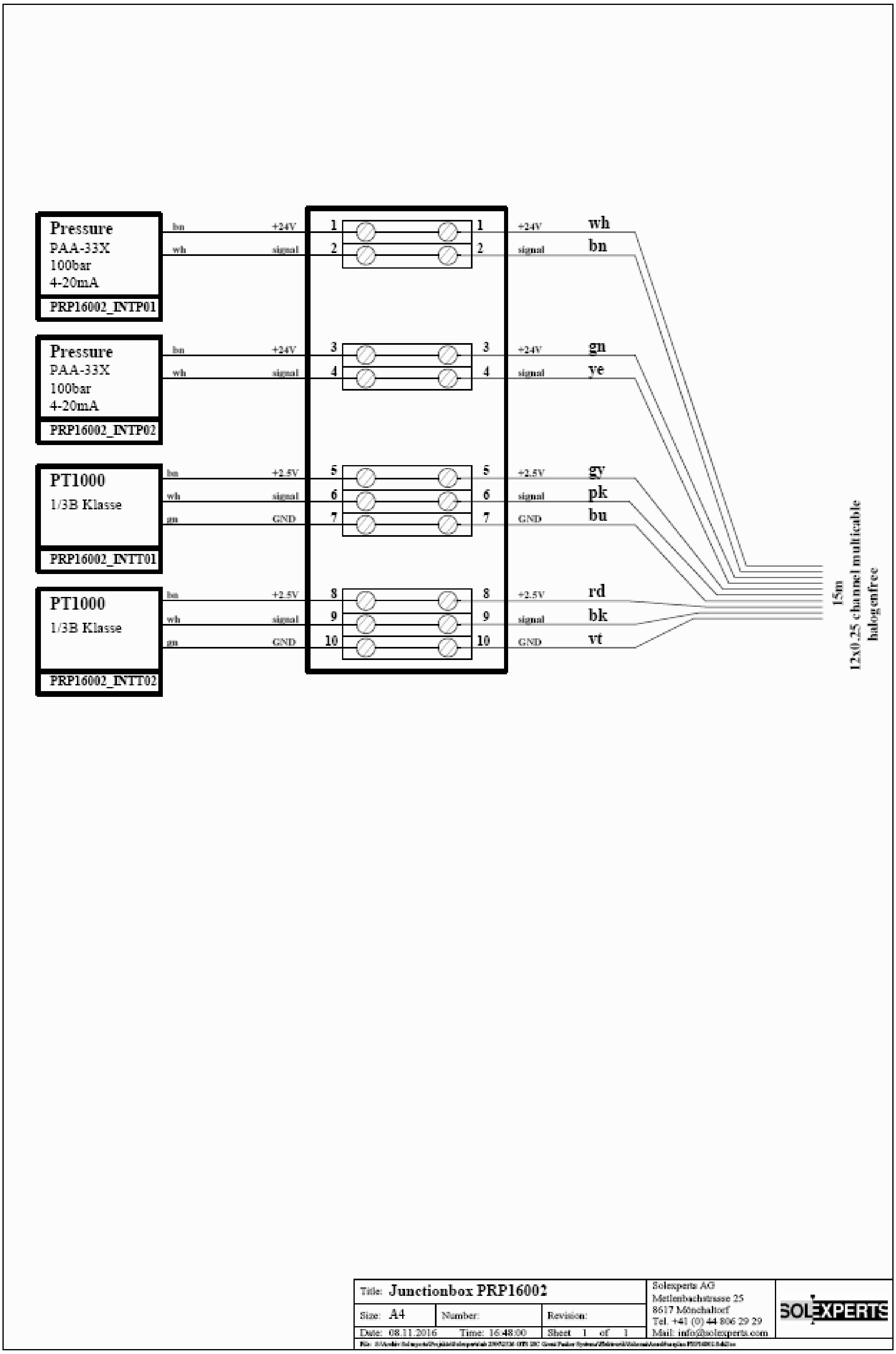


Figure D-3: Wiring diagram of junction box for PRP 16.002 sensors

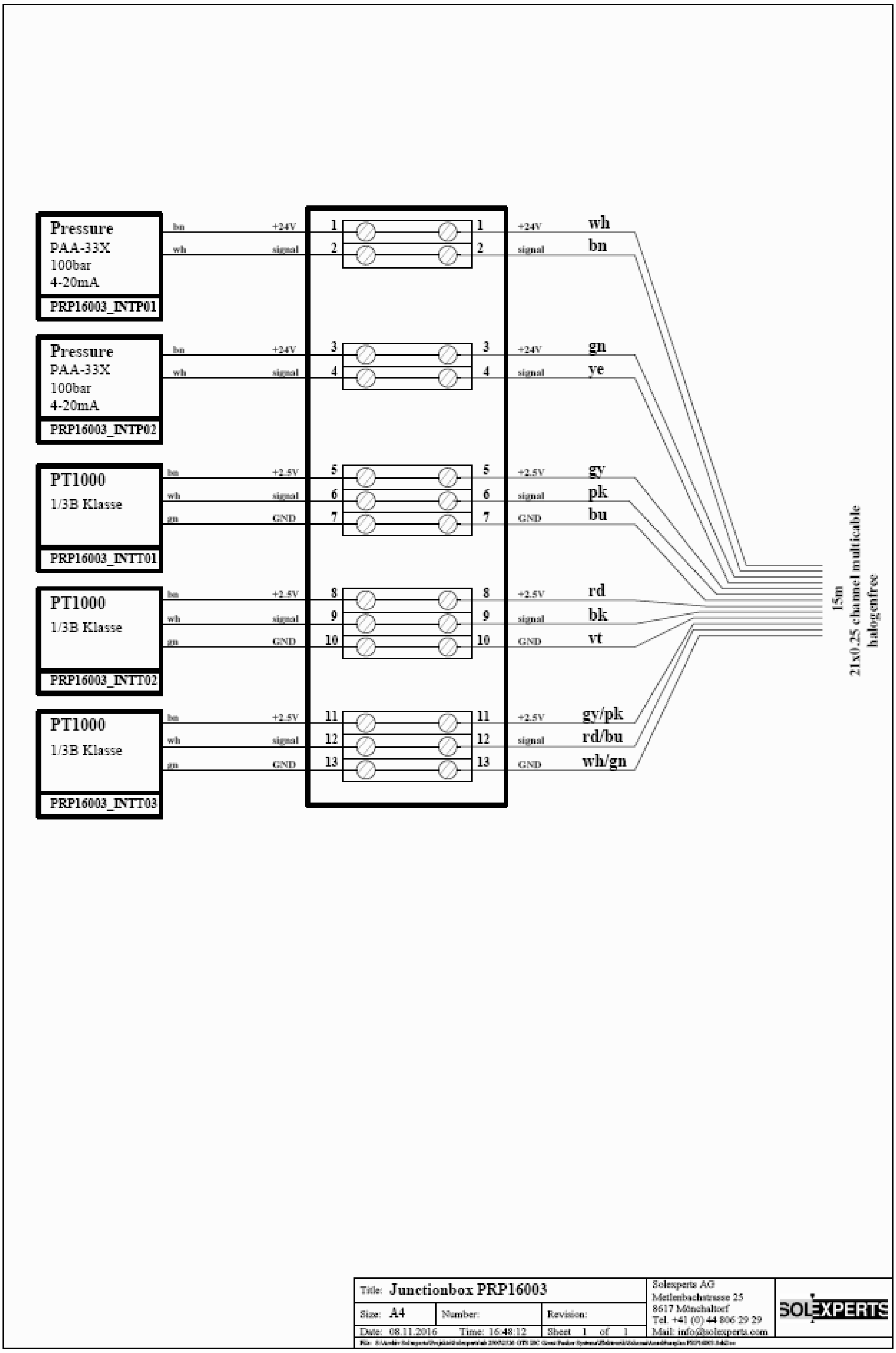


Figure D-4: Wiring diagram of junction box for PRP 16.003 sensors

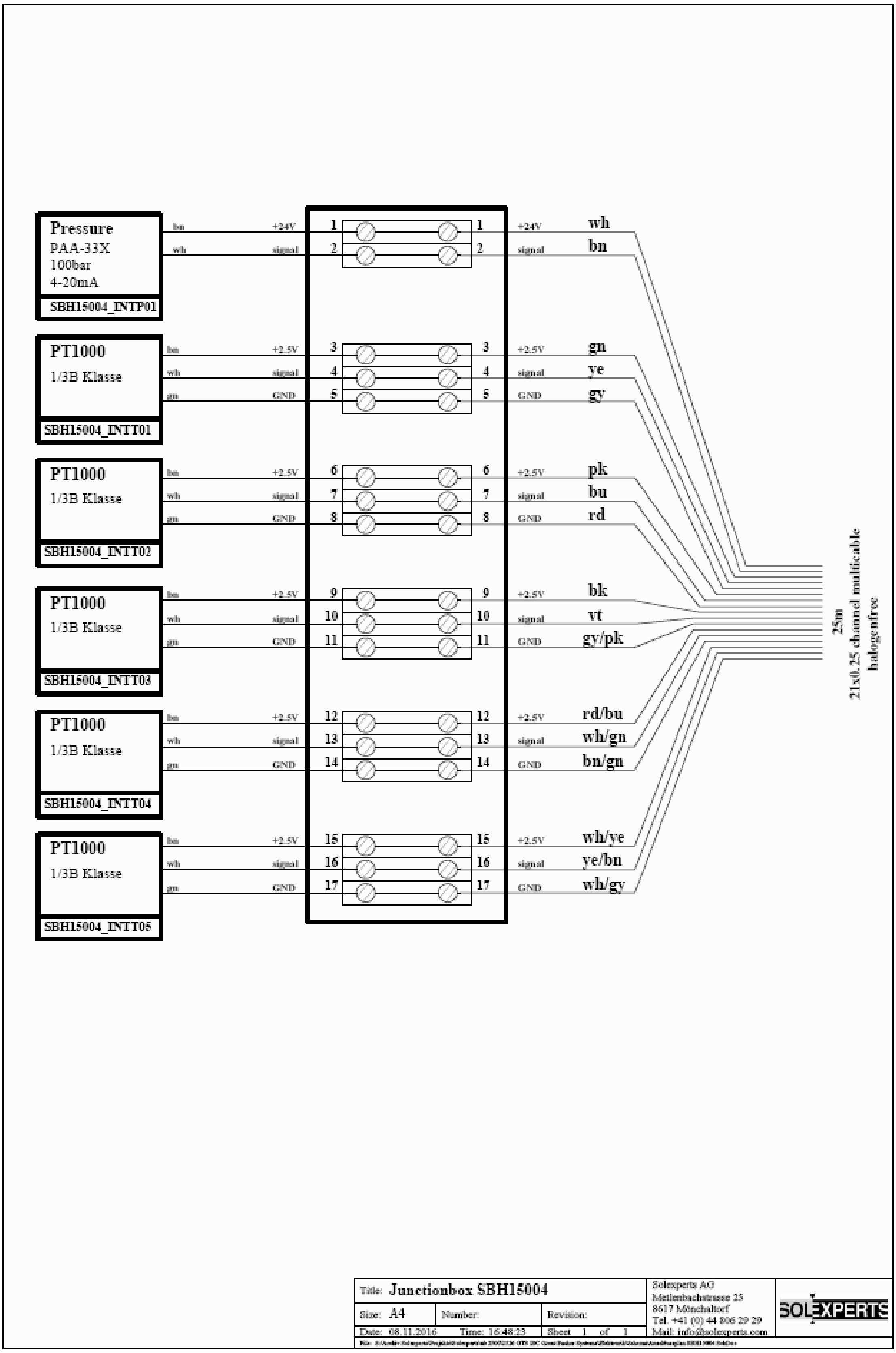


Figure D-5: Wiring diagram of junction box for SBH 15.004 sensors

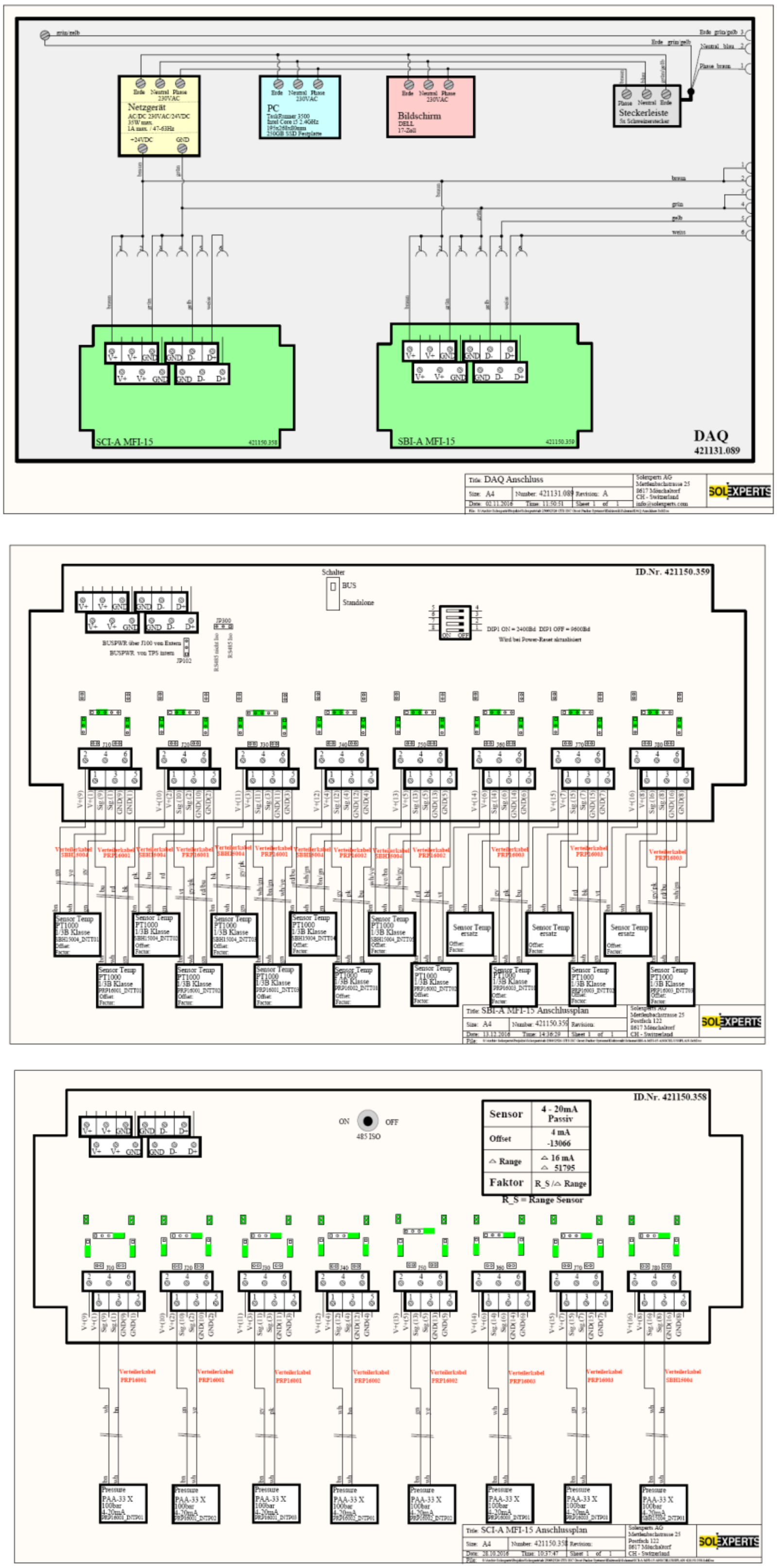
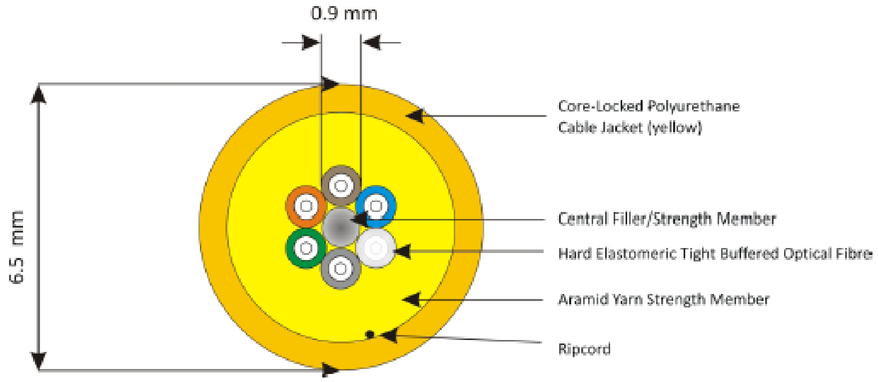


Figure D-6: Wiring diagrams of DAS and fast logger interfaces

Specification
PS-2S4M-1PU065-01-Y
6 Channel Tight Buffered Fibre Optic Cable



* Drawing not to scale

Typical characteristics

Fibre Code/Type	OM2/Multimode		Singlemode / ITU-T G.652.A	
Fibre Count	4		2	
Core Diameter	50 µm		9 µm	
Cladding Diameter	125 µm		125 µm	
Primary Coating Diameter (UV cured acrylate)	500 µm		500 µm	
Secondary Buffer Diameter (hard elastomeric)	900 µm		900 µm	
Numerical Aperture	0.20		--	
Proof Test Level	100 kpsi		100 kpsi	
Wavelength	**850 nm**	**1310 nm**	**1310 nm**	**1550 nm**
Maximum Attenuation	3.5 db/km	1.5 dB/Km	0.5 dB/Km	0.5 dB/Km
Bandwidth	500 MHz-Km	500 MHz-Km	-	-
Nominal Zero Dispersion Slope			.092 ps/(nm^2 Km)	

Mechanical Properties

Cable Diameter	6.5 mm (0.26 in)
Total Cable Weight	38 kg/km (26 lbs/1000')
Installation:	
Max. Tensile Load	1,800 N (360 lbs)
Min. Bend Radius	9.6 cm (3.8 in)
Operating:	
Max Tensile Load	600 N (130 lbs)
Min Bend Radius	6.5 cm (3.9 in)
Impact Resistance	1500 impacts
Crush Resistance	1800 N/cm
Operating Temperature	-55ºC to +85ºC
Storage Temperature	-70ºC to +85ºC

Silixa Ltd
Silixa House, Centennial Park
Centennial Avenue, Elstree
WD6 3SN, UK

t: +44 (0) 208 327 4210
f: +44 (0) 208 953 4362
w: www.silixa.com
e: enquiries@silixa.com

Figure D-7: Fibre optic temperature cable specifications

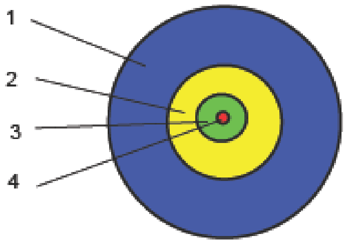
Fibre Optic Sensing Cables

BRUsens strain V1

3_50_2_004

LLK-BSST V1 2.8 mm

Small, lightweight, sensitive, metal free fiber optic strain sensing cable, one optical up buffered fiber, protection and strain transfer layer, EPR outer sheath, strain range up to 1% (10000 µstrain)



Construction:
- 1) EPR outer sheath
- 2) Plastic protection layer with interlocking system
- 3) Multi layer buffer and strain transfer layer with interlocking system
- 4) Special strain sensing optical single mode fiber

Description:
- One tight buffered optical fiber
- Longitudinally and laterally watertight
- All dielectric design
- High strain sensitivity
- Compact design, good flexibility, small bending radius
- Robust outer sheath
- Halogen-free cable sheath

Applications:
- Distributed strain sensing
- Sensing technologies: Brillouin, FBG
- Precision measurement and alarm systems
- Soil movement, ground monitoring
- Pipeline monitoring
- Structural monitoring
- Direct burial in sand layers
- Harsh environment, outdoors

Standard optical fiber:
- Single-mode fiber: ITU-T G.657
- Other fiber types and fiber quality available upon request

Temperature range:
- Operating temperature: - 30° C ... +70° C
- Storage temperature: - 40° C ... +70° C
- Installation temperature: - 10° C ... +50° C

Cable sheath color:
- Blue, similar RAL 5005
- Other colors upon request

Standards:
- Cable tests complying with IEC 60794-1-2

Remarks:
- Fiber colored
- Final test reports OTDR, BOTDA measurement available upon request
- Other cable designs and temperature ranges available
- Standard cable marking with meter marks, special labeling of outer sheath upon request
- Preassembled cable sets available, special field termination kit available
- Accessories such as anchors, loops, fan-outs, splice enclosures, connectors, etc. available
- Deployment training upon request
- For improved UV resistance, black cable sheath available upon request

Technical data:

Type	Max. no. of fibres	Cable ø	Weight	Max. tensile strength installation	Typical Load at 1% elongation
	units	mm	kg/km	N	N
1F	1	2.8	5.9	5	26

Type	Min. bending radius		Max. crush resistance
	with tensile mm	without tensile mm	N/cm
1F	56 (20xD)	42 (15xD)	150

Optical fiber data (cabled) at 20°C

Fiber Type	Attenuation, dB/km 1550 nm	Typical Brillouin parameters BOTDR or BOTDA at 1550 nm		
		Temperature sensitivity df_B / dT	Strain sensitivity $df_B/d\varepsilon$	Centr. Brillouin Freq.
SMF	≤ 0.5	≈ 4.2 MHz/K	≈ 450 MHz/%	10.5 GHz

BRUGG CABLES Well connected.
SENSING TECHNOLOGIES
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Figure D-8: Fibre optic strain cable specifications technical data sheet

Denepox 40

An ultra low viscosity, 2-component epoxy injection resin for structural injections in concrete. Denepox 40 can be used in a dry or wet environment.



• field of application

- Low pressure injection for the structural bonding of cracks and micro-cracks in dry or wet concrete.
- Bonding and anchoring.
- Sealing of porous low density concrete.
- Denepox 40 is not suited for applications in contact with moving water.

• advantages

- Insensitive to humidity.
- Cures in damp/wet environment.
- Low viscosity: deep penetration in the cracks.
- Very good adhesion: exceeds the cohesion of the concrete.
- Solvent free.
- Long pot life.
- Cured Denepox 40 is resistant to acids, alkalis, oils, greases and petroleum derivatives(*).

• description

Pre-weighted 2-component epoxy resin, which cures into a rigid compound.

• application

1. Surface preparation

Surfaces to be repaired or sealed need to be clean and sound. The concrete surface must be free of dust, laitance, sealers, grease or any other contaminants that might influence bonding of the resin to the concrete.

2. Injection ports

Entry ports for injecting should be approved devices spaced at appropriate intervals to accomplish full penetration of the resin into the cracks or voids.

Drilled ports

- Drilling of cracks for packers needs to be executed in accordance with local regulations. After drilling the hole, insert packer.

Glued ports (plastic or metal)

- The injection ports should be fixed to the surface of the crack with Multitek Adhesive SD (dry surface) or Multitek Adhesive SDW (damp surfaces).
- Apply a layer of Multitek Adhesive SD, Multitek Adhesive SDW (damp surfaces), polyester paste or fast curing cement to the surface of the crack.

de neef® conchem

ISO 9001

3. Mixing

- Mix the pre-weighted quantities of resin (A-component) and hardener (B-component) with a low speed mixer (300 rpm) until a homogeneous liquid is obtained. Never mix more material than the quantity that can be used up within 60 minutes.
- Mixing ratio A/B = 100/30 (mass).
  91/32 (volume).

4. Injection

- The crack can be injected with a manual (single piston) pump or a mechanical (single or double piston) injection pump.
- Initial hardening time: approx. 24h. at 20°C.
- Uncured material and equipment should be cleaned with solvent MEK.

• technical data/properties

Property	Value	Norm
Bonding strength on dry concrete	Exceeds coherence of concrete	ISO 4624
Bonding strength on damp concrete	Exceeds coherence of concrete	ISO 4624
Compressive strength	Approx. 100N/mm²	NBN EM 196
Tensile strength	> 50 N/mm²	
Bending strength	> 60 N/mm²	NBN EM 196
Elongation at break	< 10%	
Glass transition temperature	> 60°C	EN 12614
Density	1-1,1 kg/dm³	
Viscosity (mixture) at 25 °C	Approx. 85	Test DNC
Pot life	Approx. 80 minutes (100 g at 25°C)	Test DNC
Minimum application temperature	Approx. 10°C	

Full chemical or mechanical resistances are only reached after a curing period of 7 days at 20°C. Mechanical properties of epoxy resins decrease at temperatures higher than 50°C

• appearance

Pre-weighted

A-component : epoxy resin, transparant.
B-component : polyamine hardener, light yellow.
Colour : transparent.

• consumption

Has to be estimated by the engineer or operator and depends on width and depth of the cracks and voids.

• packaging

Denepox 40 (3 kg set)

A-component: metal pail

net : 2,3 kg (gross: 2,47 kg).

B-component: metal pail

net : 0,7 kg (gross: 0,78 kg).

1 box

5 pails of A-component and 10 pails of B-component.

1 pallet

16 boxes of A-component and 8 boxes of B-component.

• storage

Denepox 40 is sensitive to moisture and should be stored in original containers in a dry area. Storage temperature must be between 5°C and 50°C. Once the packaging has been opened, the useful life of the material is greatly reduced and it should be used as soon as possible.

Shelf life: 2 years.

• accessories

To be ordered separately

- IP 1C-Manual hand pump.
- IP 1C-Compact electrical airless diaphragm pump.
- Packers and connectors.
  (Please consult the relevant data sheet).

• health & safety

Denepox 40 A-component is classified as irritating.
Denepox 40 B-component is classified as corrosive.
Always wear protective clothing, gloves and protective goggles.
For full information, consult the relevant Material Safety Data Sheet.
(*) For chemical resistance please contact your De Neef representative.

• certification

CE

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EN 1504-5
Concrete Injection
Force transmitted filling of cracks
U (F1) W(3) (1/2) (10/40) (0)

Adhesion by tensile bond strength	≥ 2 N/mm²
Adhesion by slant shear strength	Monolithic failure
Shrinkage	< 3%
Glass transition temperature	> 40°C
Workability	Crack width from 0,3 mm
Moisture state of the crack	dry, damp and wet
Durability	Pass
Corrosion behaviour	Deemed to have no corrosive effect
Dangerous substances	Complies with 5.4

Figure D-9: Epoxy resin technical data sheet