Geothermics 71 (2018) 320–330

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Quality management and improvement for geothermal energy projects using the platform-based tool development technology – ZWERG

Benedict Holbein*, Stefan Dietze, Franziska Hurst, Jörg Isele, Luigi Spatafora, Friedrich Wiegel, Veit Hagenmeyer

Institute for Applied Computer Science IAI, Karlsruhe Institute of Technology KIT, Germany

ARTICLE INFO

Keywords:
Quality management
Deep geothermal energy
Downhole tools
System platform development
Risk mitigation
Maintenance

ABSTRACT

Operations in deep geothermal boreholes are a technical challenge due to harsh conditions such as high pressures, high temperatures, limited space and corrosive thermal water. Therefore the development of tools for inspection, investigation and maintenance for geothermal applications is a challenging and expensive task. In consequence the operations in most cases are limited to simple measurements of pressure (p), temperature (T) and diameter (caliper). Other restrictions are waving of real-time data transfer and a limitation of operation depths at above the open-hole.

The approach of ZWERG uses know-how from other industrial sectors for a modular design of downhole tools based on a system platform. This way it allows creating reproducible and reusable solutions for the main technical challenges: housing, sealing, compact interior design, heat management and data processing. It is supposed to build the basis for more widespread and more complex applications in deep boreholes and to support an economic development of new tools.

Reliable modular platform solutions for basic challenges support an enhanced quality management for geothermal systems which profits from suitable tools for measurement, inspection, sample recovery, maintenance and repair that can be used all the way from the surface to the open hole.

1. Introduction

Borehole data are important for both scientific investigation and technical usage of geothermal systems. However, even simple measurements such as pressure and temperature logs meet technical limitations. For example, Pfister and Rybach (1995) were able to determine temperatures using a PT100 sensor at a 2-km depth, 200 bar and up to 150 °C with an absolute accuracy of ± 0.05 °C compared to 0.001 °C of the sensor. At about > 125 °C, temperature becomes a critical factor. Targeting the development of tools for supercritical reservoir characterization above 300 °C, e.g. in the FP7 project HiTI (Asmundsson et al., 2014) successful tests of different temperature logging tools were presented. Distinctive temperature sensing using fiber optics allowed measurements up to 300-m depth and a wireline sensor for temperature measurements was demonstrated at 316 °C. Additionally, memory based tools for temperature, pressure, fluid flow and casing collar measurement using a slick-line were developed and tested. Since direct measurements beyond these condition such as temperature logging in the IDDP-2 well in Iceland at 426 °C require cooling (Friđleifsson et al., 2017), temperature and hydraulic data are often derived from water-rock interaction and tracer tests.

In addition to the acquisition of reservoir parameter, harsh conditions are also a challenge during drilling, operation and maintenance of the well. In MWD technology, silicon-based high temperature electronics for directional MWD at > 300 °C provided limited power for components such as FPGAs or controller ICs. Thus, an active cooling system for cooling from 300 °C to 175 °C for a limited time was developed (Chatterjee, 2015). In the extreme case of the IDDP-1 well at temperatures of 450 °C and pressures of < 150 bar, the well was quenched with cold water before video inspection was carried out (Ingason et al., 2014).

Generally, technologies that are missing the step from laboratory level to downhole operation ability are chemical sensors, which require electronics for data recovery and transmission in a housing with heat shield and cooling system for longer operations (Gerlach et al., 2014). Optical sensors for water analysis or borehole wall inspection require optical windows, thus a ceramic metal connection for the given ambient constraints as well as protected electronics able to process visual data are required (Sauer et al., 2014). In general, there is a lack in seismic measurement devices for real-time monitoring during drilling (Jakusch,

* Corresponding author at: Hermann-von-Helmholtz Platz 1, 76344 Eggenstein-Leopoldshafen, Germany.
E-mail address: Benedict.holbein@kit.edu (B. Holbein).

http://dx.doi.org/10.1016/j.geothermics.2017.10.010
Received 22 June 2017; Received in revised form 20 September 2017; Accepted 17 October 2017
Available online 06 November 2017

Nomenclature

Acronyms

ADC	Analog digital converter
CAN	Controller area network
DAC	Digital analog converter
DDR3L	Double data rate low power 3rd generation
DDRM	Double data rate memory
I^2C	Inter-Integrated circuit communication
SD/SDIO	Serial Digital/Serial digital input output
SNR	Signal noise ratio
UART	Universal asynchronous receiver transmitter
ZWERG	Name of platform approach with basic components and modules for downhole tools

Symbol

A	Surface (m^2)
cp	Heat capacity (kJ/(kg*K))
D0	Outer diameter (m)
Db	Borehole diameter (m)
E	E-modulus (N/mm^2)
f1	Wall reduction factor (–)
f2	Abrasion factor (–)
L	Length (m)
m	Mass (kg)
p	Pressure (Pa)
Q	Heat (J)
Rp0.2%	Elastic limit (N/mm^2)
S	Plastic security factor(–)
s	Distance (m)
s	Entropy (kJ/(kg*K))
SK	Elastic security factor (–)
t	Time (s)
u	Un-roundness factor (–)
W	Power (W)
Δhv	Evaporation enthalpy (kJ/kg)
ΔT	Temperature gradient (K)
λ	Heat conductivity (W/(m*K))
ν	Poissońs ratio (–)

2014). Therefore, a sufficient energy supply and electronics for processing as well as components for heat management are necessary.

Here, we present a comprehensive concept for logging and sampling geothermal wells that addresses harsh conditions that are encountered in geothermal wells. The ZWERG system platform approach is the first to target complete mastering of geothermal wells by engineering methods. This includes real-time remote controlled tools for measurement but also more complex operations as video-inspection, fully controlled sample taking, downhole tracer testing and maintenance operations as downhole repair of casing leakages. In a first step, the modular system platform with important components is being developed matching the Soultz-sous-Forêts' reservoir condition with 200 °C, 600 bar at 5.000 m depth and open-hole diameter 8 ½ inch (Gerard et al., 2006). Supported by a modular design, the platform solutions will be enhanced subsequently.

The following sections describe the modular system platform concept (Section 1) and important components managing the challenging pressure and corrosion (Section 2), space and weight restrictions (Section 3), heat management including insulation and cooling (Section 4) as well as data processing and transfer (Section 5).

2. Modular system platform concept

In large industry sectors, the system platform approach is a common method to allow rapid development and the continuous realization of new products at reduced costs and without quality losses (Sheridan, 2013; Danilovic et al., 2007). This is done in the complex interplay between main corporations and suppliers for different components and modules, by following a structured modular design concept (Münster et al., 2016). A basic element in this strategy is the combination of parts and components from different producers in complete end products (Lemke, 2017).

The system platform concept for borehole tools in deep geothermal boreholes is illustrated in Fig. 1 together with examples for the different component types, functional modules and complete tools.

The system platform contains basic components, which are identified to be necessary for every wireline operation, including pressure resistant housing, energy supply, heat shield, cable connection, control electronics, housing connectors and seals among others. In combination with functional modules, as − camera or cooling systems −, functional tools can be completed. The platform is supposed to be usable also

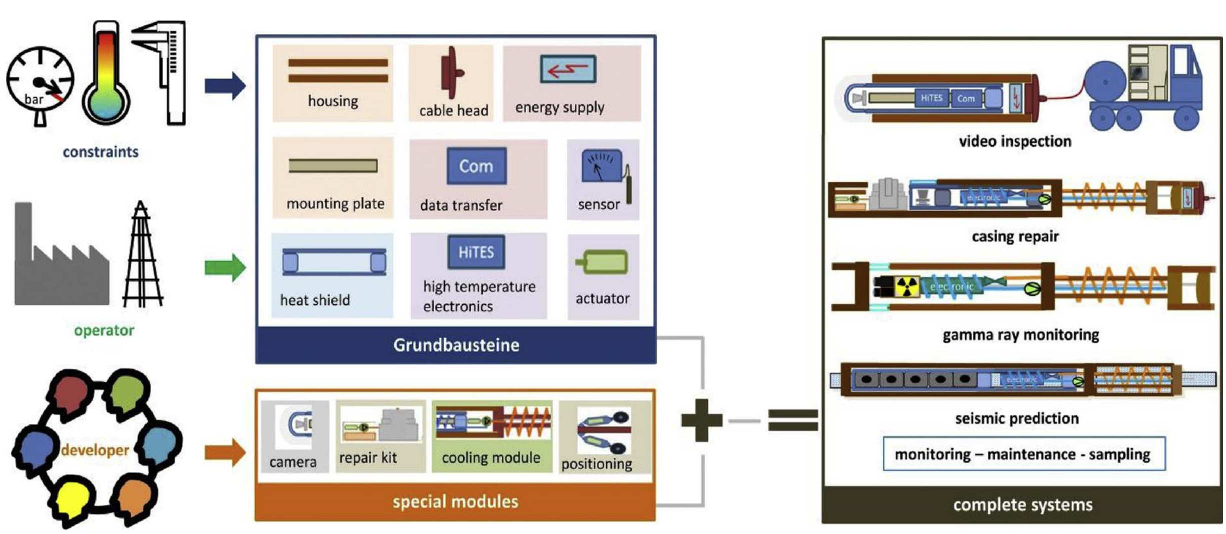

Fig. 1. System platform concept for borehole tools in deep geothermal boreholes with basic components, special modules and complete systems of the open-source system-platform ZWERG.