Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

ADVANCED DRILLING THROUGH DIAGNOSTICS-WHILE-DRILLING

Arthur Mansure,[1] John Finger,[1] Michael Prairie,[1] David Glowka,[2] and Bill Livesay[2]
[1]Sandia National Laboratories, [2]Consultant
P.O. Box 5800, Albuquerque, NM 87185-1033, USA

Key Words: geothermal, drilling, telemetry

ABSTRACT

A high-speed data link that would provide dramatically faster communication from downhole instruments to the surface and back again has the potential to revolutionize deep drilling for geothermal resources through Diagnostics-While-Drilling (DWD). Many aspects of the drilling process would significantly improve if downhole and surface data were acquired and processed in real-time at the surface, and used to guide the drilling operation. Such a closed-loop, driller-in-the-loop DWD system, would complete the loop between information and control, and greatly improve the performance of drilling systems.

The main focus of this program is to demonstrate the value of real-time data for improving drilling**.** While high-rate transfer of down-hole data to the surface has been accomplished before, insufficient emphasis has been placed on utilization of the data to tune the drilling process to demonstrate the true merit of the concept. Consequently, there has been a lack of incentive on the part of industry to develop a simple, low-cost, effective high-speed data link.

Demonstration of the benefits of DWD based on a high-speed data link will convince the drilling industry and stimulate the flow of private resources into the development of an economical high-speed data link for geothermal drilling applications**.** Such a downhole communication system would then make possible the development of surface data acquisition and expert systems that would greatly enhance drilling operations. Further, it would foster the development of downhole equipment that could be controlled from the surface to improve hole trajectory and drilling performance.

Real-time data that would benefit drilling performance include: bit accelerations for use in controlling bit bounce and improving rock penetration rates and bit life; downhole fluid pressures for use in the management of drilling hydraulics and improved diagnosis of lost circulation and gas kicks; hole trajectory for use in reducing directional drilling costs; and downhole weight-on-bit and drilling torque for diagnosing drill bit performance. In general, any measurement that could shed light on the downhole environment would give us a better understanding of the drilling process and reduce drilling costs.

1. INTRODUCTION

Drilling is an essential, ubiquitous, and expensive part of the oil, gas, geothermal, minerals, water-well, and mining industries. Improving the drilling process carries great interest, but research targets are not obvious because the technology is very mature. Drilling technology improvements can fall in one of two categories: reducing the cost of conventional drilling processes, where "conventional" includes even high-risk, high-cost operations such as off-shore horizontal drilling; or providing a revolutionary new capability that did not exist, regardless of cost.

DWD is a technology that addresses both kinds of drilling improvement. The central concept of DWD is a closed feedback loop, carrying data up and control signals down, between the driller and tools at the bottom of the hole. Up-coming data will give a real-time report on drilling conditions, bit and tool performance, and imminent problems. The driller can use this information to either change surface parameters (weight-on-bit, rotary speed, mudflow rate) with immediate knowledge of their effect, or to send control signals back to active downhole components. DWD will reduce costs, even in the short-term, by improving drilling performance, increasing tool life, and avoiding trouble. Its longer-term potential includes variable-damping shock subs for smoother drilling, self-steering directional drilling, and autonomous "smart" drilling systems that analyze data and make drilling decisions downhole, without the driller's direct control.

2. SYSTEM DESCRIPTION

Specifications for a DWD system are driven by four functional requirements:

1) Identify the information that is useful to the driller.
2) Process surface and downhole measurements to provide that information.
3) Collect downhole data with appropriate sensors.
4) Use telemetry to bring downhole data to the surface and return control signals downhole.

These four requirements translate into hardware and software needs, as shown by the schematic of a DWD system in Figure 1. Data from all parts of the drilling system, both downhole and on the surface, will be acquired, analyzed, and displayed for the driller at a rate fast enough to provide feeling of response.

EXAMPLE: *The driller will be able to watch a trace of weight-on-bit, measured at the bit. If the bit is bouncing, which is often the case, the driller would try to attenuate this by adjusting rotary speed and/or weight-on-bit at the surface. Research has shown that it is possible to eliminate bit bounce by adjusting these parameters (Heisig et al.).*

The following components make up the DWD system:

DWD TOOL, to acquire data from downhole sensors, condition it for transmission, and deliver it to the high-speed data link;

HIGH-SPEED DATA LINK, which carries downhole information to the surface and carries surface control signals back downhole;

DRILLING ADVISORY SOFTWARE, which acquires, analyzes, and displays downhole and surface data in real time to provide the driller with a complete and accurate status of drilling conditions and system performance;

DRILLER, who uses traditional methods as well as the Drilling Advisory Software to direct the drilling process, setting controllable drilling parameters at their optimal levels;

DRILL RIG/DRILL PIPE, which is the primary component the driller uses to interact with the drilling process through weight-on-bit, rotary speed, and mud flow.

3. DATA RATE REQUIRED FOR DWD

To meet the goal of the driller "visualizing and feeling" what is happening downhole a high data rate is required. The most common drilling telemetry technology is 'mud pulse telemetry.' In this technique, pressure pulses in the mud are used to digitally encode information. The technique is very slow, typically <5 bits/s. With this technique it is only possible to send flags indicating drilling dysfunction updating the driller's console approximately every 8 sec. (see Table 1). If the bandwidth is shared with other MWD functions the refresh slows to about once every 2 minutes. Drill bit dynamics can change from stable to large oscillations, capable of damaging bits, in tens of seconds (Warren et al.). Thus mud pulse telemetry is incapable of adequately supporting DWD.

Rudimentary DWD becomes possible when the bit rate approaches 1k/s. Full function DWD requires bit rates approaching 100k/s (see Table 1).

4. TECHNICAL CHALLENGES

Considering the components discussed above, development of a DWD system appears to face four major technical challenges: the high-speed data link; the drilling advisory software; the surface-controllable downhole tools; and advanced downhole sensors.

- The principal technical challenge in the DWD system is the high-speed data link. To minimize downhole signal processing, the data link should have a high transmission rate, e.g. 100 kbits/sec.
- Of the critical elements shown in Figure 1, the only one for which prototypes do not currently exist is software for the driller's console. Raw data is of little value to the driller, so a major task in this project is to work with the driller and determine the best way of processing and presenting the data.
- With a high-speed data link to transmit control signals downhole and transmit sensor data back uphole, a wide range of downhole tools that have not been feasible to this point will become practical.
- Development of advanced downhole sensors with high-temperature, high-shock capability may be evolutionary from existing devices, but may require significant innovation. This will become clearer after the proof-of-concept tests help to refine a list of measurements to be taken and conditions under which the sensors will have to operate.

5. PROGRAM PLAN

The program to develop an advanced DWD system will have four phases:

- Phase 1 – Project planning and consortium development,
- Phase 2 – Proof-of-Concept testing – assembly of a prototype DWD system, using modified existing downhole components and a hardwired data link, and demonstration of its benefits through field tests,
- Phase 3 – Development of systems needed for cost-effective, commercialized DWD for the geothermal and O&G industries, and
- Phase 4 – Research, development and field-testing of enhanced (primarily surface-controllable) tools for DWD applications.

The program is currently in Phase 2. The entire program is a joint endeavor with industry, universities, and US DOE. As the program progresses, if successful, funding will shift from the DOE to industry.

6. RATIONALE

Without this aggressive approach to lower costs, geothermal energy will not capture a significant portion of the world's growing demand for electricity. DOE and Sandia have worked for more than 20 years to reduce drilling cost through a combination of incremental and revolutionary improvements in drilling technology, and are well positioned to lead this activity. Coupling geothermal drilling expertise to the vast technology resources that support the DOE weapons program, Sandia is in an unparalleled position to lead the DWD Program. DOE/OGT funding will catalyze the program and assure that the technology is available to enhance worldwide development of geothermal energy, but the geothermal, oil, and gas industries also have crucial roles, through their contributions, in making DWD technically viable and marketable.

7. SUMMARY

A Diagnostics-While-Drilling system, either as a stand-alone tool or as a precursor to a smart, semi-autonomous drilling method, has been industry's goal for years, if not decades. An explanation for their marginal success to date lies more in the cyclic nature of drilling R&D, which rises and falls with the oil market and has been notably volatile for almost twenty years, than in any lack of talent or motivation. Many of the issues that we propose to address in this program can also be attacked more effectively now because of advances in associated technologies such as computing power, information processing, expert systems, and improved materials.

ACKNOWLEDGEMENTS

Sandia is multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

REFERENCES

Heisig, G.; Sancho, J.; and Macpherson, J.D.: "Downhole Diagnosis of Drilling Dynamics Data Provides New Level Drilling Process Control to the Driller," SPE 49206, SPE Annual Technical Conference and Exposition, New Orleans LA, September 27-30 1998.

Warren, T.M.; and Oster, J.H.: "Torsional Resonance of Drill Collars with PDC Bits in Hard Rock," SPE Annual Technical

Conference and Exposition, New Orleans LA, September 27-30 1998.

Bits/s	Information transmitted	Refresh time on driller's console	Benefits/Limitations	Telemetry Technology
4-10	Two dysfunctions & average values	8 sec	After-the-fact information on two drilling problems No real-time data	Existing Mud-pulse
<500	Eight dysfunctions & ten measured parameters	>0.6 sec	Identification of drilling problems Enables control No raw data Requires significant downhole processing	Developmental Acoustic/ Acoustic with repeaters or existing wet-connect systems
>100k	Raw data in real time on all dysfunctions and measured parameters	0.05 sec	Real-time control and optimization Control of downhole subs Advanced diagnostics Raw data for post analysis and system design Minimal downhole processing	Advanced DWD telemetry E.g., fiber optics

Dysfunctions: Bit bounce, whirl, stick/slip, torque shocks, axial acceleration problems, lateral acceleration problems, bending, cutting efficiency (gage, etc.)

Basic Measurements: WOB, torque, bending, pressure (annular, internal), acceleration (3 axes), temperature, magnetic field

Table 1: Data rates compared to what drilling diagnostic information can be transmitted.

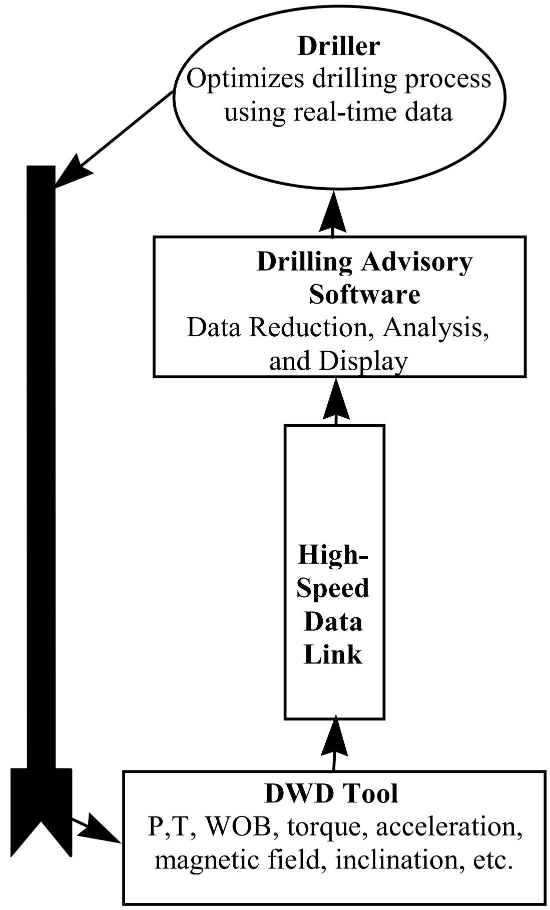

Figure 1 - Schematic representation of the Diagnostics-While-Drilling System