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The All Electric BHA: Recent Developments toward an Intelligent Coiled-Tubing Drilling System

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Abstract

This paper considers the ongoing development of an electrically powered bottom hole assembly that has been designed for use in closed-loop, coiled tubing drilling (CTD) applications.

The electric BHA has been conceived and designed through a European Drilling Engineers Association [DEA(E)[1]] joint industry project. This paper introduces the project and reviews its progress to date.

Electric coiled tubing drilling, or E-CTD, was delineated as a three phase project to stage progress and reduce technical risk. Phase I of the project, completed in late 1997 was designed to prove the feasibility and concept using standard motor technology.

Phase II, currently in a bench testing programme, intends to deliver a fit-for-purpose electric downhole motor (EDM) suitable for drilling a 3.75” hole. The motor is being incorporated into an electric bottom hole assembly (BHA) which incorporates pressure, temperature and vibration sensors. This is shortly to be field tested in Aberdeen.

Phase III of the project, scheduled to start mid-1999, integrates geo-steering and variable-bend directional technology to provide what has been termed the ‘all electric’ BHA. The ultimate goal of the project is to integrate the electric motor into a closed-loop drilling system. It is envisaged that, based upon feedback from near-bit sensors, such a system would be able to automatically adjust drilling parameters to optimise drilling performance.

Upon successful completion of basic closed loop functions, the intention is to incorporate the controlability of the BHA into what they describe as an ‘intelligent’ drilling system. This paper outlines a definition of this ‘intelligence’ and the authors also provide an insight into how far they believe that this technology may be taken, in terms of the autonomous decision making ability of a surface computer.

Introduction

In the vast majority of coiled tubing drilling services, downhole power is provided by positive displacement motors (PDM). The output profile of these motors is well suited to the drilling environment, providing high torque at low rotational velocities. However, PDMs have many weaknesses such as short motor run life and poor performance in high temperature operations. PDMs are also sensitive to choice of drilling medium. Aerated or energised fluids will adversely effect the life expectancy of a PDM. This is compounded at elevated downhole pressures and temperatures. Electric motors appear to offer an efficient and reliable alternative.

The idea of electric drilling is not new. Electric motors have been used to great effect[2] for horizontal well drilling in the Former Soviet Union. However, more recent attempts to integrate electric motors[3,4] into a rotary drilling assembly have not suceeded, mainly due to the difficulties of providing a high capacity electric link to the downhole drilling. Coiled tubing has provided an excellent means of achieving this through the installation of high capacity power cables within the coil[5,6]. It is this single development above all else that has done most to enable electric coiled tubing drilling (E-CTD). The authors consider that this technology will progress further as the embedding of power cables inside composite coil becomes routine for drilling operations.

The E-CTD Research Project

The project development schedule is illustrated in figure 1. The development adopted a staged philosophy to ensure that the technical risk was split into independent, and manageable, stages.

Phase I – Feasibility and Prototype Testing

Phase I involved an in-depth paper study into the technology that would be required to enable E-CTD. After successful completion of this study a prototype was built using electrical submersible pump (ESP) motor technology. This type of motor has a solid shaft and delivers maximum power at a relatively high speed. Therefore a 7:1 mechanical gearbox reduction was required in conjunction with an overbody annular mudflow passage to provide variable rotational speed from 0-400rpm. All command and control functions were delivered via a laptop computer linked to a variable speed drive. Although crude in nature, the Phase I BHA was tested successfully in Aberdeen late in 1997. The controlability of the motor and the additional information provided by the BHA gave a 'hands-on' feel to the drilling process. The phase I testing provided the inspiration to continue into Phase II of the project.

Phase II – Motor Development and Sensor Integration

The BHA, currently under manufacturing and selective bench testing, consists of the following (refer to figure 2):

CT connector

Comprising weakpoint and electro-hydraulic bulkhead the connector has been especially designed for the rapid assembly/disassembly requirements of the project.

Oil compensation system

As the oil filled motor heats and cools, the volume of oil contained within varies. The compensation system allows for expansion and contraction without tool damage.

Electric motor modules

Each 1.1m length module of motor (3 1/8" OD) supplies around 12HP, or 9kW, of power at 500rpm delivering close to 150ft-lbf of torque, without a gearbox. For the purposes of phase II bench and field testing, two of these modules are connected for higher torque and power output. The motor modules have been specifically designed with this flexibility in mind.

Sensor pack

The phase II sensor package incorporates temperature, internal/annular pressure sensors and a tri-axial vibration tool for drilling diagnostics.

Bearing pack and bit box

The assembly is protected by an industry standard bearing pack for the purposes of the field trial.

Bit

As in the phase I testing, it is proposed that multiple bits will undergo testing with the BHA dependent upon downhole drilling conditions. Although Phase II testing concentrates upon formation drilling, cement and metal milling is also planned.

Phase III – Integration of Geo-Steering and Directional Drilling Capabilities

Phase III takes the concept further by incorporating electronically controlled orientation and traction tools. These are combined with geosteering functions to provide a BHA with full directional drilling capabilities. The proposed BHA is illustrated in figure 3. Many of the same components in Phase II are reused including the electric motors themselves. It is planned that these motors will undergo additional testing during the course of the phase III development in order to further prove their longevity and flexibility.

A Common Test Platform

Throughout all of the three phases a common test setup is utilised, see figure 4. Most of the components would be required for any coiled tubing drilling activity and only a minimal amount of additional surface equipment is required to incorporate E-CTD functionality.

A small control unit houses the transformers and inverter required to power the motor. This plugs directly into a three phase control point. A slip ring is then required on one side of the coiled tubing reel to route this power through the cable and down to the motor. All telemetry signals are passed up and down the power conductors to simplify cabling considerations.

Test results

Whilst results from the phase I testing have been published elsewhere[7] it is hoped that some early results from Phase II will be available to present to the conference.

Initial Conclusions on the Advantages of E-CTD

Phase 1 clearly demonstrated some fundamental benefits of electric drilling by providing superior feedback and control of drilling processes in real-time. These are discussed in detail elsewhere[8] but key advantages of the electric drilling concept are summarised below:

- Drive power provided independent of fluid flow
- High tolerance of energised drilling fluids
  - ideal for underbalanced drilling
  - ideal for subsea drilling applications
- High temperature operation
- Flexible control of electric power with instantaneous feedback for closed loop drilling and optimisation of drilling efficiency
- Motor operation is scalable. The same drive may be used for auxiliary actuation, e.g. orientation, active traction and formation testing.
- Real-time transmission of data to surface using power cable
- Extended longevity of motor
- Reduced vibration (affects gyro placement, reliability of other equipment, eg NMR magnets)
- Reversible direction of rotation (passive or active traction capabilities)

Future E-CTD Developments – An intelligent drilling system?

'Smart', 'automatic' or 'expert', drilling systems are based around some form of feedback loop. Input from sensors directly involved in the drilling process is used to regulate the behaviour of the drilling operation. [See figure 5 for an example of some feedback loops associated with drilling operations.] The decision making process is termed 'closed loop' because no outside (human) intervention is required to control the system; it controls itself (in much the same way as a dynamically positioned vessel maintains station). The level and scope of feedback can of course vary significantly to provide differing degrees of automated control.

The electric BHA does not, in itself, provide intelligence. However, the constant supply and feedback of information does lend itself to easy integration into some form of intelligent system. For clarification, three basic levels of intelligence are defined:

'Stabilising'
The surface computer is able to recommend and take action, based upon parameter input, but within strict limits. Most commonly this involves one or more independent feedback loops and is intended to simplify operations by substituting manual intervention with rapid automatic adjustments.

A good example is where the rate at which coiled tubing is injected into a well is controlled by reference to a down hole weight indicator. Manual adjustment, in an attempt to maintain weight on bit at a constant value, is difficult to achieve and cannot follow the momentary changes that characterise real drilling. Automation, with safeguards, can work quickly and within a scope of control that is understandable and acceptable to most drilling personnel. The stabilising influence may also be utilised to generate an alarm when operating conditions move outside of a pre-defined envelope.

'Semi-intelligent'
Provides the ability to decide upon a suitable combination of parameter settings, such as weight on bit or drilling speed, with reference to predetermined drilling 'rules'. With operator approval, the system then stabilises these parameters. This will most likely include two or more codependent, and independent, feedback loops.

For example, a goal may be to maximise rate of penetration (ROP) of a coiled tubing drilling process. The system would consult historical data on the most appropriate way to increase ROP. One of these would most likely be to evaluate the change in ROP after increasing weight on bit. However, the system would also recognise that an increase in ROP may well require an increase in mud flow rates to ensure that cuttings are cleared effectively. Thus not only would weight on bit be increased, but pump rates would also increased as a consequence.

In a similar application, armed with the well plan, lithology, survey and ROP information, a semi-intelligent system could make course adjustments to azimuth and inclination so as stay on the desired trajectory. Although one would expect this to involve control of the variable bend and orientation tool the values of rotational speed and weight on bit necessary to achieve directional control may not be so obvious. It is anticipated that the semi-intelligent system will achieve this more efficiently through incremental experimentation than through the large step changes usually associated with manual control.

'Autonomous'
Independent and able to access and interpret the data required to provide optimal drilling decisions. A fully autonomous system will usually include multiple feedback loops and is characterised by the fact that it requires minimal, albeit vital, human interaction.

This type of system takes a wider view of the drilling operation, based on knowledge of the well plan and an extensive database of drilling operations and BHA specifications.

To illustrate, sensors in the BHA might suggest that ROP could be improved by increasing weight on bit. The system then looks for the most economic solution based upon the present stage of drilling and likely bit performance. This could be mean drilling at higher WOB and risking the need for a bit trip or maintaining reduced ROP so as to ensure that the bit finishes the current section of openhole intact. See figure 6 for an illustrative picture of the 'intelligent' closed loop drilling concept.

It should be noted that such high levels of automation are only possible given drilling components such as downhole-adjustable steering and traction tools, sensors and communications. In addition a robust reduction of human knowledge to database and algorithms is a prerequisite. Automation at any level aims to combine these with continuous adjustment and review to produce the optimum drilling operation. How this optimum is defined depends upon the particular objective of the drilling operation. Usually this will be a trade-off between securing the geological target, safety and cost.

Status of Intelligent Drilling Technology
Current systems can only be described as stabilising, or initial attempts at semi-intelligence (trajectory control). In, what is perceived to be, the most advanced system available[9] an operator is still required to constantly update target coordinates when a change in direction is required. It has been proven that this kind of feedback loop can improve the quality of the borehole whilst also tending to reduce doglegs and their associated problems.

Technology Benefits
The direct technical goals of automatic drilling technology are to constantly review and automatically adjust the drilling process so as to improve performance. Continuous review of progress also ensures that undesirable developments are anticipated and circumvented. These could include bit stalls when using down hole motors or deviation from geological targets that would result in doglegs when corrected. This has the effect of producing straighter, smoother well bores with better hole cleaning properties, key issues for CTD applications. Over the life cycle of the well, these factors can become significant, particularly when one considers that casing, completion and workover operations are conducted

more easily and hence more cost effectively in high quality wellbores.

Future development of intelligent drilling systems

Smart drilling systems have a place in virtually every coiled tubing drilling operation, including re-entry, through tubing and under balanced operations. The growth of coiled tubing drilling and its acceptance as a mainstream drilling operation has been slow. It is generally perceived as a low cost, 'no frills' service that provides only limited functionality. As pressure continues on the oil price, it is likely that low-end drilling applications will become more widespread as operators seek to extend the life of assets and explore for new assets in the most cost-effective way possible. This will result in increased demands upon coiled tubing drilling technology and functionality.

The electric CT drilling system offers to meet this demand by enabling a truly intelligent system that could optimise the drilling process through review of knowledge and experimentation. As experiences with so-called expert systems over the last twenty years have been mixed, caution is advised. They have given best results where knowledge is readily codified though subtleties are more difficult. Not only is the knowledge base subject to the fallibility of even the most experienced providers of input, but the 'intelligence' of each system ultimately depends upon a programmer's implementation of computerised reasoning.

Conclusions

Drilling is an expensive and high-risk undertaking. Planning involves a huge range of considerations, both for the well itself and in the general context of reservoir management. An intelligent drilling system should only try to automate that which is usefully, or must be, automated. High speed control of sensors and actuators, interpretation of appropriate guidance from databases and the provision of reasoned recommendations to experienced personnel are all reasonable objectives. They ensure consistency of approach based on an improving knowledge base, and most cost-effective pursuit of a well plan with maximum chance of success.

An electrically powered bottom hole assembly provides hardware which is well suited toward integration into an intelligent system. The total and instantaneous control of the motor and other BHA components make a compelling argument when comparing against available hydraulic/electric hybrids. The early successes of the E-CTD joint industry project have demonstrated many of the proposed advantages that stimulated the original development. But perhaps most importantly, the electric BHA ensures the rapid and accurate transfer of information between well design and drilling which is becoming the key to the successful development of marginal reserves.

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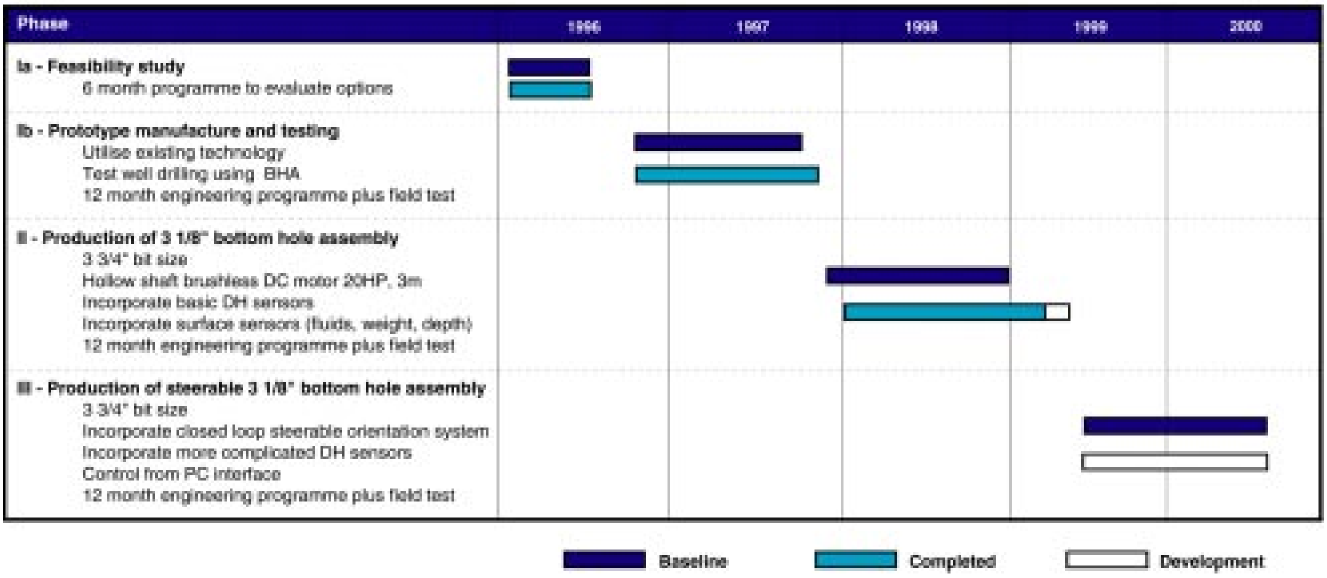

Figure 1 – Electric Coiled Tubing Drilling Project Development Plan

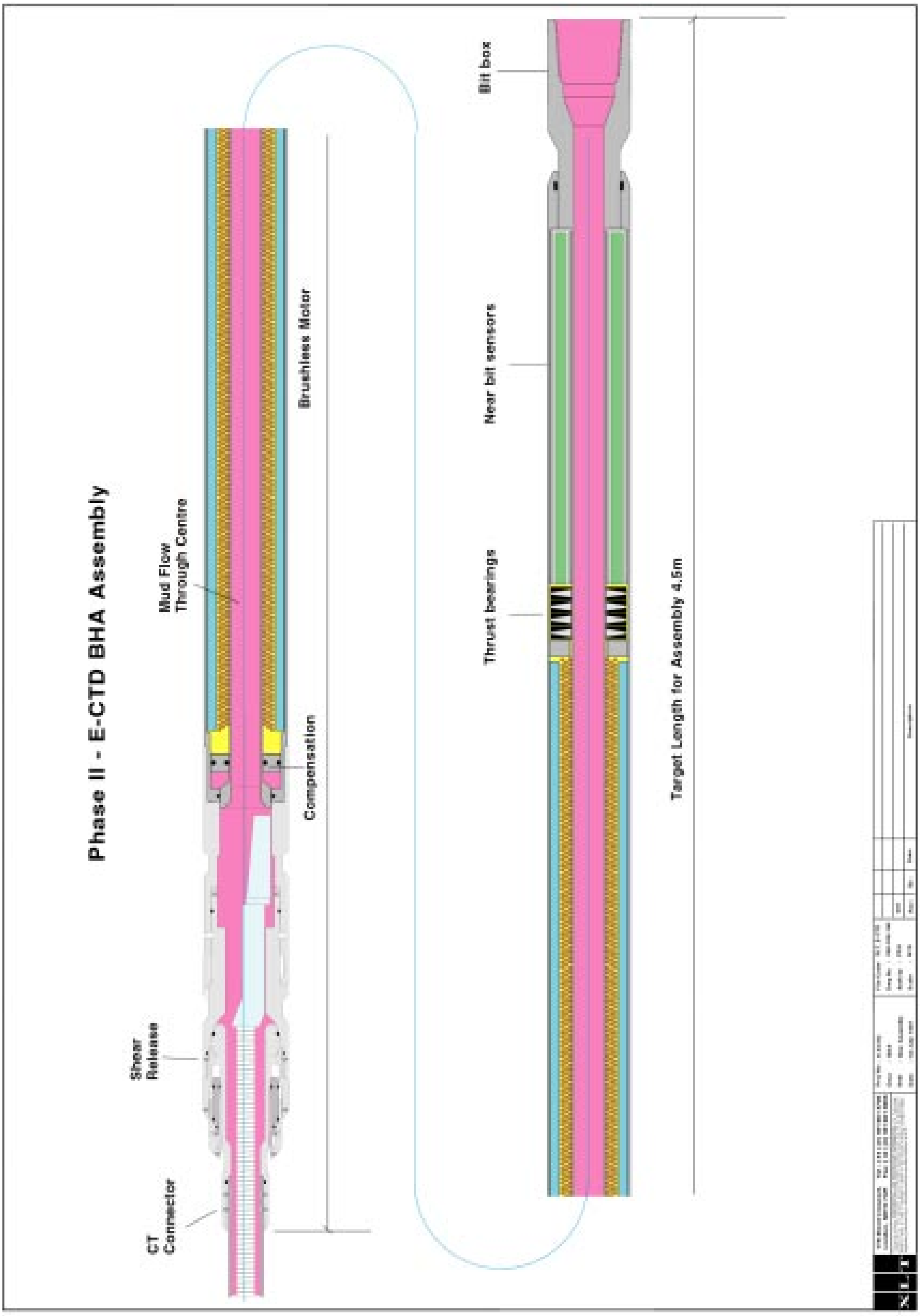

Figure 2 – Phase II E-CTD Bottom Hole Assembly

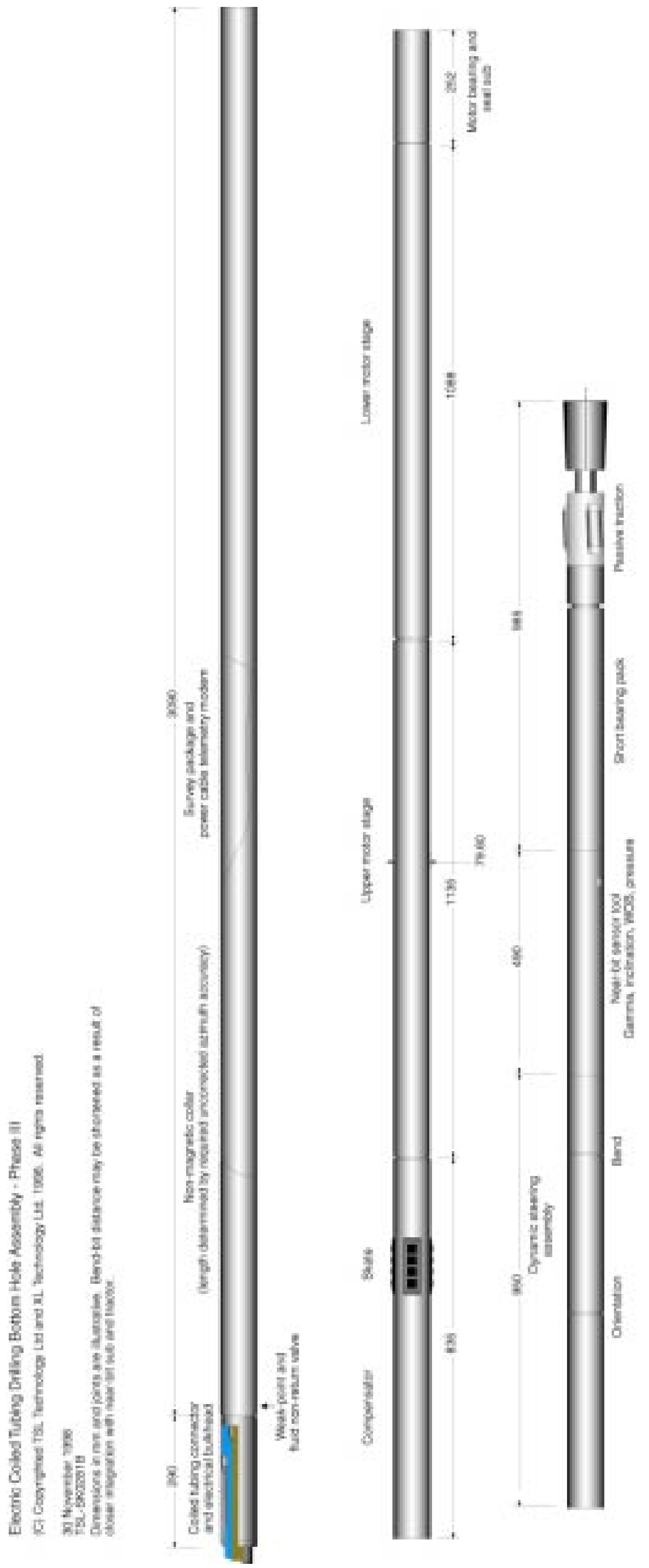

Figure 3 – Phase II E-CTD Bottom Hole Assembly

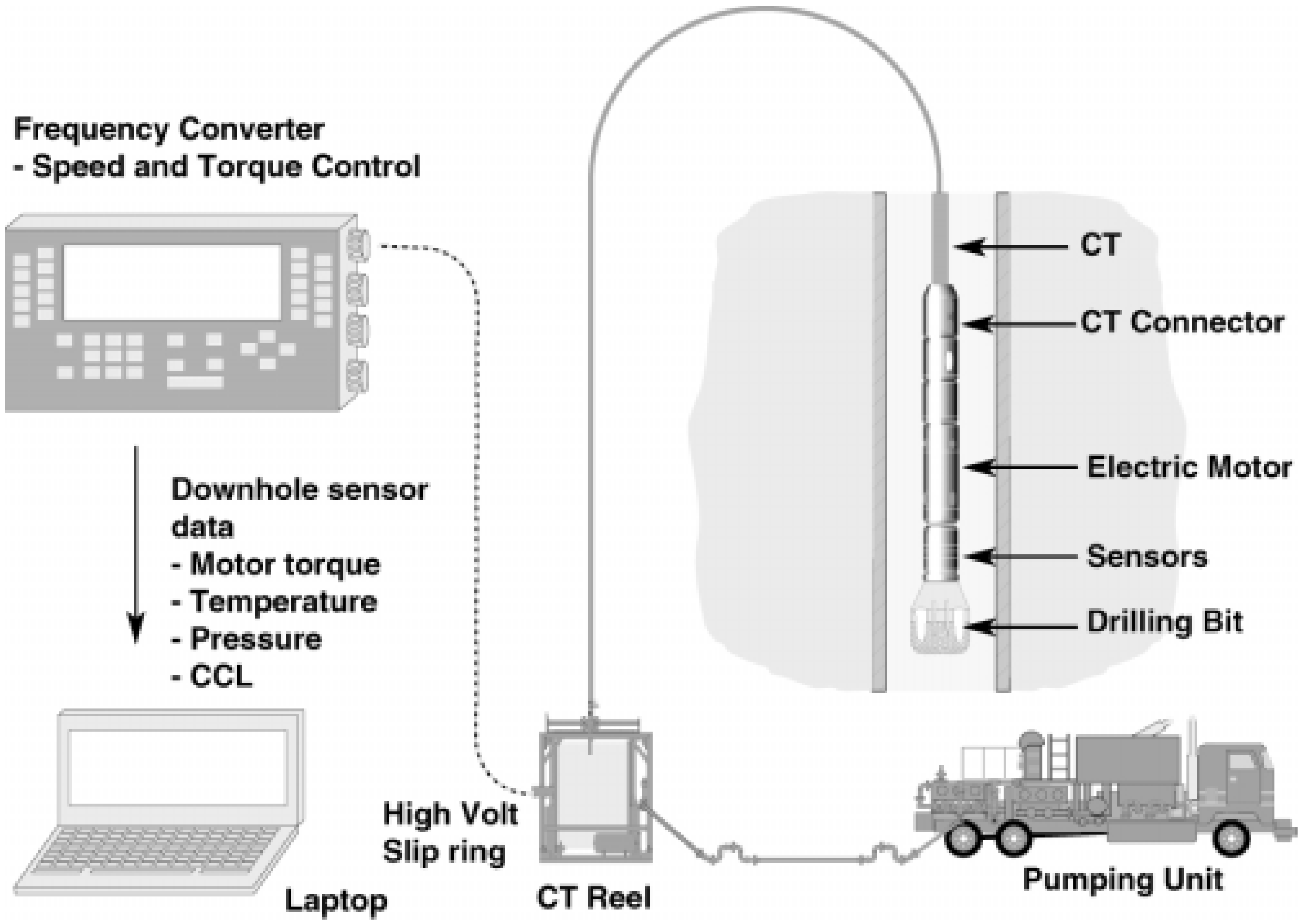

Figure 4 – E-CTD Test Setup

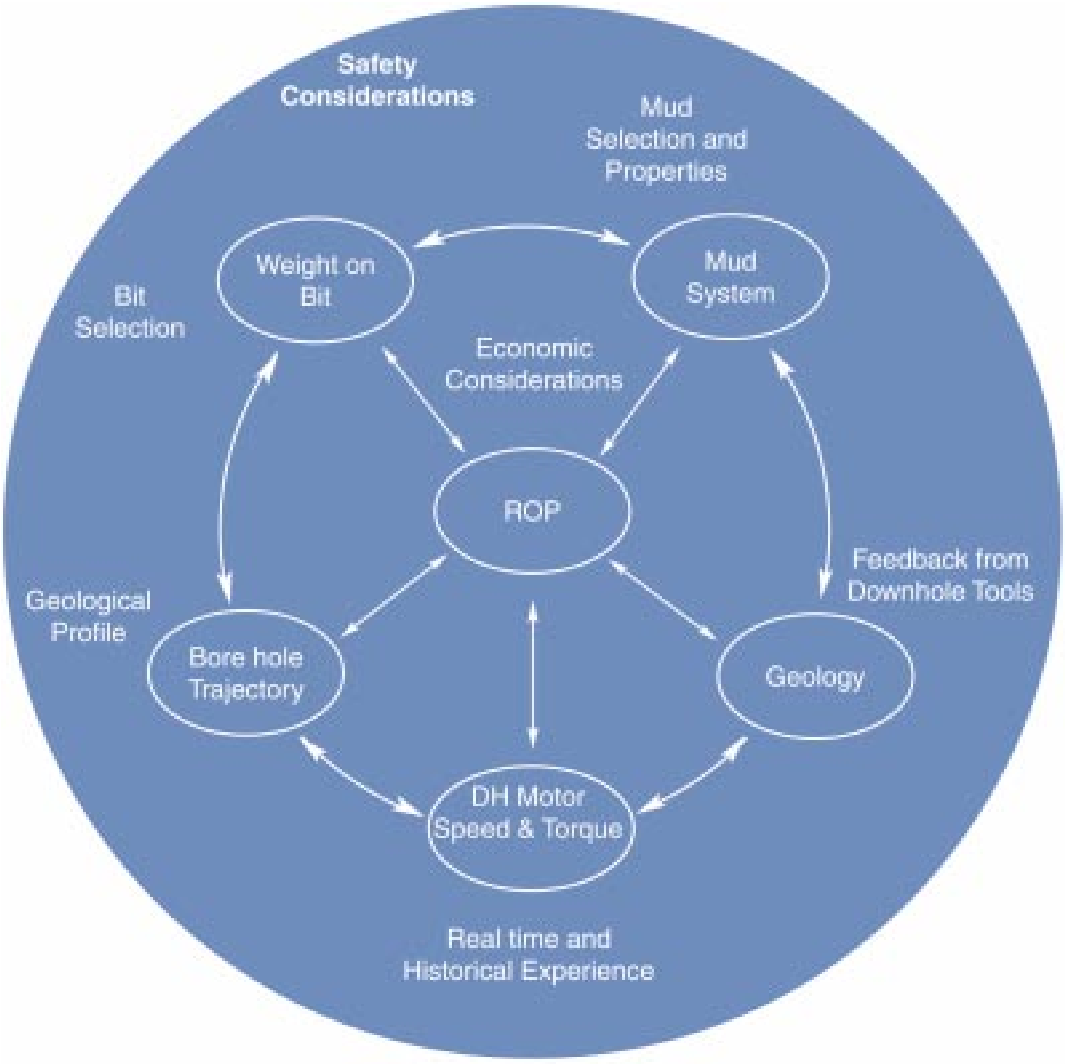

Figure 5 – Example of Feedback Loops in the Drilling Process

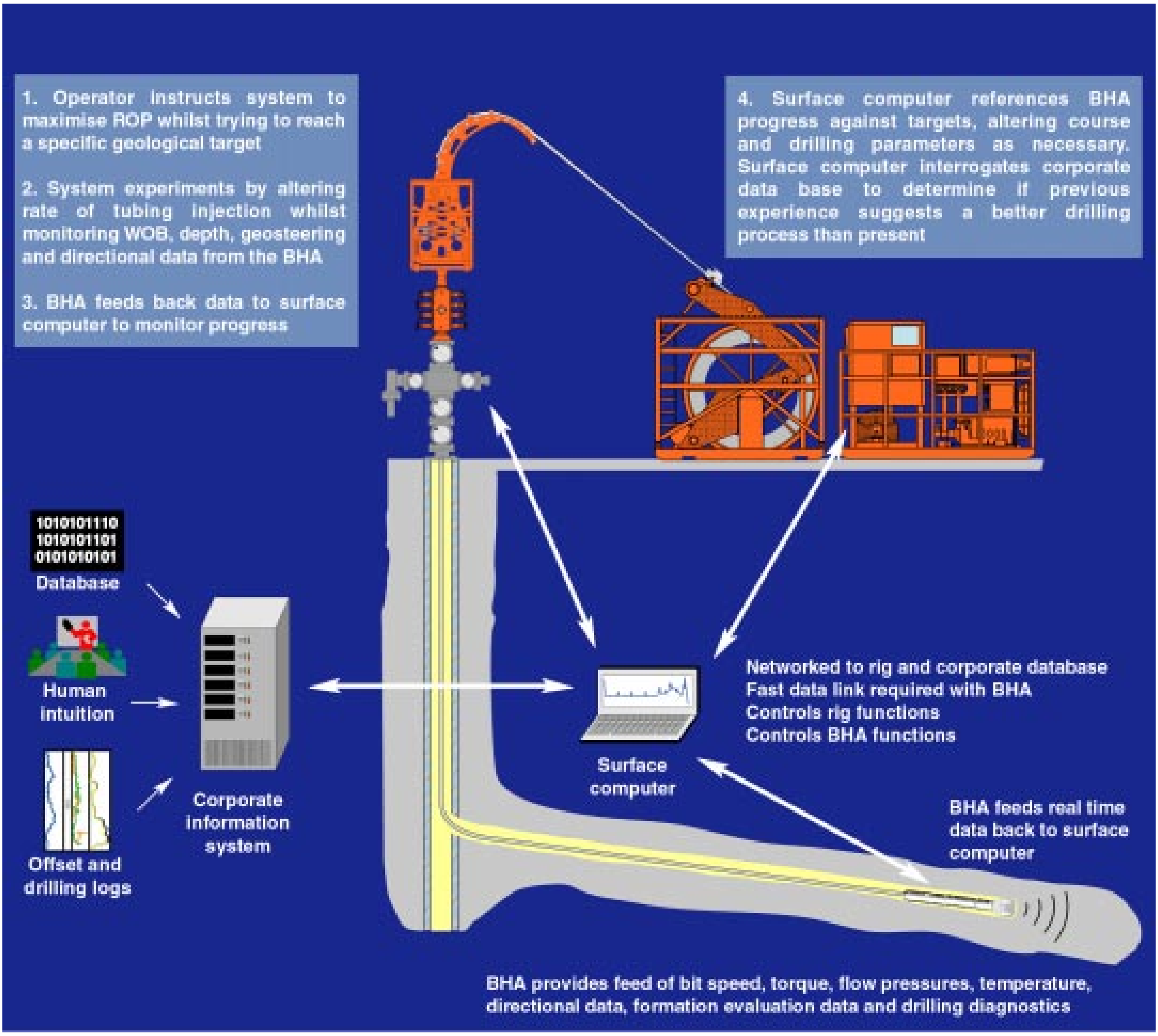

Figure 6 – Illustration of an 'Intelligent' E-CTD Drilling Operation