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NEW ADVANCES IN DIRECTIONAL DRILLING TECHNIQUES

Paper to be presented at the International symposium on Mine Drainage and Environmental Protection, to be held at Konkola Copper Mine, Zambia, during September 1993.

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SYNOPSIS

Directional drilling has been practised in the Oil Industry since the late 1930's with the aim of controlling the trajectories of wells drilled into producing formations thus optimising yields. This technology has been developed to enable multi-well completions from single offshore platforms, the drilling of relief wells in the treatment of blowouts, and multiple deflections from the same surface location for otherwise inaccessible targets.

Work done by Lubinski, and others, since the early 1950's has also provided an understanding of the effects of the borehole geometry on the downhole equipment, the resultant drilling parameters and thus, the ultimate completion of the borehole.

Modern computerised drilling engineering capabilities provide the means by which drilling programmes can be formulated to assure optimum control of drilling parameters throughout operations. This practice minimises the occurrence of avoidable catastrophic failures in the downhole equipment, whilst providing a means of optimising borehole configurations with effect to the quality and quantity of information

The traditional oilfield directional drilling technology has been hybridized and applied to the small diameter drilling systems used in the mining industry. This paper outlines the background technology and application of this technology to mining exploration and production drilling and examines recent developments in this field concomitant with Unidrilling's commitment to the improvement of the quality of drilling services offered to the industry.

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INTRODUCTION

The Development of Directional Drilling and Surveying

Interests in well surveying, and subsequently in directional drilling, have been pursued in the oil industry since the late 1930's, when it was deemed necessary to know exact bottom hole locations in relation to administration of the laws relating to oil leases. This was especially prevalent in oilfields where leases were small and numerous, and consequently disputes were common.

The requirement for accurate surveying methods led to the development of the first downhole gyroscopic survey instruments by Elmer Sperry who, together with Sun Oil, formed Sperry Sun.

In August 1939 an article in the magazine "Scientific American" published an article from which the following extract is drawn;

> *"...by drilling deliberately crooked oil wells instead of straight ones, a young Oklahoman has added immeasurably to the dwindling oil resources of the world. H. John Eastman, though told by engineers that it couldn't be done, showed them how drilling on curve and slant can outwit geology, put a subterranean cork in wild and flaming wells and, by angling out under the ocean, open up to man's use huge new reserves of petroleum. Where oil is found under cities, buildings, parks and cemeteries, Eastman's process can tunnel down at an angle from far enough away to make unnecessary such projects as putting derricks on the lawn of Oklahoma's state capitol..."*

In the same year Boeing Clipper ships had inaugurated a transatlantic airmail service with the anticipation that a transatlantic passenger service would soon be flying on a regular schedule. Today, fifty years later, like Boeing, Sperry Sun Drilling Services and Eastman Christensen still retain their position as market leaders in their respective highly developed and competitive international service industry.

The oil industry now routinely practices complex directional drilling programmes where Measurement While Drilling (MWD) packages, utilising sophisticated telemetry systems, send survey information as well as a complete suite of geophysical logs to surface as the bit advances. Oil and gas production is enhanced by drilling multiple wells from a single surface location into selected targets. Relatively thin producing formations are rendered viable producers through the drilling of high angle (often horizontal) wells thus increasing effective intake area.

Application of mathematics to drilling

Whereas it had been established that a drilling bit would tend to climb up-dip in laminar formations with dips of up to 40 degrees, Arthur Lubinski is credited with being one of the first to apply mathematics to drilling. In 1953 he stated that another factor to consider was

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the bending characteristics of the drill stem. With no weight on the bit the only force acting on the bit would be the resultant of the weight of the drillstring between the bit and the tangency point. This force would tend to bring the hole toward vertical. Similarly, when weight was applied another force would be exerted on the bit tending to direct the hole away from vertical. The resultant of these two forces may be in such a direction as to increase angle, to decrease angle or to maintain angle. This statement was based on the assumption that the drill stem lies on the bottom side of an inclined hole. This principle led to the development of Bottom Hole Assemblies (BHA's) for primary deviation control aimed initially at drilling straighter holes (by "controlled deviation drilling").

Restriction of total hole angle in accordance with legal and physical project constraints was found to solve some problems but did not assure a hole free of dog-legs. In the early 1960's Lubinski pointed out that due to downhole equipment limitations in terms of material strengths and fatigue parameters, the rate of change of hole angle and not necessarily the maximum hole angle should be the main concern.

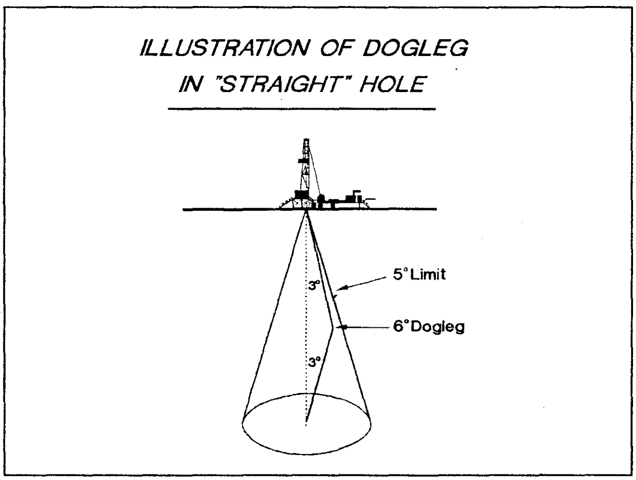

Figure 1.1 Illustrating dogleg severity in "straight" hole

This led, in 1961, to an API study group publishing a tabular method of determining maximum permissible dog-legs. It had thus been established that the main objective was to drill a "useful" hole with a full gauge, smooth bore free of dog-legs, key seats, spirals and ledges.

The advent of computer systems has dramatically increased the capacity to practically apply complex mathematical models to drilling parameters. Furthermore, the development of PC's has brought sophisticated analytical capabilities to within economic and practical parameters for daily use in drilling operations.

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EFFECTS OF HOLE GEOMETRY ON DRILLING EFFICIENCIES

Drillpipe Fatigue

The extent to which a dog-leg is going to cause fatigue in the drillpipe depends on the severity of the dog-leg and its position relative to the final depth of the hole (and thus the axial load to which the drillpipe will be subjected across the dog-leg).

Maximum permissible dog-leg severity will vary for each different drillpipe configuration dependent on the material of construction and dimensions.

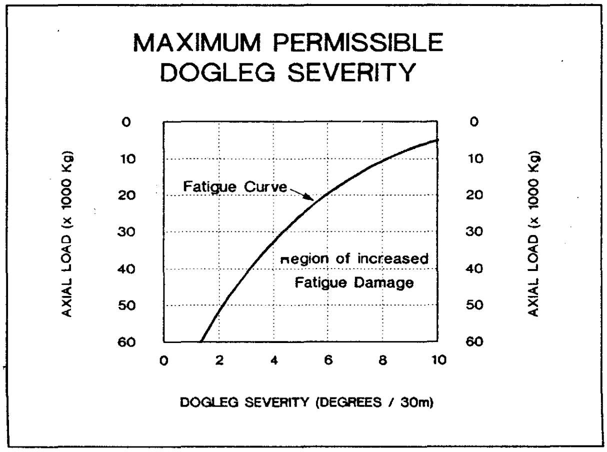

Figure 1.2 Typical fatigue curve for determining Maximum permissible dogleg severity

The extent to which the pipe will fatigue will be directly related to the extent to which the pipe is subjected to loads entering the region of increased fatigue, and the number of cycles to which the pipe is subjected under these conditions. This may have the effect of a reduced dog-leg tolerance and consequently future failure due to dog-legs below theoretical "safe" levels.

Since the effect of the dog-leg may not be apparent until drilling has advanced for a considerable distance, the risk of costly remedial action (by way of reaming or redrilling) and increased frequency of fishing operations is likely to impact adversely on drilling efficiencies. This fact could be further aggravated if the dog-leg had subsequently been cased off.

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Friction

Whereas the primary objective should be to drill a hole wherein dog-leg severity is maintained within maximum permissible limits to avoid fatigue damage, and probable catastrophic failure of the drillstring, and utopia would be a perfectly straight hole, drilling realities dictate maximisation of productivity and, thus, minimisation of costs.

Primary efficiency, by way of penetration rates, is determined by the ability of the surface and downhole equipment to deliver sufficient power to the bit to optimise performance within the given bit design parameters. A major source of power loss lies in friction due to the contact between the drillpipe and the walls of the hole. Given a constant coefficient of friction, due to the lubricity of the mud system, it follows therefore that the hole geometry could have a major detrimental effect to production rates. Decreasing the coefficient of friction by improving mud lubricity would tend to increase costs. Similarly, increasing power input at surface would also increase operating costs. The above "solutions" would be limited by the absolute coefficient of friction attainable and the torque limitations of the tool joints respectively

UNIDRILLING - TOWARDS 2000

Exploration Drilling Market Needs

The South African Mining Industry is currently faced with increased competition and costs for leases and options in the endeavour to increase reserves. Productivity is paramount with increasing production costs applying increased pressure to margins.

Ultimately deeper, and consequently higher risk, exploration and subsequent mining operations, with increased capital budgets, will tend to increase the requirements for the quantity and quality of information demanded from exploration and mine evaluation drilling programmes.

Accordingly Unidrilling perceives a drilling market demand for improved value and the application of technology to controlled drilling with enhanced confidence levels along with the capability to effectively perform long, directional deflections with substantial displacements.

In order to satisfy these requirements Unidrilling is committed to increased professionalism through application of improved risk management techniques and the requisite application of technology.

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Drilling Risk Management

Effective management of risk is seen comprise three major areas namely;

- Maintenance of a market differential
- Effective management information systems and
- Planning and control of operations

Maintenance of a market differential is directly related to the capability, reliability and the provision of value to the client.

Management information systems enhance the ability of drilling operations management to monitor actual against planned performance on a routine basis. This enables proactive, as well as reactive planning, in improving operational efficiencies. These systems provide current, as well as historical information at operations levels to facilitate optimisation of daily decisions on site and ultimately provide the means for improved accuracy in relation to budgets and forecasts.

Figures 2.1 and 2.2 show information requirements by decision category and the resultant format currently being implemented.

INFORMATION REQUIREMENTS
BY DECISION CATEGORY

Information Characteristics	Operations Control	Management Control	Strategic Planning
Source	Largely internal	⟶	External
Scope	Well defined, narrow	⟶	Very wide
Aggregation	Detailed	⟶	Aggregate
Time horison	Historical	⟶	Future
Currency	Highly current	⟶	Quite old
Accuracy	High	⟶	Low
Frequency of use	Very frequent	⟶	Infrequent

Ref: R. Anthony & H. Simon

Figure 2.1 Showing characteristics of information required

Concomitant with improved capability is a commitment to training with the objective of maximising productivity through improvement of skills, the promotion of greater operational safety and the effective application of technology.

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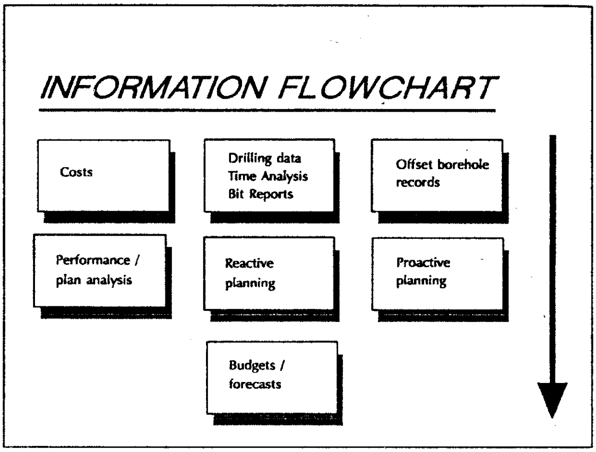

Figure 2.2 Information system flowchart per implementation in Unidrilling

Enhanced Borehole Planning Capability

Complimentary to the establishment of a drilling database Unidrilling has acquired a fully integrated drilling engineering software package, Wellplan, which has been tried and tested in the oilfield as well as under drilling conditions in South Africa. This package provides a comprehensive capability for the analysis of borehole geometry in relation to proactive and reactive decision making thus enhancing confidence factors by maintaining high levels of control over the borehole geometry.

Wellplan Capabilities

Survey

Borehole survey information is input to obtain reports on measured depth vs. true vertical depth at each survey station, Displacement of the stations relevant to a fixed point at surface and dog-leg severity of each interval between stations.

Calculation method options include;

- angle averaging
- tangential
- radius of curvature and
- minimum radius of curvature.

Of these options minimum radius of curvature is most widely accepted as being the most appropriate.

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Drillstring

This module utilises the survey information with input data relating to dimensions and weights of the drillstring components to calculate the following information;

- total torque
- torque distribution throughout the borehole
- hookloads during trips
- surge / swab pressures during trips and
- neutral point in the drillstring.

Coefficients of friction, rotary speeds and casing configurations are input allowing monitoring of theoretical conditions against actual field measurements. This capability provides useful information in optimising drilling parameters for maximum productivity.

Bottom Hole Assembly (BHA)

This module utilises state of the art dynamic finite element analysis algorithms to calculate the bending characteristics of the bottom 30 meters of the drilling assembly. Displacements, contact points and contact forces are calculated. This allows accurate monitoring of;

- side forces
- bit tilt and
- resultant forces (direction and magnitude) at the bit.

Casing

This module provides information with which to optimise casing selections in the borehole. This capability is more relevant to oilfield applications where high pressure gas may be anticipated, nevertheless useful mining applications may include pre-cementation, backfill and refrigeration applications.

Wellpath

This module is used to optimise the borehole path to achieve specific targets within allowable borehole geometry considerations. Utilised with the drillstring and BHA modules it provides useful information for the optimisation of kick off points in long directional deflections with due regard to equipment and power limitations.

Drillahead

The programme has the capability to use drillstring and BHA inputs to effectively model the anticipated borehole trajectory under desired weight on bit conditions. In directional boreholes this provides a significant capability for the optimisation of desired drift thus minimising the requirements for more costly directional correction methods.

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Hydraulics

State of the art hydraulics algorithms utilise input mud properties and drillstring configurations to analyse;

- pressure losses throughout the circulating system and
- calculation of equivalent circulating densities.

This capability is useful in diamond drilling applications in minimising burn-ins and controlling mud losses in pressure sensitive formations.

DIRECTIONAL CONTROL METHODS IN THE SOUTH AFRICAN DRILLING MARKET

Directional drilling may be defined as;

The practice of intentionally deviating the borehole from its natural course.

This definition covers not only the drilling of intentionally crooked holes but also the application of the same principles to straight hole drilling.

Directional Control Methods

Current methods available to the South African mineral exploration industry have almost exclusively been based on applications using wedges. This encompasses use of either permanent or retractable wedges in either directional or non directional configurations.

Whereas in many instances this practice is sufficient, recent analyses indicate that wedge systems, especially multi-wedge applications tend to be inefficient. This is mainly due to the resultant complex borehole geometry and the consequential impact on the BHA forces. For instance, certain recent applications of retractable wedges have been found to produce results inconsistent with expectations. Detailed analysis with the Wellplan capability has, in fact, indicated that results obtained were in accordance with computed predictions. Analysis also indicates that dog-leg severities, resulting from wedge applications in the upper sections of boreholes, exceeded the maximum dog-leg tolerance of the drillpipe.

Application of bottom hole assembly principles to the standard hole sizes and drillpipe configurations is severely restricted by the small annulus available. Applications of basic BHA design have, however, proved valuable with significant reduction in the number of retractible wedges used to maintain hole angle under severe crooked hole conditions.

With this experience Unidrilling has embarked on a programme to develop an enhanced directional drilling capability. This has involved the development of a 96mm system with a configurable BHA and 18 meter wireline corebarrel, to be run below DH5000 drillpipe.

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Complimentary to the above BHA is a capability to operate a steerable downhole motor in the 96mm hole size. To this end Unidrilling has sourced a wireline steering tool and appropriate positive displacement downhole motors to enable increased capability to meet requirements for enhanced directional control on a cost effective basis

Figure 3.1 illustrates a comparison of different directional control methods in relation to directional control applications in South African drilling applications. As applications will differ from hole to hole, careful analysis of the relevant merits of each system need to be evaluated in order to establish the most cost effective method (or combination of methods).

COMPARISON OF
DIRECTIONAL CONTROL METHODS

	Perm. Wedges	Retract. Wedges	BHA	D/H Motor
Minor changes	Good	Fair	Good	Excellent
Major changes	Fair	Poor	Poor	Excellent
Building	Good	Good	Good	Excellent
Holding	Good	Fair	Good	Excellent
Dropping	Fair	Poor	Poor	Excellent
Dogleg severity	High	V. high	Low	Controlled
Performance	Fair	Poor	Good	Excellent
Cost	Fair	High	Low	High

Figure 3.1 Comparison of directional control methods

FORESEEABLE APPLICATIONS FOR DIRECTIONAL DRILLING

Future potential applications for directional drilling include the following;

- Multiple long deflections
- Mine evaluation drilling
- Pre-cementation boreholes
- Raisebore piloting
- Backfill holes
- Mine service holes

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