eLAD

E-Centre Laboratory for Automated Drilling processes

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IRIS

eLAD: Well Simulator Specifications

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Sign date

Preface

eLAD is a laboratory for evaluating new drilling automation tools, new drilling advisory systems, new work processes within drilling operations, the consequences of wired pipe telemetry. The kernel of the laboratory is a well simulator which is behaving as a well would have under the simulated drilling circumstances. This document describes the requirements of such a well simulator.

Stavanger, 20.08.2007

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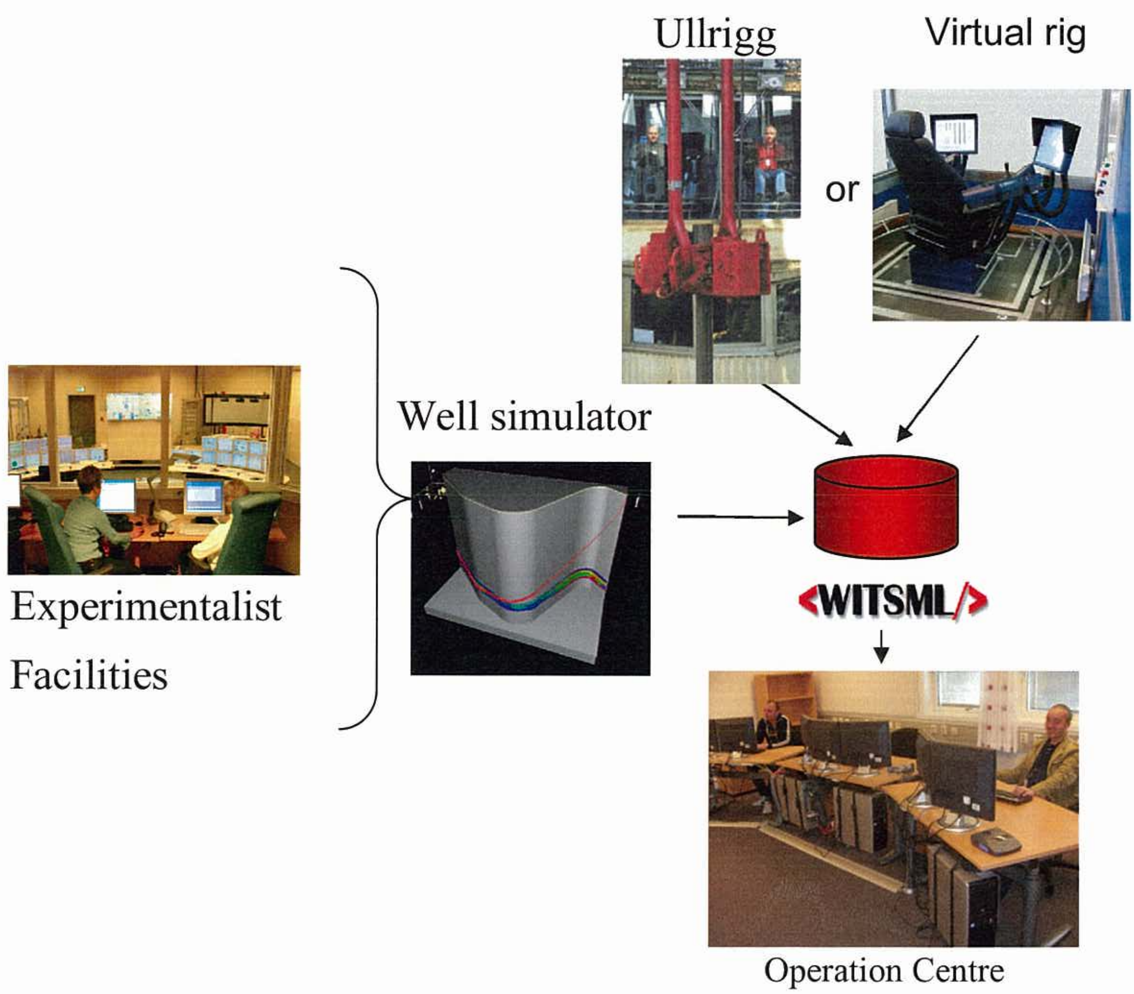
Summary

During drilling operations, the well and the equipment used in the drilling process are reacting to the drilling conditions. Unexpected events can occur during drilling operations ranging from erroneous assumption on the position of the wellbore relatively to the formations, to lost of control of the well, or mechanical failure of surface or downhole equipments.

The purpose of the well simulator is to mimic the response of a well to dynamically changing drilling conditions. The well simulator is working with its own description of the earth model which can be different from the assumed geological model. The difference between the actual model used by the well simulator and the assumed model used during an experiment can generate unexpected events. In addition, experimentalists can trigger incidents to test the reactivity of both systems and people participating to the experience.

1 Introduction

Drilling operations are steered from different locations by various actors obeying to a chain of command and control. The rig site is the primary location for control of the drilling process. The driller and his drilling crew operate the drilling machineries (draw-work, top-drive, mud pumps, iron roughneck, star racker, BOP) and performs the first level of command. They can be assisted by service companies providing the necessary manpower and expertise to operate downhole steering tools and downhole measurement instruments. The tool pusher and the drilling supervisor performs the second level of command directly onsite. Onshore operation centres can assist the drilling operations by providing engineering surveillance and on demand expertise. The operation manager assures the third level of command, while the project leader assumes the upper most level of command.



eLAD shall provide an environment which replicates as accurately as possible the context for decision making during drilling operations. The laboratory is therefore including a rig site where a drilling crew can perform the drilling operations and an operation centre where data can be analyzed. The rig site can either be Ullrigg which provides a full size drilling rig equipped with modern drilling machineries and a top of the line drilling control system. However, to test new drilling automation or to minimize the risk for injuries during hazardous operations, a virtual rig can also be used. The operation centre provides standard facilities found in modern onshore drilling centre (multiple projectors and workstations with multiple screens).

Even though, 8 wells of different shape and lengths can be used from Ullrigg, it would be rather hazardous to replicate serious incidents in those wells due to the possible damage which could be caused to installations or personals. Therefore a well simulator should be developed to mimic as closely as possible the actual response of a wellbore or the equipment used in the drilling process, to the manoeuvres performed by the drilling team. Furthermore, the well simulator can be remotely controlled by experimentalists who can trigger unexpected situations to test the reaction capabilities of systems and people.

2 Typology of incidents

Different type of incidents can occur during the drilling process.

2.1 Tool failure

Surface or downhole equipments can fail during the drilling process. This can concern the major drilling machineries: draw-work, top-drive, mud pumps, iron roughneck, automatic slips, pipe handling equipment such as a star racker. Failure on these piece of equipments can delay the operation not under estimating the possible consequences of staying inactive in an open hole section.

Bits are the most likely piece of downhole equipment to fail requiring lengthy trip out and trip in operation for replacement.

Downhole motors, turbines, steerable rotary, MWD/LWD, under-reamer can also fail with the possible consequence of necessitating a pull out of hole for replacement.

Washout can occur in any of the pipe connections requiring tripping out to replace the faulty pipe.

Mechanical failure of pipes can also occur due to excessive stress or pipe fatigue. In addition to pulling out of hole a fishing operation can be necessary.

Pieces of metal can also fall in the hole from downhole equipments for instance and necessitate a fishing operation.

2.2 Well control problems

During drilling, it is possible to loose control of the wells in different ways:

- Mud losses: because of excessive pressures in the open hole formations, formation fracturing can occur and the drilling fluid can flow in the formation through those fractures. In addition to loosing expensive drilling fluids, the situation can degenerate furthermore if all of the reserved drilling fluid is lost in the borehole, because then one of the major barrier protecting against a formation fluid influx is gone.
- Lost circulation: if there is an obstruction in the string or in the annulus, the circulation of the drilling fluids is interrupted with the consequence of not being able to transport cuttings, activate downhole tools, lubricating for pulling out of hole,...
- Formation influx (kick): if the pressure in the borehole is below the formation pressure, the formation fluids are flowing in the annulus and are transported to surface. If hydrocarbons are present in the formation fluids there is a risk for ignition.

- Blow-out: a formation influx which is cannot be controlled turns into a blow-out. One distinguished between an internal blow-out where the BOP is sealed and no formation fluids are streaming outside the well, and an external blow-out where formation fluids are expelled outside the well.
- Formation collapse: when excessive pressures are fracturing the formation or when downhole pressures are getting below the formation collapse gradient, blocks of formation can fall in the borehole. Depending on the size of the blocks, the drilling process can be impaired with high torque problems or worse with a stuck pipe situation.

2.3 Stuck pipes

A stuck pipe situation is characterized by the impossibility to move the pipes in one or several directions (up, down or rotation). The different stuck pipes categories are:

- Differential sticking: the difference of pressure between the open hole and the formation tends to engrave the string inside the formation. This only occurs when the pipe are not moving. The longer the pipes are kept steady the larger is the force necessary to release from differential sticking at some point it can be impossible to retrieve the pipe at all.
- Formation collapse: if the formation collapses, the pipes can be buried under large of amount of rocks rendering impossible to move the string
- Key seat: in section with high curvature, the contact forces between the pipes and the casing can be so high that the casing starts to be eroded. This erosion can leave a trace in the casing which later on prohibit the passage of larger elements like drill collars or stabilizers.
- Formation swelling: some formations can extrude after being drilling (salt, plastic shales, swelling clays) impairing the passage of larger drill string components when pulling out of hole
- Packing: in case of poor hole cleaning, cutting beds can form and when the drill-string is retrieved cuttings can pack behind the larger elements of the string (stabilizer, collars,...)
- Junk in hole: piece of junks (typically a roller cone) can obstruct the hole
- Undergauge bit: if the bit gauge is worn the hole size may be to small to let larger elements of the BHA to go through the hole and forward movement is therefore no longer possible.

2.4 Collision

While drilling a well it can be possible to come close to neighbouring wells. Due to the wellbore position uncertainty, it is not possible to know for certain the exact distance with those wells and therefore a risk of collision may exist even though the trajectories are not theoretically intersecting. A collision with another well means loosing both the well being drilled but also the well involved in the collision. Furthermore, if fluids are being produced or injected in the collided well, an influx can occur during the collision.

2.5 Positioning the well in the pay zone

The combination of the uncertainty on the wellbore position with the uncertainty on the geology of the reservoir make it difficult to land the well in the pay zone. Small variations of incidence angles and depth can reduce substantially the length of the reservoir section.

When inside the reservoir section, the exact geology may not be exactly the one expected (changes in formation depths, dips and thicknesses, but also in reservoir quality like porosity, permeability and fluid saturation). Sub seismic faults may be penetrated as well changing abruptly the depth the target zone and necessitating revision of the target geometry.

3 Well simulator functionalities

The well simulator shall mimic as closely as possible the response of the well on the surrounding based on simulated drilling operations. These responses are collected through sensors both on surface equipment and downhole. Here is a typical list of such sensors:

Surface equipment:

- Hook load
- Surface torque
- Pump pressure
- Flow rate out
- Fluid temperature in and out
- Mud density out
- Tank volumes

Downhole equipment:

- Directional measurements
- Downhole pressures and temperatures
- Formation evaluation measurements (gamma ray, resistivity, neutron density, sonic, NMR)
- Vibrations measurements
- Downhole WOB and torque

The simulator shall also account for telemetry limitations (mud pulse or wired pipe). It also shall simulate the response to downhole tool activation (dropping ball to activate circulation subs or under-reamer). Correct behaviour of complex components shall also be simulated (downhole motors, turbines, steerable rotary)

The well simulator is working with its own description of the earth model (which may differ from the presumed geological model used during an experiment). This earth model shall include a velocity model, stratigraphic model, a facies model, a petro-physical model and a geo-mechanical model. Unexpected events can occur during manoeuvres due to the different limits used by the well simulator compare to the assumed earth model used by the drilling team.

Experimentalists can remote control the well simulator to generate unexpected events. They can, for instance, bias the directional survey measurements (within the tolerances of standard survey instruments). This bias on the inclination and azimuth readings will put the well in a different location to the one reported by the measurements. Combined with the different stratigraphic model used by the well simulator can simulate the kind of uncertainty arising during drilling operations.

Another action performed by experimentalists is to generate failure of components either at surface or downhole. Examples of such failures could be one or several bit nozzles being plugged, or communication errors with MWD/LWD, etc.

Experimentalists shall also have a full overview of what are the conditions of the drilling system as modelled by the well simulator in order to estimate how far from reality the drilling team is working with.

4 Well simulator synoptic

To fulfil the functionalities described above, it is foreseen that the well simulator shall include the following modules:

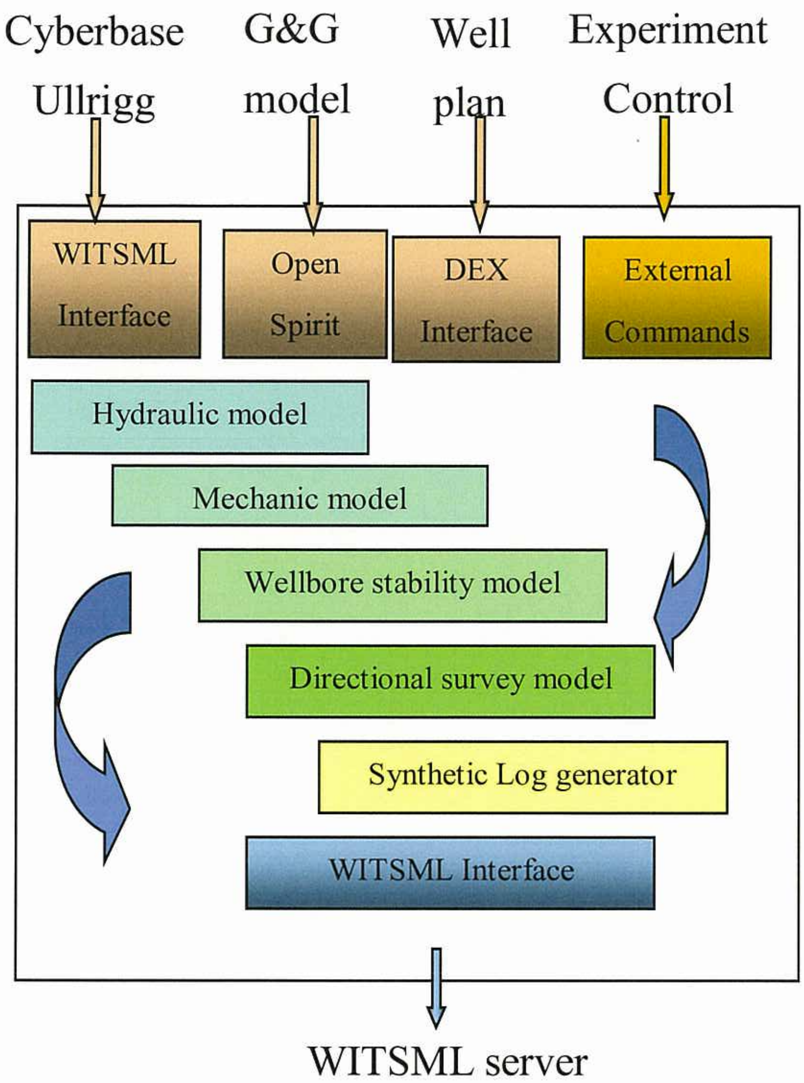
- a hydraulic model with modelling of transient phenomenon, heat transfer, barite sag, cuttings transport and formation influx;
- a mechanical model with modelling of coupling with hydraulic effects, stiffness and vibration phenomenon;
- a wellbore stability model coupled to hydraulic, thermal, mechanical and chemical constraints;
- a wellbore position uncertainty model based on standard instrument performance model (Wolff & de Wardt, ISCWSA) to model possible deviation from actual position;
- a synthetic log generator to generate LWD response based on the real wellbore position and the internally used earth model.

The well simulator will take its real-time input from a WITSML server and will communicate the response of the well through the same WITSML server. Several alternatives for downhole communication shall be available: mud pulse or wired pipe.

Configuration of the internal earth model will be made using either OpenSpirit, possibly Ocean from Schlumberger or RMSOpen from Roxar can be used.

Landmark's well planning applications being used in the majority of operating companies, the well simulator will therefore retrieve the well planning information through the DEX format.

A dedicated Graphical User Interface (GUI) will be developed to present the internal status of the well simulation to experimentalists and to let them generates unexpected events.


Cyberbase Ullrigg
G&G model
Well plan
Experiment Control
WITSML Interface
Open Spirit
DEX Interface
External Commands
Hydraulic model
Mechanic model
Wellbore stability model
Directional survey model
Synthetic Log generator
WITSML Interface
WITSML server

5 Well simulator development plan

The well simulator will be developed incrementally. It will make use of IRIS's drilling models like WEMOD (drilling hydraulic), TModel (heat transfer during drilling operations) and TDModel (drillstring mechanics). Access to third party sources will be made using drivers developed by IRIS in its CommonLib (access to WITSML, SDI/DA, RMSOpen, …). The well simulator GUI will also be developed using the CommonLib. However additional drivers and libraries need to be developed like access to DEX, OpenSpirit, …

The following milestones are proposed:

1. initial implementation of a simple hydraulic and mechanical response using WEMOD, TModel and TDModel with communication via SDI/DA and WITSML (70% complete, remaining 5-6 man weeks);
2. connection to earth model using RMSOpen, wellbore position uncertainty based on Wolff & de Wardt and initial GUI for presenting internal status and controlling well bore position bias (30% complete, remaining 10-12 man weeks);
3. management of surface and downhole component failures associated with upgraded GUI for experimentalists (0% complete, remaining 15-17 man weeks);
4. wellbore instability and formation influx handling based on internal earth model and real-time drilling manoeuvres;
5. formation log generation based on the internal earth model and using a simple stretch/squeeze strategy;
6. connectivity to other earth models via OpenSpirit and Ocean;
7. connectivity to well planning software via DEX;
8. formation log generation based on instrument log response modelling;
9. wellbore position uncertainty based on the ISCWSA model;

Tasks 1, 2 and 3 are estimated to be completed before the end of year 2007 (remaining work about 30-35 man weeks)