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Newly Designed Soft Drilling Simulator A computer based drilling simulator

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Abstract

This paper introduces the Soft Drilling Simulator (SDS) which provides a complete simulation of the rig systems. Being able to simulate drilling operations with the accompanied drilling problems and well control situations will enable drilling crews ,engineers and students to be fully aware of all drilling practices . The soft simulator presents a lot of scenarios which cover most operations with a realistic environment supplied with audible effects and visual animations.

Development of the soft drilling simulator (SDS) will make training and practicing easier than it has ever been as it combines between feasibility and ease of usage. Using unique programming and graphical design approaches, an integrated software has been customized to facilitate the learning process. The user can practice all drilling activities such as tripping, reaming and back reaming using tow rig types (Kelly or Top Drive).

A complete well monitoring system is included to figure out any problems down hole such as lost circulation, differential sticking, mechanical stuck pipe, lost cone, twist off, nozzle plugged and kick occurrence. Each drilling problem could be identified the same way it happens in the field through realistic and interactive panels. Complete hydraulic System simulates the mud cycle around the well. Well control Equipment and practices have been integrated such that the user can shut -in the well, read pressures, kill sheet calculations, circulate kick out of the hole, perform leak-off test on different formations. This integrated system can introduce new capabilities within the field of coaching for Oil industry.

Keywords*: Oil well simulation; Simulator based training; Computer Based Drilling Simulator software; Training software for oil and gas drilling; Well control simulator; Realistic data modelling.*

1. Introduction

Drilling for oil and gas can continually be related to the danger of incidents inflicting hazards to personnel, instrumentation and atmosphere. One in all the most tasks to the drill crew is to discover → react → recover a happening before crucial things arises. Hence, a serious part of well incidents that have occurred throughout the years is due to human errors.

This can be explained by misunderstanding of signals and/or that policies and procedures among firms don't seem to be followed. Operations that don't seem to be seen as routine work would require coaching to sustain information and handling of operational challenges so as to avoid well management incidents. Well management incidents will expose the rig personnel and atmosphere to unwanted circumstances, that each BP`s Macondo incident within the Gulf of North American nation and plenty of different incidents illustrate pretty much as good examples. However, a well-trained drill crew will make sure that reactions and actions on well management incidents are going to be in accordance with procedures and policies among a corporation.

In Egypt we had a Blow out in RAS SUDR and rig was set on fire, and the investigation of the incident shows that identical causative relation was sorted into the subsequent main areas:

- Deficient compliance with governing roles.
- Deficient hazard management.
- Deficient supervision.

Drilling simulator software system that allows safe coaching at a low cost without perturbing current operations we will improve risk handling, increase potency of labour processes and to confirm continuing development of leadership skills. Through this there's a possible to create up confidence to drilling & well personnel before exacting operations that's to be dead offshore.

2. Problems and background

Drilling oil wells is a very expensive process including many challenges and risks and there are a lot of drilling problems that could be encountered during drilling a well. Some of these problems are related to formations being drilled, other are related to equipment and personnel. Understanding and anticipating drilling issues, understanding their causes and designing solutions are necessary for overall-well-cost management and for with success reaching the target zone. Raising the skills of the drilling team using new techniques of training will make them able to take the right decision while facing different types of drilling problems to save their lives and equipment.

Examples of drilling topics included in the simulator software:

- Differential sticking
- Well control problems
- Shut-in procedures
- Killing methods
- Mechanical stuck
- Formation problems
- Loss of circulation
- Pipe failures
- Bit problems
- Borehole instability

SDS offers problems diagnosis through the real time data monitoring and a computer based data processing model. Not only problems diagnosis that SDS can perform, but also it provides well control practices such as kick circulation, operating well control equipment using realistic designed panels and kill sheet. Well control and blowout prevention became very serious topics in the Oil and Gas industry for wide range of reasons. Among these reasons are higher drilling costs, waste of natural resources, and the possible loss of human life when kicks and blowouts occur. Having such a tool will make well control training a very interesting process and will provide the drilling team with the necessary technical and practical knowledge as well. The evolution of the Soft Drilling Simulator (SDS) will contribute greatly to the training process in Oil and Gas industry. This software will provide a very realistic training with low budget for students, engineers and professionals in the field of drilling oil wells. All what you need is a computer and start full training with different modules covering all field problems that could be encountered.

3. Comparison between SDS and full scale simulators

Currently in the business of specialized training in the drilling industry, we have very expensive simulators up to 1 million USD. These types of full scale simulators are only available for large training centres which could afford the high cost. Beside the high cost, current drilling simulators focus on hardware simulation but don’t consider realistic data modelling to give trainees the taste of real drilling. Our main focus on SDS simulator is to provide accurate and realistic data modelling for all drilling parameters.

The immediate result of this effective approach will be the increased efficiency of trainees which by default reflect on field of drilling and reduction in Non Productive Time resulting from wrong decisions due to lack of proper training. See Table 1

4. Simulation algorithm

Our target was to provide simulation model that captures realistic environment not just mathematical approach and this represented our big challenge. In this paper we will go through one example to represent the difference between Full scale simulators’ approach and the Soft Drilling Simulator (SDS) and will preview how a realistic simulation model could be developed against a real field data.

Torque simulation was used as an example to show difference in simulation approach and real data analysis.

Table 1. Comparison between current business simulators and the Soft Drilling Simulator SDS

Comparison between current business simulators and the Soft Drilling Simulator SDS		
Item	Full scale drilling simulators	Soft Drilling Simulator SDS
Cost	Very high up to 1 million dollar for one work station	Limited cost and ease of access
Time of training	Only available to trainees during training courses	Available all time on computers or laptops.
Requirements	Need professional trainer and large place to accommodate.	Simple and friendly user interface
Simulation Model	• Use mathematical approach only • Doesn't include real time variance in pressure, WOB, RPM. • Doesn't include delay time response for pressure and well control. • Need complicated settings. • Can be used Only by professionals • Monitoring system and charts doesn't consider similarity to real screens on drilling rigs. • Any upgrade is very expensive and has to change in hardware configuration.	• Use mathematical and realistic approach. • Models are developed to simulate drilling torque, ROP, RPM and other drilling parameters (proven example of drilling torque model covered in this paper) • Real time response is highly considered and captured in code algorithm. • Simple settings required. • Give a wide spread for knowledge among university students, engineers and field professionals • Monitoring system and charts highly similar to rig actual charts. • Can be upgraded easily. • Combines between complicated simulators and simple ones and provide efficient and realistic environment.

4.1. Torque monitoring importance in drilling operations

Torque is a key factor to monitor during drilling operations as changes in torque could indicate serious down hole problem. Therefore torque watching and interpreting sense should be delivered during training to drillers, students and engineers. Here are some examples of how torque can relate to drilling problems:

- Torque variation could indicate different formations boundaries and correlations could be made to expect top formations.
- High and erratic torque can indicate bit problems (lost cones, bit wear, junk in hole….etc.)
- Changes in torque and drag could be a primary indication of hole cleaning efficiency
- Well control problems can also be accompanied by torque and drag changes.
- Torque can be used as warning sign prior stuck or hole pack off tendency.
- Torque erratic variation can lead to string fatigue and twist off.

4.2. Comparison between real torque and torque on full scale simulators

If we watch the Torque chart on Full scale drilling simulators currently serving in the market of training, we will find that torque is shown as a constant value against depth or time while monitoring actual torque on drilling rigs will show that torque has variant values all the time and these variant values have inherent relevance to formation type, bit aggressiveness, flow rate, formation type, formation compaction, WOB and RPM.

4.3. Torque model simulation in soft drilling simulator

We first need to define factors that could affect torque and then produce the model that could predict how these factors could affect torque. Then compare results against filed data. In our approach we developed an empirical equation that predicts torque depending on other drilling parameters. These drilling parameters can be divided into two categories: Controllable factors that can be controlled by driller and uncontrollable.

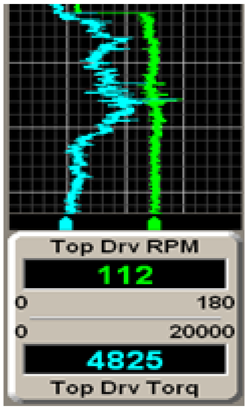

Figure 1. (Rig sense chart showing actual,torque versus RPM)

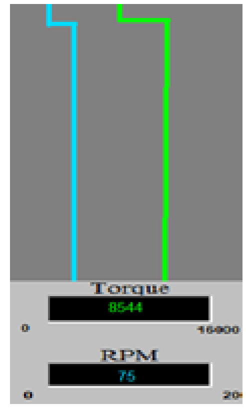

Figure 2. (Capture from other simulators, torque versus RPM)

Controllable factors	Uncontrollable factors
Weight on bit	Formation hardness
Revolution per minute	Formation pressure
Diameter of bit	
Rate of penetration	

The model introduced incorporates two factors (Formation hardness index and "D" Exponent) where Fi represents the effect of uncontrollable factors and "D" exponent represents the effects of either controllable factors. Mud weight correction factor is added to consider mud weight changes. This equation was developed and validated against actual drilling data form different wells in Egypt's western desert.

$$T = F_i x D x 10^3 x \frac{M_{wt} normal}{M_{wt} actual} \qquad (1)$$

where: T = Torque (Ft-lb); Fi = formation hardness index (dimensionless); D = D exponent; M_{wt} normal = Normal hydrostatic gradient (ppg); M_{wt} actual = current mud weight (ppg).

To understand this equation we need to break it apart and understand each factor separately.

4.3.1. Formation hardness index

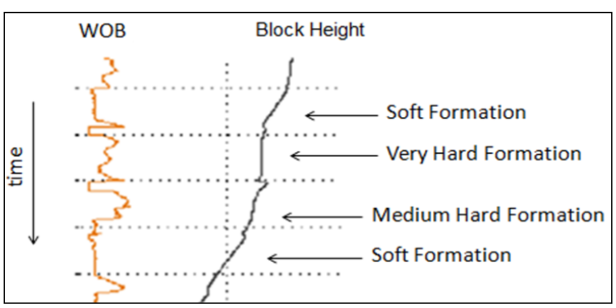

Figure 3. WOB and Block height are plotted vs. time

This factor represents the uncontrollable factors affecting drilling. Looking at rig charts during drilling and analyzing drilling real-time curves, difference between hard and soft formations can be identified especially from the relation between WOB and Block height which is remarkable. This can be seen in Figure 3, where both soft and hard formations are highlighted.

Hard formations could be identified with increase in weight on bit while the speed of the block is reduced on the other hand; Soft formations are indicated by decrease in weight on bit when the speed of the block is increased.

Based on the field data analysis and geological interpretation, the formation hardness index is given values ranging from 1 to 10 based on formation type, depth and lithology.

- From (1-3) for soft, shallow and unconsolidated formations.
- From (4-6) for medium depth consolidated formations free of Chert and abrasive sand.
- From (7-10) for hard and deep formations including compacted shale and abrasive sand.

The formation hardness index could be evaluated depending on field experience and offset data from near-by wells and then incorporating this factor it the equation to predict torque in next drilling operations.

4.3.2 The "D" Exponent

This factor combines the controllable factors that affect drillablity of rock as it incorporates Rate of penetration ROP, weight on bit (WOB), bit rotating speed (RPM) and bit diameter (D). This equation was introduced with the target of predicting the penetration rate from drilling parameters. This equation was proposed by Jorden and Shirley [6] depending on the Bingham [7] equation. Rehm and McCledon [8] updated Jorden & Shirley's equation to combine mud weight changes effect, as shown in Equation (2). This expression is known as the "D" exponent formula.

$$D = \frac{Log\left(\frac{R}{60N}\right)}{Log\left(\frac{12W}{10^6 D}\right)} * \left(\frac{\rho_{normal}}{\rho_{actual}}\right) \quad (2)$$

where: R = penetration rate (ft/h); N = RPM (revolutions per minute); D = Bit diameter (in); W = weight on the bit (lb); ρ_{normal} = normal hydrostatic gradient (ppg); ρ_{actual} = current mud weight (ppg).

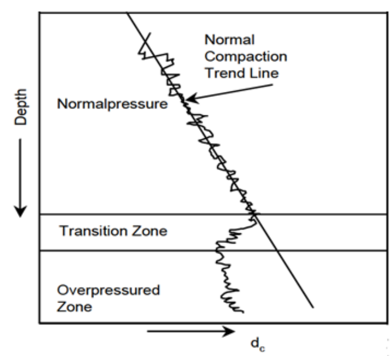

Figure 4. Sample plot showing normal trend of compaction for the "D" exponent and deviation In over pressured zones

As can be observed from equation (2), the "D" Exponent tries to predict the ROP in case of changes in RPM, WOB and Bit diameter. The "D" exponent is directly related to rock strength for normal pressured formations, the "D" exponent has a trend of increase with depth, showing the increased compaction of formation lithology.

In case of abnormal pressured formations, the "D" exponent doesn't follow the normal trend of increase and tend to decrease.

4.4. Torque model validation and testing against real field data

The proposed model was validated against real field data for different wells in Egypt's western desert. The accuracy of produced values of torque depends on some factors can be summarized as follow:

- Good determination of Fi (formation index) this can be accomplished by proper study of offset data and formation properties from well logs.
- Downhole assembly can highly affect the values taking into account that this model doesn't apply to motorized BHA which have down hole RPM not included in our model.
- The model doesn't apply During sliding or kicking off the well
- Inclination up to 5 degrees, the model can still be within range. Higher inclination will need updating the model with the side wall drag effects.
- Down hole problems like junk in hole or other torque altering reason as this model is only for simulating drilling torque resulting from engagement with formation.

Model validation was performed against several wells, but here we will apply the model on well sitra8-30 that was drilled by Bapetco in March 2015 (all data obtained under written approval from owner Company).

4.4.1. Real Data collection

Data were collected from the ASCII file in the final geological report. The actual data table includes sample data points each one meter drilled till TD. About +/- 3000 data points were included in the model validation.

Data have been used under authorization from owner company. Each row of data represents one meter drilled in the formation. real time parameters recorded by mud logger and kept in the DGR and ASCII file in EOWR. Example from ASCII file: can be shown in Figure 5.

Depth (m)	ROP1 (m/hr)	WOB	RPM	Real Torque	SPP	SPM1	SPM2	Flow in	M.Temp in	M.Temp out	M.Wt in
14	14.7	4	49	1288	101	0	49	243	21	22	8.7
15	6.3	6	50	1314	143	0	53	263	21	22	8.7
16	6.4	7	51	1331	111	0	52	260	21	22	8.7
17	3.5	8	51	1337	155	0	60	299	21	22	8.7
18	4.2	10	50	1358	175	0	60	301	21	22	8.7
19	7.5	13	62	1479	146	0	60	298	21	22	8.7
20	5.5	12	63	1413	158	0	61	302	21	22	8.7
21	8.1	13	62	1437	163	0	61	304	21	22	8.7
22	8.3	14	62	1480	120	0	59	296	21	22	8.7
23	9.5	11	63	1288	141	0	59	297	21	22	8.7
24	11.4	3	62	1269	146	0	60	298	21	22	8.7
25	24.7	16	63	1631	245	0	72	358	21	22	8.7
26	47.3	14	63	1488	256	0	71	356	21	22	8.7
27	75.2	16	63	1558	265	0	71	355	21	22	8.7
28	73.2	15	63	1581	230	0	71	355	21	22	8.7
29	71.7	15	63	1658	251	0	71	356	21	22	8.7

Figure 5. Example for actual data table extracted from well Sitra 8-30 well

4.4.2. Real Data analysis and plotting

Actual torque curve was plotted against depth and formation tops and lithology were included to view torque variations while switching between formations.

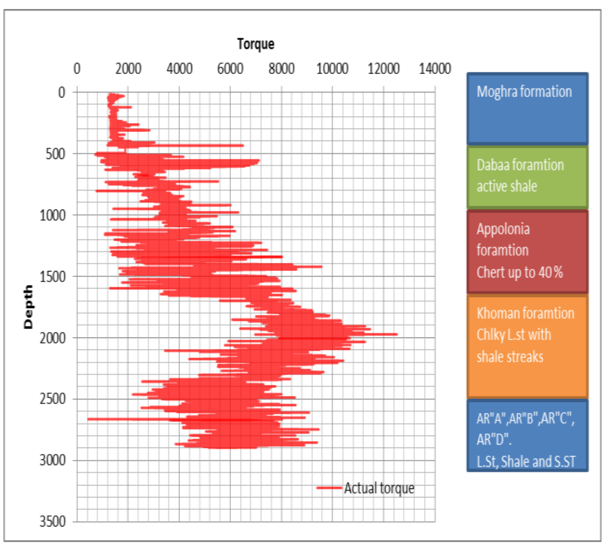

Figure 6. Actual Torque plotted against depth from well Sitra 8-30 well

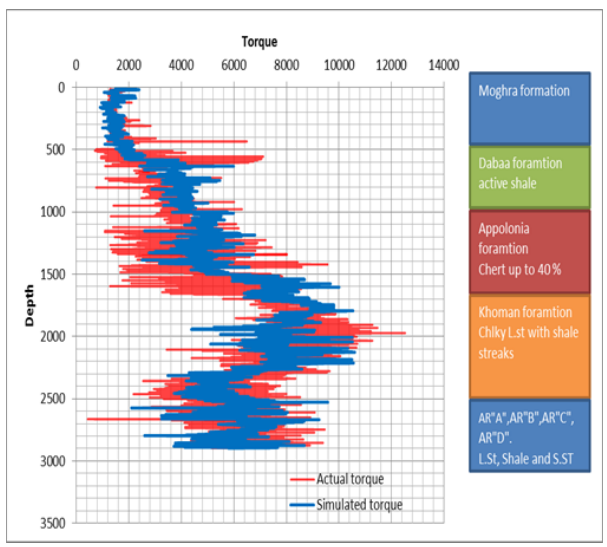

Figure 7. Actual Torque and Simulated torque plotted against depth from well Sitra 8-30 well

4.4.3. Simulated data and plotting against real data

Used torque simulation model to produce values for torque, compare against actual data.

4.4.4. Results discussion

Having a look at the comparison graph, we can see that torque values and torque trends are approaching along most of the drilling column except at sliding intervals. The model is also validated against other wells showing similar results. This can lead to a safe introduction of this model into torque simulation based on drilling and formation parameters.

5. Software framework

The software is developed using Visual basic language as programming platform and the following tools used:

- Data Active object (DAO3.6) Library.
- Graphics modifier.
- SQL engine
- Microsoft access as database engine.
- OLE automation
- Microsoft Comm. control library
- Common Language Execution runtime 2.4
- Microsoft ADO data control library
- Simultaneous Data transfer

5.1. Software logic flow diagram

The following flow diagram represents the basic structure of the soft drilling simulator.

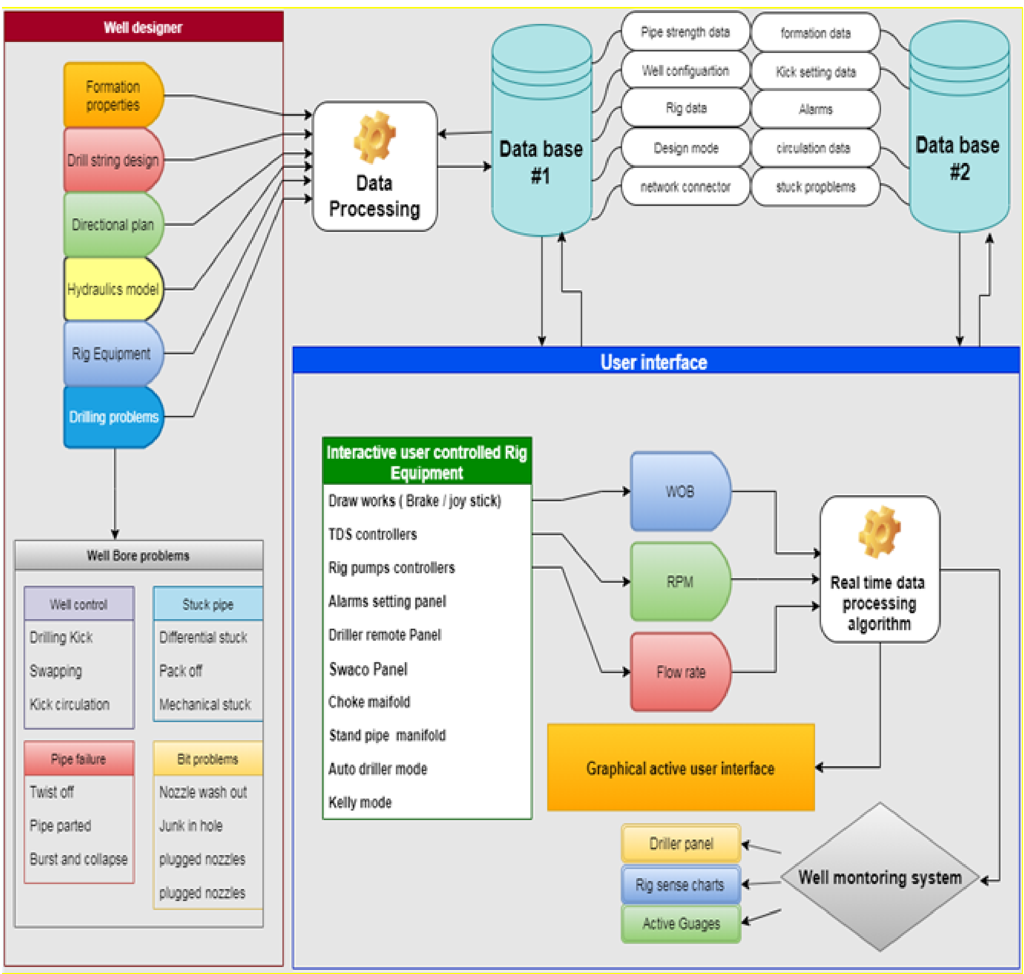

Figure 8. Logic flow diagram for the soft drilling simulator

5.2. Software functionalities

- The simulator gives the user the full ability to practice drilling in the way it happens in the field giving the user realistic environment of all drilling technologies including sound effects and visual design of screens like those existent on rig site.
- Top drive and Kelly are involved in the system allowing the trainee to practice on a variety of drilling equipment.
- The user interface is designed in a way that simulates the real screens.
- Well designer can be used to simulate customized drilling experiments.
- Well monitoring system is included that allows the trainee to have a clear and realistic view of what is happening down hole by interpreting different surface data.
- Rig sense charts are added to monitor different drilling parameters versus depth
- All drilling problems can be simulated like stuck pipe, lost circulation, kicks, wash outs, worn bits and plugged nozzles.
- Complete well control module to simulate all well control related problems and shut the well and circulate the kick in controlled manner.
- Visual and sound alarms are present to be set to higher and lower values to alert the user when there is a problem developing to start corrective actions.
- Different drilling techniques are included like using manual brakes, joy stick and Automatic Driller System (ADS).
- Complete circulation system including mud pumps, mud system, mud flow returns and flow meter.
- Driller's remote panel is added to simulate the real process of shutting in the well and monitoring the gauges of both annular regulator, manifold pressure and accumulator pressure to be aware of how this happen in real situations.
- Realistic SWACO panel simulation which gives the user a spectacular ability to circulate a kick out of the hole by controlling the remote choke. The panel also has pressure gauges of casing and drill pipe pressure to have a full view of what's happening upon kick circulation.
- Tripping and back reaming operations can be easily performed through the realistic user interface.
- Kill sheet calculations screen that gets updated with different parameters to view well killing parameters such as RRCP, Total strokes and KMW.
- Leak off test can be performed on formations using mud pumps to determine the leak off pressure for each formation.
- The software is supported with a data base and each well being drilled has a record can be saved separately and recovered when you need to resume drilling in that well.
- Drill string design screen to select the design of the drill string and BHA.
- Set fluid parameters: mud weight, plastic viscosity, yield point and initial gel.
- Select rheological models, Power or Bingham.
- Set gradients, absorption, fracture and temperature.

5.3. Software code snippet

The following code implemented in a timer to produce rotation effect on the screen and activate audible effects.

```
Private Sub Timer2_Timer()

If rotation1.x1 <= 270 Then
        rotation1.x1 = 450
rotation2.x1 = 450
rotation3.x1 = 450
rotation4.x1 = 450
rotation4.x2 = 510
rotation1.x2 = 510
rotation2.x2 = 510
rotation3.x2 = 510
```

```
Else
rotation1.x1 = rotation1.x1 - Val(RPM_TEXT.Text) / 5
rotation2.x1 = rotation2.x1 - Val(RPM_TEXT.Text) / 5
rotation3.x1 = rotation3.x1 - Val(RPM_TEXT.Text) / 5
rotation4.x1 = rotation3.x1 - Val(RPM_TEXT.Text) / 5
rotation4.x2 = rotation1.x2 - Val(RPM_TEXT.Text) / 5
rotation1.x2 = rotation1.x2 - Val(RPM_TEXT.Text) / 5
rotation2.x2 = rotation2.x2 - Val(RPM_TEXT.Text) / 5
rotation3.x2 = rotation3.x2 - Val(RPM_TEXT.Text) / 5
End If
rotation = 1
mmcrotate.Refresh
mmcrotate.Command = "open"
mmcrotate.Command = "play"

End Sub
```

5.4. Software user interface

Now we will show some of software screens to present the user friendly designs and similarity to real equipment.

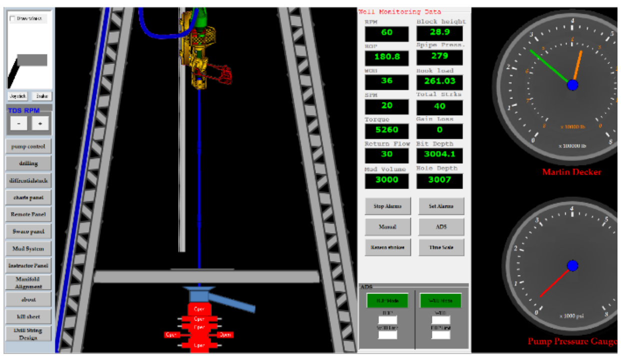

Figure 9. User interface screen (Top Drive system simulation)

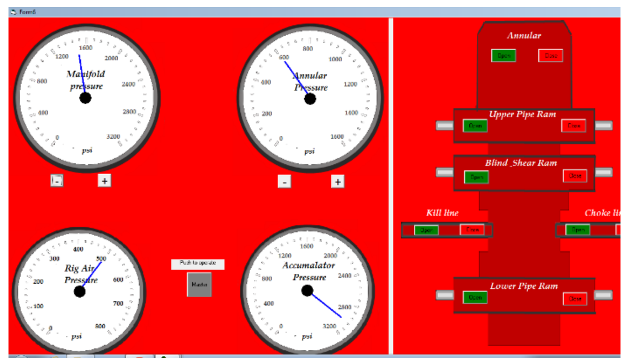

Figure 10. User interface screen (Driller remote panel simulation)

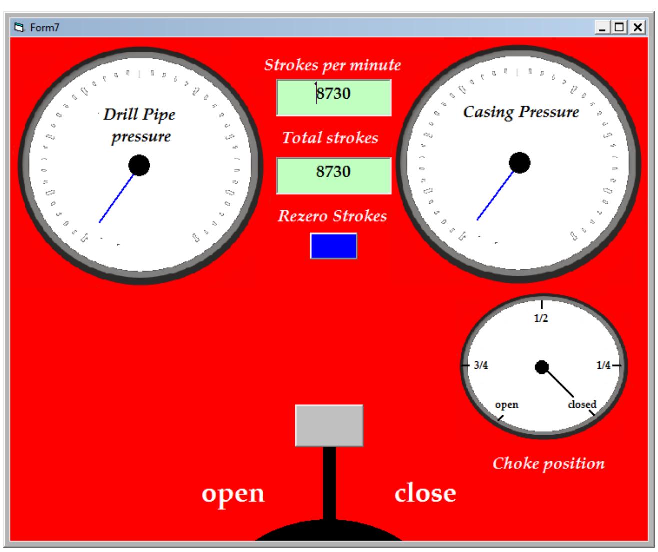

Fig. 11. User interface screen (Swaco Simulation)

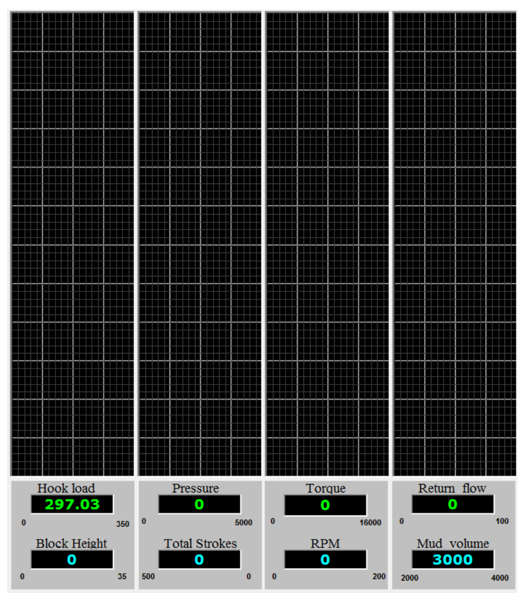

Figure 12. (Rig Sense Simulation)

6. Conclusions

At the end of this discussion about the soft drilling simulator, we can say that a new concept of training in drilling industry will be introduced. Due to its reality, feasibility and low cost, training over the SDS will give both knowledge and real sense of drilling problems. The drilling simulator models didn't depend only on theoretical approach but also considered data realization to capture the final output similar to real time scenarios. Well control simulator model will also take the trainee in realistic well control journey to get the taste and the art of handling well control issues.

First version is intended to be on computers to be easy and cost effective for student. Further versions will consider implementing hardware controls.

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