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KNOWLEDGE DRIVEN GENERIC DRILL STRING MODELING

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ABSTRACT

This paper presents a knowledge driven system for oil well drill string design with a computer aided design (CAD) tool. Such design requires geological information input and carried out upfront with very much knowledge and experience. The authors developed a semi-automated and functional drill string design module, as a part of a preliminary and more comprehensive and intelligent drilling design package named as “DrillSoft”. The approach is to automate the engineering and three dimensional (3D) modeling processes where built-in rules and knowledge are used in the conceptual design of a drill string and then the system automatically generates the assembly configuration based on the conceptual design and retrieves part specifications from the part database to generate the CAD parametric files. The conceptual design and CAD modeling system are integrated in such a way that any changes in the design will be reflected to the CAD model. Such intelligent CAD design practice is new in the drilling industry.

INTRODUCTION

A drill string on an oil rig is a column of drill pipes, drill collars, heavy weight drill pipe, crossover sub and bit sub that transmits drilling fluid and rotational power to the drill bit. According to Chunha [1], drill string design is the most important part for operations in drilling engineering. Drilling engineer is responsible to design a system suitable for a variety of options. It is a well known fact that drill-string failure represents one of the major causes for “fishing” operations which may lead to millions of dollars in loss for the industry. To reduce the risk of drill string failure the design should be justified beforehand by simulation or finite element analysis. Austin [2] stated that, 3D model provides closer links between geoscientists and reservoir engineers while promoting an integration as well as interaction of the two. At present an analytical model, and if necessary a finite element analysis model for whole drill string are used to compute torque and drag. It will be very much useful if a 3D model can be used in simulation and finite element analysis [3] to predict the behavior of the well. However it is cumbersome to develop the repetitive 3D models for each section of the well in order to perform such analyses. To eliminate the repetitive modeling tasks, a parametric and smart oil well drill string modeling CAD tool has been prototyped that enables generation of 3D models with built-in engineering rules, constraints and controls on different changing situations throughout a well-drilling lifecycle. A common part database has been integrated into the system so that they can be reused from a library.

LITERATURE REVIEW

Kasravi [4] pointed out that, the human expertise and knowledge are scarce and a need of knowledge embodiment within the geometric model is obvious. Zha et al. [5] developed a knowledge-based expert design system for assembly oriented design. Koo et al. [6] developed an expert paper feeding mechanisms system, where the physical part of the paper feeding mechanisms were represented as objects, and the design knowledge and design constraints are represented by rules and methods without the interface to CAD. Myung et al. [7] developed a design expert system to redesign assemblies of machine tool in a CAD environment. Transferring KBE intelligence to CAD system is challenging because there is no mechanism to enable such information flow as identified by Ma et al. [8]. As introduced in [4], parametric engineering uses the design requirements as the input data, and the output data consists of the parameters of the key features of the constituent components. Commonly, most researchers used parametric part templates to generate new 3D designs and changes are realized by setting values to the driving parameters [9, 10]. Ma et al. [10] considered the topological and configuration changes of parts.

RESEARCH APPROACH

The current research is to develop a generic and parametric drill string CAD model driven by knowledge-based rules, which can be reused repetitively. This system can now produce the conceptual design by considering the built in rules and constraints; and the conceptual design is used to generate the parametric 3D model of drill string. Unlike those efforts using CAD templates, which require a part libraries and are difficult to manage, this research work uses generative approach to program generic drill string model. The advantages of using program instead of template files are that: (1) geometry and feature can be easily created and edited; (2) parameters can be created and manipulated in more controlled manner; (3) geometry analysis and part standardization can be easily achieved; (4) files can be managed more efficiently; (5) data access and family of parts creation are more convenient.

PROPOSED SYSTEM STRUCTURE

Development of oil well drilling plan is a very complex process. It is a combination of different segments. All of these segments are connected with each other. Manually managing a complete drilling plan is a difficult task; hence a computer program "DrillSoft" has been developed by using Microsoft Visual Basic application in Excel for engineering rules and calculations and user interfaces, Siemens NX6 for CAD modeling via NX Open C Application Programming Interfaces (APIs). The concept is to make full use of the capability of CAD API functions that can be called under an object-oriented system environment to generate standard component and assembly models. The CAD API functions are also available to integrate CAD functions with EXCEL application programs. The DrillSoft system consists of three modules: (1) Casing Design, (2) Drill String Design, and (3) Operational Parameters.

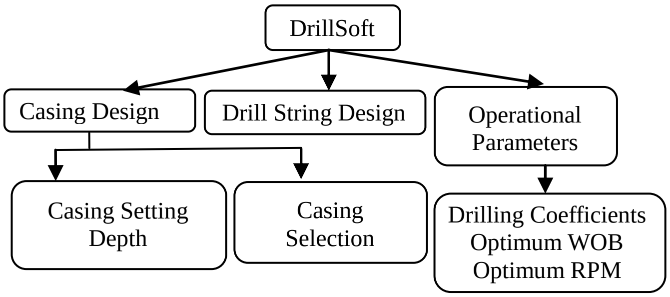


Fig. 1: DrillSoft modules

Casing design module calculates casing setting depth by using formation pore pressure and fracture pressure, and determines the size of hole and casing of each section of the well. It then selects the optimum combination of casing string from the available inventory. Operational Parameter module works out drilling coefficients, the optimum weight on bit (WOB) and the drilling rotary speed (RPM). Drilling Coefficients are determined according to Bourgoyne and Young et al. [11] regression analysis procedure, at least 30 offset drilling data sets are required. Optimum WOB and RPM are determined for the minimum cost. This program also generates six different tables of economic performance as a function of weight on bit and rotary speed as an operational guide. DrillSoft also produces formal reports for design details.

DRILL STRING DESIGN

Drill string design starts after the operational requirements have been defined based on the casing design output and the customer input. The operational requirements include type of the well, depth, mud specific gravity, maximum WOB, margin of overpull, safety factor for collapse, type of drill pipe available in the inventory, drill collar, heavy weight drill pipe size, etc. The drill string design module of DrillSoft system then generates the conceptual design based on a set of built-in engineering rules embedded in the module following the recommended practice for drill stem design standards [12].

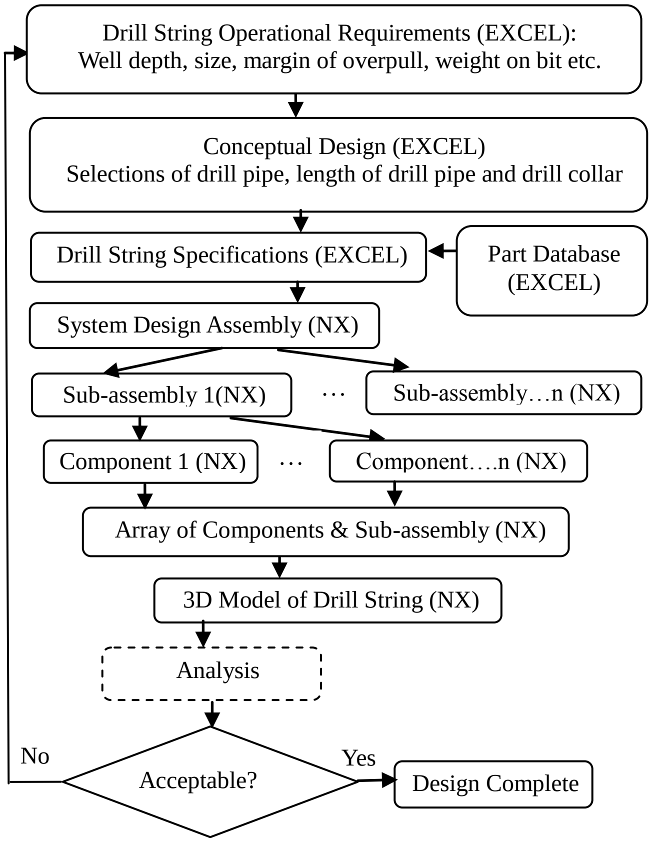


Fig. 2: Drill string design module

For example, one such rule is that "*drill pipe should always be under effective tensile stress, neutral point of buckling should be in the drill collar*". In the conceptual design stage calculating the length of drill collar requires to the WOB data. Then the system selects the cheapest (in most of the cases also weakest) drill pipe type from the available inventory and check against the loading criteria. If the type is not safe to run the whole length of the drill string, the allowed maximum length of that drill pipe type is worked out. The selection cycle of the drill pipes continues until the whole length of the drill string is achieved. Hence, the algorithm selects the cheapest drilling string assembly based on the lowest grade and the unit weight of the pipes in the inventory.

Once the conceptual design of drill string is complete the next step is to determine the drill string component specifications and configurations. The configuration design determines the number and types of components, their orientation and position in the drill string assembly. A well defined part database has been developed; it contains the geometric and non-geometric specifications of each component. For example, a drill pipe has the length, OD, ID and tool joint diameter, upset diameter, etc. Figure 3 shows a drill pipe subassembly with its components.

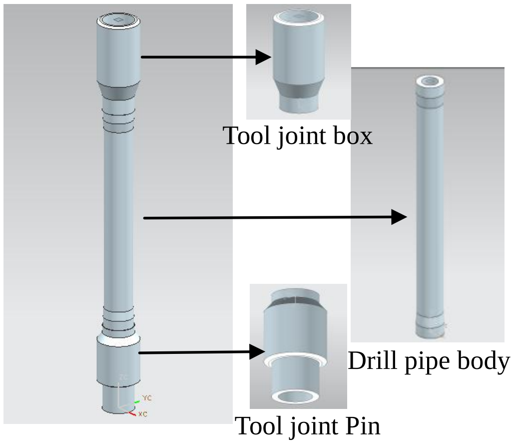
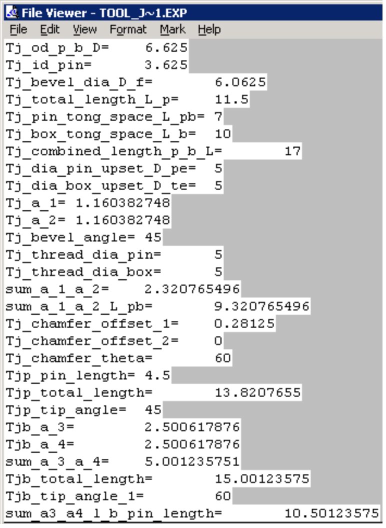


Fig. 3: Drill pipe sub-assembly and components

The system automatically retrieves necessary data according to the library specifications of each component and generates the 3D CAD model as well as a parametric data file known as CAD expression file. Figure 4 shows a drill pipe tool joint pin and box parametric data set. NX Open API functions with C programming language are used to generate 3D models. A "top-down" assembly approach has been followed, where the structure of the whole assembly of the drill string is first created; the generic configuration of drill string assembly contains all possible components of drill string. For example, a drill string assembly composed of drill pipe, drill collar, heavy weight drill pipe, bit sub, cross over sub, drill bit etc. Depending on the operational requirements some components may not be required. For example, sometimes "heavy weight drill pipe" is not used in the drill string; then in that case, the module which creates assembly structure, will suppress the "heavy weight drill pipe" from the assembly.

The next level is sub-assembly generation. The program first finds out which member of the assembly contains sub-assembly from a configuration definition and then fire the rule to initiate sub-assembly creation. Refer again to Figure 3. A drill pipe sub assembly contains three parts – drill pipe body, tool joint pin and tool joint box. Such structure generation algorithm continues iteratively until all the configuration of the whole assembly is completed. It should be worth mentioning that, in the "top-down" approach, though assembly structure is first created but in each of the structure members, no physical geometry entities are created until the program reaches to the next stage. The next stage is to create the component geometry entities. Individual parametric program has been written for each component to generate the generic 3D model. To reflect the topological variations, the algorithm selects which generation functions to run. As for example, as shown in Fig. 5, a drill pipe body may have three different topologies – internal-external upset, external upset and internal upset.



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Tj_id_pin=       3.625
Tj_bevel_dia_D_f=        6.0625
Tj_total_length_L_p=     11.5
Tj_pin_tong_space_L_pb= 7
Tj_box_tong_space_L_b=  10
Tj_combined_length_p_b_L=        17
Tj_dia_pin_upset_D_pe=  5
Tj_dia_box_upset_D_te=  5
Tj_a_1= 1.160382748
Tj_a_2= 1.160382748
Tj_bevel_angle= 45
Tj_thread_dia_pin=       5
Tj_thread_dia_box=       5
sum_a_1_a_2=     2.320765496
sum_a_1_a_2_L_pb=        9.320765496
Tj_chamfer_offset_1=     0.28125
Tj_chamfer_offset_2=     0
Tj_chamfer_theta=        60
Tjp_pin_length= 4.5
Tjp_total_length=        13.8207655
Tjp_tip_angle=  45
Tjb_a_3=         2.500617876
Tjb_a_4=         2.500617876
sum_a_3_a_4=     5.001235751
Tjb_total_length=        15.00123575
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sum_a3_a4_l_b_pin_length=        10.50123575
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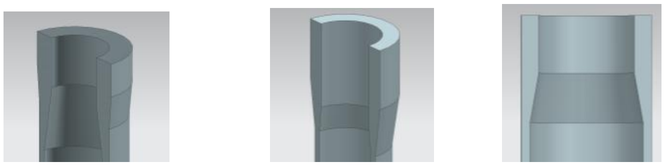
Fig. 4: Expression file of a drill pipe tool joint pin and box



(a) Internal-external upset (b) External upset (c) Internal upset

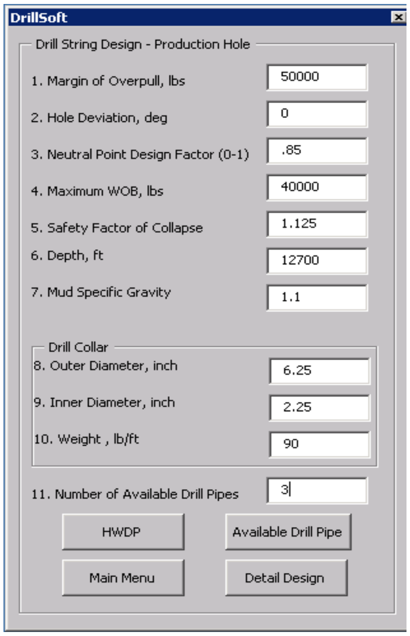
Fig. 5: Drill pipe features

An array method has been implemented to repeat the component and subassembly instantiation as shown in Figure 6, which helps to reproduce a large quantity of drill pipes of similar types and other components throughout the assembly. After the arrays of components and sub-assemblies are generated, the 3D model of the whole drill string assembly is realized. They can be used to do finite element analysis and simulation. If the result of the analysis is not satisfactory then the program can assist redesign of the drill string by following the same steps mentioned earlier; then the whole design loop is integrated with higher productivity. More work is to be done in the future.

Fig. 6: Partial drill string assembly

CASE STUDY

To proof the concept of the developed module, a drill string is designed. The case is taken from API standard handbook. Figure 7 shows the user interface of drill string module filled with input. Table 1 shows three drill pipe types available in the inventory. Based on the operational input the rule based system designed the drill string that uses two different types of drill pipes. The program first considers the most economic drill pipe type among the available three, and chooses grade E75 and determines the safe length of 6750 ft. After checking the length of 21 drill collars and the drill string developed has reached a length of 7380 ft before the required depth of 12700 ft. Then the second pipe type, grade X95 is selected for rest of 5320 ft. When checking the collapse loading, in this case, the program works out as 10267 ft and drill string is limited to this depth for avoiding damage.



Drill String Design - Production Hole

1. Margin of Overpull, lbs: 50000
2. Hole Deviation, deg: 0
3. Neutral Point Design Factor (0-1): .85
4. Maximum WOB, lbs: 40000
5. Safety Factor of Collapse: 1.125
6. Depth, ft: 12700
7. Mud Specific Gravity: 1.1

Drill Collar
8. Outer Diameter, inch: 6.25
9. Inner Diameter, inch: 2.25
10. Weight , lb/ft: 90

11. Number of Available Drill Pipes: 3

Fig. 7: Drill string design user interface

Table 1: Conceptual design parameters for a drill string

Drill String Components	Length (ft)	No of array
Drill Collar: 6 ¼"OD X 2 ¼"ID	630	21
Drill Pipe Type 1: 4 ½" X 16.6lb, Grade E75, Class2	6750	225
Drill Pipe Type 2: 4 1/2 " X 16.6lb,Grade X95, Premium Class	5320	178
Drill Pipe Type 3: 4 1/2 " X 16.6lb, Grade G105, New Class	0	N/A

CONCLULSION

The drill string design module is capable of handling different configurations as well as different topologies of components. So far, only vertical oil wells are considered. More research work aiming at a more generic model is needed for horizontal, extended reach and multilateral wells.

ACKNOWLEDGMENTS

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