Reverse Engineering of PDC Drill Bit Design to Study Improvement on Rate of Penetration

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Abstract: - In exploration and production of oil and gas, drilling process is one of the most crucial due to its economics implications. Reduction in drilling completion by increasing drilling rate of penetration is desired to lower overall production costs. This research focuses on design improvement of Polycrystalline Diamond Compact drill bit by analyzing on effect of chamfer cutter angle, number of blades and size of cutter diameter on rate of penetration. Reverse engineering using a 3D laser scanner is adopted to generate cloud model and extract the existing Polycrystalline Diamond Compact drill bit design. Finite element method is utilized to analyze the effect of design feature modification. Result shows that the optimum PDC Drill Bit design is achieved for 5 blades cutter with cutter edge geometry at 20° and cutter diameter of 19.05 mm. The average ROP for this PDC drill bit is found to highest among all design at 10.6mm/s.

Key-Words: - PDC Drill Bit; Rate of Penetration; Reverse Engineering; Finite Element Analysis

1 Introduction

Drilling process plays a vital role in oil and gas Exploration and Production (E&P). Efficiency of the drilling operation is partly measured based on the rate of penetration (ROP) in meter/hour. Overhead cost for hiring a drill-rig can run up to a few hundred thousand dollars daily. Thus a higher ROP contributing towards shorter time taken for drilling completion is highly desired. One of the factors which affect the ROP is drill bit design. Drilling industry and research community embark on continuous research in search for improved drill bit design to improve the overall drilling performance and reduce drilling costs and thus increase their margins.

Reverse engineering (RE) is a very effective method for reconstruction of existing product design. The application of reverse engineering is robust in a wide spectrum of engineering field. Often RE is associated with obtaining computer-aided design (CAD) model for quality control application, reproduction and replication function. According to [1], the advancement of scanning and CAD technology in recreating geometric models of existing objects by various RE techniques can be quickly and almost seamlessly executed. RE are now widely used in various industries such as automotive, aerospace, and ship building.

2 Problem Statement

Failure of PDC drill bit often happens during drilling operation due to cutter damage such as lost cutter, broken cutter, chipped cutter, and junked damage. These problems lead to lower penetration rate which significantly affects the drilling performance and increases the drilling cost. Hardness of formation is one the factor that causes cutter damage. However, low ROP and cutter failure can also be due to poor drill bit design.

3 Objective

The objective of this paper is to analyze various bit design in order to increase ROP. This paper aims to optimize drill bit design in relation to number of blades, cutter angle and size of cutter diameter by conducting Finite Element Analysis (FEA).

4 Review

4.1 Reverse Engineering

Engineering is a profession to develop and apply structures, machines, materials, devices and systems

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through various technical, scientific, and mathematical analyses [2]. There are two types of engineering which are forward engineering and reverse engineering. Forward engineering is traditional process of engineering where the development of such inventions comes from critical thinking, to creation of logical design up to implementation and production [3]. RE is a process to reproduce an existing part in order to analyze the design and to modify the design to improve its function, to change its dimension and design for the aesthetic value, or to reproduce the object that is specially made for a product to be used by others.
RE typically starts with measuring or scanning an existing object, so that a solid model can be deduced in order to make use of the advantages of CAD/CAM/CAE technologies [3].

4.2 Drill Bit

The success of drilling operations depends on drill bit performance. According to Schlumberger oilfield glossary, drill bit is a tool used to crush or cut rock. Drill bits come in many sizes, types, and shapes and are designed to drill all types of rocks [4]. The choice of bit depends on several factors. One is the type of formation to be drilled, whether it is hard, soft, medium hard or medium soft. Type of drill bits that are often used in drilling operation are shown in Fig.1, from left, Polycrystalline Diamond Compact (PDC) bit, Diamond bit and Tricone bit, respectively.

Fig.1: Type of Drill Bits

4.3 Drill Bit Design

Drill bit design is one of the major factors affecting the ROP during drilling process [5]. According to [6], drill bit designers improve some design features in order to obtain desired drilling performance [6]. There are two main design feature affecting PDC drill bit performance according to [7] in his journal entitled “PDC Drill Bit Design and Field Application Evolution”. The features are:

- Number of blades with cutters
- Cutter edge geometry
- Diameter of the cutter

4.4 Finite Element Analysis

Finite Element Analysis (FEA) is a computer model of a material or design that is analyzed to get more specific results. It is used in existing or new product improvement. A company can verify a proposed design to meet client's specifications subject to the manufacturing, fabrication and construction [8]. Modifying an existing product or model is utilized to improve or qualify the product for a new service condition and purpose. If the model fails, FEA is very useful to help designer to modify back the design to meet the desired condition and optimal design.

5 Methodology

Research procedure used in this project is divided into 5 stages:-

i. Defining stage: Understanding the project background, problem statement, setting the objectives, methodology to be adopted and identifying the required tools.
ii. Research stage: Conducting extensive study on the literatures related to the project.
iii. Analytical stage: Analysis and classification of drill bit designs based on feasible parameters and features.
iv. Modeling stage: Performing design optimization for four (4) drill bits using CAD software.
v. Interpretation stage: Analyze the effect of optimized drill bit design on the ROP using Finite Element Analysis (FEA).

5.1 Reverse Engineering

A 3D laser scanner is used to obtain cloud model of PDC drill bit. The cloud model is then converted to 3D CAD model using a 3D modeling software. Once the 3D CAD drawing is obtained, design modification is executed by changing the design parameters, i.e., the number of blades, cutter edge geometry and diameter of cutter. Finite element analysis is conducted on each of the new drill bit design in order to find the optimal design.

5.2 Analysis on Drill Bit Features

The above mentioned parameters and features are modified and adjusted to test and analyze their

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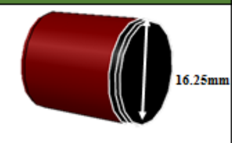
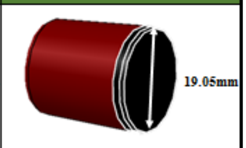
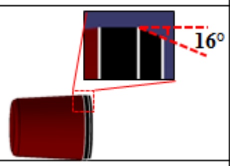
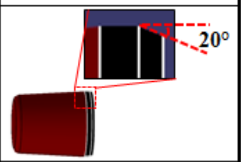
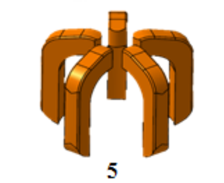
effect on ROP. Original chamfer edge angle is adjusted to 16° and 20° and drill bits with 5 and 6 blades were also tested for effect on ROP (Table 1). Apart from that, 13mm cutter size was replaced by 16.25mm and 19.05mm size of cutters.

Table 1: Modified features

Design Features	Factor 1	Factor 2
Diameter of Cutter		
Chamfer Edge Geometry		
Number of Blades		

5.3 Taguchi Method for Design Optimization

Taguchi method which is widely used in manufacturing field is adopted in order to reduce the number of experiments to a practical level by automatically selecting the optimal parameters for simulation purpose [9]. In this research the total number of runs using Taguchi is shown in Table 2.

Table 2: Total number of Runs using Taguchi

Runs	No.of Blades	Chamfer Edge Geometry	Cutter Diameter (mm)
1	5	16°	16.25
2	5	20°	19.05
3	6	16°	16.25
4	6	20°	19.05

5.4 FEA of Drill Bit ROP

The purpose of FEA is to understand the physical behaviors of a complex object and to predict the performance and behavior of the design; to identify the weakness of the design accurately [8]. A total of four drill bits and rock interface is modeled by using 3D CAD model.

Features of the drill bit model developed and parameters used in the analysis are shown in Fig.2. Sandstone is used as rock type formation for this case study project. This material is selected for its high homogeneity and medium strength.

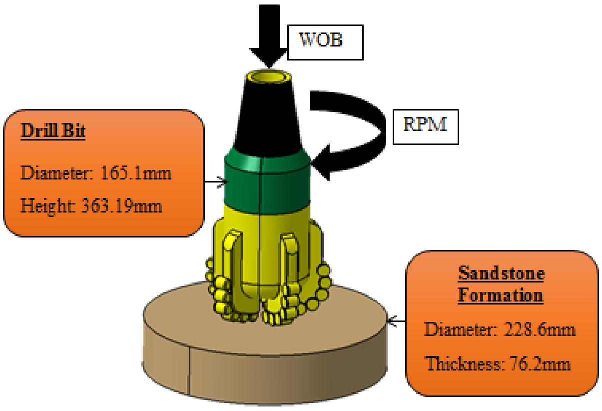


Fig.2: Drill Bit and Rock Analysis

Based on inputs from drilling companies an angular velocity of 350 rpm is defined in initial condition system. The direction of the rotation is defined by Z-axis component and Sandstone formation is kept as a static object with fixed support feature. Analysis and simulation on the four different drill bit models is conducted using a target solver (Fig.3).

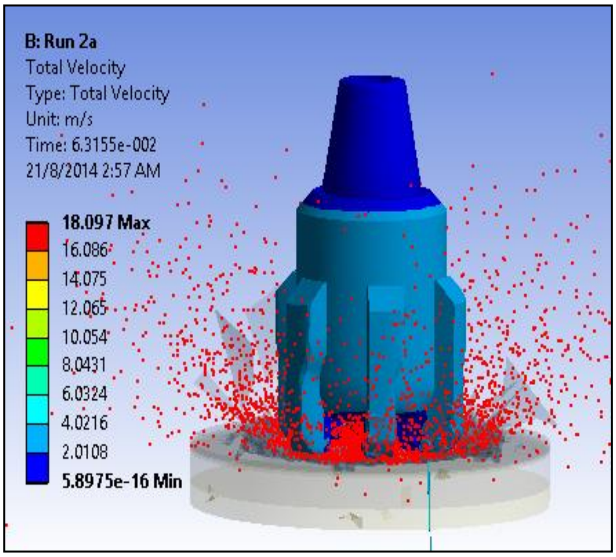


Fig.3: Analysis and Simulation on ROP

ROP is defined as the speed at which a drill bit breaks the rock under it to deepen the borehole. In the simulation, total velocity is selected to measure the rate of penetration. Table 3 shows the ROP result on the four different drill bit models tested.

Table 3 : Average ROP for Drill Bit Models

Model	ROP (mm/s)
1	8.4
2	10.6
3	8.6
4	9.6

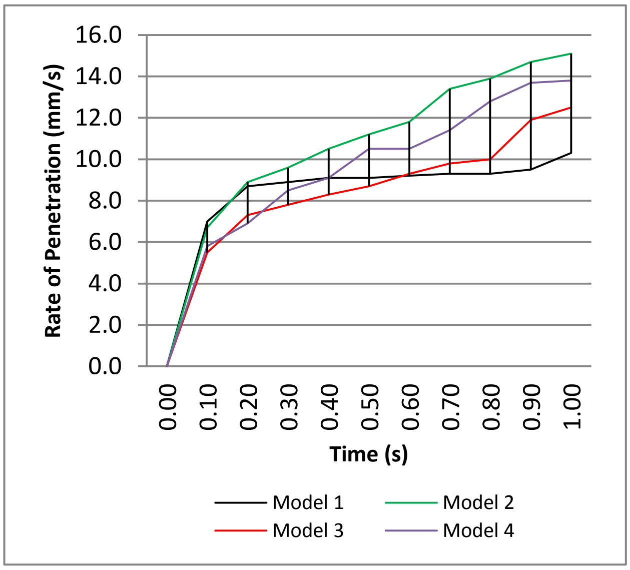


Fig.4: Analysis data of four different models

Fig.4 shows the comparative study of the penetration rate between the four drill bit models. Result shows that the optimum PDC Drill Bit design is for 5 blades cutter with cutter edge geometry at 20° and cutter diameter of 19.05 mm. The average ROP for this PDC drill bit is found to highest among all design at 10.6mm/s. A calculation is made to calculate the percentage of improvement of ROP as shown in Fig.5. PDC Drill bit capable of drilling a sandstone formation for 35.3m/hr which is about 9.8mm/s per second.

$$\frac{Optimized\ ROP - Normal\ ROP}{Normal\ ROP} X\ 100\%$$

$$\frac{10.6\ mm/s - 9.8 mm/s}{9.8 mm/s} X\ 100\%$$

$$8.16\ \%$$

Fig.5: Percentage improvements in ROP

6 Conclusion

Design feature such as cutter edge geometry, cutter diameter and number of blades can be analyzed and manipulated to improve the performance of the drill bit in terms of ROP as shown in this research work. To further improve the drill bit design other parameters need to be considered as well. Also, further analysis need to be conducted to consider the effect of these design parameters on the PDC bit wear rate as well.

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