PDC Drill Bit Design Improvement using Reverse Engineering Method to Analyze Effect on Rate of Penetration

By

Mohamad Zamri B. Ismail

Dissertation submitted in partial fulfilment of

the requirement for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(DR AHMAD MAJDI BIN ABDUL RANI)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHAMAD ZAMRI B. ISMAIL

ABSTRACT

In the petroleum industry, drilling is one of the most important aspects due to the economics. Reduction in drilling time is required to minimize the cost of operations. This study focuses on the Polycrystalline Diamond Compact (PDC) drill bit which is categorized as fixed cutter of drilling bit. Problem such as wear and tear of PDC cutter is one of the main factor in drilling process failure and this would affect the rate of penetration. Thus, an intensive study in drill bit design would save a lot of money if the efficiency of drill bit can be improved. The objective of this project is to improve the design of PDC cutter and study the effect of design improvement to the rate of penetration. Reverse engineering (RE) method will be used to study the design and analyse the effect of the design to performance of the drill bit. Due to unavailable drill bit blueprint from the manufacturer due to propriety and confidential, RE non-contact data acquisition device, 3D laser scanner will be used to obtain cloud data of worn drill bit. Computer Aided Design (CAD) software is used to convert cloud data of the PDC drill bit into 3D CAD model. Optimization of PDC Drill bit is focused on feature design such as back rake angle, side rake angle and number of cutters. CAE software is used to analyse the effect of the design feature modification to rate of penetration. The results show rate of penetration increase as the angle of both rake angle and number of cutter decrease.

ACKNOWLEDGEMENT

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Lastly, the author would like to express special gratitude to his family for their endless support and MARA for sponsoring the scholarship to him.

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ABBREVIATIONS AND NOMENCLATURES

RE	Reverse Engineering
PDC	Polycrystalline Diamond Compact
ROP	Rate of Penetration
WOB	Weight on Bit
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAE	Computer Aided Engineering
3D	Three Dimensional
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
CT	Computer Tomography
CATIA	Computer Aided Three-dimensional Interactive Application
STL	Stereo Lithography
IGES	Initial Graphic Exchange Specifications
STEP	Standard for the Exchange of Product
UTP	Universiti Teknologi PETRONAS
FYP	Final Year Project

CHAPTER 1

INTRODUCTION

1.1 Background of study

Drilling process is one of the major parts in Exploration and Production (E & P) of oil. Once a promising geological structure has been identified, the only way to confirm the presence of hydrocarbon is to drill exploratory boreholes. All wells that are drilled to discover hydrocarbon are called ‘exploration well’. Drilling operation are generally conducted around-the clock. Cost and time depends each other in deciding the profit of an Oil and Gas company during drilling operation. The shorter the time taken for finishing drilling operation, the lower money will be consumed. As lower money consumed during the operation, profit can be obtained by the company. However, due to unexpected circumstances such as failure of drilling tool can cause loss to the company. Drilling activities has to stop in order to fix the failure consequently affect the drilling operation time and cost. In addition, the rate of penetration can be considered as one of the primary factors which affect drilling cost. There are several factors affect rate of penetration but the author will focus on drill bit design.

Advanced technology is trying to explore ways to enhance the system, product or model in order to increase the productivity. There are several factors need to be consider to achieve the goal. The most important factors are cost and time. A short lead-time in product development is strongly demanded to satisfy needs, resulting from the globalization of manufacturing activities and the changes in market requirements [3]. The application of reverse engineering is robust. Often reverse engineering correlate with obtaining CAD model for reproduction or replication function. According to Y.Zhang (2003), the difficulties to create a CAD model of an existing product that has a free-form surface or a sculptured surface in engineering area such as aerospace, automotive, shipbuilding and medicine can be solved by using RE approach. Oil and gas industry also gain benefits from the application of reverse engineering.

1.2 Problem Statement

Failure of PDC drill bit often happen during drilling operation due to cutter damage such as chipped cutter, lost cutter, broken cutter and junked damage (Figure 1). This problem lead to low rate of penetration which consequently affect the drilling performance and cost. Hardness of formation is one the factor that lead to cutter damage. However, low rate of penetration also caused by the design of the drill bit.

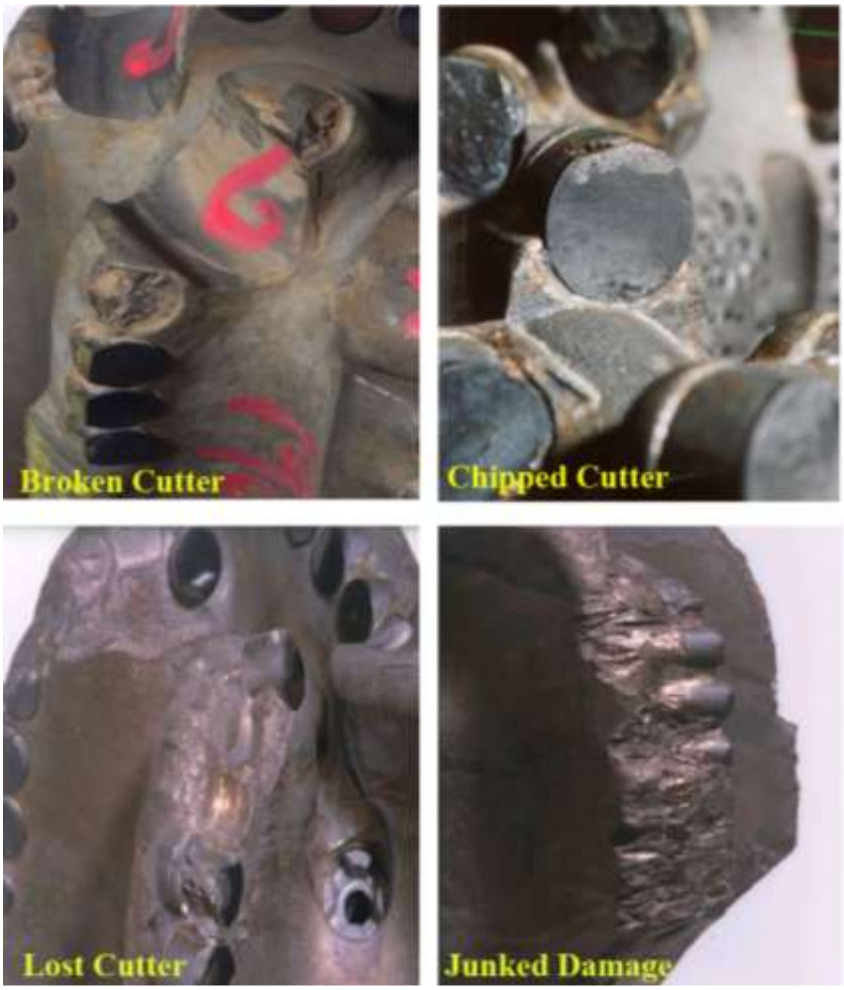

Figure 1 Types of wear usually occur to drill bit

Unavailability of CAD drawing of drill bits due to old design or the manufacturer has not produce it anymore poses difficulty to analyse the failure of drill bit. The design of the drill bit is complicated hence it is impossible to reproduce the drawing at short time period. In addition, without the blueprint it is impossible for engineer to study and optimize the drill bits to overcome the failure. Thus, a more effective solution should be implemented to overcome the problem.

1.3 Objective

The main objectives of this study are:

i. To develop an analysis by using Reverse Engineering method on PDC drill bit in order to increase rate of penetration (ROP).
ii. To scan worn PDC Drill Bit by using 3D ViuScan scanner into a cloud model.
iii. To convert the cloud model into a CAD model by using 3D modeling software.
iv. To regenerate CAD model of worn drill bit by using 3D modelling software.
v. To optimize drill bit design in relationship to increase rate of penetration (ROP)
vi. To conduct Finite Element Analysis (FEA) studies by using Explicit Dynamic (ANSYS 14) on the worn part and the new redesign model.

1.4 Scope of Study

The scope of study based on the objectives can be simplified as follow:

i. Reverse Engineering
ii. Non-contact method of reverse engineering data acquisition.
iii. PDC Drill bit
iv. Analysing redesign and original model using Finite Element Analysis (FEA).

1.5 Relevancy of the project

A short lead-time in product development is strongly demanded to satisfy needs, resulting from the globalization of manufacturing activities and the changes in market requirement [4]. Time is important in Oil and Gas fields. The ability of reverse engineering to produce high efficiency and long lifetime drilling component can decrease the downtime cost and give profit to the company. By applying reverse engineering approach, time taken for the maintenance of drilling part that damaged during the operation can be shorten. In addition, reverse engineering can be used to optimize the drilling component for more efficiency during the drilling operation.

1.6 Feasibility of the project

This project is feasible to complete within the timeline which in 2 semesters. Universiti Teknologi PETRONAS (UTP) has enough equipment and facilities to do this project from the preliminary work until it is completed. In this project, 3D scanner which is 3D VIUScan scanner will be used. This scanner is owned by UTP. UTP has provided various types of 3D modelling software for their student in the provided laboratories. The main important part of this project which is drill bits can be obtained from UTP Petroleum Engineering department. Thus, it will be easy for the mobility and study of the component to be completed in two semesters.

CHAPTER 2

LITERATURE REVIEW

2.1 Reverse Engineering

Engineering is profession and an art to develop and apply structures, machines, material, devices, process, and systems through scientific, technical and mathematical methods [1]. There are two types of engineering which are forward engineering and reverse engineering. According to G. Palayo (2010), 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. In contrast, Reverse engineering (RE) is a well-defined process to determine the technological principles of a system by analysing its structure, purpose and complete/process [2]. In addition RE can be defined as a process of analysing an object or existing (hardware and software) to identify its components and their interrelationship and to investigate how it works to redesign or produce a copy without access to the design from which it was originally produced [6]. Collin Bradley through his journal entitled *The Application of Reverse Engineering in Rapid Product Development*, proposed RE is the process of capturing the three dimensional object and transferring it to a computer compatible representation (i.e. a CAD/CAM solid model) [7].

In manufacturing, RE process begins with digitization of part by using contact method or non-contact method. The method chosen depends on the object's complexity and the accuracies required. 3D laser scanner which is non-contact method often used for RE data acquisition nowadays as its offer fast digitizing of substantial volume and good accuracy [6]. Next, reverse engineering software such as Geomagic is used to transform data gathered into 3D model which can be further manipulated by modelling software (i.e. FEA analysis). After 3D model obtained and modified, manufacturing process can be proceed. Figure 2 show process of reverse engineering.

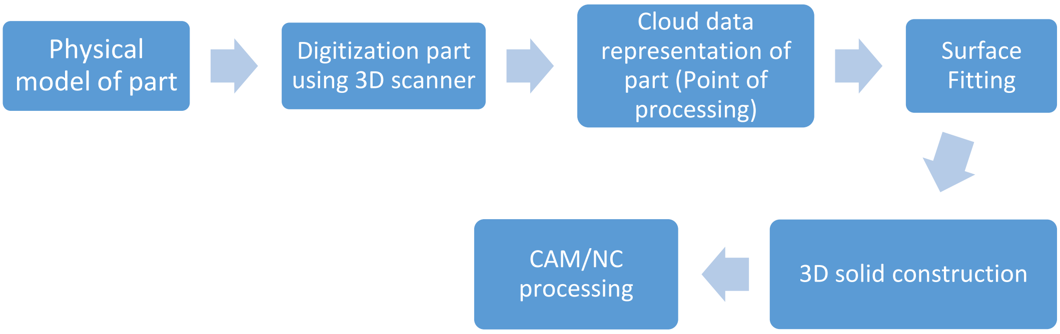

Figure 2 Process of Reverse Engineering

RE is often applied in cases as follows [1]:

- The original developer of the product is no longer producing the product.
- The original developer does not exist but the consumer needs the product.
- The documentation of the product is not enough or was lost.
- To investigate the opponent's product features and to modernize the outdated materials and some obsolete manufacturing technique.

This process can be achieved by using two methods which are contact method and non-contact method. Contact method uses sensing device with mechanical arms, coordinate measurement machines (CMM), and CNC machine to digitalize surface [6]. There are two types of data collection technique employed in contact method; point to point sensing and analogue sensing. A touch trigger probe that is installed on a CMM is used in point to point sensing technique to gather the coordinate point of surface. Meanwhile, in analogue sensing, a scanning probe that is installed on CMM or CNC machine is used. In contrast, for non-contact method there is no contact between RE hardware and object during data gathering. The point of cloud is captured by projecting energy sources onto an object. This method can be classified to two categories which are reflective or transmissive. Figure 3 below shows the summary of RE data acquisition technique.

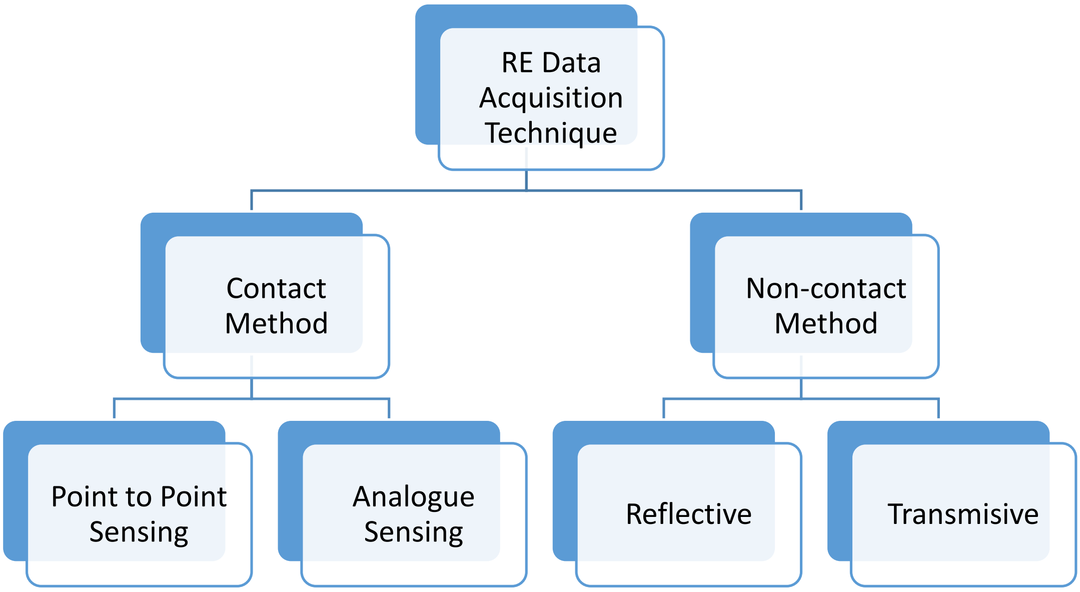

Figure 3 RE Data Acquisition Technique

2.2 Non-contact method in RE

For this project, the author will use VIUScan (Figure 4) scanner which is non-contact method device to obtain point of cloud data. Non-contact method use light, sound or magnetic fields to acquire shape from objects [8]. The geometric data for an object are calculated by using optical method which are triangulation, time of flight, wave interference information and stereo analysis. Figure 5 presents a classification of non-contact RE hardware based on data acquisition techniques. There is no contact between the RE hardware and object during data acquisition [6]. According to the paper entitled *Reverse Engineering of Automotive Parts Applying Laser Scanning and Structured Light Technique* by Ngozi Sheery Ali (2005) triangulation is a method, which uses location and angles between light sources and photo sensing devices to deduce position. A high-energy light sources is focused and projected at a pre-specified angle at the surface of interest. By applying triangulation method, the data can be acquire at very fast rates. The accuracy is determined by the resolution of the photosensitive device and the distance between the surface and the scanner. Time of flight can be classified to ranging method. Ranging method measures distance by sensing time-of-light of beams; practical methods are usually based on lasers and pulsed beam [9]. The author claimed interferometer methods can be very accurate method of measurement since visible light has a wavelength of the order of hundreds of nanometres, while most RE applications distances are in centimetre to meter. Other optical method such as structured lighting involves projecting patterns of light upon a surface of interest and capturing an image of the resulting pattern as reflected by the surface [8]. The image must then be analysed to determine coordinates of data points on the surface. A popular method of structured lighting is shadow Moiré, where an interference pattern is projected onto a surface producing lighted contour lines. These contour lines are captured in an image and are analysed to determine distances between the lines. This distance is proportional to the height of the surface at the point of interest and so the coordinates of surface points can be deduced. Structured lighting can acquire large amounts of data with a single image frame, but the analysis to determine positions of data can be rather complex.

Figure 4 VIUScan Scanner

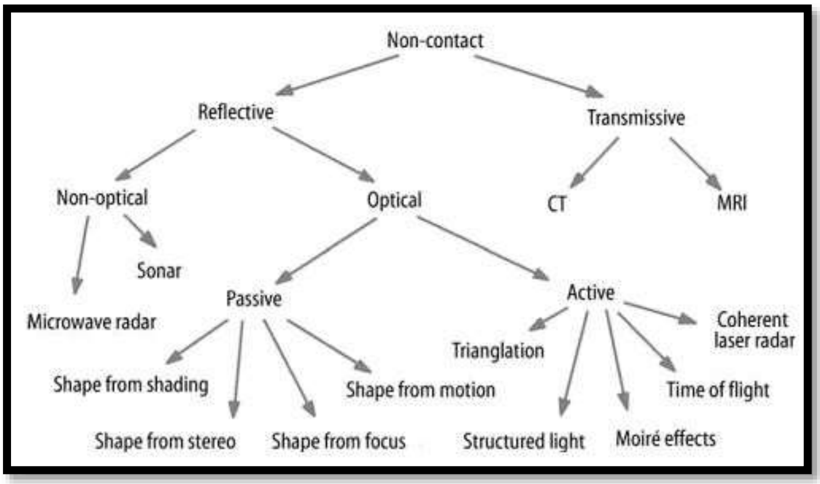

Figure 5 RE hardware Classification for non-contact method

2.3 Drill Bit

Drilling operation represent the major cost in finding and developing new petroleum reserves [16]. Poor drilling performance has a significant detrimental impact on drilling cost. The success of drilling operations depends on drill bit performance. Bit performance is usually defined in terms of the cost per foot drilled. Drill bit is defined as a device that excavates the rock from the bottom of the well as it is being drilled [10]. According to Schlumberger oilfield glossary, drill bit is a tool used to crush or cut rock [11]. Drill bits come in many sizes, types, and shapes and are designed to drill all types of rocks. 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 often used in drilling operation are Polycrystalline Diamond Compact (PDC) bit, Diamond bit and Tricone bit.

PDC bit (Figure 6) is a drilling tool that uses polycrystalline diamond compact cutters to shear rock with a continuous scraping motion [11]. PDC bits are effective at drilling shale formations, especially when used in combination with oil-base muds. The introduction of PDC in 1973 has facilitated the development of the first drill bit that used synthetic diamond as cutting elements [13]. During last decade PDC drill bit performance has been improved by innovation in PDC wear, impact resistance and better vibrations understanding. A diamond bit (Figure 7) is used in very hard rocks that require a long period to time to grind away the rock [10]. Diamond bits typically drill very slow and are used as a last resort to drill hard rocks. Diamond Bits have industrial diamond implanted in them to drill extremely hard surfaces. Each diamond bit is designed and manufactured for a particular job rather than being mass produced as roller cone bits are.

Figure 6 PDC Drill Bit

Figure 7 Diamond Bit

Roller cone bit is a tool designed to crush rock efficiently while incurring a minimal amount of wear on the cutting surfaces [11]. Invented by Howard Hughes, the roller-cone bit has conical cutters or cones that have spiked teeth around them. As the drill string is rotated, the bit cones roll along the bottom of the hole in a circle. As they roll, new teeth come in contact with the bottom of the hole, crushing the rock immediately below and around the bit tooth. As the cone rolls, the tooth then lifts off the bottom of the hole and a high-velocity fluid jet strikes the crushed rock chips to remove them from the bottom of the hole and up the annulus. As this occurs, another tooth makes contact with the bottom of the hole and creates new rock chips. Thus, the process of chipping the rock and removing the small rock chips with the fluid jets is continuous. The teeth intermesh on the cones, which helps clean the cones and enables larger teeth to be used. There are two main types of roller-cone bits, steel milled-tooth bits and carbide insert bits.

Figure 8 Steel Milled-tooth bits

Figure 9 Carbide Insert bits

2.4 PDC drill bit design

Drill bit design is one of the factor affecting the rate of penetration. According to L.Gerbaud et al., 2006, to obtain required drilling performance, drill bit designer adjusts some features in the drill bit. There are three main design feature affecting PDC bit performance according to Kerr, C.J, 1998 in his journal entitled "PDC Drill Bit Design and Field Application Evolution". The features are:

- Number of cutter
- Back Rake Angle
- Side Rake Angle

The cutter of a PDC bits are mounted on a bit body. There are two types of bit body used for PDC drill bits which are steel and matrix body bit. Steel body bits (Figure 10) use a stud cutter that is interference-fitted into a receptacle on the bit body [13]. The advantage of using a stud is it can be removed or replaced if the cutter is damaged and the body of the bit is not damaged. However, erosion of the cutter often happens when using this type of bit body. Kerr, C. J, 1998 stated that matrix bit body (Figure 11) uses cylindrical cutter that is brazed into a pocket after the bit body has been furnace by conventional diamond contact bit techniques. The advantage of this type of bit is both erosion and abrasion resistant. However, matrix body bit has economic disadvantages because raw materials used in their manufacture are more expensive.

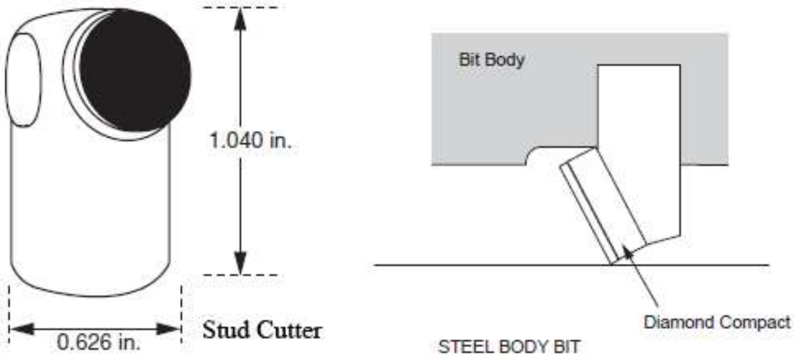

Figure 10 Steel Bit Body & Stud Cutter

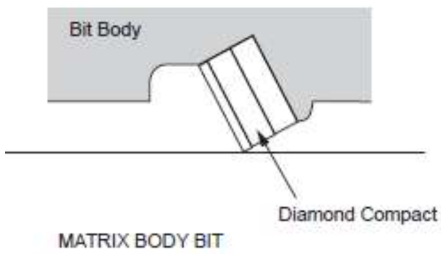

Figure 11 Matrix Body Bit

There are two rakes angle can be set for PDC cutters which are back rake and side rake. Both these rakes angle affect performance of PDC drill bit. Back rake angle is determined the size of cutting that is produced. Meanwhile, side rake is used to direct the formation cutting towards the flank of the bit and into annulus. According to previous research conduct by Rajabov, V et al., 2012, indicates that a cutter with low back rake angle requires less horizontal cutting force. PDC with lower back rake angle drill more efficiently. Side rake angle affect the cleaning of a PDC bit in that a cutter that uses side rake mechanically directs cuttings towards the annulus [13]. In addition, Kerr, C. J states that a greater depth of cut is achieved with a smaller back rake angle, which generally produces a larger chip. In addition, the smaller the rake angle, however, makes the cutter more vulnerable to impact breakage should a hard formation be encountered. Figure 12 shows the position of back and side rake angle PDC cutter.

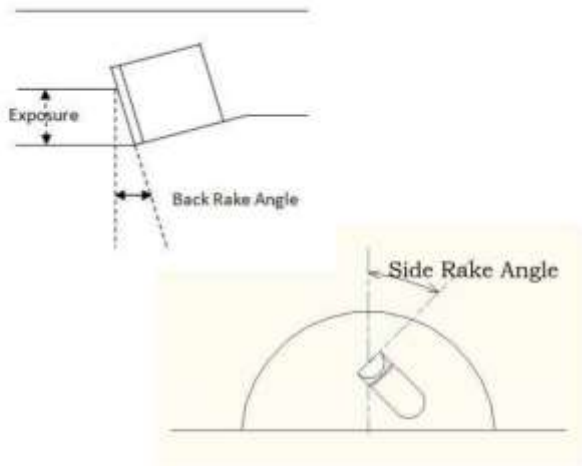

Figure 12 Position of back and side rake angle

Pain, D et al., 1985 indicates that as cutter density or the number of cutters of PDC but increase, ROP will decrease. Adding more cutters to the bit face reduces the efficiency of cleaning, which directly affects ROP's. However, increasing cutter density of a given PDC drill bit will reduce the effective load per cutter [13]. Kerr, C. J explains the work rates and wear rates of individual cutters will be decreased, which extend bit life.

2.5 Finite Element Analysis (Explicit Dynamics)

Finite Element Analysis (FEA) is a computer model of a material or design that is analysed to get specific results. It is used in existing or new product refinement. A company can verify a proposed design to meet client's specifications subject to manufacturing or construction. Modifying an existing product or structure is utilized to improve or qualify the product for a new service condition. If the model fails, FEA is very useful to help designer to modify back the design to meet the targeted condition. FEA help analyst to predict failure due to unknown stresses by showing problem areas on an object and giving chances for designers to see all of the theoretical stresses within. This method can help to reduce manufacturing costs and time rather than making and testing the real component [16]. Explicit Dynamics is one of the feature in Finite Element Analysis. The ANSYS explicit dynamics product suite helps user to gain insight into the physics of short-duration events for products that undergo highly nonlinear, transient dynamic events. These specialized, accurate and easy-to-use tools have been designed to maximize productivity. With the ANSYS explicit dynamics products, user can study how a structure responds when subjected to severe loadings. Algorithms based on first principles accurately predict responses, such as large material deformations and failure, and interactions between bodies and fluids with rapidly changing surfaces [17].

CHAPTER 3

METHODOLOGY

3.1 Overview

This project is done step by step. In general, the step for conducting the project is similar to reverse engineering process as mentioned in the literature. Figure 13 illustrate the flow chart diagram for this project.

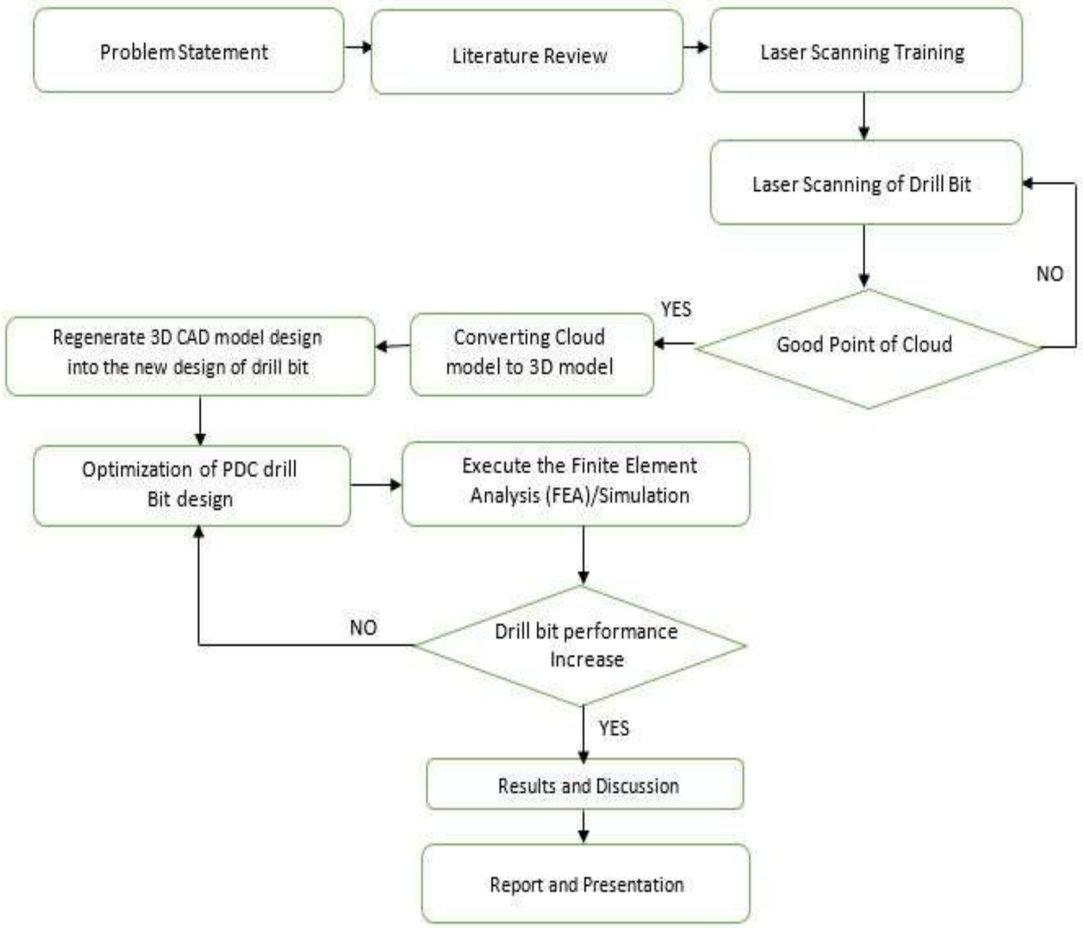

Figure 13 Process Flow Chart

3.2 Gantt Chart and Key Milestone

Activities / No. of Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Literature Review														
Identify feasible Oil and Gas component for the project														
Drill Bit model selection														
Scanning Drill Bit														
Convert cloud model into 3D CAD model														

Activities / No. of Week	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Literature Review														
Optimization of drill bit design														
Analysis on the new and old drill bit 3D CAD model														
ROP analysis of new Drill Bit														

	Project Progress
1	**Key Milestone 1**: Completed identify Oil and Gas Component to be used for Reverse Engineering (PDC Drill Bit)
2	**Key Milestone 2**: Completed scanning Drill Bit and obtain cloud model
3	**Key Milestone 3**:Completed converting Cloud model to 3D CAD model
4	**Key Milestone 4**: Completed improving drill bit design
5	**Key Milestone 5**: Completed conducting FEA Analysis of new and old Drill bit design
6	**Key Milestone 6**: Completed conducting analysis of new drill bit in relationship of ROP.

3.3 Scanning/Digitization of the Worn Drill Bit.

As mentioned earlier, digitization is a process of data acquisition. In this project, non-contact method of data acquisition will be used. 3D VIUSCAN (Figure 4) scanning device which is available in UTP laboratory will be used to obtain cloud model of worn drill bit (Figure 14). A proper instruction and training from laboratory technician about scanning device will be provided in order to understand the full use of the scanner. The process of obtaining cloud data of drill bit using this scanner is fast and detailed because the system of the scanner is laser based. This scanner do not require external positioning system. In addition, position of the scanner in relation to the part is determined by triangulation (real time). An advantage of this scanner is the parts can be moved during data acquisition. This scanner is connected to the laptop and VXelement software is used to monitor the process of data acquisition. Setup of 3D scanner is shown in Figure 15. Configuration and calibration of the scanner is important to produce a good point of cloud. This process is conducted after system connection process is completed. Scanning of the worn drill bit can be done when calibration and configuration is finished. Figure 16 shows process of drill bit scanning using 3D scanner. After the scanning process completed, cloud model is evaluated. The cloud model is then converted to 3D CAD model by using 3D modelling software such as Geomagic.

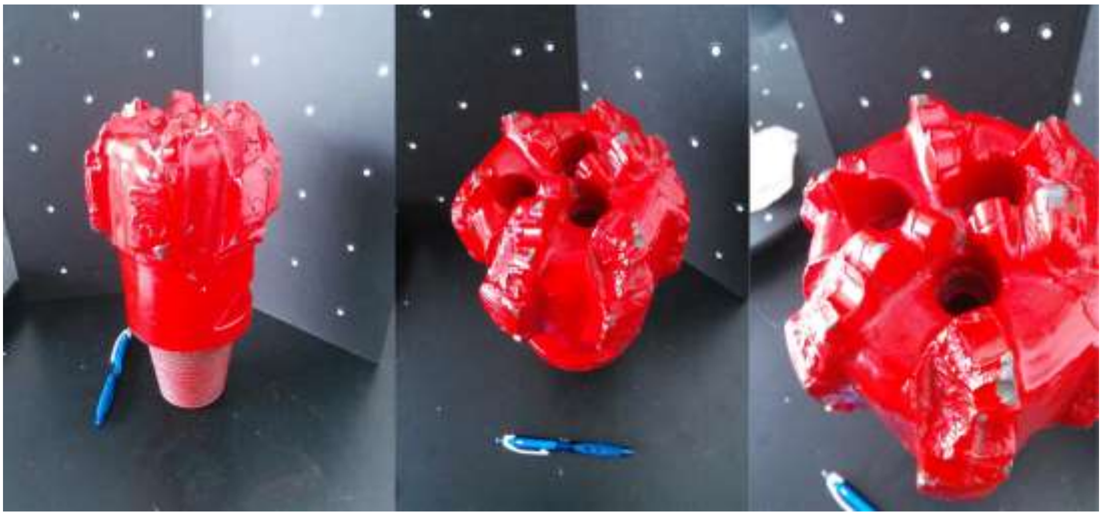

Figure 14 Worn Drill Bit

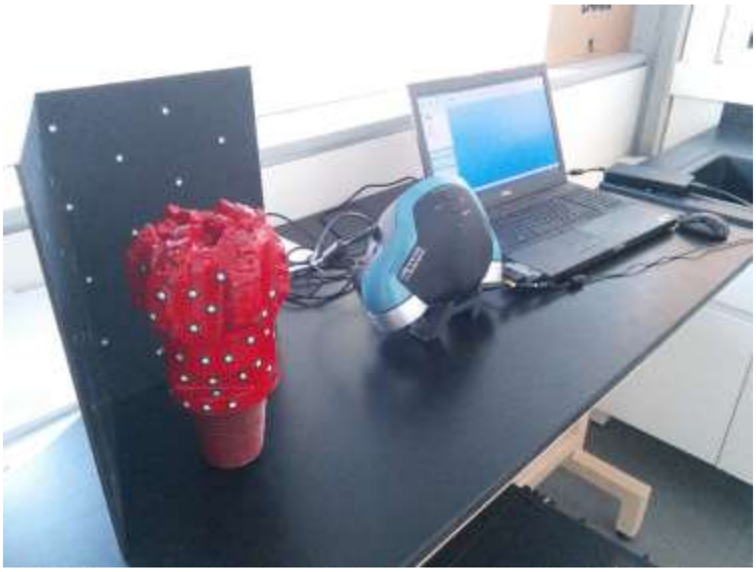

Figure 15 3D Scanner Set Up

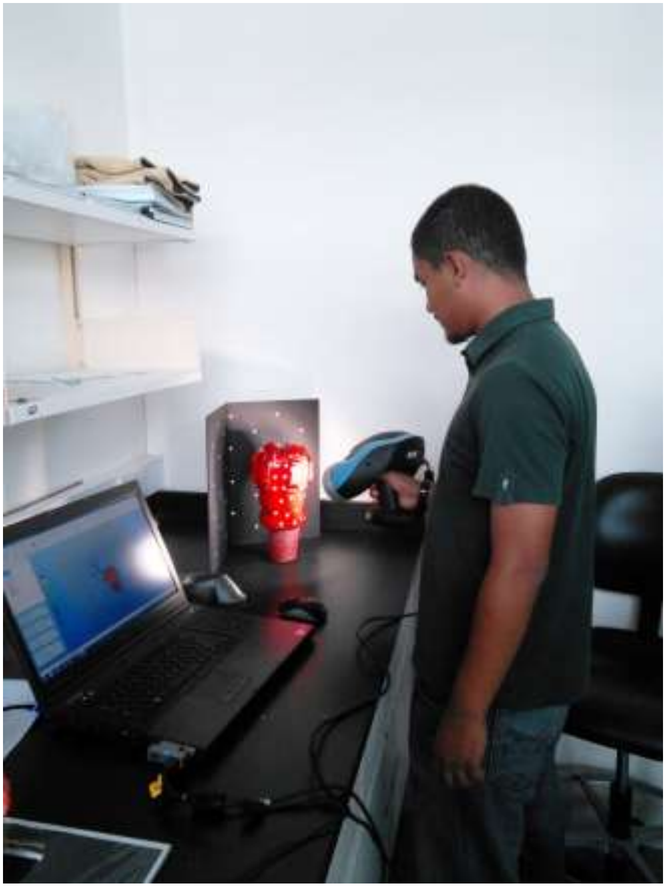

Figure 16 Process of Scanning Worn Drill Bit Using 3D scanner

3.4 Processing Captured Data

From the scanner, cloud model of the worn drill bit can be obtained. Figure 17 shows raw cloud data obtained from the scanner. The presence of noise or extra facets (Figure 18) during scanning process affect the accuracy of the data. Thus, before converting the cloud data to CAD model, all the noise and error need to be removed. This can be done by using VXelement software. By adjusting the feature "Remove Selected to Smaller" will remove the extra facets or noise in the scanned object.

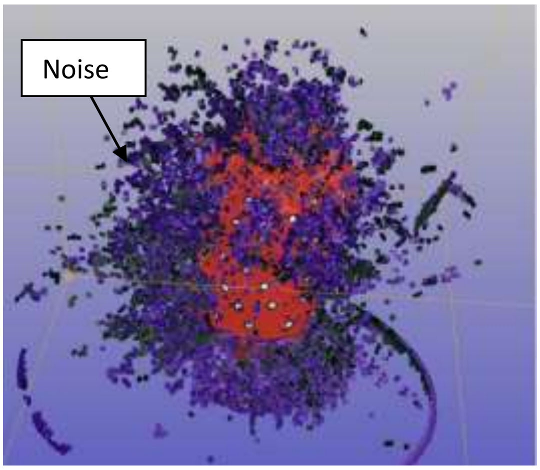

Figure 17 Raw cloud data of scanned drill bit

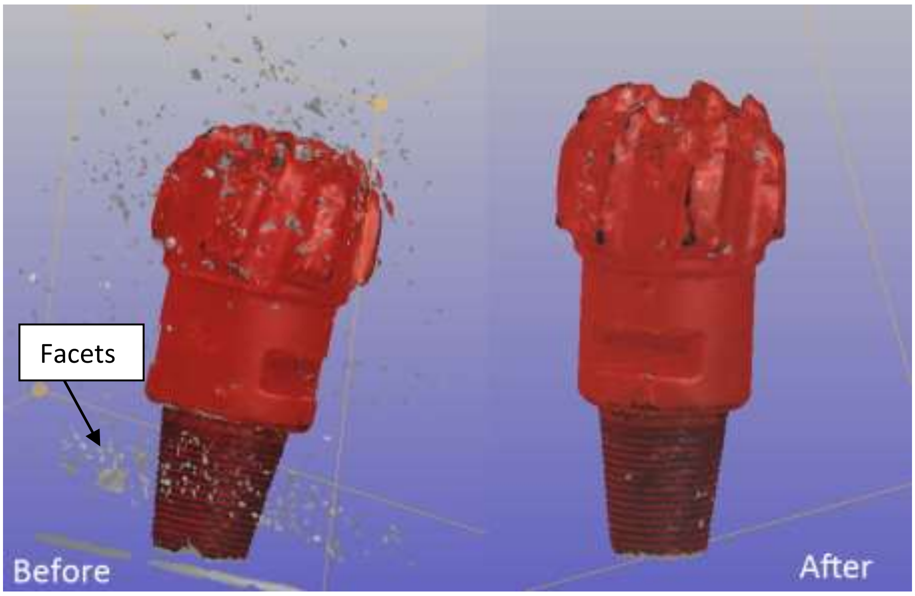

Figure 18 Noise and Extra Facets Removal

3.5 Converting Cloud Data to 3D CAD Model

There are several steps to convert cloud data to 3D CAD model. For this project RapidformXOR software will be used to convert cloud data into 3D CAD model.

1. First of all, cloud data is transformed into the mesh mode. All the hole or critical damages in the cloud data is repaired during this stage.

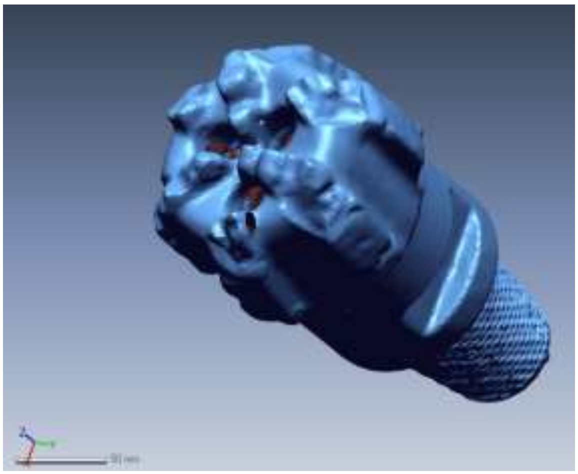

Figure 19 Mesh mode of Worn Drill Bit

2. After all the repairing process is done, the mesh data is divided into region group by using “Region Group” feature in Rapidform XOR. Region group is conducted in order to define the geometry region of the drill bit features and body.This feature helps users to automatically classify regions by estimating curvature flow on surfaces of a mesh and categorize those regions as geometries, such as planes, cylinders, spheres, cones and freeform shape.

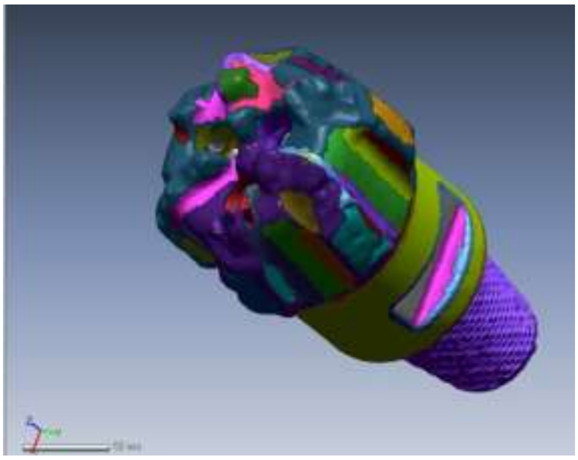

Figure 20 Region Group of Worn Drill Bit

3. "Mesh Sketch" feature is used to draw the features and body of the drill bit. Based on the mesh data and region group converted from the cloud model, the sketch of the features and body of the drill bit can be drawn and defined by using this option. The purpose of the drawing is to repair the worn drill bit to its original condition.

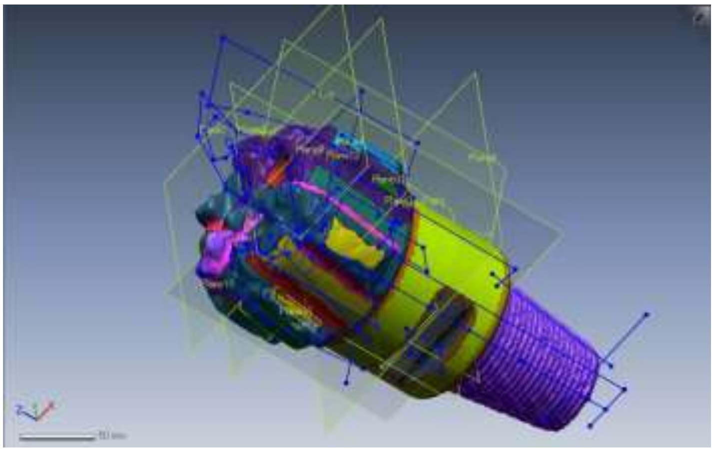

Figure 21 Mesh Sketching Process

4. 3D CAD model of the repaired worn drill bit is saved to Parasolid *(x_t)* file type for future use in ANSYS for analysis.

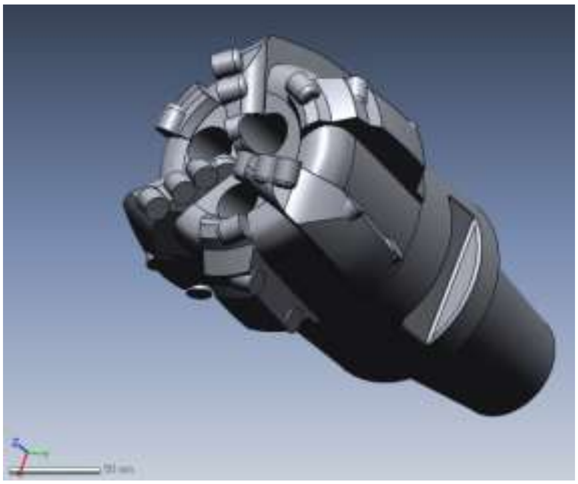

Figure 22 3D CAD model of Repaired Worn Drill Bit

3.6 Analysis of Original (Repaired) Drill Bit.

After 3D CAD model obtained, Finite Element Analysis (FEA) will be conducted. FEA analysis will be conducted to both worn drill bit and new optimize drill bit will by using software ANSYS 14.0 Release. In this stage, all the analysis of the design features will be analysed. The purposes of FEA are:

i. To understand the physical behaviours of a complex object (Strength, heat transfer capability and fluid flow).
ii. To predict the performance and behaviour of the design; to identify the weakness of the design accurately.
iii. To identify the optimal design with confidence.

3.6.1 Modelling of Bit Assembly and Rock Formation

First of all, drill bit and rock interface is modelled by using Solidwork2011 software. Figure 23 show the model developed for the analysis process. All the features of the component used in the analysis are shown in Table 1. Limestone is used as rock type for this case study. This material is selected for its high homogeneity and medium strength.

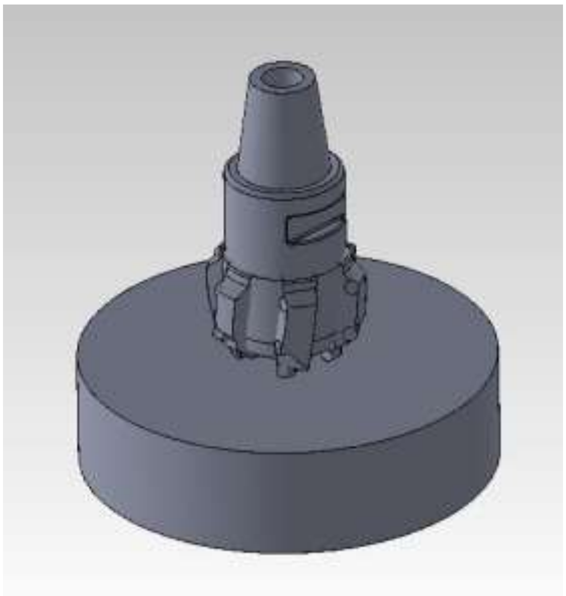

Figure 23 Model of the Drill Bit and Rock for Analysis

Table 1 Geometric Features of the Components Used

Cylinder Block	Drill Bit
Diameter : 40cm Thickness : 10.8cm Volume : 0.01357m^3 Rock type : Limestone	Diameter: 15.4cm Height : 28.441 cm Volume : 0.002710413m^3

3.6.2 Development of Finite Element Analysis.

There are a various analysis systems in ANSYS software. It is important to select the suitable type of analysis from option menu bar in order to obtain correct result and analysis. For this project Explicit Dynamics will be used as analysis system. According to Amnesh (2012), explicit dynamics analysis are used to determine the dynamic responses of a structure due to impact, rapidly changing time dependent load, or stress wave propagation. Figure 24 shows the components for explicit dynamic analysis.

Figure 24 Explicit Dynamic Component Analysis

1. Engineering data of the component used for the analysis is defined. The properties and material for the component will be used in the analysis is defined in engineering data. Table 2 show the material and properties used for the analysis.

Table 2 Engineering data of Material used for Analysis [18]

Material Properties		
Limestone:	Carbon steel:	Tungsten carbide:
Density (2600 kg m^-3), Tensile ultimate strength (4.0 e+06 Pa), Young's Modulus (5.e+010 Pa), and Poisson's ratio (0.22).	Density (7850 kg m^{-3}), Young's modulus (2 E+11 Pa), Poisson ratio (0.3), tensile yield strength (2.5 E+08 Pa), compressive yield strength (2.5 E+08 Pa), tensile ultimate strength (4.6 E+08 Pa), isotropic thermal conductivity (60.5 $Wm^{-1}C^{-1}$), and specific heat (434 $Jkg^{-1}C^{-1}$).	Density (14700 kg m^{-3}), young's modulus (6.3 E+11Pa), Poisson ratio (0.24) and tensile strength (0.3448 GPa), ultimate tensile strength(5.27 E+11Pa)

2. The assembly model of drill bit and rock is imported into ANSYS. The imported file will be opened in design modeller. Figure 25 show the interface of design modeller in ANSYS14.0

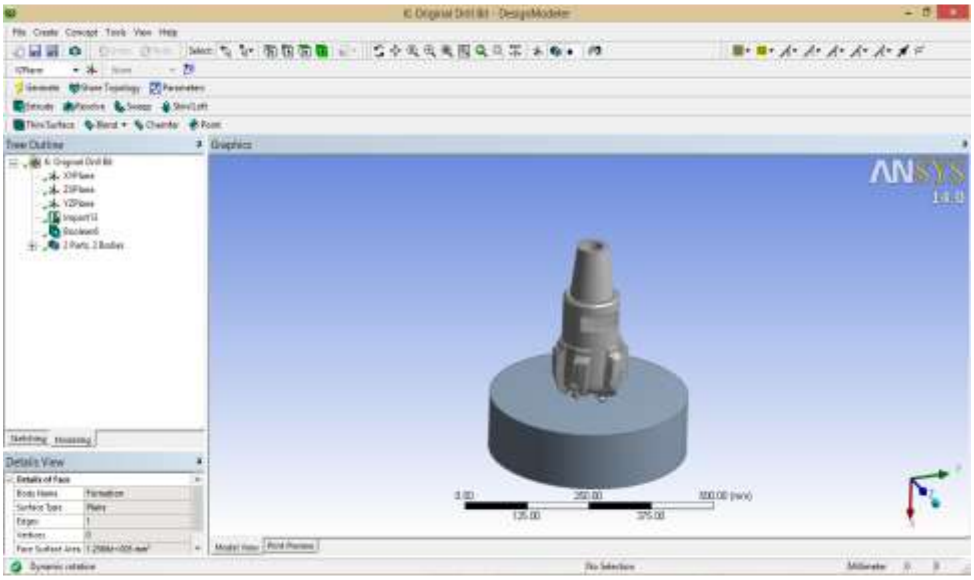

Figure 25 Design Modeller Interface

3. Double click the "Model" tab to open the Workbench Mechanical. Material of the assembly model, meshing properties, initial condition and analysis setting will be defined in Workbench Mechanical. Meshing is one of the most critical aspect of engineering simulation. In addition, appropriate meshing is required to have accurate results. For this project, the meshing setting and pattern is set as shown in Figure 26.

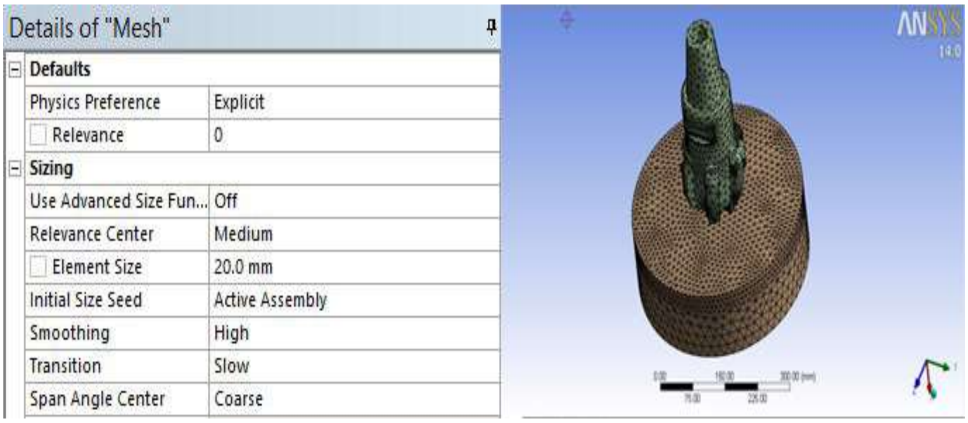

Figure 26 Meshing setting and pattern

Angular velocity of 100rpm is defined as initial condition. Other parameters such as weight on bit (WOB), pressure and temperature is defined as constant. The direction of the rotation is defined by X-axis component. Fixed support for the Limestone rock (Block) is defined in order to prevent it from moving due to impact. The outer diameter of cylinder is selected as fixed support as shown in Figure 27.

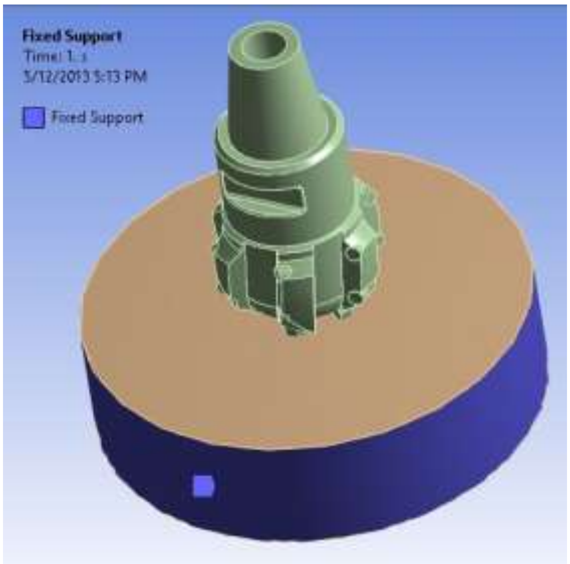

Figure 27 Fixed Support for the Block

Details of analysis setting is illustrated in Figure 28 below.

Details of "Analysis Settings"

Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	1. s
Maximum Energy Error	5.
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled
Maximum Time Step	Program Controlled
Time Step Safety Factor	3.
Characteristic Dimension	Diagonals
Automatic Mass Scaling	Yes
Minimum CFL Time Step	1.e-004 s
Maximum Element Scaling	1000.
Maximum Part Scaling	10000.
Update Frequency	0

Figure 28 Analysis Setting Data

Time duration for this analysis is 1 seconds since the time duration for an explicit dynamics analysis is very small value. Auto mass scaling is switched off in order to get more accurate result. This will cause the analysis to become slower and consume a lot of time.

4. After all the meshing setting, initial condition and analysis setting is defined, the analysis now can be solved. For this project, the type of solution used is "Total Velocity". The target solver for this analysis is AUTODYN.

3.7 Optimization of Original Drill Bit.

After the analysis of original drill bit is finished, optimization process can be conducted. For this project, optimization of the drill bit will be based on three main design feature as mentioned earlier in literature review which are back rake angle, side rake angle and number of cutter. The original design feature of the PDC drill has 38° of back rake angle, 18° of side rake angle and 24 pieces number of cutters. In order to demonstrate the good relation between the modification designs with rate of penetration, numerous single cutter tests were done with different design features. Original back rake angle is adjusted to 20°, 25°, 30° and 35° respectively. Meanwhile, for side rake angle the angle is adjusted to 10°, 15°, 20° and 25° respectively. The angle measurements for both back and side rake angle are represented in Figure 29.

Number of cutter is adjusted from original to 30 and 36 pieces. For this drill bit, 36 is the maximum number of cutter can be put on the body of the drill bit due to limited space. After all the adjustment is made, the drill bit will be tested again with the same procedure in Section 3.6. All the results is collected and analysed in the next chapter.

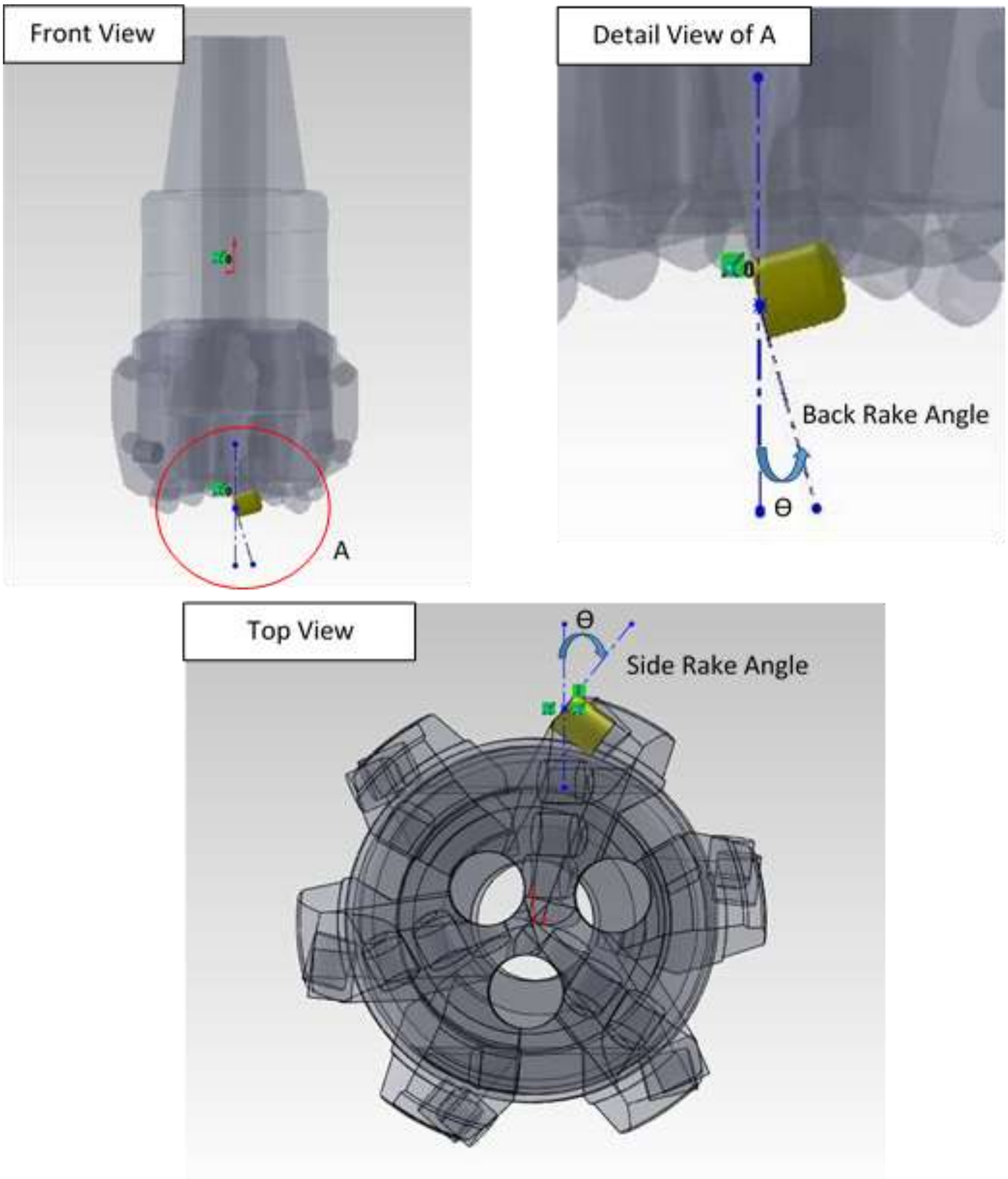

Figure 29 Angle measurement for back and side rake angle

CHAPTER 4

RESULTS AND DISCUSSION

Rate of penetration (ROP) is the speed at which a drill bit breaks the rock under it to deepen the borehole. For this simulation, total velocity is selected to measure the rate of penetration. The simulation of the entire analysis has been carried out according to setting set earlier. The penetration of drill bit into the limestone rock is best represent through a video media. Figure 30 shows the screenshot of penetration of original drill bit into the formation at time of 0s, 0.5s and 1.0s respectively.

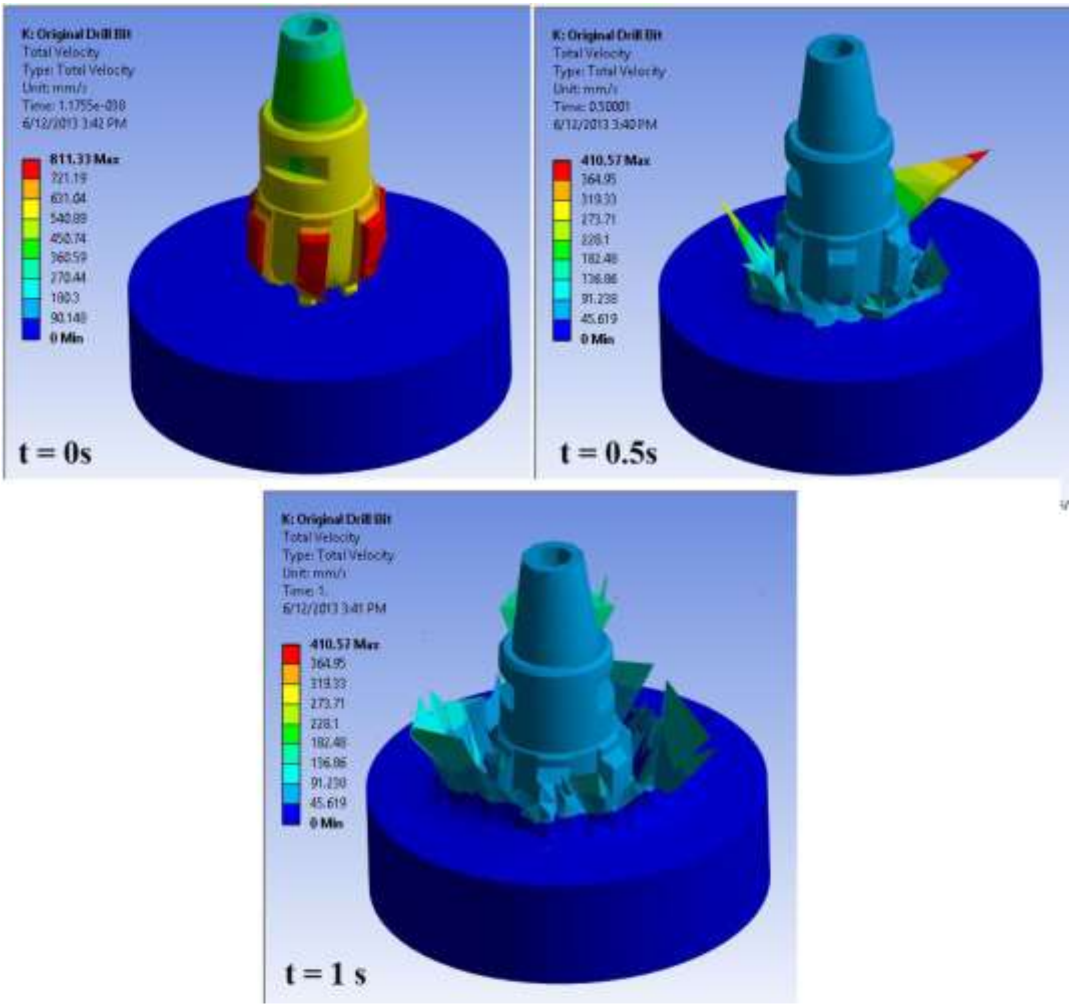

Figure 30 Analysis Steps at Various Stages of Penetration Process (Original Drill Bit)

Table 3 below shows results of rate of penetration for original drill bit.

Table 3 Analysis Data for Original Drill Bit

Time (s)	ROP (mm/s)	Time (s)	ROP (mm/s)
0.000	0.0	0.550	410.6
0.050	443.1	0.600	410.6
0.100	422.9	0.650	410.6
0.150	427.4	0.700	410.6
0.200	421.9	0.750	410.6
0.250	411.6	0.800	410.6
0.300	410.6	0.850	410.6
0.350	410.6	0.900	410.6
0.400	410.6	0.950	410.6
0.450	410.6	1.000	410.6
0.500	410.6		

From the result above, the average rate of penetration for original drill bit is 394mm/s. Rate of penetration of original drill bit maintain as time increasing. A graph of Time is ROP is plotted to show the interaction between them.

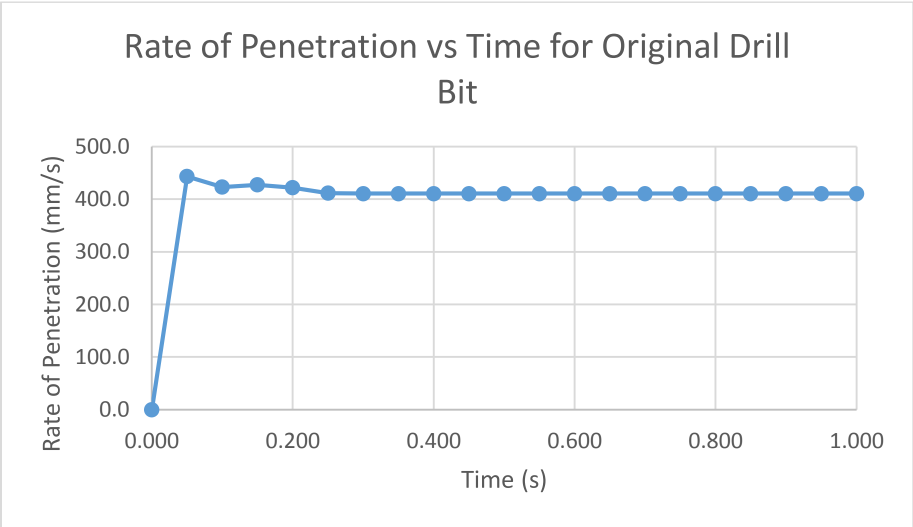

Figure 31 Plot of ROP vs. Time for Original Drill Bit

Same methodologies applied to all modified drill bit. The results can be shown in Table 4. The average of ROP for all drill bit is calculated and summarize as shown in Table 5, 6 and 7 respectively.

Table 4 Rate of Penetration of modified drill bit based on design feature change

Rate Of Penetration (mm/s)											
Time(s)	*Back Rake Angle (degree)*				*Side Rake Angle (degree)*				*Number of Cutter (pcs)*		
	20°	25°	30°	35°	10°	15°	20°	25°	24	30	36
0.000	0	0	0	0	0	0	0	0	0	0	0
0.050	377.6	357.0	340.28	474.3	395.1	377.9	410.1	385.2	395.1	391.8	410.1
0.100	476.6	511.5	498.7	465.0	594.8	496.7	575.1	568.8	594.8	569.5	575.1
0.150	476.6	473.8	439.5	428.9	521.6	496.7	477.1	470.2	521.6	498.2	477.1
0.200	476.6	473.8	439.5	428.9	518.4	496.7	477.1	470.2	518.4	481.4	477.1
0.250	476.6	473.8	439.5	428.9	518.4	496.7	477.1	470.2	518.4	481.4	477.1
0.300	476.6	473.8	439.5	428.9	518.4	496.7	477.1	467.1	518.4	481.4	477.1
0.350	476.6	473.8	439.5	428.9	518.4	496.7	477.1	464.7	518.4	481.4	477.1
0.400	476.6	473.8	439.5	428.9	518.4	496.7	477.1	464.9	518.4	481.4	477.1
0.450	476.6	473.8	439.5	428.9	518.4	496.7	477.1	464.9	518.4	481.4	477.1
0.500	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.550	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.600	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.650	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.700	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.750	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.800	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.850	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.900	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
0.950	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1
1.000	476.6	473.8	439.5	428.9	518.4	496.7	477.1	465.0	518.4	481.4	477.1

Table 5 Average ROP for variation of back rake angle

Back Rake Angle (degree °)	ROP (mm/s)
20	429.7
25	428.3
30	399.1
35	395.2

Table 6 Average ROP for variation of side rake angle

Side Rake Angle (degree °)	ROP (mm/s)
10	469.7
15	446.9
20	436.0
25	425.7

Table 7 Average ROP for variation of cutters numbers

Number of cutter (pcs)	ROP (mm/s)
24	469.3
30	439.7
36	436.8

From the above table a graph is plotted in order to know the interaction between rate of penetration and variation of design feature.

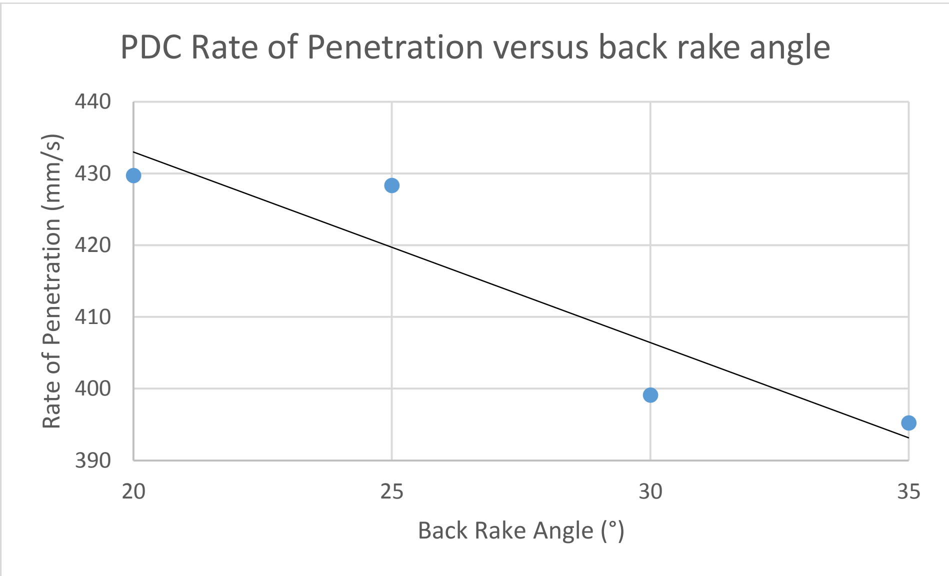

Figure 32 PDC rate of penetration versus back rake angle

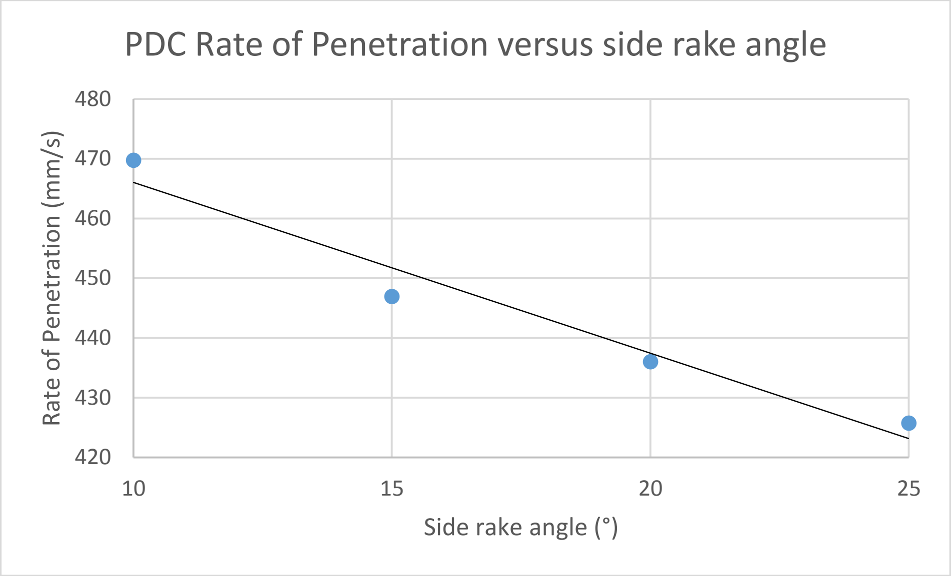

Figure 33 PDC rate of penetration versus side rake angle

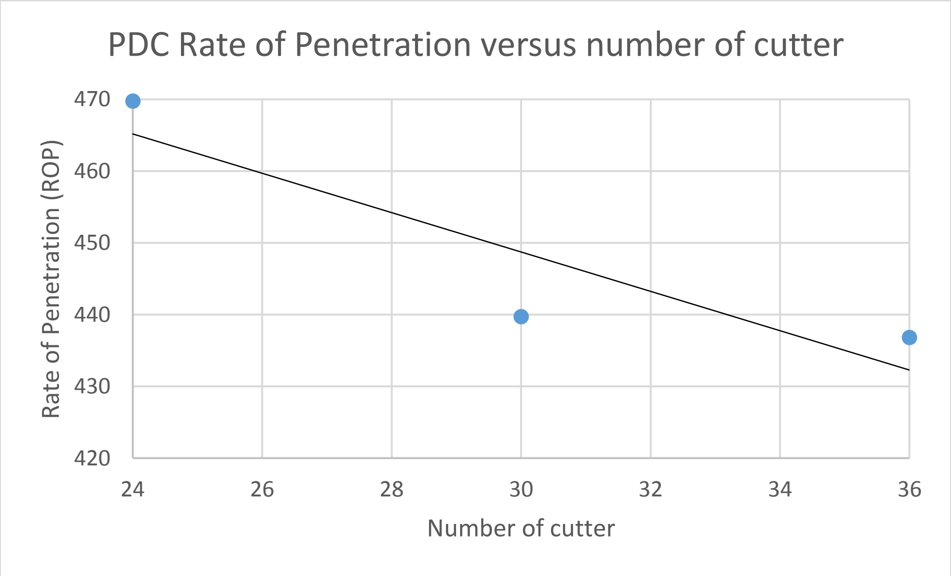

Figure 34 PDC rate of penetration versus number of cutter

The graph in Figure 32 shows that rate of penetration is decreasing when the value of back rake angle increases. Back and side rake angles affect the cutting face force only through the frictional contact between the build-up of the crushed material and rock surface. Back rake angle determines the size of cutting that is produced. As the back rake angle is decreased, the cutting action become more efficient. In addition, a greater depth is achieved with a smaller back rake angle, which generally produces a larger chip. This make the bits more aggressive hence increase rate of penetration. Aggressiveness of drill bit for this project refers to total velocity of deformation of formation. However, smaller rake angle makes the cutter more vulnerable to impact breakage should a hard formation be encountered. Conversely, a larger rake angle will produce a smaller chip, but will be more durable in a hard formation and giving linger bit life.

Side rake angle is used to direct the formation cuttings towards the flanks of the bit and into annulus. There is no specific conclusion or findings regarding the side rake angle to ROP from previous literature review. However, based on the simulation conducted, average rate of penetration is high as lower side rake angle was used. This phenomenon can be shown in Figure 33. From the simulation, it can be concluded that side rake angle have some effect on rate of penetration.

Numbers of cutters also have effect to performance of drill bit. The number of cutters must be balanced against the size of cutter. If a high number of cutter is used the cutter must be small enough to allow efficient cleaning of the face of the bit. From figure 34, rate of penetration is decreasing as numbers of cutters increase. Increasing number of cutters will decrease efficiency of cleaning hence affecting directly rate of penetration. In contrast, increasing the cutter density of a PDC drill bit will reduce the effective load per cutter. The work rates of individual cutters will be decreased, which will extend bit life.

Optimum design of the PDC is selected which consist of 20 degree of back rake angle, 10 degree of side rake angle and original number of cutter which is 24 pieces. The optimized drill bit is simulated again using ANSYS Explicit Dynamic in order to measure its performance. The results of the simulation is illustrated as shown in Figure 35.

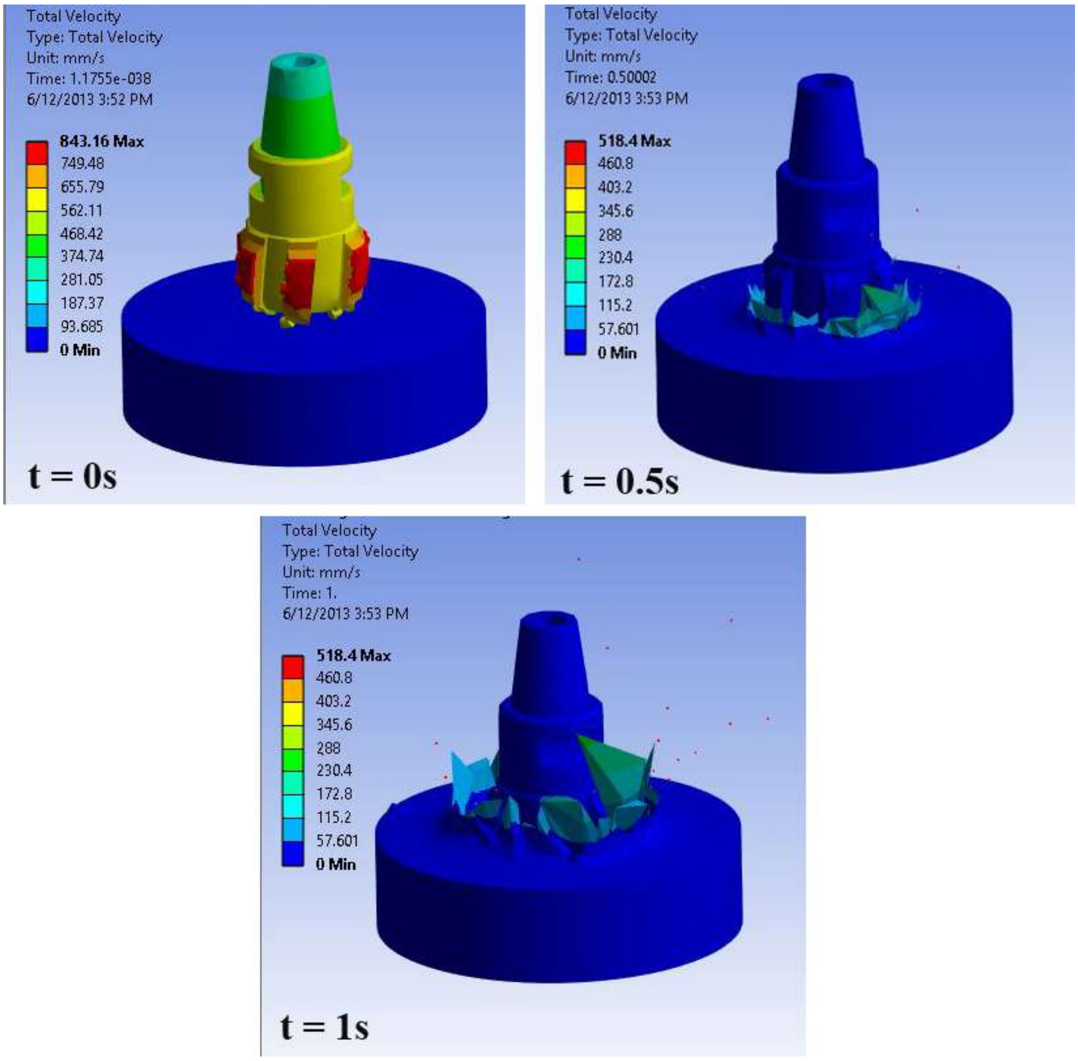

Figure 35 Analysis Steps at Various Stages of Penetration Process (Optimized Drill Bit)

Table 8 Analysis Data for Optimized Drill Bit

Time (s)	ROP (mm/s)	Time (s)	ROP (mm/s)
0.000	0	0.550	518.4
0.050	395.1	0.600	518.4
0.100	594.8	0.650	518.4
0.150	521.6	0.700	518.4
0.200	518.4	0.750	518.4
0.250	518.4	0.800	518.4
0.300	518.4	0.850	518.4
0.350	518.4	0.900	518.4
0.400	518.4	0.950	518.4
0.450	518.4	1.000	518.4
0.500	518.4		

A graph of analysis data of optimized and original drill bit is plotted for comparison purpose.

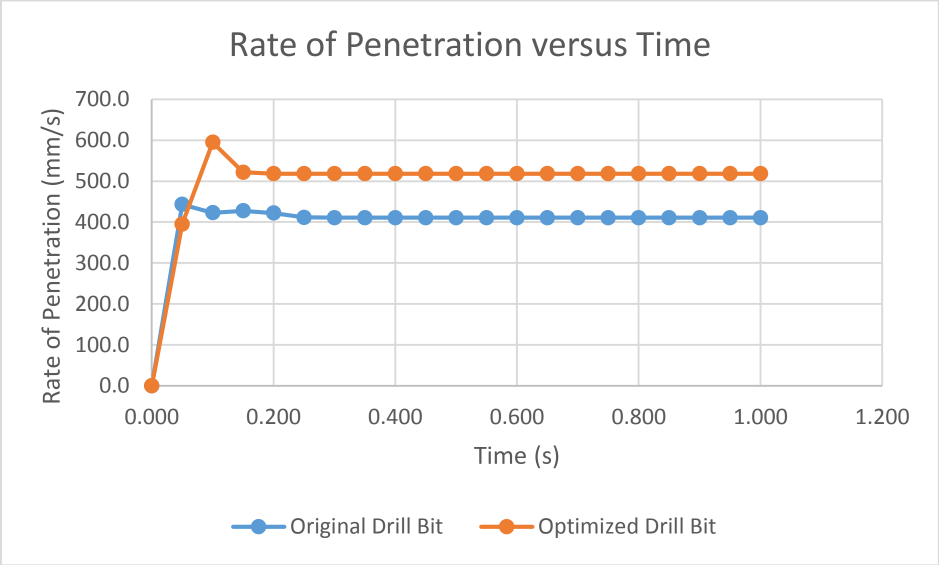

Figure 36 Plot of rate of penetration versus time for optimized and original drill bit

The average ROP for optimized 469.7mm/s. A calculation is made to calculate the percentage of improvement of ROP.

$$\frac{Optimized\ ROP - Original\ ROP}{Original\ ROP}\ x\ 100\%$$

$$\frac{469.7 - 394}{394}\ x\ 100\%$$

Percentage of improvement = 19.21%

CHAPTER 5

CONCLUSION

In conclusion, reverse engineering is convenient and reliable to use in oil and gas field. Analyzing the effect of design modification for tools and equipment using Finite Element Model such as ANSYS can help oil and gas field in the future determine the optimum design for the tools and equipment. Explicit Dynamic which is one of the analysis component in ANSYS is powerful tools to study the drill bit rate of penetration.

Based on the results, design feature such as back rake angle, side rake angle and number of cutter affect the performance of the drill bit. Different back rake angle and side rake angle gives different outcomes on the performance (ROP) of the drill bit. Decrease in back and side rake angle of PDC drill bit will results high reading of ROP. In addition, the number of cutter also affects the performance of drill bit. Increasing number of cutter will decrease the performance of the PDC drill bit. However, a general hypothesis or conclusion cannot be made, as some controllable factor of PDC drill bit such as weight on bit (WOB), rotary speed and bit hydraulics are assume to be constant in this project. These results and simulation can only be used as reference, in order for the readers to get the overview of the relationship between design features with performance of drill bit by using ANSYS Explicit Dynamic simulation.

Last but not least, all the objectives for this project is achieved which include develop an analysis by using RE method on PDC drill bit, scan worn PDC drill bit to obtain cloud model, convert the cloud model into CAD model and conduct Finite Element Analysis (FEA) studies by using Explicit Dynamic (ANSYS 14) on the worn part and the new redesign model.

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