CERTIFICATION OF APPROVAL

MODIFICATION AND FABRICATION OF ENHANCED DRILL-BIT DESIGN

by

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14695

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MAY 2015

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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(Emadeldin Ali Mahmoud Khairy Ali)

ABSTRACT

Drill-bit performance is evaluated by two factors, durability and rate of penetration. This project aims at enhancing the durability of PDC drill-bit by introducing new blade design for the PDC drill-bit. Different aspects of the design of the PDC drill-bit blades were analyzed to reach to the optimum durable design.

These aspects include,

- Varying direction of the top of the blades from vertical to tilted
- Varying number of blades in both cases of tilted blades and vertical blades.
- Effect of adding an asymmetric blade.
- Effect of changing tip of the blade geometry.

These aspects were analyzed by the complete 3D designing of several PDC blade designs. And performing stress simulation on all the designs using fixed parameters.

Based on the results of these analyses, the optimum design was chosen.

The new design improvements were verified by computerized stress simulation. And in the results it was shown that stress endurance for the new design is better by a factor of 19.5 %.

ACKNOWLEDGEMENT

First and foremost, I would like to thank and express my greatest appreciation to my supervisor Dr. Khurram Altaf for his guidance, kindness, patience, and encouragement throughout the Final Year Project. Moreover, I would like to thank Petronas Technology University which gave me an opportunity to get academic knowledge to follow my higher education. Additional gratitude is also extended to all lecturers and staff in Petroleum Engineering Department. I am also very grateful to all my friends who make the supportive environment for me. Last but not the least; I would like to appreciate Petronas Company for supporting me by academic scholar-ship and providing me the chance to study in Malaysia.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Drill bits are one of the most essential components in oil and gas discovery systems. The drill bits play the main role in drilling, which in turn allow us to find and develop new oil and gas fields. The drill bit performance is the key to successful drilling operations.

Drill bit is a tool that is attached to the bottom of the drill string. It crushes, cuts or breaks apart the rock beneath it. This is due to the effect of weight on bit supplied by the heavy drill string (heavy drill collars) and the rotation supplied by the top drive or the rotary table.

Thus, Drill bits would have to endure enormous stresses resulting from the huge weight on bit applied. Also, drill bits would have to endure huge frictional forces with formation rocks that can cause wear and tear or even breaking.

Drill bit performance is evaluated by two factors, durability and rate of penetration. The design and material of the drill bit determines the amount of stresses and frictional forces, the drill bit can endure. Thus, determines the durability of the drill bit. Usually the material of the drill bit is (steel or tungsten carbide) with or without (synthetic or natural diamonds). However, for rate of penetration several other factors plays important roles; like mud properties, mud nozzle sizing, cutting transportation, rock properties and also drill bit design.

Lots of researches have been done around the globe to improve the drill bit performance in both aspects of durability and rate of penetration. Latest work has been done by a team in UTP that resulted in the development of a functional PDC drill bit using 3D printer and investment casting process. The use of this technique allows a totally different approach for drill bit manufacturing. Thus, allow for new materials to be used in drill bits and allow very economical manufacturing.

In this project, the researcher will be working on enhancing the durability of the PDC drill bit by introducing a new design that the researcher believes, will have a huge impact on stress endurance of the drill bit. The new design improvements will be verified by computerized stress simulation. And then the researcher will follow the footsteps of the previous UTP team by using 3D printer and investment casting processes for fabrication. As a result, produce a functional PDC drill bit that has enhanced durability and that is extremely economical.

1.2 Problem statement

A previous study by UTP has resulted in the fabrication of an optimized drill bit design by the aim of producing it by 3D printing and investment casting. However, in the researcher point of view the design can be further modified. In the previous design the blades had weak points due to an angle present in the shape which would be subject to wear and tear also would make the whole design having risk of breaking.

For a drill bit, design integrity is extremely important. As for any failure, the drill bit would have to be changed. And for this to happen, all the drill pipes (typically 30feet increments) would have to be lifted out of the well. And then with the new drill bit the whole string would have to be lowered. A trip that can reach several thousand feet, resulting in huge loss of time and money.

Therefore, design modification is needed to ensure optimum drill bit durability and stress endurance. Thus, ensure maximum distance to be drilled in a single run and reduce lost time and drilling costs.

1.3 Objectives

The objectives of this project are:

1. To investigate the weakness points of the old PDC drill bit design
2. To propose a new PDC drill bit design.
3. To prove by simulation the stress endurance improvement.
4. If possible, to fabricate the enhanced PDC drill bit body through 3D printing and investment casting processes.

1.4 Scope of Study

The scope of study of this project is as follows:

1- Analyzing CAD drawing of old PDC Drill bit.
2- 3D drawing of enhanced PDC drill bit design.
3- Computerized stress simulation to validate durability enhancement.
4- Preparing 3D model for 3D printing
5- Produce a Rapid prototype using 3D printing technique.
6- If possible, fabrication of a functional prototype of the enhanced PDC drill bit using 3D printing and investment casting techniques.

CHAPTER 2

LITERATURE REVIEW

2.1 Development of PDC Drill Bits

According to kerr, C.J.(1988), PDC was first introduced to the industry back in 1973, It was the first drill bit that used synthetic diamonds as cutting elements. Through that time, the design features having impact on performance have become apparent. The progress and improvements done on PDC drill bits made PDC drill bits sit on the crown of the fierce competition between all the types of drill bits. Thus, PDC drill bit has become the preferred Drill bit type for manufacturers to meet the desired performance requirements. Due to that, several designs of PDC drill bits have become available in the market with each of them designed specifically for a certain type of formation and to be able to perform different applications.

In the past, Based on Symonds, D.H.(1999), Drill bits manufacture included heavy machining of a solid billet of steel to obtain the desired final drill bit form. This process was further improved by the introduction of investment casting, allowing minimal machining inclusion. The procedure of investment casting includes several steps. However, it saves time and cost considerably thus became more efficient.

Figure 1 PDC drill bit

2.2 PDC bit design

Factors to be considered in designing PDC drill bits

- Materials
- Mechanical design parameters
- Hydraulic conditions
- Properties of the rock being drilled

Geometric attributes of PDC bit design

- Blade geometry
- Cutter geometry
- Cutter placements
- Cutter density
- Abrasiveness and strength of the formation
- Hydraulic requirements

Cutting mechanics:

Rock fails in two types; brittle failure and plastic failure. How the formation fails is dependent on rock strength. Rock strength in turn is dependent upon the following.

- Pressure
- Temperature
- Depth

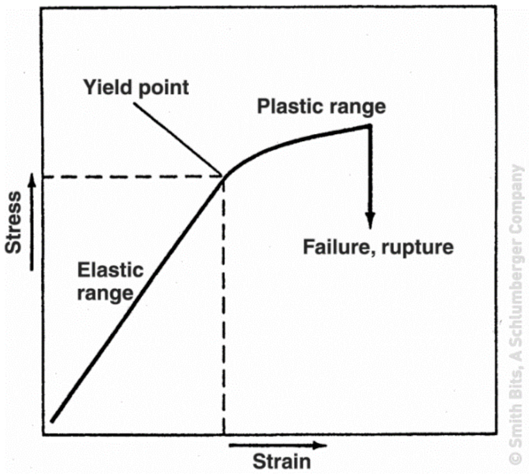


Figure 2 Rock failure types as a function of stress and strain

Formation failure can be (compressive, tensile, shear or torsional). PDC drill bits primarily drill using shear failure. It uses a type of action called crushing and gouging. Vertical force acting due to the weight of the drill string and the horizontal force acting due to rotation are transmitted to the cutters. A resultant force can be expected at the cutters that produce a plane of thrust. Rock cuttings are then sheared off at an angel related to the plane of thrust.

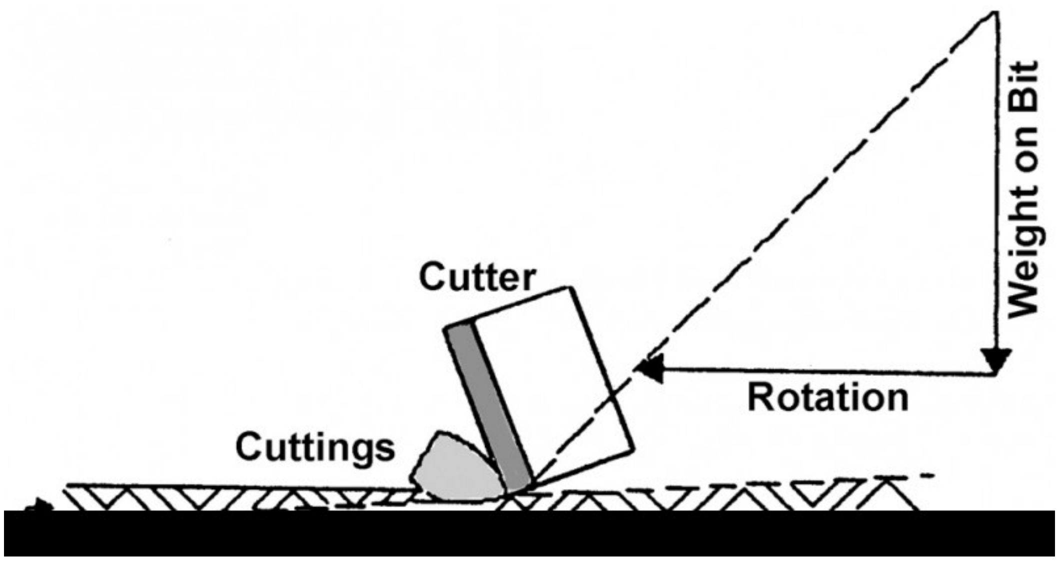


Figure 3 Shear and thrust effect by a PDC cutter

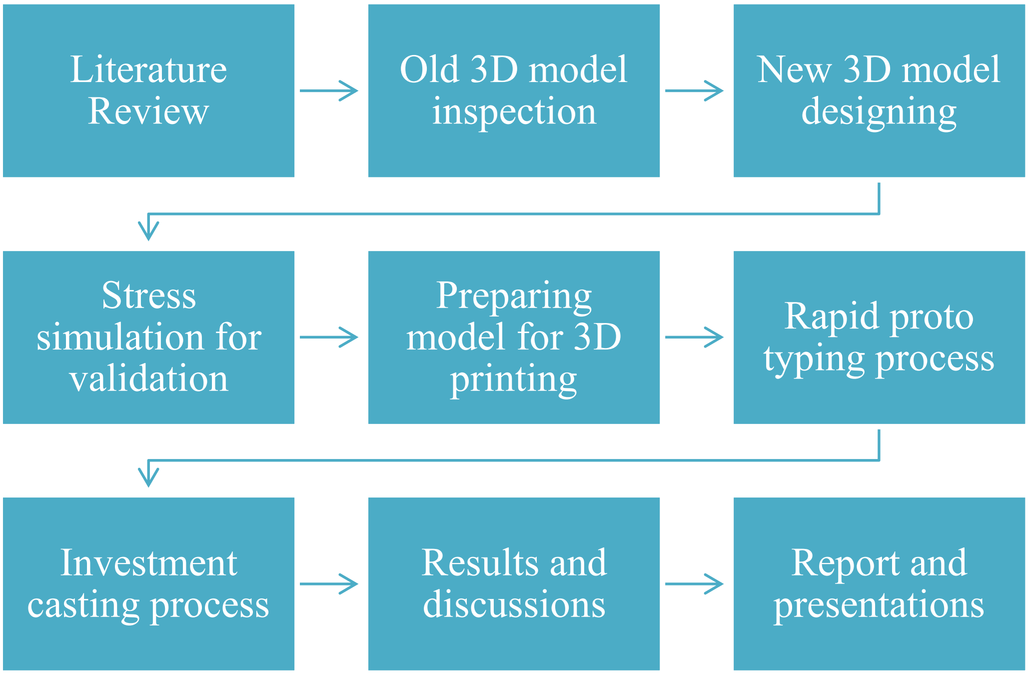
In fact, the shear and thrust effect is what gives PDC drill bits an edge over roller cutter drill bits. As in shear, lower energy is required to achieve plastic limit for rapture as compared to compressive stresses employed by drill cutters. Thus, lower weight on bit is required for drilling using PDC drill bit.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Project Flow Chart

Table 1 Project Flow Chart



3.2 Tools and Equipment

- Auto-Desk inventor Pro (for 3d designing)
- Ansys Simulation software
- ZPrinter and thermojet 3D printer
- Investment casting

3.3 Grant chart

Table 2 FYP1 Grant chart

Activities/ week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Preliminary research work		■	■	■	■									
Initial designing						■	■	■	■					
Simulation validation										■	■	■	■	■
Redesigning if needed													■	■

Table 3 FYP2 Grant chart

Activities/ week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Redesigning model for rapid prototyping		■	■	■	■	■	■	■	■					
Investment casting										■	■	■		
Fabrication												■	■	■

3.4 Key milestone

1- 3D drawing of enhanced PDC drill bit design
2- Computerized stress simulation to validate durability enhancement
3- Produce a Rapid prototype using 3D printing technique

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 First proposed design

4.1.1 First proposed design specifications

The new design maintained a straight blade with a tilted angle of 20 degreed all across the drill bit from top to bottom.

- In the previous design the blades had weak points due to an angle of bended blades present in the shape which would be subject to wear and tear.
- As well, having PDC blades with the design shown in figure with the bended portion of it decrease the design integrity significantly. It decrease the support given to the top portion of the blades by the rest of the blade structure. Which would make the old design subject to breaking.

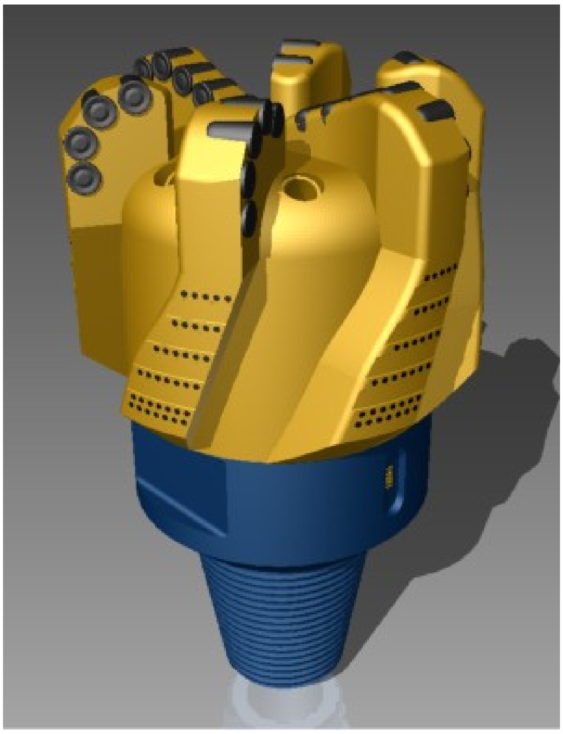


Figure 4 Old design 3D scanned from an old PDC drill bit from a previous study by UTP

- As the aim of this project is to increase drill bit structural integrity. The Student thought of a design that would omit the presence of the bended portion of the PDC blade. And thus, eliminate the weak point of the current PDC drill bit.
- The student made a new design that maintained most of the properties of the old PDC drill bit to maintain performance but with the blades straight all across the drill bit and tilted angle of 20 degree.

Figure 5 Isometric view of the new straight blade design (Designed by student)

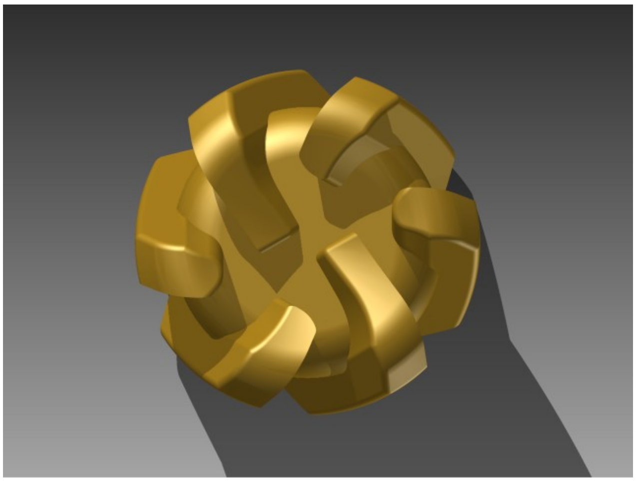


Figure 6 Top view of the new straight blade design (Designed by student)

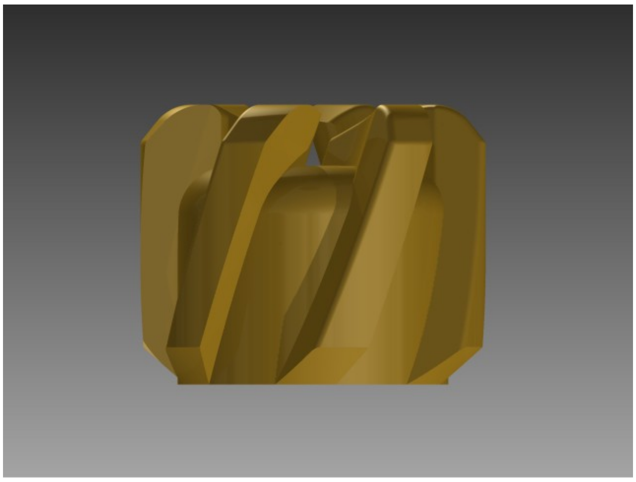


Figure 7 Front view of the new straight blade design (Designed by student)

Maintained number of blades to be 6 and over all shape of the blades to be straight. (Achieving highest shape integrity)

- In the previous design there were 6 blades distributed symmetrically around the drill bit.
- To test the effect of straightening the blade. The student chose to keep as much constants as possible. And as will be seen in next section the design showed more integrity and more ability to with stand stresses

Lighter in weight

- The proposed design used less material. Due to maintaining the shape of the blade to be straight.
- There was no need to reinforce the blade with extra material as have been done in the previous design.
- The new design top portion (blades and body without adding nozzles) weighed 28.677 kg by Autodesk inventor material calculation.
- While the old weaker design (Same portion) weighed 28.983 kg.

Bigger area for mud flow in between the blades

- As compared to the old design. Due to the omission of the reinforcement of the blades. And maintaining the smallest thickness of 30 mm blade all across the drill bit.
- It allowed the shape to maintain the mud flow area to be as big as possible.
- Compared to the old design when the mud reaches the mud nozzles and come out it has a cross sectional flow area that keep on decreasing as the end of the blade towards the drill string had extra material reinforcement.

- Thus even though it is outside the scope of this project, the student believe the new design would enhance ROP as well as the proved enhancements in durability shown in next sections.

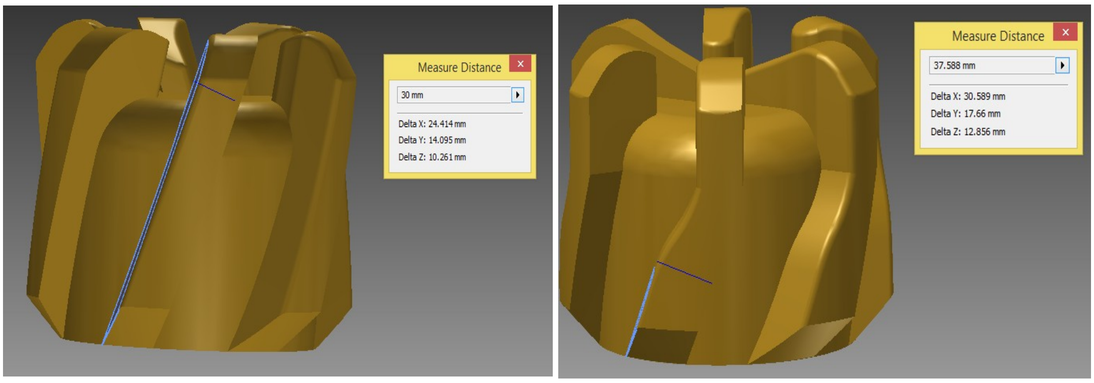


Figure 8 new design (on left) vs old design (on right). Old design showing bigger Blade thickness. Thus, reduced cross sectional mud flow area.

4.1.2 Computerized stress analysis simulation

To prove the durability enhancement, the student performed computerized stress simulations on both the old design and the student's proposed design. With the same parameters applied on both designs (which resemble real working parameters of a PDC drill bit), the student was able to verify the better integrity of the new design.

At first how the stress simulation was approached. It was by the application of real weight of (50000 lbf) on bit and real torque of (18000 ft.lbf).

The student at first thought of the application of the reaction forces acting on the PDC cutters directly. However. It would be a complex and unreliable kind of simulation. As every force would have to be identified with its direction vector and magnitude which also change with time. Also, the forces would be dependent on the type of formation being drilled.

Then, the simulation was approached differently. During drilling there are sensors that show weight on bit and torque applied. Which means we have reliable estimate of this force of weight and this torsional force of the torque.

So, the student searched the literature for reasonably maximum values of these forces and it was found to be real weight of (50000 lbf) on bit and real torque of (18000 ft.lbf). And applying constraints on the tip of the blades to react evenly for these forces.

Then the student had to modify the designs to be able to compare to the same kind of structure. Just with the blade modification difference.

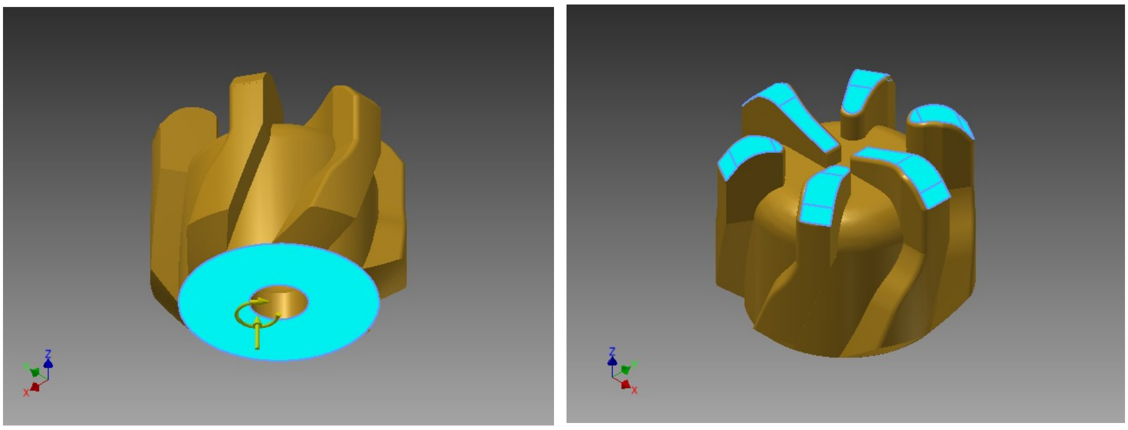


Figure 9 Weight on bit and torque applied on the old drill bit on the left side. Fixed constraints applied on the old drill bit on the right side

And as will be shown now, the new design has managed to show remarkable structural integrity and ability to withstand stresses before failure as compared to the old design.

Some of the simulation results will be explained in this section of the report.

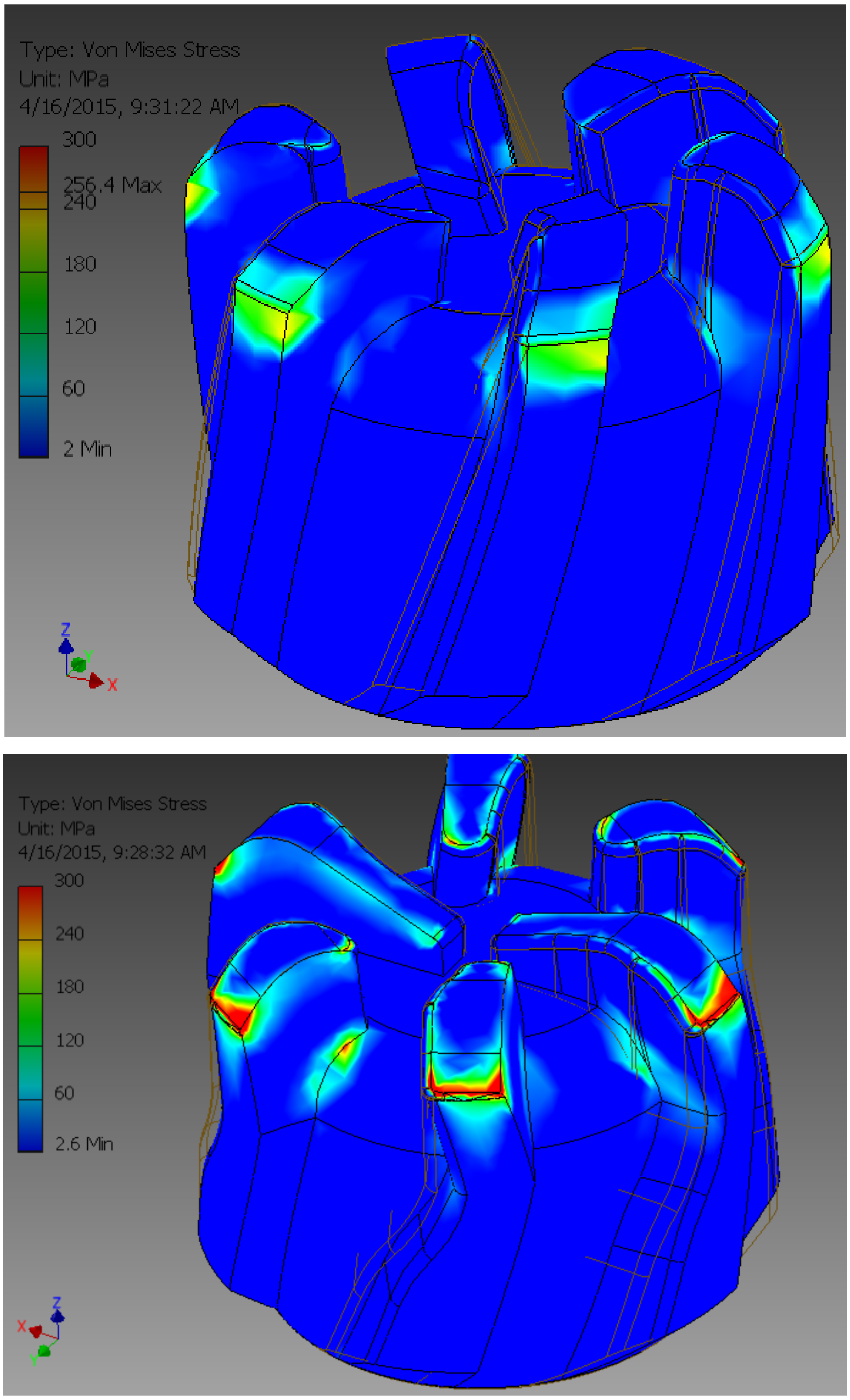


Figure 10 The new design stress is shown on top. The old design stress is shown on bottom. The old design shows much higher stress distribution as compared to the new design with the same applied forces.

The previous figures show the stress distribution due to the applied forces on the designs. The tensile strength of steel varies between 200 to 250 MPa, tensile strength is the maximum stress the material can with stand before plastic deformation (permanent non recoverable deformation). Which means, with the applied forces if the stress on the structure increases more than tensile strength, failure has occurred and the structure is permanently deformed.

As can be seen in the previous figure the color scale is set to show what-ever is greater than 250 MPa (steel tensile strength) in red.

And as it is clear the proposed new design has much better stress endurance. It doesn't show any red regions as compared to the old design that shows it would be subject to plastic failure and breaking.

It is to be noted also that, in the old design there is too many red spots. However not all of them are significant. The red spots very near to the constraints are due to the simplified simulation approach and should not be considered. However, the main concern is the regions connecting the blade to the body of the drill bit. These shows failure as well and they hold true that the old design would fail under the maximized force and torque applied.

Another important result of the simulation is the displacement. Since the structure is set to have motion constraints as shown before. Structure is not expected to have any displacement. However, due to the elasticity and plasticity of the metal when forces are applied the metal deform and some parts are moved due to this deformation.

It is to be noted that, elastic deformation is acceptable and is not considered failure however plastic deformation is a non-recoverable failure.

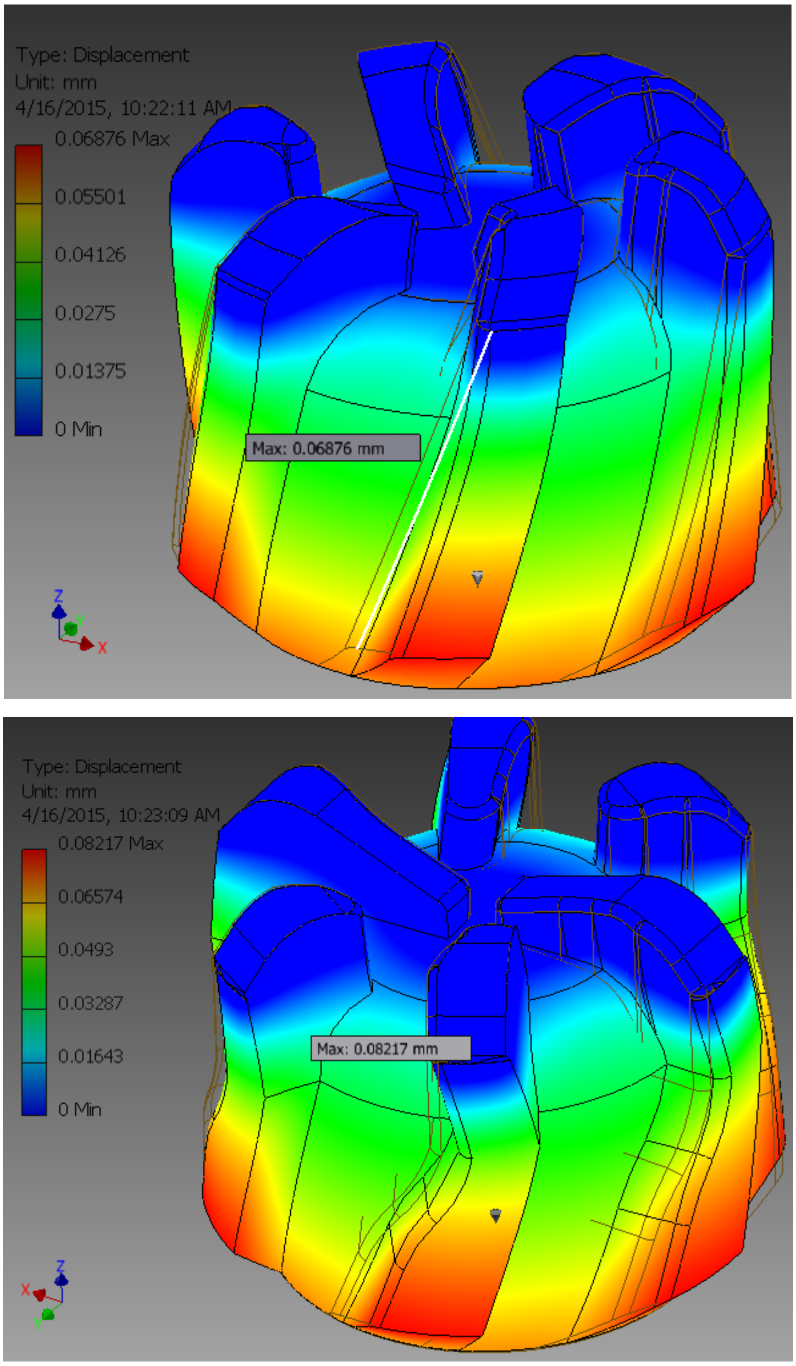


Figure 11 Structural displacement of new design on top vs old design on bottom. The old design shows Max diplacement of 0.082 vs 0.069 for the new design. Which shows huge structural integrity for the new design.

As can be shown in the previous figure, the old design shows Max diplacement of 0.082 vs 0.069mm for the new design. Which shows huge structural integrity for the new design.

The more displacement the more deformation. Which shows that the new design has much more ability to withstand forces and torques without deformation.

In fact, since the displacement is quantified we can say that the new design has better integrity by a factor of (0.08217-0.06876)/0.08217 = 0.16319824753.

So it can be concluded that the first proposed design has much higher integrity and has almost 16 % better durability performance.

4.2 Varying number of blades effect on the old design integrity

To assess the effect of varying number of blades on the old drill bit integrity. The student made two new designs alongside the old 6 blades design. The new designs had 5 blades and 4blades respectively.

- The new designs maintained the overall structure of the old design. Same angle and dimensions.
- However, the new designs benefited from the extra space allowed due to the less blade numbers. Thus, the top portions of the blades were all long towards the center of the bit surface as shown in the following figures (omitting the weak short blades).

Figure 12 Old design (6blades)

Figure 13 (5blades) design

Figure 14 (4blades) design

A stress simulation was made with the same parameters used for the first proposed design simulation, It was by the application of real weight of (50000 lbf) on bit and real torque of (18000 ft.lbf). And applying constraints on the tip of the blades to react evenly for these forces.

And the results were as following,

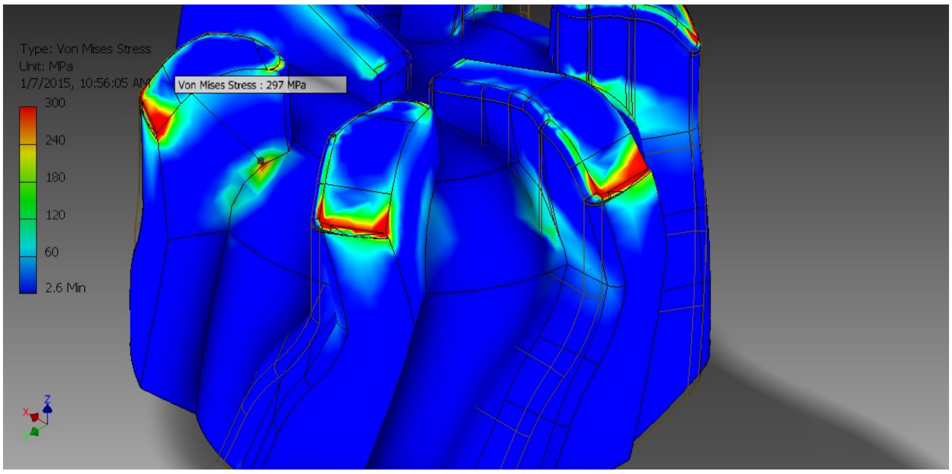


Figure 15 Stress simulation result for the old design (6blades)

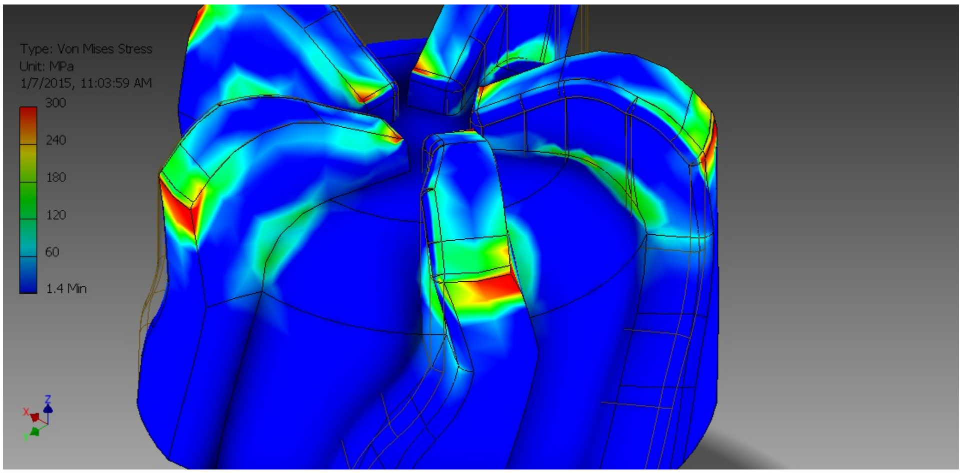


Figure 16 Stress simulation result for the old design (5blades)

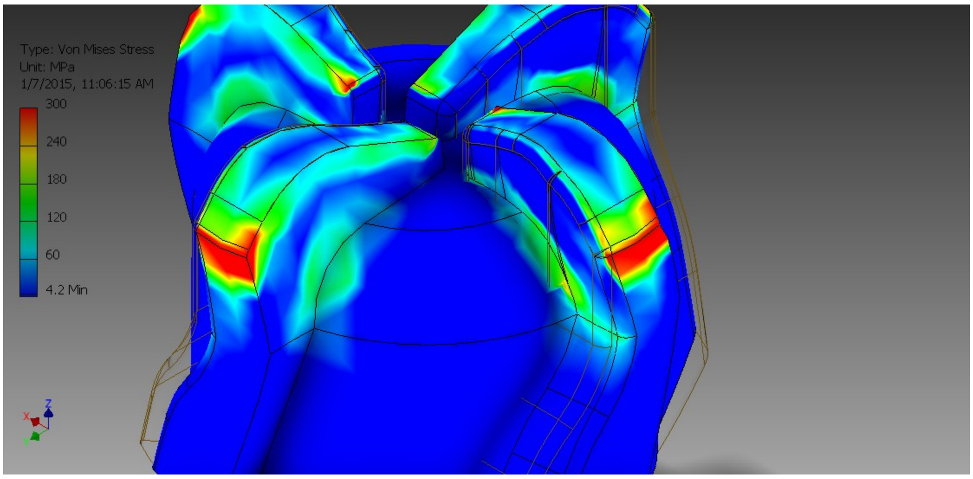


Figure 17 Stress simulation result for the old design (4blades)

The previous figures shows the stress distribution due to the applied forces on the designs. The tensile strength of steel varies between 200 to 250 MPa, tensile strength is the maximum stress the material can with stand before plastic deformation (permanent non recoverable deformation). Which means, with the applied forces if the stress on the structure increases more than tensile strength, failure has occurred and the structure is permanently deformed.

As can be seen in the previous figure the color scale is set to show what-ever is greater than 250 MPa (steel tensile strength) in red.

It is to be noted also that, the red spots very near to the constraints are due to the simplified simulation approach and should not be considered on the tip of blades. However, the main concern is the regions connecting the blade to the body of the drill bit. These shows failure as well and they hold true that the old design would fail under the maximized force and torque applied.

In the Old design (6blades), the smallest blade had a weak spot at the smallest blade with presence of stress up to 296 MPA under the applied forces. Shows bad stress endurance.

However for the (4blades and 5blades design), they show better stress distribution. And this is due to omitting the small blades and keeping only the long ones reaching to the center.

Another important result of the simulation is the displacement. Since the structure is set to have motion constraints as shown before. Structure is not expected to have any displacement. However, due to the elasticity and plasticity of the metal when forces are applied the metal deform and some parts are moved due to this deformation.

Generally, the displacement is representative of the structure résistance to be deformed under certain applied forces. However, what shows true points of failure is Stress distribution at the points where stress exceeds tensile strength.

In the following figures the displacement results are shown.

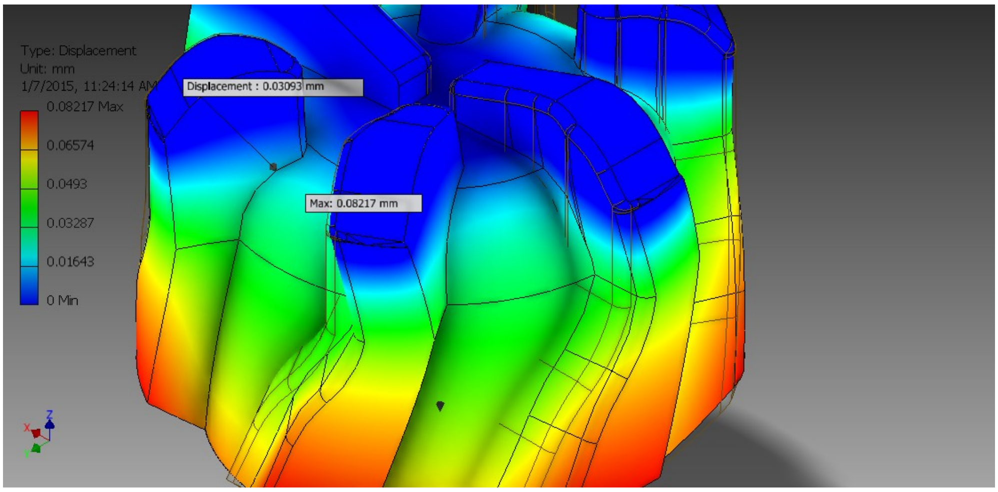


Figure 18 Structural displacement of the old design (6blades)

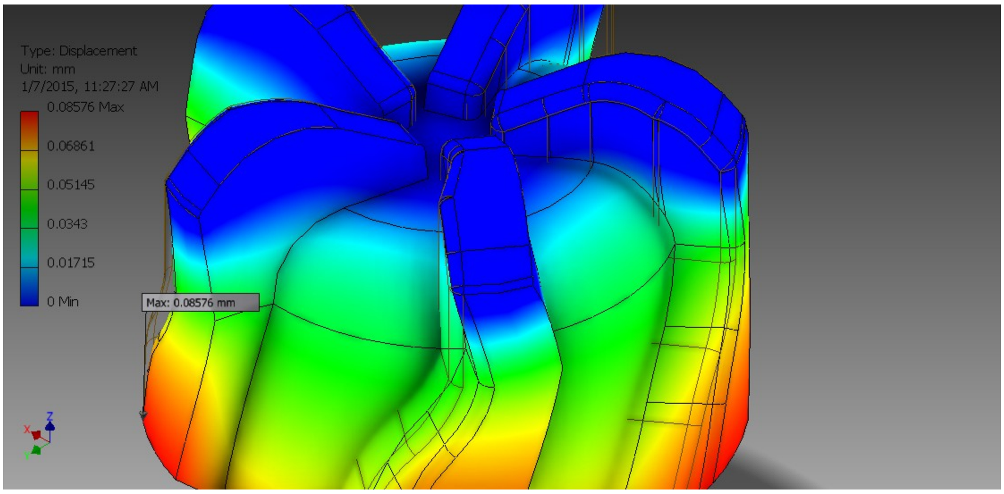


Figure 19 Structural displacement of the (5blades) design

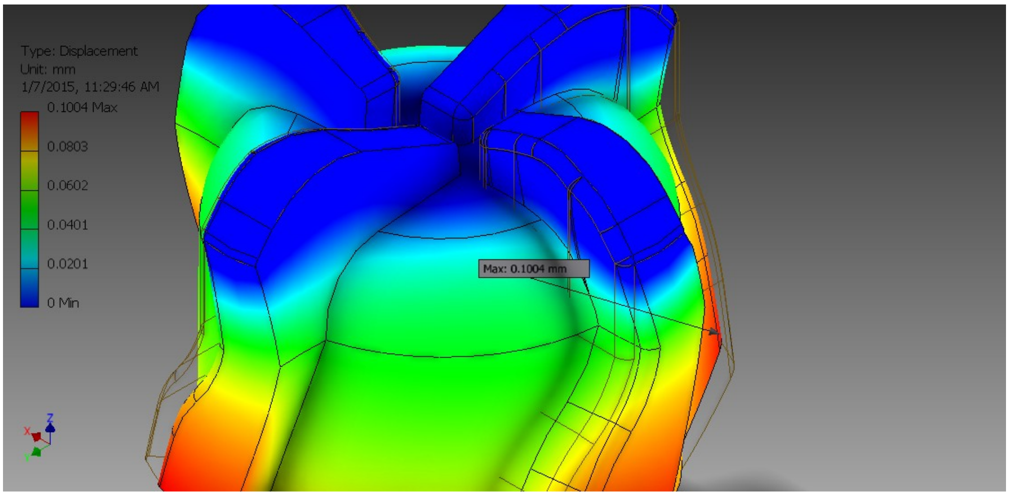


Figure 20 Structural displacement of the (4blades) design

As can be seen from the previous figures, the old design (6blades) has the smallest displacement with value of 0.08217mm. While the (5blades) and the (4blades) designs had 0.08576 and 0.1004mm displacement respectively.

Which means the overall stress endurance for the old structure (6blades) is better. It can withstand more forces without deforming on it-self. However, in the weak points stress exceeds 250 MPA which means plastic failure occurring for the (6blades) design.

This expected due to the support given by the extra blades to the overall structure as compared to the (4 or 5blades). However the extra blades are small and week and can be broken easily.

Thus the (4 blades) and (5blades) show better distribution of stress than the (6 blades) old design.

4.3 Effect of asymmetry on the old design

To assess the effect of asymmetric blades on the old drill bit integrity. The student made a new design with asymmetric blades (6 in total) 1 short blade and 5 long.

- The new design maintained the overall structure of the old design. Same angle and dimensions.
- However, the new design benefited from the extra space allowed due to the less blade numbers. Thus, the top portions of the blades were all long towards the center of the bit surface as shown in the following figures (omitting the weak short blades). Except for 1 short blade.
- The new design is asymmetric as can be shown in the following figures.

Figure 21 Old design

Figure 22 Asymmetric design

A stress simulation was made with the same parameters used for the first proposed design simulation, It was by the application of real weight of (50000 lbf) on bit and real torque of (18000 ft.lbf). And applying constraints on the tip of the blades to react evenly for these forces.

And the results were as following,

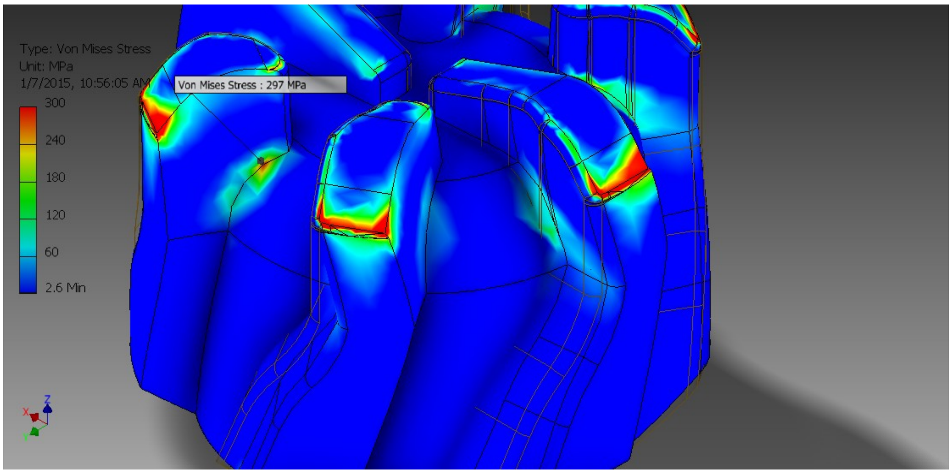


Figure 23 Stress distribution for the old design

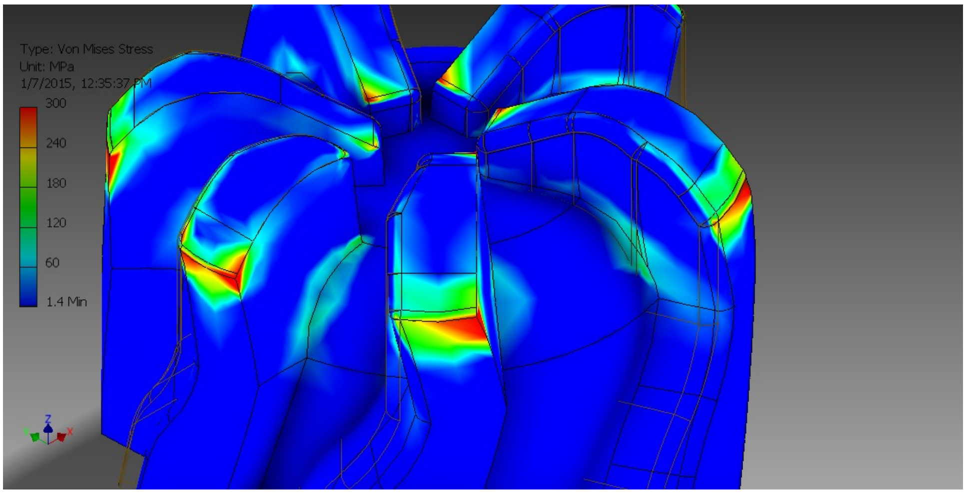


Figure 24 Stress distribution for the asymmetric design

The asymmetric design is showing better stress distribution, all of the stress is lying below the tensile strength. Thus, no plastic failure.

And the displacement distribution is shown in the following figures.

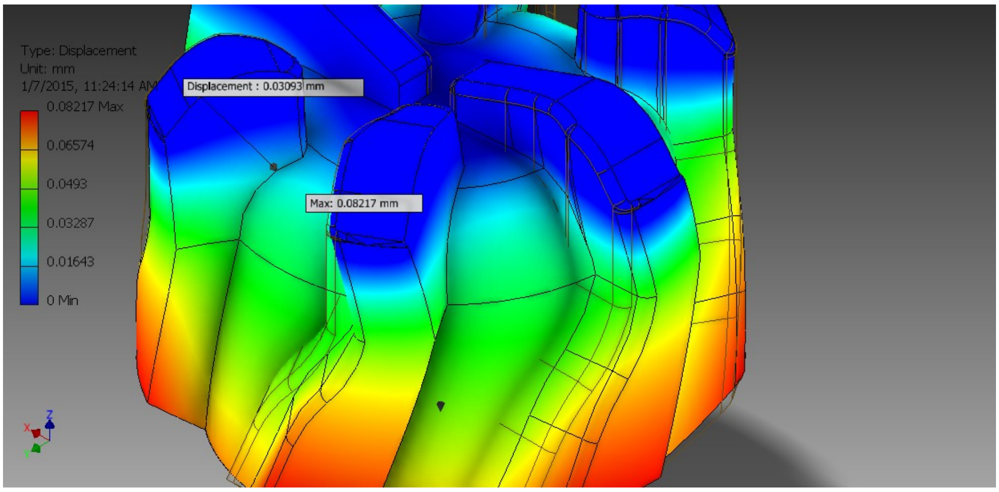


Figure 25 Structural displacement distribution

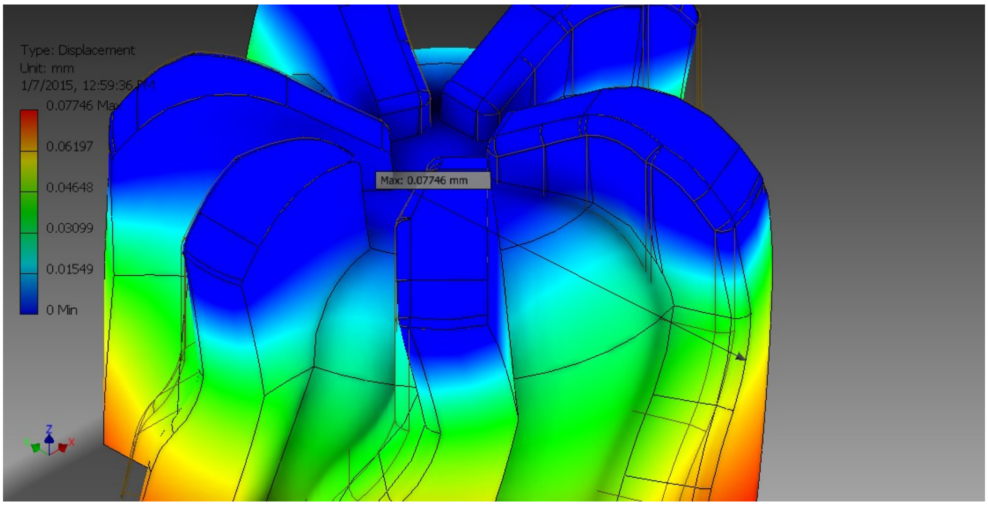


Figure 26 Structural displacement distribution for the asymmetric design

As can be seen in the previous figures, the asymmetric design is showing better results with 0.07745mm displacement. While the old design had 0.8217mm

Thus, the asymmetric design has shown better results in both stress distribution and displacement. However, the effect of asymmetry on bore whole stability has not been assessed.

The better results are expected as the number of long blades has increased in the asymmetric design as compared to the old design.

4.4 Varying number of blades effect on the first proposed design integrity

To assess the effect of varying number of blades on the first proposed design drill bit integrity. The student made two new designs alongside the first proposed 6 blades design. The new designs had 5 blades and 4blades respectively.

- The new designs maintained the overall structure of the first proposed design. Same angle and dimensions.
- All of the blades maintained the uniform straight tilted angle that proved to be strong and durable (in section 4.1.2).
- However, the new designs benefited from the extra space allowed due to the less blade numbers. Thus, the top portions of the blades were all long towards the center of the bit surface as shown in the following figures (omitting the weak short blades).
- The new designs features are shown in the following figures.

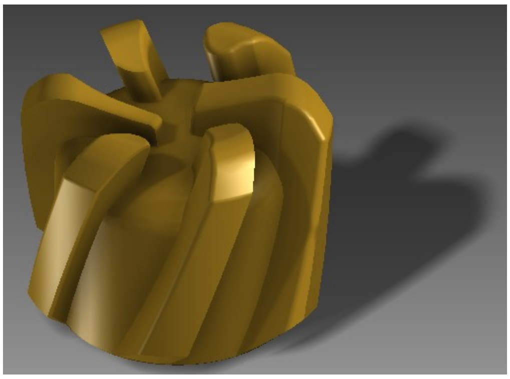


Figure 27 first proposed design (6 blades)

Figure 28 First proposed design modified (5blades)

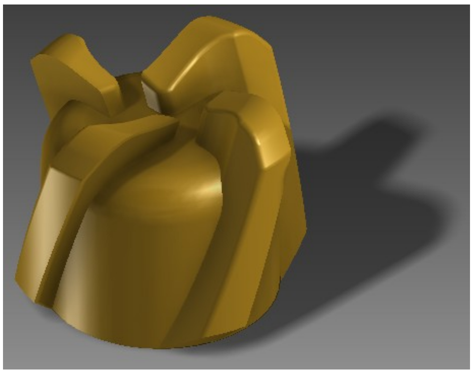


Figure 29 First proposed design modified (4blades)

A stress simulation was made with the same parameters used for the first proposed design simulation, It was by the application of real weight of (50000 lbf) on bit and real torque of (18000 ft.lbf). And applying constraints on the tip of the blades to react evenly for these forces.

And the results were as following,

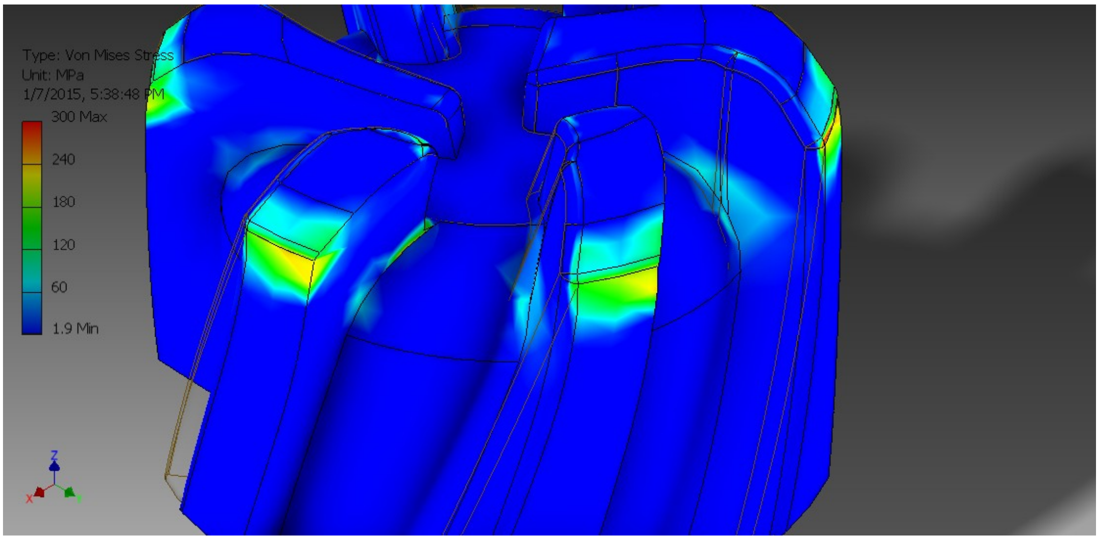


Figure 30 first proposal (6blades) stress distribution

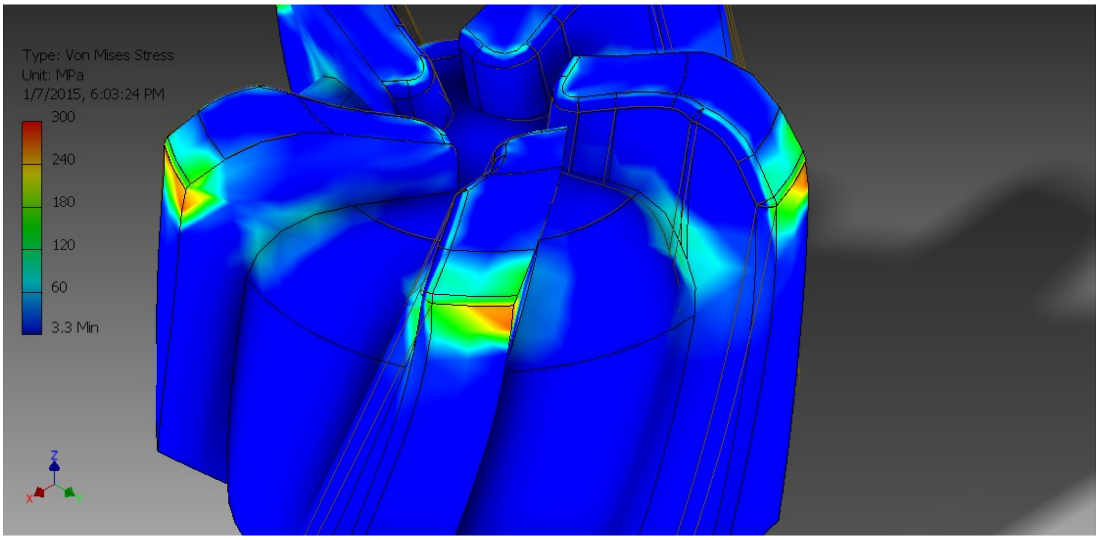


Figure 31 first proposal modified design (5blades) stress distribution

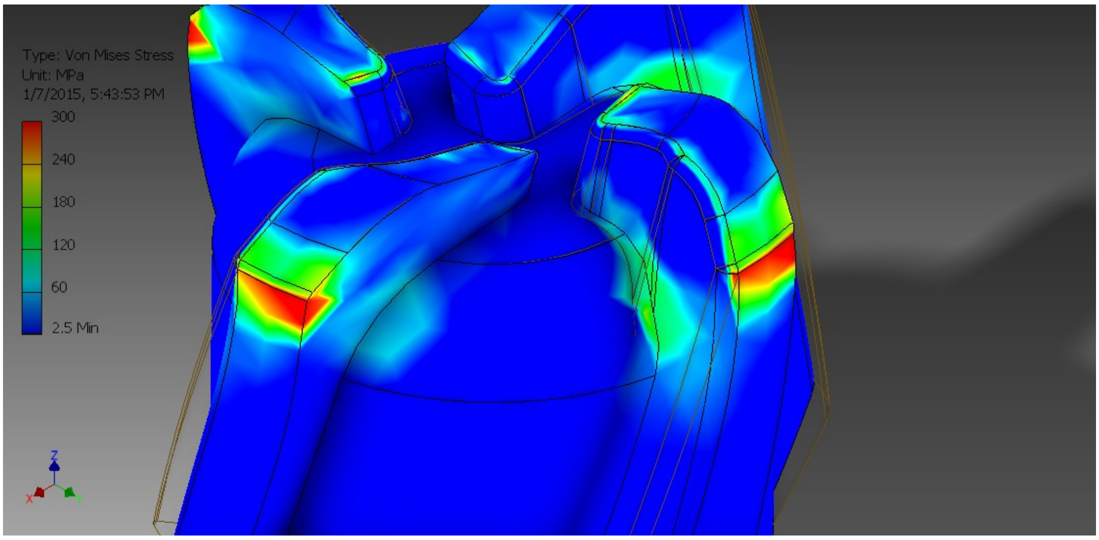


Figure 32 first proposal modified design (4lades) stress distribution

The previous figures show the stress distribution for the three different designs. As seen, all of the designs stress lie below the tensile strength thus no plastic failure is expected. This due to the structure of the blade that maintained the uniform tilted angle all across the bit.

However, The 6 blades design shows slightly better stress distribution than the 4 and 5 blades designs. This is due to, the support of the extra blades in withstanding the applied forces.

In fact if compared to all the other designs including the old design (4,5 and 6 blades) and the asymmetric design, it is seen that the first proposal 6 6blades design has the best stress distribution so far.

To check the overall structural deformation under the applied forces, the structural displacement results are shown in the following figures.

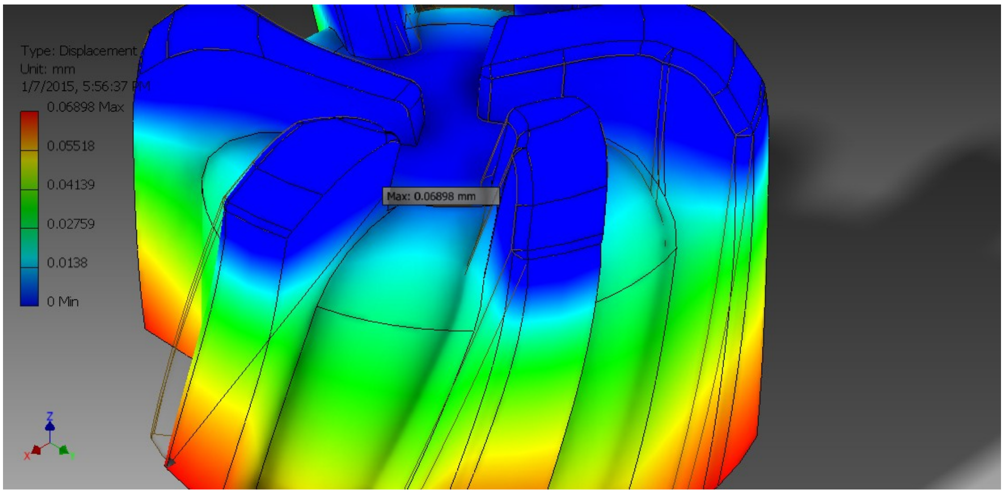


Figure 33 first proposed design (6blades) structural displacement

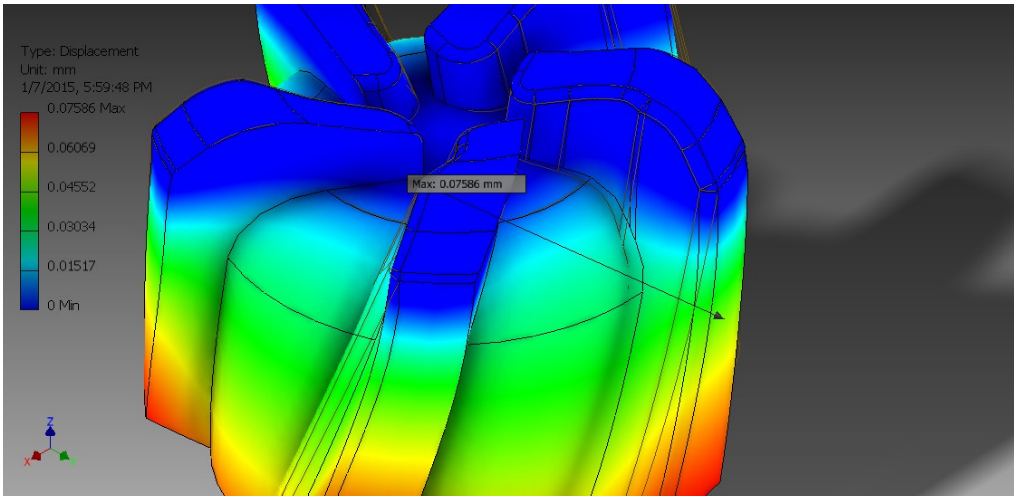


Figure 34 first proposed design (5blades) structural displacement

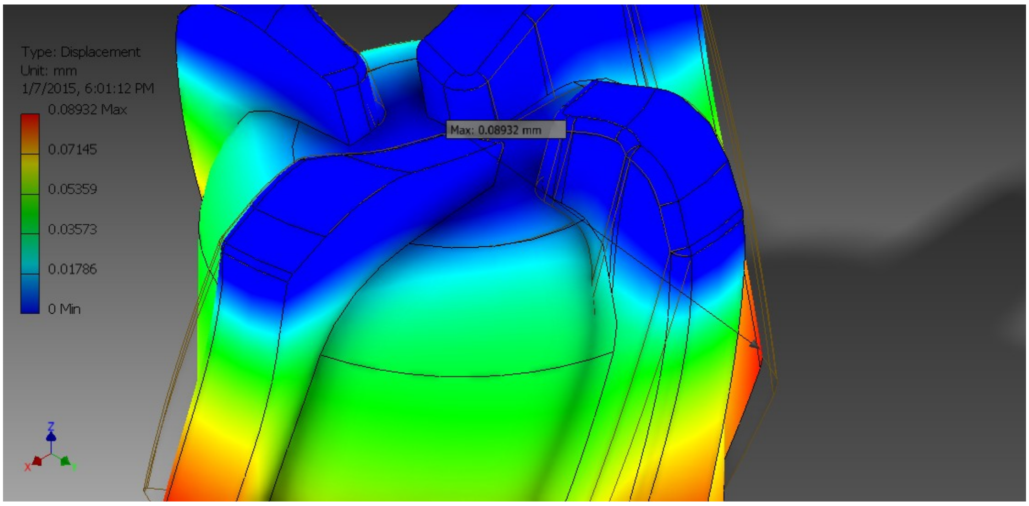


Figure 35 first proposed design (4blades) structural displacement

As can be shown in the previous figure, the 6blades design shows the best diplacement 0.06876mm. Which shows better structural integrity for the 6 blades drill bit.

The more displacement the more deformation. Which shows that the 6blades design has much more ability to withstand forces and torques without deformation.

In fact, since the displacement is quantified we can say that the first proposed 6blades design has better integrity as compared to the original old design by a factor of (0.08217-0.06876)/0.08217 = 0.16319824753.

So it can be concluded that the first proposed design has much higher integrity and has almost 16 % better durability performance.

4.5 Second proposed design

4.5.1 Effect of changing tip of the blade geometry on the proposed drill bit design integrity

Since the first proposed design with the six blades has proved to be the most durable so far. Optimizing the blade geometry was the next step.

A designs was made with different blade geometry.

- The design maintained a straight tilted angle of the blade that has been proved by simulation to be strong and durable in section 4.1.2 of this report.
- The previous design used only two long blades reaching the center of the bit surface and two medium finally two short lades.
- The reason why all the blades cannot be long extending to the center is, the limited surface area and the existence of enough space for mud flow and mud nozzles to be placed.
- The new design kept three instead of two blades as long blades reaching to the center of the surface. The three remaining blades were short blades.

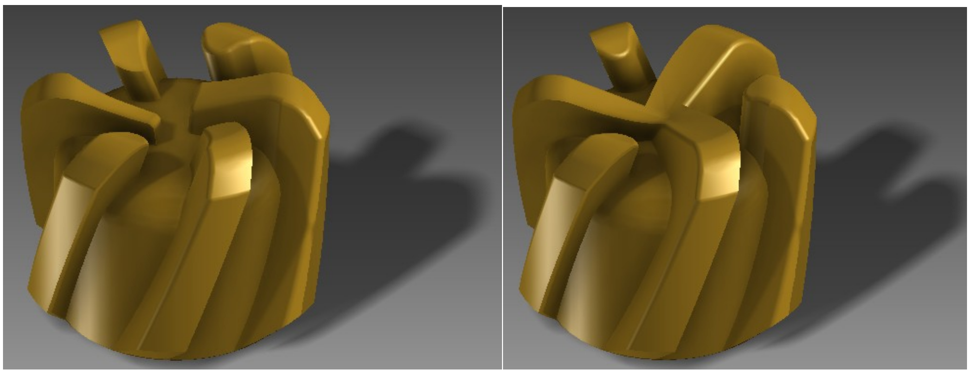


Figure 36 first proposed design on the left Vs second proposed design on the right

In the stress simulation, the second proposed design has shown remarkable results.As shown in the following figure.

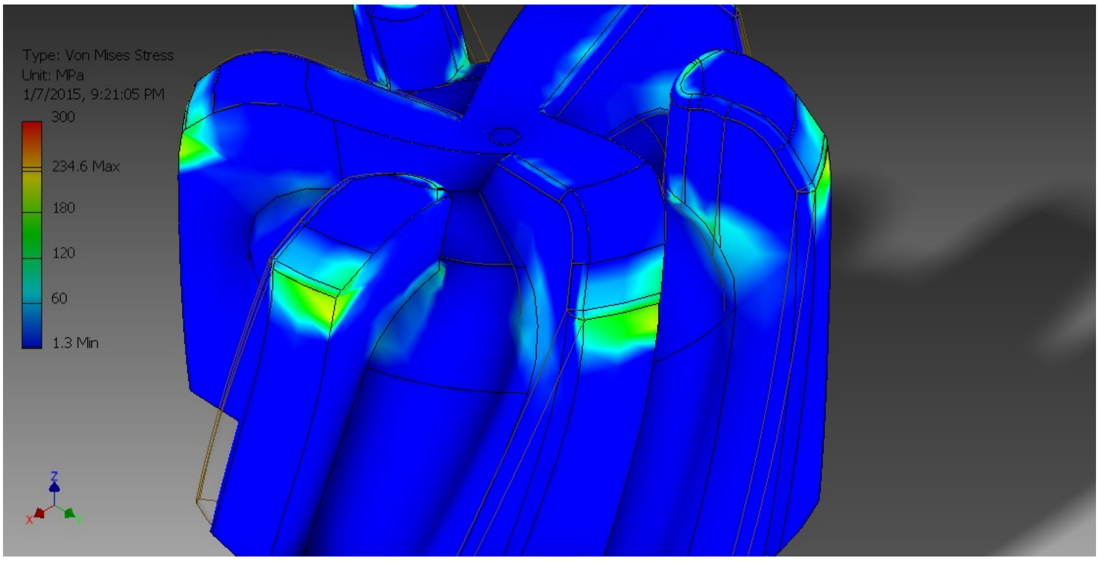


Figure 37 second proposed design stress distribution

As can be seen in figure the second proposed design has shown the best stress distribution among all of the designs.

Which shows that plastic failure would be practically impossible as the maximum value recorded for stress is below 250 Mpa the tensile strength for steel.

Also the design has shown very little displacement as shown in the following figure.

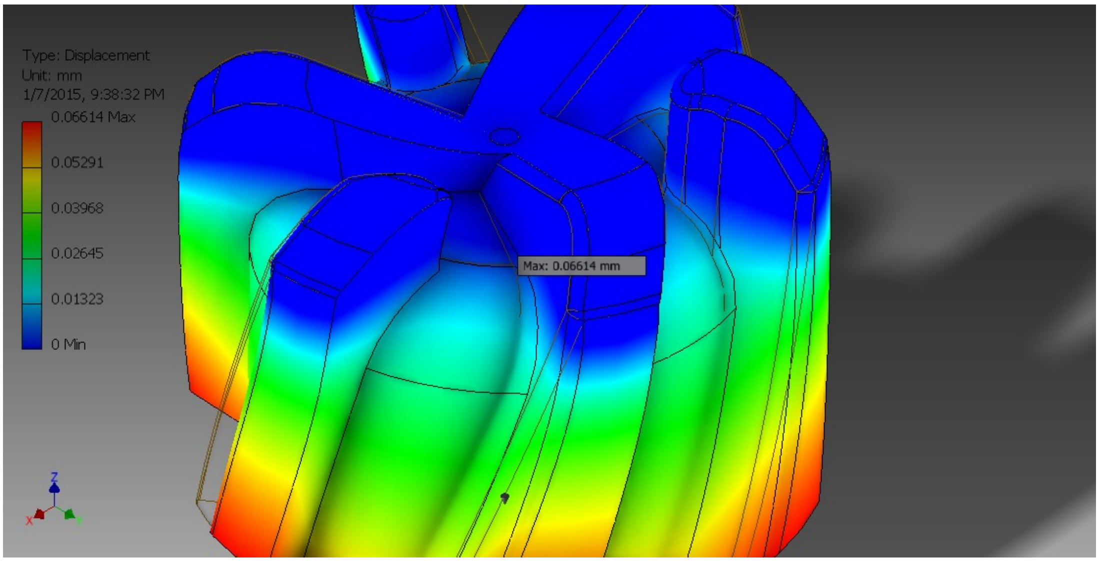


Figure 38 second proposed drill bit design structural displacement

As can be seen the second proposed drill bit design has recorded the minimum structural displacement in all the designs.

With a value of 0.06614 mm it is believed the overall integrity of the drill bit would be enhance by a factor of (0.08217-0.06614)/0.08217 =0.1950833637

It is believed the enhancemnt is due to, the tilted blades structure and also due to the support of the long blades on each other at the intersection point at the center of the drill bit face.

Thus, The second proposed design can be assumed as the optimal design for the PDC drill bit. With enhancement in integrity up to 19.5 %.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The project have been a success in the milestones pursued so far. Several new designs of the drill bit were successfully 3D modelled. Sensitivity analysis has been made by using simulation to find the optimized drill bit design, studying different aspects of the blades design. A new optimized design has been chosen and has been proved by simulation to have enhanced structure integrity and durability.

Important conclusions can be summarized as follows:

1. Varying number of blades effect on the old design integrity has been studied, and it was proved that the overall stress endurance for the old structure (6blades) is better. It can withstand more forces without deforming on it-self. However, in the weak points stress exceeds 250 MPA which means plastic failure occurring for the (6blades) design. However, the (4 blades) and (5blades) show better distribution of stress with reduced week points stress.
2. Effect of asymmetry on the old design has been studied and the asymmetric design has shown better results in both stress distribution and displacement. However, the effect of asymmetry on bore whole stability has not been assessed.
3. Varying number of blades effect on the first proposed (tilted angle blades) design integrity has been analyzed and The 6 blades design shows slightly better stress distribution than the 4 and 5 blades designs. This is due to, the support of the extra blades in withstanding the applied forces. Also, the 6blades design shows the best diplacement 0.06876mm. Which shows better structural integrity for the 6 blades drill bit with a quantified percentage of 16.32%.
4. The tilted blade design (6 blades) has been further optimized by changing the tip of the blade design. And the new design (second proposed design)

has shown the best stress distribution among all of the designs. Also, it has recorded the minimum structural displacement in all the designs. With a value of 0.06614 mm it is believed the overall integrity of the drill bit would be enhanced by a factor of (0.08217-0.06614)/0.08217 =0.1950833637.

5. Thus, The second proposed design can be assumed as the optimal design for the PDC drill bit. With enhancement in integrity up to 19.5 %

Important recommendations and future work can be summarized as follows:

1. It is recommended to further develop the project by modifying the design for 3D printing approach. And, fabrication of a functional prototype of PDC drill bit design using; 3D printing and investment casting.
2. It is also recommended, to test the functional prototype into real work environment and to assess its maximum durability by experiment. In order to support the simulation results.
3. Finally, it is recommended to optimize the design in terms of rate of penetration as well as the durability. And this can be achieved by the choice of proper mud nozzle sizing and mud nozzle placement. Also, by the choice of number of PDC cutters and their placement.

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