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DESIGN MODIFICATION AND ANALYSIS OF PISTON AND DRILL BIT FOR ROCK DRILL

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ABSTRACT

This study is focused on reducing the pressure and rock dust between the drill bit and rock, which is achieved by slight design modification and analysis of piston and drill bit. A 3D model of piston and drill bit are prepared in CATIA V5 with slight modification from base design by making few slots on cross section of piston as well as drill bit. 6 slots are made on piston with dimensions of 7 units of radius and 12 units of length each. And also 8 slots on drill bit with dimensions of 5 units of radius and 9 units of length each. These slots are useful in removing pressure and dust formed between drill bit and rock. And same modified design is analyzed by using ANSYS for displacement and stresses at low and high pressures. After comparing, base design analysis and modified design analysis at low pressure and high pressure, it shows that pressure, displacement and stresses are reduced in modified design which helps in enhancing life of piston and drill bit.

1.0 INTRODUCTION

Pneumatic DTH hammer drilling is a rotary percussive drilling technique widely used in many fields, such as open-pit mines, geological core exploration, and petroleum exploration. The existing pneumatic hammer drilling technology has many advantages: high drilling efficiency, excellent bit lift, and good hole quality. In conventional DTH hammer drilling, the hammer is fixed at the bottom of the drill string that has the primary function of providing rotational torque and axial pressure. The hammer driven by compressed air transforms the inner energy into the kinetic energy of the piston, and the impact energy is transmitted to the bit in the form of stress wave for rock breaking. Meanwhile, the rotational torque rotates the bit to tear and cut rock. Many scholars have performed theoretical and experimental research on the improvement of pneumatic DTH hammers. Furthermore, we redesigned the air distributor, a special-purpose piston, and the rotation joint. The ratchet wheel mechanism is also introduced to realize the separate motions of the drill pipe and the bit. Rock drilling is an essential part of several important industrial activities: mining, oil and water well drilling and civil engineering, the latter concept covering a large variety of different contract work applications. Two main rock drilling methods are available:

- Rotary drilling of large diameter holes from above ground in all kind of rocks.
- Percussive drilling of small to medium diameter holes in all kind of rocks, both under and from above ground.

Fig. 1.1: Atlas Copco Rocket Boomer XL C30

Figure 1.1 .Shows a drill rig Rocket Boomer XL C30. It is used for tunnel drifting under-ground. The rocket boomer has four rock drills, which all can be operated at the same time. Percussive method of rock drilling differs from the other in one fundamental aspect: the drilling equipment is comparatively light and accordingly easily maneuverable. The percussive rock drilling system may be regarded as a force amplifier, which transforms a constant low thrust force to a periodic force on the bit, alternating between almost zero for most of the time and the same high force as for the rotary bit for only a few percent of the blow period.

- **Background and Purpose**

Since our focus is on design, we will choose to work with tetrahedral- this allows us to focus on the design aspects without getting tied down meshing complications. Since solid elements have 3 degrees-of-freedom per node, a 19,041 node model has 57,123 DOF's. This is reasonable for static analysis.
This project involves mechanics for stress analysis, and rigid body dynamics for calculation of displacements. The modeling focus is on creation of joints and bodies. RADIOSS requires that the two grids be used to define revolute and translational joints – one grid on each of the bodies. The grids that define the joints need to be on the axis of rotation, for a revolute joint. Since there may not be elements at the desired location, we make liberal use of "rigid" elements. This approach allows us to define the grids for the joints at locations that are correct from the view of the multi-body solver.
The use of "ground" bodies means we do not need any restraints on the FEA model. We provide an initial velocity to the piston, to simulate the effect of a "kick-start". Unlike an FEA solution, the time – integration scheme used by the MBD solver embedded in RADIOSS calculates the step-size for time-integration internally. Running Optistruct / Analysis is easy.

1.3. TYPES OF ROCK DRILLINGS

1.3.1. A Typical Percussive Rock Drilling System

In the percussive machine itself a piston is given a reciprocating motion by a working fluid pressure over the two pressure areas, one for each direction of piston motion. The distribution of the working fluid to these pressure areas is controlled by the motion of the piston itself, either directly or indirectly via a valve. Each cycle of the piston motion includes a blow of the piston against the shank of the drill steel. Thereby all or at least most of the piston blow energy is transmitted to the drill steel as a compressive stress wave running along the drill steel towards the drill bit.
By increasing the hydraulic pressure on the impact piston rear side, the piston is moved towards the shank adapter. This striking piston gives the impact force to the shank adapter. For optimal drilling, different velocities are needed especially for different rocks. The change of stroke length and thereby change of striking velocity, is achieved by changing a special "regular pin".

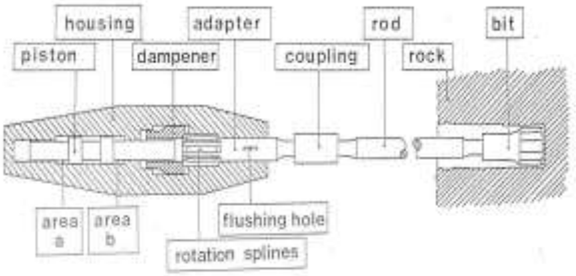


Fig 1.2: The Percussive Rock Drilling Principle

Drilling equipment is the collective term used for machines that apply impact and rotation forces to drill (for the most part) surfaces and blast holes, and it is classified as top-hammer drilling (THD), down-the-hole (DTH) drilling, and rotary drilling (RD) rigs, depending on the operating method. In general, THD is used mostly for mining and civil blasting works, where the rig drills into the earth usually to a depth of 1–20 m and at most 40 m; DTH is used mainly for groundwater development and can create holes to a maximum depth of 4000 m; and RD bores the deepest holes, most commonly for petroleum gas extraction and geothermal development, being propelled by its own weight to reach depths of up to 10,000 m.

1.3.2. Down the Hole Rock Drilling

In DTH drilling, there is no drill steel between the rock drill and the drill bit. The rock drill is mounted in a cylinder, which is pushed down the hole. The rotation of the drill bit is performed by a rotation unit located outside the hole. The rotation is transferred by pipes, to which the rock drill is connected. Most DTH hammers are pneumatic driven, and the air is led through the pipes that transfer the rotation. The air operating the percussion mechanism is led out through the drill bit, where it flushes the cuttings out of the hole. The advantage with DTH drilling is that there are neither drill steels, nor threads transferring the shock wave produced by the rock drill. DTH hammers are used for large holes from approximately 120 mm.

1.3.3. Valve less Rock drills

In a valve less rock drill, the piston is the only moving part. The term "valve less" is however not quite adequate since the piston itself is used as a valve. In this kind of drill, compressibility of the fluid plays an important role in the operation of the drill machine. The basic aim to design rock drills without any valves is to increase their overall efficiency.

Working Mechanism

Consider the valve less rock drill schematically shown in given fig 1.3.

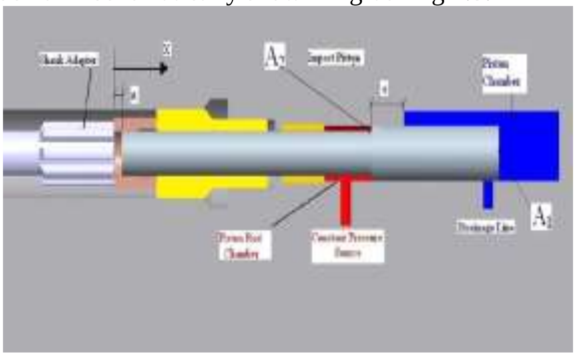


Fig 1.3: Valve less Rock Drill

The valve less rock drill mechanism consists of an impact piston, two chambers, piston chamber(rear side) area A1 and piston rod chamber (front side area A2), which are connected periodically with each other. Furthermore, piston rod chamber is permanently connected with the inlet constant pressure source p, whereas the piston chamber is connected with the drainage line periodically. After a blow, the piston is first accelerated by force F = pA2 to the position X = a. Next it continues to compress the fluid in the piston chamber. It is assumed that the pressure in the piston chamber increases linearly with the piston displacement X - a.

When the piston reaches the position X = a+s, the working fluid pressure p is suddenly connected to

When impact piston reaches its rear most position away from the drill steel, the pressure is above 200 bars. This high pressure fluctuation results in fatigue strength problems in the housing due to high pressurized large volume of oil. The other issue which needs to be taken into account is to achieve high efficiency of the rock drill. During the impact piston movement within rock drill, a certain volume of oil with a pressure of around 40 bars is drained off. The performance of this particular drill machine can be improved if some mechanism is proposed which could eliminate the strength problems along with no need of the relatively high pressure oil to be drained off. This could certainly lead to increased efficiency. The plot describes the waste of power occurs due to pressurized oil at pressure of p0 is drained off. The energy loss is the area enclosed by points A, D and E. In practice,

It can be as large as 30% of total useful energy.

A =effective area of piston in piston chamber

X = impact piston part of stroke length for which oil volume is drained off. The frequency of the rock drill is rather high and around 120 Hz.

2.0 LITERATURE REVIEW

Gunnar Wijk [1] discussed in his thesis – ‘‘devoted to problems, processes and systems related to the recently developed water powered percussive rock drilling method. The technology, which uses ordinary water to drive down-the-hole hammers, has been used to produce more than 6 million meters of blast holes within the mining industry. The method has several advantages such as low energy consumption, dust free environment and the capability to drill to virtually any depth. A natural disadvantage of this method is the need for relatively large amounts of preferably high quality water to drive the hammer tool, occasionally also leading to waste disposal problems’’.

Dae-ji Kim, Jaewon Kim, Changheon Song et al. [7,8] developed a pneumatic dynamic model of DTH hammer to predict drilling performance and validated the model through laboratory tests. The application of the DTH hammer in the vertical section of oil fields has shown that its penetration rate is several times that of conventional rotary drilling. However, many technical problems persist in using a DTH hammer for directional wells and horizontal wells, such as greater friction and rotary table driving difficulty. The gas screw cannot drive the air hammer due to a low-pressure drop and other issues, especially the issue that friction force consumes a tremendous amount of energy im parted to the drilling string. This often generates torsional vibration [5]. The authoritative publication *Air and Gas Drilling Manual* states that pneumatic DTH hammer has only been applied in vertical drilling.

Xinxin Zhang, Yong-jiang Luo, Li Fan, Ji-You Peng, K. Yin [9] designed a novel rotation air hammer and used the LS-DYNA program to analyze the impact dynamics problem of its piston and drill bit to obtain their stress change rule in the impact process. The present article introduces a novel DTH hammer and describes its working principle and design method. This hammer inherits the pneumatic hammer’s advantages, adequately utilizes the energy of the returning stroke of the piston, and achieves a self-propelled round of the bit [6].

Gunnar Wijk [3], In hammer theory and practice in order to study the elementary process of more or less worn insert penetration into a rock surface, designed the Stamp Test. In the Stamp Test a single flat-ended cylindrical tool is pressed against a sawed rock surface until fracture occurs. With a flat-ended tool rather distinct force, distinct penetration depth and distinct crater volume are obtained, whereas a spherical tool yields continuous increase of these quantities. The crater volume is, in principle, a measure of rock drill ability, with which drilling rate can be calculated, whereas the force and the penetration depth determine mass (or length) and impact velocity of the striker in the hammer that are required to produce such craters.

V. Klishin, V. Timonin, Di Kokoulin, S. Alekseev, B. Kubanychbek et al. [10] The fatigue life of the piston can be increased by changing the geometry and increasing the mass. In this study only the fatigue strength of piston accumulator for given geometry and mass is predicted. From this analysis it can be concluded that the higher fatigue life can be achieved for a piston accumulator with a light weight piston by using a smart shape of piston. For this shape optimization can be per 100 formed to find the optimum design of piston in the accumulator that can give high fatigue life by the reduction of stress concentration at critical points. Furthermore, the analysis performed by using a very conservative approach as no damping has been used as a material property. If an exact value of material damping is used in this analysis, better fatigue life can be achieved.

3.0 DESIGN AND ANALYSIS SOFTWARES

Altair Ansys is a high-performance finite element pre-processor to prepare even the largest models, starting from import of CAD geometry to exporting an analysis run for various disciplines. Importing the CAD model in the Preprocessing Software and meshing is done for the model and property and material is assigned to the model and Strength analysis for Piston and bit is carried out.

3.1.1 Introduction to CATIA

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite. CATIA competes in the high-end CAD/CAM/CAE market with Cero Elements/Pro and NX (Unigraphics).

The 3-D CAD system CATIA V5 was introduced in 1999 by Dassault Systems. Replacing CATIA V4, it represented a completely new design tool showing fundamental differences to its predecessor. The user interface, now featuring MS Windows layout, allows for the easy integration of common software packages such as MS Office, several graphic programs or SAPR3 products (depending on the IT environment).

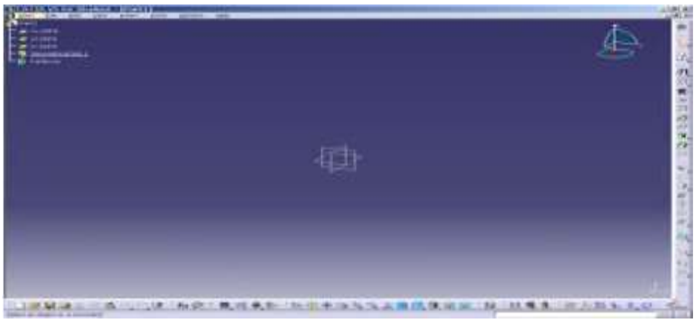
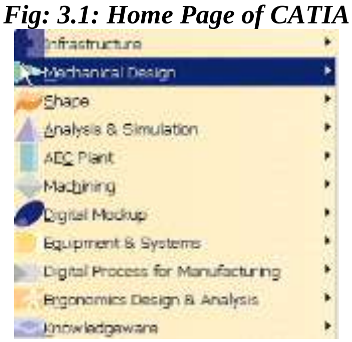


Fig: 3.1: Home Page of CATIA



The concept of CATIA V5 is to digitally include the Complete process of product development, comprising the First draft, the Design, the layout and at last the production and the assembly. The workbench Mechanical Design is to be addressed in the context of this CAE training course.

Vol 13, Issue 04, APRIL/2022
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Sets of workbenches can be composed according to the user's preferences. Therefore Dassault Systems offers three different software installation versions. The platform P1 contains the basic features and is used for training courses or when reduced functionality is needed. For process orientated work the platform P2 is the appropriate one. It enables, apart from the basic design features, analysis tools and production related functions. P3 comprises specific advanced scopes such as the implementation of external software packages.

3.2 Scope of Application

Commonly referred to as 3-D Product Lifecycle Management software suite, CATIA supports multiple stages of product development (CAx), from conceptualization, design (CAD), manufacturing (CAM), and engineering (CAE). CATIA facilitates collaborative engineering across disciplines, including surfacing & shape design, mechanical engineering, equipment and systems engineering.

CATIA provides a suite of surfacing, reverse engineering, and visualization solutions to create, modify, and validate complex innovative shapes. From subdivision, styling, and Class A surfaces to mechanical functional surfaces.

CATIA enables the creation of 3-D parts, from 3-D sketches, sheet metal, composites, and molded, forged or tooling parts up to the definition of mechanical assemblies. It provides tools to complete product definition, including functional tolerances, as well as kinematics definition.

CATIA facilitates the design of electronic, electrical as well as distributed systems such as fluid and HVAC systems, all the way to the production of documentation

4.0. MODELING OF HAMMER ASSEMBLY

4.1 Sketch Drawing of Master Hammer drill

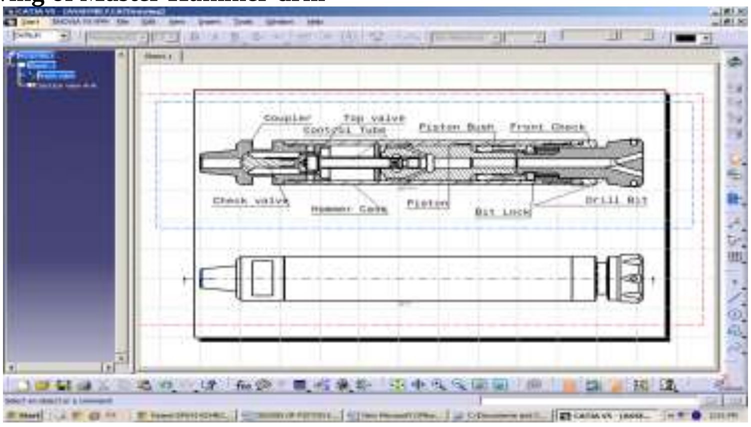


Fig: 4.1: 2-D figure of Master Hammer Drill

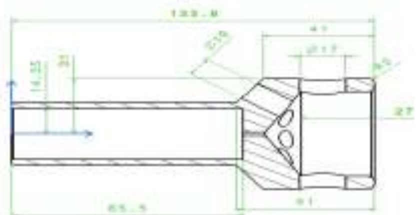


Fig: 4.2: 2-D Sketch of Top valve OF ROCK DRILL

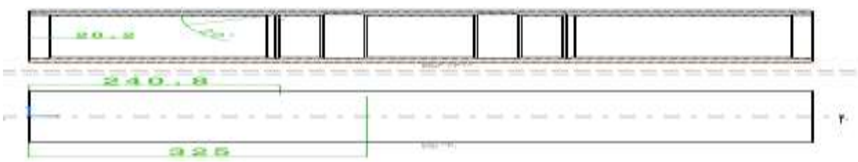


Fig: 4.3: 2-D Sketch of Hammer Case OF ROCK DRILL

Vol 13, Issue 04, APRIL/2022
ISSN NO:0377-9254

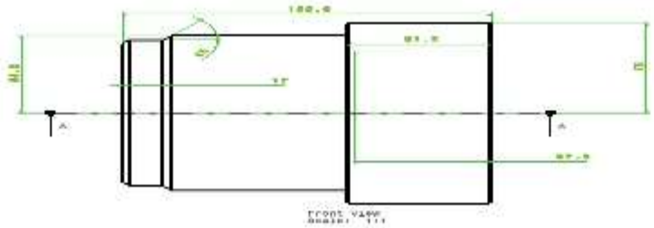


Fig: 4.4: 2-D Sketch of Front Chuck OF ROCK DRILL

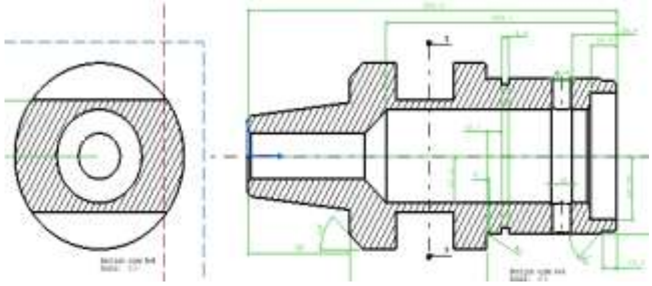


Fig: 4.5: 2-D Sketch of Coupler OF ROCK DRILL

Fig: 4.6: 2-D Sketch of Control Tube OF ROCK DRILL

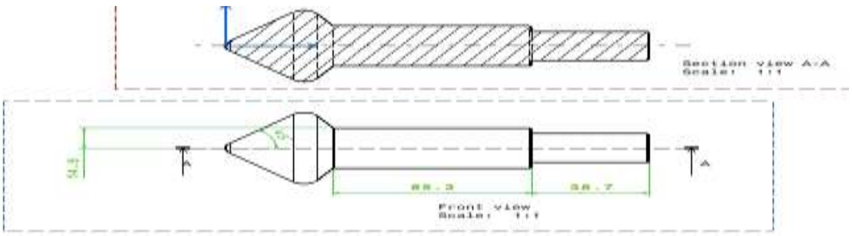


Fig: 4.7: 2-D Sketch of Check Valve of ROCK DRILL

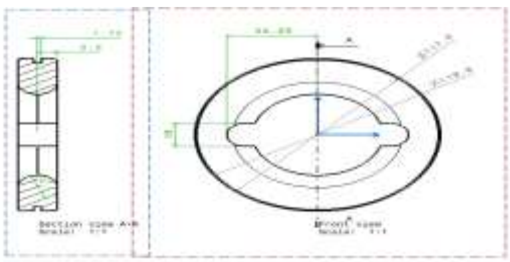
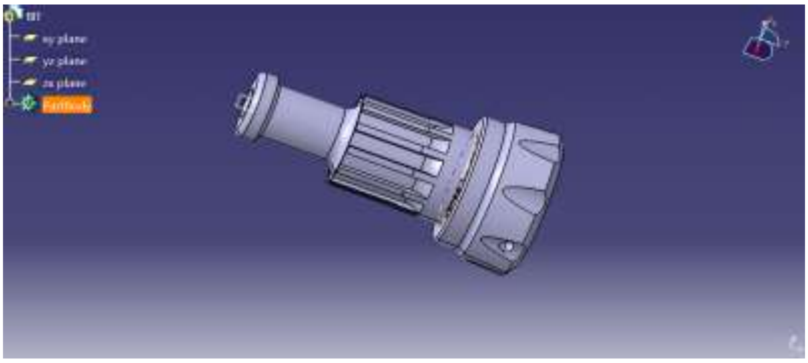


Fig: 4.8: 2-D Sketch of Bit Lock OF ROCK DRILL

4. 5 Modeling of Master Hammer Assembly in CATIA



5.0. RESULTS AND DISCUSSION

This study and analysis helped in analyzing the performance of valve less rock drill when it is allowed to operate with and without gas accumulators. In this thesis work, the following tasks are performed:

The design running drill bit and piston is considered for the finite element analysis using Altair Hyper works software. Here we need to do show the best and perfect design of drill bit and piston with application of high pressure load and low pressure load.
Aim of this project is to smoothen the work flow while drilling the ground. The drill bit should withstand the applied pressure load of high and low. A piston and drill bit has been modeled in CATIA and its characteristic behavior has been studied. In this modeling, all the important factors which have effect on the piston have been taken into account, such as mass, inertia of piston, friction in sliding contact between piston and cylinder and effective bulk modulus for oil, gas and mixture of oil and gas.
Firstly, the results of base design of Drill bit and Piston are not satisfied. Based on the results the design has been changed for both the components which are very important in rock drill machine.
Using CATIA software, design has been changed and analysis is carried out by the given loading conditions. Results are discussed in next chapter. Finally, by seeing the results of modified designs and base designs what design perfectly suit the requirement of strength of the design.

- **Results of Kinematics of Rock Drill**

Fig: 5.1: Starting Movement showing in shaded view and transparency view

The above figure explains about the multi body dynamics of complete assembly of rock drill machine. Multi body dynamics is nothing but seeing the simulation using the applied joints using Motion View software.

Fig: 5.2: Second Movement showing in shaded view and transparency view

Vol 13, Issue 04, APRIL/2022
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The first 5.1 shows first movement and the above figure 5.2 shows second movement while it is simulating.

5.2 Calculations of Reference Piston & Modified Piston Strength Analysis

5.2.1 Calculation of Reference (Base) Piston are shown below

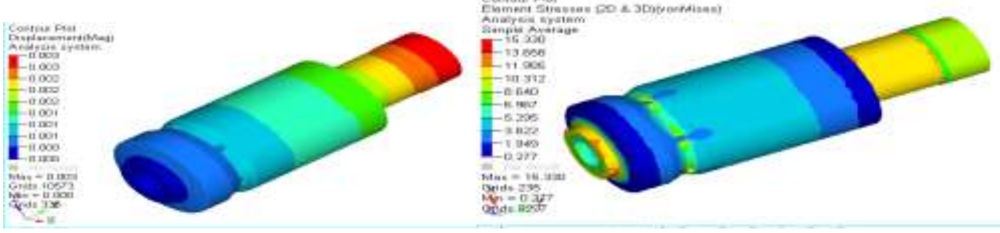

Fig: Displacement is 0.003 mm for applied 2.4 Mpa (Low Pressure)& Stress is 15.33 MPa for applied 10MPa pressure (High pressure)

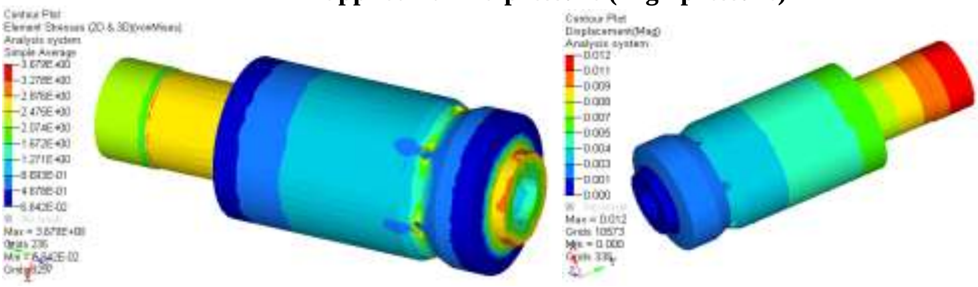

Fig: Stress is 3.679 Mpa for applied 2.4 Mpa (Low Pressure)Displacement is 0.012 mm for applied 10MPa pressure (High Pressure)

Stress is very less which beyond the yield value of Piston under small accumulator pressure and high pressure accumulator pressure.The design modification is required to reduce the stress and displacement, using experience knowledge on manufacturing requirement. The Piston Design is changed and rerun the strength analysis is carried and check the results comparison.

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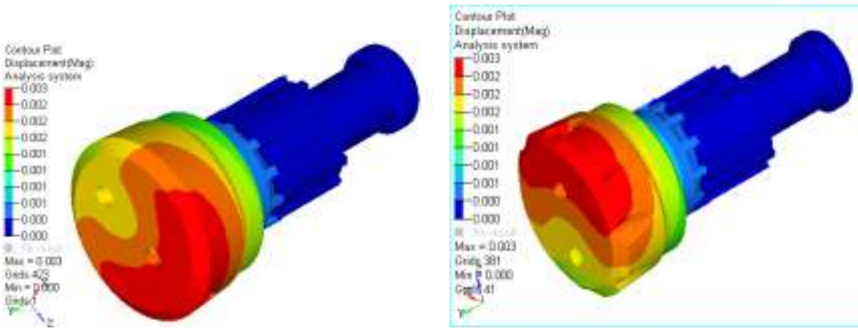
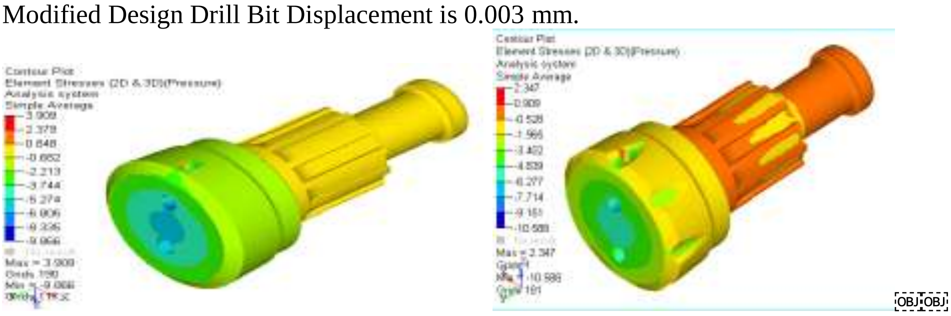


- **Base Design Drill Bit** **(b)Modified Design Drill Bit**

Fig: 5.23. Displacements of Drill Bits

- Base Design Drill Bit Displacement is 0.003 mm.
- Modified Design Drill Bit Displacement is 0.003 mm.



- **Base Design Drill Bit** **(b)Modified Design Drill Bit**

Fig: 5.23. Pressures of Drill Bits

- Base Design Drill Bit pressure is 3.909N/M2
- Pressure for Modified Design Drill Bit is 2.347N/M2

Rotation force is applied to the base drill bit and finding out rotational stress and rotational pressure while in motion. Pressure value for base design is 3.909N/M2 and minimum stress is -9.866 N/M2.

Rotation force is applied to the modified drill bit and finding out rotational stress and rotational pressure while in motion. Pressure value for modified design is 2.347 N/M2 and minimum stress is -10.588 N/M2.

- Base Design Pressure is 3.909N/M2 and stress is 17.805 MPa
- Modified design Pressure is 2.347 N/M2 and stress is 29.986 MPa.
- Displacement and stress is less compare to the yield point of base drill bit.

Modification is done to drill bit for smoother drilling, when it is drilling the ground, the sand should come outside smoothly which should not create any damage to the drill bit. For that purpose, the design has been changed from base to new design which is shown above. The results are also changing for both designs, comparing the stress and displacement. Rotational pressure to the surface is very less compare to the base design.

	Base Design Drill bit	**Modified Design Drill bit**
Stress	17.805 MPa	29.986 Mpa
Displacement	0.003 mm	0.003 mm
Pressure	3.909 N/M2	2.347 N/M2.

Comparison of Low Pressure and High Pressure Results for both Base and Modified Design Piston

	Base Design Piston Displacement	**Modified Design Piston Displacement**
Low Pressure	0.003 mm	0.002 mm
High Pressure	0.012 mm	0.008 mm

	Base Design Piston Stress	**Modified Design Piston Stress**
Low Pressure	3.6 Mpa	2.232 Mpa
High Pressure	15.330 Mpa	9.298 Mpa

CONCLUSION

This study helped in analyzing the performance of valve less rock drill when it is allowed to operate with and without gas accumulators. In this thesis work the following tasks are performed:

A piston and drill bit has been modeled and its characteristic behavior has been studied. In this modeling, all the important factors which have effect on the piston have been taken into account, such as mass , inertia of piston, friction in sliding contact between piston and cylinder and effective bulk modulus for oil, gas and mixture of oil and gas. As the piston is designed to work over high and low pressure loading.

- Displacement is reduced for modified piston design.
- For high accumulator pressure value and low pressure value the piston was analyzed and it is having more strength than the base design.
- Modified design of piston is suitable for industry requirements.
- Air pressure outlet is very less for modified design of drill bit.
- Yield point stress value for both the components are very less which is below the yield value.
- Pressure which is formed between drill bit and rock is eliminated through slots on drill bit and piston.
- Micro structural failures like surface lines also eliminated.

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