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Research paper

Design improvement and manufacturing of water down the hole hammer for bore drilling

Muhammad Sajjad [1], Dong Won Jung [2]*

[1,2] Department of Mechanical Engineering, Jeju National University, 1 Ara1 - Dong, Jeju-Si, Jeju, Republic of Korea
**Corresponding author E-mail: jdwcheju@jejunu.ac.kr*

Abstract

Drilling method is being used from centuries for creating holes in the field of mining and geological application. Due to this method we are able to get useful resources from earth, economically and with greater ease. Oil, gas, water and many kinds of minerals has been collected by using drilling to create boreholes in the ground. Drilling with liquid-driven down hole hammers is a new competitive method for production of boreholes. In water down-the-hole (DTH), water acts as a working fluid which transfer the energy from the piston to the hammer. There are certain parameters and by improving these we can increase the efficiency of bore drills. In our research study we are going to optimize the following, bore diameter, no of strikes and perforation speed by increasing the impact frequency of piston. The piston operates at 3102 beats per minute (51.7 Hz) which create pressure of 150 bar as a result impact energy of 1070.8 J is generated which transfer in the form of kinetic energy to the hammer. As a result of this energy output, we are able to achieve the diameter of perforation up to 1 m with penetrating speed of 1.6 m/h.

Keywords: *Borehole; Bore Diameter; Perforation Speed; Down the Hole (DTH).*

1. Introduction

In recent years, due to the demand of geothermal resources, the drilling method gains a lot of interest in the production part. Energy comes out from geothermal sources take much more important role as it is base load proven, being available 24 / 7, independent of weather and seasonal changes. However, in many places, the geothermal reservoirs tend to be found in deeper and harder geology than the typical hydrocarbon reservoirs till now. A similar useful resource like gas, oil and water are secured from the earth through drilling process. Thus, there is an increasing demand for the applied drilling industry to drill more efficiently into hard rock as being possible up to now, especially with the geothermal industry typically requiring a larger borehole diameter, meaning yet more energy and time required to making the hole. In order to improve the performance of drilling, many authors were conducted a numerous studies and the results were found to improve the performance of geological drilling process.

Air-flushed drilling with top hammers began in the mining industry in Sweden in 1873, while down-the-hole (DTH) drills, again with air flush (and activation) became operational in 1950. During that same time interval, Simon Ingersoll had patented the first steam-powered, top hammer rock drill to provide higher productivity in blast hole drilling. It is well known that water, as an activating flushing and cooling medium has many significant advantages over the use of air. However, it was not until 1973 that top hammer systems (either air or hydraulically activated) for larger rigs were adapted to the use of water flush, typically via “under the head” swivels. The concept of a water-powered, down-the-hammer (WDTH) had been explored prior to G. Drill acquiring the original patent from Atlas Copco in 1988. LKAB, a huge underground mining company owned by the Swedish Government and providing about 90% of the European Union’s iron ore, purchased G. Drill in 1991 and encouraged the commercial development of the WDTH. The first full-scale WDTH production works were carried out for LKAB in 1995, since when over 25 million lineal meters of drilling have been recorded in both underground and surface applications.

Water and mud-driven DTH rock drill hammers are today accepted and used as general-purpose drilling tools. Of the many advantages, the most important are cost-effectiveness and competitive performance. It also offers high penetration rates, low energy consumption, and the possibility to drill to virtually any depth [1]. Goran Tuomas, Bo Nordell objectives were to increase the knowledge, determine vital process parameters, and develop models, systems, and processes for water powered DTH hammer drilling. A new method to evaluate the ground’s thermal conductivity is suggested. The idea is to use energies released during ordinary rock drilling for determination of thermal conductivity data. The function of a 100 mm diameter hammer has been analyzed, modelled and simulated. For water DTH drilling method the drilling water has to be cleaned and re-circulated [2]. Later, he concluded in their research work that we can optimize and improve hammer functions as well as analyze other vital components like pressure accumulators, pressure relief valves, nozzles, etc. [3]. Bo Kun et al. used the simulation technology to assist the drilling tool design to optimum designed DTH hammer for stable performance and the bit has reverse circulation ability [4].

Dr. Donald A. Bruce, Rudy Lyon and Stefan Swartling, practice and describes the numerous steps which have been followed to make contemporary hammers especially efficient and cost effective [5]. Volker Wittig, Rolf Bracke and Yoon Hyun-Ick studied about hydraulic DTH Fluid / Mud Hammers with Recirculation Capabilities to improve rate of penetration and Hole Cleaning for Deep and Hard Rock Geothermal Drilling [6]. D. Vollmar, V. Wittig and R. Bracke find out in their study drilling recommendation for different rock sources e.g. limestones or quarzitic for better performance efficiency of drilling [7]. Nordlund [8] also developed models for simulation of the percussive drilling process and he later analyzed the effect of thrust on the performance of the drilling process.

Lundberg [9] analytically derived equations that describe the efficiency for different drilling systems. For DTH-drilling, he analyzed the energy transfer efficiency for when a uniform piston impacts a rigid drill bit, initially in contact with the rock, and assumed that the time between the impacts was long enough to fade out generated vibrations before the next impact occurred. A single piston blow could then be performed to analyses the drilling process. Lundberg later presented schemes, based on one-dimensional wave theory, to evaluate the efficiency for a single piston blow [10-12]. Here, the components were considered as straight bars made of linearly elastic materials with piecewise varying cross-section area, and the rock was modelled as an elastic-plastic material. Based on previous study we found out that water has been used for DTH drilling long time ago but their drilling time is more and its radius of drilling is comparatively small. Even in case of large diameter it required more time to finish the operation for same length. In our paper we are going to work on impact frequency and energy transfer by piston to maximize the efficiency of drilling operation.

In relation to pure rotary drilling, DTH drilling is faster, due to the more focused and intensified stresses imposed on the rock, and does not require sophisticated drilling mud preparation, handling and cleaning systems. Air-powered equipment has the obvious yet distinct advantage of exhausting energy-depleted air directly into the atmosphere, where the difference between rock and air density makes separation direct and simple. Air-powered DTH hammer consist of many parts as shown in Figure 1, these parts such as drill bit, piston, air distributer, air control valve, cylinder, back head and casing. In our research study we are going optimize bore diameter, no of strikes, perforation speed and many more. After optimization the diameter of perforation is up to 1 m with penetrating speed of 1.6 m/h. With 50 strikes per minute and maximum operation pressure of water will be 150 bar.

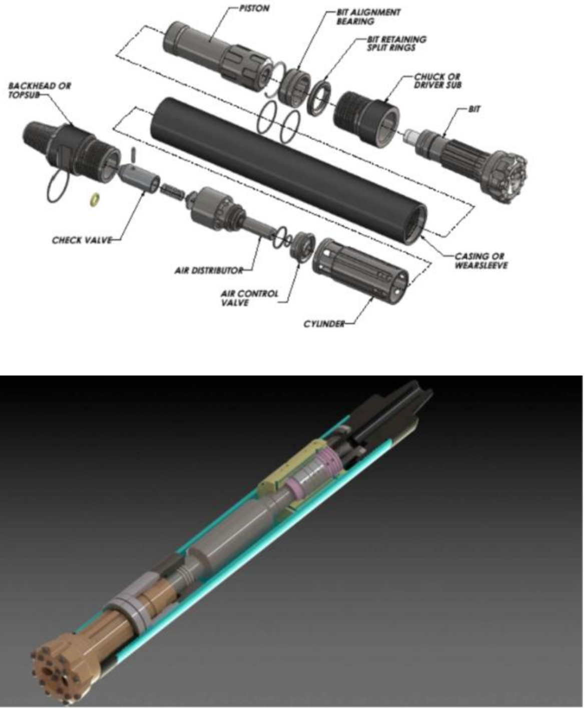

Fig. 1: Components of A Typical Air-Powered Down-the-Hole Hammer.

2. Working principle of water DTH hammer

Down-hole drilling is a method where the percussive hammer is positioned at the front of the hole during drilling, with energy supplied through the drill string in the form of pressurized fluid. The purpose of the hammer tool is thereby to convert a portion of this energy into mechanical impacts on the integrated drill bit. The actual rock fragmentation occurs at the high-pressurized contact zones between the buttons of the drill bit and the rock, as a result of the impact energy received from the piston. By rotating the drill bit and thereby creating new impact positions for the buttons, new rock will be fragmented and the penetration process continues. Fragmented rock is flushed away by the outlet water from the hammer flowing upwards to the ground surface on the outside of the drill string. This working principle for the down-hole hammer, are principally the same, regardless what type of drilling fluid that is being used. A complete water driven down-hole hammer system is similar to a system for the air-driven hammer. The main difference is that a high-pressure water pump, usually a plunger pump, replaces the air-compressor. Another important difference is that a water cleaning system is required, if the water has to be re-circulated for re-use in the system. This is caused by the strong relationship between the hammer life and the quality of the feed water. Some factors of importance for the life are the pH-value, hardness, corrosive properties, and the particle content in the water. A large number of hard particles in the driving water drastically reduces the life of an ordinary hammer. Wear in the moving parts causes increased internal leakage.

An example of this comes from the well-documented drilling data, belonging to the 100 mm down-hole hammer in the Wassara series. A new tool of this type needs about 190 cycle/min to achieve 18 MPa (180 bar) operating pressure, while a worn out still working hammer, requires the double flow rate at the same operating pressure. In addition, pure erosion effects can be seen in hammers as a result of heavily contaminated feed water. Hammers with higher quality and wear resistant materials are usually economically feasible when drilling with feed water containing large amounts of abrasive particles.

2.1. Principal comparison between water and air driven down-hole hammer

Major differences occur when water is used as drilling fluid in a down-hole hammer instead of air. This is the case even though the hammer-tool itself principally works the same way, regardless of what drilling fluid is used. Some of these principal differences are listed in the following notes [13];

1) Input power: Air-driven systems require significantly more energy at the same penetration rate. This is mainly caused by the high energy-losses in air-compressors.
2) Output power: The water-driven hammer gives about twice as high output power. The main reason is the high percussion rate (60 Hz).
3) Energy transfer: Transmitting energy by water-hydraulics can be extremely energy-efficient.
4) Penetration rate: Though the piston output power to the drill bit is much higher in the water driven hammer, the penetration rate is only slightly higher than air-driven tools with (150 bar) working pressure. Water damping and problems with flushing the hole, seem to be the explanation. Drill bits especially designed for the water hammer are being developed.
5) Deep drilling capability: The air-hammer has a limited drilling depth in water rich rock since the normally used air-pressure of 2.4 MPa (24 bar) corresponds to about 240 meters of water. No theoretical depth limit exists for the water-driven hammer and the tool has successfully performed work at 4300 meters depth.

6) Hammer cost: The hammer cost is higher for the water-driven tool because of more expensive materials, more hammer parts, and smaller manufacturing series.
7) Environment: The water hammer is much more environmentally friendly. Dust is eliminated and the atmosphere is oil free and without grease residues.
8) Water: Water is not always freely available. This motivates the use of a water cleaning system for recirculation and re-use of the water. Waste handling is thereby also achieved because of the de-watering of the drilling waste, which makes it more easily managed.
9) Drill pipes: The water hammer requires heavier drill pipes due to the higher operating pressure in the water driven hammer. The higher corrosive load from the water may also motivate the use of more corrosive resistant materials. Check valves are also recommended in some applications.
10) Erosion: Erosion of drill-pipes and hammer casing is significantly reduced when low-velocity water (0.5-1 m/s) is used for flushing, instead of air with recommended velocity between 15-30 m/s [13].

3. Designing of water DTH hammer

The structure of the WDTH Hammer is shown in Figure 2, components includes back head which is connected to the drill tube, valve which controls the reciprocating motion of the piston, valve housing that determines the flow path according to the position of the valve, a sliding tube that guides the reciprocating motion of piston's and a bit that protects the striking energy of the piston against the arm.

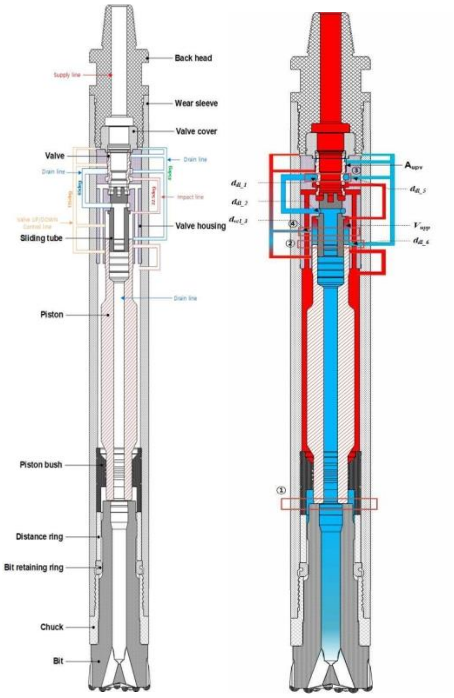

Fig. 2: Schematic Diagram of Water Powered DTH Hammer.

In Water DTH hammer Water has been used to transfer the kinetic energy from piston to the hammer and its physical properties are shown in table1.

Table 1: Physical Properties of Working Fluid

Fluid	Temperature [℃]	Kinematic viscosity [mm^2/sec]	density [kg/m^3]	Viscosity [Pa-sec]
Water	20	1.0105	998	0.00101

3.1. Valve modelling

WDTH Hammer Parts that move back and forth with reciprocating motion of pistons flow of fluid is controlled through valves depending on the position of the piston, as the flow path of the valve housing changes depending on the position of the piston. The flow paths of these valve housings are complex Euro shapes in the three-dimensional model as shown in Figure 3.

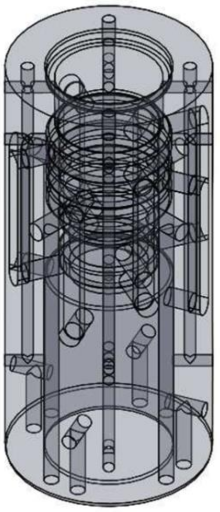

Fig. 3: Valve Housing 3D Model.

The flow paths are divided according to the section angle of the WDTH Hammer, but each flow path can be arranged by four major functions.

1) Supply line: Water pressure is supplied to the piston and valve by the line receiving water from the drill tube connected to the back head.
2) Valve control line: The flow path that causes the valve to rise and fall due to the change in position of the piston.
3) Impact line: When the piston reaches the upper dead point, it is the line that injects the high-pressure water of the supply line into the piston to apply the force of the blow to the piston.
4) Drain line: Drain water outward through valve housing, piston and drill bit into sliding tube line to discharge high pressure water from piston and valve.

In DTH hammer the engine converted fluid energy to mechanical energy, while relief valves control the pressure of the system. Stroke volume is the pump's discharge amount represented by volumetric displacement and rated speed of the pump, and this relationship is as follows:

$$Q_p = D_p.\omega_p$$

Here, Qp is the discharge flow rate of the pump, Dp is the administrative volume of the pump, and Wp is the rotational speed of the pump. The relief valve serves as a safety and output adjustment for the hydraulic unit by limiting the formation of pressure above the set pressure within the hydraulic circuit, and the relief valve may be indicated as follows.

$$\frac{(Ps - Pcracking)}{(Psetp - Pcracking)}$$

$$Q_r = Q_{setp} \text{ If, } P_{cracking} < P_s < P_{setp}$$

$$Q_r = 0 \text{ If, } P_{cracking} > Ps$$

Qr Flow rate, which is a relief valve discharge to the reservoir via the line, here Qr and Pcracking is a relief valve discharge to the tank to begin cracking (setting pressure). Relief valve Pressure Pstep is the step pressure, Ps is line pressure of inlet side.

Table 2: Specifications of the Water Pump and Relief Valve

Components	Parameters	Value	Unit

Pump	rated speed	1000	Rpm
	displacement	250	Cc/rev
	efficiency	95	%
Relief valve	relief valve cracking pressure (setting pressure)	150	bar
	gradient (flow/pressure)	50	Ipm/bar

The valve model constructed by entering detailed parameters as shown in Figure 4 through the relationship between the hydraulic area and the flow path in which the fluid acts.

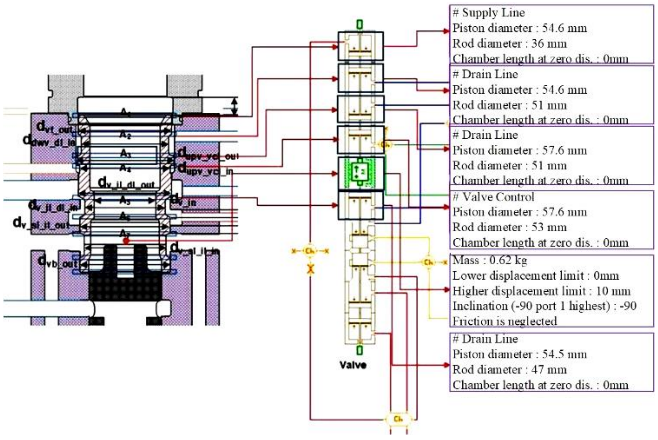

Fig. 4: Value Model with Parts Specifications.

The geometries and mesh models of the valves were conducted in Ansys to perform mesh, a type of ANSYS mesh set the average length of the element to 0.005 m and the number of nodes is 20,690 and the number of elements is 11,690. At this point, the support condition of the valve was fixed with a plane tangential to the valve housing by gravity.

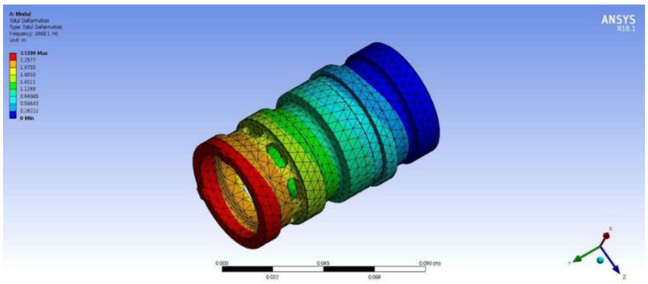

Fig. 5: Numerical Results of Valve Model (Deformation).

The modal analysis of the valve showed that the primary mode was generated at 3865 Hz, and there was zero change due to the blow. Complete simulation results are shown in the next chapter (Experiment results).

3.2. Piston modelling

After the geometries of the pistons were brought into Ansys to the mesh model was constructed. The piston mesh was selected by the ANSYS mesh type Sizing and the average length of element was entered to perform simulation. The average length of the element was 0.01 m, and the number of nodes was 35,675 and 22,935 Element were configured shown in figure 6.

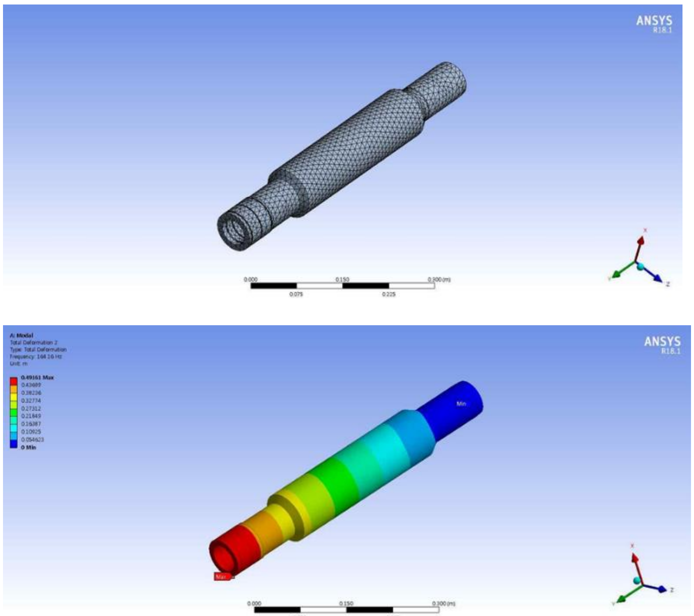

Fig. 6: Ansys Mech and Result Model of Piston.

In order to get the natural frequency of the model, the fixed boundary condition is applied to one end of the piston and another end is free from the external load. The modal analysis results are displayed, and the primary and secondary modes of the piston are occurred at 52 Hz and 164.16 Hz, respectively.

4. Experiment results

By looking at the piston and valve behavior of WDTH Hammer, we can see that the maximum displacement of the Peace Tone is 54 mm and the valve is 10 mm. In addition, for piston strikes, the maximum speed is 11 m/s, and the impact energy is derived from the formula below to 1070 J, and it is necessary to verify that it is consistent with the design figures.

$$E = \frac{1}{2} m_p \upsilon^2 = 0.5 \times 17.7\ \mathrm{kg} \times 11\ \mathrm{m}^2/\mathrm{s} = 1070.8\mathrm{j}$$

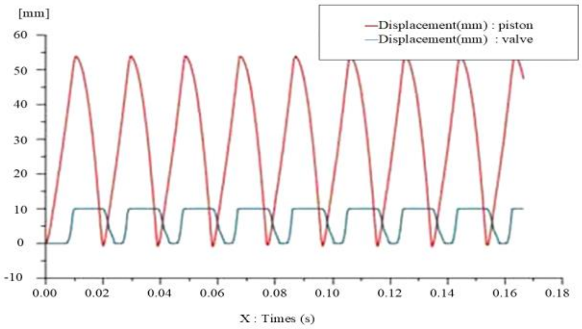

Fig. 7: Simulation Results of Piston and Valve's Displacement.

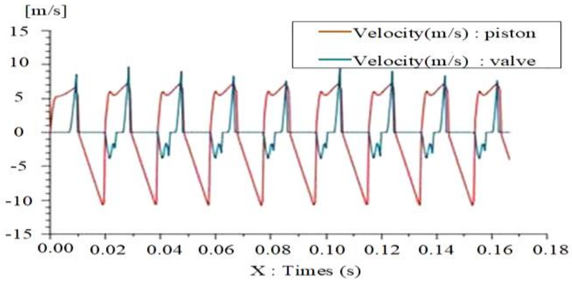

Fig. 8: Simulation Results of Piston and Valve's Velocity.

The pressure change for each flow path of the WDTH Hammer is shown in Figure 9 and can be verified by the impact that the pressure of the impact line and the pressure of the valve control line fluctuates. In particular, the pressure changes in the valve control line in detail as shown in Figure 10, the pressure rises and releases at 0.08sec. Which is caused by the reaction force from the drill bit to the piston, caused by the fluid flow of the valve control line and the fluid. It is deemed necessary to extend the drain line of the valve housing as a way to resolve this.

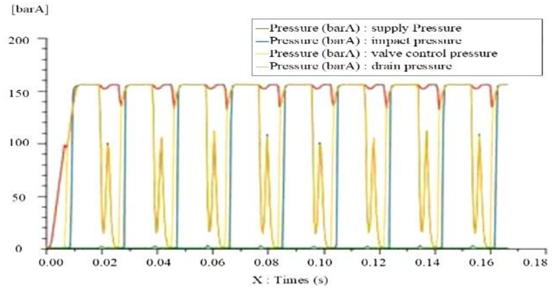

Fig. 9: Simulation Results of Each Chambers' Pressure.

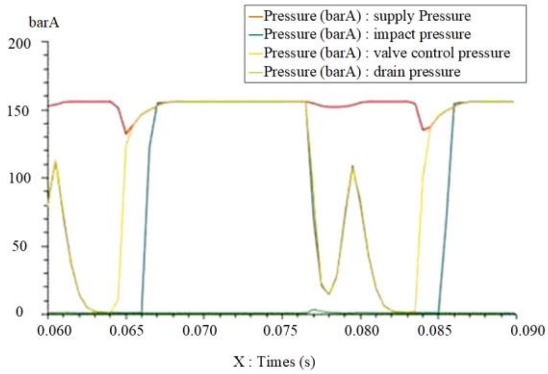

Fig. 10: Detail View of Each Chambers' Pressure.

To support this analysis, the pressure change on the displacement of the piston is shown in Figure 11, and as the piston displacement rises, the pressure is shown to rise and release.

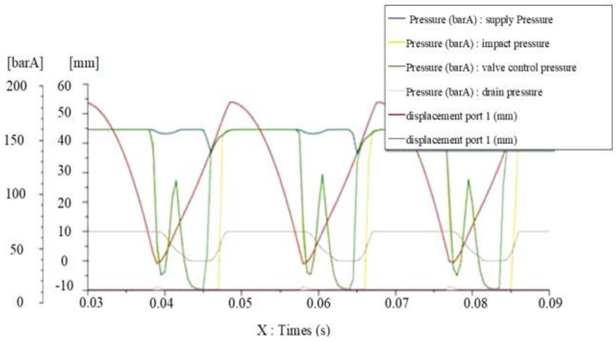

Fig. 11: Simulation Results of Piston and Valve's Displacement with Each Chamber's Pressure.

The number of blows due to the displacement of the piston can be represented as shown in Figure 12 and a result of 3102bpm (Beat Per Minute: Is the back and forth movement of hammer in one minute) was obtained at 51.7 Hz during the impact. This can be determined from the effects of rebound force due to hitting of steel plates, and it is thought that it will be necessary to analyse strike numbers under various rock conditions to verify the more precise strike numbers.

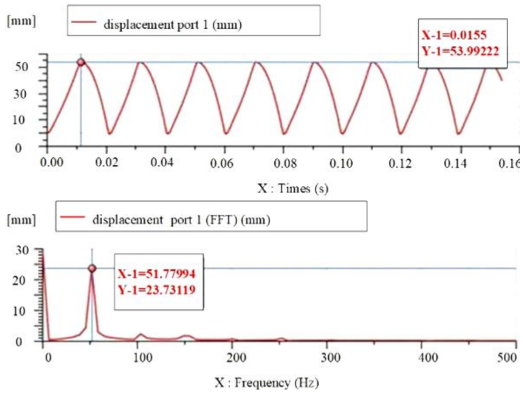

Fig. 12: Simulation Results of Impact Frequency.

5. Conclusion

The technique of using water instead of air as an energy carrier in down-the-hole (DTH) drill hammers has been known for years in the mining and geotechnical industry. Recent technical developments in terms of tooling and drilling fluid circulation systems enables the utilization of this drilling method for medium deep geothermal energy applications. The main task of the water-powered DTH hammer tool is to convert the potential energy of pressurized water into an oscillating piston movement. By mechanical impact the kinetic energy of the piston is transferred to the bit and finally into the rock. By rotating the bit, thereby creating new impact positions for the bit buttons, the rock can be fragmented and the fast penetration process can be achieved. The cuttings are flushed to the outside of the drill string by outlet water from the hammer up to the ground surface along the annulus of the borehole. Moreover, the water-powered DTH hammer has some principal advantages as it gives about double the output power achieved with air-driven hammers. The main reason is the high percussion rate, resulting in a penetration rate which is two times higher than air-driven tools. From overall outcome, it was found that the piston can generate impact energy of 1070.8 J and as a result, we are able to achieve the diameter of perforation up to 1 m with penetrating speed of 1.6 m/h.

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