

Investigation of Drilling Performance in Core Bit Drilling using passive-Vibration Assisted Rotary Drilling (p-VARD) Technology



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ABSTRACT

Diamond core drilling is the primary means of exploration drilling for mineral deposits and in Canada is stipulated to the meet legislative requirements for mineral deposit evaluation. However, it is the slowest and thus most expensive form of drilling in the mineral industry, and economic analysis has shown that increase in drilling Rate of Penetration (ROP) can have a significant impact on drilling costs and overall levels of exploration. The passive-Vibration Assisted Rotary Drilling (p-VARD) technology was developed to improve the ROP for drilling with the roller cone and PDC drill bits used in the oil and gas industry, and the purpose of this investigation was to evaluate the potential for p-VARD to improve ROP for natural diamond coring bit. In the Drilling Technology Laboratory (DTL) of Memorial University of Newfoundland (MUN), a small drilling simulator (SDS) was used at this stage of experiments using 26 mm diameter coring bit drilled into a 154.54 MPa hard rock material. Drill-off tests were conducted by applying a series of weight-on-bit (WOB) and evaluating the drilling ROP at various p-VARD tool configurations and comparing these with drilling without the p-VARD technology. Rate-of-penetration (ROP) was well correlated with WOB and drill string compliance. From results, the increase of ROP was observed using two p-VARD configurations, with a maximum increase of 28% from one p-VARD configuration compared to drilling without p-VARD. This study demonstrates the potential of decreasing the time for core drilling in hard rock using p-VARD technology.

Résumé

Le forage au diamant est le principal moyen de forage d'exploration pour les gisements minéraux. Au Canada, il est stipulé de respecter les exigences législatives en matière d'évaluation des gisements minéraux. Cependant, il s'agit de la forme de forage la plus lente et donc la plus chère de l'industrie minière, et une analyse économique a montré que l'augmentation de la vitesse de pénétration du forage peut avoir un impact significatif sur les coûts de forage et les niveaux globaux d'exploration. La technologie de forage rotatif assisté par vibration passive (p-VARD) a été développée pour améliorer le ROP pour le forage avec le trépan conique et les forets PDC utilisés dans l'industrie du pétrole et du gaz. Le but de cette enquête était d'évaluer le potentiel de -VARD améliorera la POR pour le foret diamant naturel. Dans le Drilling Technology Laboratory (DTL) de l'Université Memorial de Terre-Neuve (MUN), un petit simulateur de forage (SDS) a été utilisé à ce stade des expériences en utilisant un foret de 26 mm de diamètre foré dans un matériau de roche dure de 154,54 MPa. Les tests de forage ont été réalisés en appliquant une série de poids sur l'outil (WOB), en évaluant la POR de forage pour diverses configurations d'outils p-VARD et en les comparant à un forage sans technologie p-VARD. Le taux de pénétration était bien corrélé avec la conformité WOB et de la colonne de forage. D'après les résultats, l'augmentation de ROP a été observée avec deux configurations de p-VARD, avec une augmentation maximale de 28% d'une configuration de p-VARD par rapport à un forage sans p-VARD. Cette étude démontre le potentiel de réduction du temps de carottage dans les roches dures utilisant la technologie p-VARD.

1 INTRODUCTION

Drilling activities are associated to the lower rate of penetration (ROP) at depth. In any case, the similar rock can be drilled with higher ROP under atmospheric circumstance. The most important distinction among drilling situations at surface and depth is the stresses performing at the rock, which embody the pore pressure, borehole pressure and the geostatic overburden pressure. Cunningham and Eenink. (1959) investigated the effect of the stresses on drilling response (Khorshidian et al. 2014). The Drilling Technology Laboratory (DTL) of Memorial University of Newfoundland (MUN) introduces the technology that provides higher penetration rates and greater monetary value within the manner of drilling by analyzing Vibration Assisted Rotary Drilling (VARD). During the drilling process, vibrations are typically undesirable and exertions are done to mitigate

them. There are three types of vibrations exemplary; axial vibration, torsional vibration and lateral vibration that are linked to whirl, stick-slip and non-uniform dynamic loading, which causes damage to bits and down-hole equipment (Rana et al. 2015). Institute of Technical Mechanics, National Academy of Sciences of Ukraine experimented devices that work on the principle of excavation which resulted in two to three times of increase in ROP (Pilipenko et al. 2005). Al Ali et al. (2011) studied an Axial Oscillation Generator tool (AGT) which was observed significantly reduces of stick-slip. Forster (2011) developed a small-scale vibration test-rig to simulate stick-slip and study stick slip reduction methods which effects in an enhancement in ROP and better Mechanical Specific Energy (MSE). Using a coring bit, Li et al. (2010) experimental results showed that the combined effect of vibrations and rotation increases the rate of penetration. Babatunde et al. (2011) investigated the influence of vibration

frequency on penetration rates using natural diamond drag bits that consequence the VARD improved the penetration rates. To further study the effect of vibrations on drilling performance, a lab scale p-VARD tool was designed and tested. Rana et al. (2015) used the SDS setup using p-VARD tool to enhance the drilling ROP approximately 50% for fine-grained concrete sample using Poly-crystalline Diamond Compact (PDC) drill bits by modulating the rock-bit interactions.

In this paper, the p-VARD technology is incorporated into drilling tests using a coring bit aiming to study the drilling performance or ROP on hard rock drilling.

2 EXPERIMENTAL EQUIPMENT AND PROCEDURE

2.1 Drill-off Tests

Drill-off tests (DOT) are the drilling experiments where drilling parameters are systematically varied and the impact on ROP is measured (Xiao et al. 2018). Figure 1 shows the setup for DOT using a laboratory drilling setup, i.e. small drilling simulator (SDS) which was used by previous researchers and described in detail by Khorshidian et al. (2014). A suspended weight is applied through a wheel which transmits the torque to drive the rig top move down. In this way, a weight on bit (WOB) is obtained and applied on the drill bit which makes the drilling penetration process possible. Drilling parameters include WOB, rotary speed, rock strength, bit type, flow rate, and drill string compliance, p-VARD tool etc. Generally, drilling parameters are confirmed during this drilling process except WOB. A series of WOB is solely applied which correspondingly lead to a series of ROP. The "Perfect-Cleaning Theory" describes this relationship between ROP and WOB, rotary speed and rock strength for roller cone bit (Maurer. 1962). A maximum ROP is then found as the "founder point", which describes the best drilling performance under the specific conditions.

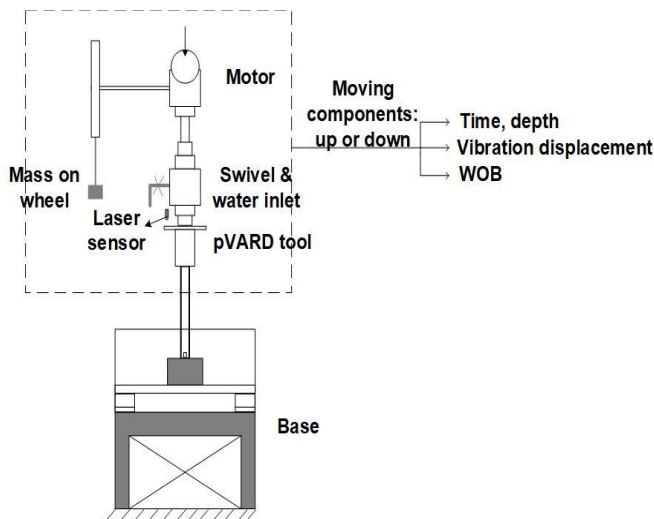


Figure 1. Schematic of the SDS with p-VARD tool

In this experiment, a 26 mm Outside Diameter of coring bit is utilized. Rotary speed is set at 300 revolutions per minute

(RPM). Drilling parameters and the process are also shown in

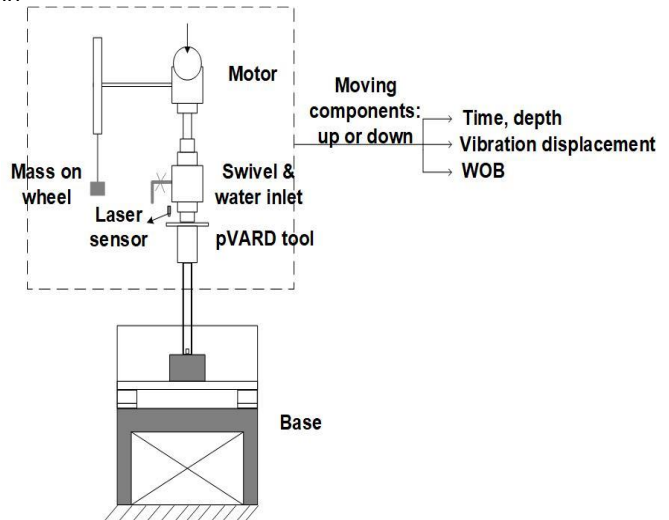


Figure 1.

2.2 Drill String Compliance

The p-VARD tool has been schemed that turns to advantages of the bit-rock interactions and creates axial vibrations, providing full rotary speed and torque to the drill-bit. The tool has been designed to be continuously functioning above the drill bit. It has three segments; a compliant segment, a dampening segment, and a torque transmitting unit (Rana et al, 2015). The compliance of the tool can be modified for various measurements.



Figure 2. Configurations of the Belleville spring setting in the p-VARD tool, with 8 sets of single parallel soft springs (left), 8 sets of single parallel stiffer springs (middle) and 4 sets of double parallel stiffer springs (right).

For this experiment, three configurations of p-VARD have been exercising including SinSoft, SinStiff and DouStiff that are given in Figure 2.

Table 1. Details of spring configurations

p-VARD configurations	Details	Stiffness (N/mm)
SinSoft	Single Soft-8 Springs+ 2 SPACERS	278.4
SinStiff	Single Stiff-8 Springs+ 2 SPACERS	840.7
DouStiff	Double Stiff-8 Springs+ 3 SPACERS	2438.6

Table 1 shows the details of three p-VARD settings. There are two types of Belleville springs: “soft” and “stiff”, which indicate one is stronger to the other. For the SinSoft configuration there are eight single-soft springs with two spacers. Similarly, SinStiff and DouStiff configurations are eight single-stiff springs with two spacers and eight double-stiff springs with three spacers, respectively. In every test, the p-VARD springs were lubricated with hydraulic oil decrease the friction effect. From the load-deflection tests under a loading machine, the stiffness of these configurations is respectively 278.4, 840.7 and 2438.6 N/mm.

2.3 Rock Specimen

A granite block specimen with dimensions of 304.8 mm (12 inches) x 304.8 mm (12 inches) x 203.2 mm (8 inches) was used, as shown in Figure 3, to conduct DOT aiming to investigate the effective functionality of p-VARD tool. The Unconfined Compressive Strength (UCS) of this granite was obtained at 154.54 MPa from a standard strength test, following an ASTM standard (ASTM D7012-14).

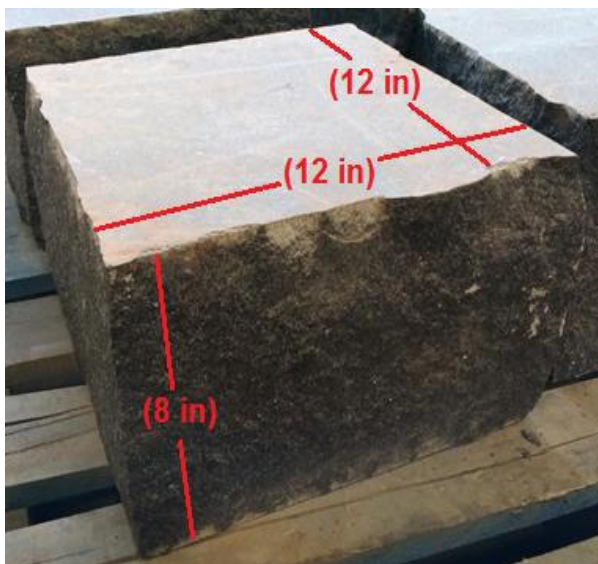


Figure 3. Granite block specimen (12 x 12 x 8 inches)

2.4 Pump off Tests

To figure out the parameters for DOT, the flow rate has to be determined. Generally, a Pump off Test (POT) is used to study the ROP with respect to flow rate. The optimized flow rate would produce the maximum ROP. In DTL, POTs have been performed at a series of incremental flow rates with the drill string have varying compliance (i.e. Rigid and soft p-VARD configurations). Figure 4 shows the assembly of POT test results. The optimized flow rate is taken an average of 18.31 L/min for various drilling conditions.

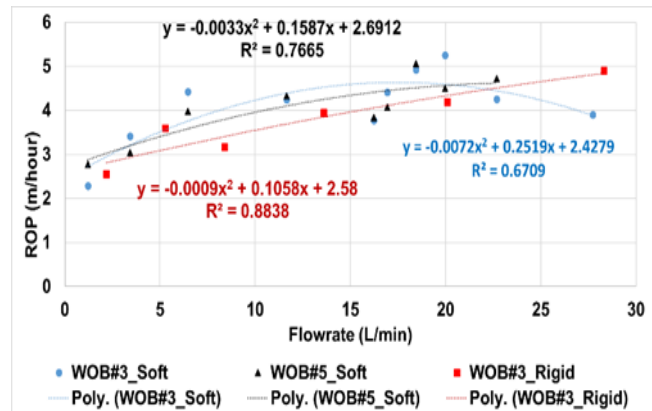


Figure 4. POT curves using different WOBs

3. RESULTS AND DISCUSSIONS

3.1 Data Acquisition and Processing

There are four types of DOT with four different drill string compliance, i.e. rigid, SinSoft, SinStiff and DouStiff. For all tests, tap water is used with a constant flow rate of ~18.31 L/min and the rated rotary speed is set at 300 RPM. For each type of DOT, a series of incremental WOB are used. The test matrix is listed in Table 2.

Figure 5 (top) provides sample data of a single DOT. Note that the bit depth is recorded versus time and the linear trend can be obtained with the slope as ROP. A laser sensor was used to detect and precisely record the relative motion of SDS and the drill string. For each revolution, six peaks of signal were recorded which corresponded to six machined grooves. The rotary speed then can be calculated by picking the time difference for specific revolutions. For example, Figure 5 (bottom) shows the laser sensor recordings of displacement peaks and two pulses at the same groove are picked for one revolution. Due to the difference in rotary speed for different runs of DOT, a normalized ROP is then obtained for the 300 RPM condition.

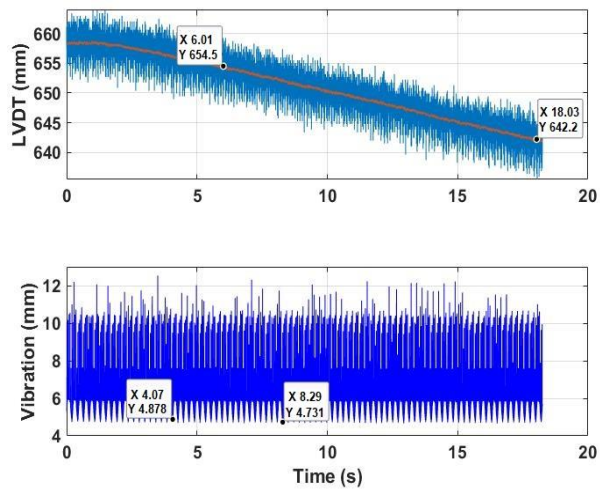


Figure 5. Demonstration of DOT data: bit depth versus time (top) and drill string displacement (bottom)

Table 2. Matrix for DOTs

Drill string setting	WOB (KN)	ROP (m/hr)	Rotary speed (RPM)	Normalized ROP (m/hr)
Rigid	0.842	2.99	288	3.11
	1.007	3.70	286	3.88
	1.172	3.32	279	3.57
	1.337	3.20	277	3.47
	1.502	3.52	272	3.88
	1.667	3.42	264	3.89
	1.832	3.41	264	3.87
	1.997	4.03	263	4.59
	2.162	3.94	259	4.57
	2.327	3.50	252	4.17
SinSoft	0.842	3.68	284	3.89
	1.007	4.63	282	4.93
	1.172	4.25	277	4.61
	1.502	4.57	269	5.10
	1.832	3.99	263	4.55
	1.997	4.18	263	4.77
	2.162	4.42	259	5.12
	2.237	3.59	259	4.17
SinSoft later	0.842	2.97	288	3.09
	1.172	4.01	281	4.29
	1.502	4.85	279	5.23
	1.832	5.31	272	5.85
	2.162	4.67	268	5.24

SinStiff	0.842	2.97	289	3.08
	1.007	3.73	285	3.93
	1.172	4.72	282	5.01
	1.337	4.84	277	5.25
	1.502	4.22	275	4.61
	1.667	3.81	270	4.24
	1.832	3.65	264	4.15
	1.997	3.59	261	4.13
	2.162	3.80	257	4.43
	2.327	5.01	257	5.84
DouStiff	0.842	2.99	287	3.13
	1.007	2.96	285	3.13
	1.172	3.67	276	3.98
	1.337	3.90	273	4.29
	1.667	3.54	269	3.95
	1.832	3.45	266	3.89
	1.997	3.54	263	4.04
	2.162	3.17	259	3.67
	2.327	3.40	260	3.92

3.2 Results

Figure 6 demonstrates the processed date in Table 2.

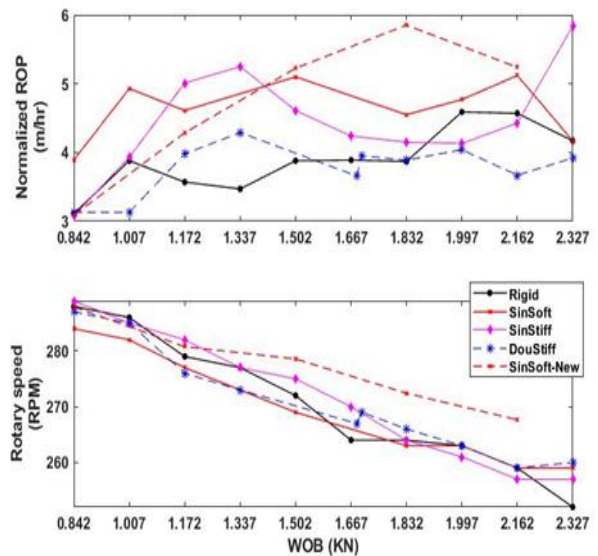


Figure 6. ROP versus WOB for various compliance settings

For rigid drilling, ROP generally increases with increasing WOB which complies with the Perfect-Cleaning Theory. The DouStiff provide no visual improvement on ROP. In the case of SinSoft configuration, the highest ROP is obtained compared to other configurations. A founder point is observed at high WOB. A 28% increase is obtained

compared to rigid or conventional drilling. This indicates that the SinSoft of lowest stiffness works the best on hard rock drilling. The ROP from the SinStiff setting ranks in the middle compared to rigid and SinSoft situations. Finally, it is concluded that the ROP for p-VARD is found to be higher than the traditional drilling methods.

4. CONCLUSIONS

Drill string with different compliance has been achieved by using the p-VARD technology. The p-VARD technology is studied on drilling hard rock and results are novel compared to previously conducted experiments on soft rocks. A lower stiffness of drill string causes the highest ROP regarding drilling performance on hard rock drilling. This was contrary to what was found for soft rock.

5. REFERENCES

- Al Ali, A., Barton, S. and Mohanna, A., 2011. Unique Axial Oscillation Tool Enhances Performance of Directional Tools in Extended Reach Applications, Brasil Offshore Conference and Exhibition, Society of Petroleum Engineers, Macae, Brasil. June 14-17.
- ASTM D7012-14. Standard test method for compressive strength and elastic moduli of intact rock core specimens under varying states of stress and temperatures. West Conshohocken, PA: ASTM International; 2014.
- Babatunde, Y., Butt, S., Molgaard, J., & Arvani, F, 2011, Investigation of the Effects of Vibration Frequency on Rotary Drilling Penetration Rate Using Diamond Drag Bit, 45th US Rock Mechanics/Geo Mechanics symposium, San Francisco, CA, June 26-29.
- Cunningham, R. A., and J. G. Eenink., 1959. Laboratory Study of Effect of Overburden Formation and Mud Column Pressures on Drilling Rate of Permeable Formations. Petroleum Transaction AIME, (217), 9-17.
- Forster, L., 2011, Axial excitation as a means of stick-slip mitigation - small scale rig testing and full scale field testing, SPE/IADC 139830, SPE/IADC Drilling Conference and Exhibition, Amsterdam, Netherlands, March 1-3.
- Khorshidian, H. Butt. S. D. and Arvani. F., 2014. Influence of High Velocity Jet on Drilling Performance of PDC Bit under Pressurized Condition. 48th US Rock Mechanics / Geomechanics Symposium, Minneapolis, MN, USA ,June 1-4.
- Li, H, S. Butt, K. Munaswamy and Farid Arvani, 2010. Experimental investigation of bit vibrations on rotarydrilling penetration rate. 44th US Rock Mechanics Symposium and 5th US-Canada Rock.
- Maurer, W.C., 1962. The "Perfect -Cleaning" Theory of Rotary Drilling. Society of Petroleum Engineers, 37th Annual Fall Meeting of SPE, Los Angeles, Calif, October, 7-10.
- Pilipenko V. V, I. K. Man'ko, S. I. Dolgopoloy and O. D. Nikolayey, 2005, Characteristics of a high frequency cavitation hydrovibrator for setting up dynamic loads on the rock cutting tool of a drilling assembly, Naukoyy Vistnyk NDU, No 1, Dnepropetrovsk, National Mining University Publishers, pp 66-70.
- Rana, P.S. Abugharara., A.N ,Molgaard,J and Butt. S. D., 2015. Influence of High Velocity Jet on Drilling Performance of PDC Bit under Pressurized Condition. 49th US Rock Mechanics / Geomechanics Symposium, San Francisc, USA ,June 28-July 1.
- Xiao, Y., Hurich, C. and Butt, S.D., 2018. Assessment of rock-bit interaction and drilling performance using elastic waves propagated by the drilling system. International Journal of Rock Mechanics and Mining Sciences, 105, pp.11-21.