CHAPTER 3

UPGRADATION OF LABORATORY DRILLING SETUP

3.1 Introduction

A laboratory scale rotary rock drilling setup was fabricated in the Department of Mining Engineering, IIT (BHU) during my M.Tech. dissertation project. It consisted of the basic components of drilling machine without much sophistication for measurement facilities [Rawal et al. 2014].

To accomplish the desired objectives of the present research work with high accuracy and wide variation in parameters, the same drilling setup was refurbished and upgraded for measurement of the parameters with precision. A picture and a schematic line diagram are shown in Fig. 3.1 and Fig. 3.2 respectively for the upgraded version of the drilling machine.

Fig. 3.1: A Picture of Laboratory Drilling Setup

Arrows in Fig. 3.2 represents the direction of the fluid flow from the fluid tank (**z**) to waste collecting tank **(a**) via drill bit (**f**). Description of the various components as tagged in Fig. 3.2 (left to right) is presented in Table 3.1.

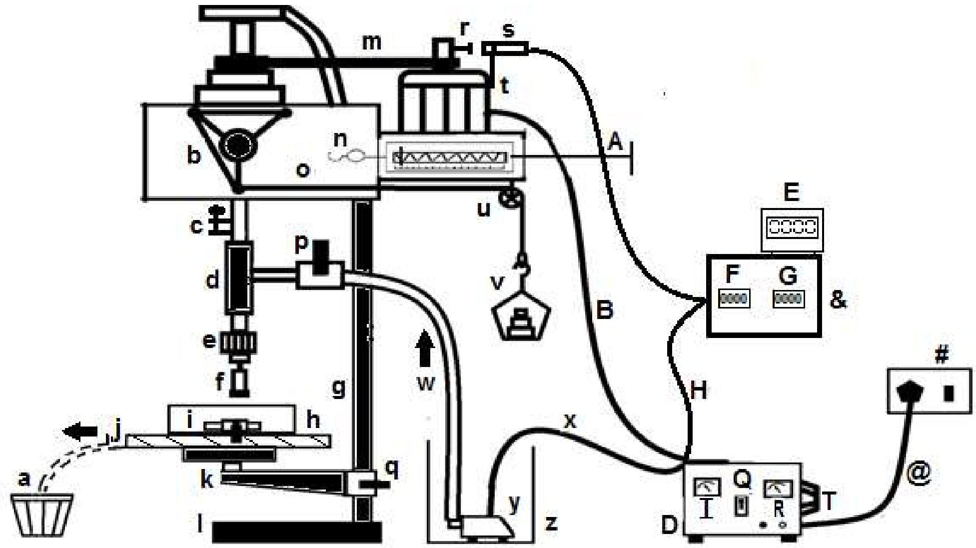

Fig. 3.2: A Schematic Diagram of Upgraded Laboratory Drilling Setup

Table 3.1: Description of tagged parts in figure 4.2 (left to right)

a:	Waste collecting tank	n:	Spring load	B:	Motor power supply
b:	Handle	o:	wire rope	D:	Control unit
c:	Depth limiting assembly	p:	Fluid flow rate adjuster	E:	Energy meter
d:	Fluid injection mechanism	q:	Sample plate height adjuster handle	F:	Watt meter
e:	Bit holder & drill spindle	r:	Metal bar	G:	RPM meter
f:	Diamond core bit	s:	RPM sensor	H:	Read-out unit power supply
g:	Main pillar	t:	Drill motor	I:	Volt meter
h:	Drilling platform	u:	Pulley	Q:	Miniature circuit breaker
i:	Jaw plate	v:	Weight bucket	R:	Ampere meter
j:	Drainage	w:	Fluid flow pipe	T:	Rpm controller
k:	Platform rotational and lifting mechanism	x:	Pump power supply	&:	Read-out unit
l:	Base plate	y:	Submerged water pump	#:	Switch board and plug
m:	Drive belt	z:	Fluid tank	@:	Main power supply
		A:	Spring load adjusting screw		

A line diagram of the ‘Pulley Loading Mechanism’ is given in Fig. 3.3. The arrows are showing the direction of the bit and load movement for drilling a hole. A pictorial view of the same ‘Pulley Loading Mechanism’ system is also provided in Fig. 3.4, in which the loading cage, weight bar, drill handle, and pulley are tagged as ‘**1, 2, 3**, and **4** respectively.

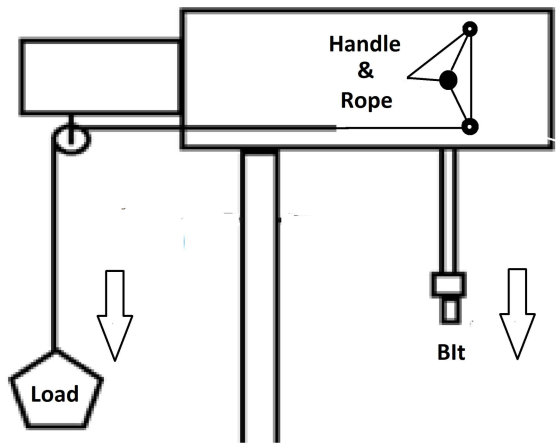

Fig. 3.3: Pulley Loading Mechanism

Fig. 3.4: Picture of Pulley Loading Mechanism

3.2 Description of Laboratory Drilling Setup

The laboratory setup can be divided into two categories namely core system and sub-systems, and ancillary systems. The core system mainly consists of the components that cause rock drilling, whereas, the components responsible for the measurement of various parameters can be called ancillary systems. By the upgradation of drilling setup, the variability and accuracy of salient parameters of both types of systems have been improved. Also, some additional sub-systems have been introduced in the setup, including RPM feedback, vibration measurement, bit temperature measurement, specific energy measurement, and real-time data measurement. This setup was fabricated by keeping various sub-systems in an appropriate arrangement with the core system, as shown in Fig. 3.2. The core system of laboratory setup consists of the following components:

1. Drilling unit,
2. Drill bit,
3. Drilling platform system,
4. Fluid flushing mechanism,
5. Control panel,

And the salient features of ancillary systems of the laboratory setup are as follows.

6. Depth limiting assembly,
7. RPM feedback system,
8. Specific energy measurement,
9. Read-out panel,
10. Real-time data measurement,
11. Bit temperature measurement, and
12. Vibration measurement.

The above systems have been arranged together in such a manner that allows them to work in conjunction.

3.2.1 Drill Unit

The drill unit consists of different parts namely motor, power transmitter, bit holder, drill handle, loading mechanism, main pillar, and base plate as shown in Fig. 3.2. Up to a certain extent, variation in bit parameters (diameter and type) and rock sample parameters (size and shape) could be done, depending on the drilling setup limitations. The various parts of the drill unit are discussed below in detail below.

3.2.1.1 Motor

A 1.0 HP D.C. motor was mounted at the backside of the drilling unit (tagged '**t**' in Fig. 3.2) and initialized by the electric power source ('**#**' in Fig. 3.2). It was used to provide rotational force to drill bit through belt and spindle. An RPM sensor was mounted on the motor body for continuous measurement of drill bit RPM.

3.2.1.2 Power Transmitter

A rubber belt ('**m**' in Fig. 3.2) was used to transmit the motor rotational power to the bit via drill spindle.

3.2.1.3 Bit Holder

The drill bit can be fixed in the bit holder ('**e**' in Fig. 3.2) and adjustment is also possible by tightening and loosening the holder with the help of a 'T' shaped key.

3.2.1.4 Drill handle

One rotating arm with three outwardly projected handle was providing to control the up & down motion of the drill bit manually. Each projected arm was mounted with pulleys and a wire rope attached to the pulley loading mechanism, which is passed through them, to support effective implementation of the constant loading system effectively (‘**b**’ in Fig. 3.2 and ‘**3**’ in Fig. 3.4).

3.2.1.5 Mechanism and Calculation of Bit Loading

The parts of this system consist of several weight bars or load (1 kg, 2 kg and 3 kg bars), bucket (**v**), wire rope (**o**), pulley (**u**), and drill handle (**b**) as given in Fig. 3.2. Load on the bit is applied at drill bit by putting the estimated weight bars in the bucket, which is hung with the wire rope passing through pulleys situated on drill handle and the main pulley (‘**u**’ in Fig. 3.2). This wire rope is wrapped around the projected arms of the drill handle to provide a continuous and constant load on the bit.

Precaution on the swinging of the cage should be kept in mind during applying weight. Whereas the weight of bit, spindle, and loading bucket were considered as dead load, and constantly acting on bit rock interface. So, the total dead weight could be calculated as given below.

Weight of Loading Bucket =	1.09 Kg
Weight of Drill Spindle =	1.54 Kg
Weight of Drill Bit (Avg.) =	0.05 Kg (19/12 diamond core bit)
Total =	2.68 Kg

The value of the constant dead weight is liable to vary according to the setup design of the setup.

3.2.1.6 Main Pillar and Base Plate

The main pillar is a cylindrical steel pillar (‘**g**’ in Fig. 3.2). It plays the role of the backbone of the drilling machine by providing support to the upper assembly including drill motor, power transmission arrangement, fluid insertion assembly, bit holder, and bit. It also supports the drilling platform and helps in its rotation and height adjustment too. Base plate (tagged ‘l’ in fig. 3.2) can be considered as legs of the whole drill unit. It provides a solid and heavy base to stand the drill unit properly.

3.2.2 Drill Bit

Diamond impregnated core bit of 19 mm (o.d.) and 12 mm (i.d.) was used to drill rocks samples. Bit assembly was made of steel and diamond cutting picks were impregnated at the cutting side of the bit, whereas the upper side of the bit was internally threaded to provide a grip. Some important dimensions of bit are shown in Fig. 3.5. An impregnated diamond bit was recommended by researchers for drilling hard formation, over a surface set diamond bit. Also, the impregnated diamond bits posses the ability to maintain a constant rate of penetration throughout the bit life [Rao et al. 1998].

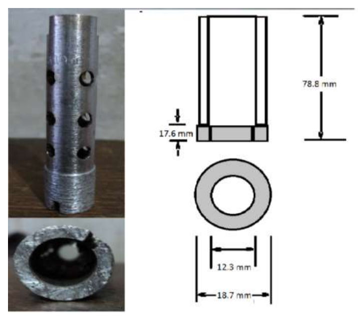

Fig. 3.5: Picture of Drill Bit and its Dimensional Sketch

3.2.3 Drilling Platform

The drilling platform was the base provider to hold the rock samples for drilling (tagged 'h' in fig. 3.2). It consists of four components namely, main plate, screw jaw system, waste carrying drainage system, and platform adjustment assembly as discussed below. Dimensions of the drilling platform in Fig. 3.6.

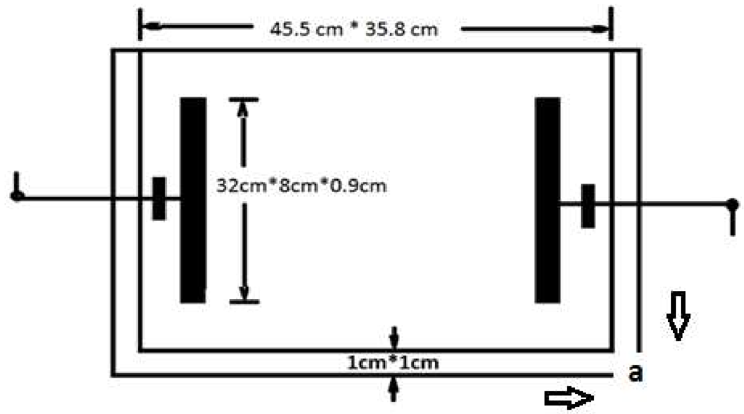

Fig. 3.6: Dimensions of Drilling Platform

3.2.3.1 Main Plate

It was made of an iron sheet of dimensions 1.0 X 35.8 X 45.5 (cm) (as shown in Fig. 3.6) and placed on a 2 cm thick circular disk ('**k**' in Fig. 3.2). The circular disk was attached to the main pillar of the drill machine through one moveable arm. The plate is equipped with an adjustable rock holding jaw ('**i**' in Fig. 3.2).

3.2.3.2 Waste Carrying Drainage

Waste carrying drainage ('**1**' in Fig. 3.7) was situated on the outer boundary of the drilling platform, having 1.0 cm^2 cross-section opening on three sides as shown in Fig. 3.6 ('**j**' in Fig. 3.2). It was created to collect drill mud (the mixture of drill cuttings and drilling fluid) and direct the way out via an outlet (**'a**' in Fig. 3.6), to the waste collecting tank ('**2**' in Fig. 3.7).

Fig. 3.7: Picture of Sludge Collecting Process

3.2.3.3 Sample Holding Jaw

A couple of iron jaw plates were used to provide grip to the rock samples. They were fixed on the main plate, facing each other (Fig. 3.6), such that the plates can have forward and backward motion. The dimensions of each jaw were, 32.0 × 8.0 × 0.9 (cm). Both plates are free from each other, so this free movement provides more flexibility in the adjustment of samples on the main plate (Fig. 3.8). The maximum possible opening of the jaw is 28.0 cm and the maximum possible movement of individual jaw plate is 15.5 cm.

Fig. 3.8: Picture of Jaw Holding Un-Parallel Rock Sample on Drilling Platform

3.2.3.4 Platform Adjustment Assembly

The platform Adjustment Assembly (Fig. 3.9), helps in vertical movement, rotation, and revolution of drilling plate, to adjust the position of a rock sample. Two adjusting handles are provided in this assembly for movement of drill plate as shown in Fig. 3.9. The flexibility of the drill plate may provide an efficient approach to the drill bit on the rock sample, as shown in Fig. 3.10.

Fig. 3.9: Picture of Platform Adjusting Assembly

Fig. 3.10: Picture of Flexibility of Platform

3.2.4 Fluid Flushing Mechanism

This system is a combination of five components, namely flushing pump (y), fluid tank (z), connecting pipe (w), flow adjuster (p), and fluid insertion assembly (d) as shown in figure 3.2. All the flushing parameters, i.e. chemical formulation, concentration, and flow rate, can be varied accordingly to the desired experimental specifications.

3.2.4.1 Flushing Pump

A small submersible water pump (Fig. 3.11) of DC 12 V, was used to flush the drilling mud to the rock-bit interface. The maximum flow rate of tap water can be achieved with this flushing pump is 183 l/hr.

Fig. 3.11: Picture of Flushing Pump

Fig. 3.12: Picture of Mud Tank

3.2.4.2 Fluid Tank

A cylindrical steel container (‘**z**’ in Fig. 3.2) having a carrying capacity of 16.4 litres was used to store the drilling fluid. And the flushing pump was submerged in this tank (Fig. 3.12).

3.2.4.3 Fluid Carrying Pipe

Flexible plastic pipes of 11 mm o.d. and 7 mm i.d. are used to flow the drilling fluid from the fluid tank to drill assembly. The pump, flow adjuster, and ‘fluid inserting assembly’ are connected by plastic pipes (‘**2a’** and **‘2b**’ in Fig. 3.16). Cross-sectional dimensions of the fluid carrying plastic pipe are shown in Fig. 3.13.

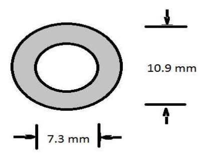

Fig. 3.13: Cross-section of Fluid Carrying Pipe

3.2.4.4 Flow Rate Adjuster

It was placed on the fluid carrying pipe between the flushing pump and fluid inserting assembly (‘**1**’ in Fig. 3.15). The function of the flow rate adjuster was to adjust the flow rate of drilling fluid.

3.2.4.5 Fluid Inserting Assembly

The fluid Inserting assembly (‘**3**’ in Fig. 3.15) and ‘**d**’ in figure 3.2), was developed to allow the flushing fluid to flow through the centre of the drill bit to the bit-rock interface. Plan view, and section view along axis AA’ is given in figure 3.14.

3.2.5 Control Panel

It is a power controlling unit, which controls the distribution of power from the main power source to various sub-systems of the drilling setup (‘**D’** in Fig. 3.2). It also consists of the following measurement meters and control keys, as in Fig. 3.2:

1. Ammeter (R)
2. Voltmeter (I)
3. RPM controller (T)
4. Miniature circuit breaker (Q)

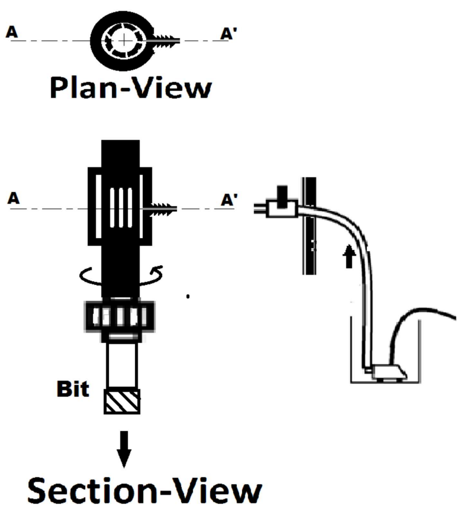

Fig. 3.14: Fluid Inserting Assembly

Fig. 3.15: Picture of Fluid Inserting Assembly

Ammeter and voltmeter were used to measure the current and voltage respectively. RPM controller was used to controlling the rotational speed of the drill bit. The rotation per minute (RPM) is used as a measurement unit for bit rotation speed. The Miniature circuit breaker (MCB) in the control panel was provided with an ON and OFF switch for controlling the power supply to the system. This also takes care power overloading of the system by auto-tripping to cut the machine power.

3.2.6 Depth Limiting Assembly

The moveable part of the drill spindle is free travels along the guide rod. Lowering of drilling bit can limit by depth limiting assembly. In this assembly, the lower moveable part and upper stable part are clamped together with the help of three bolts and one threaded rod. These bolts travel on a threaded rod, and named as limiting bolt, base bolt, and final bolt, as shown in Fig. 3.16. As their name denote, their application in a setup such as final bolt is to finalize the traveling of limiting bolt; Limiting bolt is to limit the depth drill by bit and limit can be varied by moving it on the rod, and base bolt is to provide a base of assembly movement and it holds the rod on position. Final and limiting bolts are moveable, whereas the base bolt is Fixed.

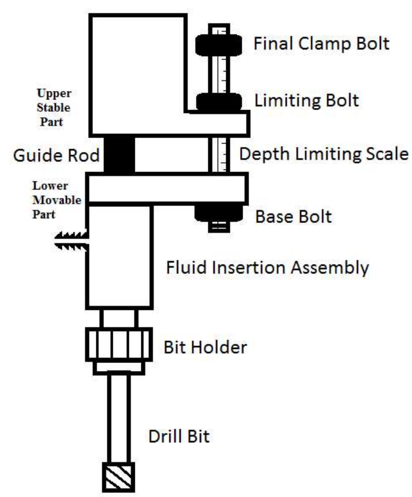

Fig. 3.16: Depth Limiting Assembly

Threaded Rod is equipped with a scale, which helps to measure the distance travelled by the bit. This threaded rod with scale is called depth limiting scale, shown in Fig. 3.17. Its position can be identified in as '**c**' in Fig. 3.2.

3.2.7 Feedback System

This system has been very important for continuous monitoring and maintaining constant bit rotational speed throughout the drilling process. This system comprises continuous working of three major parts - namely, RPM controller, RPM sensor, and digital RPM meter, tagged as '**T**', '**s**', and '**G**' respectively in Fig. 3.2. A metal bolt was projected on the spindle of the motor. Its rotational movement in the magnetic field of the RPM sensor was observed to analyze the real-time RPM of the bit. An inductive proximity RPM sensor of 8 mm range was used in this system.

3.2.7.1 Process of Feedback

Initially, bit rotation is assigned by the RPM controller via motor. The assigned value is displayed to RPM meter through the sensor. As the depth of the hole increases with time, the bit rotation rate varies due to the frictional force coming to play. This variation is sensed and displayed on the digital RPM meter as a feedback. Electrical power to the motor is then varied manually by the RPM controller to maintain constant RPM at the bit-rock interface. A diagram in Fig. 3.17 is showing the working process of this system. Progressing directions are shown by arrows. The effectiveness of this system, depends on the capability of the drilling setup, to

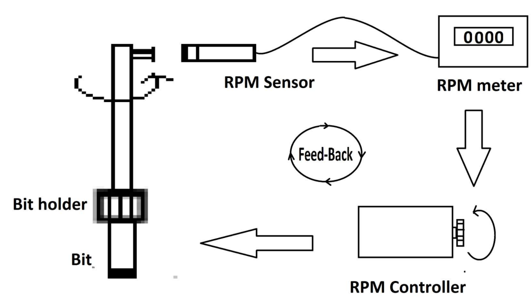

Fig. 3.17: Working process of Feed-Back System

provide enough torque to overcome the drag or friction between the drill bit and rock surface.

3.2.8 Specific Energy Measurement

For the measurement of specific energy consumption (SEC), a digital energy meter was connected with the core system ('**E**' in Fig. 3.2). It was capable of providing continuous cumulative energy consumption in drilling operation with the help of a video recorder (as shown in Fig. 3.18). The digital meter can display the energy reading up to the third decimal in the unit of 'kWh'. It can be calculated by the ratio of total cumulative energy consumed in drilling a hole (kWh) and total volume drilled (mm^3).

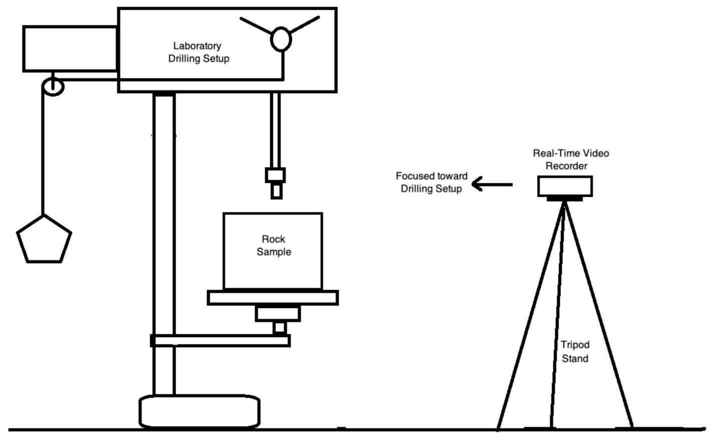

Fig. 3.18: Real-time data measurement setup

3.2.9 Read-out panel

This panel is tagged by '**&**' in Fig. 3.2. It consists of a milli-watt energy meter (E), digital wattmeter (F), and RPM meter (G). All these meters give real-time readings during a drilling operation.

3.2.10 Real-time Data Measurement

A video recorder was installed on a tripod stand, focused on drilling setup, to record the real-time data as shown in Fig. 3.18. The recorder was capable to record high quality video **in** 4,000 pixels (4K) resolution. After that, the recorded videos could be analyzed at a reduced speed with 8 frames per second (fps), as shown in Fig. 3.19. These specifications of video recorder helps in the accurate measurement of real-time data to identify depth variation with time, power fluctuation energy consumption, and promote intra-hole drilling study too.

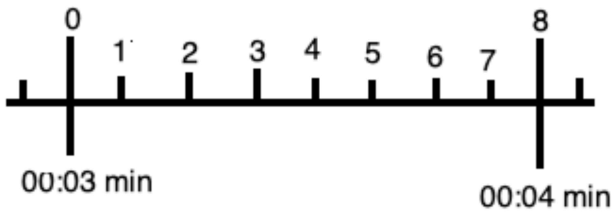

Fig. 3.19.: No. of frames recored in one second

3.2.11 Bit Temperature Measurement

The thermocouple is a thermoelectric device used to measure temperature. The handheld high precision digital K-Type thermocouple instrument was used in this study. It is having two major components namely, read-out unit, and resistance probe. The read-out unit was kept operational nearly the drilling setup, while the temperature probe was used to measurement the bit surface temperature, after drilling the desired depth. The range of temperature that can be measured with this thermocouple type of was -200°C to 1260°C.

3.2.12 Vibration Measurement

The vibration analyzer consists of a digital read-out unit, vibration transducer, holding stand, and connecting cords. The transducer (vibration sensor) on its stand was attached to the drill spindle keeping the 'Z' direction of the transducer parallel to the direction of drilling as shown in Fig. 3.20. The values of root mean square (RMS) X, RMS Y, RMS Z, and vibration total value (VTV) were taken into consideration.

3.3 Drilling Setup Upgradation for Vibration Measurement

To study the machine vibration due to drilling, the base of the drilling setup had been fixed to the ground by masonry work, as shown in Fig. 3.20. It was done to minimize the induced as well as unpredictable vibration from drilling platform 'h' and base plate **'l'** as shown in Fig. 3.2.

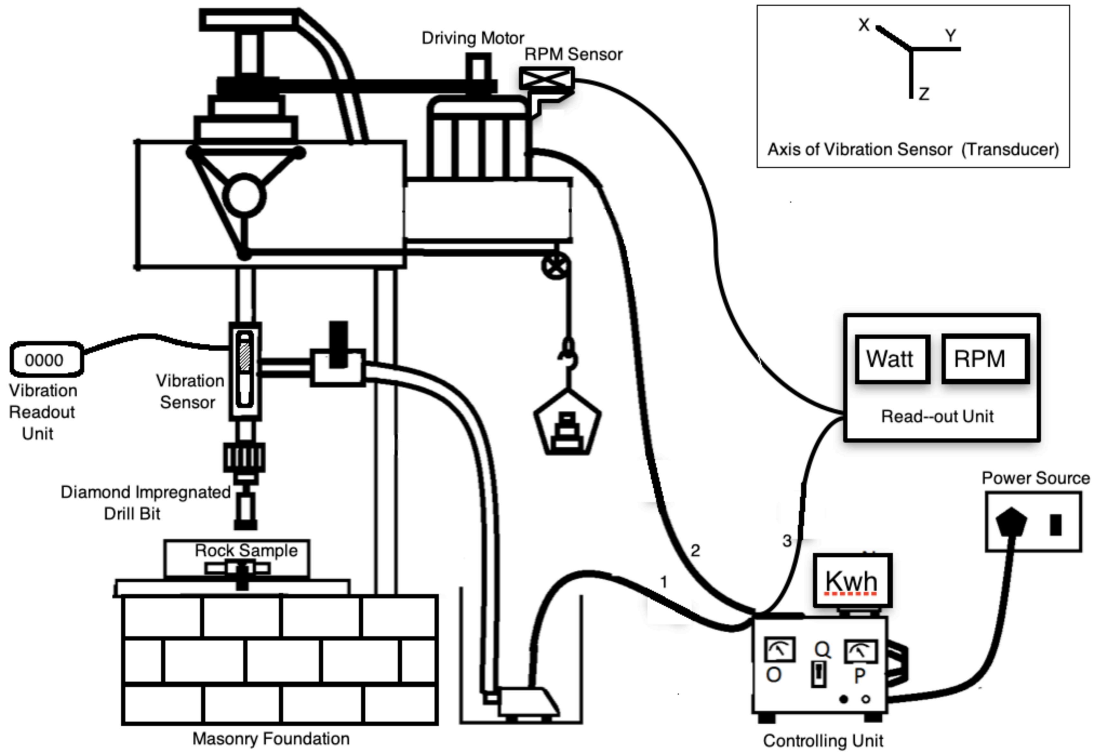

Fig. 3.20: A ungraded laboratory drilling setup to study vibration