ALOK VARDHAN
AJIT KUMAR
and
K. DASGUPTA

Effect of various parameters on the performance of the blasthole drilling

Blasthole drilling process used in opencast mines is one of the conventional methods to extract the ores from ground. During the drilling process, torque available at the bit causes various types of stresses which results in the formation of hole. Tricone bit is one of the most exclusively used bits for the blasthole drilling operation. The drill bit crushes the rock material under its teeth or edges and enables advancement of the drill hole in the intended direction. The bit undergoes very heavy wear and tear which reduces its life, leading to drastic drop in its penetration rate. In this article, the effect of major parameterson the performance of the rotary blasthole drilling as well as on the service life of the said drill bit is highlighted. In this regard, the optimum solutions to increase the service life of the tricone bit and the performance of the blasthole drilling are predicted. This paper also discusses the dynamic behaviors of the blastholedrill rig while drilling in mines.

Keywords: Blasthole drilling; opencast mines; blasthole drill rig; tricone bit.

1. Introduction

The mining industry uses blasthole drill rigs in opencast mines for drilling holes that can be loaded with explosives to fragment the rock. The fragmented material is then excavated by other mine equipment such as shovels, draglines, front end loaders etc. [1]. In this type of drilling process, mechanical energy is used to disintegrate rock. When mechanical energy is passed onto the formation, it causes various types of stresses in the formation. These stresses cause strains in the formation and subsequently formation disintegrates when the cracks formed by the strains propagate. Different modes of passing mechanical energy like crushing, impact crushing and scratching to the formation are practiced in drilling. Blasthole drilling in such formations is carried out, almost exclusively by using a tricone bit [2-3].

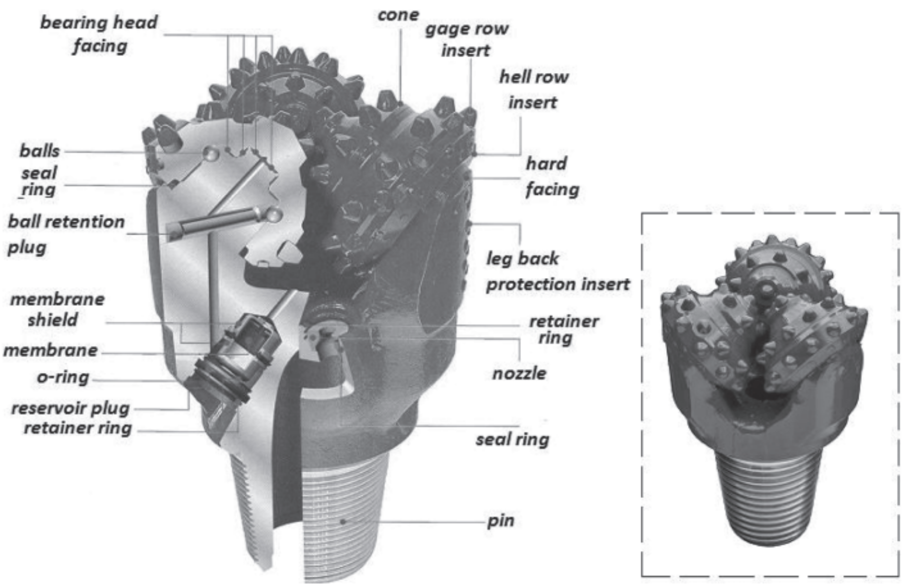


Fig.1 A typical tricone bit

Fig.1 shows a typical tricone bit [4]. It consists of three conic shaped rollers each having arrays of milled teeth or tungsten-carbide inserts, depending on the bit model, aligned in several rows. The cones have different meshing geometry and are designed to rotate about a fixed axis. The inserts are extremely resistant to abrasive wear and breakage and give consistent performance during the bit life. The insert length is usually row and cone dependent.

These bits may have a slight shearing action in soft rock formations, but primarily operate to break the rock into chips by a crushing action through indentation of the inserts under an applied feed force (weight-on-bit) and rotating action. The distance between adjacent inserts rows is designed to create a free surface which allows the chips to propagate and be removed without being completely ground. The bits differ from one another by the geometry, diameter, shape of inserts

Messrs. Alok Vardhan, Ajit Kumar and K. Dasgupta, Department of Mining Machinery Engineering, Indian Institute of Technology (ISM), Dhanbad, Jharkhand 826 004, India. E-mail: alok.or.monu@gmail.com; ajit.ism185@gmail.com; dasgupta_k2001@yahoo.co.in

Fig.2 A blasthole drill rig

at the drill head by hydraulic or electric motor fixed onto a frame that can slide along the length of the mast. The motors drive a spindle sub which connects to a steel rod via threading at one end, the other end threaded to the bit. The drill motor head assembly is pulled up and down by feed chains powered by two hydraulic cylinders. The pull down force is controlled by adjusting the feed pressure to the hydraulic cylinders. The resulting vertical force at the bit level is the weight-on-bit (feed force).

Three extra steel rods are stored in a carousel type rod changer. When the first steel rod is driven down the hole over its entire length, the driver disconnects it from the spindle sub by rotating the motors in reverse direction. He then moves the carousel into the loading position to add another steel rod on top of the previous one then resumes drilling. The steel column composed of one or more steel rods connecting the spindle sub to the bit is referred to as drill string.

and the inserts length. Bits designed for hard rock formations have short ovoid-shaped inserts while softformations bits have longer tooth-shaped inserts. John W. Speer [5] has suggested the controllable factors that affect the bit performance.

Bourgoyne and Young [6] have presented the large number of rate of penetration models in their study and it considered the effect of the rock strength on the rate of penetratio nwhereas; the roller-cone-bit model presented by Warren [7], and Cunningham's ROP model [8]. In addition, Teale [9] introduced the concept of the minimum specific energy and derived the specific energy equation for rotary drilling. He concluded that drilling attains the highest performance when the specific energy approaches, or is approximately equal to, the compressive strength of the rock to be drilled. Then, the concept of the confined compressive strength of rock and the specific energy are employed extensively to optimize the drilling parameters and to assess the bit performance [10-15].

2. Blasthole drill rig

Fig.2 shows a blasthole drill rig [16] for all the tests in this study and its specification is given in Table 1. The rotary motion for the drill bit is produced

TABLE 1: SPECIFICATIONS OF THE BLASTHOLE DRILL RIG

	Components	Parameters
1.	Drilling capacity	
	Hole size	159 to 200 mm (6 1/4" to 7 7/8")
	Drilling depth	53m (175 ft)
2.	Crawler	
	Drive	Hyd. motor thru gearbox
	Gradability	25%
3.	Mast	
	Construction	Heavy duty structural steel lattice box type
	Drill pipe length	7.62 / 9.1 / 10 / 11 m (25 / 30 / 33 / 36 ft)
4.	Feed	
	Feed system	Twin chain with twin cylinder or motor pull down
	Pull down - hyd. cylinder	13,600 kgs (30,000 lbs)
	Pull up - hyd. cylinder	9,100 kgs (20,000 lbs)
	Pull down/up - hyd. motor	13,600 kgs (30,000 lbs)
5.	Rotary head	
	System	Single or twin hydraulic motors through gearbox
	Torque	460 / 345 kg.m (40,000 / 30,000 lb.inch)
	Speed	0-90 / 100 RPM
6.	Air compressor	
	Type	Single or two stage oil flooded screw type
	Capacity	17 to 34 m^3/min (600 to 1200 cfm)
	Pressure	5 to 24 kg/cm^2 (70 to 350 psi)
7.	Power unit	
	Prime mover compressor and hydraulics	Diesel engine or electric motor driving both
8.	Leveling Jacks	
	Rear end	Two nos. (drilling end)
	Front end	One no.
9.	Drill pipe handling	
	Pipe loader	Single/three/six rods
	Pipe dia	114 to 140 mm (4 1/2" to 5 1/2")

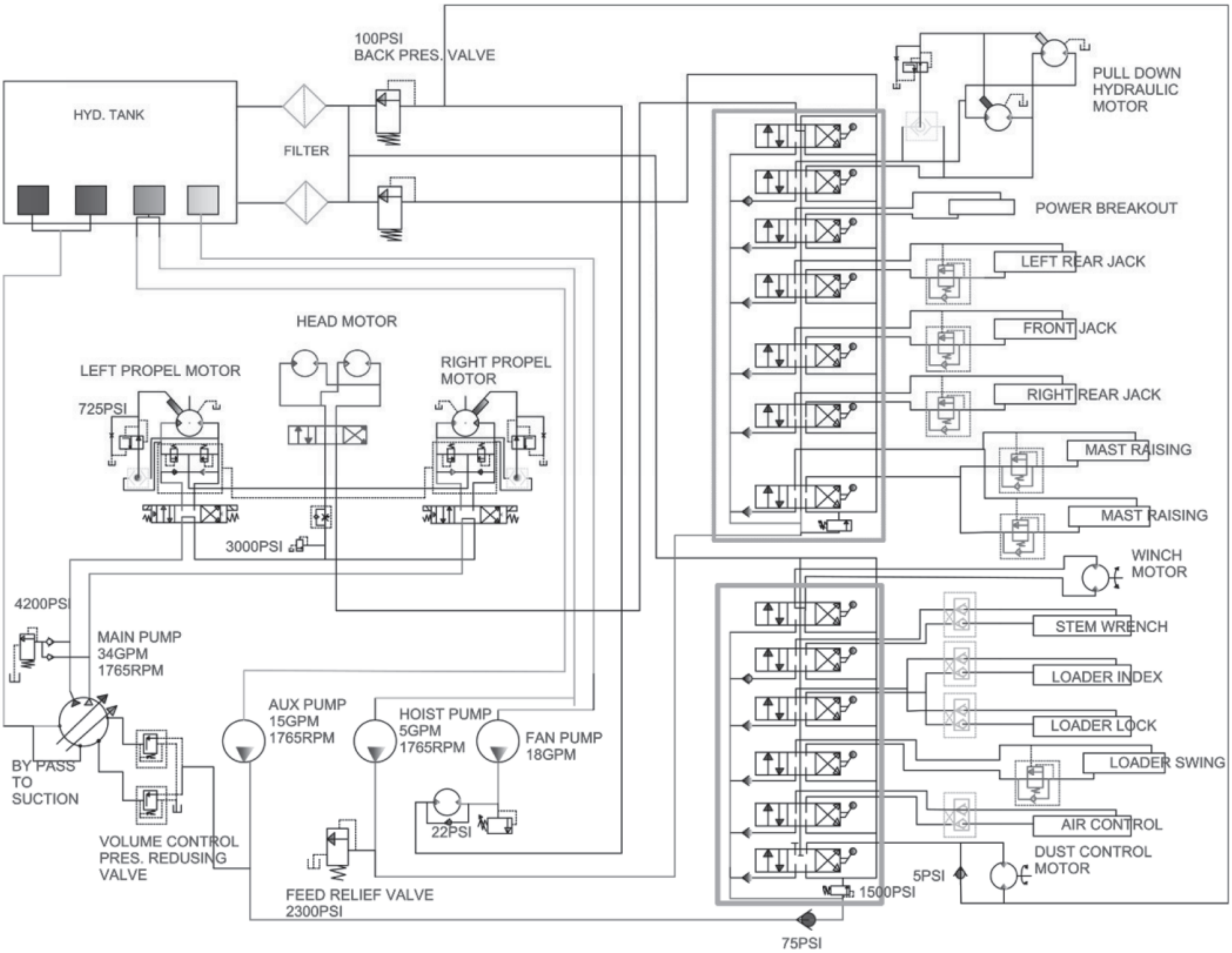


Fig.3 Hydraulic circuit diagram of the blast hole drill rig

Most of the operations of the blasthole drill rig depend on the performance of its hydraulic systems. Fig.3 shows the hydraulic circuit diagram [17] used in the given blasthole drill rig [16].

The study is performed using the given blasthole drill rig [16] in the Dhansar coal mines, India where the compressive strength of the rock is varied between 20 MPa to 60 MPa and the drilling occurs at the rotary speed of 0to 90 rpm. This study also considers the three different size's drill bits which are 159 mm, 172 mm and 200 mm, respectively.

3. Equations used in blasthole drilling

The theoretical equations which are used for the blasthole drilling with tricone roller drill bit are given below:

The minimum feed force under which a rock is not drilled, can be estimated from the following equation [2]:

$$E_{min} = 28.5 \times S \times D \quad \text{... (1)}$$

where, E_{min} is the minimum feed force (pounds), S is the rock compressive strength (MPa) and D is the diameter of the roller tricone bit (inches).

The maximum feed force (E_{max}) in pounds above which bit is buried is given by [2]:

$$E_{max} = 2 \times E_{min} \quad \text{... (2)}$$

The limit feed force on the bit under normal and safe working condition, is given by [2]:

$$E_L = 810 \times D^2 \quad \text{... (3)}$$

where, E_L is the limit feed force (pounds) and D is the diameter of the roller tricone bit (inches).

The penetration rate is given by [2]:

$$R = \frac{2.18 \times E \times N}{0.2 \times S \times D^{0.9} \times \frac{S}{10}} \quad \text{... (4)}$$

where, R is the penetration rate (m/h), E is the feed force (kg), N is the rotary speed (rpm), S is the rock compressive strength (MPa) and D is the diameter of the roller tricone bit (mm).

The torque required to rotate the tricone drill bit is given by [1]:

$$T = \frac{0.014 \times k \times D^{2.5} \times E^{1.5}}{1000} \quad \ldots \quad (5)$$

where, T is the torque required to rotate the tricone drill bit (kgm), R is the penetration rate (m/h), N is the rotary speed (rpm), E is the feed force (kg), D is the diameter of the roller tricone bit (mm) and k is the constant related to the properties of the rock.

Substituting the value of feed force (E) from equation (4) in equation (5), the torque required to rotate the drill bit is given by:

$$T = 0.014 \times k \times D^{2.5} \times E^{0.5} \times \left(\frac{0.2 \times R \times S^2 \times D^{0.9}}{2.18 \times 10 \times N} \right) \times \frac{1}{1000} \quad \ldots \quad (6)$$

where, T is the required torque to rotate the tricone drill bit (kgm), R is the penetration rate (m/h), E is the feed force (kg), N is the rotary speed (rpm), S is the rock compressive strength (MPa), D is the diameter of the roller tricone bit (mm) and k is the constant related to the properties of the rock. Values for the constant k lie between 14×10^{-5} to 4×10^{-5} and it depends upon the drillability of the rock. For hardest rocks, lower values are to be used and for soft rocks higher values are to be used.

The required rotary power to rotate the drill bit is given by [2]:

$$P = \frac{N \times T}{5.250} \quad \ldots \quad (7)$$

where, P is the required rotary power (HP), N is the rotary speed of the drill bit (rpm) and T is the required rotary torque (lbft).

The service life of a tricone bit is estimated from the following equation [2]:

$$L = \frac{28.14 \times D^{1.55} \times E^{-1.67}}{N} \times 3 \times R \quad \ldots \quad (8)$$

where, L is the service life of tricone bit (m), D is the diameter of the roller tricone bit (inches), E is the feed force on the bit (thousands of pounds), N is the rotary speed (rpm) and R is the penetration rate (m/h).

4. Results and discussion

The various characteristics of the blasthole drilling are estimated with respect to the different operating parameters. The theoretical characteristics of the blasthole drilling are obtained from the eqns. (1) through (8) given in sec. 3, whereas the actual behaviours are obtained from data collected while drilling in mines. The characteristics of the actual and the theoretical values of various parameters are shown in Figs.4 through 6.

4.1 Determination of the penetration rate

Fig.4 shows the characteristics of the penetration rate with respect to the different operating parameters of the blasthole drilling. From the characteristics shown in Fig.4, the following observations are made:

- At a given value of the feed force, bit diameter and the rock compressive strength, increasing the rotary speed increases the penetration rate (Fig. 4).

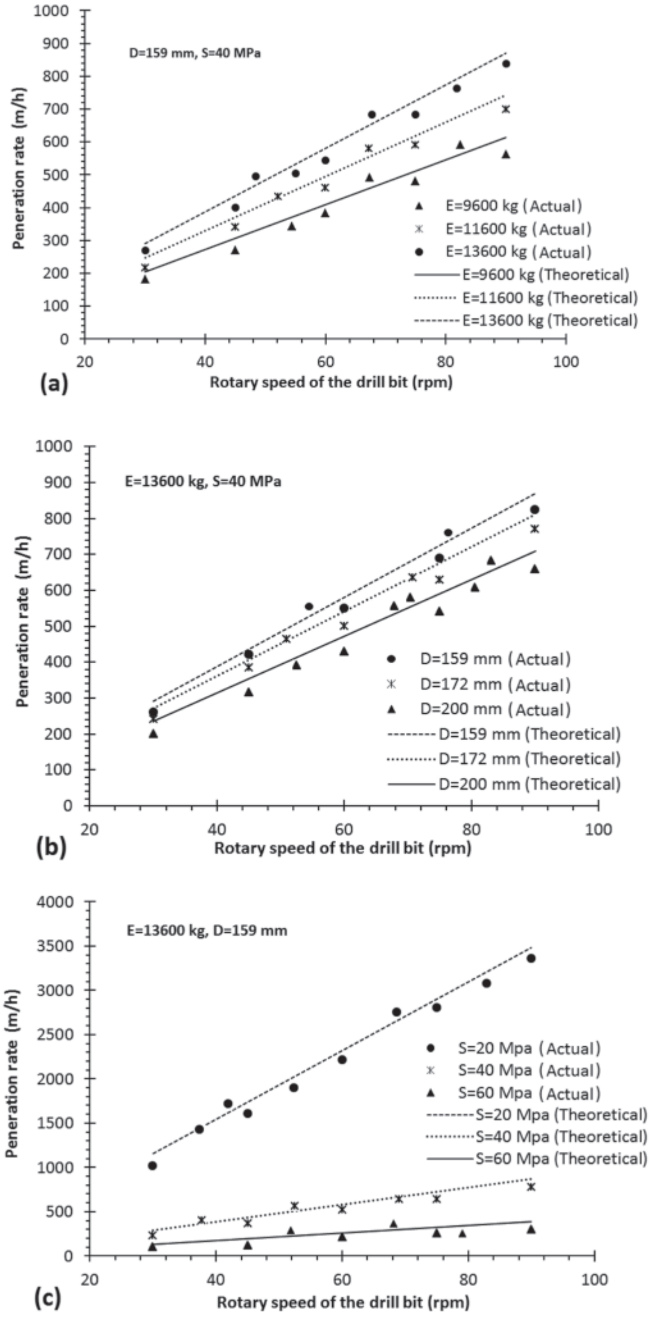
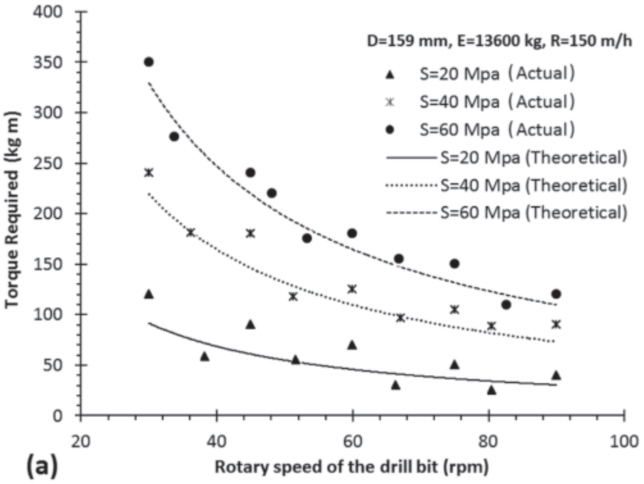
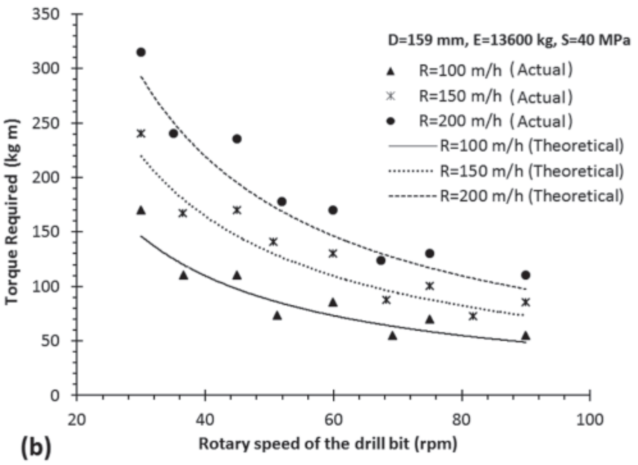
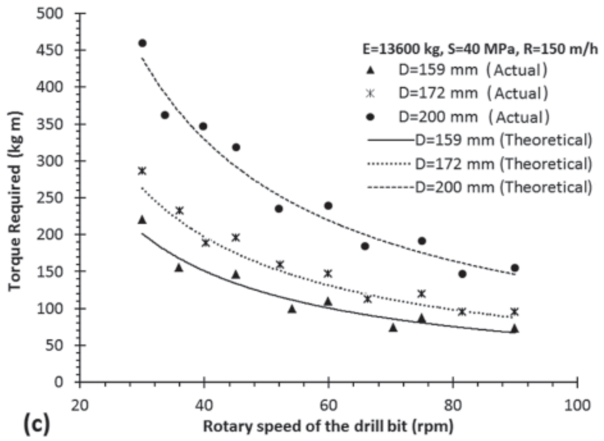


Fig.4 Characteristics curve for penetration rate of the blast hole drilling

- At a given value of the rotary speed, bit diameter and the rock compressive strength, increasing the feed force increases the penetration rate (Fig. 4a).
- At a given value of the rotary speed, feed force and the rock compressive strength, increasing the bit diameter decreases the penetration rate (Fig. 4b).
- At a given value of the rotary speed, feed force and the bit diameter; increasing the rock compressive strength decreases the penetration rate (Fig. 4c).







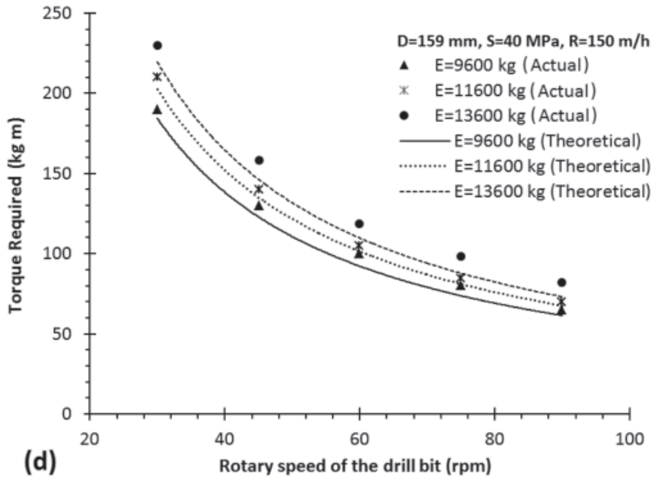


Fig.5 Characteristics curve for torque required of the blast hole drilling

4.2 Determination of the torque

Fig.5 shows the characteristics of the required torque to rotate the drill bit with respect to the different operating parameters of the blasthole drilling. From the characteristics shown in Fig. 5, the following observations are made:

- At a given value of the feed force, bit diameter, penetration rate and the rock compressive strength, increasing the rotary speed decreases the required torque to rotate the drill bit (Fig. 5).
- At a given value of the rotary speed, bit diameter, penetration rate and the feed force, increasing the rock compressive strength increases the required torque to rotate the drill bit (Fig. 5a).
- At a given value of the rotary speed, bit diameter, feed force and the rock compressive strength, increasing the penetration rate increases the required torque to rotate the drill bit (Fig. 5b).
- At a given value of the rotary speed, feed force, penetration rate and the rock compressive strength, increasing the bit diameter increases the required torque to rotate the drill bit (Fig. 5c).
- At a given value of the rotary speed, bit diameter, penetration rate and the rock compressive strength, increasing the feed force increases the required torque to rotate the drill bit (Fig. 5d).

4.3 Determination of the service life of the drill bit

Fig.6 shows the characteristics of the service life of the tricone drill bit with respect to the different operating parameters of the blasthole drilling. From the characteristics shown in Fig. 6, the following observations are made:

- At a given value of the bit diameter, penetration rate and the feed force, increasing the rotary speed decreases the service life of the tricone drill bit (Fig. 6).

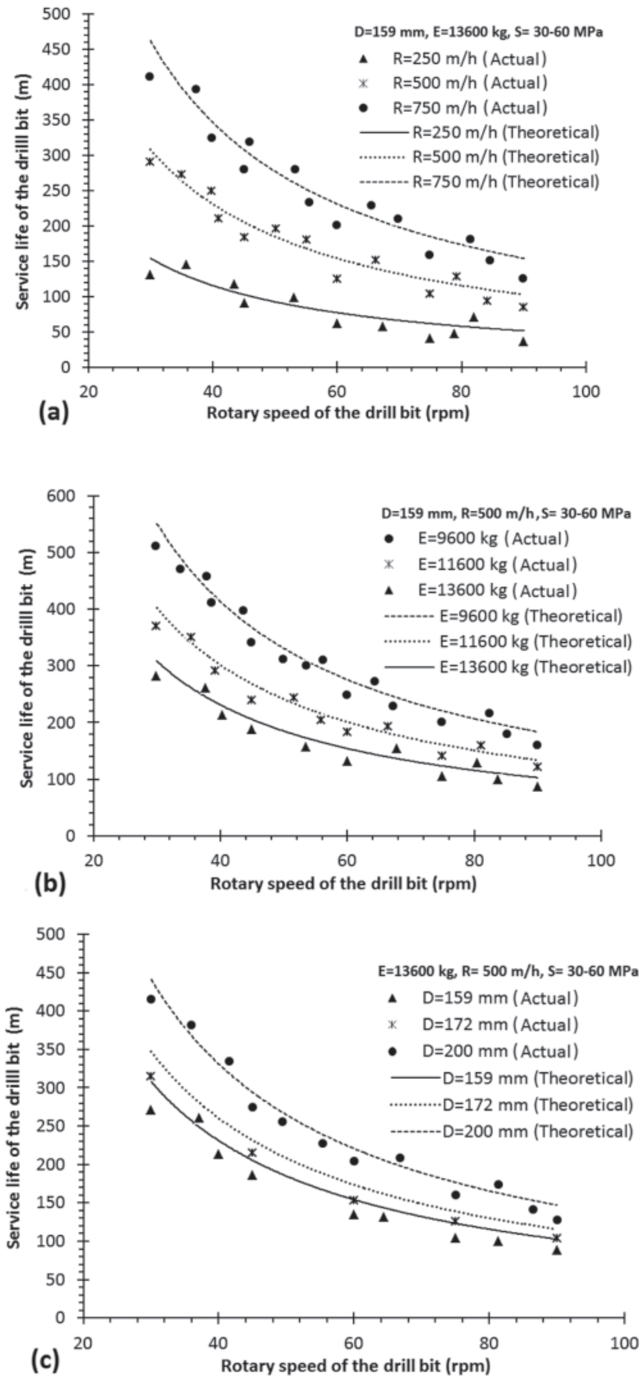


Fig.6 Characteristics curve of the service life of the tricone drill bit

- At a given value of the rotary speed, bit diameter and the feed force, increasing the penetration rate increases the service life of the tricone drill bit (Fig. 6a).
- At a given value of the rotary speed, bit diameter and the penetration rate, increasing the feed force decreases the service life of the tricone drill bit (Fig. 6b).
- At a given value of the rotary speed, feed force and the penetration rate, increasing the bit diameter increases the service life of the tricone drill bit (Fig. 6c).

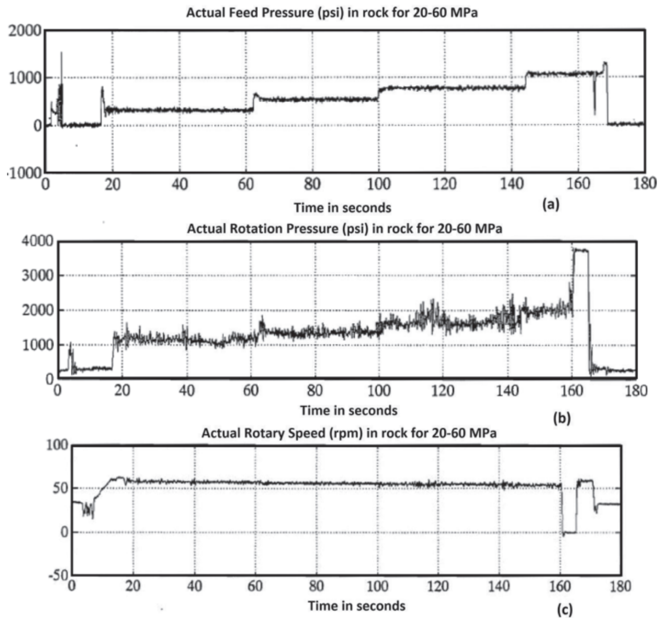


Fig.7 Dynamic behaviour of the blast hole drill rig

5. Dynamic behaviour of the system

Using the HYDAC data recorder the actual variables of feed pressure, rotation pressure and the rotary speed of the blasthole drill rig are recorded and shown in Fig.7. These characteristics curves give the dynamics response of the system with respect to the time while drilling is performed in the mines.

6. Conclusions

This paper investigated the performance of the blasthole drilling as well as the service life of the tricone bit used in the blasthole drill rig on the behalf of different operating parameters. For better performance of the blasthole drilling operation used in the opencast mines based on the predicted and the actual results, the following conclusions can be drawn as follows:

- With the increase in the rotary speed of the drill bit, penetration rate increases whereas, required torque to rotate the drill bit and the service life of the tricone bit decreases. So, for better performance of the blasthole drilling, the rotary speed should lies between 35 rpm to 75 rpm for the given rock compressive strength.
- With the increase of the drill bit diameter, penetration rate decreases whereas, required torque to rotate the drill bit and the service life of the tricone bit increases. So, for better performance of the blasthole drilling, the bit diameter should lies between165mm to 180 mm for the given rock compressive strength.
- With the increase of the feed force, penetration rate and required torque to rotate the drill bit increases whereas, the service life of the tricone bit decreases. So, for better performance of the blasthole drilling, the feed force should lies between 10600 kg to 11600 kg for the given rock compressive strength.

(Continued on page 48)