

# Research and Application of the Testing Technology for Impacting Screw Drilling Tools in Coal Mine Roadways

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## Abstract

**With the popularization and application of underground directional drilling technology in hard rock strata of coal mines, the performance test of impact screw drilling tools is of key significance for the optimization of drilling tools. Based on the working principle of the cam impact hammer-spring energy storage impact mechanism, this paper designs a test platform including a mechanical loading system, a hydraulic circulation system, and a high-speed data acquisition system, realizing the synchronous collection of parameters such as torque (1480 N·m), impact force (5-9 kN), and rotational speed. Field applications show that this testing technology can guide the service life of drilling tools to increase by more than 2 times, providing data support for the optimization of hard rock directional drilling technology.**

## Keywords

**Coal mine; impact screw drilling tool; dynamic testing; hard rock breaking; directional drilling.**

## 1. INTRODUCTION

Underground directional drilling technology in coal mines plays an important role in improving mining safety and clean energy supply [1,2,3,4]. However, due to complex coal and rock stratum conditions in China (such as sandy soft coal seams and hard rock formations), the mechanical drilling speed of conventional screw drilling tools in hard rock drilling is only 1.2 m/h, and the bit wear rate is 300% higher than that in soft coal seams [5]. Although the impact screw drilling tool developed by Xi'an Research Institute of China Coal Technology and Engineering Group has improved rock-breaking efficiency by integrating impact sub, the existing testing technology lacks quantitative research on the coupling effect of impact frequency and impact force [6,7]. This paper constructs a testing system with dynamic backpressure simulation function for drilling tools such as 7LZ89x7.0-4-640C, filling the technical gap in performance testing under hard rock working conditions.

## 2. THEORETICAL BASIS

### (1) Working Mechanism of Impact Screw Drilling Tool

The impact screw drilling tool adds an impact mechanism on the basis of the conventional screw drilling tool, which is mainly divided into two types:

Cam hammer-spring energy storage mechanism: It relies on spring compression to store energy and push the hammer to generate axial impact load. The impact frequency is positively correlated with the rotor speed (e.g., 4-6 Hz at a speed of 100 rpm) [8,9];

Self-excited oscillation cavity mechanism: Periodic impact is generated through fluid oscillation. The collision period between the hammer and the anvil is determined by both spring stiffness and fluid pressure [10,11].

### (2) Theoretical Basis for Performance Testing

According to the Bernoulli equation, the relationship between the pressure difference ( $\Delta P$ ) at the inlet and outlet of the drilling tool, the flow rate ( $Q$ ), and the torque ( $T$ ) is:

$$T = \frac{\Delta P \cdot Q}{2\pi n} \cdot \eta$$

Where  $n$  is the rotational speed and  $\eta$  is the mechanical efficiency. The mathematical model of impact force  $F$  and bit pressure  $P$  can be expressed as:

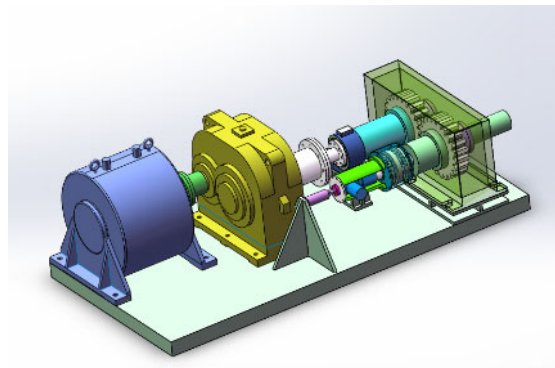
$$F = k \cdot P + F_0$$

In the formula,  $k$  is the impact coefficient, and  $F_0$  is the static preload [12,13,14,15]. This model provides theoretical support for the design of test parameters (such as the adjustment range of the backpressure valve).

## 3. DESIGN OF TESTING SYSTEM

### (1) Mechanical Structure Design

The test bench adopts a horizontal layout as shown in Figure 1, including three parts: a drilling tool clamping device, a loading system, and an impact force measuring device.



**Figure 1.** Layout of the Test Bench

Drilling tool clamping device: The outer pipe of the screw drilling tool is fixed by a hydraulic chuck with a positioning accuracy of  $\pm 0.5$  mm.

Loading system: A CW series brake (such as model CW50B with a rated torque of 100 N·m) is selected to provide reverse torque, and a supporting gearbox controls the rotational speed below 1500 rpm. The specific parameters are shown in Table 1.

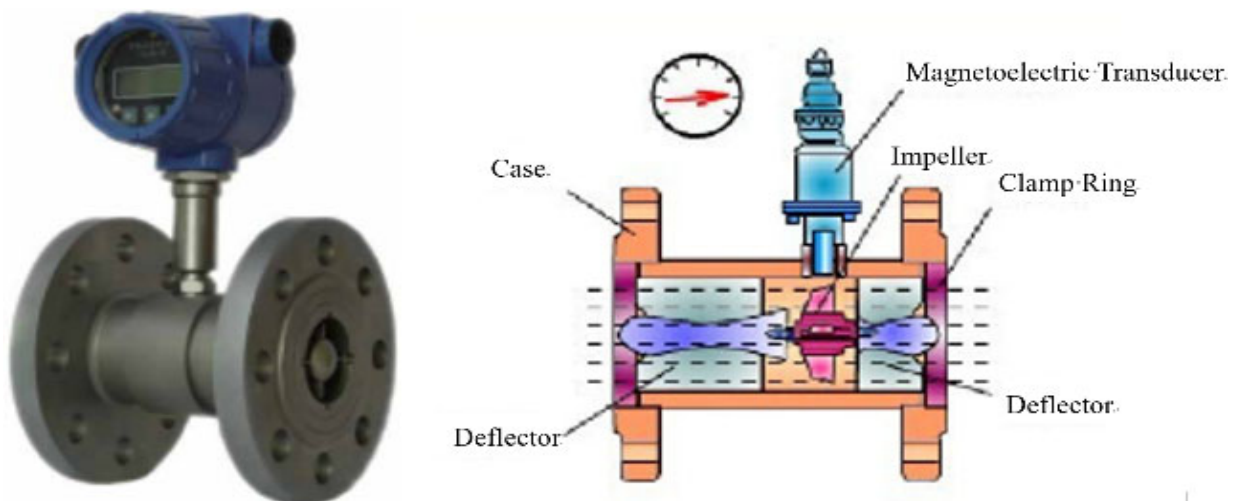
**Table 1.** Parameters of CW Series Brakes

Model	Rated Torque (N·m)	Absorbed Power (kW)	Excitation Voltage (DC V)	Weight (kg)	Input Speed (r/min)
CW5B	0.75	36	<90	10	300-3600
CW10B	40	20	<90	20	300-3600
CW20B	300	52	<90	50	300-3600
CW50B	100	83	<90	100	300-3600
CW100B	200	120	<90	150	$\leq 1500$
CW200B	300	210	<90	250	$\leq 1500$

Impact force measuring device: The backpressure single-acting device converts the rotating shaft into a fixed stator, on which a piezoelectric force sensor (range 0-20 kN, sensitivity 100 mV/kN) is installed.

#### (2) Hydraulic Circulation System

A 380V/55kW horizontal plunger pump is used, and the flow rate can be steplessly adjusted from 100 to 600 L/min through a frequency converter (accuracy  $\pm 2$  L/min). The circulating medium is clean water. The inlet flow rate is monitored by a turbine flowmeter (with an error of  $\pm 0.5\%$  FS). The backpressure valve simulates the bottom hole circulation resistance (adjustable from 0 to 5 MPa) [16]. The physical object and installation layout of the vortex flowmeter are shown in Figure 2 below.



**Figure 2.** Physical Object and Installation Layout of Turbine Flowmeter

## 4. DATA ACQUISITION AND CONTROL SYSTEM

#### (1) Sensor Array

The system integrates 9 types of sensors (Table 2), among which:

Piezoelectric force sensor: monitors impact force (sampling rate 100 kHz);

Torque and rotational speed sensor: measures output torque (accuracy  $\pm 1\%$ ) and rotational speed ( $\pm 1$  rpm);

Temperature sensor: monitors the temperature of the medium at the inlet and outlet (resolution  $0.5^{\circ}\text{C}$ ) [17,18].

#### (2) Software Algorithm Implementation

The upper computer software is developed based on LabVIEW, realizing the following functions:

a. Synchronous acquisition: Real-time synchronization of 6-channel data at a sampling rate of 10 kHz;

b. Signal processing: Using a Butterworth filter to eliminate high-frequency interference[19];

c. Dynamic display: Real-time drawing of impact force-time curve, as shown in Figure 3.

**Table 2.** Summary of Sensors

Serial Number	Sensor Name	Detection Target	Remarks
1	Flow Sensor (Hydraulic)	Detect inlet flow rate of screw drilling tool	
2	Piezoelectric Force Sensor	Detect impact force of impact screw drilling tool	
3	Pressure Sensor	Detect simulated bit pressure	Can be replaced by pressure gauge
4	Pressure Sensor	Detect inlet pressure of screw drilling tool	Pump pressure
5	Pressure Sensor	Detect outlet pressure of screw drilling tool	Backpressure
6	Temperature Sensor	Detect temperature of circulating medium at inlet of screw drilling tool	
7	Temperature Sensor	Detect temperature of circulating medium at outlet of screw drilling tool	
8	Temperature Sensor	Detect surface temperature of screw drilling tool	
9	Temperature Sensor	Detect temperature of brake cooling liquid	

## 5. EXPERIMENTAL METHODS AND RESULTS

### (1) Test Scheme

Taking the 7LZ89x7.0-4-640C drilling tool as an example, the test steps are as follows:

- Adjust the flow rate to 360-540 L/min and the backpressure to 1-4 MPa;
- Apply 35 kN simulated bit pressure through the axial pressurizing device;
- Gradually load the torque to 1480 N·m and conduct a stable test for 10 minutes.

The collected parameters such as impact force and rotational speed are shown in Table 3 below.

### (2) Test Results of Torque Impactor

The test data of the  $\varnothing 121$  mm torque impactor are as shown in Table 4:

The average impact force is 49.7 kN, and the impact frequency is 28.9 Hz;

When the flow rate is 380 L/min, the impact force-frequency response is the best.

**Table 3.** Design Parameters of Screw Drilling Tool

Specification Model	Flow Rate (lpm)	Rotational Speed (rpm)	Output Torque (N·m)	Maximum Bit Pressure (kN)	Maximum Pressure Drop (Mpa)	Impact Force (kN)
7LZ89x7.0-4-640C	360~540	120~190	1480	35	4	5~9
7LZ95x7.0-3-600C	360~540	124~186	1347	35	3.6	5~9

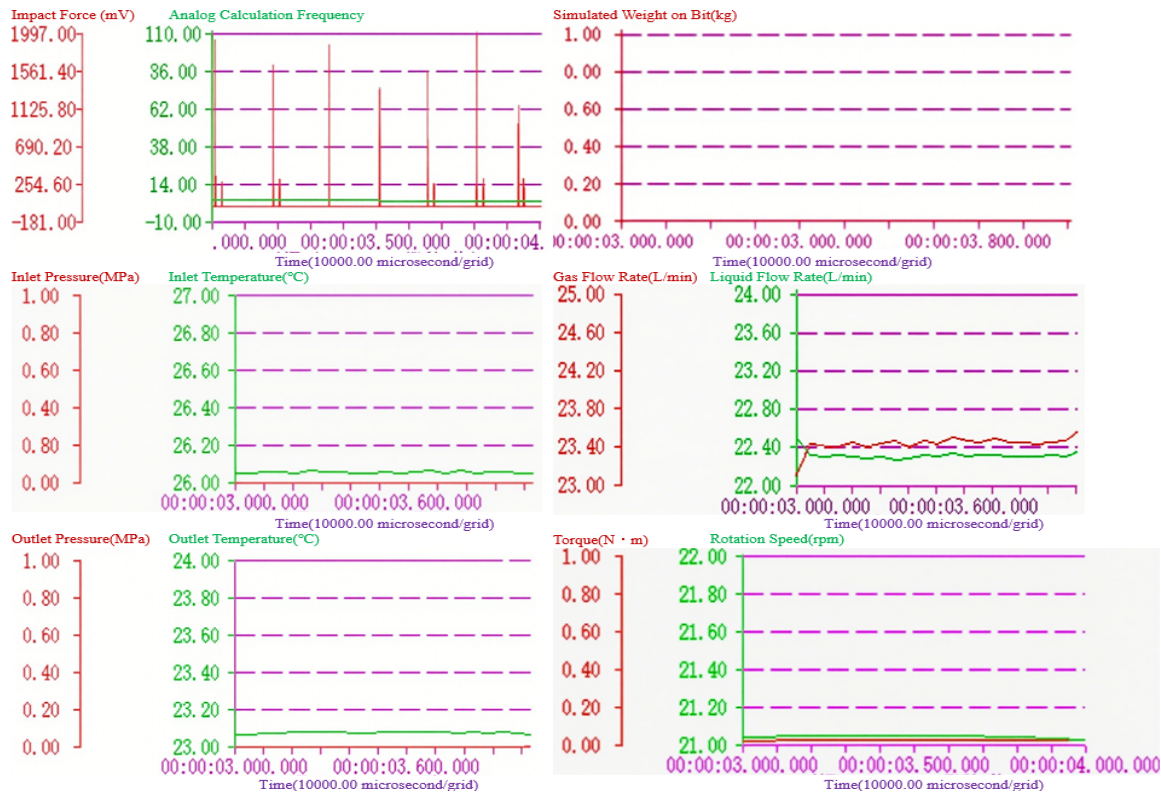


Figure 3. Impact Force Curve Diagram

Table 4. Test Data Sheet

Sampling Point Number	Impact Force (kN)	Inlet Pump Pressure (MPa)	Outlet Pump Pressure (MPa)	Flow Rate (L/min)	Impact Frequency (Hz)
1	51.7	1.94	0.26	384	30.20
2	49.2	2.05	0.30	374	29.94
3	50.7	1.99	0.33	384	27.49
4	48.9	1.90	0.28	384	28.70
5	51.2	1.84	0.26	379	27.48
Average	49.7	1.93	0.28	379	28.9

## 6. DISCUSSION

### (1) Influence of Impact Function on Rock-Breaking Efficiency

Compared with conventional screw drilling tools, impact screw drilling tools can reduce the bit stick-slip effect by more than 30% in sandstone formations, and the mechanical drilling speed is increased by 40% [20]. The optimal working conditions for the 7LZ89 drilling tool are: impact force 8 kN, frequency 5 Hz, and flow rate 450 L/min, at which time the specific rock-breaking work is reduced to 25 J/mm<sup>3</sup>.

### (2) Technical Limitations and Improvement Directions

The current platform is difficult to simulate the dynamic instability conditions of water-sensitive fractured formations. It is suggested to introduce the following in the future:

- a. Dynamic rock sample clamping device (which can simulate the change of in-situ stress);
- b. Multiphase flow circulation system (compatible with mud and foam media).

## 7. CONCLUSIONS

Designed a test platform featuring synchronized acquisition of percussion-rotary composite parameters, enabling real-time monitoring of six types of parameters (with high accuracy in impact force measurement).

Additionally, established an optimization model for "flow rate - back pressure - impact force" in hard rock drilling. Field applications demonstrated a significant improvement in the Rate of Penetration (ROP).

The proposed biaxial separation testing technology (independent measurement of impact force and torque) provides a new method for drilling tool research and development.

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