

## EVALUATIONS OF BIT SLEEVE AND TWISTED-BODY BIT DESIGNS FOR CONTROLLING ROOF BOLTER DUST

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### ABSTRACT

Drilling into coal mine roof strata to install roof bolts has the potential to release substantial quantities of respirable dust. Due to the proximity of drill holes to the breathing zone of roof bolting personnel, dusts escaping the holes and avoiding capture by the dust collection system pose a potential respiratory health risk. Controls are available to complement the typical dry vacuum collection system and minimize harmful exposures during the initial phase of drilling. This paper examines the use of a bit sleeve in combination with a dust hog-type bit to improve dust extraction during the critical initial phase of drilling. A twisted-body drill bit is also evaluated to determine the quantity of dust liberated by comparison to the dust hog-type bit. Based on these laboratory tests, the bit sleeve may reduce dust emissions by one-half during the initial phase of drilling before the drill bit is fully enclosed by the drill hole. Because collaring is responsible for the largest dust liberations, overall dust emissions can also be substantially reduced. The use of a twisted-body bit has minimal improvement on dust capture compared to the commonly used dust hog-type bit.

### INTRODUCTION

Occupational overexposure to respirable coal and quartz dust can cause coal workers' pneumoconiosis and silicosis, respectively, which are debilitating and deadly respirable lung diseases. Respirable dust exposures in United States (U.S.) coal mines are regulated by the Federal Coal Mine Health and Safety Act of 1969. The Act establishes respirable dust standards intended to reduce and ultimately eliminate the incidence of coal workers' pneumoconiosis and silicosis. To achieve this goal, coal mineworker respirable dust exposures must not exceed  $2.0 \text{ mg/m}^3$  over a working shift (Mandatory Health Standards – Underground Coal Mines, 2011). This dust limit is measured gravimetrically as an 8-hour time-weighted average concentration of the airborne respirable dust. If the dust sample contains more than 5 percent quartz by weight, the applicable reduced dust standard is computed by dividing the percent quartz into the number 10. For example, if 20 percent quartz is present, the reduced dust standard is 10 divided by 20, or  $0.5 \text{ mg/m}^3$ .

Despite these regulatory standards, recent data indicate that workers continue to be exposed to excessive levels of respirable coal and quartz dust. U.S. Mine Safety and Health Administration (MSHA) inspectors collected over 50,000 respirable dust samples for roof bolting occupations for the years 1999–2008. Of these samples, 6.3 percent exceeded the applicable dust standard for coal mine dusts. Of the 9,624 respirable quartz samples taken over the same period, 21.5 percent exceeded  $100 \text{ } \mu\text{g/m}^3$  quartz (Joy et al., 2010).

Previous studies by the U.S. Bureau of Mines (USBM) identified the largest sources of coal and quartz dust exposure to roof bolting personnel. When operating in a section with a continuous miner equipped with a scrubber unit, the roof bolting machine was found to contribute 42 and 55 percent of the bolter operator's dust and quartz exposure, respectively (Colinet et al., 1985). With the U.S. mining industry installing over 60 million roof bolts in underground applications annually (Tadolini and Mazzoni, 2006), this potential dust source and continued evidence of over exposure indicates a need for further investigations of improved dust control measures on roof bolting machines.

A majority of roof bolting machines use MSHA-approved on-board dry dust collection systems to collect drill cuttings and prevent their release into the mine atmosphere (Dust Collectors for Use in Connection with Rock Drilling in Coal Mines, 2011). These systems satisfy U.S. regulations requiring that dust generated during drilling be controlled through the use of permissible dust collectors, water, water with wetting agents, or ventilation (Health Standards for Coal Mines, 2011). A blower on the roof bolting machine draws dust and drill cuttings from the drill hole through the bit and hollow drill steel into the dust collection system. The various components work together to remove the dust from the air stream before it is exhausted to the mine atmosphere. Prior research has detailed the specific components and shown the ability of this system to successfully clean the air when both properly operated and maintained (Listak and Beck, 2008).

### Dust hog-type bit

The dust hog-type bit, with two debris collection ports on the side of the bit body, is a widely used bit design for reducing both dust liberations from roof drill holes and drilling times. Capturing the cuttings near the cutting edge has been shown to reduce escaping drill hole dust by 80 percent compared to shank-type bits (Divers, 1985). Colinet et al. observed that this difference in dust generation is largely due to the initial phase of drilling, or collaring, where the shank-type bit allowed the release of more airborne dusts (1985). In-mine studies have also observed a 63 percent increase in penetration rate compared to shank-type bits (Divers et al., 1986). An example of a typical dust hog-type bit with a length of 6 cm (2.5 in) is shown in Figure 1. One debris collection port is highlighted with the other port located on the opposite side of the bit body.

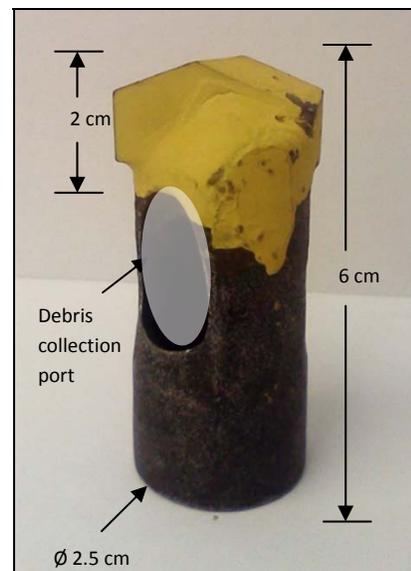


Figure 1. Detailed view of a typical dust hog-type bit.

### Bit sleeve

During the collaring phase, the inlets of a dust hog-type bit are not fully encased by rock and a portion of the dust and cuttings may escape the dry collection system. To address this issue, Kennametal Inc. (Latrobe, PA) has developed a bit sleeve intended to improve the

dust hog-type bit's ability to capture drill cuttings during this critical phase. The prototype device, shown in Figures 2 and 3, is 9 cm (3.5 in) in length and surrounds the bit, confining the cuttings as the bit advances far enough to be fully encapsulated by rock. One or more spring clips may be attached to the drill steel to support the bit sleeve, holding the sleeve flush against the mine roof until the hole is completed. Upon completion, the large washer, placed under the sleeve, may be slid up the drill steel's length to reposition the sleeve and clip combination over the drill bit for the next hole.



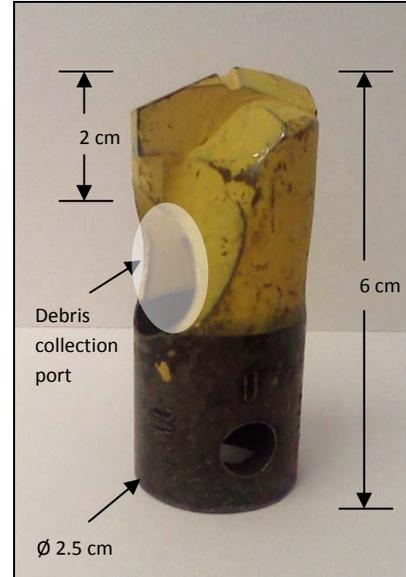
**Figure 2.** Detailed view of a prototype bit sleeve, spring clip, and washer.



**Figure 3.** Prototype bit sleeve, spring clip, and washer installed on a 22-mm-diameter (7/8-in.-diameter) round drill steel.

#### Twisted-body bit

A “twisted-body” (Kennametal product name ProBore) bit has two tapered inlets on the side of the bit body. The manufacturer has observed that these inlets allow drill cuttings and visible dust to more easily enter the collection system. The bit is designed to also reduce clogging and lower cutting forces (“Safer productivity with ProBore, ProPoint,” 2010). In operation this bit is used in the same manner as the standard dust hog-type bit. An example of this bit design is presented in Figure 4.

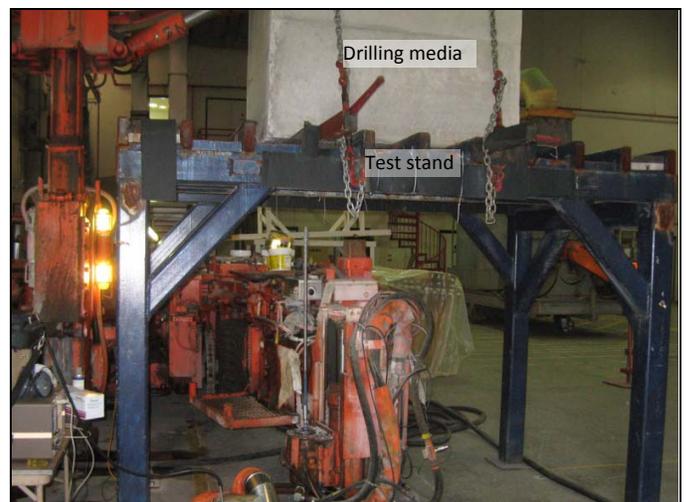


**Figure 4.** Detailed view of a twisted-body bit with tapered dust collection port inlets.

The objective of this National Institute for Occupational Safety and Health (NIOSH) study is to compare respirable dust generation using (1) the typical dust hog-type bit; (2) a newly developed drill bit sleeve with the dust hog-type bit; and (3) a newly developed twisted-body drill bit. This study evaluates the quantity of respirable dust liberated in the collaring process as well as that generated over a full drilling depth.

#### METHODS

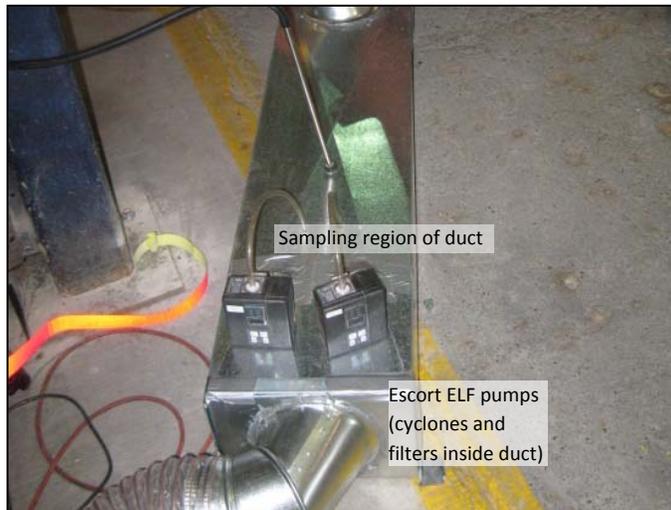
In order to obtain results that would be applicable to the underground mining environment, drill hole dust emissions were measured during the drilling of overhead, vertical holes. These tests were conducted in a surface facility of NIOSH, Office of Mine Safety and Health Research in Pittsburgh, PA. A test stand supported a block of unreinforced concrete into which holes were drilled (Figure 5). Concrete with a fully cured strength of 41.4MPa (6,000 psi) was selected to simulate the compressive strength of the shale and siltstone roof rock found in many coal mines (Rusnak and Mark, 2000). The concrete mix contained 55 percent aggregate and a 45 percent combination of mortar, sand, and water. The 1.1-m thick (42-in.-thick) block of concrete permitted 0.9-m deep (36-in. deep) holes without the risk of drilling through. The drilling media was allowed to cure for a minimum of 28 days before drilling tests commenced.



**Figure 5.** Experimental drilling test stand supporting concrete drilling media.

Holes were drilled by a J.H. Fletcher and Co. (Huntington, WV) walk-through dual-head roof bolting machine (Model HDDR-13-C-F) with on-board vacuum dust collection system. The dust collection system was cleaned prior to this study. The system was allowed to exhaust into the building atmosphere. The dust collector vacuum was monitored between holes at the drill chuck and maintained at 0.58 bar (17 in. Hg). The maximum rotational speed of the drill head was set to 400 rotations per minute for all tests while the drill thrust was maintained at 15.6 kN (3500 lbs). Holes were drilled to a depth of 0.9 m (36 inches) using a 25.4-mm-diameter (1-in.-diameter) drill bit fitted to a 22.2-mm-diameter (7/8-in.-diameter) round drill steel. A new bit was used for each hole drilled.

A containment and sampling duct was used to confine and sample the dust that escaped from the drill hole. A 15.2-cm-diameter (6-in.-diameter) inlet was mounted beneath the test block, immediately adjacent to the contact area between the drill steel and concrete. The collection inlet was moved in concert with the drilling apparatus to maintain proximity to the dust source as new hole locations were selected. A centrifugal fan, mounted at the exhaust end of the duct, induced airflow to collect and transport dusts to a sampling portion of ductwork (Figure 6) before being exhausted from the building. The air velocity in the sampling portion of the ductwork was maintained at 0.76 m/s (150 feet per minute), as measured by a TSI thermal anemometer (VelociCalc Model 8346, Shoreview, MN). This air velocity was well below the critical range for Dorr–Oliver cyclone sampling errors due to orientation and velocity effects as identified by Cecala et al. (1983), but provided positive air movement and ensured capture of fugitive dusts from the drilling zone. Respirable dust sampling was accomplished with a combination of instantaneous and gravimetric instrumentation.



**Figure 6.** Sampling portion of the dust containment and sampling duct.

For gravimetric sampling of dust, two coal mine personal dust sampling units were placed in the duct. Escort ELF constant flow pumps (Mine Safety Appliances Co., Pittsburgh, PA) pulled dust-laden air through 10-mm Dorr–Oliver cyclone separators at a rate of 2.0 L/min. The respirable mass was deposited onto pre-weighed 37-mm PVC filters that were subsequently post weighed to determine dust concentrations. Filter weights were desiccated before both pre- and post weighing and adjusted by control filters to account for any variability in weighing conditions. The gravimetric samplers were operated continuously during these drill tests to ensure sufficient mass accumulation on the filters. The average concentration of the two gravimetric samplers was used in the analysis.

Instantaneous dust measurements were made every 1 second using a personal DataRAM (pDR) light scattering dust monitor (Model pDR-1000AN, Thermo Scientific, Franklin, MA) placed inside the sampling duct. Because the pDR measurements are affected by aerosol size distribution and content, the pDR values must be corrected by the gravimetric measurements. This was accomplished by

calculating the ratio of the pDR average concentration and the gravimetric concentration for the same time period (Thermo Scientific, 2008). This field calibration procedure is presented in closer detail by Colinet et al. (2010). All pDR concentrations presented in this paper have been adjusted using this gravimetric correction.

The study included 48 trials of the following three drilling conditions:

1. drilling with the dust hog-type bit alone,
2. drilling with the dust hog-type bit and prototype bit sleeve, and
3. drilling with the twisted-body bit alone.

The first test condition was considered to be the baseline against which the other conditions were compared. Sixteen holes were drilled for each condition in a randomized order. Three times were recorded for each hole: (1) the start of drill rotation; (2) when the bit was 0.3 m (12 inches) deep; and (3) the end of drill rotation at a full depth of 0.9 m (36 inches). For the purposes of this study, the period of time from the initial start of drilling until the bit reached a depth of 0.3 m (12 inches) was considered to be “initial,” while the final 0.6 m (24 inches) was termed “final.” Penetration rates were determined based on the elapsed time from the beginning of drill rotation to the end of drill rotation. The penetration rate for each trial was calculated by dividing the total depth drilled by the elapsed drilling time.

## RESULTS

Table 1 details drilling times for the three conditions. The time to drill 0.9m deep into concrete ranges from 16 to 35 seconds, averaging 20.9 seconds for all trials. The standard deviations observed for the dust hog-type bit and bit sleeve combination are significantly higher than for the other conditions due to a 35-second trial, though there was no immediately observable cause for the extended drilling time. Overall average drill times of 20.4, 21.1, and 21.3 seconds are similar for each test condition. The time to complete each individual phase of drilling is likewise consistent among test conditions, with a range of 6.4 to 6.9 seconds for initial stages and 13.7 to 14.6 seconds for final stages. Average penetration rates of 4.52, 4.45, and 4.32 cm/sec are also similar for each test condition.

**Table 1.** Elapsed drilling times and penetration rates by test condition and phase of drilling (SD=standard deviation)

Test Condition		Initial (sec)	Final (sec)	Full (sec)	Pen. rate (cm/sec)
Dust hog-type bit alone	Mean	6.9	13.7	20.4	4.52
	SD	0.8	1.9	1.8	0.43
Dust hog-type bit and bit sleeve	Mean	6.4	14.6	21.1	4.45
	SD	1.0	3.9	4.0	0.61
Twisted-body bit alone	Mean	6.8	14.5	21.3	4.32
	SD	0.5	1.8	1.7	0.33
All conditions	Mean	6.6	14.3	20.9	4.42
	SD	0.8	2.7	2.7	0.48

The time-dependent nature of the drill hole dust emissions is demonstrated in Figure 7. The figure shows that the dust concentration for all conditions quickly rises at the start of drilling and then quickly returns to a low concentration once the bit is fully inserted into the hole. For the remainder of the drilling time there is very little dust emitted from the drill hole. This finding is consistent with the observations from similar roof drilling tests conducted by BCR National Laboratory for USBM (Colinet et al., 1985). The behavior is observed for all three test conditions, though the peak dust concentration is considerably lower for tests of the prototype bit sleeve.

A summary of the gravimetric-adjusted respirable dust monitoring results for the three test conditions is presented in Table 2. The change values in the table compare the specific method with the baseline use of a dust hog-type bit alone. Drilling vertical holes into concrete using a typical dust-hog type bit results in an average concentration of 1.30 mg/m<sup>3</sup> for the full duration of the sixteen trials, while mean concentrations of 2.76 and 0.38 mg/m<sup>3</sup> are observed for initial and final phases, respectively. Drilling holes using the same parameters with the addition of a prototype bit sleeve reduces the full

dust generation by 49 percent to 0.66 mg/m<sup>3</sup>, with the largest reduction occurring during the initial phase (57 percent). The 16 tests of the twisted-body bit do not result in a large change in fugitive dust emissions, though there is an increase of 7 percent during the initial collaring phase. The previously mentioned 35-second trial of the dust hog-type bit and bit sleeve has average dust concentrations of 1.79 mg/m<sup>3</sup> and 0.35 mg/m<sup>3</sup> in the initial and final periods, respectively, for an overall average of 0.67 mg/m<sup>3</sup>. These values are consistent with the average for this test condition, showing no abnormal dust effects associated with the extended test duration.

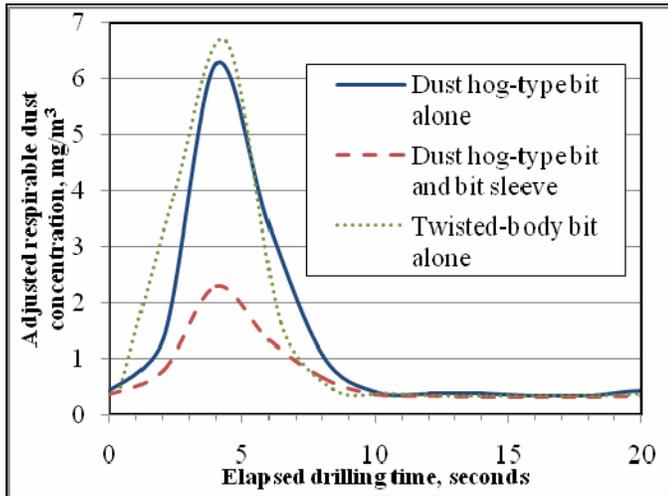


Figure 7. Adjusted respirable dust concentration over time.

The mean dust concentrations for each set of test conditions were tested for normality by one-sample Kolmogorov–Smirnov tests. Each test condition produces a distribution of values consistent with the null hypothesis of normality. Student’s t-tests were performed to compare the mean dust concentration for each phase between the baseline and both experimental test devices. The results of these tests are presented in Table 3. When comparing the dust emissions for the baseline test condition to the bit sleeve over initial and full periods, two-sided t-tests for equality of means results in t statistics of 3.191 and 3.725 and p-values of 0.003 and 0.001, respectively. At a significance level of 0.05, the null hypotheses of equal means between test conditions are rejected, and it is concluded that the bit sleeve combination produces lower dust concentrations than the dust hog-type bit alone during both initial and overall drilling periods. Similar t-tests comparing initial and overall dust concentrations of the twisted-body bit to the baseline result in t statistics of -0.352 and -0.092 for p-values of 0.727 and 0.927, respectively. At a statistical significance level of 0.05, there is not enough evidence to reject the null hypothesis that the average dust concentrations observed during baseline conditions and twisted-body are significantly different. Tests comparing the penetration rates for the tested configurations result in p-values exceeding 0.05 for no significant difference in the mean value between conditions.

Table 2. Gravimetric-adjusted dust concentrations by test condition and phase of drilling (SD=standard deviation)

Test Condition		Initial (mg/m <sup>3</sup> )	Final (mg/m <sup>3</sup> )	Full (mg/m <sup>3</sup> )
Dust hog-type bit alone	Mean	2.76	0.38	1.30
	SD	1.61	0.09	0.53
Dust hog-type bit and bit sleeve	Mean	1.19	0.37	0.66
	SD	1.15	0.08	0.43
	Change	-57%	-3%	-49%
Twisted-body bit alone	Mean	2.95	0.36	1.31
	SD	1.35	0.10	0.50
	Change	7%	-5%	1%

Table 3. Comparison of dust emissions for each test condition to the dust hog-type bit with t statistic values and two-sided p-values (\*significant at p<0.05)

Test Condition		Initial	Final	Full	Pen. Rate
Dust hog-type bit and bit sleeve	t	3.191	0.226	3.725	0.412
	p-value	0.003*	0.823	0.001*	0.683
Twisted-body bit alone	t	-0.352	0.604	-0.092	1.509
	p-value	0.727	0.551	0.927	0.142

## DISCUSSION

These laboratory tests monitored drill hole dust emissions while drilling into a block of concrete with controlled parameters. Several considerations may impact the translation of this study’s findings to the underground coal mining environment:

- When using the bit sleeve device in laboratory tests, the flat surface of the concrete allowed the sleeve to sit flush against the drilling medium. Gaps from rough and uneven roof surfaces typically found in underground mines may hinder optimal dust capture ability.
- The drilling parameters of rotational speed and thrust force were selected to maintain consistent drilling advance rates across test conditions and to prevent premature failure of the test bits. Drilling at different rates has been shown to significantly affect fugitive dust generation (Divers and Jankowski, 1987) and may alter the dust collection capabilities of the bit sleeve and twisted-body bit.
- This study evaluated normal events during drilling and did not consider potential dust release events which may occur during temporary clogging of the dust collection system. The twisted-body bit may present fugitive dust reductions if the bit design prevents debris from clogging the inlets, leading to dust release events.
- This study focused exclusively on dust from the drill hole and did not consider potential effects on dust collector emissions.
- A separate version of the prototype bit sleeve device is designed to be used with hexagonal drill steels. This study investigates the device for use with round drill steels. Consequently, the dust capture performance of the alternative version has not been evaluated and similar reductions may not be realized.
- Drill hole emissions were collected adjacent to the drilling region and were not permitted to migrate to the operator’s breathing zone. Due to the nature of the dust sampling methods used in this study, it is impossible to directly determine an operator’s exposure with the various configurations.

Even taking into consideration these potential limitations, it is apparent that drilling performed with the bit sleeve and dust hog-type bit combination presents a statistically significant reduction in drill hole respirable dust emissions. Laboratory drilling with the twisted-body bit does not present the same reductions, but use of the bit in underground settings may produce some benefits.

## SUMMARY

Recent data collected by MSHA show that roof bolting occupations are at risk of overexposure to coal and quartz dusts. Research has shown that much of this overexposure can be attributed to the dusts generated by the roof bolting process. Roof bolter drill hole dust emissions, simulated in these NIOSH laboratory drilling tests, may contribute to this hazard, especially in the presence of inadequate ventilation.

NIOSH researchers compared the dust emissions from the use of newly developed drilling tools to the baseline of dust emissions produced by a typical dust-hog type bit during laboratory drilling tests. Based on the results of these vertical drilling tests, the bit sleeve device and dust hog-type bit combination is capable of eliminating up

to one-half of the respirable dusts escaping while drilling. The reductions occur during the initial phase of drilling, where the highest dust concentrations are observed, regardless of drilling configuration. A twisted-body bit, though possibly reducing bit clogging and improving collection of larger cuttings, is found to have no impact on drill hole respirable dust emissions while drilling. The penetration rate is found to be unchanged by the choice of configuration. Though not planned at this time, further tests of the devices in an underground setting would help to test the validity of these findings and also quantify the potential impact on roof bolter operator respirable dust exposures.

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#### **DISCLAIMER**

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health. The findings and conclusions in this report are those of the author and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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