Technology Focus: Mechanical Components

Mars Science Laboratory Drill

This device also has applications for drilling in mines and other dangerous areas.

NASA's Jet Propulsion Laboratory, Pasadena, California

This drill (see Figure 1) is the primary sample acquisition element of the Mars Science Laboratory (MSL) that collects powdered samples from various types of rock (from clays to massive basalts) at depths up to 50 mm below the surface. A rotary-percussive sample acquisition device was developed with an emphasis on toughness and robustness to handle the harsh environment on Mars. It is the first rover-based sample acquisition device to be flight-qualified (see Figure 2). This drill features an autonomous tool change-out on a mobile robot, and novel voice-coil-based percussion.

The drill comprises seven subelements. Starting at the end of the drill, there is a bit assembly that cuts the rock and collects the sample. Supporting the bit is a subassembly comprising a chuck mechanism to engage and release the new and worn bits, respectively, and a spindle mechanism to rotate the bit. Just aft of that is a percussion mechanism, which generates hammer blows to break the rock and create the dynamic environment used to flow the powdered sample. These components are mounted to a translation mechanism, which provides linear motion and senses weight-on-bit with a force sensor. There is a passive-contact sensor/stabilizer mechanism that secures the drill's position on the rock surface, and flex harness management hardware to provide the power and signals to the translating components. The drill housing serves as the primary structure of the turret, to which the additional tools and instruments are attached.

The drill bit assembly (DBA) is a passive device that is rotated and hammered in order to cut rock (i.e. science targets) and collect the cuttings (powder) in a sample chamber until ready for transfer to the CHIMRA (Collection and Handling for Interior Martian Rock Analysis). The DBA consists of a 5/8-in. (≈1.6-cm) commercial hammer drill bit whose shank has been turned down and machined with deep flutes designed for aggressive cutting removal. Surrounding the shank of the bit is a thick-walled maraging steel collection tube allowing the powdered sample to be augured up the hole into the sample chamber. For robustness, the wall thickness of the DBA was maximized while still ensuring effective sample collection. There are four recesses in the bit tube that are used to retain the fresh bits in their bit box.

The rotating bit is supported by a back-to-back duplex bearing pair within a housing that is connected to the outer DBA housing by two titanium diaphragms. The only bearings on the drill in the sample flow are protected by a spring-energized seal, and an integrated shield that diverts the ingested powdered sample from the moving interface. The DBA diaphragms provide radial constraint of the rotating bit and form the sample chambers. Between the diaphragms there is a sample exit tube from which the sample is transferred to the CHIMRA. To ensure that the entire collected sample is retained, no matter the orientation of the drill with respect to gravity during sampling, the pass-through from the forward to the aft chamber resides opposite to the exit tube.

The drill spindle mechanism (DSM), nested within the chuck/spindle subassembly, provides the torque to rotate the bit for drilling and unlocking the fresh bit assemblies from the bit box. The mechanism is actuated by an electrically commutated gear motor that drives the spindle shaft via a spur gear train. The maximum mean contact stress in the bearings is kept low to prevent lube degradation. Mounted to the shaft is a dirt-tolerant torque coupling that transmits torque to the bit. The coupling accommodates axial, radial, and angular motion between the bit and spindle

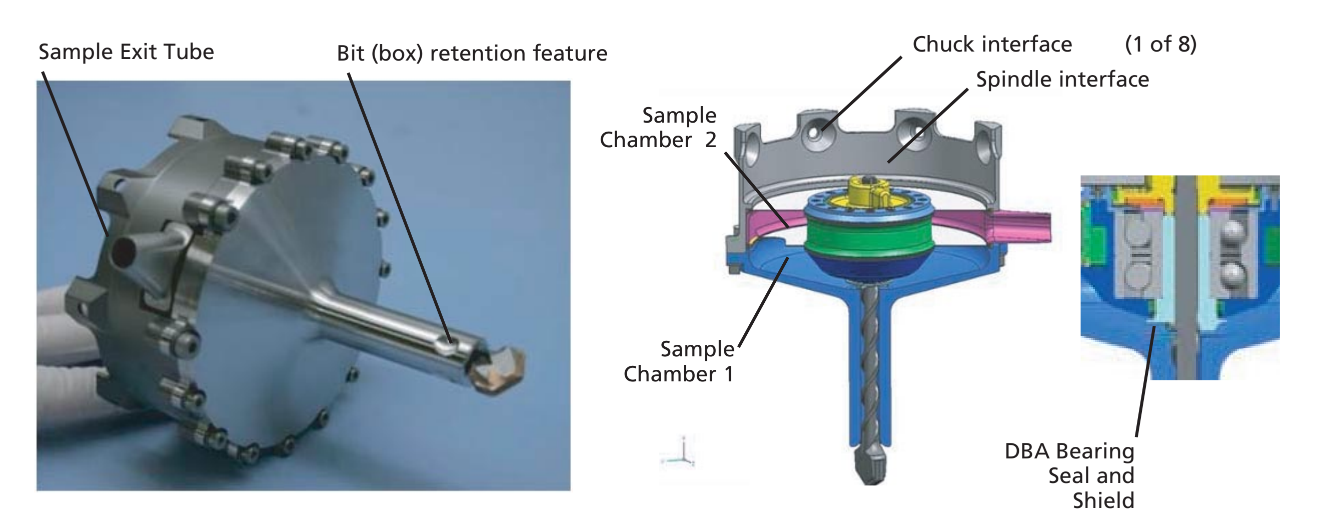

Figure 1. The **Drill Bit Assembly** (left) and **Sample Paths and Interfaces** (right) for the DBA.

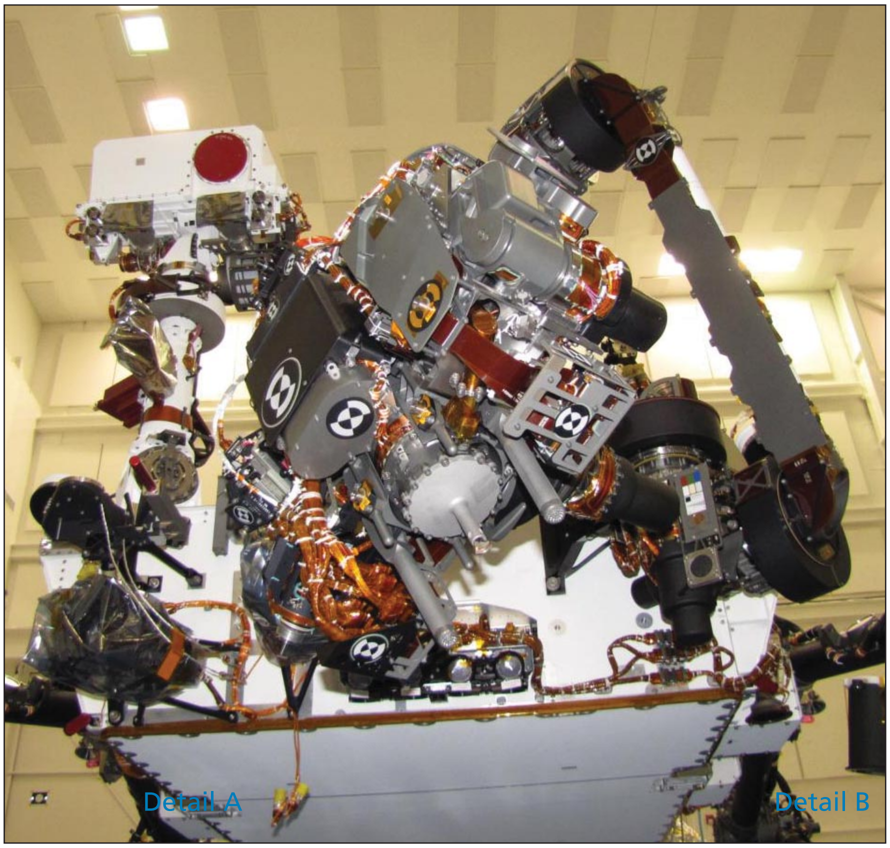

Figure 2. The flight **MSL Drill** undergoing system-level testing after it has been integrated at the end of the robotic arm on the MSL Rover.

shaft to permit the following functions: the transmission of the hammer blow directly onto the bit, the mating of a fresh bit, and release of the bit both in free space and under load.

The drill chuck mechanism (DCM), also residing within the chuck/spindle subassembly, enables the drill to release worn bits and take hold of fresh ones stored on the rover front panel. The design driver was not just to survive a worst-case load scenario — the complete slip of the rover on a Martian slope — but to release the bit while subjected to it.

The drill percussion mechanism (DPM) generates the impact needed to break the rock and the dynamic (vibration) environment required to move powdered sample through the DBA. The mechanism operates at 1,800 blows-per-minute and has variable impact energy levels that range from 0.05 to 0.8 Joules. The DPM is a functionally simple device consisting primarily of a hammer assembly, energy storage spring, and housing/linear bearing assembly. The DPM is actuated by a long-stroke voice coil that is operated using an open loop voltage drive method. Within the DPM is an array of reed switch sensors that provides coarse hammer position telemetry.

The drill translation mechanism (DTM) provides the linear motion of the bit, spindle, chuck, and percussion drill subassemblies for the following functions: maintaining 120 N weight-on-bit (WOB) during sample acquisition, generating the retraction force to extract the bit from the hole, and mating to a fresh bit in the bit box.

The dual-bridge force sensor is required to sense the low WOB because the nominal axial load is too low to be observed in the actuator current telemetry. The inner diameter of the force sensor is axially clamped to the ball nut. The force sensor outer diameter is axially constrained between two preloaded wave springs. The force sensor and wave springs are housed in a gimbal assembly, which couples the translation mechanism to the translation tube. The gimbal isolates the ball screw and force sensor from radial and bending loads.

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Ultra-Compact Motor Controller

Applications include industrial robotic arms, industrial machinery, and automobiles.

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This invention is an electronically commutated brushless motor controller that incorporates Hall-array sensing in a small, 42-gram package that provides 4096 absolute counts per motor revolution position sensing. The unit is the size of a miniature hockey puck, and is a 44-pin male connector that provides many I/O channels, including CANbus, RS-232 communications, general-purpose analog and digital I/O (GPIO), analog and digital Hall inputs, DC power input (18–90 VDC, 0–10 A), three-phase motor outputs, and a strain gauge amplifier.

This controller replaces air cooling with conduction cooling via a high-thermal-conductivity epoxy casting. A secondary advantage of the relatively good heat conductivity that comes with ultra-small size is that temperature differences within the controller become smaller, so that it is easier to measure the hottest temperature in the controller with fewer temperature sensors, or even one temperature sensor.

Another size-sensitive design feature is in the approach to electrical noise immunity. At a very small size, where conduction paths are much shorter than in conventional designs, the ground becomes essentially isopotential, and so certain (space-consuming) electrical noise control components become unnecessary, which helps make small size possible. One winding-current sensor, applied to all of the windings in fast sequence, is smaller and wastes less power