Mars Science Laboratory Drill

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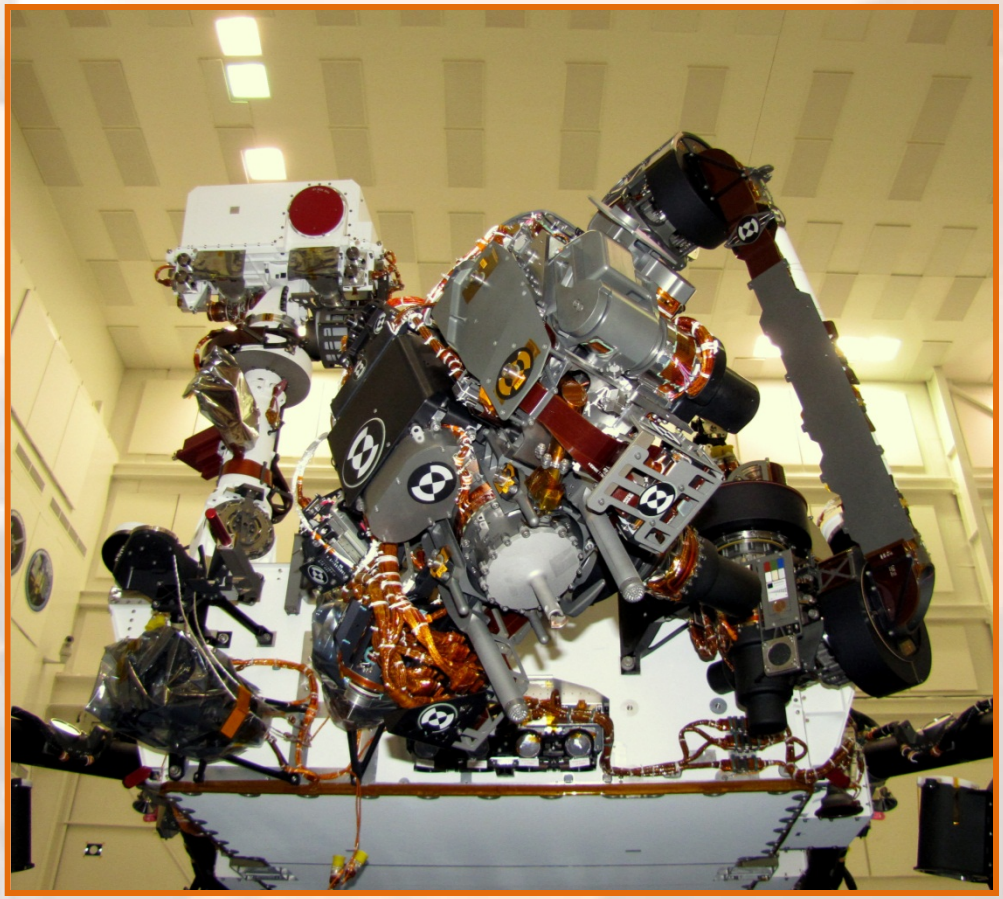
Mars Science Laboratory (MSL) Highlights

- Next rover mission to Mars landing in August 2012
- Primary mission lasts one Martian year (687 earth days)
- New Entry Descent and Landing system
- Long range mobility system capable of traveling many kilometers

- Extensive science payload to study rocks, soils, and the local geologic setting in order to detect chemical building blocks of life
- Sample Acquisition, Sample Processing and Handling system (SA-SPaH)

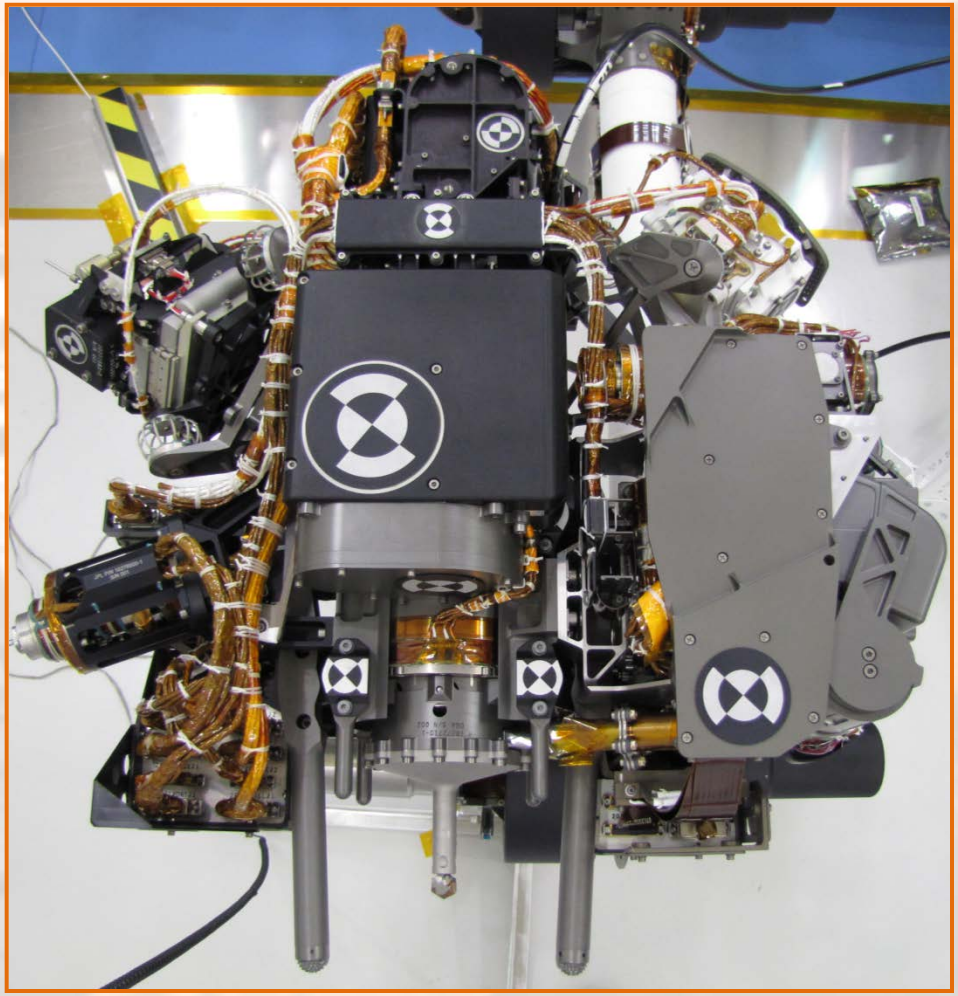
Sample Acquisition and Sample Processing and Handling (SA-SPaH) Subsystem

- 2-m long 5-DOF Robotic Arm
- Tool and Instrument laden Turret
  - Powder Acquisition Drill
  - Collection and Handling for Interior Martian Rock Analysis (CHIMRA)
  - Dust Removal Tool (DRT)
  - Alpha Particle X-ray Spectrometer (APXS)
  - Mars Hand Lens Imager (MAHLI)
- Front Panel Equipment
  - Organic Check Material (OCM)
  - Bit Boxes (2X)
  - Observation Tray
- Instrument inlet covers: SAM (2X) and CheMin



MSL Drill Description and Capabilities

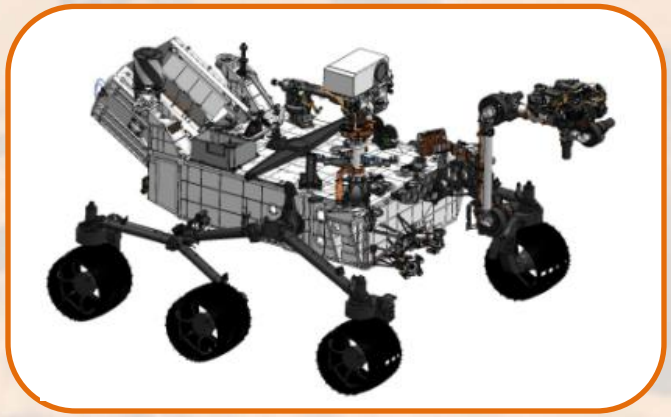
- Rotary-percussive tool that collects fine powdered rock samples and transfers them to CHIMRA for processing and delivery to the science instruments
- From 20 mm up to 50 mm sampling depth in Smectites, Phyllosilicates, Volcanic Breccia, Belleville Basalt, Saddleback Basalt (soft clay to massive basalt)
- Gravity orientations from vertical (downward) to 20° upward (horizontal w.r.t rover while the rover is pointed upslope)
- Operation over severe temperature extremes
  - Heat-to-use mechanism: to -70 C (-85 C) to +70 C
  - Non-heated items: -115 C to +70 C



Drill Operational Overview

- **Tool Placement and Preload**
  - RA engages the rock target, contact is indicated by limit switches within the Drill Contact Sensor / Stabilizers (DCSS)
  - RA pushes the Drill onto the rock to preload the DCSS
- **Sample Acquisition**
  - Drill powders and collects rocks by hammering, rotating and feeding the bit
  - Weight-on-bit (WOB) is maintained by autonomously adjusting the feed rate

- **Sample transfer to CHIMRA**
  - A combination of gravity vector manipulations by the RA and vibration environment by the percussion mechanism transfers the powder rock from Drill Bit Assembly collection chambers into CHIMRA sample transfer tube.



Design Challenge: Robustness for Operation in Martian and on Steep Terrain

- **Operation in a dirty environment without servicing**
  - **Mechanism interior and external moving elements are sealed from dust allowing**
- **Survive large lateral and moment loads generated by the rover slipping on sloped terrain**
- **Single fault can not result in anchoring the rover to the Martian surface**
  - **Two ways to get out of stuck bit scenario: generate a bit large retraction force and jettison the bit (even whilst subjected to large side loading)**

Modular Design Philosophy

- Compressed development schedule forced a parallel approach
- Early definition of simple interfaces allowed a staggered design maturity timeline
- Minimized intertwined functionality
  - Subassemblies to underwent mechanism qualification testing prior to top level integration
  - Design issues were found early
  - An issue found on a subassembly did not impede the progress of the others (in one case a preemptive correction was implemented)
  - Qualification test remains valid after integration at the top level

Drill Subassemblies

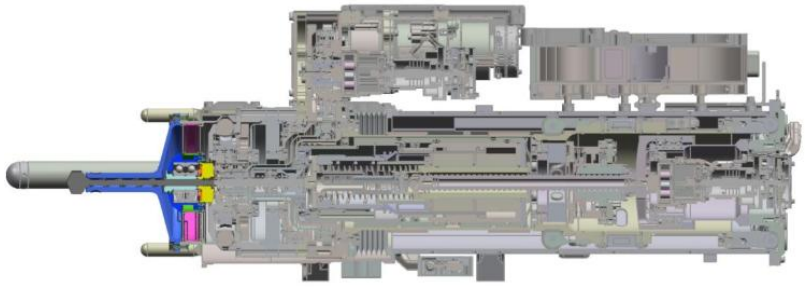
- The MSL drill is comprised of 8 functional elements:

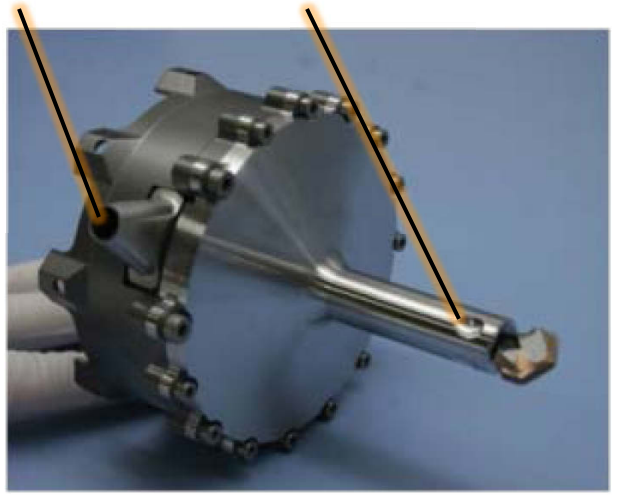
- 4 of them are active (actuated):
  - Spindle Mechanism
  - Chuck Mechanism
  - Feed Mechanism (with integral force sensor)
  - Percussion Mechanism

- 4 of them are passive:
  - Bit Assembly
  - Contact Sensor / Stabilizer
  - Structure and Linear Bearing System
  - Flex-cable Service Loop

Drill Bit Assembly (DBA)

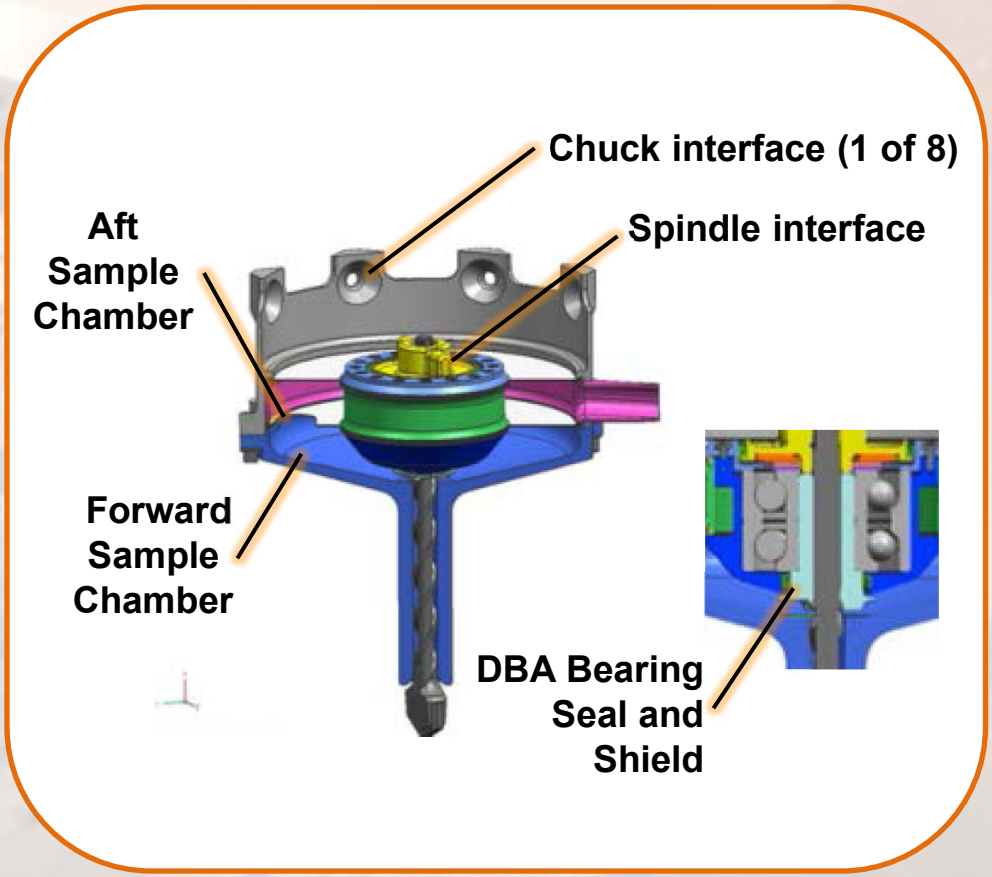
- Functional Description
  - Powders, collects and holds sample until ready to transfer to CHIMRA
  - Sample acquisition begins once collection tube is below surface (at 20 mm depth)
  - Replaceable component in operation
    - 2 spare DBA's on rover front panel
- 5/8" commercial hammer drill bit
  - Reduced in diameter and flutes machined
- Thick-walled maraging steel collection tube
- Sample exit tube is dock with CHIMRA when the drill is stowed





Drill Bit Assembly (DBA)

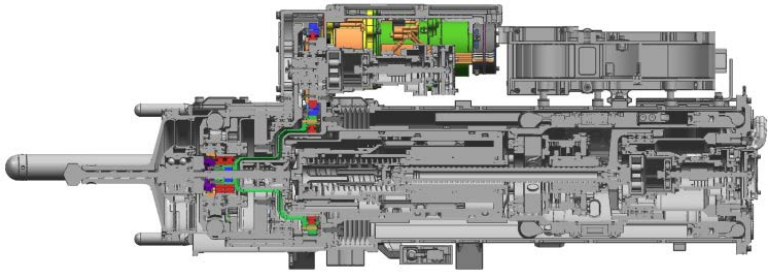
- Bit suspended by titanium diaphragms
  - Forms the sample collection chambers (labyrinth that prevents loss of sample at all required orientations)
  - Provides Radial constraint of bit
  - React WOB (along with springs in Percussion Mech.)
  - Axial compliance for effective percussion
- DBA bearings is the sole instance of a moving interface in sample path, mitigated by:
  - Shield and spring energized seal to protect bearings
  - Bit replacement capability
- DBA Interfaces
  - 8 circumferential, conical recesses in its housing
  - Torque coupling affixed to the end of the bit shank

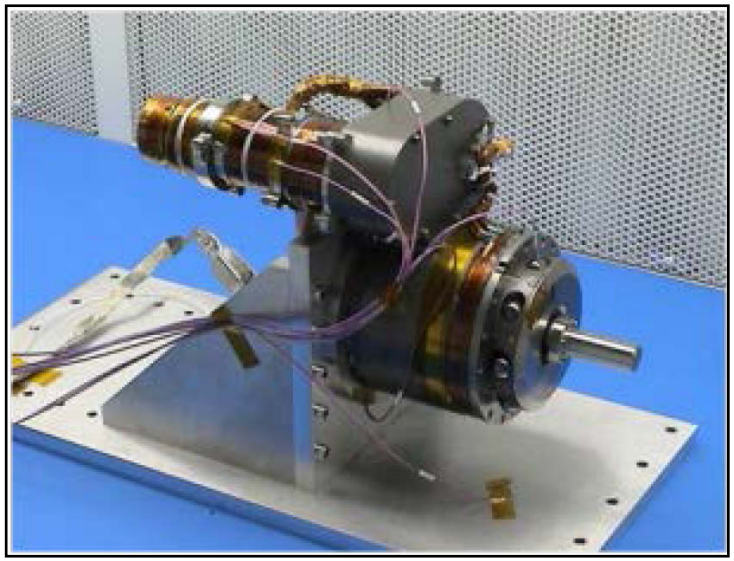


Drill Spindle Mechanism

- Distributes impacts circumferentially in hole during drilling
- Acquires (augers) powder from within hole
- Engages DBA torque coupling during bit exchange
- Unlocks DBA from bit box

- Salient Features:
  - Actuated by an electrically-commutated gearmotor
  - Spur geartrain for packaging, final gear ratio adjustability
  - Dirt tolerant torque coupling allows:
    - Hammer blow transmission to bit
    - Fresh bit mating
    - Release of bit (in free space and under load)

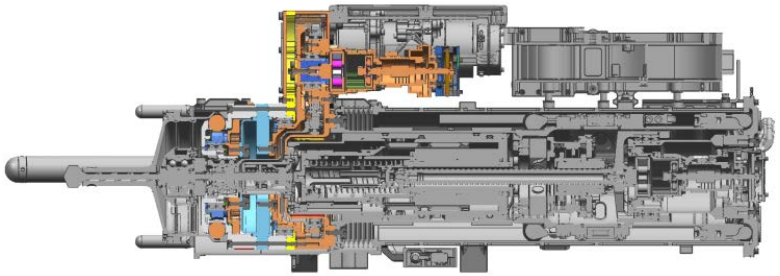


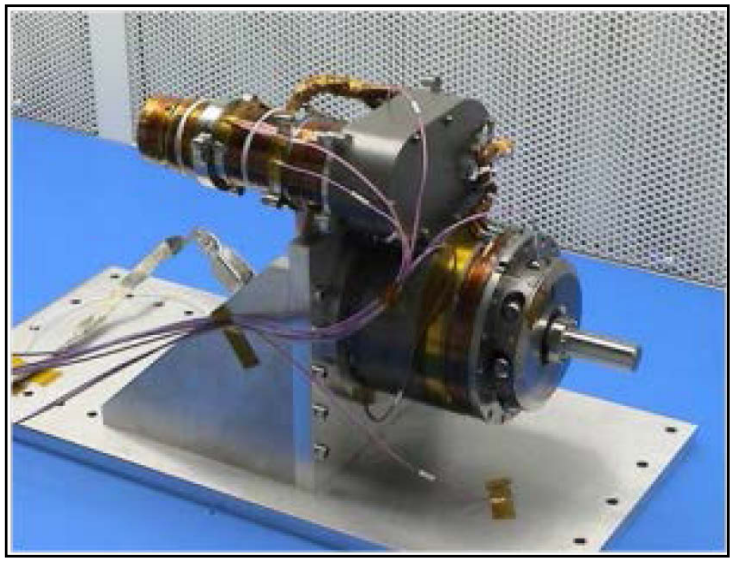


Drill Chuck Mechanism

- Releases bit (either in free space or under severe loads)
- Engage new bit assemblies

- Salient Features:
  - Dirt tolerant ball lock device
  - Cam drivetrain:
    - electrically-commutated gearmotor with a power-off brake
    - single spur gear stage
    - harmonic drive
  - Conforming cam profile implemented to reduce contact stress
  - Significant development testing to:
  - Finalize cam geometry and lubrication
  - Verify design's dirt tolerance

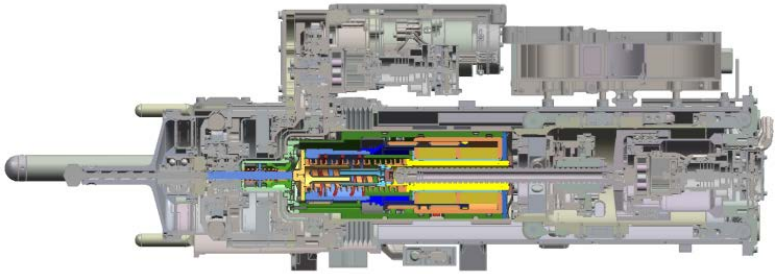


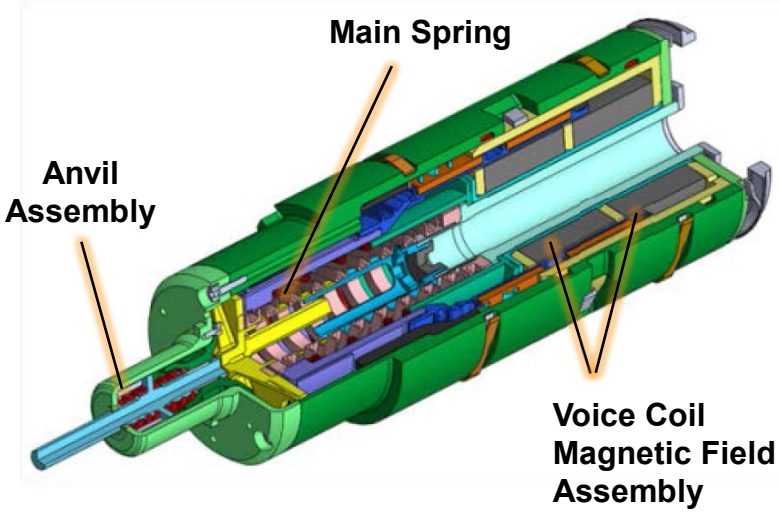


Drill Percussion Mechanism

- Provides impact to break the rock
- Generates dynamic environment required to move powdered sample through the DBA
- Anvil springs react WOB (along with DBA diaphragms)

- Salient Features:
  - Voice coil actuated
  - 1800 blows-per-minute (30 Hz)
  - Variable impact energy: 0.05 to 0.8 Joules
  - The hammer strikes an anvil rod which then transfers the stress wave to the end of the bit
  - Operates at resonance: rebounded energy is captured by a spring and reused
  - Simple and robust telemetry sensor
  - Novel open loop drive method

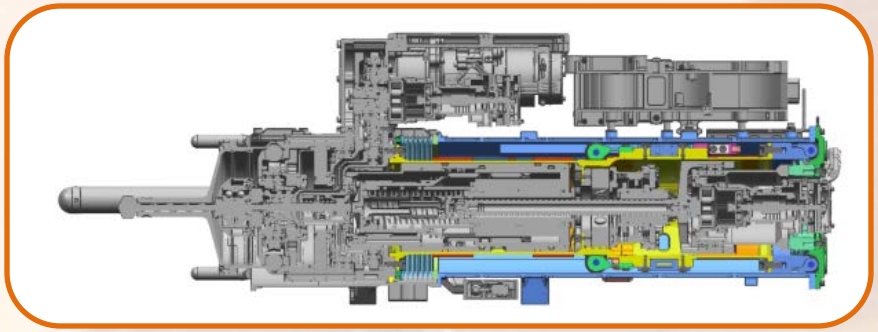




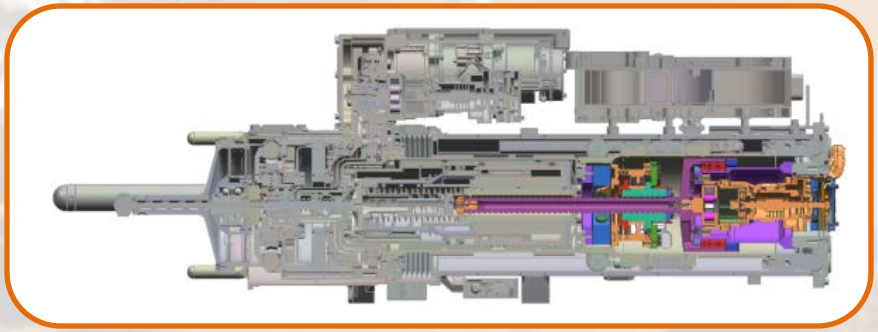
Drill Translation Mechanism (DTM)

- Provides linear motion of the Drill sub-assemblies
- Maintains and senses 120 N weight-on-bit for drilling
- Generates up to 10,000 N of retraction force
- Two primary elements:
  - Structure and linear bearing system
  - Ball screw mechanism and integral force sensor

Linear bearing / Housing



Ball Screw Mechanism



DTM Housing / Linear Bearing System

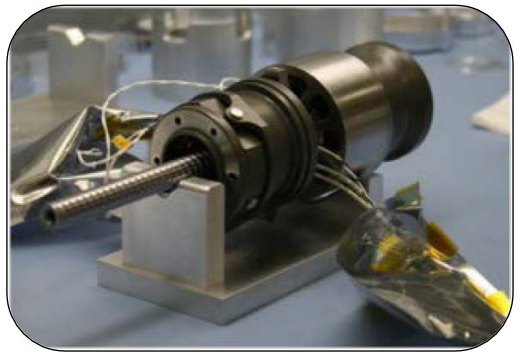
- Drill housing forms the backbone of the turret
  - Tools, instruments and cable brackets are mounted to the structure
  - Internal surfaces provided the rails for the rolling bearing elements
- Translation tube forms the backbone of the Drill
  - Chuck / Spindle and Percussion subassemblies are mounted to and within it, respectively
  - Two (fore & aft) sets of 6 pairs of roller bearings sized for operation under the worst-case load scenario
- Metal bellows between the translation tube and the housing protect all internal mechanisms from dirt

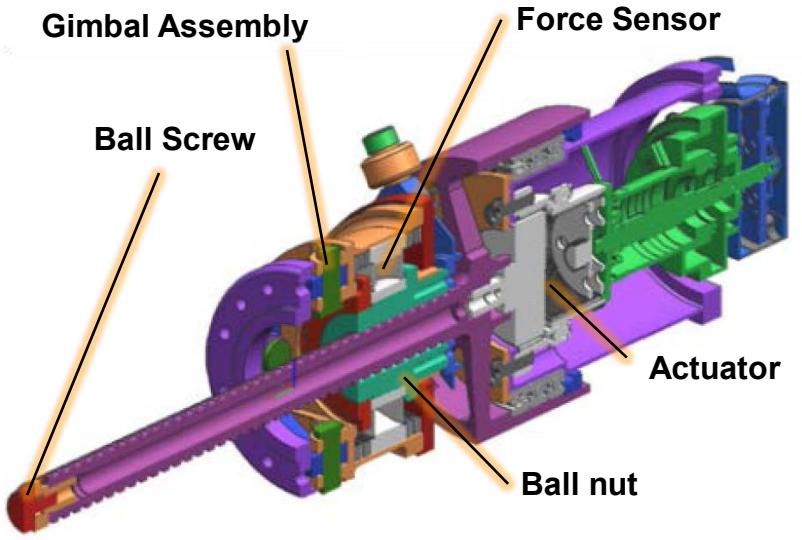
Aft Housing

Translation tube with linear bearing system

DTM Ball Screw Mechanism

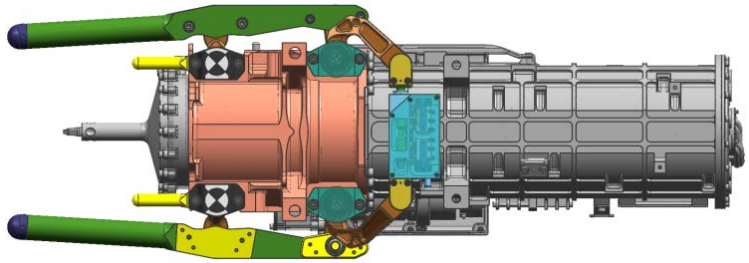
- **Salient Features:**
  - Custom ball screw supported by high axial capacity bearing
  - Integral force sensor mounted to ball nut
    - Dual bridge
  - Axial spring pack around force sensor
    - Lowers WOB feedback controller bandwidth requirement
    - Shunts high retraction load
    - Isolates turret from percussion induced vibrations
  - Gimbal assembly
    - Isolates ball screw and force sensor from moment and radial loads
    - Couples the ball screw axial output to the translation tube

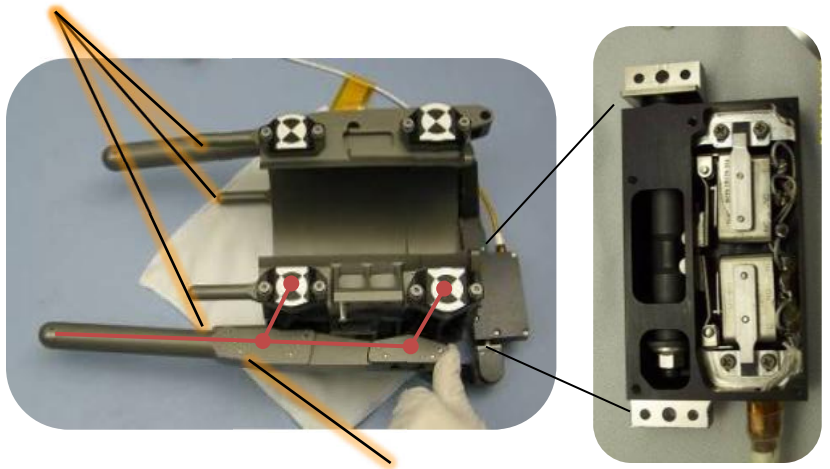




Drill Contact Sensor / Stabilizer (DCSS)

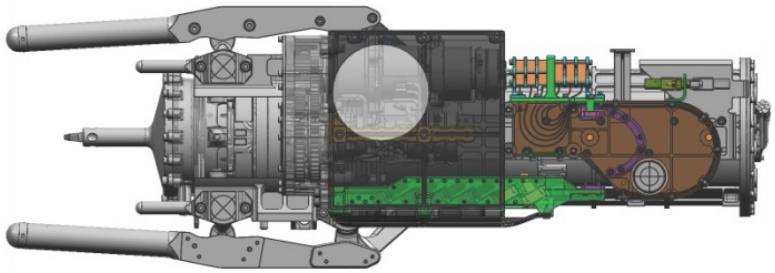
- Indicates placement of Drill on target rock with low contact force
- Accommodates rock surface variation and Drill axis misalignment
- Stabilizes Drill on rock surface
- Allows large bit retraction force in excess of RA capability
- Can withstand high loads
  - 10,000 N bit retraction load
  - Worst-case load scenario
- Salient Features:
  - Spiked tips for high grip with rock target
  - Two counter articulating 4-bar linkages
  - Coupler assembly ties the two sides together
    - Piston device that activates two (redundant) limit switches
  - Clock springs in aft links' lower joint housing returns the assembly to center and are preloaded to reset limit switches
  - Integral bit box alignment post

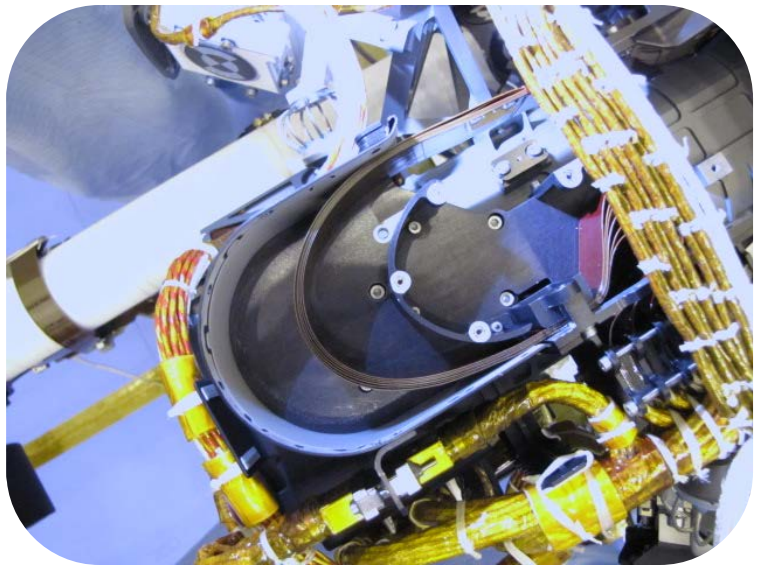




Drill Flex Cable Service Loop

- Provides the power and signals to the translating components.
- Salient features:
  - 6 belts
  - Terminated with roundwire to allow signal mixing





Sampling Observations from Testing

- **Flowing powdered material at low pressure and extremely dry environments**
  - **The process of cutting removal (collection in our case) from the bottom of the hole varies across material properties and changes at Mars pressure**
  - **Drilling at low penetration rates can cause sample to flow between the outside of the collection tube and hole wall versus collected up the flutes**
  - **Once sampling is collected, percussive dynamic environments (impact induced vibration) is very effective in moving the powered sample**

The Drill Team