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Introduction: The Kinetic Rotary Acquisition Kit for the Excavation of Nautical Substrate (KRAKENS) is a subsea coring drill system developed for acquiring 0.75-inch diameter and 4.5 inch long rock samples. The first demonstration of KRAKENS will be at the Axial Seamount (Juan de Fuca plate, 1,500 m depth) in Summer 2021, when we will collect up to 6 cores from seafloor hydrothermal vents. The drill system was designed as part of the NASA PSTAR-funded InVADER project, which will deploy and operate an innovative astrobiology sensor payload in this vent environment, analog to putative vent systems on Ocean Worlds such as Europa and Enceladus. InVADER will record geochemical, mineralogical, and biological data over its one-year long mission. KRAKENS will collect and return samples that we will use to benchmark the performance of the subsea sensor payload and design a future autonomous system to explore extraterrestrial oceans.

InVADER: The InVADER instrument is a suite of remote sensing instruments uniquely designed to function in deep ocean environments, such as the test site off the coast of Oregon, and ultimately for Ocean World applications such as Europa and Enceladus. As part of the PSTAR effort, the instrument needs to be calibrated, and the ideal way to do so is with physical samples in the lab. As such, a key part of the InVADER deployment in 2021 is based around the collection of samples using KRAKENS. These samples will be returned to shore and sent for analysis to compare to the data being collected remotely by the InVADER instrument over the course of a year.

KRAKENS: The KRAKENS system is designed to be a flexible sample collection system, made not just for the InVADER deployment, but for future deep sea missions. The KRAKENS system's main functionality is its drilling system, but also includes room for water sampling instrumentation and swing arms with baskets to allow the ROV to insert samples collected by the robotic arms. The KRAKENS system is specifically designed to fit on the Jason ROV, operated by the Woods Hole Oceanographic Institute (WHOI).

The largest driving design factor for KRAKENS was time. On Ocean Worlds, power, and thus operation time will be highly limited and a driving factor for any mission. For Earth, the InVADER project was also allocated limited time for full deployment of the instrument and collection of samples, further putting time in the spotlight. Optimizing drilling parameters, streamlining/practicing operational steps, and making hardware multifunctional helped reduce the overall time for sample collection, and overall dive time.

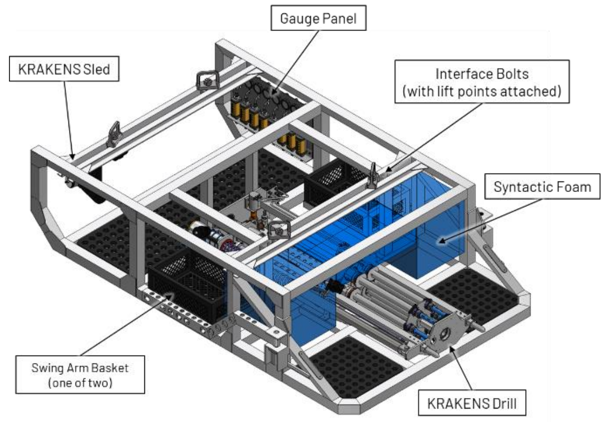

Figure 1: KRAKENS Sled and Drill

The Drill: Developing the InVADER drill was the main focus for Honeybee's PSTAR effort. It was decided early on that the drill would be based on several key principles to help streamline the process. These were: 1) Use lessons learned from the MBARI/MCS Drill and University of Washington (UW) and WHOI's experience with it, 2) Utilize the Jason hydraulics system for power and control, having no electronics for the drill, and 3) Utilize Honeybee's experience making drills and sample capture bits, including core breakoff technology.

The MCS (multiple coring system) drill was originally built by the Monterey Bay Aquarium Research Institute (MBARI) for taking deep ocean rock cores on the bottom of an ROV. The MCS drill had its own electronics and on-board hydraulics system for drill operations. Like KRAKENS, it was also integrated into its own specialty sled. The MCS drill used a bit-exchange carousel to switch between 4, 52.25-inch-long drill stems. This system was robust to the rigors of deep ocean rock sampling, so many aspects of its heritage were integrated into the InVADER drill. However, since the KRAKENS system is using Jason's hydraulics and has no electronics of its own for simplicity, not all aspects could be used.

The InVADER drill has a drill bit carousel with 6 drill strings. Each string contains a coring bit able to capture a 0.75-inch diameter core at 4.5 inches past the forward stabilizing spikes of the drill. The cutters of the bits are made from a diamond-impregnated polymer specifically designed to work on the ocean vents. The bits also contain Honeybee core-breakoff technology for capturing and maintaining the core after the hole is drilled. Each bit in the carousel has an associated color and letter to help the science team keep track of which sample is which, even after the dive. Effort was put in to test sample removal in preliminary bit design, and sample contamination and equipment cleaning was taken into account when choosing materials.

The auger motor, which spins the drill bits, was chosen with core breakoff as the driving factor. Calculations were done and compared to over a decade's worth of Honeybee rock data to choose the needed breakoff force for our intended samples. Available consumers had to be traded for Torque vs RPM vs Size, and a middle ground solution was chosen favoring torque over RPM. The drill also allows for water flow though the extended drill sting, helping to flush cuttings and increase drill efficiency.

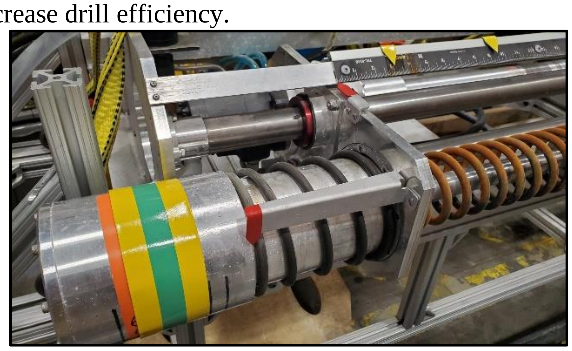

Figure 2: KRAKENS WOB and Drill Feed Scales

Weight on bit (WOB) is provided to the bit via a hydraulic cylinder. This is a similar system to the MCS drill, with the noted difference of an emergency bit ejection spring on the InVADER system. This additional spring allows the drill to automatically pull out a stuck drill bit (or sever connections to it) in case of a full loss of systems power. This was needed to ensure the ROV could not get stuck in a rock, no matter what. WOB is visually controlled via a secondary spring in line with the auger motor and piston. A brightly colored indicator shows when the WOB is in the "just right" zone to operators, allowing for easy adjustments to the piston position in real time. This method requires no additional electronics, in line with the second design principal outlined above.

Testing: The InVADER drill was tested extensively to prep for deployment. Planned testing consisted of four phases: 1) First article drill bit testing, 2) "Bench" testing of the full drill system, 3) Underwater testing in an above-ground pool, and 4) Integration testing with Jason. Because of COVID the final part of testing has been delayed until 2021, but the rest have been successfully completed.

Before some aspects of the drill had been finalized, first article drill bits were ordered and tested to confirm dimensions and parameters were appropriate from our performance predictions. When the drill was complete, it was hooked up to a copycat Jason hydraulics system for functionality testing. During this period, several fits and design aspects were tweaked and fixed (such as an alignment issue which was causing galling, and some manufacturing mistakes). Additionally, the first full drill tests were done into analog materials to collect performance metrics.

Figure 3: Assembled KRAKENS Drill

Figure 4: Testbed Operation - Control Station

Figure 5: Testbed Operation - Remote Pool Feed

Honeybee procured and set up an above-ground pool specifically for testing the drill at the Altadena facility. The test stand was equipped with lifting attachments and was forklifted in and out of the pool daily for testing. Hydraulic lines ran out of the pool to the control setup where an operator watched the drill functioning via two cameras inside of the pool, mimicking how it would be run on the ROV. These tests ranged though various sample types, including an actual vent sample, and tested parameters like varying WOB, RPM, drill angle, and even temperature (3 tons of ice was added to the pool to bring it down to -3° C). Testing also helped home in the operations, and allowed for adding indication markers for max WOB, coupling position, max depth, etc. A test was even done allowing someone completely unfamiliar with the system to run a test simply based on our procedures, which was a success.

Acknowledgments: This work was supported by the NASA PSTAR program.