Development of the Ultrasonic Planetary Core Drill

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Abstract: The percussive ultrasonic drilling technique is a developing concept for sample extraction in planetary environments, and is one that is particularly attractive because it requires less reacted force and torque than many of its competitors. The Ultrasonic Planetary Core Drill (UPCD) project seeks to build a space-compatible tool that can extract samples of rock from up to 30 cm beneath the surface using an ultrasonic-percussive technique first developed as the ultrasonic/sonic driller/corer [1] by NASA, but it will both optimise the technology and apply a new control loop to increase the autonomy of the device. This concept will be field tested at a Mars analogue site at Haughton Crater on Devon Island during the summer of 2016 [2].

Dynamic simulation of the drill tool

Thus far, the mechanical design of the drill tool has concentrated on optimising the dynamic stack and managing the loads it transfers to its host architecture. For example, assuming that the ultrasonic stack is held between two springs in a casing, a model of the core drill has been developed in Matlab to predict the force which is ultimately transferred out of the casing and the associated output effective impulses. Fig. 1 shows this relationship in a parameter space where the stiffness of the two springs are varied, where other parameters, such as free mass and drillbit mass, are fixed for the purposes of simulation. Further simulations to predict the shock load and effective impulse have also allowed for variation of the mass of components of the UPCD.

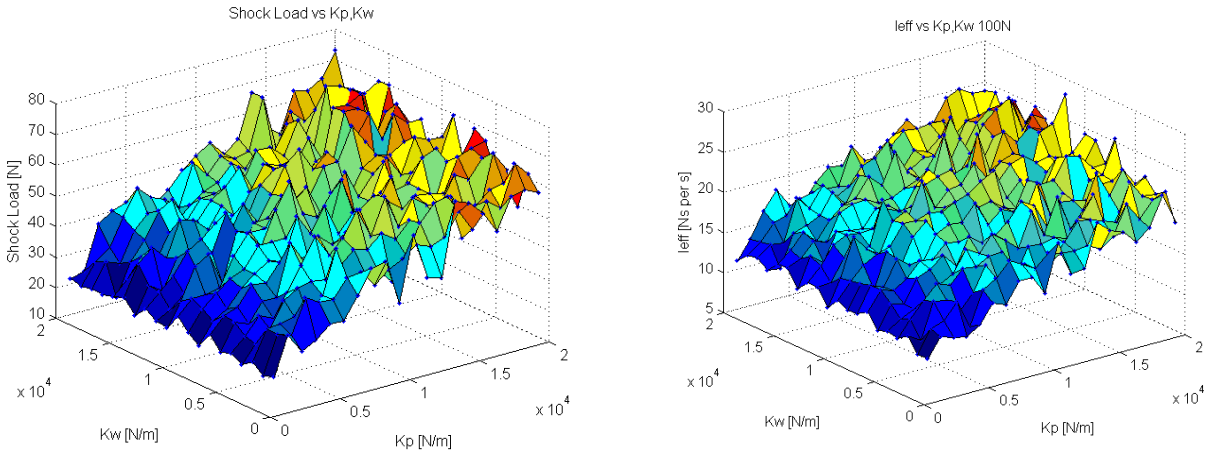

Fig. 1: Predicted transmitted shock load and effective impulse for different back and front spring stiffness.

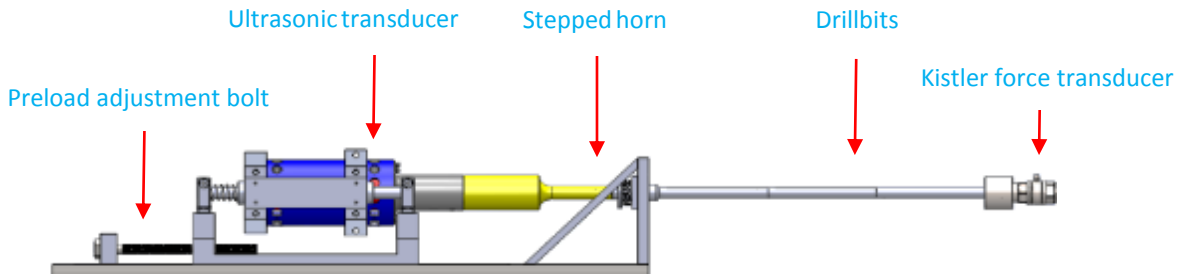

Fig. 2: Experimental test rig for validation of the UPCD dynamic model.

Experimental test rig

The results of the model are validated by using the experimental test rig shown in Fig. 2 in which an ultrasonic planetary core drill emulator acts against a force transducer. The test rig can accommodate a range of spring stiffness, component masses and internal preloads (as set out in Table 1) to recreate the modelled conditions. The aim of the model and experiments is to maximise as far as possible the effective impulse delivered by the drill tool since this allows for a maximised rate of progress through rock. In this manner, the optimal design points associated with all of these parameters are identified.

Once optimised, the second challenge is to advance into the rock at a rate which does not negatively affect the percussion dynamics. Research has indicated that the increased voltage required to maintain constant current in a preset-amplitude system, such as the Sonic Systems P100 ultrasonic transducer/generator used in this study, can act as an indicator of the weight-on-bit. A control loop has been developed that will cause an actuator to advance the drill tool into rock when this voltage drops below a preset level. The success of this method of controlling drill progress is also validated using the experimental rig. For this purpose, the optimised experimental rig was subsequently mounted on an actuator and the control loop was authorised to manage its advance as shown in Fig. 3.

Free mass [g]	Mass of drillbit [g]	Back spring constants [N/m]	Front spring constant [N/m]	Preload [N]
4 – 7	100 – 400	0 - 20000	0 - 20000	0 - 30

Table 1: The parameter space investigated.

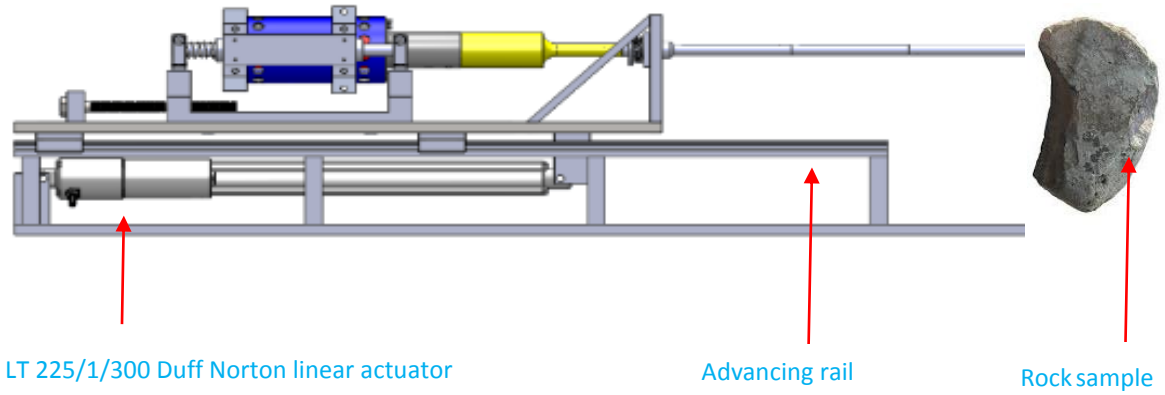

Fig. 3: Experimental test rig for validating the rock coring control strategy.

Conclusion

This body of work has therefore set out the optimisation of the dynamics through the experimental validation of a dynamic model of the UPCD. The results of the research have informed the design of the UPCD space exploration hardware for its upcoming trials on the Earth analogue site on Devon Island.

References

[1] Y. Bar-Cohen (1999), “Smart ultrasonic/sonic driller/corer,” New Technology Report 20856, Jet Propulsion Laboratory, USA.

[2] L. Preston, M. Grady, S. Barber (2012) “Concepts for Activities in the Field Of Exploration – TN2: The Catalogue of Planetary Analogues,” The Open University, UK.