Drill Tools for Earth and Space

Design of a Novel Longitudinal-torsional Ultrasonic Transducer

Measurement of complex combinations of different vibration modes operating together at ultrasonic frequencies can be carried out using 3-D laser vibrometry.

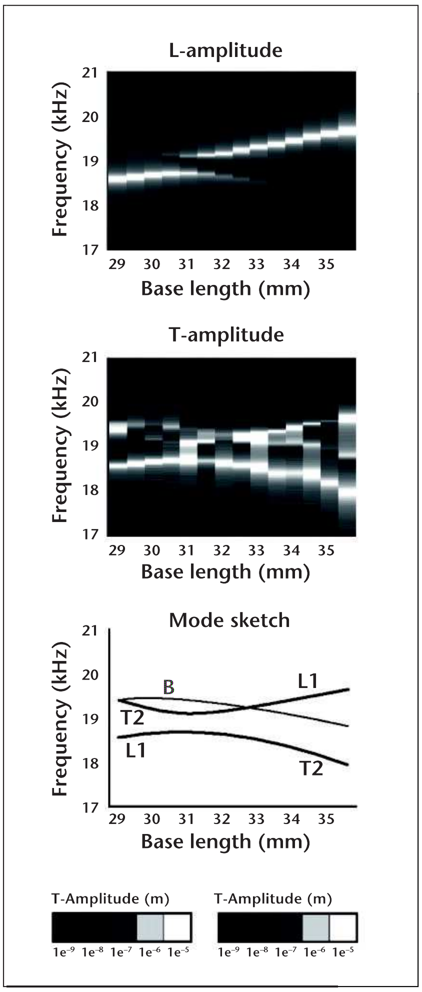

Fig. 1: The interaction of modes as the length of an ultrasonic step horn is incrementally altered.

These measurements are being used to optimize the performance of longitudinal-torsional (L-T) ultrasonic horns at the University of Glasgow. L-T ultrasonic vibration has many applications including surgical devices, industrial welding and ultrasonic motors. Researchers at Glasgow are even developing ultrasonic drill tools for planetary exploration. Due to the low gravity, traditional drilling will be difficult and the next generation Mars landers will require low-reaction devices for drilling into the surface.

Development of Ultrasonic Properties

An ultrasonic horn, also known as a sonotrode, is a metal bar commonly used for augmenting the oscillatory displacement amplitude provided by an ultrasonic transducer. The device is necessary to efficiently transfer the acoustic energy from the ultrasonic transducer into the medium being treated. The ultrasonic horn is commonly a solid metal rod with a round transverse cross-section and a variable-shape longitudinal cross-section. The length of the device must be such that there is mechanical resonance at the desired ultrasonic frequency of operation – one or multiple half wavelengths of ultrasound in the horn material.

Efforts have been made to excite longitudinal-torsional responses in devices using two different techniques; by coupling the longitudinal and torsional modes,

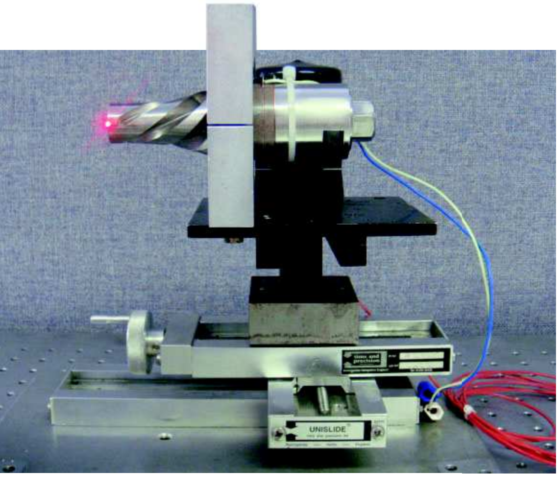

Fig. 2: The new L-T transducer.

and by causing the degeneration of a longitudinal mode into a longitudinal-torsional response by incorporating helical flutes and slits. Coupling the longitudinal and torsional modes of vibration has been found to be difficult because, as the geometry of a typical ultrasonic horn is modified incrementally, the two modal frequencies have been found to approach each other and then move apart but with no crossover point where the modes are fully coupled.

For example, using a Polytec 3-D laser vibrometer system, the interaction of the first longitudinal mode (L1), the second torsional mode (T2), and a bending mode (B) can be observed (fig. 1) in terms of longitudinal (L) and tangential (T) amplitude in a simple titanium half-wavelength step-horn as the length of the base section of the horn is gradually decreased.

As it is very difficult to achieve effective coupling between these modes, horns exploiting this approach tend to be characterized by low responsiveness or, alternatively, need to incorporate two differently poled piezoceramic stacks in the transducer to excite the two modes. Therefore, the mode degeneration method is considered to be more promising and we have developed a transducer (fig. 2) to take advantage of this technique. This transducer can deliver a longitudinal-torsional output when excited by the longitudinal vibration mode of a single piezoceramic stack.

Experimental Modal Analysis

In order to evaluate the behavior of the transducer, the operating modal response is determined by experimental modal analysis (EMA). The effectiveness of the transducer is characterized by its torsionality, which is the ratio of torsional to longitudinal vibration amplitude. The 3-D laser vibrometer was used to measure the response because it allows data to be obtained without affecting the natural frequency, mode shape, or damping, regardless of whether the device is excited in air (unloaded) or under a load representing a real-world application.

Using the 3-D laser vibrometer, responses in three orthogonal directions are acquired at a grid of surface points on the transducer and the modal frequencies and animated mode are extracted using ME'scope software. The results enable us to assess the vibrational characteristics of the operating mode and the frequency spacing between the desired mode and surrounding unwanted modes of vibration. The vibrometry measurements can also be used to validate finite-element (FE) models of the transducer (fig. 3).

Conclusion

The results show that the model can be used reliably to design novel transducer shapes and evaluate the longitudinal-torsional response characteristics to maximize performance of devices.

Authors · Contact
Hassan Al-Budairi, Dr. Patrick Harkness, Prof. Margaret Lucas
h.al-budairi.1@research.gla.ac.uk; Margaret.Lucas@glasgow.ac.uk

University of Glasgow, School of Engineering, UK

www.gla.ac.uk/schools/engineering

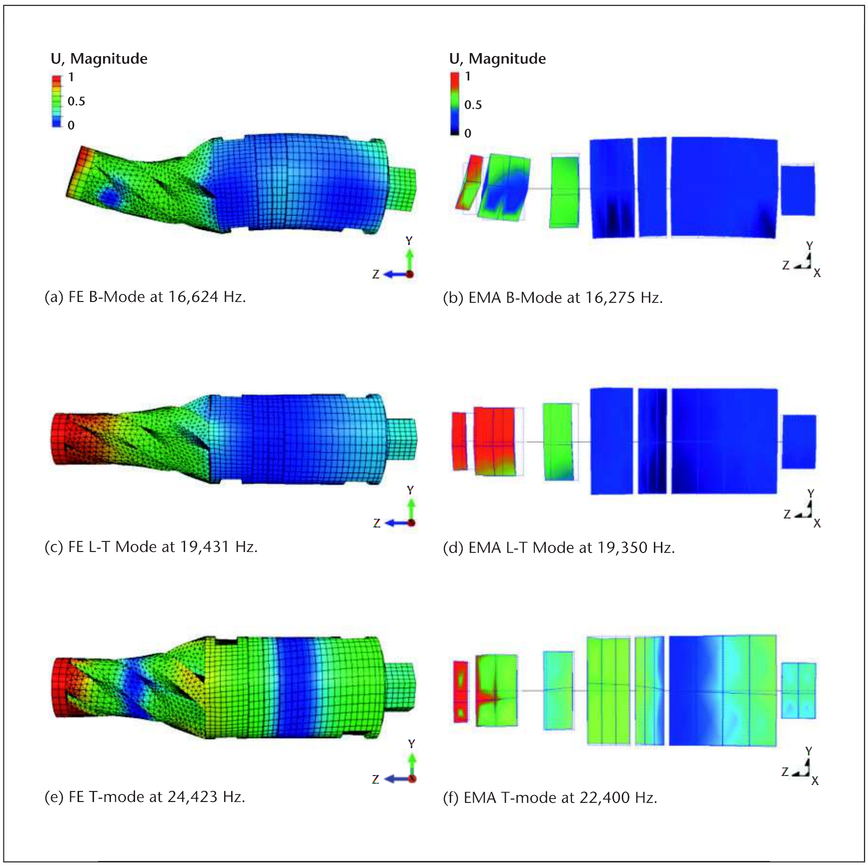

Fig. 3: Modelled and measured mode shapes of the transducer represented in Simulia Abaqus and Vibrant Technologies ME'scope.