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Ultrasonic Assisted Drilling

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Motivation

- Drilling ductile materials forms large burrs
- Burrs affect quality of parts and assembly
- Deburring is expensive
- Ultrasonic assisted drilling alter the machining process to reduce burr size

Topics of Discussion

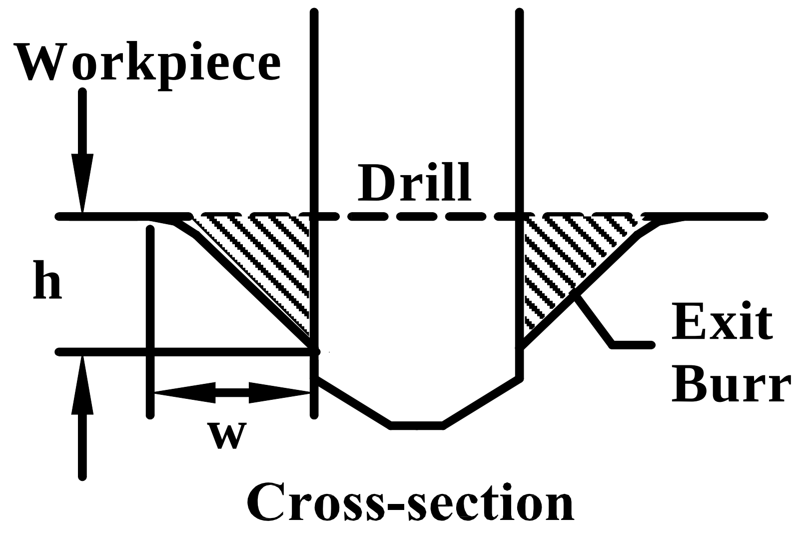
- Burr Formation
- Ultrasonic Assisted Drilling
- Actuated Workpiece Holder Design
- Drive Circuit Design
- Experimental Investigation
- Conclusion

Burr Formation

- Undesirable projection of work material
- Result from plastic deformation
- Poisson Burr, Entrance Burr, Rollover Burr, Tear Burr, Cutoff Burr
- Drilling forms combination of Rollover Burr and Tear Burr at the exit surface

Burr Formation

- Exit burr size is defined by the height and the width



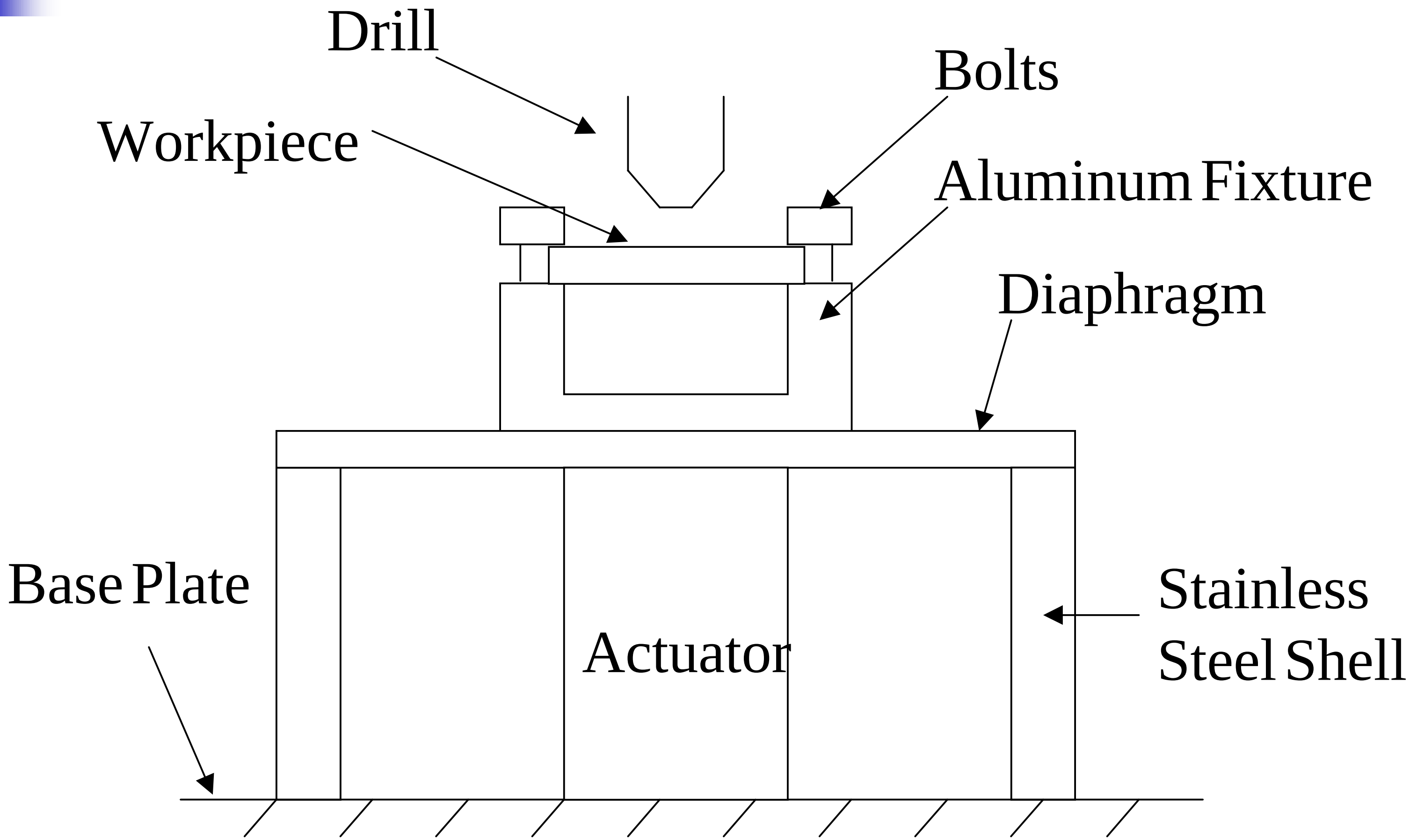
Ultrasonic Assisted Drilling

- Adding high frequency and low amplitude vibration in the direction of drill feed
- High Frequency – 1 - 200kHz
- Low Amplitude – 1 - 13μm

Actuated Workpiece Holder design

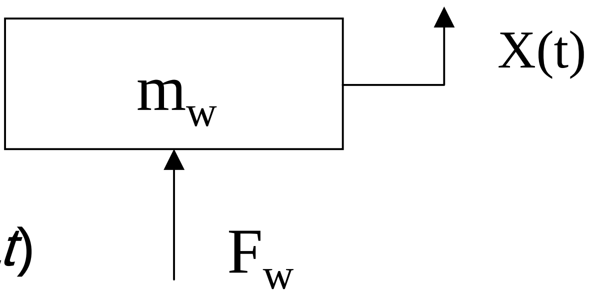
- Piezoelectric stack actuator
- Pre-loading mechanism
- Aluminum fixture
- Stainless steel shell
- Base plate

Actuated Workpiece Holder design



Actuated Workpiece Holder design

- Desired actuator performance:
  - Freq. Range 0-20kHz
  - Disp. Range 0-10μm
- Required force delivery
  - $X(t) = A_u \sin(2\pi f_u t)$
  - $V(t) = 2\pi f_u A_u \cos(2\pi f_u t)$
  - $a(t) = -4\pi^2 f_u^2 A_u \sin(2\pi f_u t)$
  - $F_w(t) = -4\pi^2 f_u^2 A_u m_w \sin(2\pi f_u t)$
  - $F_{max} = 4\pi^2 f_u^2 A_u m_w = 8$ kN



Actuated Workpiece Holder design

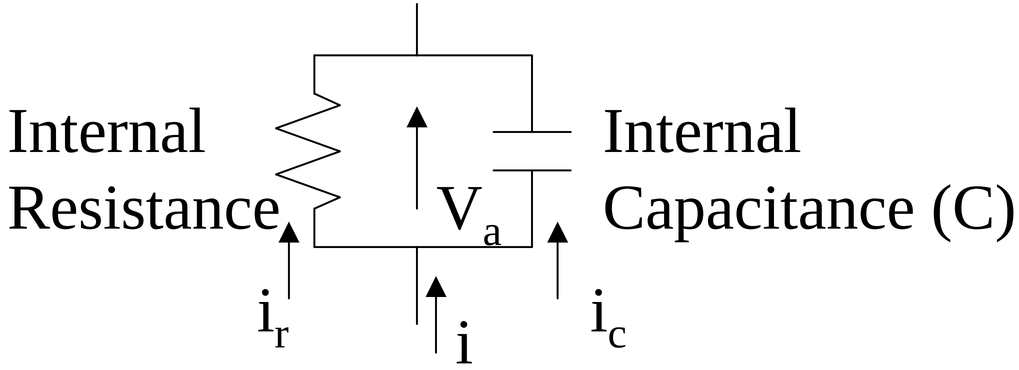
- Chosen actuator
  - Sensor Tech. Ltd. BM532 series 33 layers stack actuator
  - Freq. Range 0-20kHz
  - Disp. Range 0-4μm
  - Force Delivery 5kN
  - Applied Voltage (V_a) 200V
  - Capacitance (C) 290nF

Drive Circuit Design

- Operating frequency 20kHz
- Required 200V pk-pk drive voltage
- Required drive current can be computed by considering the electric model of the actuator

Drive Circuit Design

- Electric model of the actuator

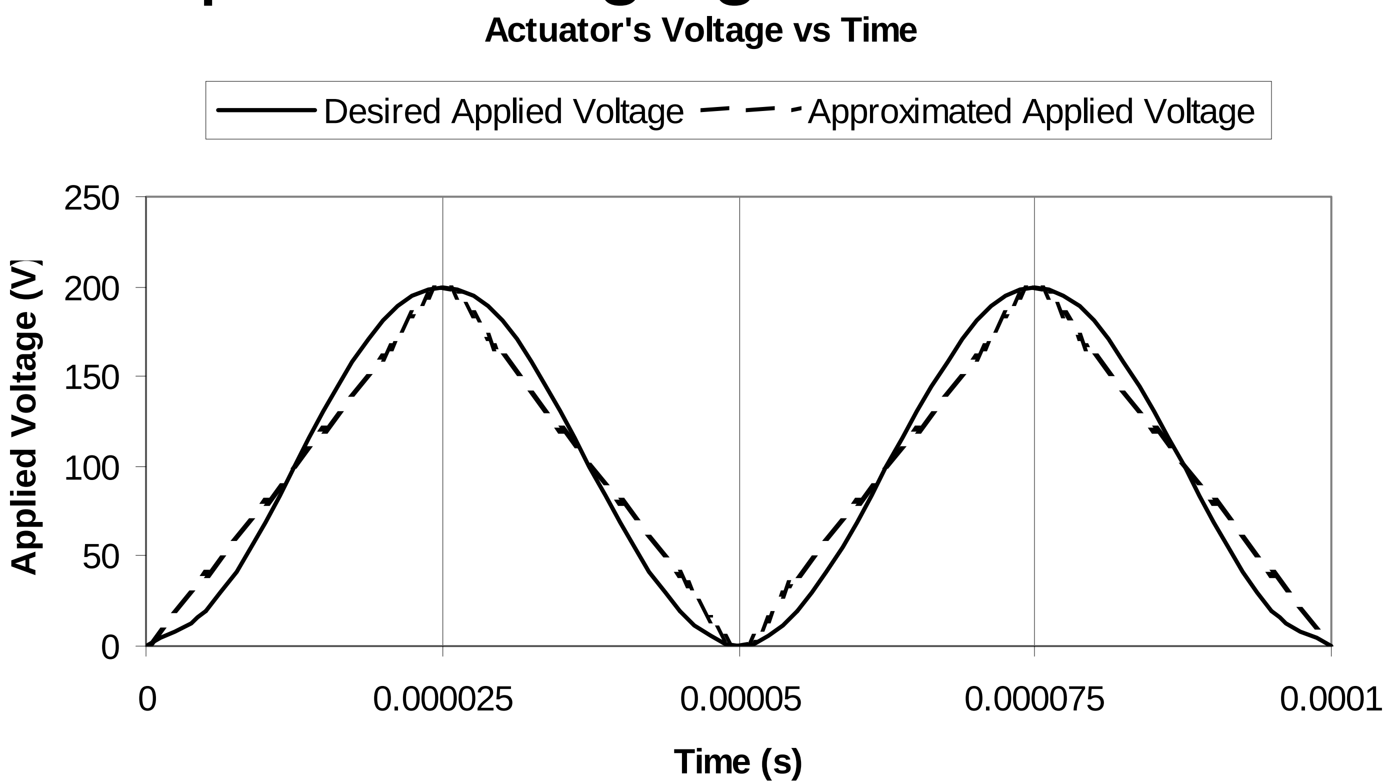


- Required charging current can be computed using the relation:

$$C\frac{dV_a}{dt} = i_c$$

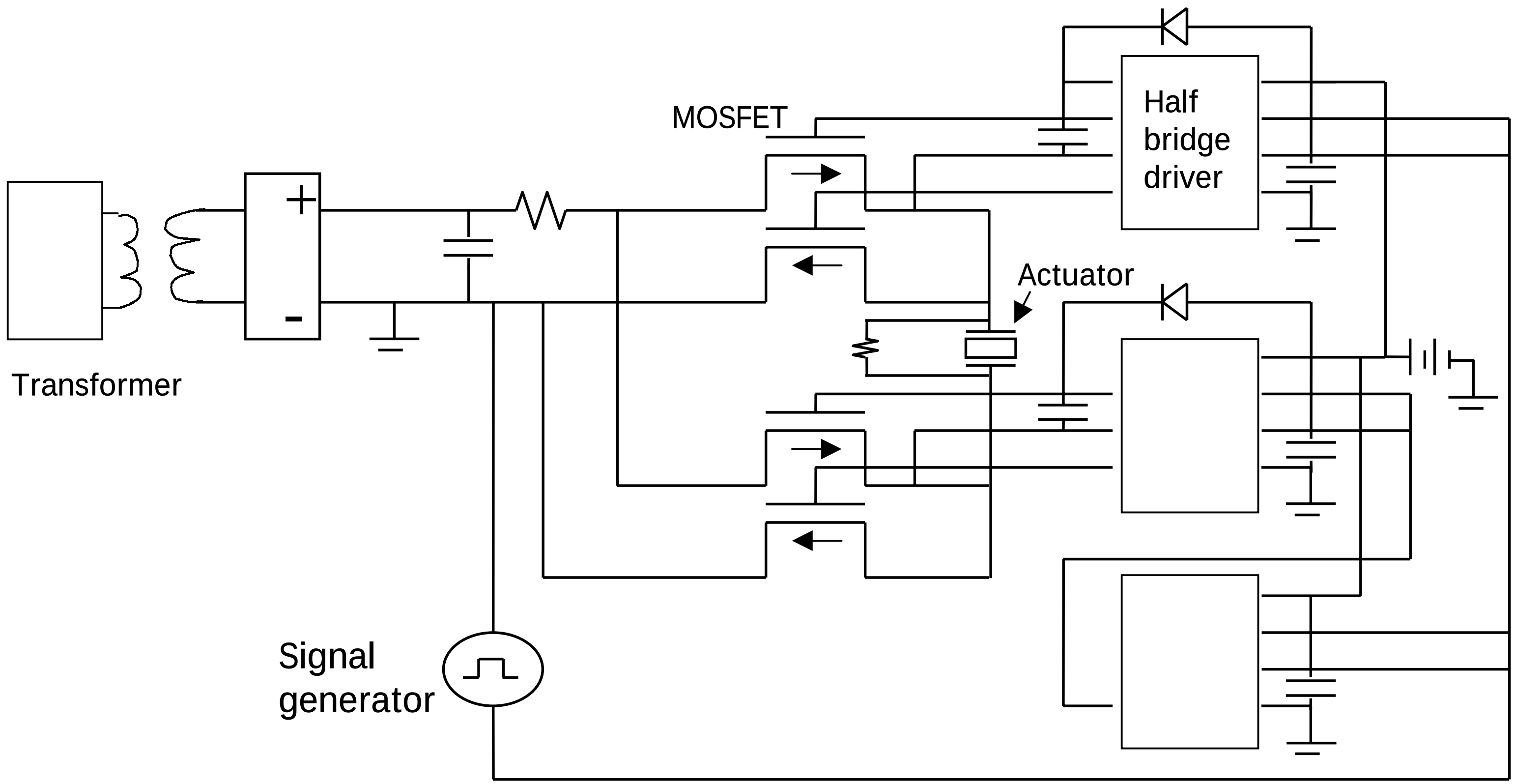
Drive Circuit Design

- Required charging current = 2.3A



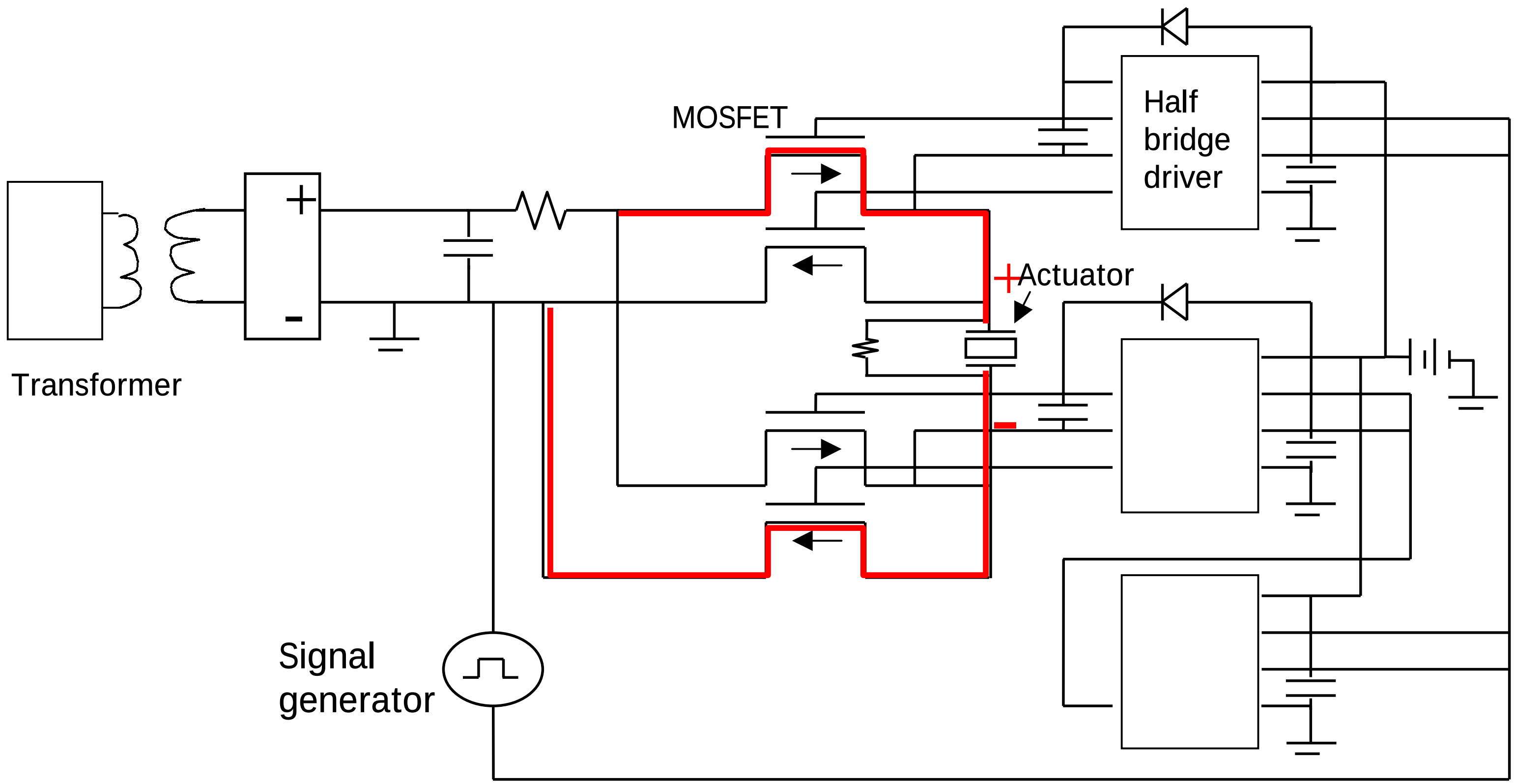
Drive Circuit Design

- Polarity Switching Circuit



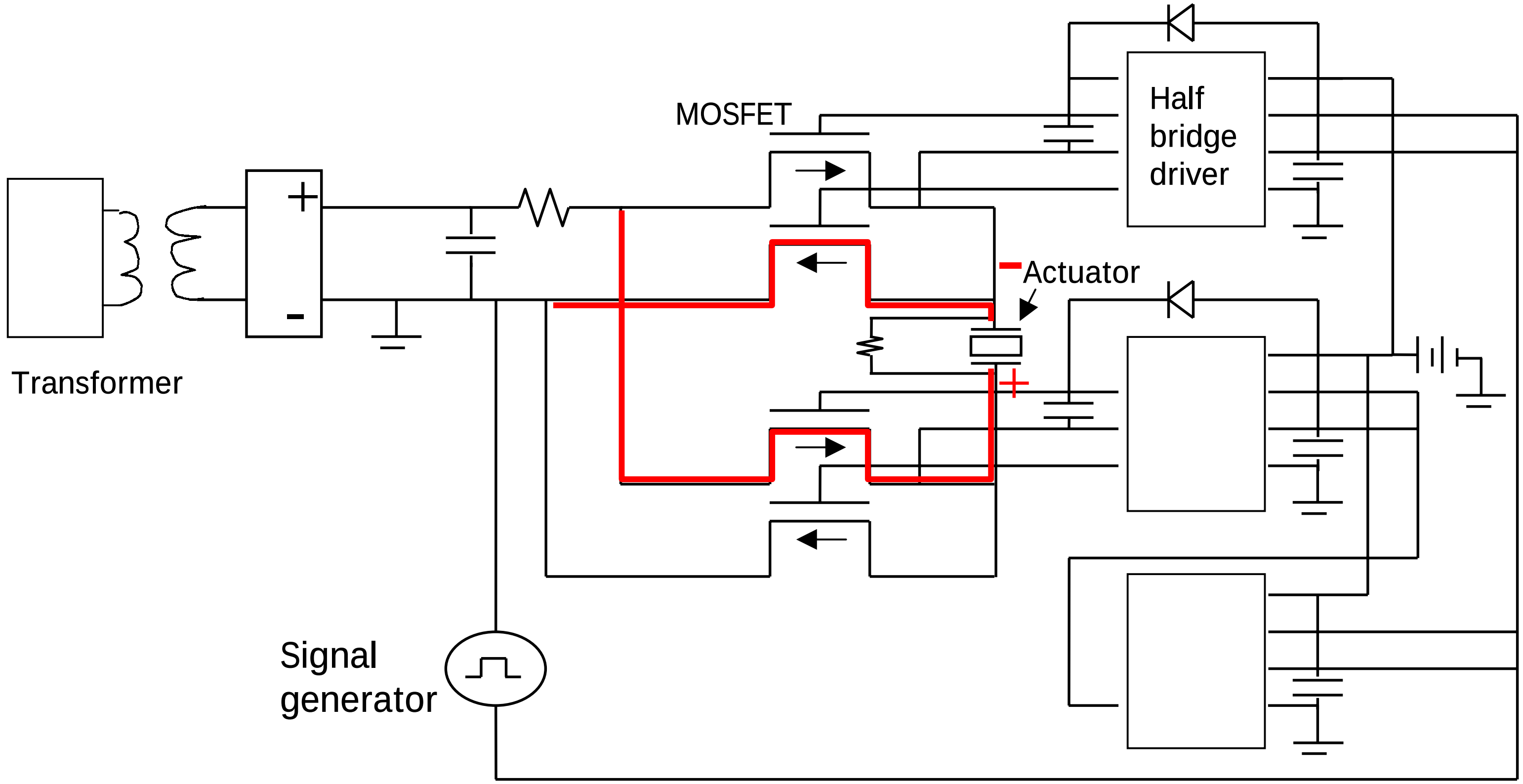
Drive Circuit Design

- Polarity Switching Circuit



Drive Circuit Design

- Polarity Switching Circuit



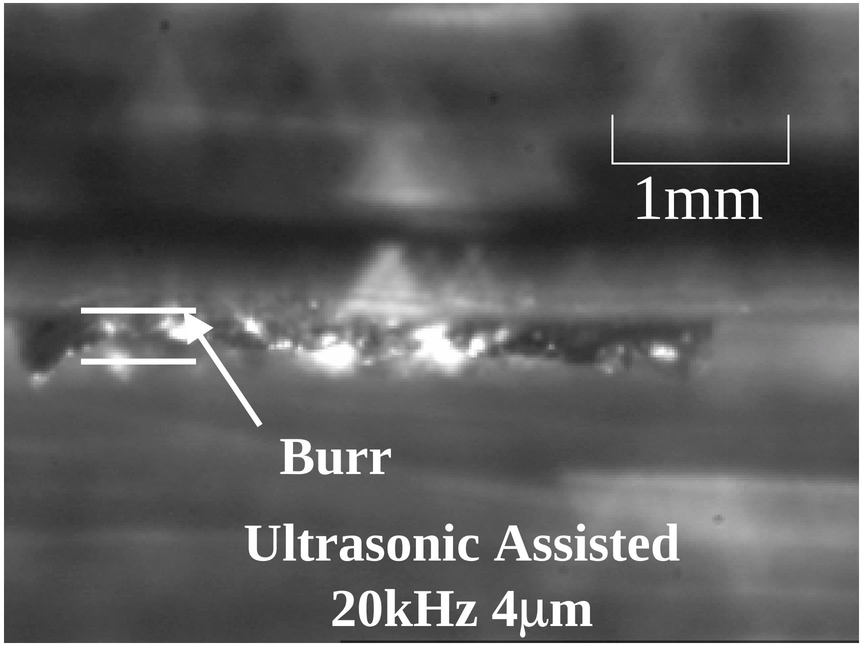
Experimental Investigation

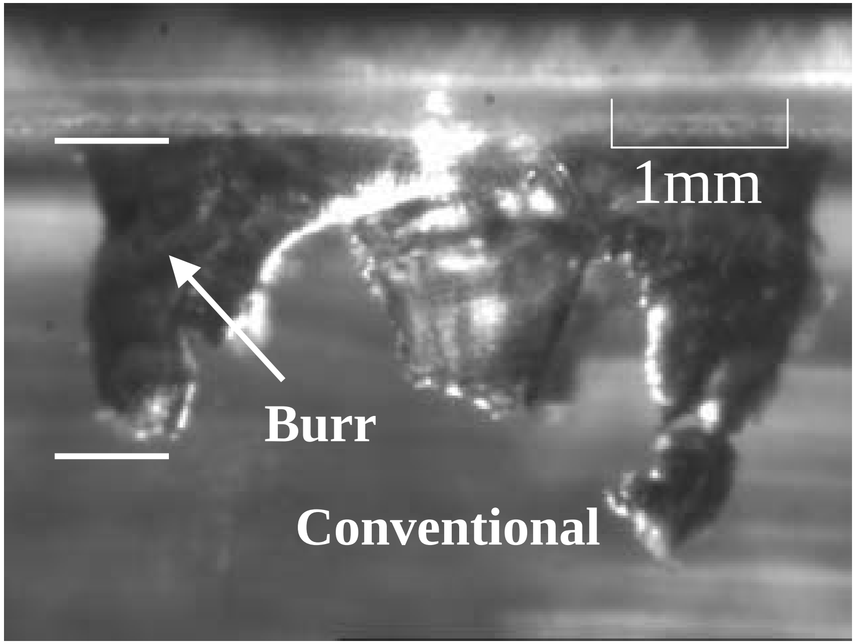
- Experimental Setup
  - CNC milling machine
  - 5 specimen for each test
  - New finished High Speed Steel twist drill
  - Burr height measured under scaled microscope
  - Burr width measured by vernier caliper

Experimental Investigation

- Example of samples

3.175mm drill 6000RPM 1.905mm/s feed





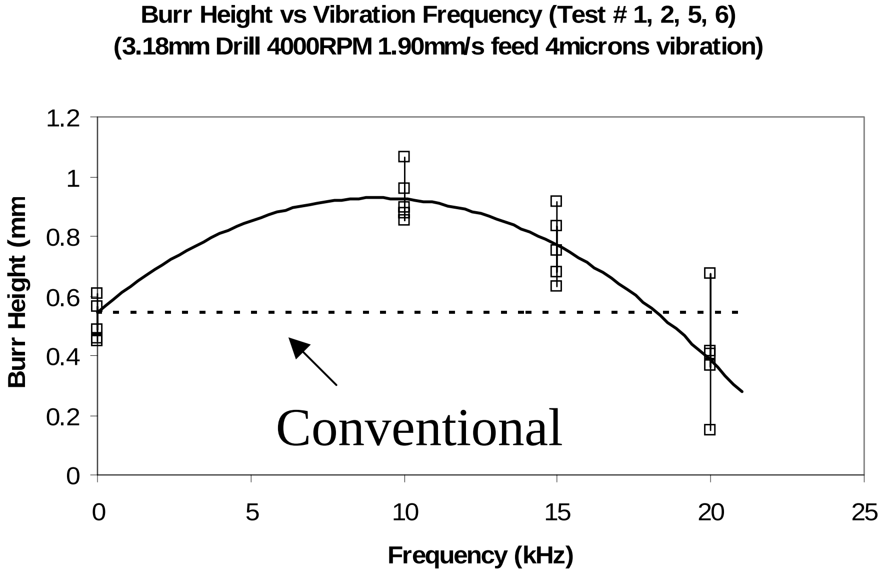
Experimental Investigation

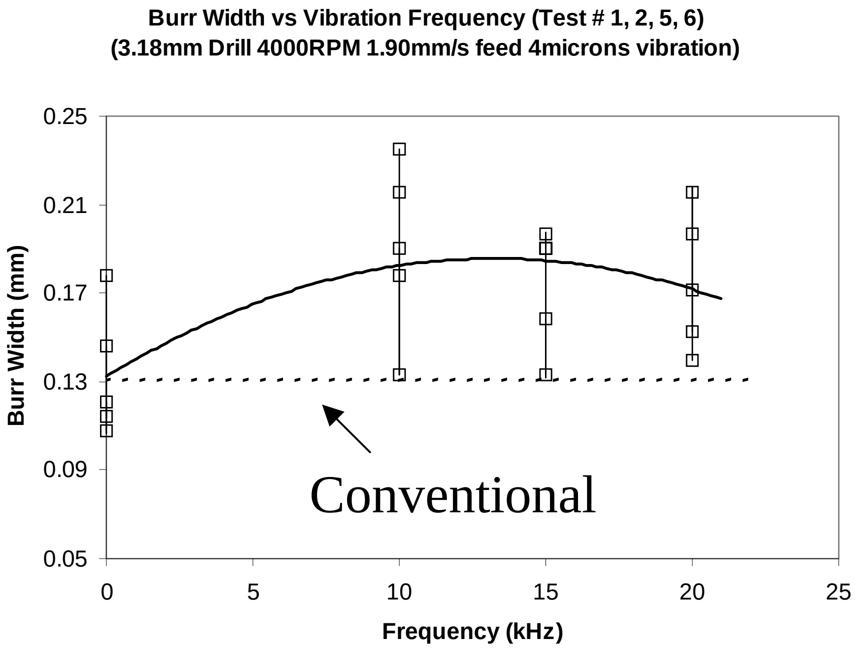
- Vibration Frequency
- Peak to Peak Vibration
- Spindle Speed
- Other Findings
- Tool Wear

Vibration Frequency

- Burr height and width decreased after the frequency reaches a threshold
- Trends suggested higher frequency results in smaller burr
- Wavy chips were found at low frequency tests

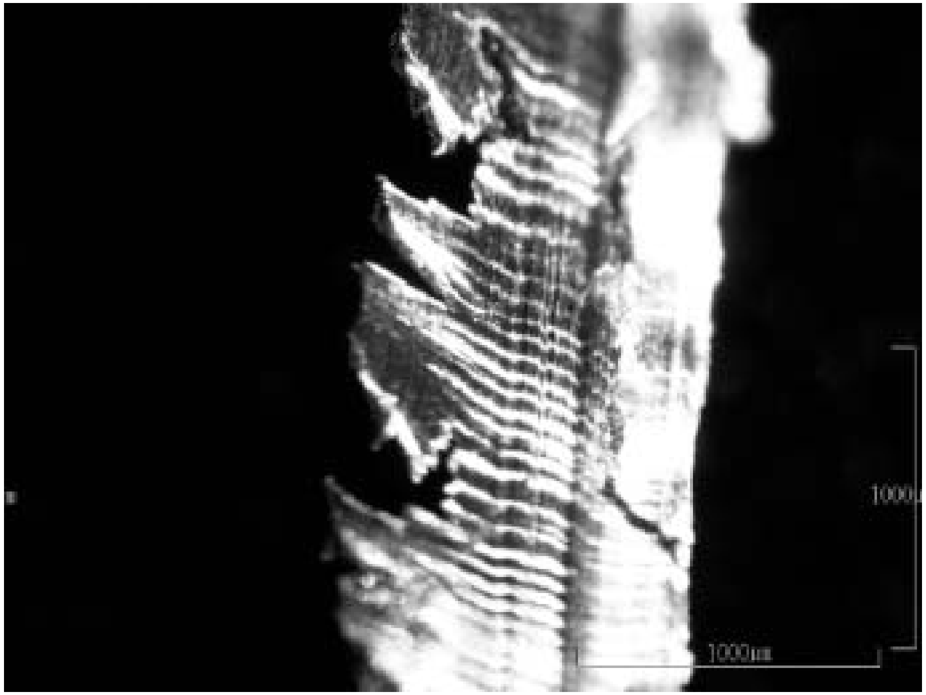
Vibration Frequency





Vibration Frequency

- Wavy chip



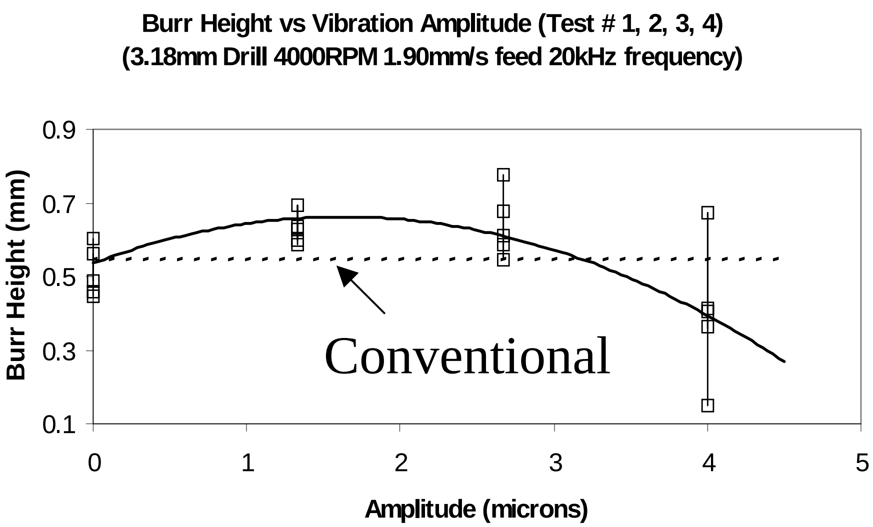
Vibration Frequency

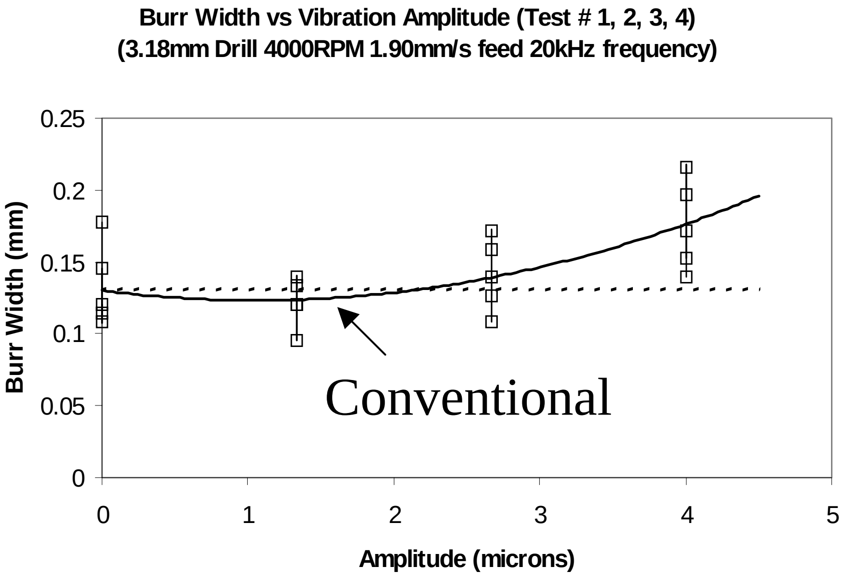
- Continuous cutting occurs at lower frequencies, forming long wavy chips
- Ultrasonic impact action occurs at higher frequencies, segmenting the chips, forming fine chips

Peak to Peak Vibration Magnitude

- Burr height decreased but burr width increased after the magnitude reaches a threshold

Peak to Peak Vibration Magnitude





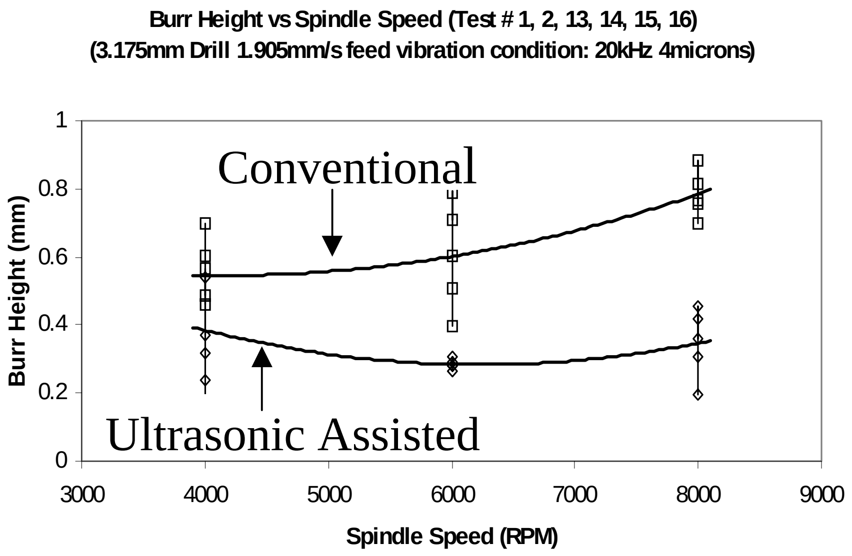
Peak-to-peak Vibration Magnitude

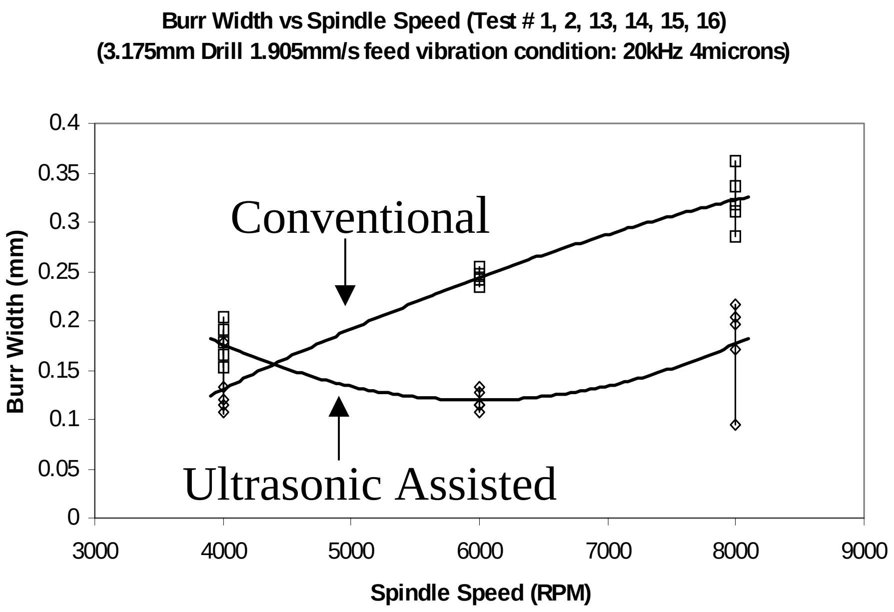
- Continuous cutting occurs at lower magnitudes, forming long wavy chip
- Ultrasonic impact action dominates at higher magnitudes
  - Rollover begins earlier
  - Forms short but wide burrs

Spindle Speed

- Both burr height and width reaches a minimum at 6000rpm, and significantly smaller than conventional drilling at 6000 and 8000rpm.
- Trends suggested a certain vibration condition can significantly reduce burr size

Spindle Speed





Effect of Spindle Speed

- Higher spindle speed with same feed results in thinner chips that are broken more easily by the ultrasonic impact action, producing smaller burr

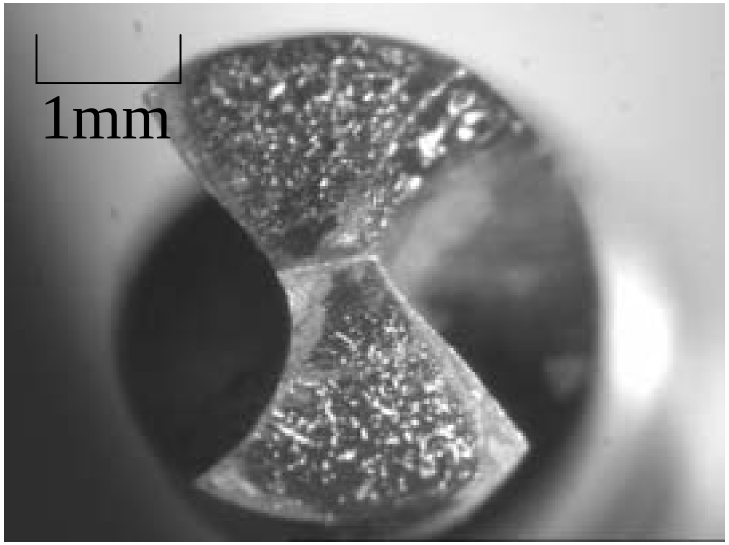
Other Findings

- Ultrasonic assisted drilling performs best in normal cutting feed, but degrades rapidly in high cutting feed
- Drill size has insignificant effect on the efficiency of ultrasonic assisted drilling

Effect of Ultrasonic Assistance in Tool Wear

- Chipping observed on drills used in ultrasonic assisted drilling experiment

8000RPM, 3.81mm/s feed (left: UA; right: conventional)



Conclusion

- Ultrasonic assisted drilling in general:
  - Reduces burr height and width if the vibration conditions for each particular cutting condition were chosen correctly
  - Introduces challenges in the context of tool strength and tool life