An objective comparison of cavitation measurement devices

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Why measure cavitation?

- To enable the application of cavitation technology on a robust metrological basis, by developing cavitating systems and sensors which enable the development, consensus and take up of standards (through IEC)
NPL Focus

Flow cavitation

Reference vessels

Cavitation standards

Cavitation detection

Microbubbles research

Industrial applications

Dissemination
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How can we measure cavitation?

- Sound
- Light
- Chemistry
- Damage

http://leaderchat.files.wordpress.com/2013/12/bigstock-measurement-with-caliper-44942719.jpg
What’s the standard way to measure cavitation?

There isn’t one. (yet)
What’s the best way to measure cavitation?

Your way. (for now)

cenblog.org
Project motivation

- A number of ‘cavitation measurement devices’ are available commercially
- Often designed for volume markets (ultrasonic cleaning etc)
- Prices range from €5 to €35,000
- Many different modes of operation, measurands and hence, applications

> How can we compare them?
Reference vessels

Our concept of a ‘reference cavitation vessel’ is summarised as being:

- Measurable
- Repeatable
- Controllable
- Predictable
- Applicable to industry

Capability built up over several programmes of UK government project support, initially using commercial single frequency systems.
Current reference system

- Built by Sonic Systems, UK
- Unique six-frequency vessel, 20 – 135 kHz
- 21 transducers arranged in three rows of seven
- Advanced lock-in amplifier drive with feedback control
- Geometry favours particular vibration modes
- Bottom-mounted transducer to monitor vessel operation

Vessel characterisation

- Characterised using acoustical, optical, chemical, (and erosive, and vibratory) methods

- Unique control and mode selection provides repeatable performance of the acoustic pressure field, and hence the vessel is suitable as a spatially-variant cavitation source

- Stability and repeatability demonstrated through consistency of vessel monitor, and through good agreement in periodic measurements
Luminol characterisation

21 kHz

37 kHz

44 kHz

60 kHz

92 kHz

136 kHz
## Roll call of devices in this study

<table>
<thead>
<tr>
<th>Cavitation Measurement Device</th>
<th>Manufacturer</th>
<th>Detection Method</th>
<th>Dimensions</th>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAV-Meter (CM-3-100) and CAV-Meter 2</td>
<td>Alexy Associates Inc. / MRC Labs</td>
<td>Acoustic energy</td>
<td>Length: 450mm  Diameter: 12.7mm</td>
<td>20 to 120 kHz</td>
</tr>
<tr>
<td>HCT-0310</td>
<td>Onda</td>
<td>Acoustic pressure (broadband)</td>
<td>Length: 300mm  Diameter: 3mm</td>
<td>30 to 300 kHz (300 kHz to 1.2 MHz optional)*</td>
</tr>
<tr>
<td>pb-502 cavitation meter</td>
<td>PPB Megasonics</td>
<td>Acoustic energy (broadband)</td>
<td>Length: 610mm  Diameter: 58mm (head)</td>
<td>0 to 500 kHz</td>
</tr>
</tbody>
</table>
| CaviSensor and CaviMeter      | National Physical Laboratory       | Acoustic pressure (broadband) | Length: 34mm  Diameter: 38mm (external), 28mm (internal) | Drive frequency detection: 20 - 130 kHz  
Cavitation activity detection: up to 11 MHz |
| SonoCheck                     | Healthmark                          | Sono-chemical             | Length: 34mm  Diameter: 11.6mm                 | “Table top ultrasonic baths”   |

* This represents the calibrated range. The frequency response extends beyond this.
Experimental protocol

- Reference vessel filled to a depth of 380 ±1 mm with 5 micron filtered, deionised water at 21 degrees C
- Sensor under test mounted with its acoustic centre / geometric tip at a depth of 74 mm beneath the water surface
- Reference vessel excitation set to 21.06 kHz, and function generator drive levels of 50 mV, 100 mV and 200 mV (corresponding to approximate powers of 38 W, 75 W and 150 W)
- Sensor scanned diametrically across vessel at each drive level, acquiring at least four values and calculating a mean at each point
Reference measurement

- Lowest selected drive level (50 mV) is close to the inertial cavitation threshold, and so a calibrated Reson TC4038 hydrophone was used to scan the field in the 74mm plane.
CM-3-100 (2/3)

- Consists of a 450mm long, 12.7mm diameter waveguide, with detecting PZT crystals at the top
- Relative cavitation activity measured in ‘Cavins’ (ref: Branson Ultrasonics work in the 1960s) on a passive needle meter
- Reading changes when meter is tilted, and by a factor of x5.5 when the expanded range is selected
- Meter box held in positioning rig, and scanned across the vessel using the protocol
Central peak and subsidiary maxima observed

Clear difference between tank drive levels

At 200 mV drive, suggestion is that cavitation is generated throughout the scan
Less well-defined subsidiary maxima seen with CM-3-100, large variations at a point

- Some scan regions are close to background noise level
pb-502 (2/3)

- Consists of a sensing element housed in a rubber hemisphere, within an embedding acoustically-matched material
- Relative cavitation energy measured as an (ADC) level from 0-255: manufacturer claims traceability to NIST for the device calibrated in W/gal: sensitivity can be set directly by user
- On-board time-averaging of signals carried out, and storage for later download to PC
- Mounting rod held at 45 degree angle to achieve parallelism between device and water surface
▪ Progression in device output again seen with increasing drive level
▪ Positional variation of measurand shows more detailed variation than CM-3-100
▪ Possibility that device output is beginning to clip around central axis
▪ Physical sensor size limits scan range
pb-502 vs Reson

- Square root of pb502 output taken for comparison with Reson
- Greater similarities to Reson than seen with CM-3-100
Device consists of a 3mm diameter shaft, with a broadband PVDF-like sensing element at the tip, with an intervening layer of a viscous oil for vibration isolation.

Usually paired with bespoke electronics (MCT-0310) which carries out signal conditioning and wireless transmission.

Device provided with an acoustic pressure sensitivity calibration certificate, traceable to International Standards.
- Clear progression in device output seen with increasing drive level
- Suggestion of double-peaked trend at centre of scan, for upper two drive levels
- Greater detail picked up in subsidiary maxima than other sensors
Good agreement seen between devices (similar dimensions and design), in field structure and measured pressure levels.
NPL CaviSensor (2/3)

- Device consists of a right circular cylindrical 30mm strip of broadband PVDF, sandwiched between an impedance matched polyurethane inner layer, and a selectively absorbing polyurethane outer layer.
- Can be paired with bespoke electronics (CaviMeter) which carries out signal conditioning into discrete bands (driving field and cavitation activity).
- Designed to be minimally perturbing to the field under test, and to possess spatial resolution when monitoring MHz frequency emissions from cavitation.
NPL CaviSensor (3/3)

- Factor of five difference in measured near-axis voltage
- Double-peaked centre to scan seen, as with HCT-0310
- Refined detail throughout scan, with sharper local features apparent at 200 mV
NPL CaviSensor vs Reson

- Good agreement seen between devices in field structure
- Suggestion of a ‘ramp’ across scan
50 mV and 200 mV comparison

- The more refined sensor designs generally agree pretty well
What do they actually measure?

- Bandwidth details on some sensors are unclear, but given the agreement with the reference (Reson), all devices resolve a similar spatial variation in the driving field at 21.06 kHz.

- Across the devices, the central pressure increases by a factor of 2 to 5 when the drive level is increased from 50 mV to 200 mV.

- But to what extent does this represent the spatial distribution in the cavitation activity, which is the driver of most applications?
Tested using NPL CaviMeter

- Two signal processing channels
  - peak notch detection up to 60 kHz
  - broadband integration from 1.5 to 7 MHz
- Enables discrimination of driving field and resulting inertial cavitation
- Broadband acoustic emission demonstrated to correlate with erosion
Studies of a novel sensor for assessing the spatial distribution of cavitation activity within ultrasonic cleaning vessels.

NPL CaviSensor and HCT-0310

- Significant difference in profile between drive levels (not simply scaled)
- Cavitation activity peaks less widespread than driving field
- Spatial averaging apparent around peaks
NPL CaviSensor and HCT-0310

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Summary and conclusions

- Commercially-available cavitation meters readily detect the driving field acoustic pressure variations within a reference field at 21.06 kHz.

- However, this spatial variation in pressure / energy density / Cavins is not the same as the cavitation activity distribution, for which more detailed signal processing and refined sensor designs are required.

- This further demonstrates the need for standards specifying methods for calibrating sensors as cavitation measurement devices.
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Thank you!
Acoustical characterisation

21 kHz

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60 kHz