An objective comparison of cavitation measurement devices

Mark Hodnett, Dan Sarno, Lian Wang, Matt Light,
Gianluca Memoli & Bajram Zeqiri

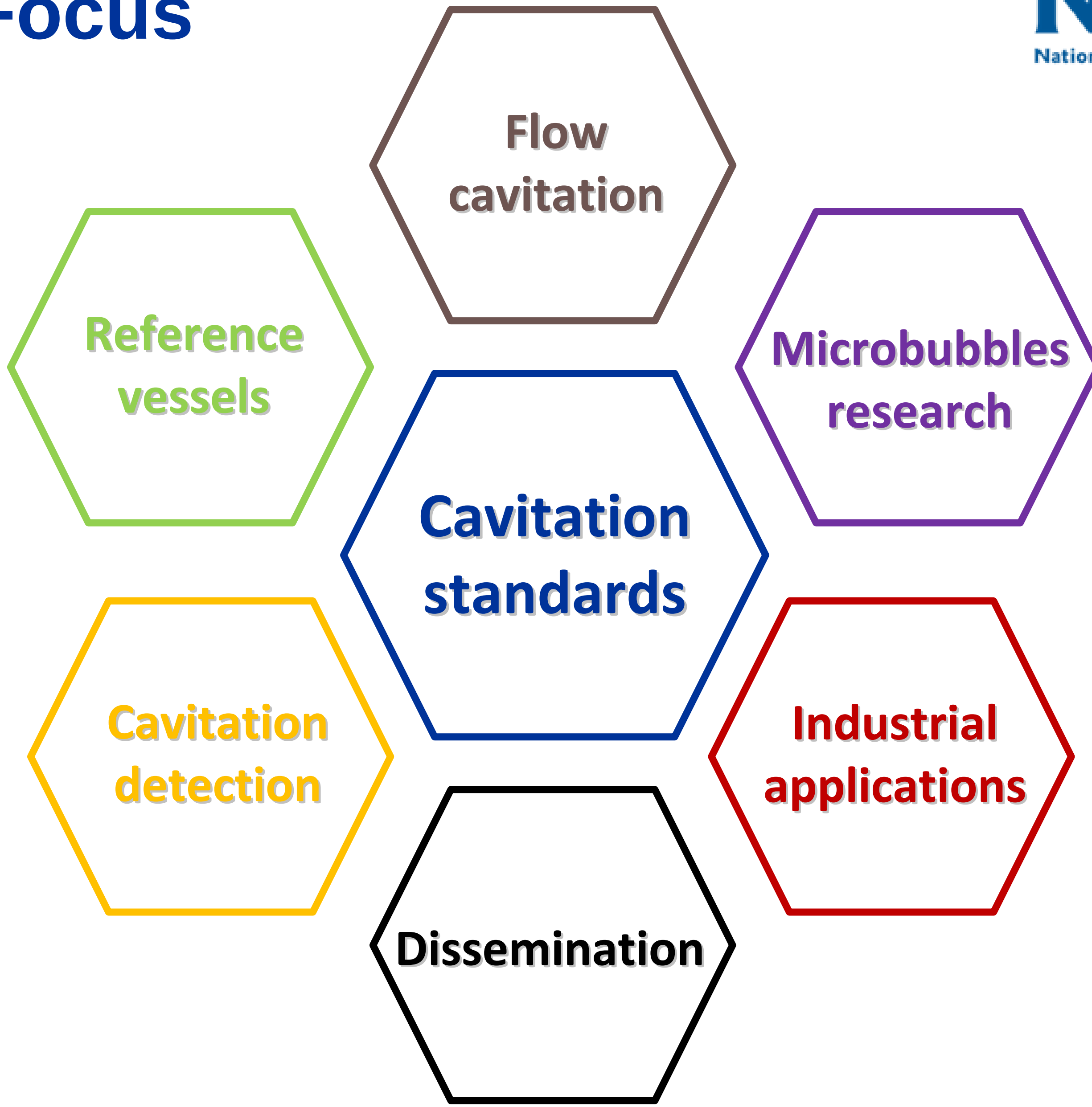
43rd Ultrasonic Industry Symposium, CSIC, Madrid

23 April 2014

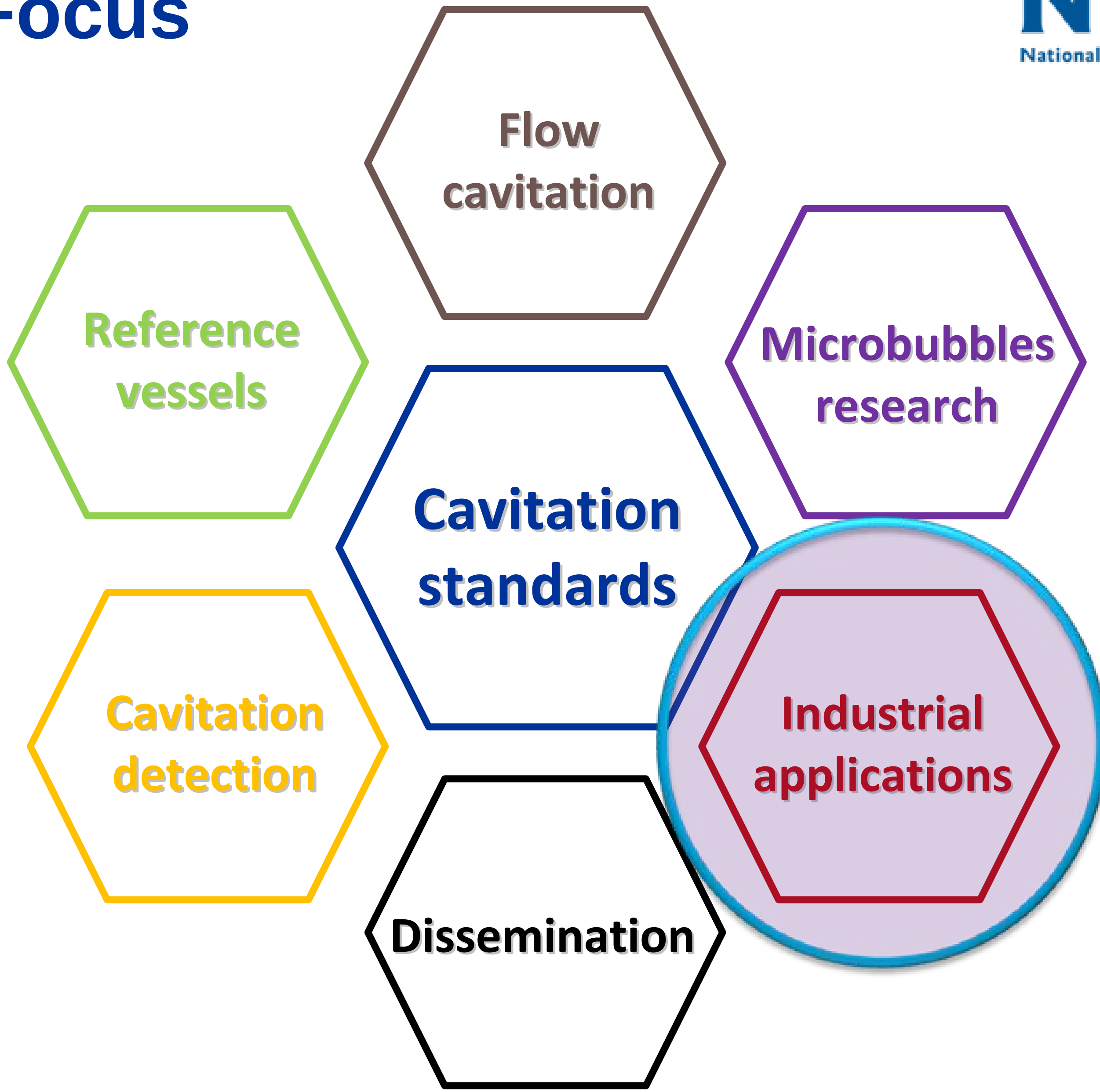
Why measure cavitation?

- 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

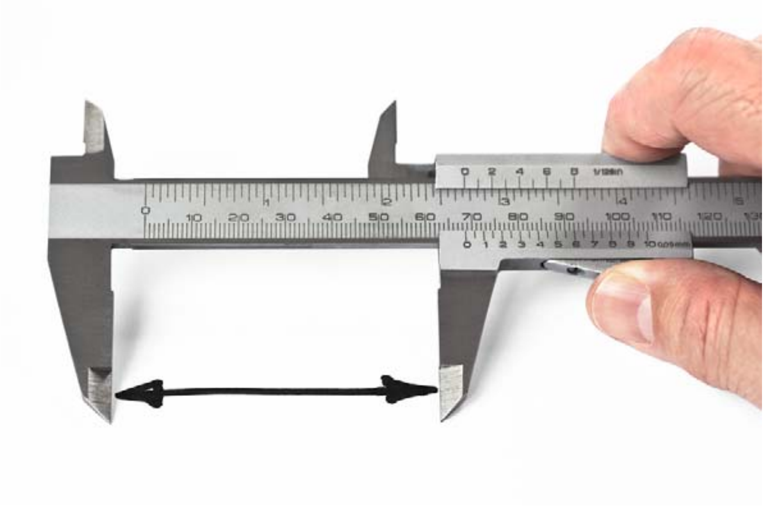

Flow cavitation
Reference vessels
Microbubbles research
Cavitation standards
Cavitation detection
Industrial applications
Dissemination

NPL Focus



Flow cavitation
Reference vessels
Microbubbles research
Cavitation standards
Cavitation detection
Industrial applications
Dissemination

How can we measure cavitation?



- Sound
- Light
- Chemistry
- Damage

http://www.mondolithic.com/wp-content/uploads/2011/10/Focus-Italy_Cavitation-Bubble.jpg
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)

www.lapetitebrique.com

What's the best way to measure cavitation?

Your way.

(for now)

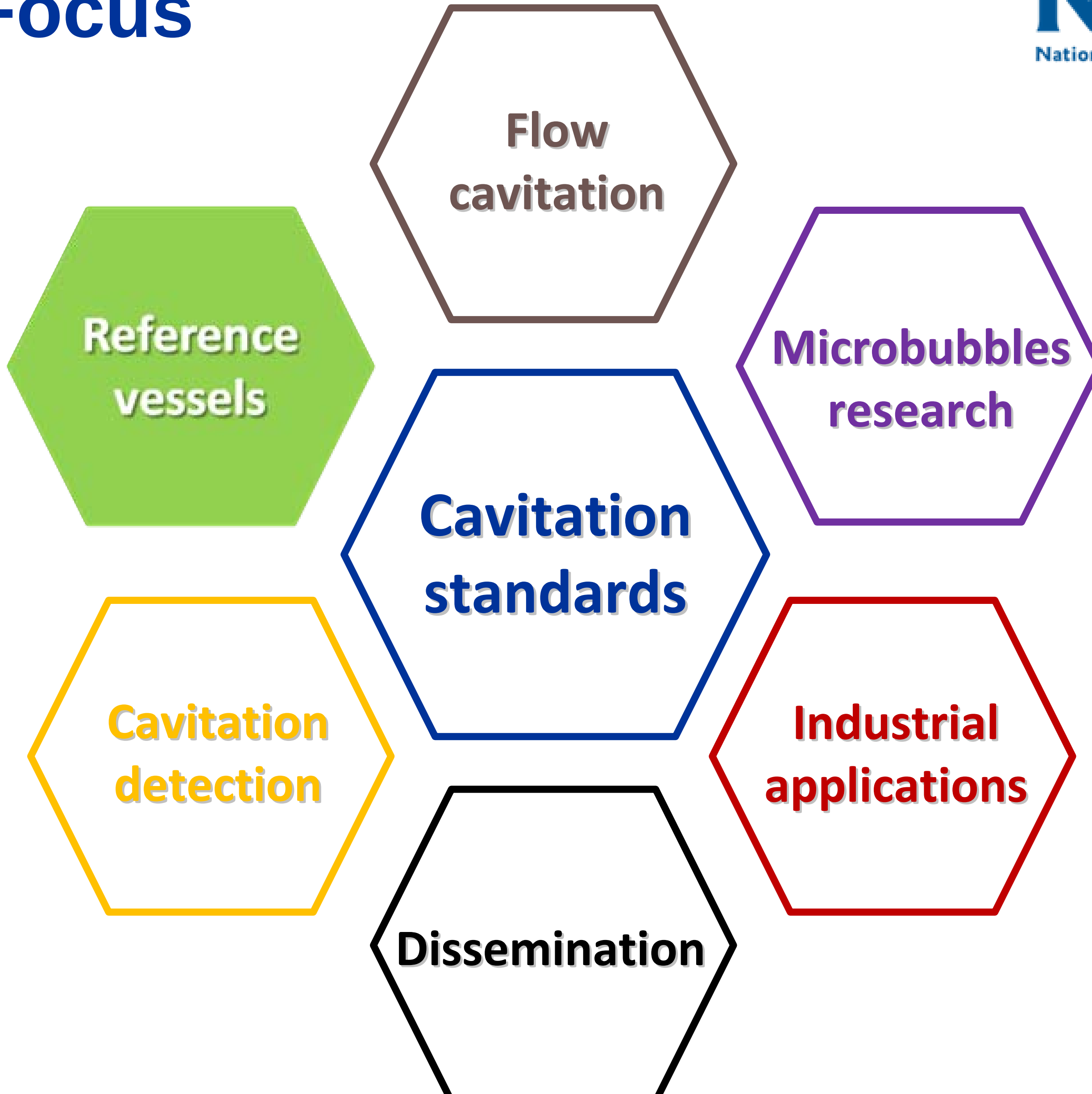
cenblog.org

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?*

NPL Focus



Flow cavitation
Reference vessels
Microbubbles research
Cavitation standards
Cavitation detection
Industrial applications
Dissemination

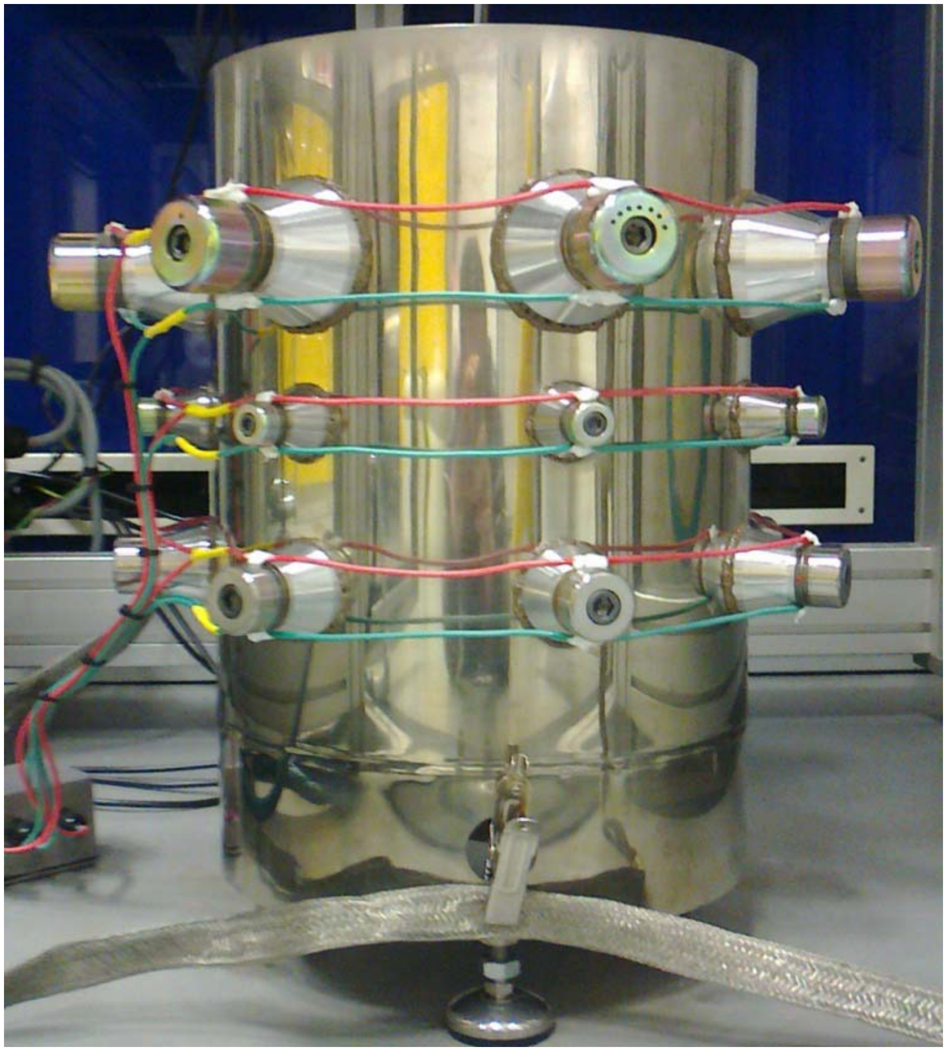
Reference vessels

- 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

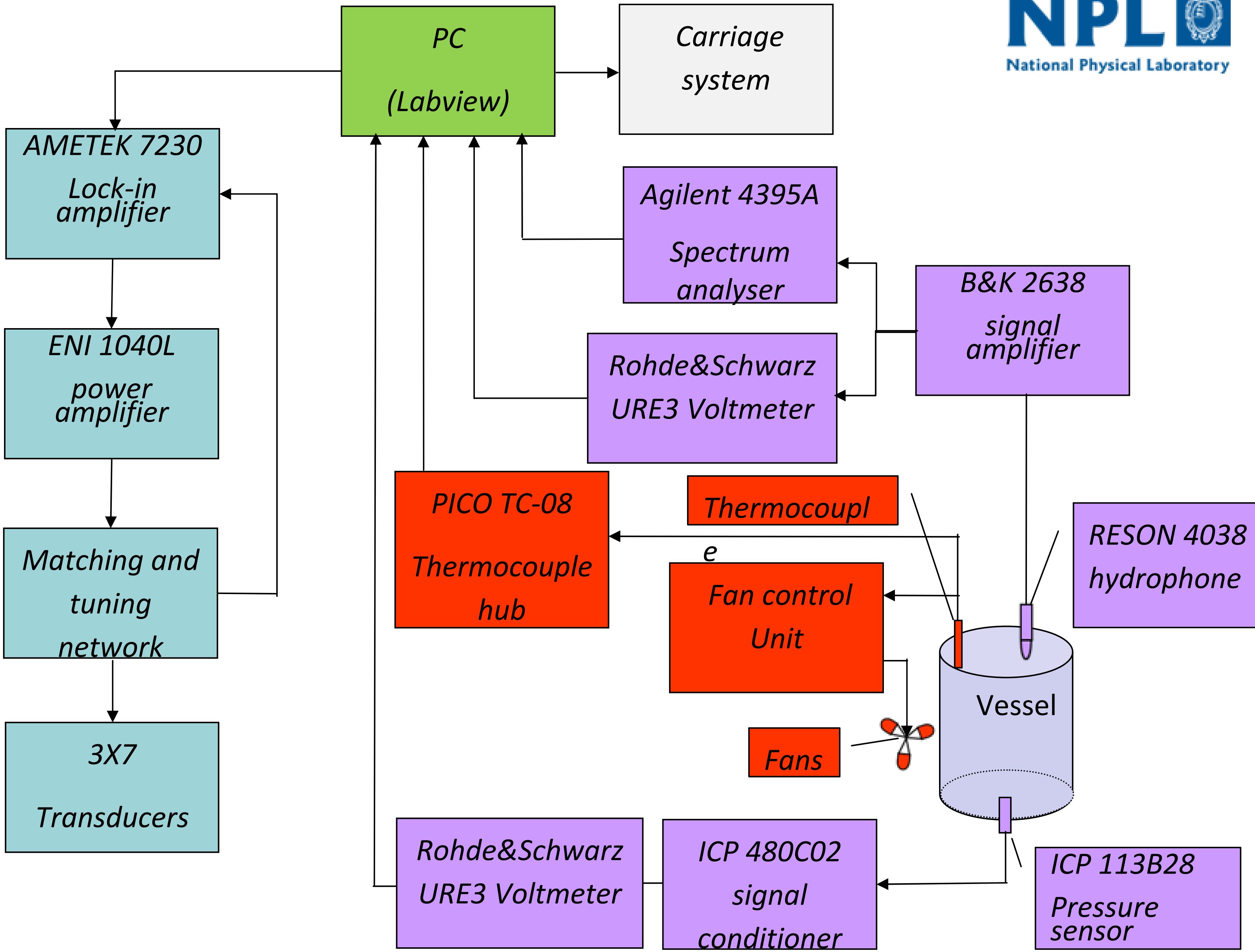
National Physical Laboratory



- 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

Wang et al., IOP Conference Series-Materials Science and Engineering. Volume 42, Article 012013 (2012)

Multi-frequency vessel system

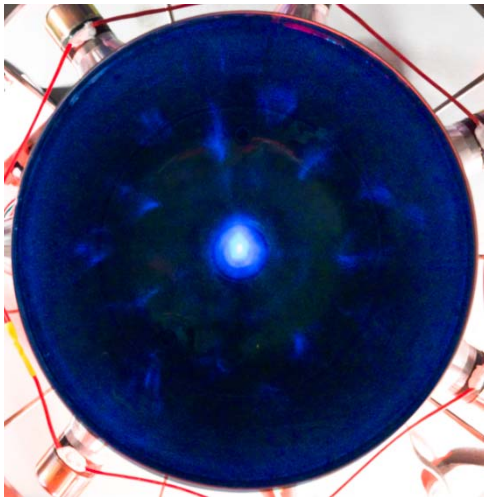


Vessel characterisation

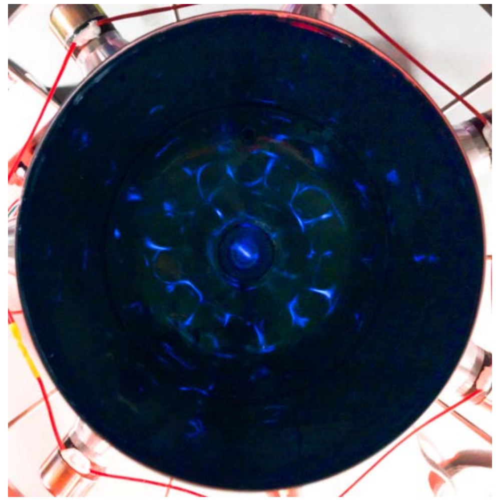
- Characterised using acoustical, optical, chemical, (& erosive, and vibratory) methods
- Unique control and mode selection provides repeatable performance of the acoustic pressure field, and hence the vessel is suitable as a spatially-variant cavitation source
- Stability and repeatability demonstrated through consistency of vessel monitor, and through good agreement in periodic measurements

Luminol characterisation

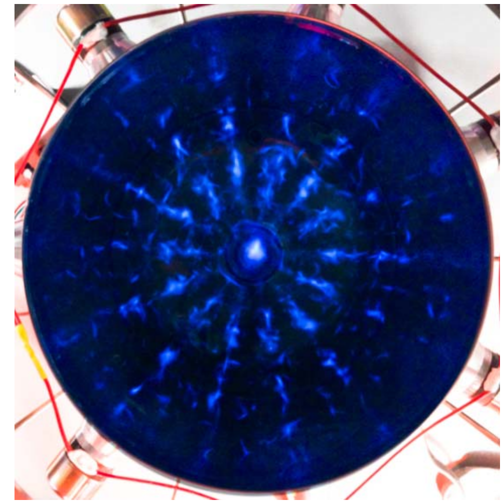
21 kHz



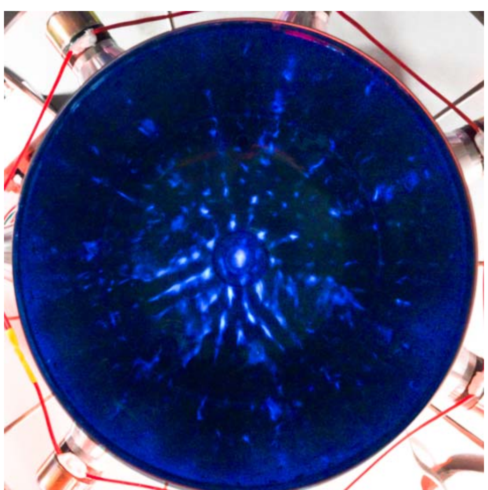
37 kHz



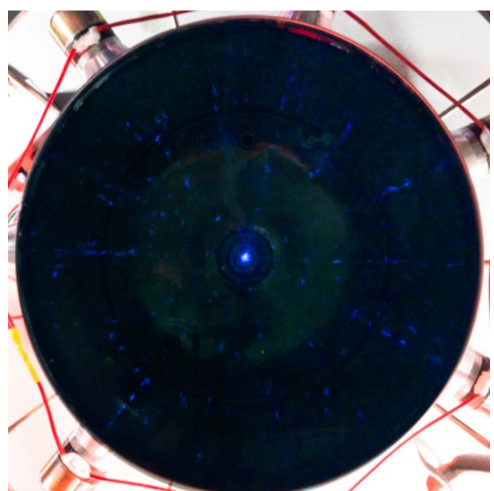
44 kHz



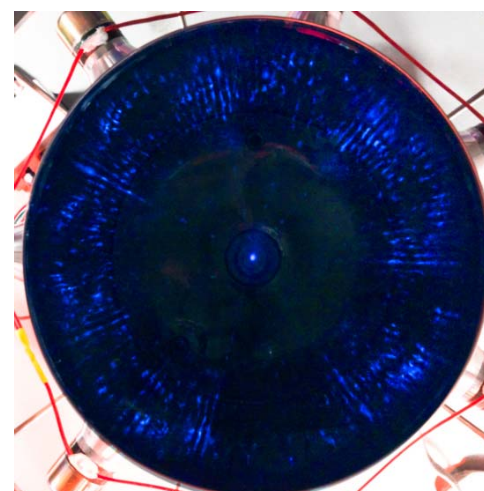
60 kHz



92 kHz



136 kHz



Roll call of devices in this study

Cavitation Measurement Device	Manufacturer	Detection Method	Dimensions	Frequency Range
CAV-Meter (CM-3-100) and CAV-Meter 2	Alexy Associates Inc. / MRC Labs	Acoustic energy	Length: 450mm Diameter: 12.7mm	20 to 120 kHz
HCT-0310	Onda	Acoustic pressure (broadband)	Length: 300mm Diameter: 3mm	30 to 300 kHz (300 kHz to 1.2 MHz optional)*
pb-502 cavitation meter	PPB Megasonics	Acoustic energy (broadband)	Length: 610mm Diameter: 58mm (head)	0 to 500 kHz
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.*

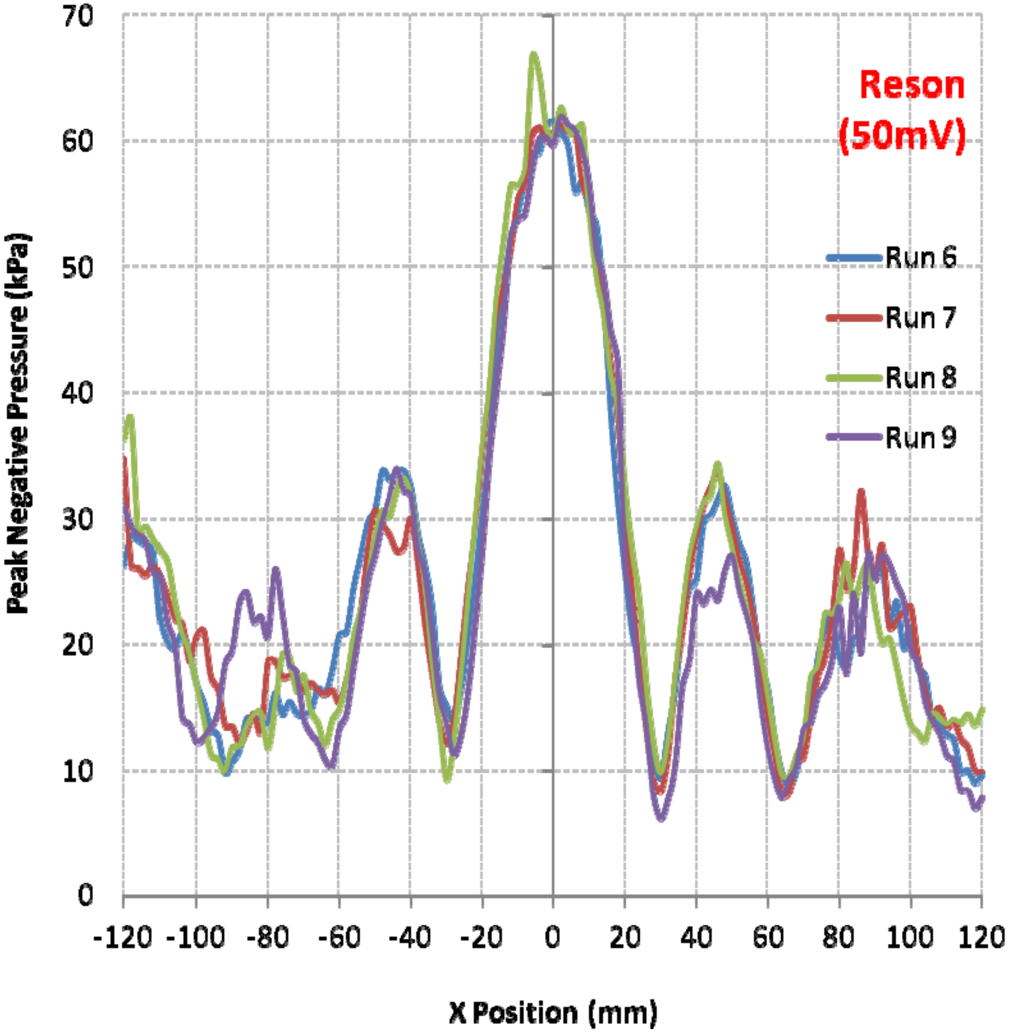
EXPERIMENTAL

Experimental protocol

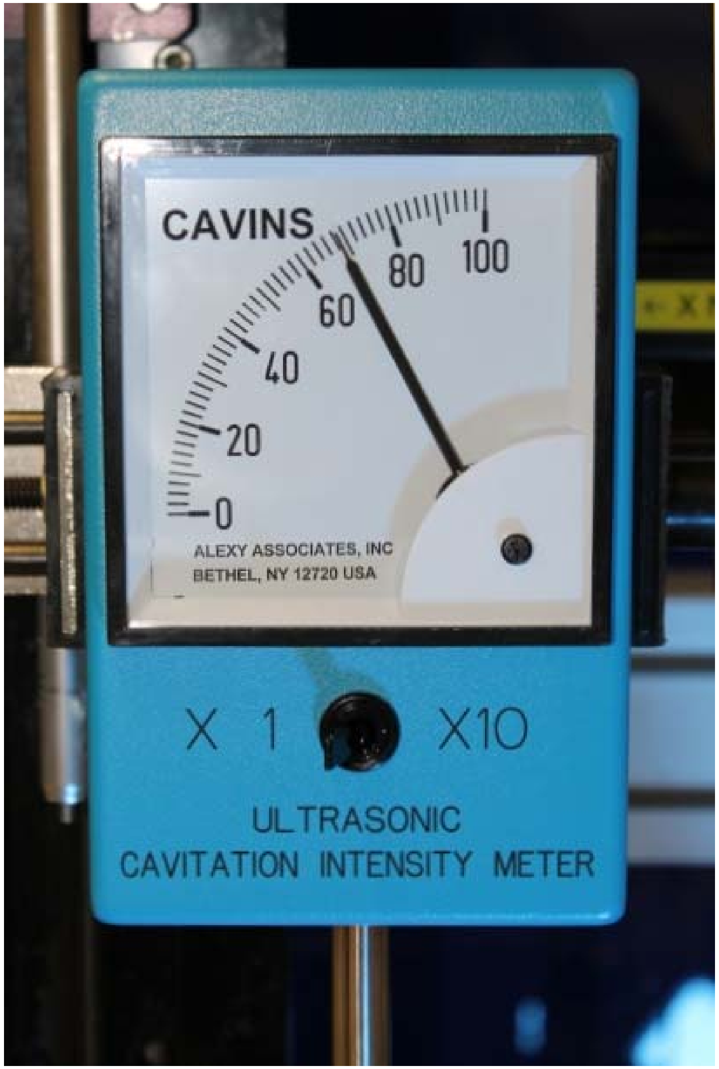
- Reference vessel filled to a depth of 380 ±1 mm with 5 micron filtered, deionised water at 21 degrees C
- Sensor under test mounted with its acoustic centre / geometric tip at a depth of 74 mm beneath the water surface
- Reference vessel excitation set to 21.06 kHz, and function generator drive levels 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

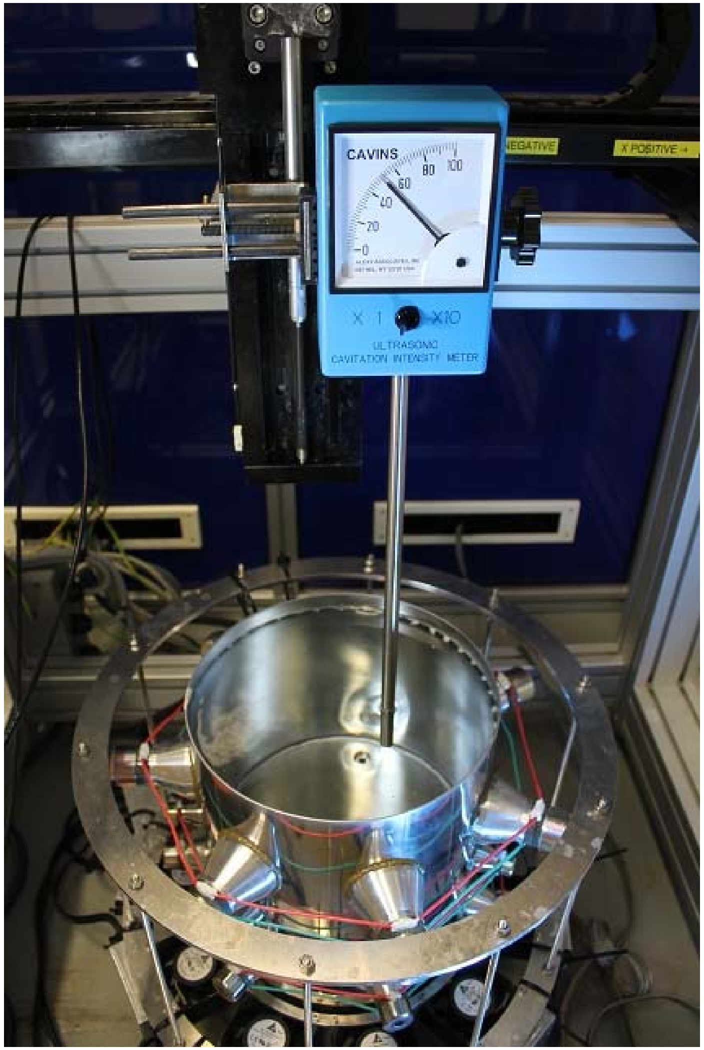
Reference measurement

- 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 (1/3)


CAVINS
0
20
40
60
80
100
ALEXY ASSOCIATES, INC
BETHEL, NY 12720 USA
X 1
X10
ULTRASONIC
CAVITATION INTENSITY METER

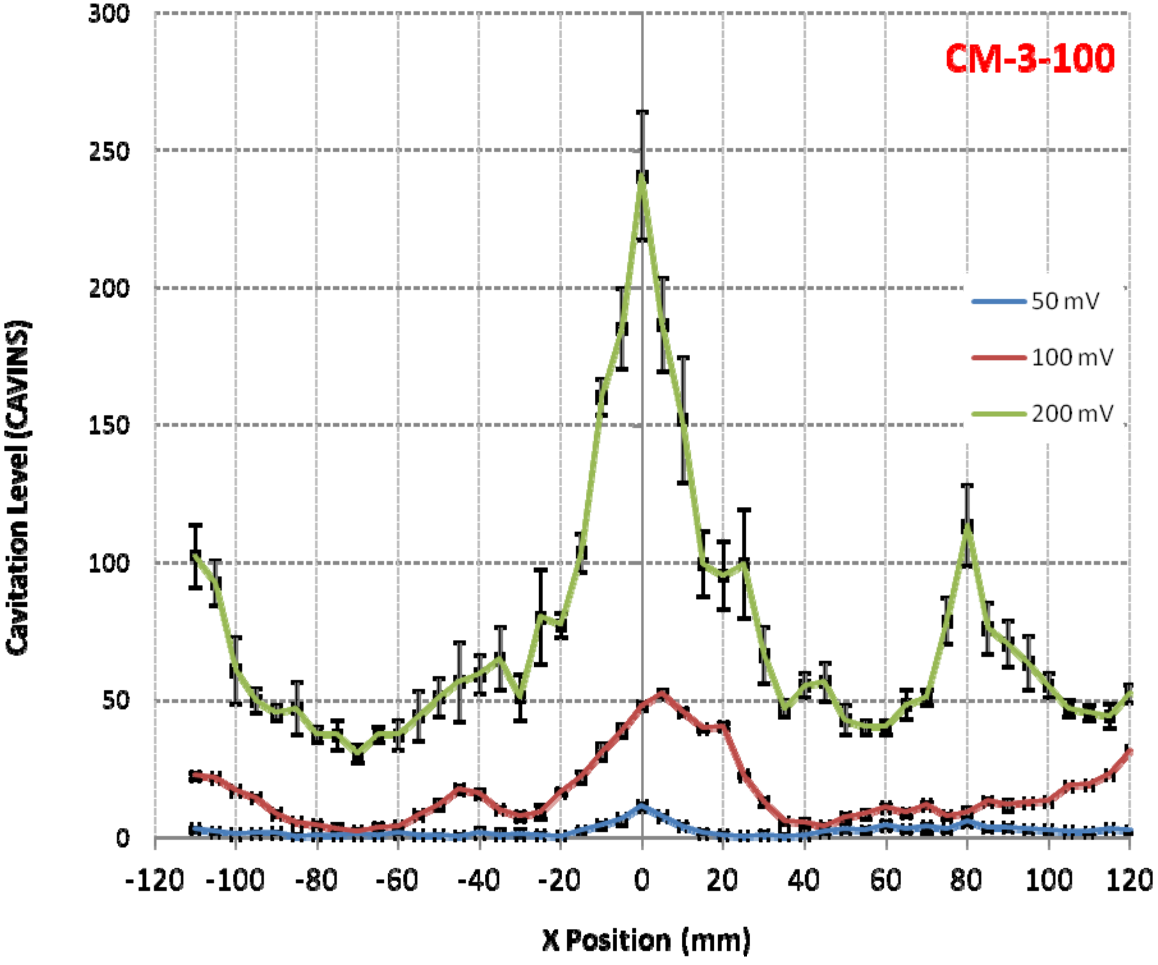

CAVINS
ULTRASONIC
CAVITATION INTENSITY METER

CM-3-100 (2/3)

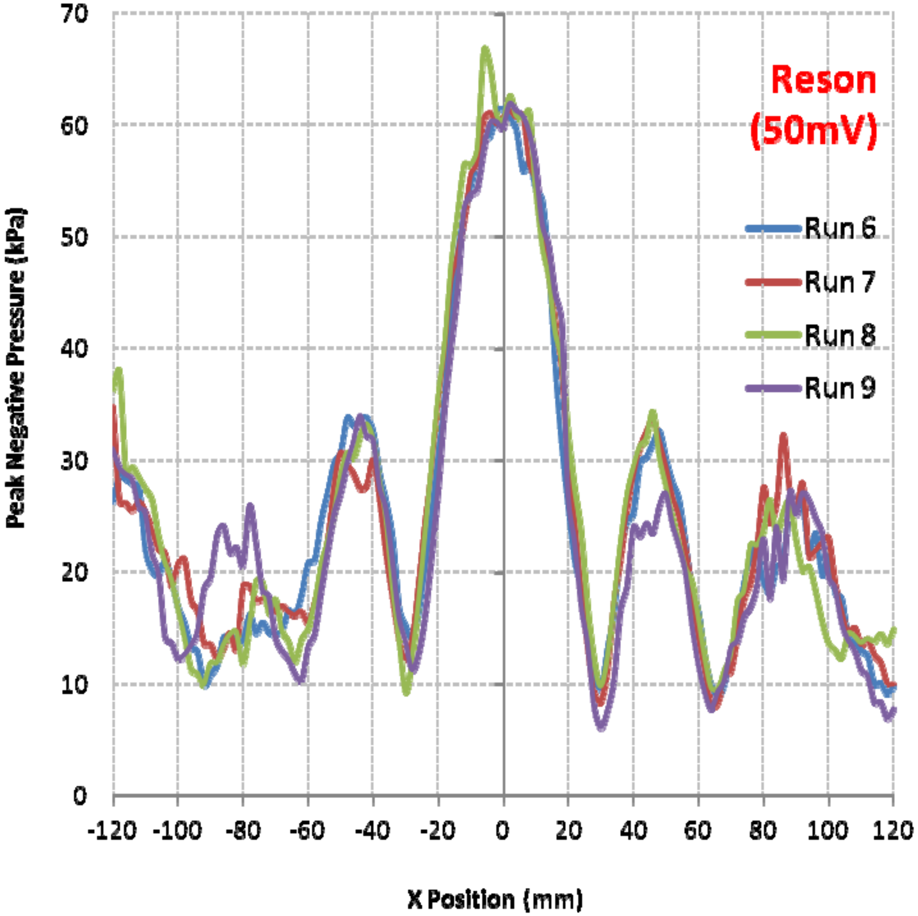
- Consists of a 450mm long, 12.7mm diameter waveguide, with detecting PZT crystals at the top
- Relative cavitation activity measured in ‘Cavins’ (ref: Branson Ultrasonics work in the 1960s) on a passive needle meter
- Reading changes when meter is tilted, and by a factor of x5.5 when the expanded range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

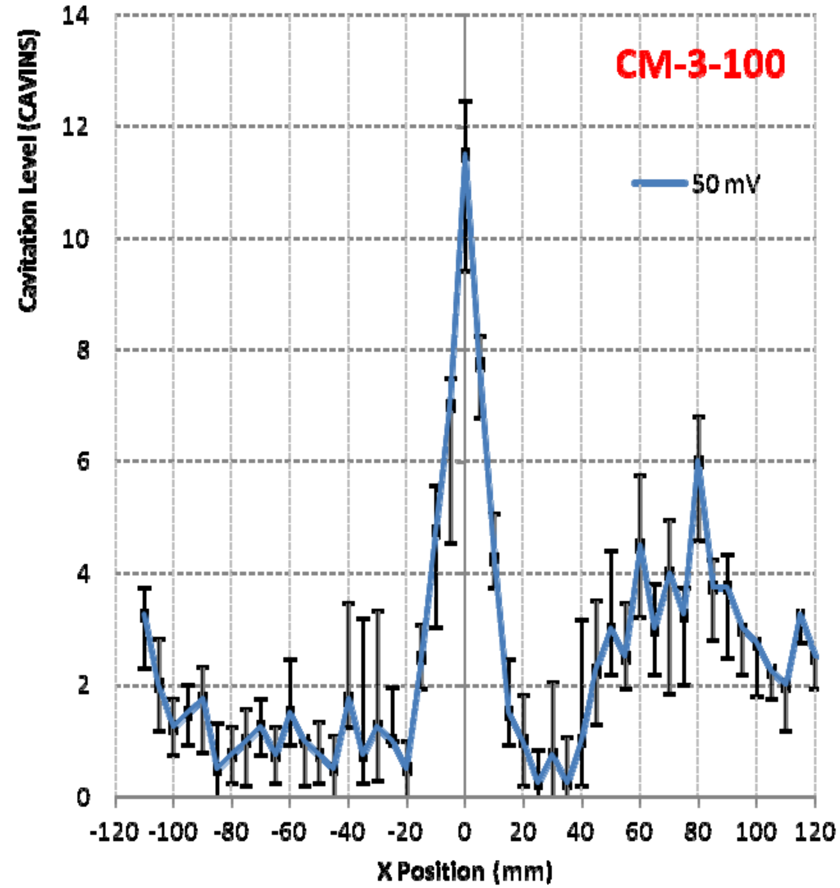
CM-3-100 (3/3)

- 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



CM-3-100 vs Reson





- Less well-defined subsidiary maxima seen with CM-3-100, large variations at a point
- Some scan regions are close to background noise level

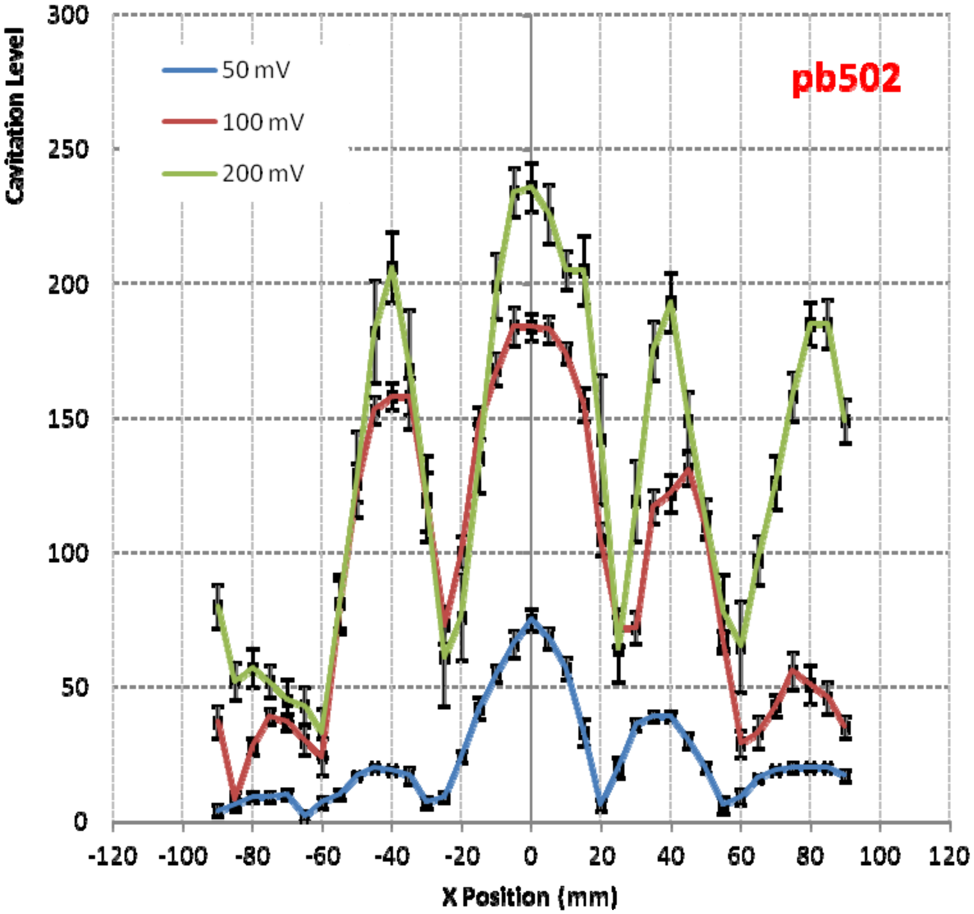
pb-502 (1/3)


US TK ENERGY METER
153
ON OFF
KHZ
PRN
DATE
TIME
SNGL
AUTO
MAX MIN
S.D.
START/STOP
STO
RCL
ppb

pb-502 (2/3)

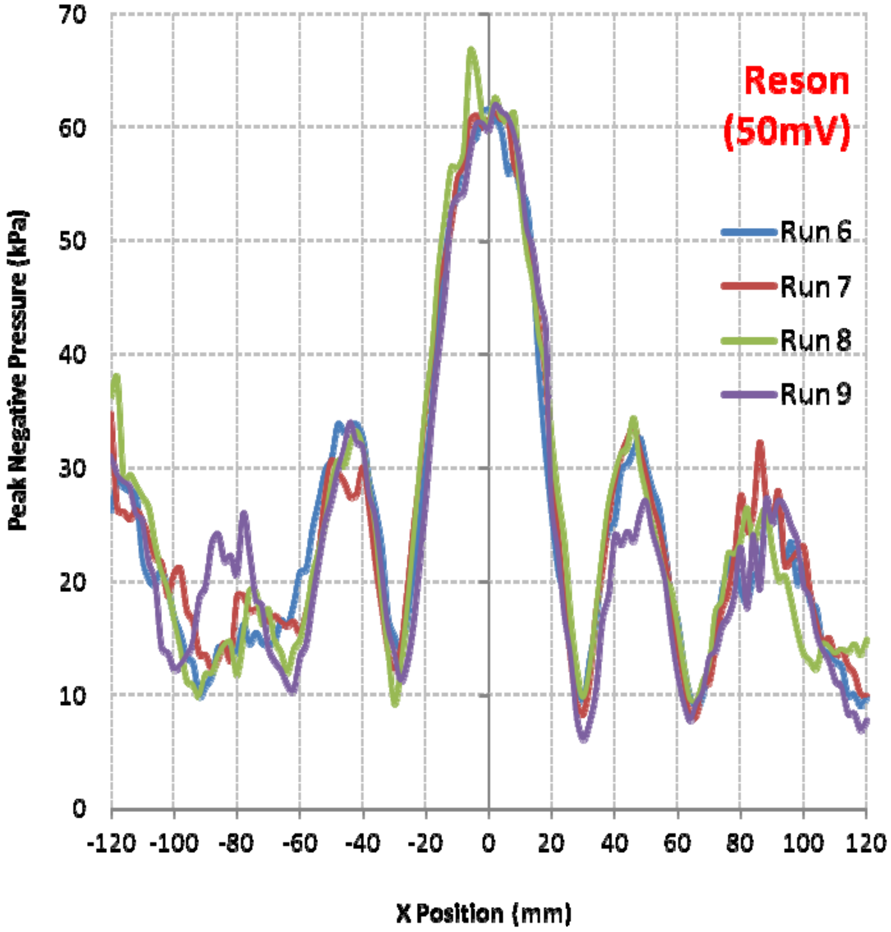
- Consists of a sensing element housed in a rubber hemisphere, within an embedding acoustically-matched material
- Relative cavitation energy measured as an (ADC) level from 0-255: manufacturer claims traceability to NIST for the device calibrated in W/gal: sensitivity can be set directly by user
- On-board 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

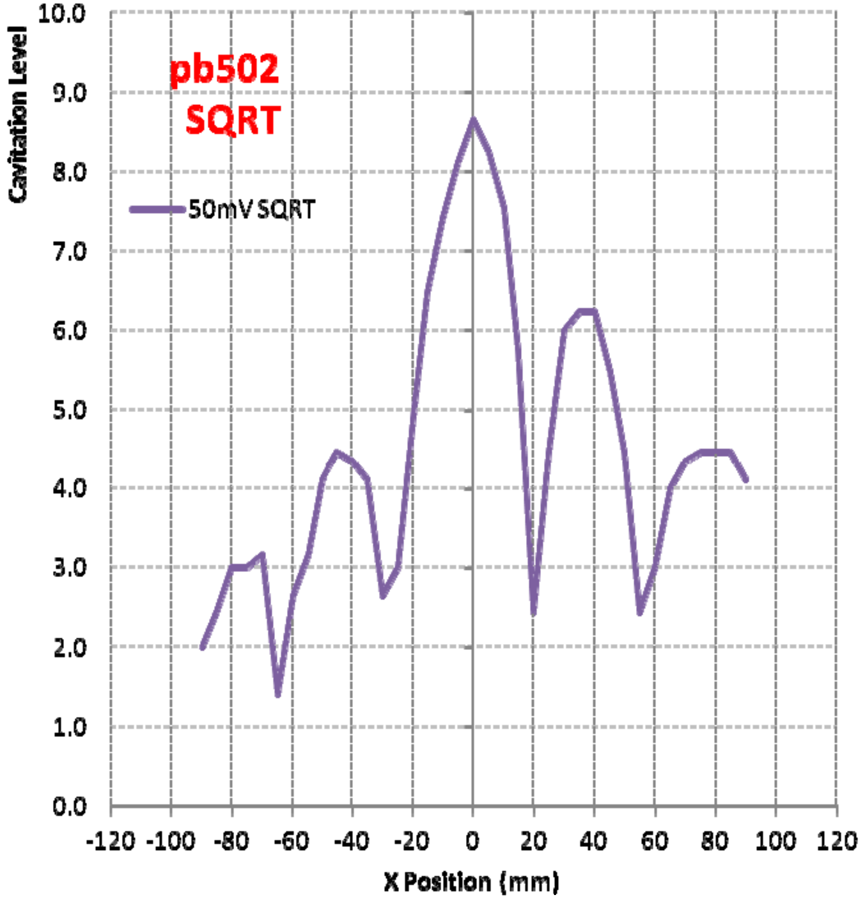
pb-502 (3/3)



- 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

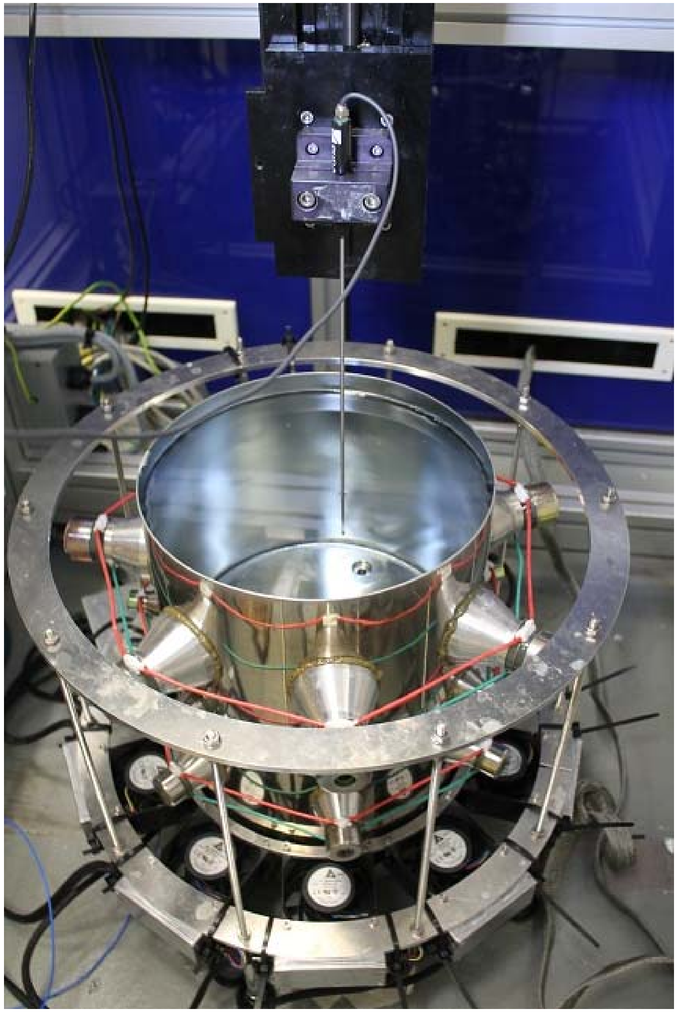
pb-502 vs Reson





- Square root of pb502 output taken for comparison with Reson
- Greater similarities to Reson than seen with CM-3-100

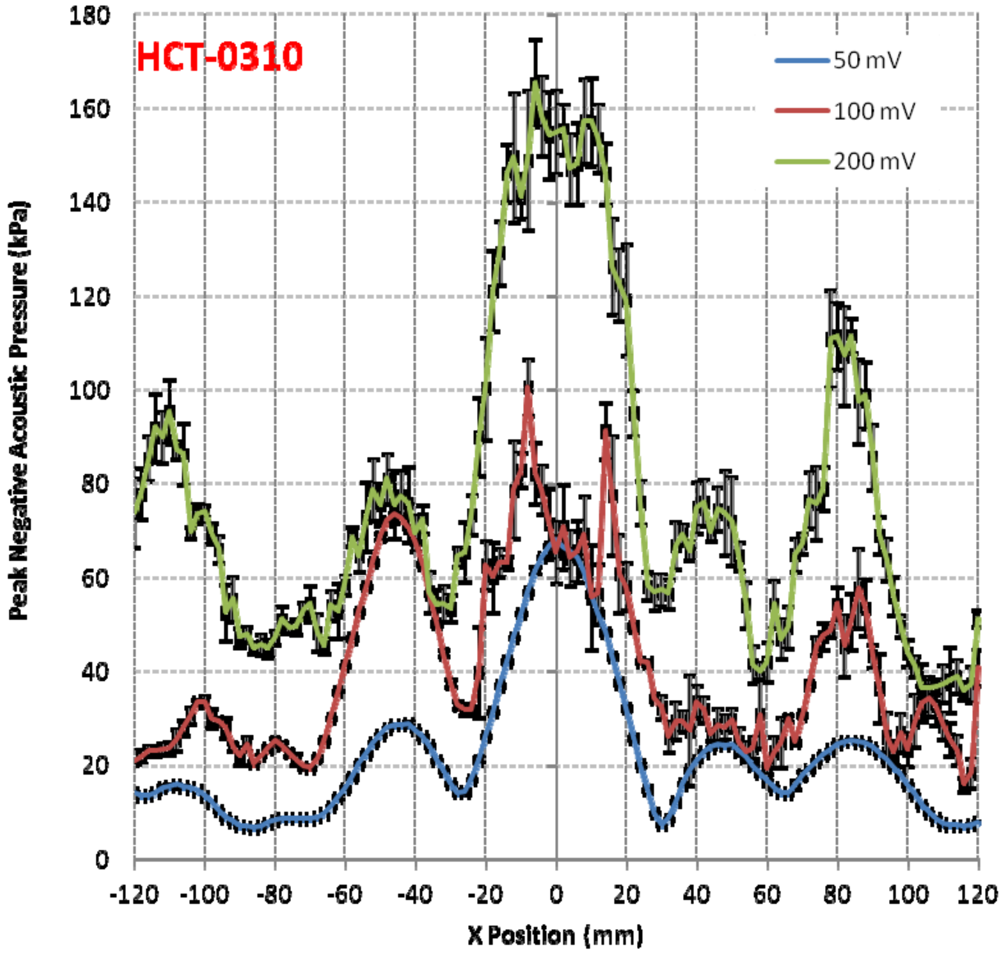
HCT-0310 (1/3)



HCT-0310 (2/3)

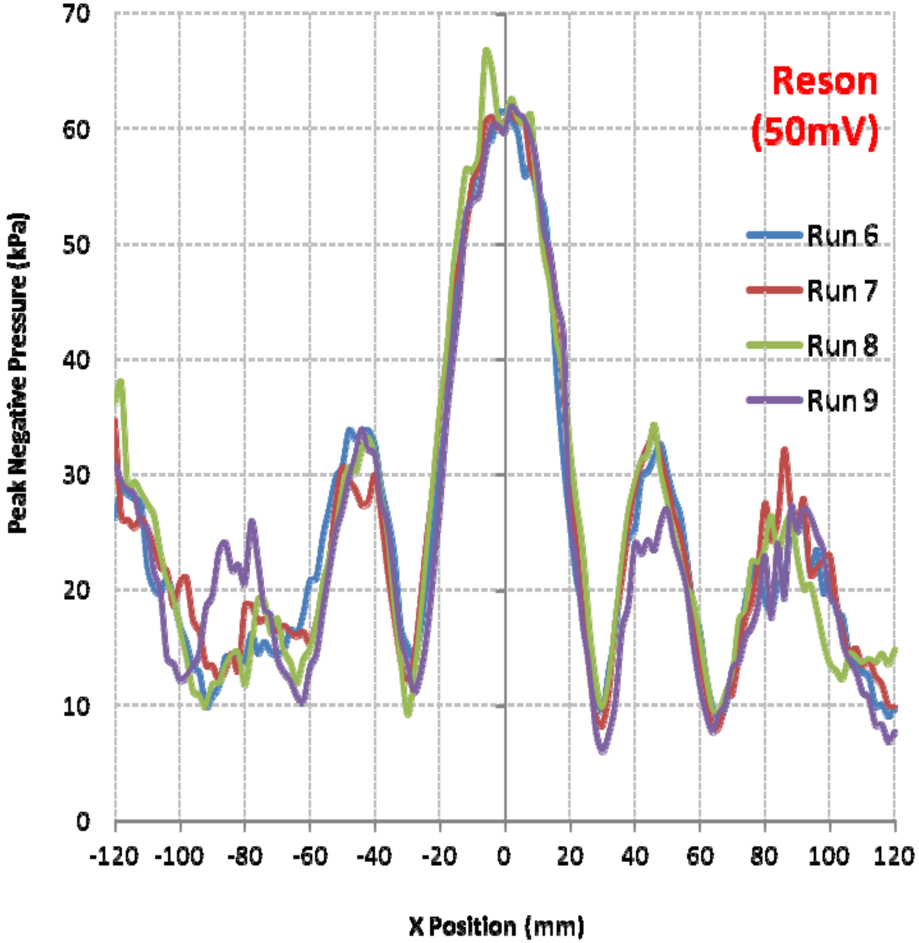
- Device consists of a 3mm diameter shaft, with a broadband PVDF-like sensing element at the tip, with an intervening layer of a viscous oil for vibration isolation
- Usually paired with bespoke electronics (MCT-0310) which carries out signal conditioning and wireless transmission
- Device provided with an acoustic pressure sensitivity calibration certificate, traceable to International Standards

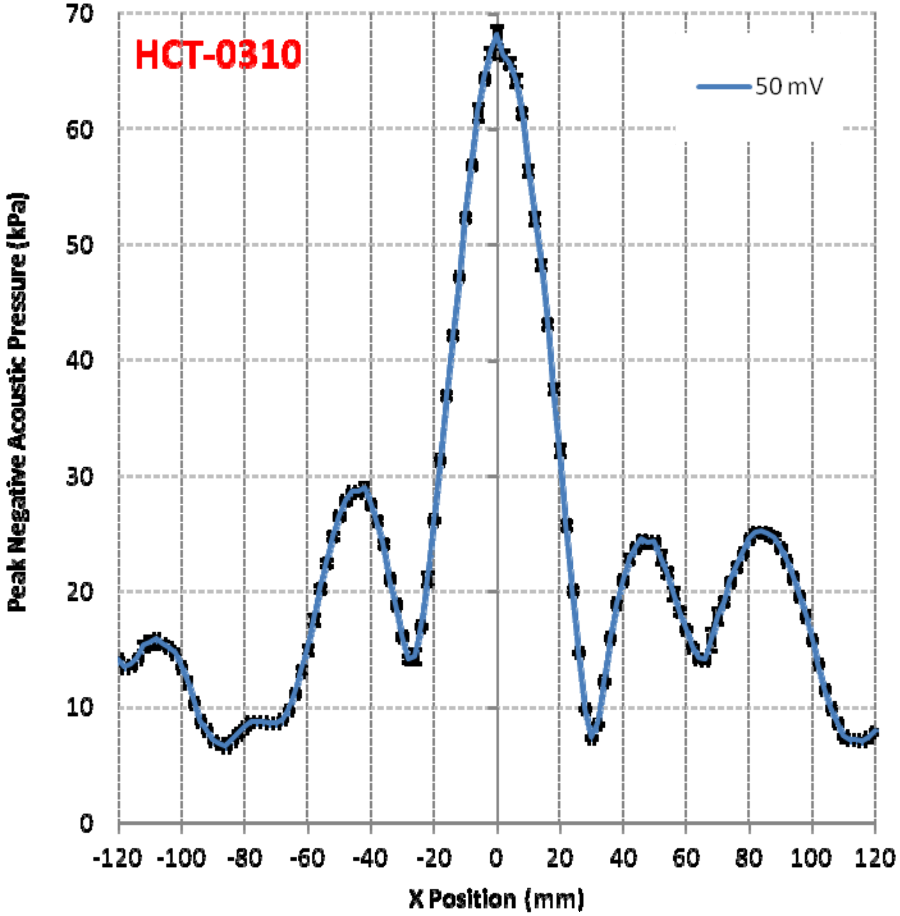
HCT-0310 (3/3)



- 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

HCT-0310 vs Reson

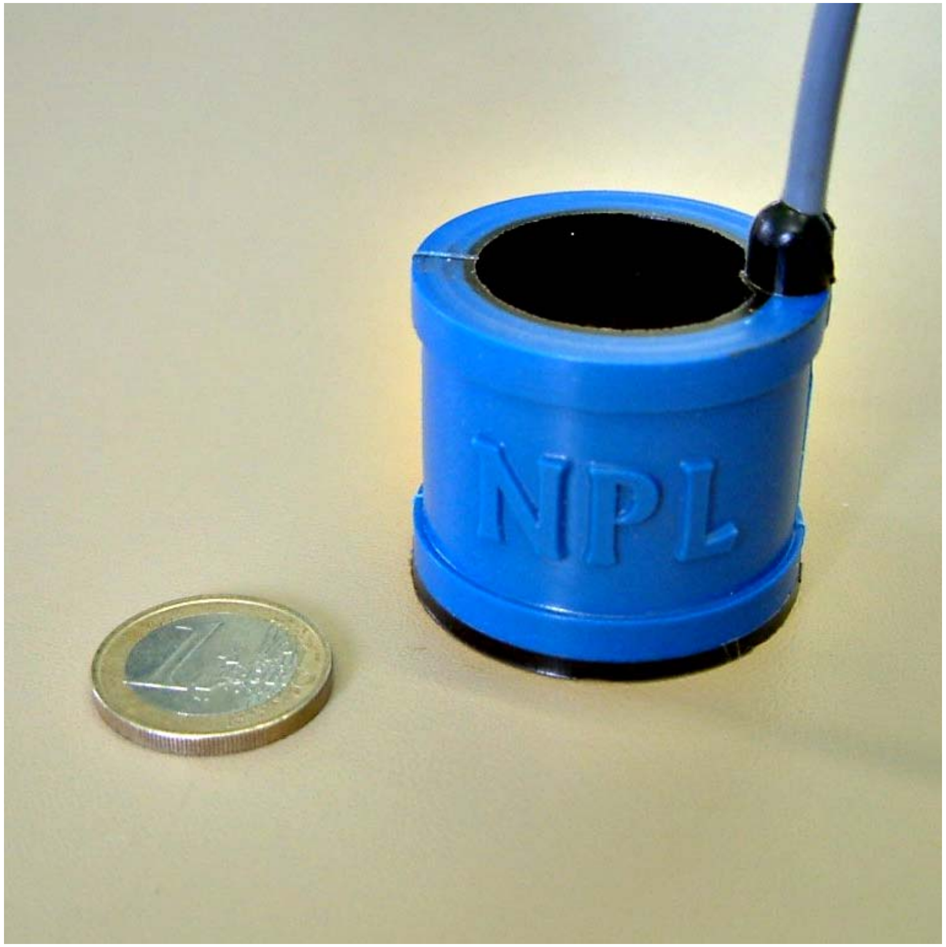


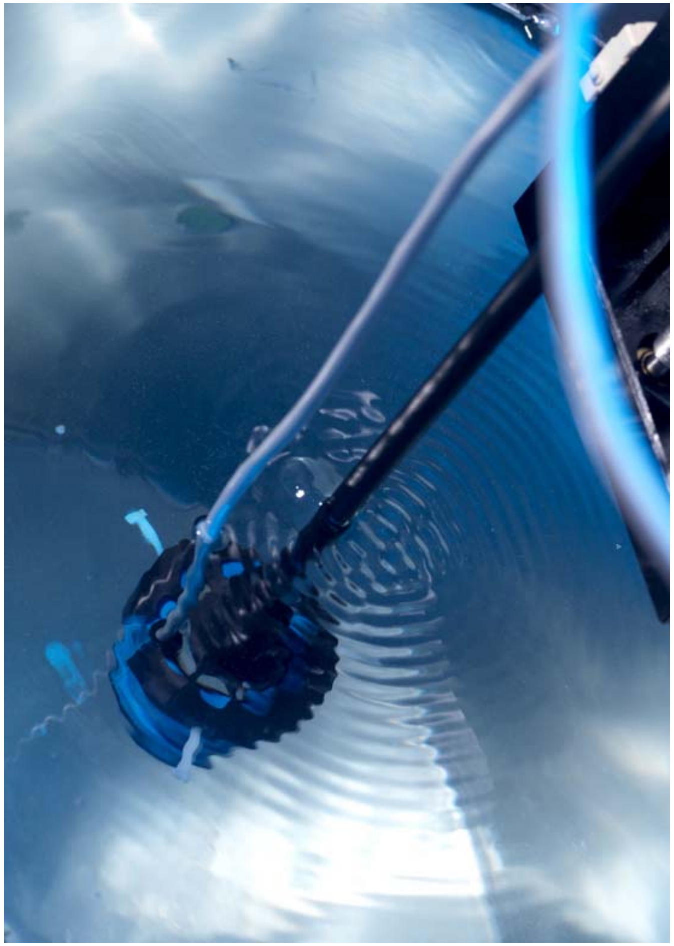


- Good agreement seen between devices (similar dimensions and design), in field structure and measured pressure levels

NPL CaviSensor (1/3)

National Physical Laboratory



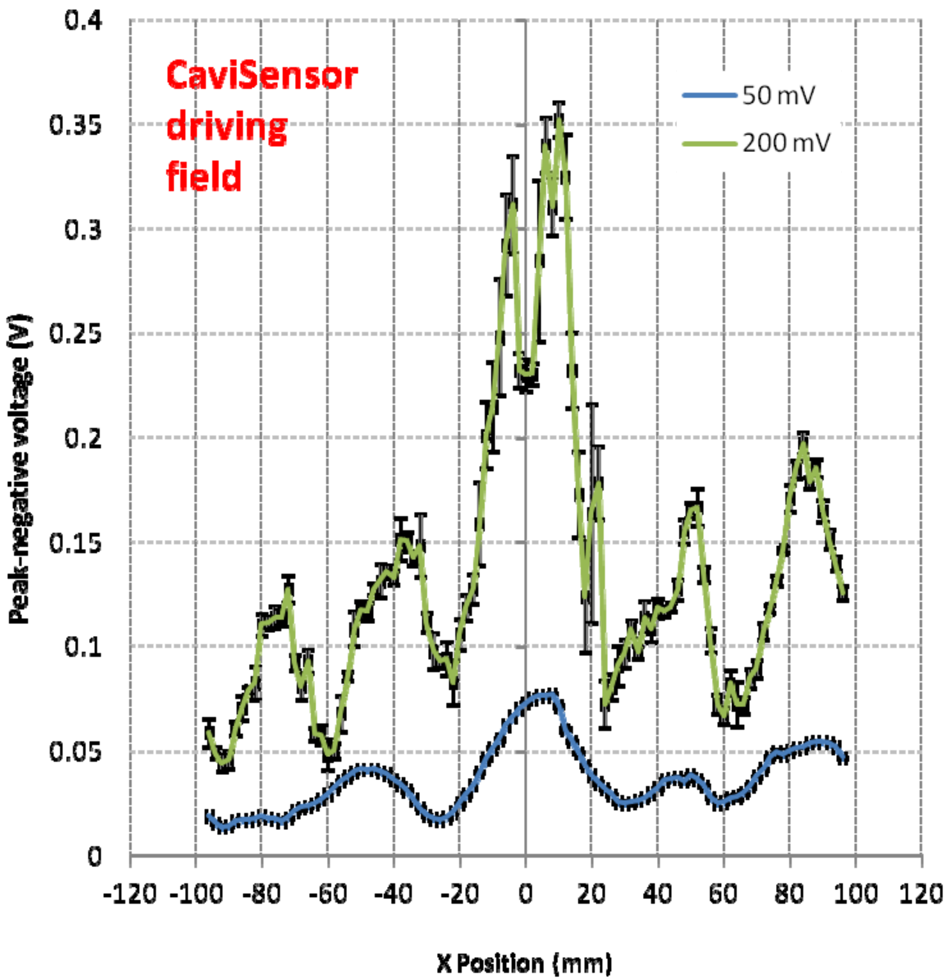


NPL CaviSensor (2/3)

- 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 posess spatial resolution when monitoring MHz frequency emissions from cavitation

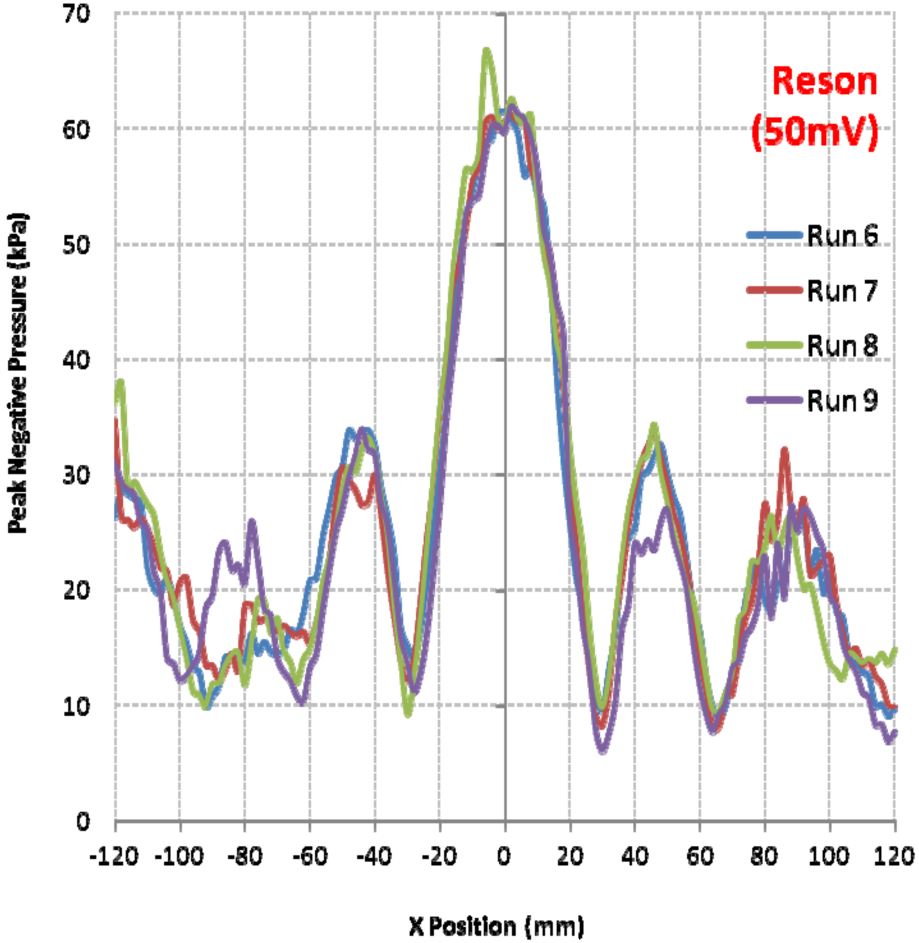
NPL CaviSensor (3/3)

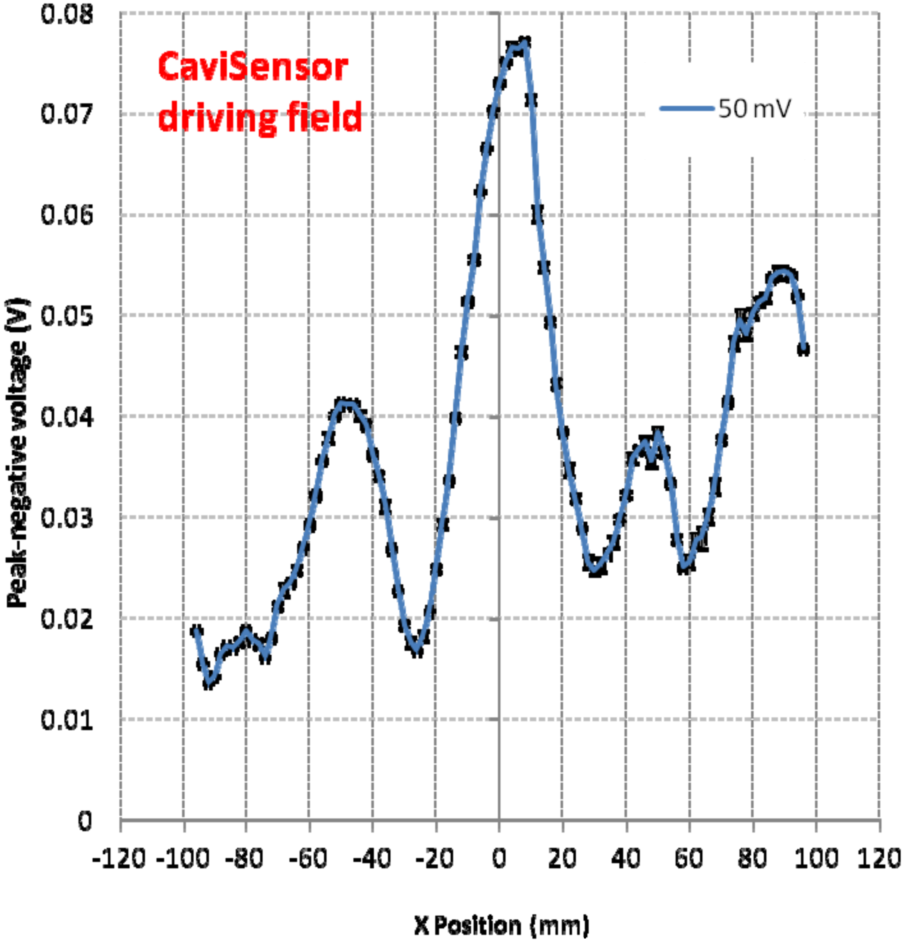
NPL National Physical Laboratory



- 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

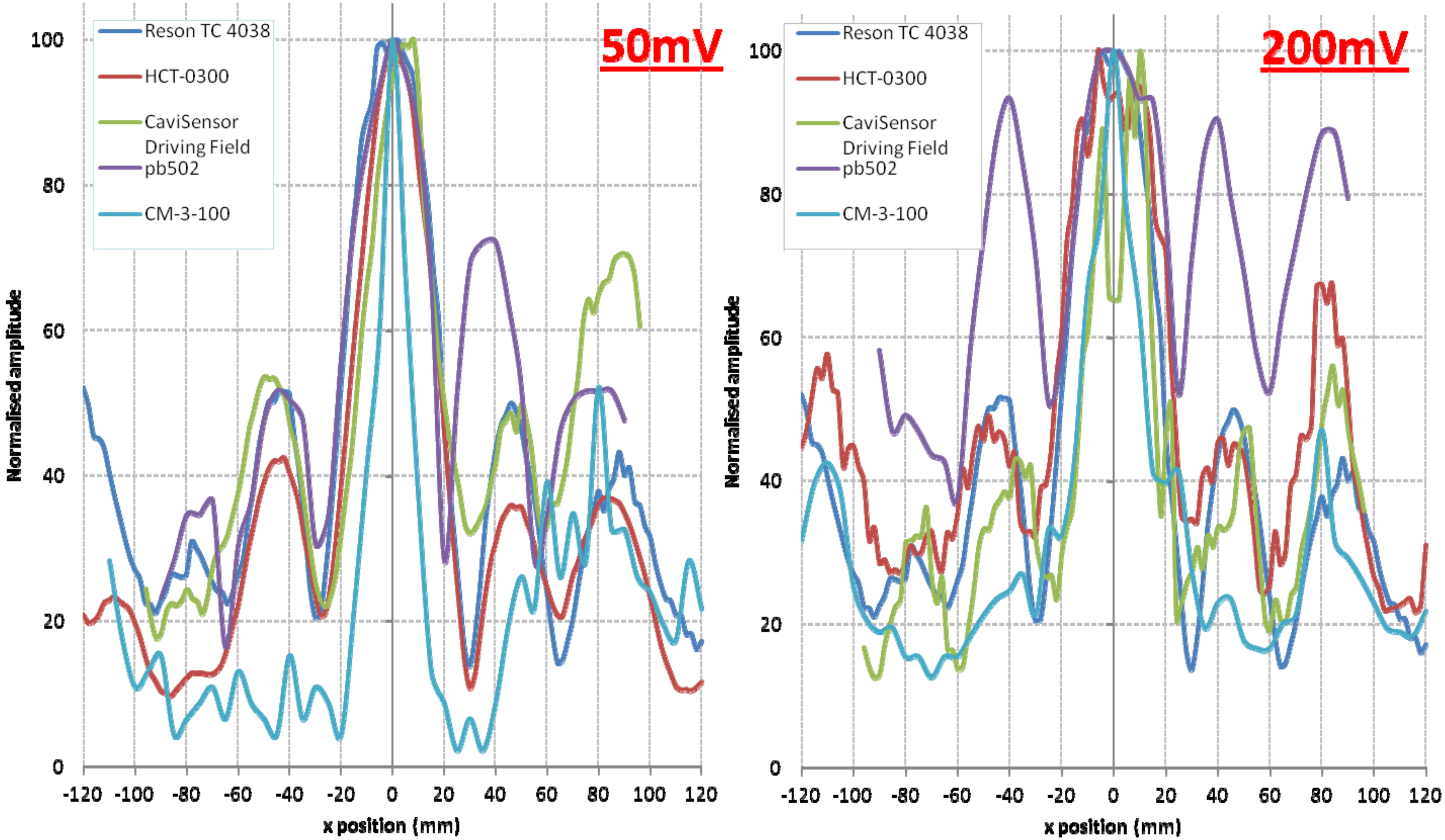




- Good agreement seen between devices in field structure
- Suggestion of a 'ramp' across scan

50 mV and 200 mV comparison

National Physical Laboratory



- The more refined sensor designs generally agree pretty well

What do they actually measure?

NPL National Physical Laboratory

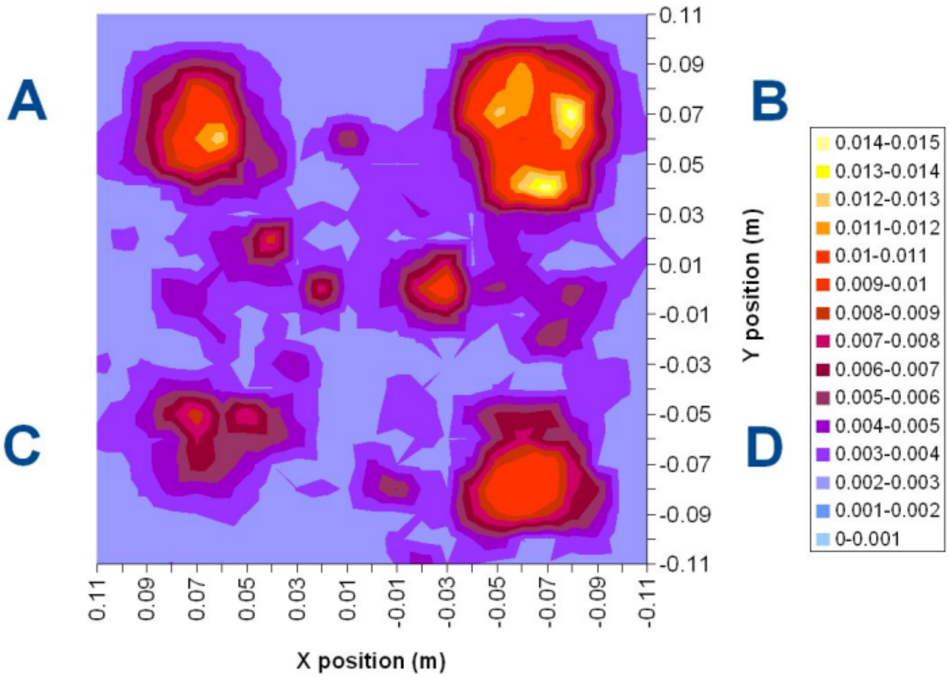
- Bandwidth details on some sensors are unclear, but given the agreement with the reference (Reson), all devices resolve a similar spatial variation in the driving field at 21.06 kHz
- Across the devices, the central pressure increases by a factor of 2 to 5 when the drive level is increased from 50 mV to 200 mV
- But to what extent does this represent the spatial distribution in the cavitation activity, which is the driver of most applications?

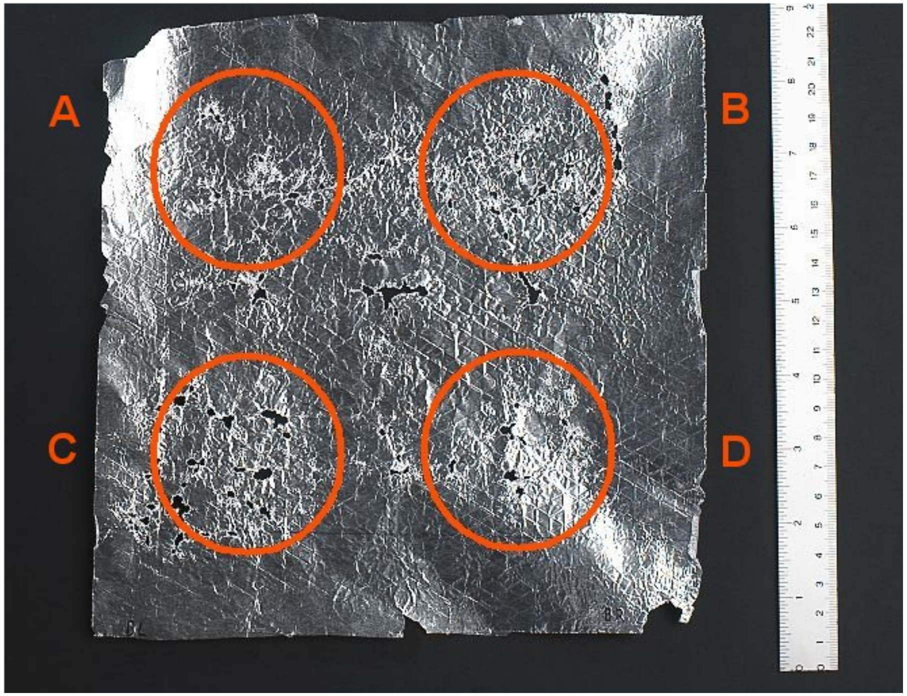
Tested using NPL CaviMeter

NPL
National Physical Laboratory

- 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

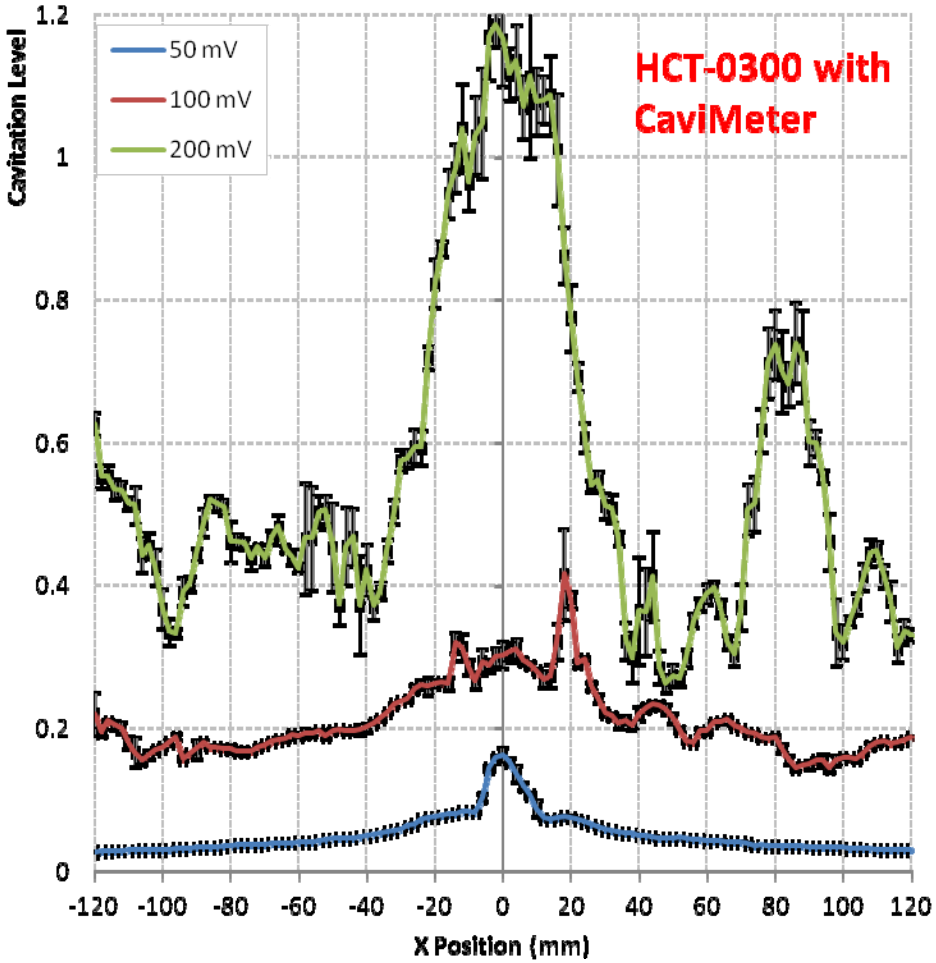
Broadband acoustic emission vs erosion

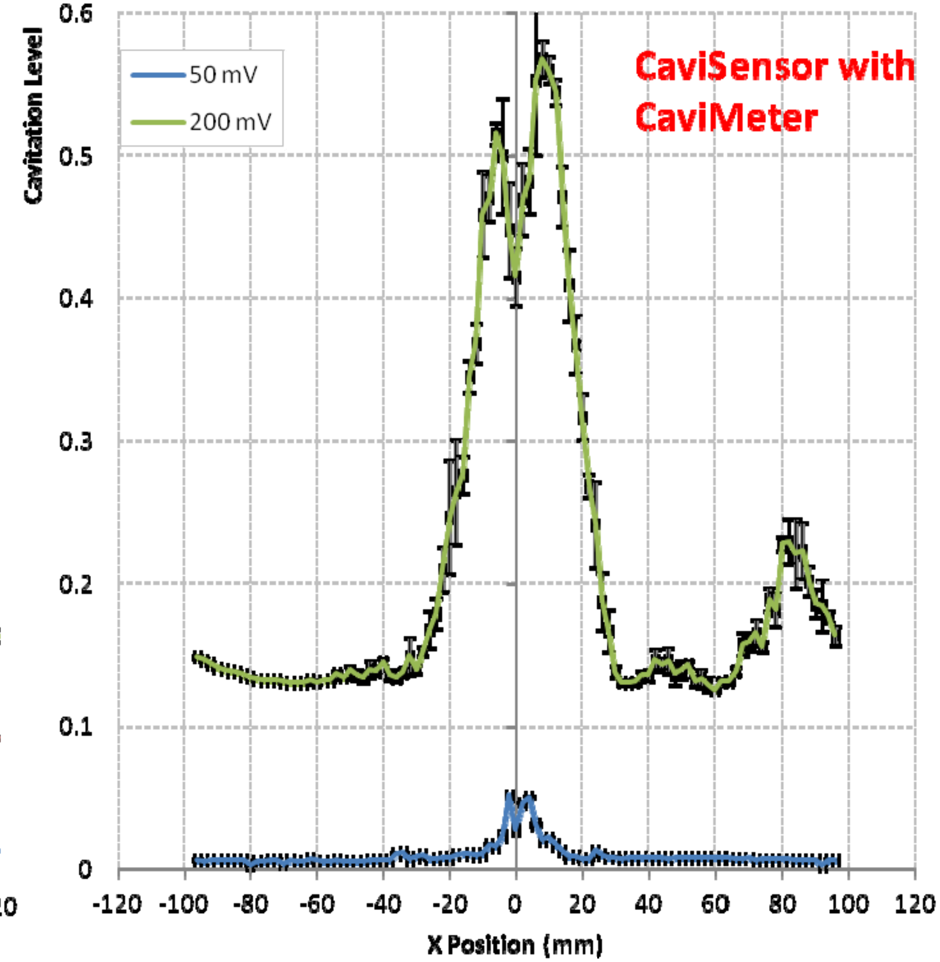




Studies of a novel sensor for assessing the spatial distribution of cavitation activity within ultrasonic cleaning vessels.
Zeqiri, Hodnett & Carroll, Ultrasonics, Vol.44, January 2006, 73-82.

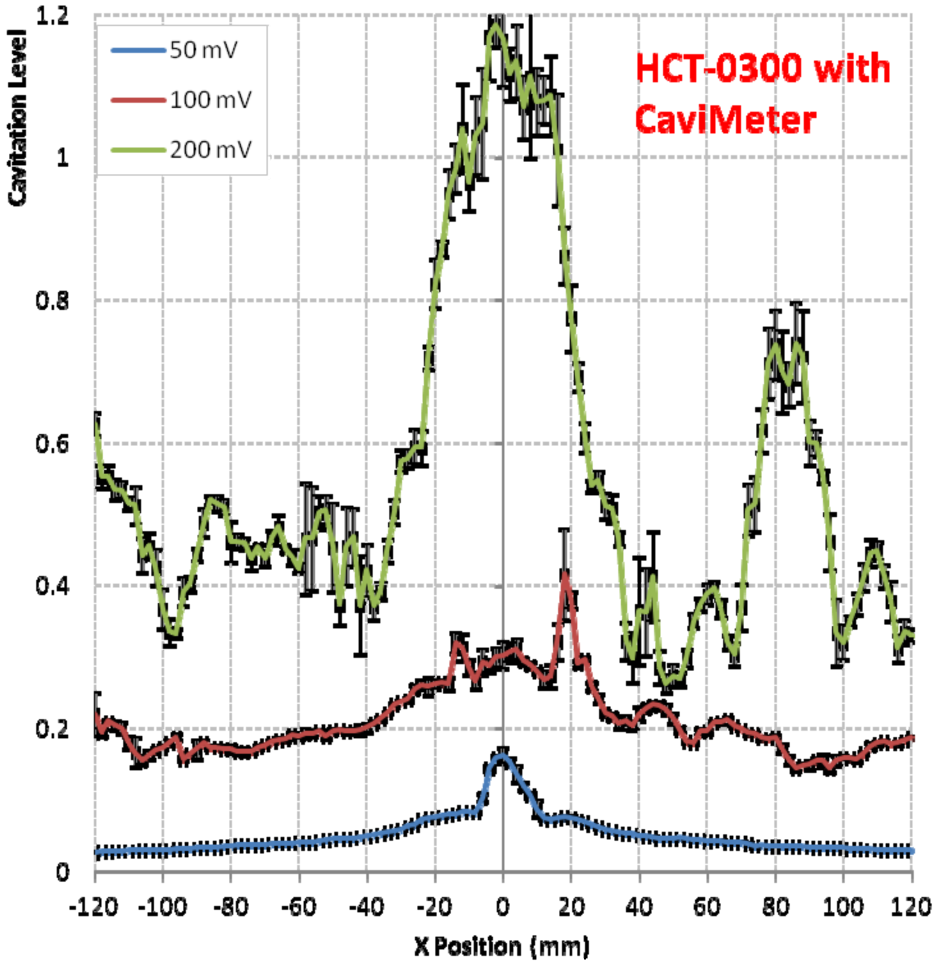
NPL CaviSensor and HCT-0310

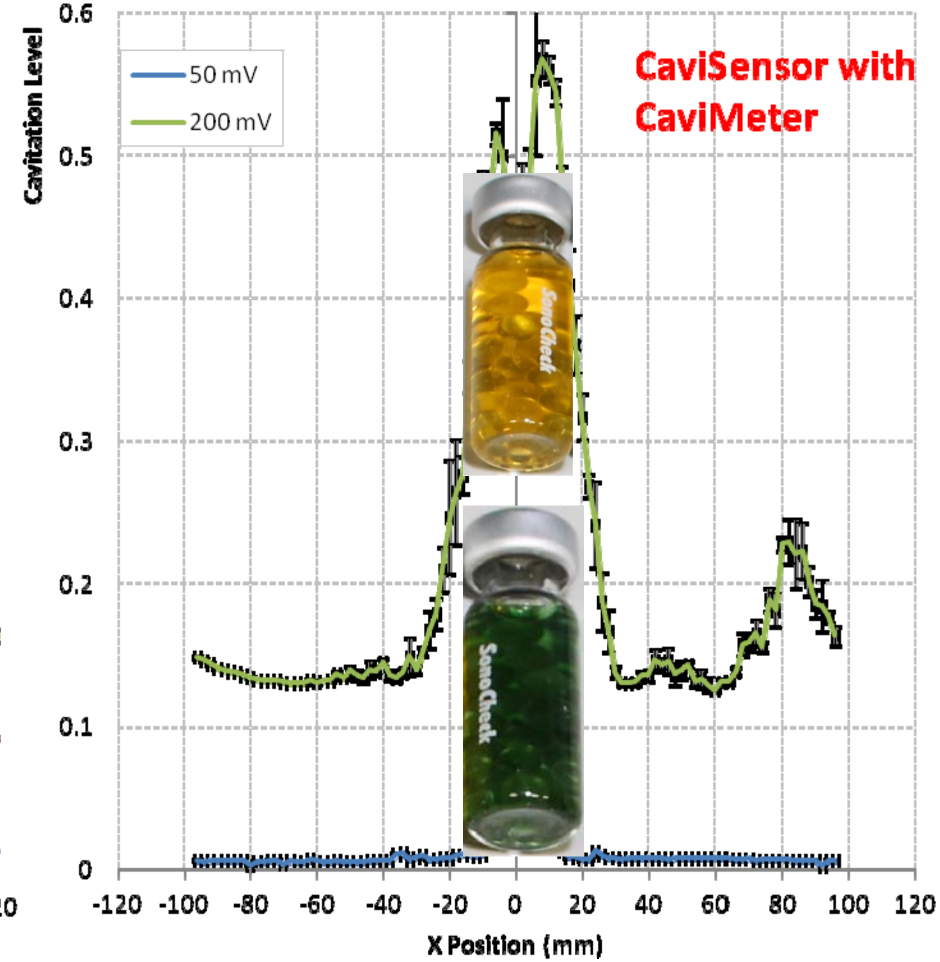




- Significant difference in profile between drive levels (not simply scaled)
- Cavitation activity peaks less widespread than driving field
- Spatial averaging apparent around peaks

NPL CaviSensor and HCT-0310





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

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 <u>not</u> 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 <u>calibrating sensors as cavitation measurement devices</u>

Acknowledgements

NPL National Physical Laboratory

The authors acknowledge the financial and technical support of:

- The UK National Measurement System (DBIS)
- NPL Strategic Research
- Petrie Yam, Claudio Zanelli and Sam Howard (Onda Corporation)

National Measurement System

The National Measurement System delivers world-class measurement for science and technology through these organisations

National Measurement Office · NPL National Physical Laboratory · LGC Setting standards in analytical science · nel technology for life

Thank you!

Acoustical characterisation