CCAUV/15-25

Status report of CENAM, Mexico to the 10th Meeting of the CCAUV 2015

In the period 2013-2015, the Acoustics, Ultrasound and Vibrations Area of CENAM has been developing measurement systems, standards and methods used to improve its scientific and technical capabilities and the means and methods to deliver traceability and knowledge to industry, stakeholders and the society.

The following sections provide details of the work performed in each of the groups.

1. Vibrations Group recent developments.

The vibrations group (VG) offers more than 40 services for measurement and calibration, every year there are 2 programmed curses for the customers and 2 additional curses demanded in average. In the period from 2013 to 2015 the VG has increased the number of services in 35% to external customers and about 15% services for internal measurement standards.

The VG is increasing the number of projects developed for customers in more than 50%, with financial support from the National Council of Science and Technology in Mexico (CONACYT), and with their own funds from industry. These projects have shown the lack of traceability in some fields, for example dynamic quantities (i.e. dynamic torque, dynamic force, dynamic pressure and angular acceleration).

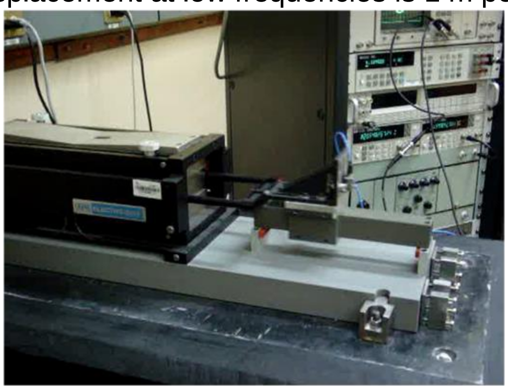
The activities of the group include training and knowledge transfer to customers in mechanical vibrations metrology, instrumentation & good practices, development of special measurements of quantities related with vibrations and uncertainty estimation techniques. Every year the group leads about three postgraduate students who develop projects related with the measurement standards and write their thesis with information from the projects.

The VG has been developing the projects described below related with continuous maintenance and improvement of measurement & calibration capabilities in dynamic quantities.

Primary calibration of vibration transducers

Low frequencies (1 Hz to 20 Hz) and very low frequencies (0.1 Hz to <1 Hz)

The lower frequency limit of the calibration capability has been extended form 0.4 Hz down to 0.1 Hz. Several low frequency accelerometers have been monitoring down to 0.1 Hz calibrating the sensitivity, in magnitude and phase, and response linearity. Two types of vibration exciters with air bearings are used, i.e. APS 500 and linear motor, the maximum displacement at low frequencies is 1 m peak-to-peak.



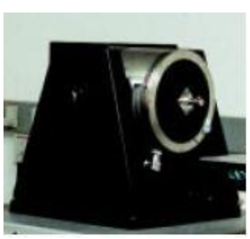
(a) APS 500 (25 cm long)

(b) Linear motor (1 m long)

Figure 1.1 Two different vibration exciters for low frequency calibrations.

Medium frequencies (10 Hz to 10 kHz)

Three vibrations exciters are been used for primary calibrations of vibration transducers in the medium frequency range, i.e. Brüel & Kjær 4811, Bouché Labs 1000, and Spektra SE09. The vibration exciter B&K4811 has a metallic suspension and the other two vibration exciters, Bouché Labs 1000 and Spektra SE09 have an air bearing suspension. Also, the material of the moving element of each vibration exciter is different and may have influence on the calibration results along with other perturbations like rocking motion and modal shapes of the moving element.



(a) B&K 4811
(40 Hz – 10 kHz)

(b) Bouche Labs 1000
(100 Hz – 10 kHz)

(c) Spektra SE09
(10 Hz – 50 kHz)

Figure 1.2 Vibration exciters for primary calibrations at medium frequencies.

The different material of vibration exciters may influence the primary calibration of accelerometer mainly in the frequency range above 3 kHz. In order to reduce the influence of the vibration exciter material a stainless steel plate is used between the accelerometer under calibration and the vibration exciter.

High frequencies (>10 kHz to 100 kHz)

To calibrate accelerometers up to its natural frequency, three vibration exciters are been used, i.e. Spektra SE09, Wilcoxon F7, and a self-made additional piezoelectric exciter shown in the figure below. With these vibration exciters it is possible to calibrate accelerometers at frequencies up to 50 kHz, or higher. Nowadays, there are secondary laboratories which use a laser vibrometer as reference measurement standard for this frequency range.

(a) Piezoelectric Shaker
(3 kHz – 100 kHz)

(b) Wilcoxon F7
(1 kHz – 100 kHz)

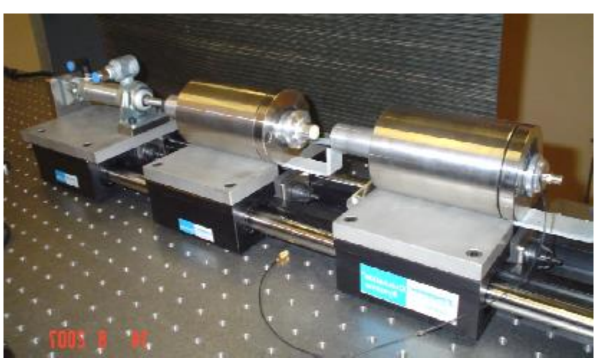
Figure 1.3 Vibration exciters used for primary calibrations at high frequencies.

Calibration of laser vibrometers (0.1 Hz to 20 kHz), and extended frequencies (20 kHz to 100 kHz)

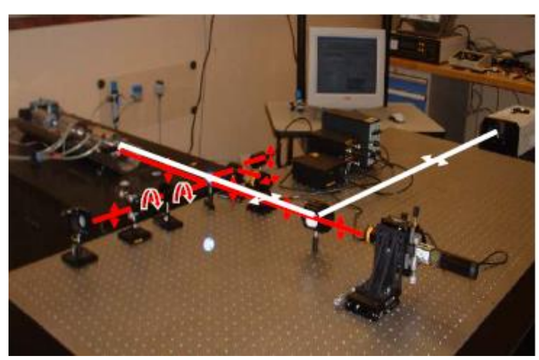
CENAM offers the calibration of laser vibrometers, including sensitivity magnitude and phase, covering a frequency range from 0.1 Hz to 20 kHz, and for high frequencies from 20 kHz to 100 kHz but the frequency can be extended up to 350 kHz with a special request from customers.

Primary calibration by medium intensity shock (100 m/s^2 to 35 km/s^2)

The shock excitation system consists of two air-borne bars, i.e. hammer and anvil. Accelerations up to 35 km/s^2 with pulse durations from 0.5 ms to 10 ms are generated. The calibration agrees with the ISO 16063-13. Homodyne and heterodyne laser interferometers are used for the calibration. The calibration service is also available for laser vibrometers which can be used as reference standard by secondary laboratories. Most of the customers ask for the calibration service only up to 20 km/s^2.



Medium intensity shock system



Laser vibrometer calibration by shock

Figure 1.4 Primary calibration system by medium-intensity shocks.

Primary calibration with high intensity shock (1 km/s^2 to 100 km/s^2)

A Hopkinson bar is been implemented to excite high-intensity shocks from 1 km/s^2 up to 100 km/s^2. Two different bars of 2 m length each are used, one bar is made of stainless steel with 1 inch diameter, and one bar made of titanium with 1 inch diameter. This system is under development.

Figure 1.5. Hopkinson bar for calibrations by high-intensity shocks.

Primary calibration of angular vibration transducers (1 Hz to 1 kHz)

Rotational laser vibrometers and angular vibration accelerometers are being calibrated by sinusoidal angular acceleration. Rotation can be added to the sinusoidal angular acceleration for the calibration of rotational laser vibrometers. The magnitude sensitivity is calibrated in the frequency range from 1 Hz to 1 kHz and from 1 rad/s^2 to 800 rad/s^2. Also, angular acceleration by sinusoidal excitation without rotation can be applied for the calibrations of angular accelerometers and angular rate sensors.

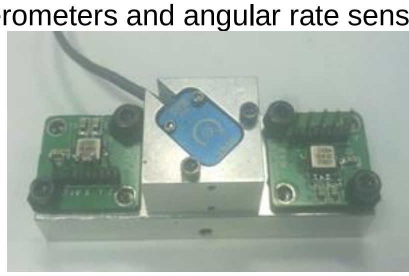


Figure 1.6. Comparing two rectilinear MEMS accelerometers and one angular rate sensor.

Calibration of vibration transducers by comparison to a reference standard

A mounting fixture can be used to calibrate accelerometers by comparison to avoid load the reference accelerometer (see figure below). The mounting fixtures can be used in the whole frequency range for secondary calibrations from 1 Hz to 10 kHz.

Figure 1.7. Mounting fixture to calibrate accelerometers by comparison (10 Hz – 10 kHz).

Dynamic torque calibration system

A dynamometer to calibrate dynamic torque is been integrated, which consists of two electric motors of 70 HP which can rotate up to 10 000 rpm with a dynamic torque of 60 N•m. This system is under development.

Input Motor | Dynamic Torque Sensor | Output Motor (Load)

Figure 1.8. Concept of dynamic torque calibration system.

2. Acoustics Group (AG) recent developments.

Facilities at the new Building for Special Laboratories and acoustic chambers at F building.

At the Sound Pressure Primary Laboratory (LPPA), the AG will develop its optical methods for acoustic measurements. CENAM had good results at the CCAUV.A-K5 (LS1P), and now we will work to develop phase measurements for LS2P microphones. For the free-field system (F020), the AG is working for having its official declaration as a National Standard.

The Laboratory of New Technologies in Acoustic Metrology (LNTMA) develops the new requirements in acoustic metrology driven by social and industrial needs of Mexico.

Figure 2.1 Q-Source built at CENAM.

The Sonometry and Electro-acoustic Laboratory (LSyE) improves and streamlines the calibration of instrumentation related to legal metrology and industrial noise measurements.

Calibration, measurement, proficiency testing and measurement services

CENAM's current catalog in acoustics includes 23 calibration services (12 declared in our CMCs); 4 Proficiency Testing (PT) exercises per year for noise measurement (environmental and workplace) and 3 scheduled training courses at CENAM's facilities. From this catalog of services, during 2014–2015, the AG performed over 338 external services.

The AG has also been participating in providing technical input related to acoustics, for the standardization organizations in México (SEMARNAT, STPS); as well as collaboration as technical experts for the Mexican Accreditation Body, ema.

As part of CENAM's events, the AG participates in the International Noise Awareness Day (INAD) since 2005.

Peer Review in AU.

Dr.-Ing. Thomas Fedtke, head of Section 1.61 - Sound in Air (PTB) carried out our peer review (PR) in acoustics and ultrasound (AU). The PR was 5-10 November 2015 and the final report for 1 December 2015. Dr. Fedtke revised CMCs in AU and the new declarations were accepted.

Figure 2.2 PR in Acoustics and Ultrasound 2015 at LSyE.

From left to right: G. Silva, A. Pérez, O. Llamas, T. Fedtke (PTB), J.S. Echeverría, H. Gasca & M. Gamiño

International collaboration.

During 2014, the AG participated in sonometry and electro-acoustic training for the Laboratorio de Electricidad, Acústica, Tiempo y Frecuencia of the Servicio Nacional de Metrología SNM-INDECOPI (Perú). The AG also trained a secondary laboratory from Colombia (Lab&Service Electrónica Especializada Ltda.).

Figure 2.3 INDECOPI training at LSyE.

From left to right: O. Llamas & L. Palma (INDECOPI)

Industry special projects.

Sound power determination for home and commercial appliances, automotive components and communication systems, among other equipment, has become an important issue in México for manufacturers (OEM and intermediate users), and end-users as well. Most industrial customers require measurements to be carried at engineering precision level according to ISO 3744, in the frequency range from 100 Hz to 10 kHz.

The AG developed a Proficiency Test for the Mexican Association of the Automotive Industry (AMIA) and ema, to measure pass-by noise according to NOM-079-SEMARNAT-1994. The car´s manufacturers were, General Motors, Ford, Volkswagen, Chrysler and NISSAN.

R&D projects.

a) <u>Research and Evaluation of the Effect of Noise Pollution in Mexico´s Households</u>

The project “Investigación y Evaluación del Efecto de la Contaminación por Ruido en Viviendas de México” has financial support from CONACyT. From 2015-2016 the AG will research the noise pollution patterns in Querétaro and the acoustic properties of the housing and materials used to build them.

Figure 2.4 Noise measurement point in Querétaro.

b) System for mapping sound sources using sound intensity:

CENAM is developing its microphone array for having different forms of measuring sound intensity. The frequency range for a 3D intensity probe goes from 100 Hz to 6.3 kHz.

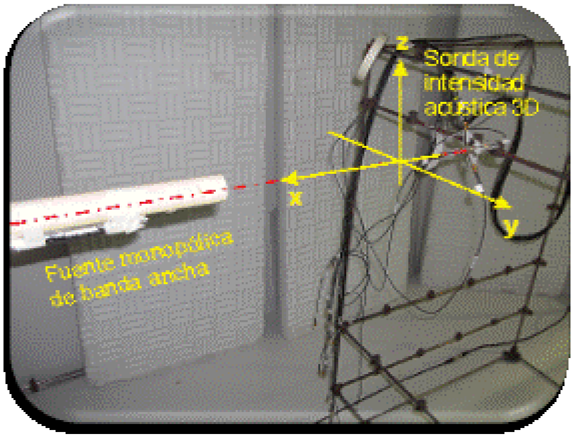


Figure 2.5 Measurement of a monopole broadband sound source with the 3-D sound intensity probe.

c) Design of an acoustic door for the hemi-anechoic chamber of CENAM

The AG is working at improving its hemi-anechoic chamber. The new acoustic door, built at CENAM, allows to measure sound sources with low noise levels of acoustic emission, in a wider frequency range and with lower measurement uncertainty.

d) Design of an impedance tube for the measurement of acoustic properties of materials

The AG is working at improving its acoustic properties measurement capabilities. The AG designed an impedance tube capable of transmission loss measurements according to ASTM 2611-09 Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method.

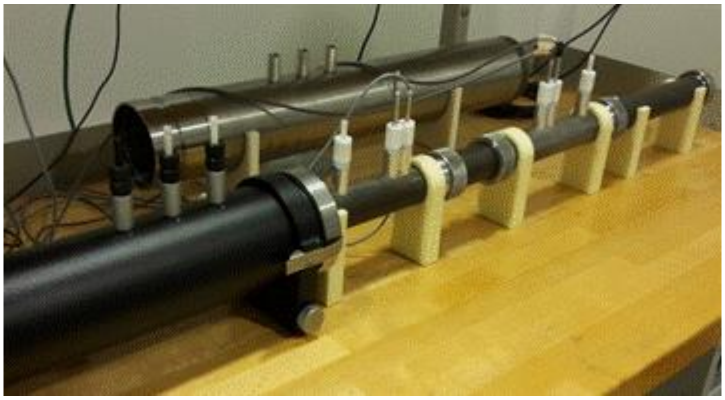


Figure 2.6 Impedance tube built at CENAM.

Comparisons:

Primary calibrations in acoustics are supported through the participation in recent key and supplementary comparisons:

CCAUV.A-K5 Comparison of laboratory standard microphone calibrations.
Pilot laboratory: NPL (UK). Participants: BKSV-DPLA (Denmark), CENAM (Mexico), GUM (Poland), INMETRO (Brazil), INRIM (Italy), KRISS (Republic of Korea), NIM (China), NMIJ (Japan), NMISA (South Africa), NRC (Canada) VNIIFTRI (Russian Federation). Final version, September 2014.

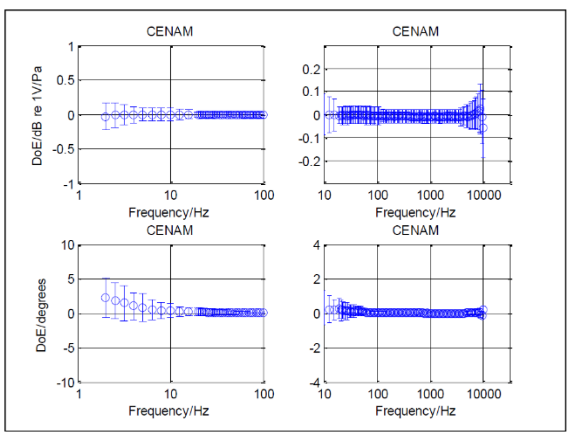


Figure 2.7 Degrees of Equivalence for CENAM sensitivity level and phase measurements with uncertainty bars corresponding to coverage factor k=2 based on microphone 4160 811012.

3. Ultrasound Group recent activities

Several improvements in the data acquisition system and analysis of ultrasonic power measurements using a radiation force balance have been achieved [3]; current CMCs

CCAUV/15-25

have recently undergone a peer review (Nov-2015). In order to support improved CMCs, an inter-comparison on output power with another NMI has been recommended. Measurement studies carried out show that expanded measurement uncertainty (k=2) may be reduced from a value of 11 % down to U(k=2) = 2.6 % at 1 W. Uncertainty estimation has been carried out following the GUM Supplement 1 using the Monte Carlo Method for the propagation of probability distributions. The measurement model is given by,

$$P = \frac{m * c * g * \exp(2\alpha l)}{2 \cdot cos^2 \Theta} \quad (1)$$

where

$$c = 1402.38754 + 5.03711129 \cdot T - (0.0580852166) \cdot T^2 + (3.34198834e - 4) \cdot T^3 - (1.47800417e - 6) \cdot T^4 + (3.14643091e - 9) \cdot T^5$$

$$\alpha = \left((56.8524 - 3.02545 \cdot T + (1.17416e - 1) \cdot T^2 - (2.95430e - 3) \cdot T^3 + (3.96985e - 5) \cdot T^4 - (2.11091e - 7) \cdot T^5) \cdot 10^{-15}\right) f^2$$

P ultrasonic power emitted by an ultrasonic transducer, W.

m effective mass, g.

g acceleration due to gravity in the measurement place, m/s^2.

c speed of sound in water, m/s.

α attenuation coefficient in water, m^{-1}.

θ angle between incident ultrasonic wave and the normal to the reflecting surface of the target, °

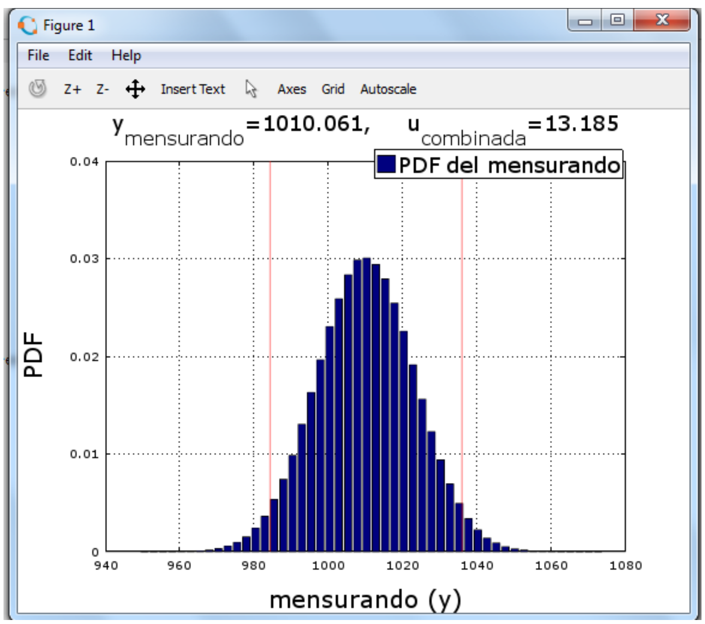
l effective distance from the apex of the reflecting target to the face of the transducer under measurement, m.

T average water temperature during the measurement process, °C.

f ultrasonic wave frequency, Hz

Monte Carlo calculations made use of a user interface described in [1]. Figure below shows a typical standard uncertainty ($u_{combinada}$) for a measured ultrasonic power ($y_{mensurando}$) at 1000 mW; corresponding coverage intervals at 95% probability are also shown.

CCAUV/15-25



a)

I.C. @ 95% de probabilidad = [984.26, 1035.89] mW

CCAUV/15-25

b)

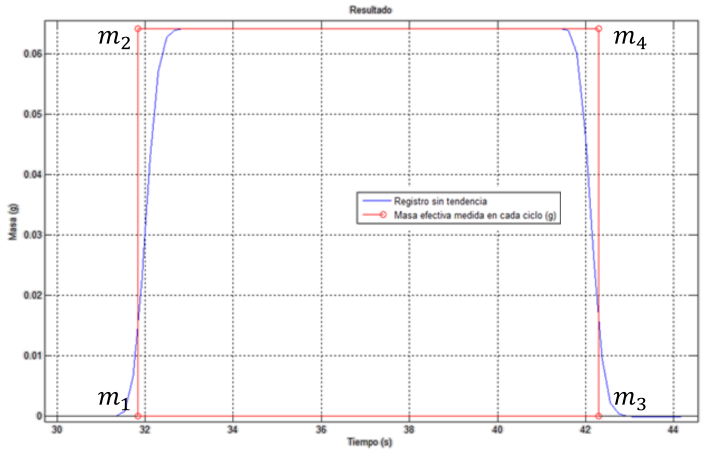


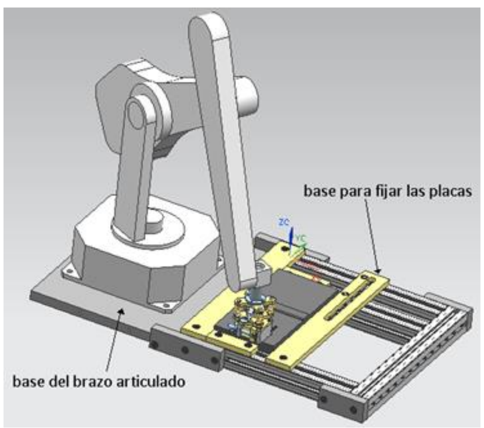
Figure 1. a) Typical PDF obtained for ultrasonic power measurements at 1000 mW, b) mass measured in each OFF-ON and ON-OFF transition using a radiation force balance.

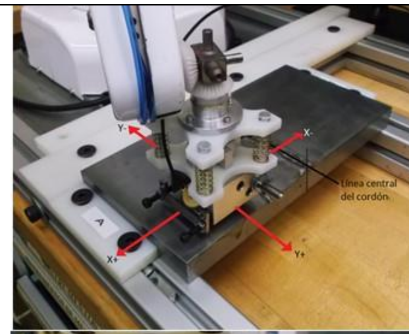
Requests from local stakeholders have led to the development of proficiency testing schemes [2,4] for ultrasonic measurements, e. g., calibration of thickness meters and flaw detectors, besides evaluation of welded unions using ultrasound. Industry oriented projects dealing with ultrasound metrology are currently moving forward.

R&D Projects

1. Ultrasonic inspection of welded unions via a robotic manipulator with 5 degrees of freedom.

This project was about the semi-automatic inspection of welded plates whose proper evaluation is expected to facilitate its designation as reference standards in future ultrasonic proficiency tests organized by CENAM. It has also allowed us to improved current measurement capabilities, both by contact and by immersion, regarding flaw detection in a wide range of materials.

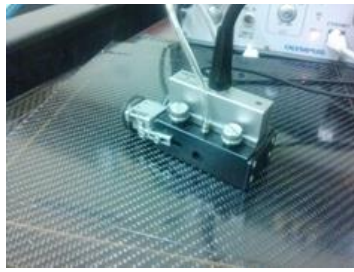
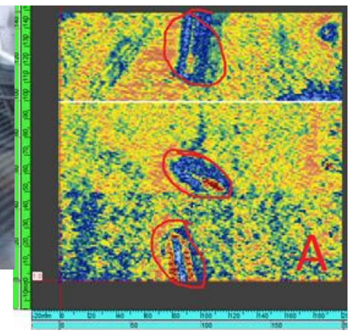




2. Determination of hardened layers in steels using ultrasonic measuring techniques.

This is an on-going non-destructive testing project aiming to measure the depth of the hardened layer in steel specimens after a stage of heat treatment. Manufacturing companies routinely perform destructive testing in order to keep under control their corresponding heat treatment processes.

Raw ultrasonic signal and its corresponding Hilbert transform after smooth filtering operations.

3. Preliminary ultrasonic studies for the evaluation of composite materials.	
This project made use of multi-element transducers to perform the evaluation of fiber carbon composite materials; mainly layered plates with known inclusions and defects at specified positions. C-scans and measurements carried out on a Tomoscan Focus system were capable of showing straightforwardly the relative location of each defect; as can be seen in the figures on the right.	 

Publications, 2013 - 2015

Vibrations

- A.A. García González, G. Silva Pineda, L.M. Muñiz Mendoza; “Development of the movement control of a hexapod system with 6 dof”; Simposio de Metrología, Querétaro, México, October 2012.

- C.J. Velázquez Roblero, G. Silva Pineda; “Design and fabrication of an anvil to generate transient acceleration”; Simposio de Metrología, Querétaro, México, October 2012.

- I. M. López Bautista, G. Silva Pineda; Calibration of non-contact velocity sensor used in automotive industry; IMEKO International Conference. South Africa; February 2014

Acoustics and Ultrasound

- Alfredo A. Elías Juárez, J. N. Razo-Razo, Ana L. López Sánchez, Gilberto Loera Medrano “Interfaz de usuario para estimar incertidumbres empleando el método de simulación Monte Carlo”, Simposio de Metrología, Querétaro, México, October 2014.

Ultrasound

- Ana L. López Sánchez, Alfredo A. Elías Juárez, Gilberto Loera Medrano, “Analizando errores de medición comunes en la detección de fallas por ultrasonido”, XXIV Congreso Nacional de Metrología, AMMAC, Mérida, Yucatán, December 2013.

- Sandra Lucía de la Fuente Bermúdez, Ana L. López Sánchez, Alfredo A. Elías Juárez, “Optimización del proceso de calibración de equipo de ultrasonido para fisioterapia”, XXIV Congreso Nacional de Metrología, AMMAC, Mérida, Yucatán, December 2013.

- A. Elías Juárez, A. López Sánchez, G. Loera Medrano, “Mediciones ultrasónicas y cómo los ensayos de aptitud ayudan a reforzar su confiabilidad”, 10ª Conferencia Mexicana de Pruebas No-Destructivas, Cd. México, D.F., August 2013.