Challenges and Recent Developments in Ultrasonic Metrology

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Abstract: ***Ultrasonic metrology includes measurement of acoustic parameters and propagation parameters such as velocity and attenuation. It also covers such parameters which are essentially not the acoustic parameters but their principle of measurement depends on ultrasonics. Present day technology keeps on increasing the range and the accuracy of measurement. It also results into introduction of new techniques and new parameters. Ultrasonic metrology keeps on facing new scientific and technological challenges. Present talk will show these challenges and also the recent achievements in this area. Measurement of high intensity focused ultrasonic waves, covering the broad spectrum of frequency with superharmonics shall be included in the talk.***

1. Introduction

A glance through the increasing applications of ultrasonics, shows a small device that analyses the milk in no time. It requires a very small quantity of milk (only 10 mL) and can be used in any environmental condition. The accuracy of the measurement by this milk analyser is comparable with that of results from a sophisticated chemical laboratory.

Yet, another application of ultrasound is removal of cancerous portion of prostate gland using a sophisticated machine with high intensity focussed ultrasound. The success and adverse effects of this technique depend upon the intensity and focal spot diameter of the ultrasonic beam falling onto the cancerous parts. This warrants a plot of the acoustic field characteristics including intensity and focal characteristics.

In fact, many new types of ultrasonic equipment and techniques are available today where it is necessary to estimate the ultrasonic parameters of the equipment. This is really a challenging task. In many cases, no technique of measurement is known and even if some technique is available, the accuracy is poor.

2. Parameters

The parameters in ultrasonic metrology can be divided into three classes. Firstly, there are parameters which depend solely upon the source of ultrasound. The medium of propagation has no effect on them. These are mainly, acoustic pressure, total acoustic power and frequency.

Besides these, there are a few ultrasonic parameters which depend only on the medium, whatever may be the source. These are called propagation parameters. Normally, there are only 2 such parameters, namely velocity and attenuation. But, now there is one more parameter, called dispersivity.

Another class of parameters which fall into the ultrasonic metrology are those which are not directly related to the ultrasonic source or medium, but the technique of their measurement depends upon ultrasonics. Following is a list of some of the parameters which can be measured with desired accuracy only by ultrasonic techniques.

i. Parallelism between two opaque plates,
ii. Uniformity of wall thickness of a hollow cylinder,
iii. Estimation of moisture in carbon fibre composites,
iv. Flatness of deep and narrow hole

Other parameters where ultrasonics offers an alternative technique are surface hardness, elastic constant, liquid concentration, compressive strength of concrete and timber, soundness of foundation pile, etc.

3. Measurement Techniques

3.1 Acoustic Pressure

The calibration of any ultrasonic equipment requires the measurement of acoustic pressure generated at the face of the transducer. This is best done using hydrophone which essentially converts the acoustic pressure into a corresponding electric voltage. Depending on the application, the pressure and frequency range of the equipment varies. The hydrophone used depends on the range of pressure and frequency. Two types of hydrophones are sufficient to cover the entire range. One type of hydrophone is actually low frequency hydrophone, whereas the other type is very high frequency hydrophone.

a) Low Frequency Hydrophones

These types of hydrophones are available in the frequency range of 0.01 Hz to 180 kHz. These are used for measurement of ultrasonic parameters generated by oceanographic equipment such as sonars. These are not made in India covering the entire range. The calibration faculties are available in 2 laboratories in India covering a range of 5 Hz to 100 Hz. To extend the range one will need very large acoustic water tank or some alternative technique.

b) High Frequency Hydrophones

These types of hydrophones are usually broad band covering a range of 0.5 MHz to 100 MHz These are used for the calibration of ultrasonic medical diagnostic equipment. Though medical equipment use usually a maximum of 10 MHz, yet these have to cover higher frequencies due to the generation of higher superharmonics. Frequency spectrum of the waves received at the focus shows higher harmonics even upto 20th. These types of hydrophones can work at high acoustic pressures, thus covering a range of 0.1 MPa to 3

MPa. The calibration of such hydrophones is done using laser interferometry which is very sophisticated and very big occupying huge space making it difficult to work. Only 3-4 laboratories the word over have such facilities. There is need to have a small interferometer that can measure vibration amplitude down to 1 nm in the frequency range of at least upto 25 MHz in the presence of low level acoustic noise.

3.2 Total Acoustic Power

Calibration of medical ultrasonic diagnostic equipment has very different type of problem. It is necessary that acoustic power be within the desired limits, else it would be harmful to the patient. In addition to this, the image quality should also be very good so that even a very minute object is detected and also that nothing spurious is present in the image. In order to ascertain both of these qualities of the machine, one will have to measure a large number of parameters. This will be very tedious if one has to measure them for all the machines and that too at regular intervals to ascertain that no degradation has taken place. In order to circumvent this issue, it is now acceptable at international levels that while phantom may be used to ensure the quality of image, one single parameter, *total acoustic power*, may be measured as it depends upon all the other parameters. The power will have to be measured in the range of 10 mW to 10 W within the frequency range of 2 MHz to 15 MHz.

Many methods have been developed to measure the total acoustic power. The International Electrotechnical Commission has recommended only the radiation pressure method. In this method static pressure on a target is estimated by measuring the change in mass. This method has been successfully developed at the National Physical Laboratory, Delhi. If however, it is desired to derive the conductance, one will have to measure the RF voltage as well. This is a challenging task.

3.3 Acoustic Intensity

Recently, a new equipment has come in medical practice for the treatment of cancer of prostate gland. It uses High Intensity Focused Ultrasound (HIFU) for ablation of cancerous tumour. At the same time low level high frequency ultrasonic waves are used to monitor the on-line treatment. The ablation of tumour is a result of thermal, mechanical and cavitation at the point of focus. This technique uses ultrasound of frequency in the range of 0.5 to 3 MHz, intensity of more than 1000 W/m^2.

There are many challenges in the measurement of HIFU. Cavitation affects the acoustic field and hence does not allow free field conditions. Then there exists a possibility of damage to sensor due to high acoustic pressure. High intensity at focus produces non-linearity which in turn gives rise to higher harmonics. Measurement of HIFU therefore requires special types of hydrophones. Polymer based needle hydrophones or fibre optic hydrophones are being considered for these measurements. Polymer hydrophones are cheaper and the equipments required are generally available in most of the labs. The Fibre Optic Hydrophone technique is expensive but gives higher accuracy. However, calibration procedure is not available for any of the techniques.

3.4 Ultrasonic Velocity

There are many methods for the measurement of ultrasonic velocity. However, there is a desperate need of a Reference Liquid which could provide calibration of all the velocity measurement techniques. This liquid be such that its ultrasonic velocity does not change with temperature in the range 20 to 25^{0}C and also with frequency at least in the range 2 to 5 MHz. It should also be stable with time. Once the Reference Liquid is available, the accuracy obtained in velocity measurements will increase.

3.5 Ultrasonic Attenuation

Measurement of ultrasonic attenuation severely lacks in accuracy and repeatability. Though measurement of this parameter has been going on for several decades, yet no reliable value is available in literature for any liquid. The value differs from one lab to another lab. The measurement of ultrasonic attenuation remains a challenge even today.

3.6 Dispersivity

One of the reasons for non-availability of reliable value of ultrasonic attenuation is the difficulty in the measurement of RF voltage. A new parameter has therefore been thought of which has all the characteristics of attenuation and can be measured accurately.

Dispersivity is such a parameter. Attenuation may be replaced by dispersivity because this parameter also changes with frequency due to loss of energy. Main difference is that it is evaluated by time interval and not by change in RF voltage, and it is well established that time interval can be measured much more accurately and precisely than voltage.
Now the challenge is to establish the Dispersivity by measuring it in several liquid mixtures.

4. Calibration of Ultrasonic equipment

a) Sonicator

One of the extensively used equipments in bio labs today is sonicator. It produces low frequency (a few kHz) vibrations in the liquid resulting into some change in chemical reactions. These changes depend upon the frequency and vibrational amplitude of the sonicator's tip. Need of the day is to make available such sonicators that have provision of user controlled frequency and power. The challenge is to develop method of calibration of sonicator by measuring the power and frequency.

b) Atomiser

This equipment makes very fine droplets which can produce nanoparticles through reactor. The need of the day is to establish a relationship between droplet size and ultrasonic power.

c) Ultrasonic cleaner

A very extensively used ultrasonic equipment today is cleaner. The challenge is to develop method of calibration to estimate its effectiveness by measuring the output acoustic power and then to map it in the cleaner tank.

d) Ultrasonic Nondestructive Testing Equipment

Thousands of ultrasonic NDT equipment are in use in India. Calibration procedures are available, but what is not available is the artefact for intercomparison.

5. Conclusion

Ultrasonic metrology is full of challenges. New problems keep on surfacing. NPL today is the only place in India where work is going on to solve these problems. Very bright scope exists for other labs and universities to jump into this area. The work done in this area will earn international reputation, promptly and surely.