46º CONGRESO ESPAÑOL DE ACÚSTICA
ENCUENTRO IBÉRICO DE ACÚSTICA
EUROPEAN SYMPOSIUM ON VIRTUAL ACOUSTICS AND AMBISONICS

NON-INVASIVE TEMPERATURE ESTIMATION ON TMM BASED ON THE ECHO-SHIFT METHOD

PACS: 43.80.Jz

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ABSTRACT

Using a modified US imaging device a non-invasive temperature measuring method based on determining time shifts in ultrasound echo signals, originally developed at the Dutch TNO, has been implemented.

Measurements have been made on two pieces of Agar based tissue mimic phantom (TMP), using a 3MHz physiotherapy transducer as heater, and a 7 MHz linear probe. One of the TMP was cut in several slices to allow the use of monitoring thin-film thermocouples.

Measurements have been done at different depths and in a range of temperatures 25 – 50 °C.

The obtained the results are discussed: further improvements are required.

RESUMEN

Utilizando un dispositivo de imagen por ultrasonidos modificado, se ha desarrollado un método no invasivo de medida de la temperatura, basado en determinar desplazamientos temporales en ecos ultrasónicos.

Se han realizado mediciones sobre dos piezas de simuladores de tejidos (TMP) utilizando un transductor de fisioterapia de 3 MHz como calentador, y una sonda lineal de 7 MHz. Uno de los TMP fue cortado para facilitar la utilización de termopares de control.

Se han realizado mediciones a diferentes profundidades y en un rango de temperaturas entre 25 °C y 50 °C.

Se discuten los resultados obtenidos: mejoras adicionales son necesarias.

1 INTRODUCTION

Within the recently completed JRP of the EMRP "Dosimetry for Ultrasound Therapy (DUTy)" [1], the aim of the Task 2.4 of the work pack 2 (Laboratory dosimetry standards (WP2)) has been to develop and evaluate invasive and non-invasive measurement methods suitable for laboratory dosimetry standards for quantities related to thermal mechanisms. Within the DUTy project, it has been evaluated the suitability of different US techniques to serve as a laboratory dosimetry standard for thermal dosimetry. One of main results of this evaluation has been to consider the echo-shift method [2, 3, 4]. as the most promising method to estimate temperature variations in phantoms.

CSIC, through its Laboratory of Medical Ultrasound Metrology (LMUM), has implemented and evaluated a version the echo-shift method to estimate temperature changes in tissue mimic phantoms (TMP). The implementation, done manually with the aid of an Excel sheet, is based in determining velocity changes caused by heating from an ultrasonic physiotherapy transducer within TM phantoms.

2 MEASUREMENT ELEMENTS AND CONDITIONS

2.1 Measurement Elements

2.1.1 Tissue mimic: The measurements have been made on two agar-based phantoms produced by the NPL in accordance with the specifications of IEC 60601-2-5 [8]. One of them was sliced in three parts to enable the insertion of thermocouples to check the temperature reached inside the phantom.

2.1.2 Ultrasound imaging device: A modified Philips sono Diagnost 360 diagnostic ultrasound device, equipped with a 7,5-MHz linear array probe, LA10040, has been used to acquire the echoes from the scatterers in the TM phantoms.

2.1.3 Heating system: A TNO-made physiotherapy transducer, TNO-CS G301 (5 cm^2, 3,0025 MHz, variable power), connected to a generator, HP 3336C, and a power amplifier, AR 75A250, has been used to rise the temperature of the phantoms. A digital oscilloscope, Tektronix TDS 2002, has been used to monitor the input voltages.

2.1.4 Temperature measuring system: An Omega 0,013 mm foil (thin film) thermocouple, together with a FLUKE 51 II thermometer, has been used to measure the temperature inside the sliced TM phantom.

2.1.5 Data acquisition system: A fast digital oscilloscope, Tektronix TDS 3052C, 500 MHz, 5 Gs/s, has been used to record the backscattered echoes, so that a later analysis could be done in a computer.

2.2 Measurement Conditions

The following input voltages have been used to feed the heating physiotherapy transducer (TNO-CS G301): 30 V (pp), 40 V (pp) and 55 V (pp).

All the measurements have been made in air under the following ranges of environmental conditions: air temperature: 21 °C – 22 °C; relative humidity: 40 % - 45 %. A coupling gel was applied between the phantom surface and the applied transducers and between the contacting surfaces of the phantom slices.

3 TEMPERATURE ESTIMATION PROCEDURE

Our implementation of the echo-shift method is based in the procedure developed by the TNO in the nineties [5, 6, 7]. In this procedure the changes of the sound velocity within a TMP caused by heat were determined. An experimental set-up as the one showed in figure 2 has been used. An ultrasound beam emitted by an ultrasound imaging transducer propagates through a medium that is heated by another ultrasonic transducer. As the medium contains scatterers, the emitted beam is partially reflected black. The backscattered signals received by the echo transducer are then recorded and processed. This process had already been made before applying the heating in order to establish a zero reference. In these measurements the diagnostic device has been working in the M mode.

The recorded beams can be divided into small regions identified, in the oscilloscope or computer screen, as time packages of the signal that have a length of about 2 to 4 periods of the echo signal. Each small signal package before heating is then matched – by a least squares fitting algorithm, in the original procedure, and manually in our case, representing the recorded beam data in an Excel sheet to the almost identical signal package after heating. Since the local backscattering is specific to that region, a small time difference, with respect to the front TMP echo, will exist between each package pairs. By this, for each package, a determined time shift equal to the amount of time that the packages had to be moved to match is obtained. When going further in the signal, i.e. further from the front echo, this time difference or ‘shift’ increases as long as the temperature in the corresponding physical region is elevated with respect to the “no heating” case, see figure 1.

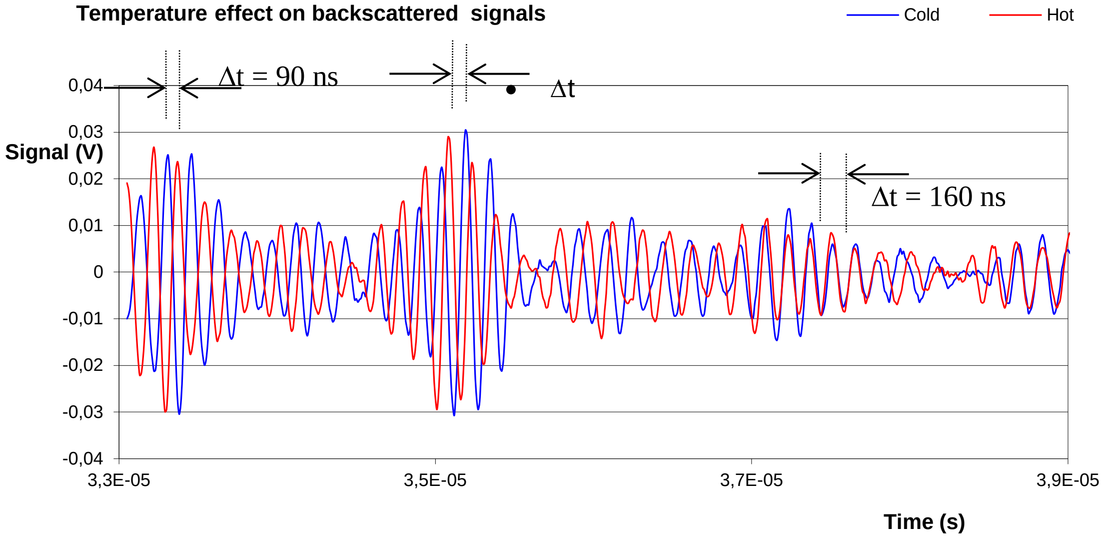


Figure 1: Backscattered echo-signal before (blue) and after (red) heating. The shift between the signals increases, indicating a temperature rise. The increase per time unit is higher on the right than on the left, indicating a higher temperature rise in the right than on the left (The graph has been taken from the original TNO work)

The physical locations, in mm, of these small regions are calculated from the time intervals between the echo of the front of the TMP and the echoes from two consecutive regions, the one concerned and the previous one. At the same time, the time interval associated to any of these regions is obtained from the average of the times corresponding to the heated, or shifted, and non-heated situations. Then, the change of the speed of sound for any of these particular regions is calculated as its relative time shift, difference between the time shifts corresponding to the concerned region and the previous one, divided by its associated relative time, difference between the times corresponding to that region and the previous one, and multiplied by the value the speed of sound in the TMP at the non-heated condition.

To obtain the temperature change in the concerned region from the estimated change in speed of sound it is necessary to know the relation between the speed of sound and the temperature for the concerned TMM. The obtainable accuracy of this method to estimate temperature changes within a TMP will depend on the accuracy with which this relation is known. In most cases this relation can be determined experimentally.

Unfortunately, for the results presented in this report, this was not possible and values provided by the PTB have been used instead.

For our measurements beam fragments of 140 μs have been used. The signals have been acquired by a digital oscilloscope and recorded for their later processing,

In order to obtain a better spatial resolution and to avoid the effects of possible hot points, our recorded beams were divided in fragments of 3 μs which in turn were analysed in intervals of 1 μs, in such way that 3 time shifts were determined. These values were averaged and the result was the value of the time shift corresponding to each 3 μs fragment. The time position associated to each fragment was the average of the three pairs for which the shifting process was carried out.

To obtain a smoother temperature profile, the shifts at the different locations were approximated by a polynomial fit. Though the order of this polynomial should be even and as low as possible, since the resulting temperature profile should be an even function of location and approximately Gaussian, a six order polynomial has been chosen as it rendered the best results.

4 MEASUREMENT RESULTS

4.1 Temperature Estimation on a Sliced Phantom

As it can be seen in figure 2, in order to be able to check the estimated results with real temperature measurements, the phantom was cut in three parts. The first one had a mean thickness of about 13 mm, while the second had a mean thickness of about 10 mm. The third layer was, then, the rest of the phantom, with a thickness of about 75 mm.

Unfortunately, it was not possible to find a way to make clean, uniform cuts in the phantom. This caused that the sliced layers had rough borders and not completely parallel. This brought about the need to be very careful when choosing the measuring scan line for the nominal distances corresponding to the layers in order to avoid crossing discontinuities that could cause disturbing scatters. Usually it was decided to move the line about 1 – 2 mm to avoid the discontinuities.

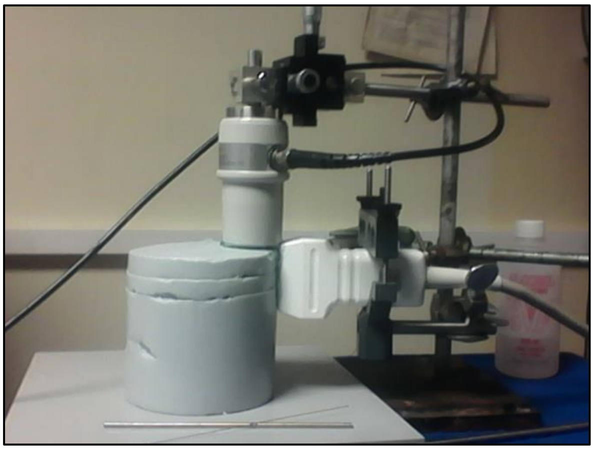


Figure 2. View of the measured sliced TM phantom

Especial care was taken in maintaining the relative positions of the two transducers involved constant, in order to make the comparison of estimations made under different conditions and in different days more reliable Throughout all the measurements process, the distance between the centre of the heating transducer and surface of the imagining transducer was about 22 mm.

Temperature estimations have been made for different depths within the phantom using different M scan lines, at about 9 mm, 13 mm, 19 mm and 28 mm, from the top of the phantom. For each depth, or, in other words, for each scan line, estimations have been made for three different input voltages, whose nominal values have been 30 V(pp), 40 V(pp) and 56 V(pp).

Control temperature measurements with a thermocouple have been made for the three input voltages at two depths: about 13 mm and about 23 mm. At each depth, measurements have been made at three locations: at about 10 mm, 22 mm and 30 mm from the emitting surface of the imaging transducer (lateral of the phantom.).

Unfortunately the results obtained have not been good, with irregular temperature profiles, far from the Gaussian shape, bad repeatability and important differences with the control temperatures measured with the thermocouple, especially for the highest voltages.

In what follows, due to space limitations, only some of the results are presented in figures 3 and 4, In the graphs, the dark blue curve corresponds to measured time shifts, the red to the estimated relative increase of temperature, with respect to the initial temperature (no heating), where a constant value, the one corresponding to the initial temperature, has been used for the relation between the increase of speed of sound and the temperature. The green curve is the results of using a polynomial fit for the determined time shifts. The purple curve is obtained when both the polynomial fit for the time shifts and a temperature dependent relation between the change of the speed of sound and the temperature are used. Finally, the black curve corresponds to the polynomial fit of the temperatures measured with the thermocouple. The equation and the corresponding regression coefficient are shown for the polynomial fitted curves. The input voltage used, the initial (before heating, for the sliced TMP, or ambient, for the non-sliced TMP) temperature, *T*i, and the line distance are also showed.

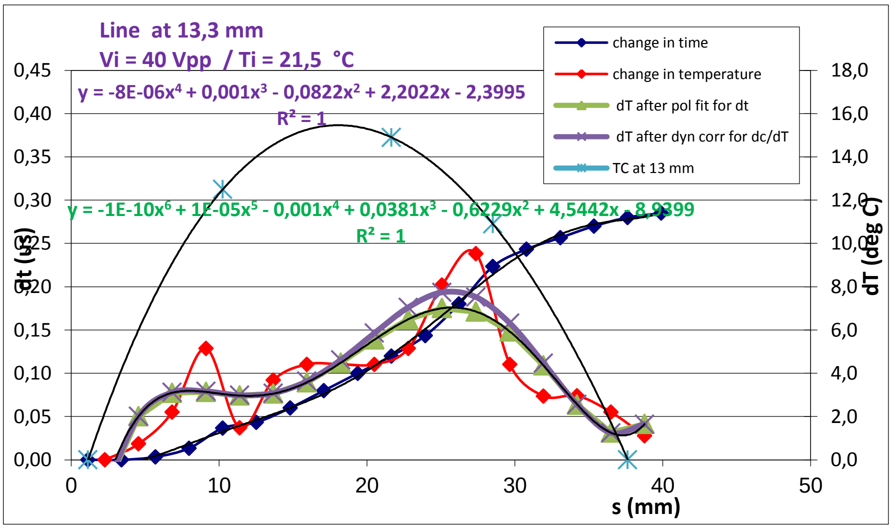


Figure 3: Rise of temperature estimation at 13,3 mm from the phantom top

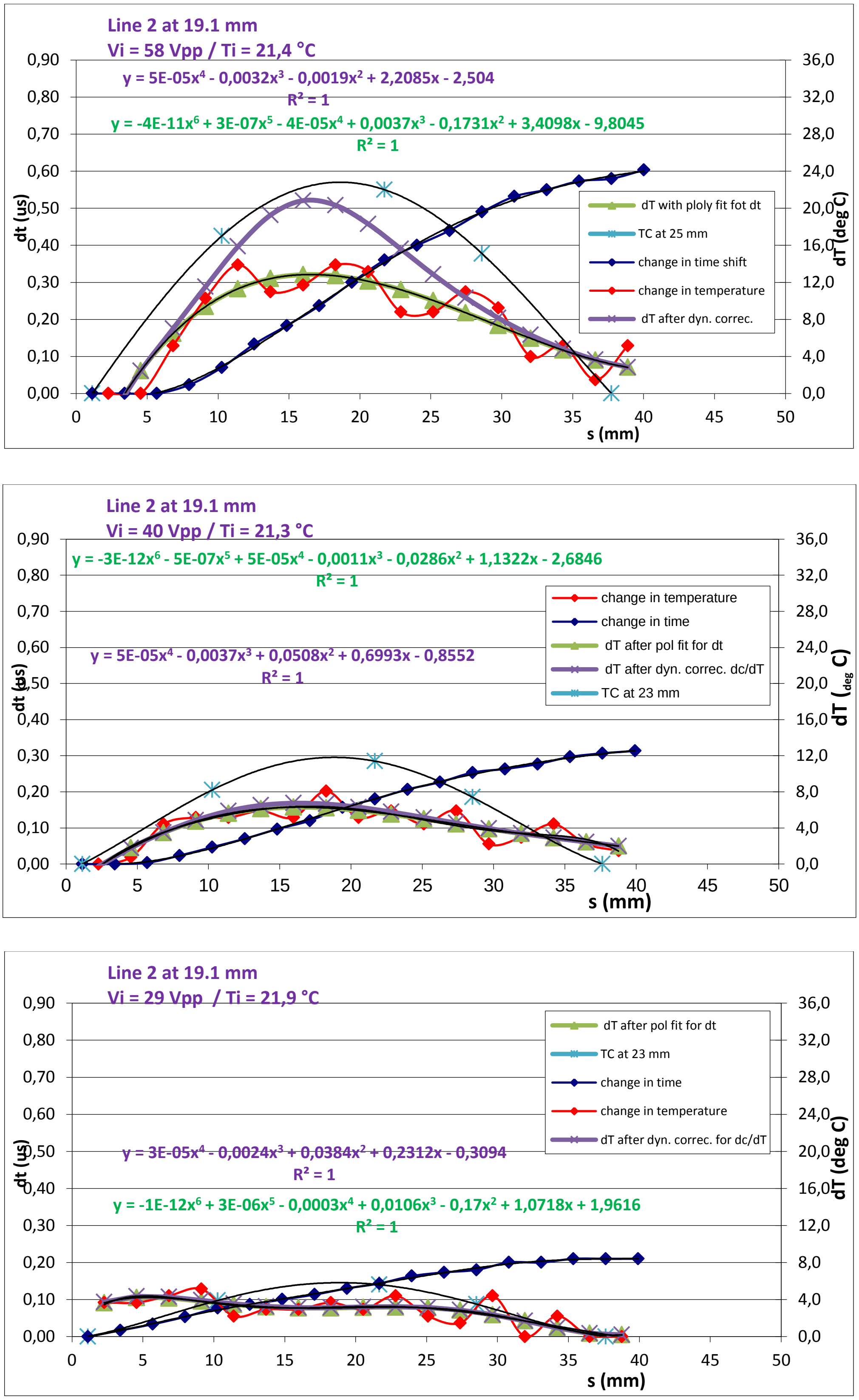
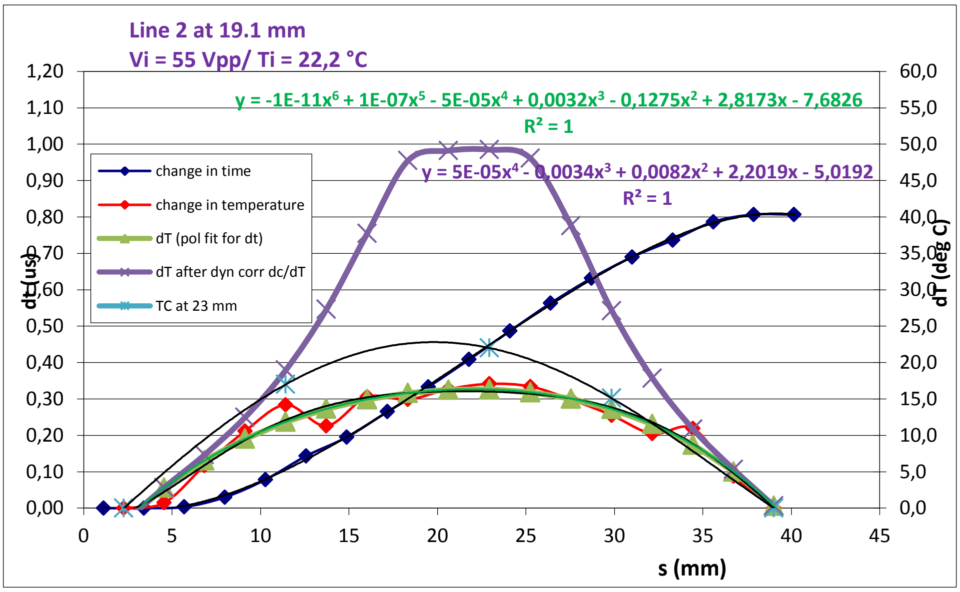


Figure 4: Rise of temperature estimation at 19,1 mm from the phantom top

4.2 Temperature Estimation on an Sliced Phantom

Although the results have improved, especially as it regards the temperature profile shapes and the repeatability, the obtained values are not satisfactory yet, especially as it regards the comparison with the “real” temperature values. Certainly, those values were measured for another phantom, which besides was somehow damaged by the cutting procedure, but it is surprising that the estimated values obtained when the temperature dependent relation between the change in the speed of sound and the change in temperature (dc/dT), derived from the PTB data, is applied (purple curve), most of the new estimations are much higher, especially for higher input voltages, than those obtained with the thermocouple (black curve). The situation is the opposite when a constant relation is assumed (green curve).

A sample of the results is showed in figure 5



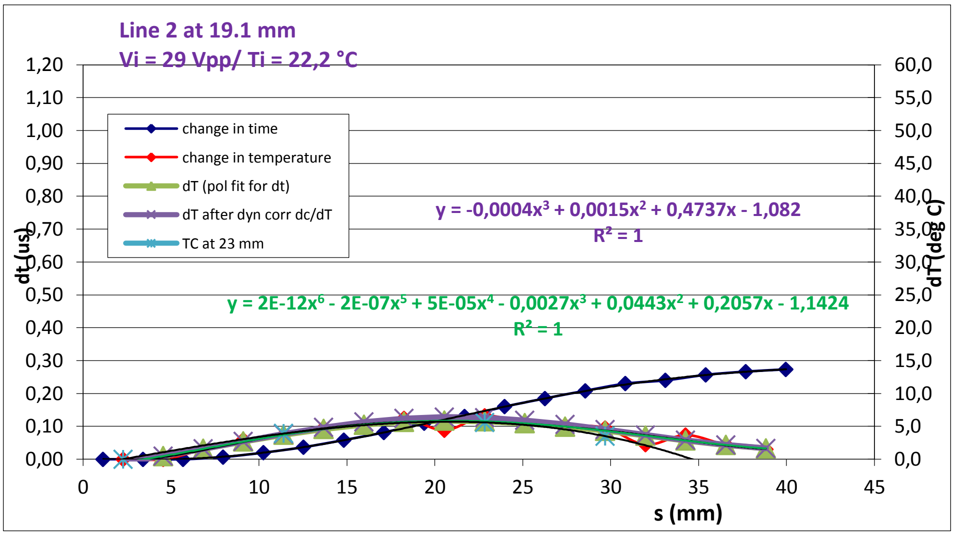


Figure 5: Rise of temperature estimation at 19,1 mm from the phantom top

5 CONCLUSIONS

LMUM has implemented and evaluated a manual, Excel-based version of the echo-shift method to estimate temperature changes in TM phantoms.

The results obtained on sliced phantoms, to enable the use of control thermocouples, have not been good, with irregular temperature profiles, far from the expected Gaussian shape, bad repeatability and important differences with the control temperatures measured with thermocouples, especially for the highest input voltages.

The results have improved with the use on a new non-sliced TM phantom, especially as it regards temperature profile shapes and repeatability, but the obtained values are not satisfactory yet, especially as it regards the comparison with the “real” temperature values.

Since the echo-shift method to estimate temperature changes in TMP is well established and, besides, its suitability has been positive evaluated within DUTy, much more work has to be done with our implementation, especially in determining the elastic, acoustic and thermal properties of the phantom and in measuring the real inner temperature, as in our experience, the cutting process can badly damage the phantom. Besides, a review of the estimation process employed is necessary. It is clear that the manual process used for these measurements needs to be substituted by a computer controlled procedure which will allow a faster and more comprehensive estimation.

6 REFERENCES

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