EXPERIMENTAL EVALUATION OF SOME NARROW-BAND ULTRASONIC TRANSDUCERS AS THERAPY APPLICATORS

PACS REFERENCE: 43.35, 43.38

González, G.[1] ; Azbaid, A.[2] ; Leija, L.[1] ; Ramos, A.[2] ; Rami, X.[3] ; San Emeterio, J.L.[2] ;Moreno, E.[4]

- 1 - Dpto. Bioelectrónica, CINVESTAV
Av. Instituto Politécnico Nal. 2508. México 07000 D F
Phone : 52-57473850; Fax:: 52-57477080. E-mail: gglez@mail.cinvestav.mx
- 2 - Dpto. Señales, Sistemas y Tecnol. Ultrasónicas - Insto. de Acústica, CSIC
Serrano 144, 28006, Madrid, España
Phone : 34-91-5618806; Fax: 34-91-4117651. E-mail: aramos@ia.cetef.csic.es
- 3 - ELECTROMEDICARIN S.A.
Torre de Cellers, 6 - 08150, Paret del Vallés, Barcelona, España
Phone : 34-93-5730724; Fax: 34-93-5730331. E-mail: id@electromedicarin.com
- 4 - Dpto. Ultrasónica, ICIMAF, ICIMAF, Calle 15 No. 553, Vedado, 10400, Havana, Cuba
Phone: (537) 8322701, E-mail: moreno@cidet.icmf.inf.cu

ABSTRACT

Conventional narrow-band applicators used for diathermy and hyperthermia purposes in therapy treatments present certain limitations to depose energy accurately and uniformly in the desired target. In addition they could radiate some energy away the treatment field, by insonifying neighbour tissues. With conventional ultrasonic transducers, the classical CW radiation presents near and far field patterns having notable irregularities and secondary lobes more accentuated in the real radiators, which could create undesired hot points or could attain healthy tissues. In this paper, the possible incidences of the above mentioned aspects are experimentally evaluated by arranging commercial and own-developed diathermy applicators radiating into a water tank as an artificial propagation medium.

INTRODUCTION

The controlled application of ultrasonic radiations for medical therapy is broadly accepted as a non ionising technique with remarkable capacity to tissue penetration applying heating energy in deep areas of the human body [1, 2]. However, the technological implementation to treat very defined areas, of great interest for example on the selective therapy of cyst in its very beginning, finds serious difficulties to concentrate with effectiveness the radiated ultrasonic energy, selectively on the area of interest and without producing collateral damages [3, 4]. Conventional applications usually use radiation of narrow band in a frequency range 1-3 MHz, what produces secondary radiation lobes and very irregular patterns of near field, with spatial peaks potentially dangerous inside of and outside of the field of the treated area. Some studies exist on the radiation of ultrasonic focalized arrays for therapy [5, 6], which assume an electric excitation near to the classic conditions of narrow band. Generally, they are extensions to the field of therapy from techniques and previous studies in the area of the medical echography.

Nevertheless, the insufficient knowledge about radiation-propagation patterns and heating patterns in biological tissues, as well as the non availability of alternative radiant configurations, both reduce the precision of this therapy, resulting in a serious limitation for the efforts in apply the most appropriate time and space dosage patterns and also for a dynamical adaptation of patterns to the variable conditions of the tissue treated.
In fact, it seems difficult to depose uniformly ultrasonic energy over the complete treatment field by using the conventional applicators because of the irregularities associated to typical CW

ultrasonic fields [7-8]. These problems notably increase with focusing multi-aperture radiators due to the complex multi-lobe patterns involved in such radiation arrangements [6,9].

In this paper, some ultrasonic patterns radiated by commercial and own-developed diathermy applicators (in the 1-MHz range) are experimentally evaluated in laboratory conditions. Concretely, radiation effects, related to certain incomplete CW diffraction lobes and also due to the interference of secondary radiations, non predicted by the piston theory, can be detected by means of a detailed analysis of the ultrasonic field radiated by some practical therapy applicators. These effects perturb the desired spatial uniformity in the emitted ultrasonic field.

PRESSURE PATTERN DISTRIBUTIONS AND ULTRASONIC POWER RADIATED BY 1 MHz (CARIN, 34 MM IN DIAMETER) DIATHERMY APPLICATORS

The evolution of quasi-CW ultrasonic pulses, generated by two conventional circular diathermy applicator heads (models Carin LOT 99000 and 99137, 34 mm in diameter) was analysed by means of a bi-dimensional detection of the spatial distribution in two transverse field-patterns at very distinct depths, and by measuring the applicator pressure axial profiles. These applicators are related to a Megasonic 212K ultrasonic therapy equipment, patented by Electromedicarin S.A., which includes a head auto-calibration system, by reading the memorised data in each head, in order to assure that each particular applicator is always driven at the more efficient frequency.

The scannings were performed into a water-tank (commercial system Tecal S.A.) containing the diathermy ultrasonic emitter and a mechanical holder for the measuring hydrophones: 0,3 and 0,6 mm in diameter, which had a quasi-plane response in the used frequency range. Their sensitivities are close to -140 dB and - 127 dB, respectively, refereed to 1 Volt / Pascal. In order to obtain far field plots, a tone burst of 50 µs was chosen to emulate a driving very close to an 1 MHz continuous-wave excitation, as it happens in the working regime of these therapy units, even when they are operated in a pulsed mode (typical t_{on} of the order of ms). In measurements at the very near field, a single driving cycle was used to minimise the possible electrical noise induced on field signals during the driving interval.

TRANSVERSAL SPATIAL PATTERNS MEASURED BY AUTOMATIC SCANNING

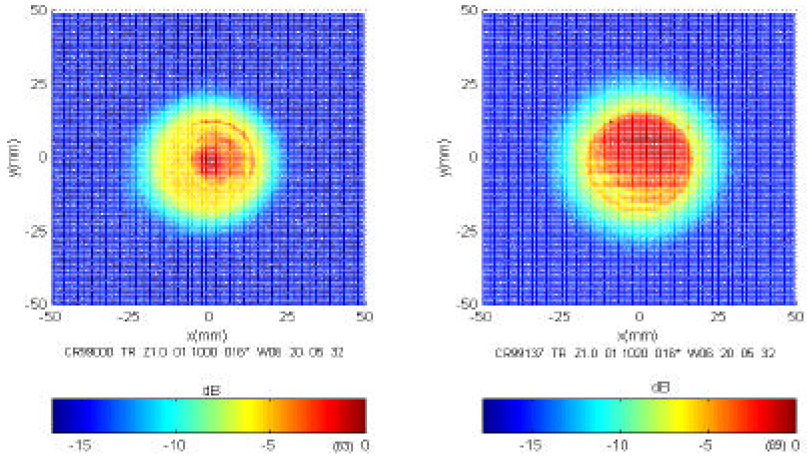
In both devices the two lower order lobes are not very visible. Nevertheless, the far-field experimental plot in applicator a) LOT 99000 exhibited very marked but incomplete lateral lobes, with a rather chaotic pressure deposition having irregular and very intense spots located (when they appear) at certain radial distances nearby those predicted by diffraction theory for the complete lobes in the pressure distribution of an ideal piston with radius a. These radial distances x_n can be approximated by:

$$x_n = (n + 0.73) (\lambda z) / (2a) \qquad (1)$$

On the other hand, the model b) LOT 99137 presents a low lateral lobes activity, under CW excitation. Additionally, other acoustic patterns measured in both therapy devices have presented important alterations at particular near field depths, specially around the axial zones.

In order to analyse all these aspects, transverse cross-sectional scannings were made at two depths: 1 mm and 150 mm. A field of 100 x 100 mm was scanned with 0.5 mm steps. The driving tone bursts were fitted to the respective applicator resonance. In order to produce a more representative (pressure levels) - (colour scale) assignation, by making evident only the mayor pressure levels in a logarithmic detection, the dynamic range of the displayed transversal plots was limited to 20 dB.

Figure 1 shows 2-D pressure patterns, detected at a depth close to the emitting surface (z = 1 mm) with a single cycle driving. A circular crown around the rim projections from the nominal apertures denotes a notable radiation level (≈ - 11, -13 dB) outside of the expected very near field beam. In Figure 1.b), the width of this ring is in agreement with a radiation from the more extern frontal part of the applicator carcass. A light lack of radiation uniformity at the below part of the aperture is observed in this case.



1.a 1.b

Figure 1. Transversal patterns measured near to the emitting surface (z = 1 mm) for the 1 MHz, 34 mm in diameter applicators: a) - LOT 99000; b) LOT 99137

Figure 1.a) depicts the result for the device LOT 99000. Both devices a) and b) belong to the same fabrication series. A circular-crown around the nominal aperture, narrower than the corresponding one in plot (b) was detected. In addition an appreciable difference between radiation levels from central and peripheral zones (≈ 8 dB) can be observed. The more external part of this radiator produces a very-near pattern with a notably asymmetric distribution. Their effects in the ultrasonic field at near-far field transition depth (150 mm) can be appreciated in the two comparative transversal plots shown in Figure 2.

The pattern (2.a) in Figure 2 presents a notable lateral lobes activity in comparison to plot (2.b), but a marked lack of uniformity accentuated by a pronounced fragmentation of the distinct lobes is observed. In fact, only some arc fractions are present. These isolated fractions are generally located near to some of the radial distances corresponding to x_n, in equation (1) when the effective diameter of the radiant aperture (30 mm) is considered. The amplitudes of these deformed lobes attain notable values, around -13 dB, at punctual locations quite distant from the projection of the rim applicator, for instance at some radial distances around 43 mm [x_n for the 5^{th} lobe in expression (1)].

These effects seem to be originated by complex interferences between the lateral lobes coming from a non-ideal radiator and other secondary lobes perhaps related to anomalous vibration modes in the PZT and field perturbations coming from certain extra-vibrations induced on the applicator external structure. Other anomalies were observed in near field patterns measured at the central zones of both applicators, which could correspond to radiations to medium of vibrations with a lateral origin coming from the ceramic rim [11-13] and from the applicator carcasses.

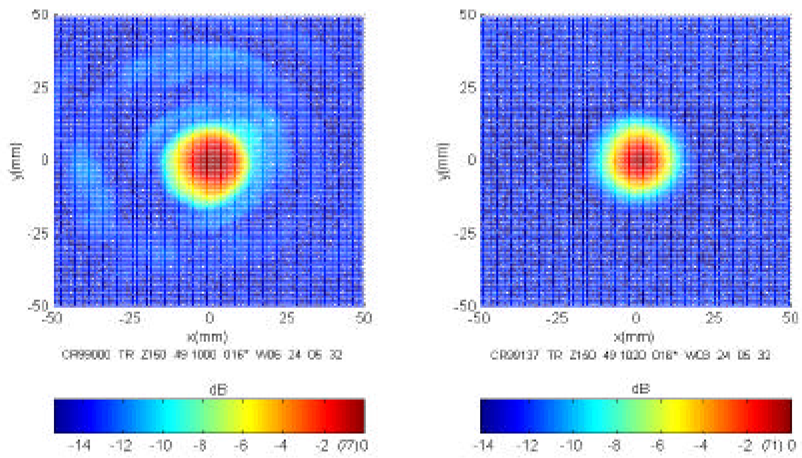


Figure 2. Transversal patterns measured at z = 150 mm for the same applicators of Figure 1.

MEASURE OF THE AVERAGE ULTRASONIC POWER BY A RADIATION FORCE BALANCE

The analysis, previously described for the assessment of the field radiated from therapy equipment, by means of successive scans performed in an automated tank, are not yet required by the current international standard in metrology. In fact, the two Carin applicators evaluated in this work satisfies the current normative EN 60601-2-5:2000 (IEC60601-2-5:2000) related to ultrasound equipment used for physiotherapy. Applicator acoustic responses were analysed in the Electromedicarin laboratory by using an UPM-30 OHMIC Instruments ultrasound power meter, specially designed to measure output powers (up to 30 Watts) in transducers testing, (Figure 3), according to international guidelines for applicator heads (NIST, AIUM, FDA). It use the radiation force balance method for metering the average ultrasonic powers radiated over a conical target.
The testing of the applicator LOT99137 performed with this meter gave the following results:

- Output average continuous power (CW) : 15,1 Watts
- Total output pulsed power, 1:9 mode (1 ms “on” / 9 ms “off”) : 1,5 Watts
- Total output pulsed power, 2:8 mode (2 ms “on” / 9 ms “off”) : 3 Watts

These results are in a full agreement with the nominal values registered in this type of diathermy applicators and fulfil the average intensity levels recommended in the current therapy guidelines.

Figure 3. Radiation Force Balance

The detection and analysis of spatial patterns similar to those shown in the previous section, as a precise tool complementary to these standard “power integrated” methods, can provide very useful information of the energy distribution, for periodically controlling the therapy equipment quality and also for design of new ultrasound therapy technology with increasing efficiency and safety level.
In devices suffering alterations from fabrication or by ageing during their normal use, these adverse effects attain a greater importance
These ultrasonic distribution aspects, together with the standard power measure methods, would be taken into account for new equipment designs, because a notable ultrasonic energy could be deposed at points quite distant of the zone to be treated.

BEAM PROFILES RADIATED BY A 0.97 MHz (38 MM IN DIAMETER) RICH MAR, MOD V COMMERCIAL DIATHERMY APPLICATOR

The ultrasonic field generated by another conventional circular diathermy applicator (Rich Mar Corp., Mod V), 1 MHz in nominal frequency and 38 mm in diameter, was also analysed by plotting the spatial distribution of transverse field-patterns.
The ultrasonic field was detected by means of a hydrophone 0,4 mm in diameter Model H863 with a sensitivity of –120 dB refereed to a 1 Volt/Pascal. A preamplifier Model 523 was used.
The scanning was performed in a water tank with an automatic commercial system (Specialty Engineering Associates).

VERY-NEAR FIELD PATTERN MEASURED WITH QUASI-BROADBAND EXCITATION.

A tone burst having only two 1 MHz cycles was used to obtain the plot in Figure 4. In general terms, a notable irregularity can be observed over the whole aperture. Concretely, there are zones with intensities ranging into an interval of 16 dB. Irregularities are particularly significant in the left lower part where a band at -10 dB below the maximum value and a spot at -16 dB appear.

Additionally we can observe high values in the radiation pattern at zones faraway the aperture, for instance at 6 mm from the aperture rim projection, with a –2dB level in the radiation.

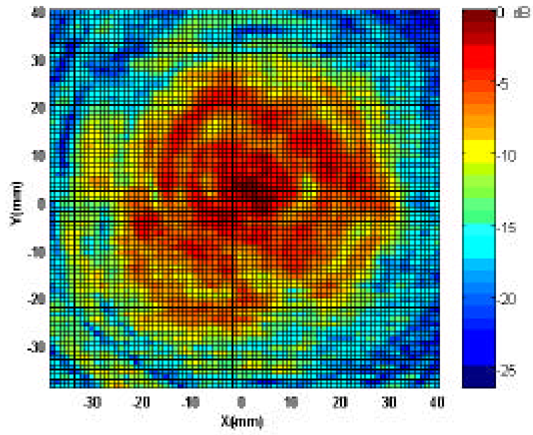


Figure 4. Transversal pattern measured at z = 3 mm from the applicator Rich Mar V

FAR FIELD QUASI CONTINUOS-WAVE PATTERN

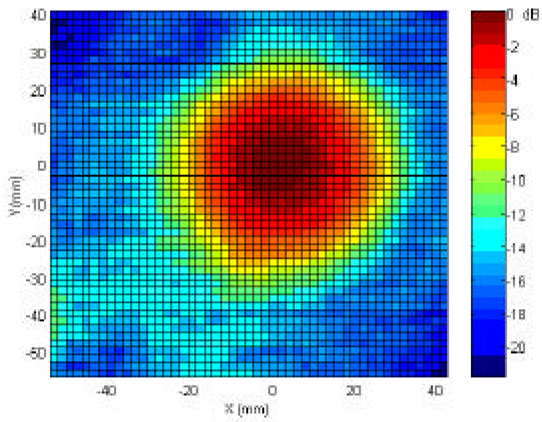


Figure 5. Transversal pattern measured at z = 233 mm for the same applicator of Figure 4

In order to check the radiation conditions in the far field zone and evaluate the possible influence of the irregularities found near the aperture, we performed a transversal scan at 233 mm in the Z direction, following a plane parallel to the aperture.
The resulting plot is shown in Figure 5. Like in the Carin applicator case, but in a more attenuated way, certain fragments of lateral lobes appear with intensities about –13 dB (referred to the maximum value). Also in this case this value is over the level predicted by piston theory.
A more significant distortion in the radiated fields is clearly observed in the left lower zone, in apparent correspondence with the anomalous radiation behaviour found in the very near field pattern in Figure 4. This distortion includes two asymmetric branches with a very notable radiation level between –11 dB to –13 dB, which extend too faraway from expected radiation field

Therefore, from these results it can be concluded that depositions of considerable energy with rather complicate distributions at unexpected zones have been clearly shown and certain extra-lobes could be radiated by some diathermy applicators. From the point of view of the therapy context, the above-mentioned anomalies at the very near zone and far field of conventional devices could produce undesirable hot points in the treatment zone. Moreover an appreciable ultrasonic energy could be deposed at points away the projection of the nominal radiation aperture in therapy applicators.

CONCLUSIONS

Anomalous lateral lobes and ultrasonic field patterns having local energetic peaks in some points inside and away the treated zone, have been detected in single-aperture diathermy applicators. The origin of this behaviour is related to the quasi-narrow band ultrasonic radiation associated to CW and long-burst pulsed modes usually adopted in the diathermy practice. Moreover, the presence of non-ideal anomalous behaviours in the vibrations of some real applicators, generally not very well known, impairs this situation. These phenomena must be taken into account in a therapy context and further research efforts must be focused on methods for a more precise evaluation of radiation patterns and their therapy effects in tissues [10]. In addition, alternative design ways to improve uniformity and safety in radiated patterns must be investigated.

Acknowledgements: The work described in this paper has been supported by the CONACYT-CSIC Project Nº 2001MX0004, the National Mexican Project Nº. 31959-A, and the National Spanish R&D Project C.I.C.Y.T. - Ref. TAP99-0864. Part of the work has been developed in the frame of the co-operative project Pulsets of CYTED-AECI.

REFERENCES

1. *Treatment Planning and Modelling in Hyperthermia*, Tor Vergata Medical Physics Monograph Series, A Task Group Report, Postgraduate School of Medical Physics, II University of Rome, (1992) pp.72-81.
2. D.A. Christensen, C.H. Durney. *Hyperthermia Production for Cancer Therapy: A Review of Fundamentals and Methods*, Journal of Microwave Power 16 (2), pp.89-104, 1984.
3. H. Wang, R. McGough, C. Cain. *Limits on Focused Ultrasound for Deep Hyperthermia*, Ultrasonics Symposium, (1994), pp.1869-1872.
4. H. Wang., E. Ebbini, and C. Cain. *Effect of phase errors on fields patterns generated by an ultrasound phased array hyperthermia applicator*, IEEE Trans. UFFC (1991) 38, pp.521-531.
5. M. Ibbini, E. Ebbini, C. Cain. *Ultrasound phased arrays for hyperthermia: New techniques based on the field conjugation method*, Proc. IEEE Ultrasonics Symp., (1987) pp.863-866..
6. R. Seip, P. VanBaren, E. S. Ebbini, *Dinamic focusing in ultrasound hyperthermia treatments using implantable hydrophone arrays,* IEEE Trans. UFFC (1994) 41, 5, pp.706-713.
7. Zemanek, *Beam behavior within the nearfield of a vibrating piston*, J. Acoust. Soc. Am., (1971), Vol. 49, N. 1 part 2, pp. 181-191
8. Hutchins, D.A., Hayward, G., *Radiated fields of ultrasonic transducers. In Physical Acoustics* (Ed. Thurston, R.N. and Pierce, A.D.), Vol. XIX, Academic Press, London (1990), pp. 1-80.
9. L. Gomez-Ullate, A. Ramos, J.L. San Emeterio, *Analysis of the ultrasonic field radiated by time-delay cylindrically focused linear arrays*, IEEE UFFC, (1994), Vol. 41, 5, pp. 749-760.
10. Pulsets - Cyted international cooperative project, *Determination of Efficient Ultrasonic Patterns for Safe Therapy by Control of Distributed Pulsed Radiation*. (2002-2005).
11. H. Uberall, Physical Acoustics Vol. X, Ch. 1, *Surface Waves in Acoustics* (W. P. Mason, Acad. Press), New York (1973) pp. 1-20.
12. Hayman, A.J. and Weight, J.P. *Transmission and reception of short ultrasonic pulses by circular and square transducers*. J. Acoust. Soc. Am. (1979) 66(4), pp. 945-951
13. E. Riera, A. Ramos, F. Rodríguez, *Temporal evolution of transient transverse beam profiles in near field zones*, Ultrasonics, (1994), vol.32, nº 1, pp. 47-56.