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PRELIMINARY ULTRASONOGRAPHIC STUDIES ON AN ELECTRONIC SYSTEM FOR FOCUSING AN ULTRASONIC BEAM

TOMASZ WASZCZUK, GRAŻYNA ŁYPACEWICZ

Department of Ultrasonics, Institute of Fundamental Technological Research, Polish Academy of Sciences
(00-049 Warszawa, ul. Świętokrzyska 21)

JAN SOMER

Biophysics, University of Limburg, 6200 MD Maastricht, the Netherlands

In conventional mechanical contact scanners the lateral resolution is inferior to the axial one. Improving the lateral resolution over a wide range of depth requires the use of variable focusing system. We choose the phase annular array system which may be used in obstetrics and gynaecology.

Measurements of the ultrasonic beam were carried out. Visualisations two different phantoms AIUM-100 and RMI-402 were performed during work: a typical B-scanner, and the annular array system. The results indicate a considerable increase in the lateral resolution when works the annular array system.

W typowych ultrasonografach rozdzielczość poprzeczna jest znacznie gorsza niż rozdzielczość podłużna. Poprawa rozdzielczości poprzecznej w całym badanym zasięgu wymaga stosowania różnego typu ogniskowania wiązki. Autorzy wybrali system ogniskowania wiązki ultradźwiękowej z wykorzystaniem wieloelementowej głowicy pierścieniowej. Taki system może znaleźć zastosowanie w ginekologii i położnictwie.

Przeprowadzono pomiary wiązki ultradźwiękowej zbudowanego systemu. Oceny rozdzielczości dla: a) typowej pracy ultrasonografu, b) pracy w systemie dynamicznego ogniskowania, przeprowadzono z wykorzystaniem dwóch wzorców AIUM-100 i RMI-402. Otrzymane wyniki pokazują wyraźną poprawę rozdzielczości poprzecznej podczas pracy systemu dynamicznego ogniskowania wiązki ultradźwiękowej.

1. Introduction

In ultrasonic diagnosis in medicine, the very essential parameters include the longitudinal and lateral resolution of the ultrasonic system. In investigation of a soft tissue by means of typical ultrasonograph the lateral resolution varies between 2 and 4 mm, whereas the longitudinal resolution is about 1 mm.

In the present state of the ultrasonic technique, the greatest impact on the resolution of the system is exerted by that of the ultrasonic probe. The lateral resolution of the probe can be improved by focusing the ultrasonic beam by means of a lens placed on the ultrasonic probe or by using a probe with an appropriately profiled concave transducer. A disadvantage of these methods is focusing only over a narrow depth range.

Focusing is possible along the whole observation range if a special multi-element ultrasonic probe is controlled by an appropriate electronic system.

The aim of this study is to show how the smaller width of the ultrasonic beam radiated by the probe affects the images obtained on the screen of the ultrasonograph.

2. Method

Electronic focusing along the whole range of depth is possible using one of two different types of ultrasonic probes: a linear array or an annular array [1, 2, 3]. In the case of interest, the conception was chosen in which a multi-element annular ultrasonic probe is controlled by an appropriate electronic system [4, 5, 6]. In view of the predicted use of the system for focusing an ultrasonic beam in obstetrics and gynaecology, 2.5 MHz was chosen as the resonance frequency of the probe, along with the range from 0 to 24 cm, and with the surface of the probe in contact with that of the investigated body. From theoretical analysis [7], an ultrasonic probe was designed and built, consisting of seven coaxial elements: a disk and six rings of piezoelectric ceramics. The disk diameter is about 10 mm and the external diameter of the last ring is about 40 mm. All the elements have the same surface area. An appropriate electronic system was designed and built for controlling the probe. The whole range from 0 to 240 mm was divided into five zones: zone I: from 0 to 50 mm, with only the disk transmitting, zone II: from 50 to 70 mm, with the focus at 60 mm, with the three central elements transmitting, zone III: from 70 to 90 mm, with the focus at 80 mm, zone IV: from 90 to 140 mm, with the focus at 110 mm, and zone V: from 140 to 240 mm, with the focus at 180 mm.

In zones III, IV and V all the elements transmit. During detection, dynamic focusing is ensured by the system, i.e., the focus is varied at the velocity of the ultrasonic wave propagation in a human body. For such a system, the 20 dB width of the ultrasonic beam was measured [6]. Throughout the range, i.e. 0–24 cm, the 20 dB width of the beam varies from 2.5 mm (over the range 40–120 mm) to about 6 mm (for the range 220–240 mm). All over the range under study, beam width changes are very regular. It was determined that for a 20 dB drop of the signal from the main lobe with respect to the maximum value, no side lobes can be seen.

The investigations of the whole system for dynamic focusing of an ultrasonic beam were carried out after it was connected to a USG-P30 ultrasonograph manufactured by Techpan. The imaged elements were two phantoms:

a) the phantom AIUM-100 (Fig. 1), and

b) the phantom RMI-402 (Fig. 2).

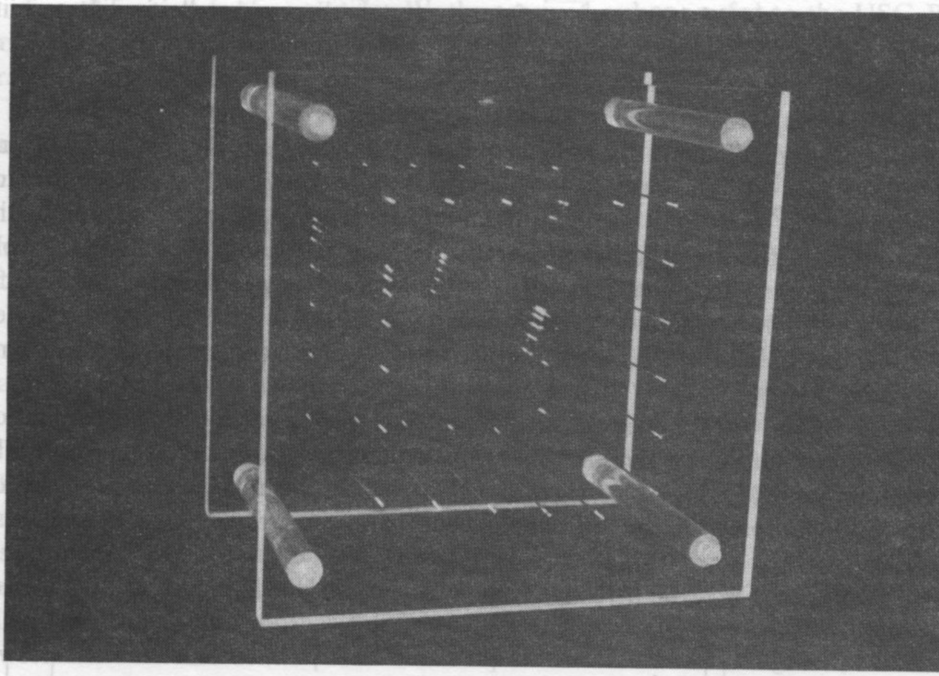


FIG. 1. Phantom AIUM-100

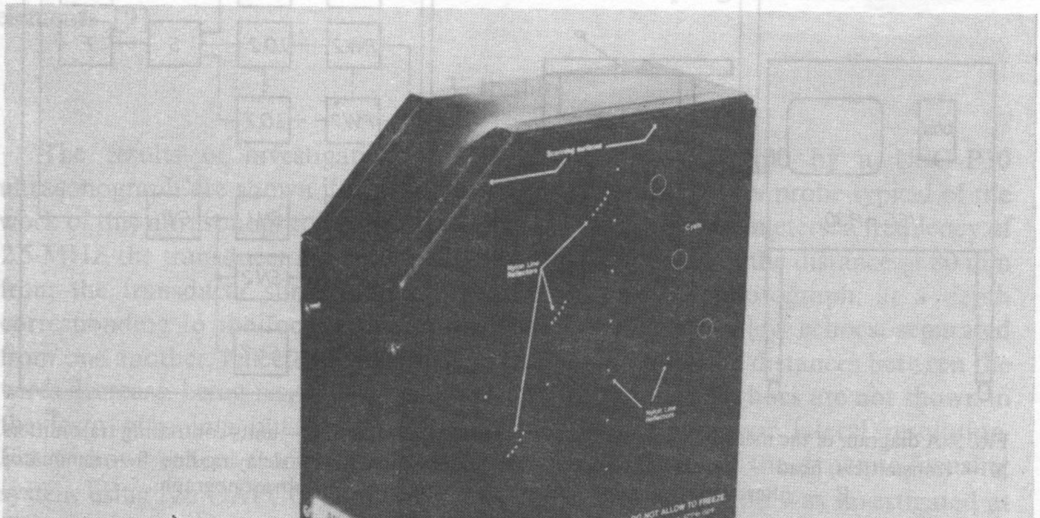


FIG. 2. Phantom RMI-402

The phantom AIUM-100 consists of appropriately disposed stell wires. It permits the determination of the longitudinal and lateral resolution and the accuracy of presentation on the ultrasonograph screen.

The phantom RMI-402 consists of:

a) three groups of nylon threads, disposed at different depths, 3, 7 and 12 cm, from the surface, with five threads in each group. The distance between the threads varies from 0.5, 1, 2 and 3 mm. These three groups of threads permit the determination of the longitudinal and transverse resolution of the ultrasonograph.

b) nylon threads distributed crosswise. The distance between each of the vertical threads is 2 cm. The horizontal threads are 3 and 4 cm apart. The threads distributed in this make it possible to evaluate the accuracy of presentation on the ultrasonograph screen.

c) three "cysts" with a diameter of 7.5 mm each. They permit the determination of the ability of maping of the internal body structures by the ultrasonograph. The whole phantom RMI-402 is filled with gel in which the ultrasound propagation velocity and damping of the ultrasonic beam are similar to those in a human body [8].

The system in which the investigations were carried out is shown in Fig. 3. Each

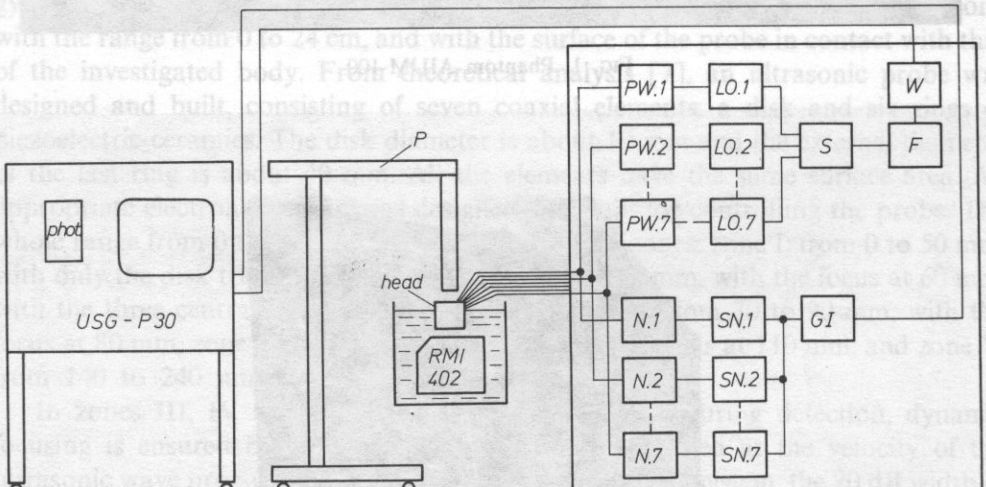


FIG. 3. A diagram of the measurement system: GI — pulse generator, SN — units controlling transmitters, N — transmitters, head — ultrasonic probe, PW — preamplifier, LO — delaying line, S — summator, F — filter, W — amplifier, P — pantograph of the ultrasonograph

of the phantoms separately was set in an container of distilled water. The multi-element annular probe was fixed in the pantograph P of the USG-P30 ultrasonograph. Particular elements of the annular probe are excited to vibration by pulses from the transmitters N_1–N_7. After amplification in the preamplifiers PW1–PW7, delaying in analog delay lines LO1–LO7, summation in the summator

S and amplification in the amplifier W, the received pubes are fed to the USG-P30. After appropriate electronic processing the detected signals are shown on the ultrasonograph screen.

In the course of the investigations the work of a USG-P30 ultrasonograph equipped with a typical probe was compared with the performance of the system for dynamic focusing of an ultrasonic beam. The investigations on the dynamic focusing system were carried out using two annular probes working at 2.5 MHz, with the same dimensions of particular elements: a probe manufactured by DAPCO-USA and a probe constructed in the Ultrasonics Department, Institute of Fundamental Technological Research, Polish Academy of Sciences. These probes are different in terms of constitution. The DAPCO probe is made of metaniobite piezoelectric ceramic material. The particular elements of the probe: the disk and successive rings are separated from one another by grooves filled with silicon rubber. The purpose of this is to decrease the mechanical coupling between elements of the probe. Compared with PZT-5 ceramic material, metaniobite is characterized by worse sensitivity and better matching to load, exerting a direct impact on the shape of the transmitted pulses. The probe built at the Ultrasonics Department was made of PZT-5 piezoelectric ceramic material. One side of the piezoelectric plate is fully covered by a silver electrode. On the other side of the plate, part of the silver which used to be between the elements of the probe was evaporated. There are no grooves between particular elements of the probe. Such a construction of the probe is supposed to decrease the harmful side lobes as the mechanical coupling increases between the elements [9].

3. Results

The results of investigations of the phantom AIUM-100 by a USG-P30 ultrasonograph are shown if Fig. 4. During the investigations, a probe typical of the work of this ultrasonograph was used. It has the following parameters: a frequency of 2.5 MHz, the transducer diameter of 20 mm and focal point of the distance of 80 mm from the transducer surface. In the central part of the photograph, at a depth corresponding to the focus, it is impossible to distinguish a few echoes, separated from one another, reflected from six wires in the phantom (the distances between the wires decrease, being respectively 5, 3, 2, 1 and 0.5 mm). The echoes are not shown in the form of points but as horizontal dashes, indicating poor lateral resolution. Fig. 5 shows echoes from the same phantom for the work of the dynamic focusing system using the DAPCO annular probe. The lateral resolution was investigated at the same depth as for the previous case, i.e., 7–8 cm. In the case of the dynamic focusing system, it is distinctly better, since in the central part of the photograph very distinct echoes from the six wires can be seen. In the lower part of the photograph, corresponding to depth of 13–14 cm (the boundary between zones IV and V), double echoes can be seen, probably because of side lobes.

Fig. 6 shows the results of investigations on the phantom RMI-402 by

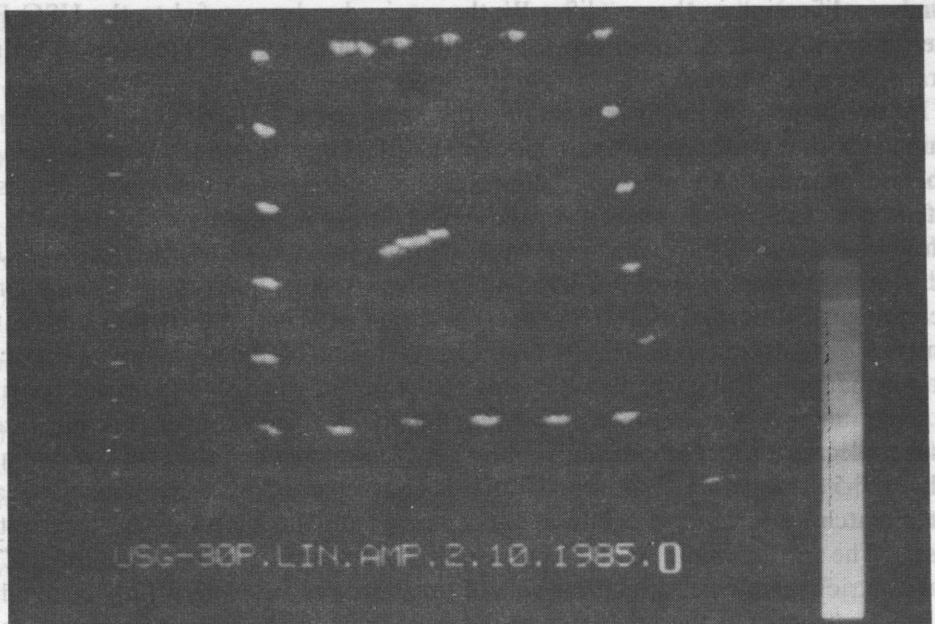


FIG. 4. Study on the phantom AIUM-100 by the USG-P30 ultrasonograph

FIG. 5. Study on the phantom AIUM-100 by the dynamic focusing system

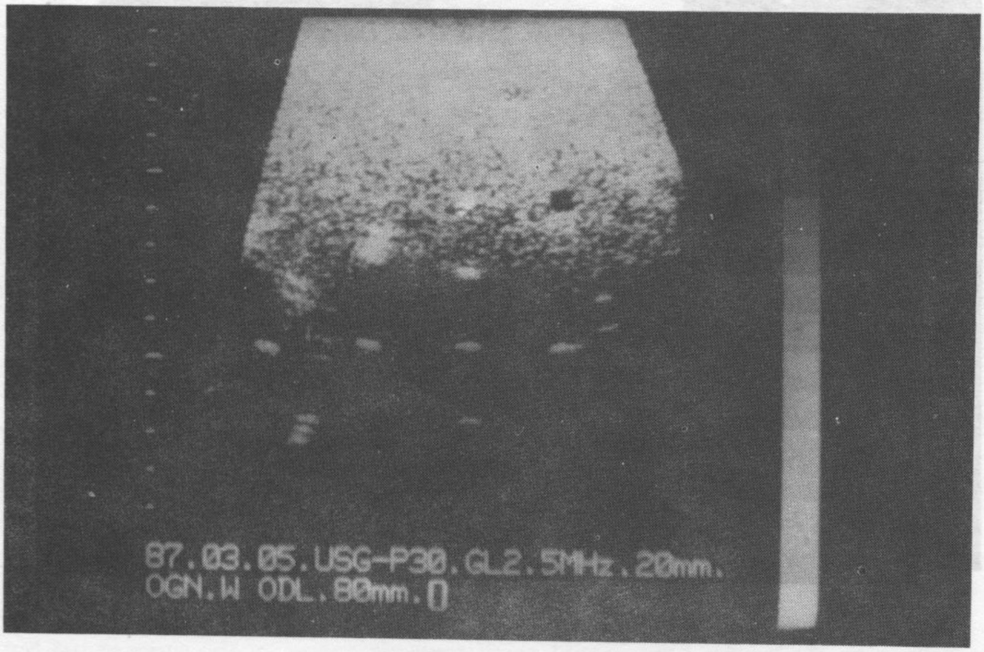


FIG. 6. Study on the phantom RMI-402 by the USG-P30 ultrasonograph

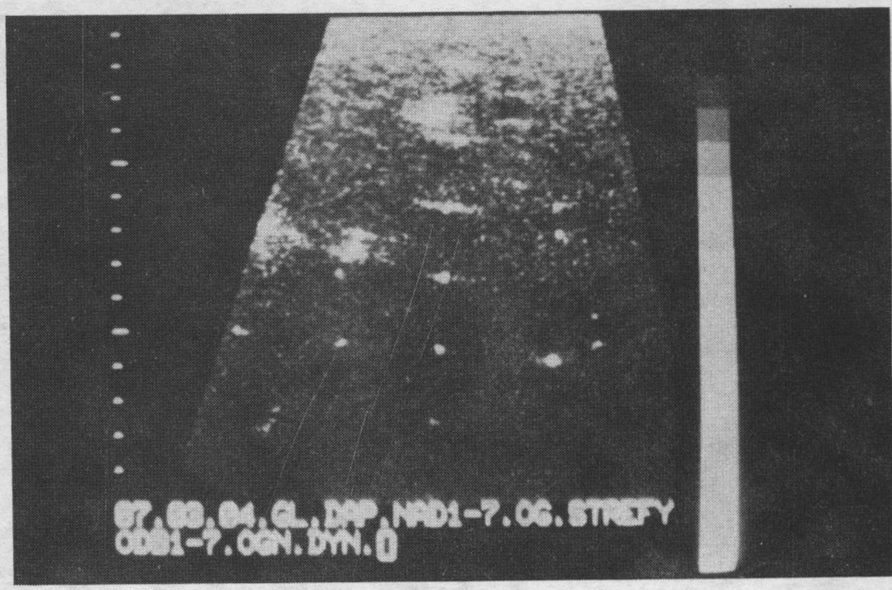
an USG-P30 ultrasonograph. All the elements of the phantom are visible, namely three cysts, all the threads in vertical and horizontal rows and three groups of five threads. The echoes from the threads can be seen as dashes rather than points.

Fig. 7 shows the results of investigations of the same phantom for the work of the dynamic focusing system using two different annular probes. The investigations were carried out using focusing in the zones during transmission and dynamic focusing during reception. In Fig. 7 a three cysts are visible, and so are all the threads in vertical and horizontal rows and three groups of five threads. The lateral resolution for structures situated over the range 0–5 cm is poorer than that for deeper-lying ones. This is caused by the fact that over the depth range 0–5 cm it is only the disk that works, and so there are no possibilities of electronic signal focusing.

For the probe made at the Institute of Fundamental Technological Research (Fig. 7b) one can see distinctly poorer echoes than those for the DAPCO probe. The image is more blurred. This results from much longer transmitted pulses. It also causes poorer lateral resolution of the system for work with this probe, compared to that involving the DAPCO probe.

In general, all the elements of the phantom RMI-402 are much more visible for the work of the dynamic focusing system compared with the typical work of the USG-P30 ultrasonograph [10, 11].

Fig. 8 shows the results of investigations of the phantom RMI-402 for the work of the dynamic focusing system for two annular probe, but for a constant focusing at transmission 110 mm and dynamic focusing at reception. Compared with the a)



b)

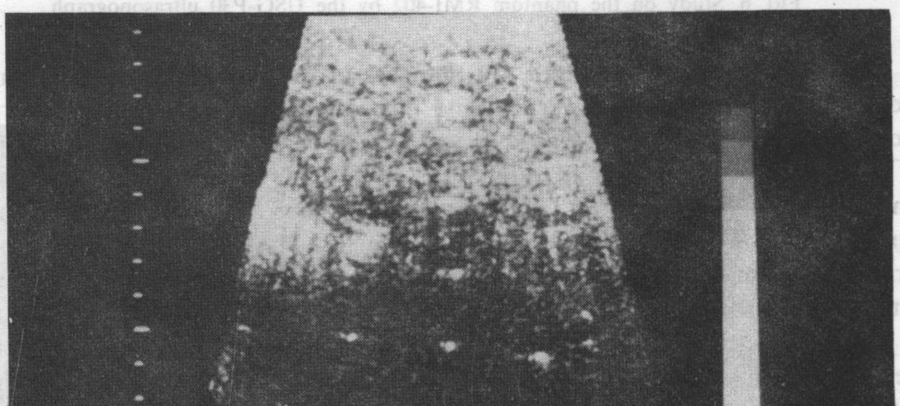


FIG. 7. Study on the phantom RMI-402 by the dynamic focusing system A – DAPCO probe, B – Institute of Fundamental Technological Research's probe

FIG. 8. Study on the phantom RMI-402 by the focusing system. A constant focus of 110 mm at transmission. Dynamic focusing at reception A – DAPCO probe, B – Institute of Fundamental Technological Research's probe

previous case focusing in the zones at transmission, some poorer resolution can be seen for structures closer to the probe. The probe produced by the Institute of Fundamental Technological Research is more sensitive than the DAPCO one, but because of longer transmitted pulses, its resolution is worse than that of the DAPCO unit.

4. Conclusions

Considering the results of investigations of the dynamic focusing carried out for two probes: of DAPCO and of the Institute of Fundamental Technological Research, using two phantoms AIUM-100 and RMI-402 the following conclusions can be drawn:

1. Focusing for drawn points at transmission and dynamic focusing at reception considerably decrease the width of the ultrasonic beam. This affects the improvement of lateral resolution of the ultrasonograph.

2. The greatest influence on improvement in lateral resolution has dynamic focusing at reception; focusing in the zones at transmission has a lesser effect.

3. To a large extent the focusing effect is influenced by the shape of pulses transmitted by the probe. One should work towards pulses, of the same shape but with short duration, transmitted by all the elements of the probe.

4. In the existing dynamic focusing system, it is necessary to increase the signal to noise ratio, decreasing the blurring of the image.

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