(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 373 603 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 89122956.9

(22) Date of filing: 12.12.89

(51) Int. Cl.[5]: **B06B 1/06, G10K 11/32**

(30) Priority: 14.12.88 JP 315422/88

(43) Date of publication of application: 20.06.90 Bulletin 90/25

(84) Designated Contracting States: DE FR GB

(71) Applicant: Matsushita Electric Industrial Co., Ltd.
1006, Oaza Kadoma
Kadoma-shi, Osaka-fu(JP)

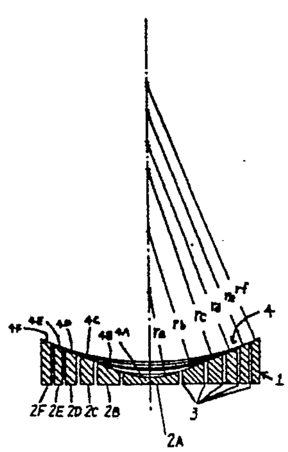
(72) Inventor: Tanaka, Hideyuki
1-5-10, Naka Aoki
Kawaguchi-shi Saitama-ken(JP)
Inventor: Saito, Koetsu
4-8-1, Higashi Nakano Nakano-ku
Tokyo(JP)
Inventor: Sakai, Ikuo
Paashimonzu Minami Ikuta 205 4-7-6, Minami Ikuta
Tama-ku Kawasaki(JP)
Inventor: Kawabuchi, Masami
2710-157, Miho-cho Midori-ku
Yokohama(JP)

(74) Representative: Grupe, Peter, Dipl.-Ing. et al
Patentanwaltsbüro
Tiedtke-Bühling-Kinne-Grupe-Pellmann-Grams-Struif Bavariaring 4
D-8000 München 2(DE)

(54) **Ultrasonic probe.**

(57) An ultrasonic probe includes a plurality of piezoelectric elements extending concentrically. The elements have respective surfaces via which ultrasonic wave is transmitted and received. The surfaces of the elements are concave and have predetermined radii of curvature respectively. The radii of curvature increase as the elements are farther from an innermost place and closer to an outermost place.

FIG. 1 (b)



EP 0 373 603 A2

ULTRASONIC PROBE

BACKGROUND OF THE INVENTION

This invention generally relates to an ultrasonic probe for an ultrasonic system, and specifically relates to an ultrasonic probe moved mechanically to generate a "B-mode" image of an examined object.

In some ultrasonic systems, an ultrasonic probe is mechanically moved to generate a "B-mode" image of an examined object.

The Journal of the Acoustical Society of Japan Vol. 32, No. 6, Jun. 1976, pages 355-361 discloses such a ultrasonic probe. As will be explained later, the prior-art ultrasonic probe of this Journal has problems.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an excellent ultrasonic probe.

According to this invention, an ultrasonic probe includes a plurality of piezoelectric elements extending concentrically. The elements have respective surfaces via which ultrasonic wave is transmitted and received. The surfaces of the elements are concave and have predetermined radii of curvature respectively. The radii of curvature increase as the elements are farther from an innermost place and closer to an outermost place.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1(a) is a plan view of a piezoelectric element array in an ultrasonic probe according to an embodiment of this invention.

Fig. 1(b) is a sectional view of the piezoelectric element array which is taken along the line L-L of Fig. 1(a).

Fig. 2 is a diagram showing results of a computer simulation of dynamic focusing in the ultrasonic probe of Figs. 1(a) and 1(b).

Fig. 3(a) is a plan view of a piezoelectric element array in a first example of a prior-art ultrasonic probe.

Fig. 3(b) is a sectional view of the piezoelectric element array of Fig. 3(a).

Fig. 4 is a plan view of a piezoelectric element array in a second example of the prior-art ultrasonic probe.

Fig. 5 is a diagram showing results of a computer simulation of dynamic focusing in the second example of the prior-art ultrasonic probe.

Fig. 6 is a diagram showing results of a computer simulation of dynamic focusing in a third example of the prior-art ultrasonic probe.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Before a detailed description of this invention, the prior-art ultrasonic probe will be explained for a better understanding of this invention.

As shown in Figs 3(a) and 3(b), a first example of the prior-art ultrasonic probe includes a piezoelectric element array (a transducer element array) 51 which has a central disk piezoelectric element (a central disk transducer element) 52A and ring piezoelectric elements (ring transducer elements) 52B, 52C, 52D, and 52E concentrically extending around the central piezoelectric element 52A. A pulse beam of ultrasonic wave is transmitted from and received by the piezoelectric element array 51. The piezoelectric elements 52A-52E form a front surface 54 via which the ultrasonic wave beam is transmitted and received. The transmission/reception surface 54 is concaved to structurally focus the transmitted and received ultrasonic wave beams. The whole of the transmission/reception surface 54 is spherical with a predetermined common or uniform radius "r" of curvature. In general, the ultrasonic wave beam is also focused through signal processing called "electronic focusing". The electronic focusing offers suitable delays to output signals from the respective piezoelectric elements and then combines the delayed signals.

Fig. 4 shows a second example of the prior-art ultrasonic probe which is basically similar to the prior-art ultrasonic probe of Figs. 3(a) and 3(b) except for design changes indicated hereinafter. The prior-art ultrasonic probe of Fig. 4 includes a piezoelectric element array 51 of a six-segment type. Specifically, the piezoelectric element array 51 has a central disk piezoelectric element 52A and ring piezoelectric elements 52B, 52C, 52D, 52E, and 52F concentrically extending around the central piezoelectric element 52A. The piezoelectric elements 52A-52F are separated by annular gaps 53. The piezoelectric elements 52A-52F form a flat transmission/reception surface. The areas of the respective piezoelectric elements 52A-52F over the transmission/reception surface are set approximately equal to each other. The widths of the gaps 53 are set to 0. 2 mm. The dimensions of the

piezoelectric elements 52A-52F are chosen as follows:
The outside diameter of the element 52A: 9.64 mm
The inside diameter of the element 52B: 10.04 mm
The outside diameter of the element 52B: 13.92 mm
The inside diameter of the element 52C: 14.32 mm
The outside diameter of the element 52C: 17.26 mm
The inside diameter of the element 52D: 17.66 mm
The outside diameter of the element 52D: 20.12 mm
The inside diameter of the element 52E: 20.56 mm
The outside diameter of the element 52E: 22.66 mm
The inside diameter of the element 52F: 23.06 mm
The outside diameter of the element 52F: 25.00 mm

Fig. 5 shows results of a computer simulation calculating conditions of dynamic focusing which occurred while the prior-art ultrasonic probe of Fig. 4 was receiving echo signals. The dynamic focusing is explained in various published documents, for example, the Journal of the Acoustical Society of Japan Vol. 32, No. 6, Jun. 1976, pages 355-361. In the computer simulation related to Fig. 5: the central frequency of the echo signals was set to 3.5 MHz; the pulse length of the ultrasonic wave beam was set equal to three times the wavelength of the central-frequency ultrasonic wave; and the envelope of the pulses of the ultrasonic wave beam was of the half-sine shape or the half-sinusoidal form. In addition, this computer simulation ignored a non-linear effect on the pulse propagation in an ultrasonic wave transmission medium.

It is seen from Fig. 5 that a beam width determined by -20 dB lines is relatively large and the degree of focusing is insufficient in an examined region of 50-70 mm although the ultrasonic wave beam is intended to be focused on an examined distance of 70 mm by electronic focusing using the two inner piezoelectric elements 52A and 52B. Furthermore, in an examined region of 0-50 mm, since only the central piezoelectric element 52A is used in electronic focusing, the degree of focusing tends to be insufficient.

A third example of the prior-art ultrasonic probe is similar to the prior-art ultrasonic probe of Figs. 4 and 5 except that the piezoelectric elements 52A-52F form a spherically concave transmission/reception surface having a predetermined common radius of curvature which equals 50 mm. The concave design of the transmission/reception surface of the piezoelectric element array 51 functions to structurally focus the transmitted and received ultrasonic wave beams. Fig. 6 shows results of a computer simulation calculating conditions of dynamic focusing which occurred while the third example of the prior-art ultrasonic probe was receiving echo signals. In the computer simulation related to Fig. 6: the central frequency of the echo signals was set to 3.5 MHz; the pulse length of the ultrasonic wave beam was set equal to three times the wavelength of the central-frequency ultrasonic wave; and the envelope of the pulses of the ultrasonic wave beam was of the half-sine shape or the half-sinusoidal form. In addition, this computer simulation ignored a non-linear effect on the pulse propagation in an ultrasonic wave transmission medium.

It is seen from Fig. 6 that electronic focusing is essentially ineffective in a far examined region over 100 mm while the focusing is improved in a close examined region relative to the case of Fig. 5.

As understood from the previous description, the examples of the prior-art ultrasonic probe can not have adequate characteristics of focusing of ultrasonic wave beams in both of a close examined region and a far examined region.

This invention will now be explained in detail. Figs. 1(a) and 1(b) show a part of an ultrasonic probe according to an embodiment of this invention. This embodiment is directed to an ultrasonic probe having a piezoelectric element array of a six-segment type.

The ultrasonic probe of Figs. 1(a) and 1(b) includes a piezoelectric element array (a transducer element array) 1 of a six-segment type. Specifically, the piezoelectric element array 1 has a central disk piezoelectric element (a central disk transducer element) 2A and ring piezoelectric elements (ring transducer elements) 2B, 2C, 2D, 2E, and 2F concentrically extending around the central piezoelectric element 2A. During a scanning process, the piezoelectric element array 1 is mechanically moved within liquid in a direction perpendicular to its axis by a known drive mechanism (not shown). The piezoelectric elements 2A-2F are separated by annular gaps 3. The piezoelectric element array 1 has a concave front surface 4 via which ultrasonic wave beams are transmitted and received. The concave design of the transmission/reception surface 4 functions to structurally focus the ultrasonic wave beams.

Specifically, front surfaces 4A, 4B, 4C, 4D, 4E, and 4F of the respective piezoelectric elements 2A, 2B, 2C, 2D, 2E, and 2F form the transmission/reception surface 4. The surfaces 4A, 4B, 4C, 4D, 4E, and 4F are spherically concave and have predetermined different radii ra, rb, rc, rd, re, and rf of curvature respectively. In general, the radius of curvature of the transmission/reception surface of a piezoelectric element determines the structural focal point of the piezoelectric element. Specifically, as the radius of curvature of the transmission/reception surface of a piezoelectric element increases, the structural focal point of the piezoelectric element is farther. The curvature radius ra of the central piezoelectric element 2A is the smallest. The curvature radius rb of the piezoelectric element 2B is greater than the curvature radius ra of the central piezoelectric element 2A. The curvature radius rc of the piezoelectric element 2C is greater than the curvature radius rb of the piezoelectric element 2B. The curvature radius rd of the piezoelectric element 2D is greater than the curvature radius rc of the piezoelectric element 2C. The curvature radius re of the piezoelectric element 2E is greater than the curvature radius rd of the piezoelectric element 2D. The curvature radius rf of the piezoelectric element 2F is greater than the curvature radius re of the piezoelectric element 2E and is the greatest. In this way, inner piezoelectric elements have smaller radii of curvature or closer structural focal points, and outer piezoelectric elements have greater radii of curvature or farther structural focal points. In other words, the curvature radius of a piezoelectric element increases as the location of the piezoelectric element is closer to the outermost place. Specifically, the radii of curvature of the piezoelectric elements 2A-2F are chosen as follows:

The curvature radius of the element 2A: 50 mm
The curvature radius of the element 2B: 80 mm
The curvature radius of the element 2C: 120 mm
The curvature radius of the element 2D: 130 mm
The curvature radius of the element 2E: 140 mm
The curvature radius of the element 2F: 150 mm

The areas of the respective piezoelectric elements 2A-2F over the transmission/reception surface 4 are set approximately equal to each other. The widths of the gaps 3 are set to 0. 2 mm. The dimensions of the piezoelectric elements 2A-2F are chosen as follows:

The outside diameter of the element 2A: 9.64 mm
The inside diameter of the element 2B: 10.04 mm
The outside diameter of the element 2B: 13.92 mm
The inside diameter of the element 2C: 14.32 mm
The outside diameter of the element 2C: 17.26 mm
The inside diameter of the element 2D: 17.66 mm
The outside diameter of the element 2D: 20.12 mm
The inside diameter of the element 2E: 20.56 mm
The outside diameter of the element 2E: 22.66 mm
The inside diameter of the element 2F: 23.06 mm
The outside diameter of the element 2F: 25.00 mm

Fig. 2 shows results of a computer simulation calculating conditions of dynamic focusing which occurred while the ultrasonic probe of Figs 1(a) and 1(b) was receiving echo signals. The dynamic focusing is explained in various published documents, for example, the Journal of the Acoustical Society of Japan Vol. 32, No. 6, Jun. 1976, pages 355-361. In the computer simulation related to Fig. 2: the central frequency of the echo signals was set to 3.5 MHz; the pulse length of the ultrasonic wave beam was set equal to three times the wavelength of the central-frequency ultrasonic wave; and the envelope of the pulses of the ultrasonic wave beam was of the half-sine shape or the half-sinusoidal form. In addition, this computer simulation ignored a nonlinear effect on the pulse propagation in an ultrasonic wave transmission medium.

It is seen from Fig. 2 that the characteristics of focusing are satisfactory in both of a close examined region and a far examined region. The satisfactorily focusing results from the following facts. In a close examined region, dynamic focusing is effective since only inner piezoelectric elements are used in the dynamic focusing and the inner piezoelectric elements have closer structural focal points. In a far examined region, dynamic focusing is effective since all the piezoelectric elements 2A-2F are used in the dynamic focusing and many piezoelectric elements having far structural focal points are used in the dynamic focusing.

The previously-mentioned advantages of this invention which are shown in Fig. 2 denote unexpected results or unobviousness of this invention over the prior art.

An ultrasonic probe includes a plurality of piezoelectric elements extending concentrically. The elements have respective surfaces via which ultrasonic wave is transmitted and received. The surfaces of the elements are concave and have predetermined radii of curvature respectively. The radii of curvature increase as the elements are farther from an innermost place and closer to an outermost place.

Claims

1. An ultrasonic probe comprising a plurality of piezoelectric elements extending concentrically; the elements having respective surfaces via which ultrasonic wave is transmitted and received; wherein the surfaces of the elements are concave and have predetermined radii of curvature respectively; and wherein the radii of curvature increase as the elements are farther from an innermost place and closer to an outermost place.

2. An ultrasonic probe comprising a transducer element array having a surface via which ultrasonic wave is transmitted and received; the surface being concave; wherein a portion of the surface has a predetermined radius of curvature which increases as the portion moves from a center of the surface to an outer edge of the surface.

5-89104-TH

FIG. 1 (a)

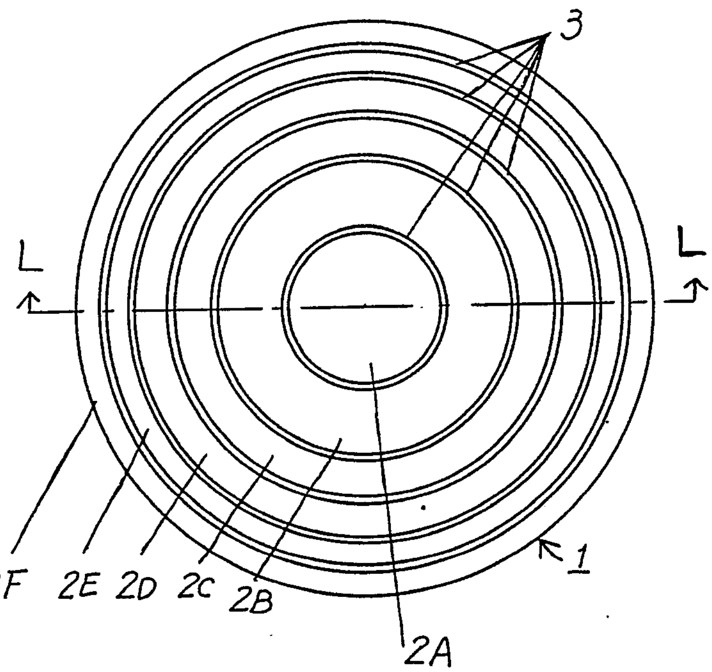


FIG. 1 (b)

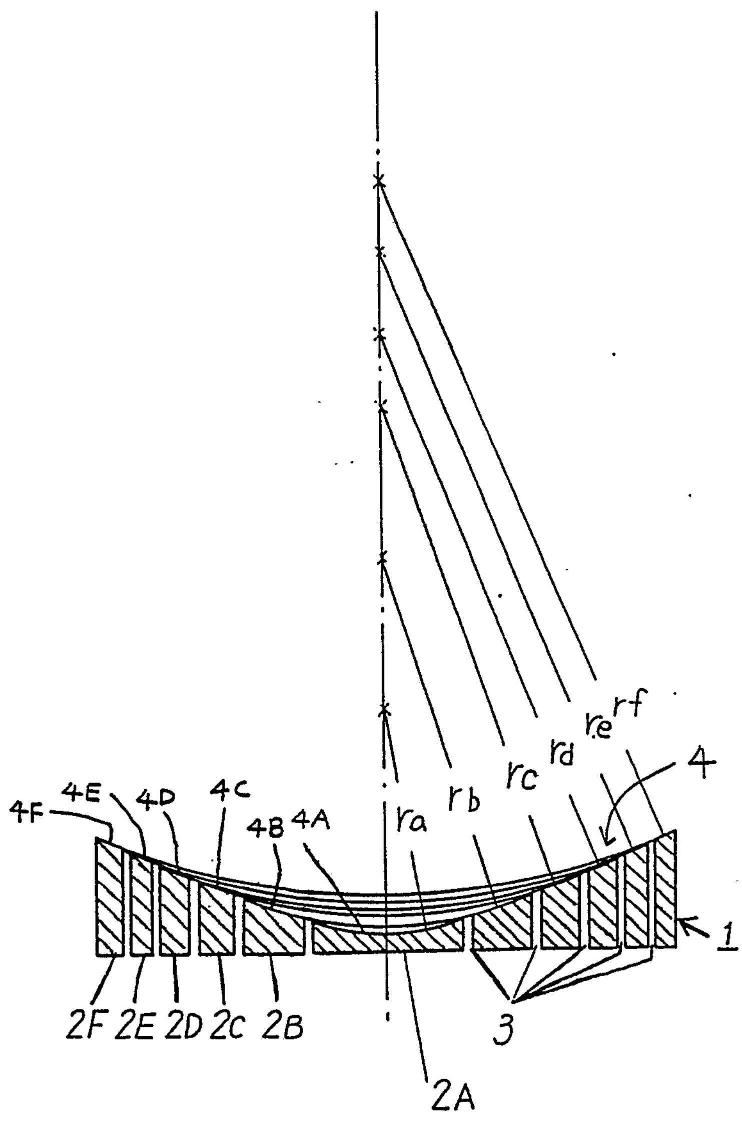


FIG. 2

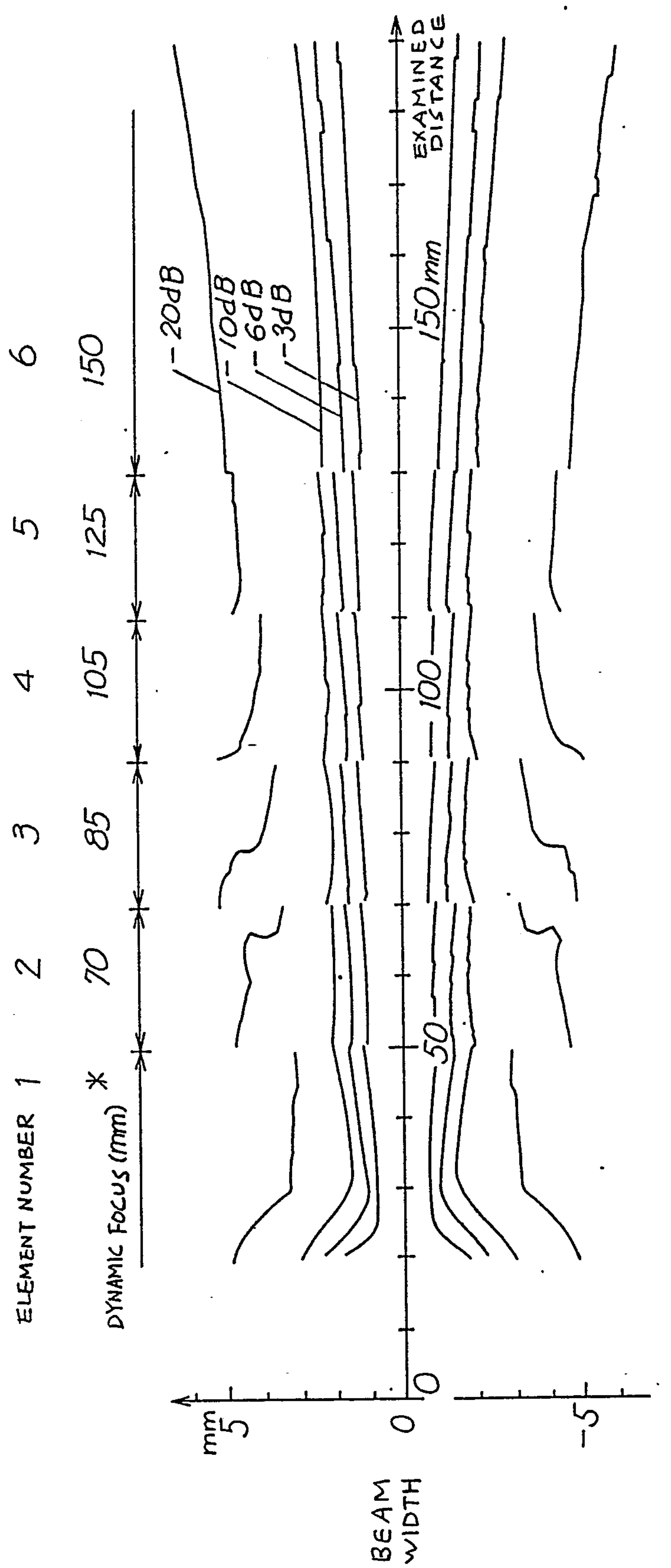

ELEMENT NUMBER 1 2 3 4 5 6
DYNAMIC FOCUS (mm) * 70 85 105 125 150
-20dB
-10dB
-6dB
-3dB
0
50
100
150mm
EXAMINED DISTANCE
BEAM WIDTH
mm
5
0
-5

FIG. 3(a) (PRIOR ART)

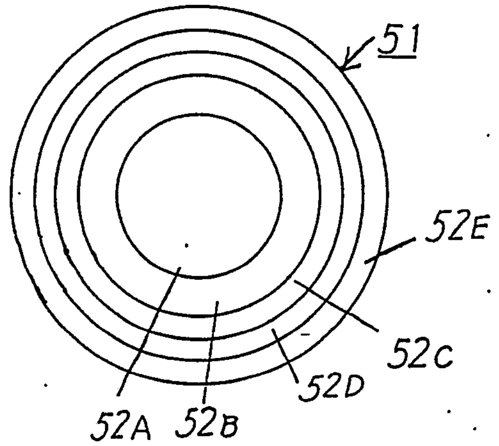


FIG. 3(b) (PRIOR ART)

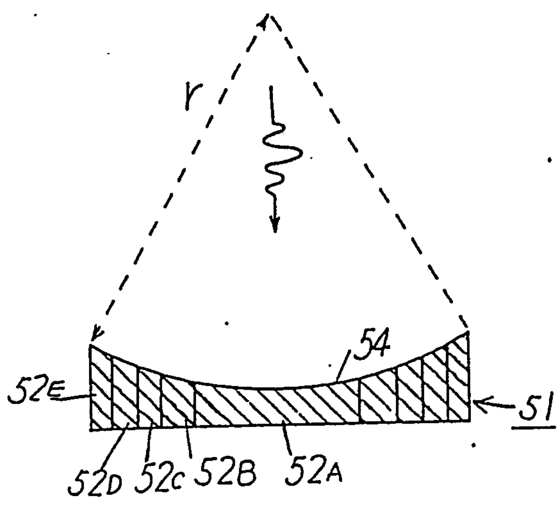


FIG. 4 (PRIOR ART)

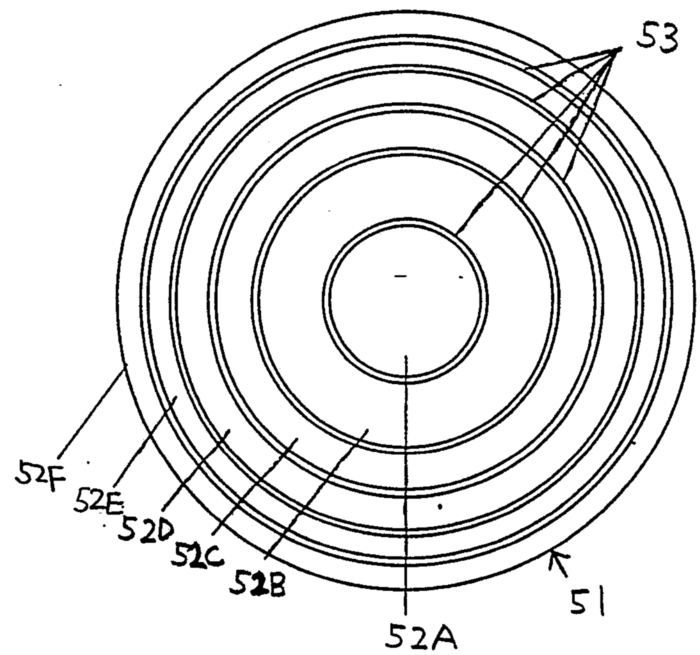


FIG. 5 (PRIOR ART)

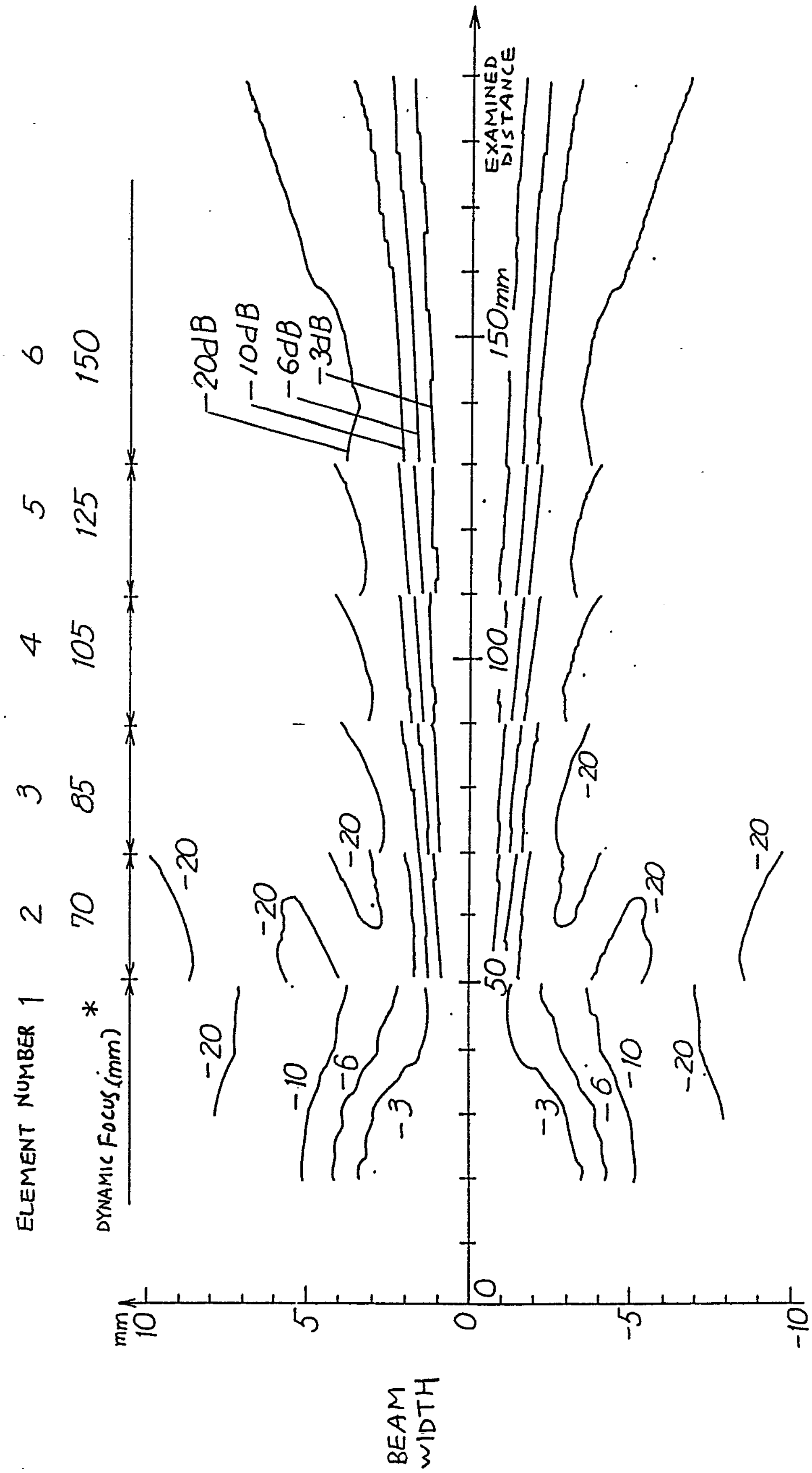


FIG.6 (PRIOR ART)