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

(11) Publication number: **0 339 746 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **89201068.7**

(22) Date of filing: **25.04.89**

(51) Int. Cl.[4]: **G10K 11/00 , G10K 11/02**

(30) Priority: **29.04.88 US 187754**

(43) Date of publication of application: **02.11.89 Bulletin 89/44**

(84) Designated Contracting States: **DE FR GB NL**

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(54) Acoustic transducer backing in the shape of a Wood's horn.

(57) The unwanted acoustic energy from the back side of an acoustic transducer is fully absorbed in a Wood's Horn styled acoustic energy trap embedded in an acoustically absorbing material. Also, the impedance of the transducer and backing can be exactly matched, thereby increasing the frequency bandwidth.

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WOOD'S HORN ACOUSTIC TRANSDUCER BACKING

The present invention relates to borehole logging technologies, and more particularly to an improved acoustical transducer configuration and method for borehole logging applications.

In the petroleum industry, several important wellbore and formation surveying and analysis tools employ acoustical techniques. These include the Borehole Televiewer, the Pulse Echo Tool, and the Cement Evaluation Tool, for example. With such tools, an acoustic pulse is generated, injected or directed into the target of the survey (depending upon the tool involved), subsequently received, and then analyzed to determine the effects which the target environment had upon the pulse. The analysis is then interpreted to provide a description of that environment. The steps are repeated for thousands upon thousands of such pulses to generate a permanent record or log, typically as a function of depth within the borehole.

In many cases, an ideal pulse would be one cycle or waveform long. In practice, real world physical systems cannot be started and stopped quite so sharply. A common problem is the "ring-down" of the transducer after the electrical impulse has been discontinued. Being a physical system, the acoustical inertia of the transducer will cause it to oscillate for a short period thereafter. This increases the pulse width, which not only makes analysis of the subsequently received returning acoustical signal more difficult, but can also reduce the repetition rate at which distinct pulses can be generated.

Several known techniques for improving transducer performance include sound absorbing/damping materials physically coupled to the transducer and electrical circuits which follow the initial driving pulse with a reverse polarity pulse of lower magnitude to dampen the residual oscillation in the transducer. For physical damping, which also helps to improve the signal-to-noise ratio, it is common to mount a piezoelectric transducer on a sound absorbing backing such as high temperature rubber impregnated with tungsten cuttings. Such tungsten loaded rubber closely matches the acoustic impedance of the transducer, thereby reflecting very little energy back into the transducer and accordingly shortening the transducer ring-down time.

As far as is known, no backing has been described or is available in which all the acoustical energy appearing on the back of the transducer disappeared into the backing.

Thus, it is an object of the invention to construct a transducer backing which appears to be acoustically infinitely deep, or in other words, which will return no energy to the back of the transducer.

It is a further object of the invention to construct a transducer backing which should be inexpensive, uncomplicated, and sufficiently compact to be usable in virtually any such borehole acoustic logging application.

Therefore the present invention provides an acoustical transducer provided with a sound attenuating backing for decreasing the ring-down time of the transducer, comprising a tapered backing having a face portion and a wall portion said, face portion being acoustically coupled to the transducer, said backing having an acoustical impedance substantially the same as the transducer, and the taper of said backing terminating substantially in a line or point on the backing substantially opposite the face, and comprising sound absorbing means acoustically coupled to the wall portion of said backing.

Advantageously said backing is formed of substantially the same material as the transducer, the backing and the transducer being both ceramic material, the transducer being a poled ceramic and said backing being an unpoled ceramic of the same type as the transducer. More advantageously said backing has the form of a wedge. In another advantageous embodiment in accordance with the invention the wedge has the shape of a cone, the cone being curved and tapered in the shape of a Wood's Horn. Furthermore the sound absorbing means is advantageously a tungsten loaded rubber, the wall portion of the backing being embedded in the sound absorbing means.

Furthermore the present invention provides a method for attenuating sound from the back of such a transducer for decreasing the ring-down time of the transducer, comprising the steps of:

- absorbing substantially all the acoustic energy from the back of such an acoustical transducer in a tapered backing having a face portion and a wall portion, the face portion being acoustically coupled to the transducer, the backing having an acoustical impedance substantially the same as the transducer, and the taper of the backing terminating substantially in a line or point on the backing substantially opposite the face; and
- attenuating the sound in the backing with a sound absorber acoustically coupled to the wall portion of the backing.

It is noticed that although a Wood's Horn type device has not heretofore been used in acoustics, historically it is known from and has been used in optics. Its function is to reduce extraneous reflections in an optical device by trapping, attenuating, and ultimately extinguishing any light which enters it. The optical Wood's Horn is typically made of glass, coated on the inside with carbon black, and otherwise hollow. However, the sound attenuating backing for borehole logging applications is significantly different in several respects. First, it is not hollow. Secondly, the sound absorption does not all take place at the back wall of the Wood's Horn backing. Instead, by essentially matching the impedances at the back wall interface, the largest portion of the acoustical energy at each encounter with the wall is encouraged to exit the Horn into a highly attenuating medium on the outside thereof. Thus, the Horn is preferably embedded in tungsten loaded rubber sound absorbing material, and the Wood's Horn itself is either a solid or liquid of the desired shape located within the sound absorbing material.

Thus, rubber impregnated with tungsten cuttings has been used, for example, in prior art borehole televiewers to absorb the sound on the back of a piezoelectric acoustical transducer. In the prior art, the transducer was simply attached to a piece of the sound absorbing rubber of about the same size as the transducer itself. While acoustical energy received by the sound absorbing rubber from the back of the transducer was quickly attenuated in the rubber, the acoustic mismatch between the transducer and backing would cause some of the energy to reflect back and forth within the transducer, and in so doing extended the transducer ring-down time.

Advantageously said transducer and said method are suited to the widest possible utilization in acoustical type borehole logging applications.

These and other objects and advantages of the invention will be apparent from the following description, the accompanying drawings, and the appended claims.

Fig. 1 is a somewhat figurative illustration showing a borehole televiewer type logging tool which incorporates a sound attenuating backing according to the present invention, and located within a borehole within an earth formation;

Fig. 2 is a vertical sectional view through the transducer and backing combination shown generally in phantom in Fig. 1;

Fig. 3 is a cross-sectional view taken generally on line III-III in Fig. 2; and

Fig. 4 is a graphical illustration showing representative reflection/attenuation paths within the sound attenuating backing.

With reference to the drawings, a sound attenuating backing for decreasing the ring-down time of an acoustical transducer in borehole logging applications, and a method therefor according the present invention, will be described. Fig. 1 shows, somewhat figuratively, a borehole televiewer 10 suspended in a borehole 14 penetrating earth formations 16. A motor 17 within the televiewer 10 drives a shaft 18 which in turn rotates a cylindrical transducer assembly 20 located on the bottom of the borehole televiewer 10.

As shown in greater detail in Figs. 2 and 3, the transducer assembly 20 includes a transducer 25 to which thin front and rear metallic electrodes 26 and 27 are attached in conventional fashion. In the illustrated preferred embodiment, the transducer is a 1.0 inch (2.5 cm) diameter, 1 megahertz transducer of poled lead metaniobate ceramic, available from Keramos, Inc., Indianapolis, Indiana under the name Kezite K-81 (registered trademark). The transducer has a mechanical Q measured in the thickness mode which is less than 15.

Attached to the rear electrode 27 of transducer 25 and thus acoustically coupled thereto is a backing 30 shaped in the form of a Wood's Horn. Backing 30 has a face 31 in contact with electrode 27 and a tapered, curvilinear wall portion 32 extending rearwardly from the face 31 and ultimately terminating in a point 33 substantially opposite the face 31. Transducer 25 and the backing wall 32 are, in turn, embedded in a rubber sound absorber 35. Backing 30 is also made from Kezite K-81 ceramic but is unpoled (i.e., does not have piezoelectric properties).

It will be immediately seen that there are several favorable phenomena at work here. First, the acoustic properties of the backing 30 and the transducer 25 are as closely matched as possible. The Wood's Horn shape of the backing wall 32 reduces multiple scattering in the backing 30 as much as possible. Additionally, the rubber sound absorber 35 is a high temperature tungsten loaded rubber which also has an acoustical impedance nearly identical to that of the transducer 25 and backing 30, and further is highly attenuating to sound energy which passes into it. A suitable such loaded rubber for absorber 35 may be, for example, any high temperature silicone elastomer.

Thus, as previously described, the backing 30 and absorber 35 combination provides essentially no opportunity for acoustical energy coupled thereto from the transducer 25 to find its way back to the transducer. That is, since the impedances of the materials are matched, the interfaces between and among the several materials are almost invisible to the sound energy, so very little is reflected. What reflections do occur in the Wood's Horn backing 30 cause the sound energy to travel deeper into the Horn and not to return to the transducer 25. Energy which enters the absorber 35 is quickly damped. Thus maximum attenuation for the transducer is provided, substantially shortening the ring-down time characteristics thereof.

While a Wood's Horn configuration for the backing is preferred, it will be immediately apparent that other variations on the invention will conceptually and physically provide remarkably improved attenuation. For example, a wedge-shaped backing is much easier and less expensive to fabricate than one shaped as a Wood's Horn. Compared to the simple prior art block of elastomeric sound absorbing material, the attenuating characteristics of a suitably shaped wedge are extremely favorable. Such a wedge would terminate in most cases in a line defined by the intersection of the major planar surfaces on the rear of the wedge-shaped backing. The important concepts here are the absence of a rear surface area which might reflect acoustic energy directly back to the front face of the backing, and a small reflection angle that maximizes the number of reflections suffered by the acoustic beam within the wedge before it can return to the front face. Thus, as used in the present specification and claims, the phrase "terminating substantially in a line or point" is to be taken to mean that there is not a surface, as such, where the backing terminates opposite the transducer. Such a line may be straight or curved, and the term "point" would be taken to be the extreme situation of a line infinitely short.

Fig. 4 is an example of such a wedge 40 that is easy to machine, yet very efficient in reducing unwanted energy returned to the transducer. The representative ray or beam path 45 experiences six reflections before being reversed at the seventh to return back to the face 31 -- a total of thirteen reflections in all. In the limit in which the ray path approximation is valid, the total energy returned, assuming even a large reflection coefficient of 0.1 (i.e., a poor match between the wedge and the tungsten-rubber absorber in which it is embedded), will be reduced by a factor of 10^{-13}. In common usage at normal frequencies (1 MHz - 200 kHz) beam spreading and beam front curvature will cause a fraction of the energy to turn back before seven reflections. However, in practice reflection coefficients lower than 0.1 can be achieved with the result that the reflected signal returning to the transducer is reduced several orders of magnitude.

Effectively, this means that with the present invention, after a few reflections the backing contributes no signal. Therefore, the only limiting factors remaining are the quality of the attachment of the transducer to the backing, and the electronic matching and signal-to-noise ratio (which should be better than 60 dB).

A progression of suitable shapes, all conceptually embraced by the present invention, is thus now suggested. For example, intermediate the wedge shape and the Wood's Horn would be a cone shape. Thus, within the context of the present invention, a cone may be considered to be a special case of a wedge, and the Wood's Horn a special case of a cone, all terminating substantially in a line or point opposite the face of the backing at the transducer.

As may be seen, therefore, the present invention provides numerous advantages. Principally, it significantly shortens the ring-down time of a transducer utilized in borehole logging applications while maintaining a very good signal-to-noise ratio for the transducer. With the present invention, a short pulse length of only about 2 cycles can be achieved without reduction in the transducer signal-to-noise ratio. The acoustically matched backing and absorber, and the special shape of the backing, while of convenient finite physical length, appear acoustically to be virtually infinitely deep, so that essentially none of the acoustic energy coupled thereto from the transducer returns to the transducer.

A further advantage of the matched backing is the much lower Q, hence increased bandwidth of a transducer so backed. That is, by exactly matching the backing impedance to the transducer the length of the transducer is effectively extended to infinity. The transducer can then be electronically tuned to operate efficiently over a broad band of frequencies. In tests, for instance, a 1 MHz transducer mounted on such a wedge has been run between 1 MHz and about 200 kHz with no noticeable change in peak voltage of the detected signal.

Due to this finite size, the invention can be readily and easily incorporated into many different types of borehole logging tools, such as the borehole televiewer illustrated generally in Fig. 1, in which acoustical transducers are utilized in a pulsed mode. The invention is fully functional in borehole environments, is inexpensive, uncomplicated, durable, versatile, relatively easy and inexpensive to manufacture and implement, and thus readily suited to the widest possible utilization in such borehole logging applications.

While the methods and forms of apparatus herein described constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise methods and forms of apparatus, and that changes may be made therein without departing from the scope of the invention.

Claims

1. An acoustical transducer provided with a sound attenuating backing for decreasing the ring-down time of the transducer, comprising:
- a tapered backing having a face portion and a wall portion, said face portion being acoustically coupled to said transducer, said backing having an

acoustical impedance substantially the same as said transducer, and the taper of said backing terminating substantially in a line or point on said backing substantially opposite said face; and
- sound absorbing means acoustically coupled to said wall portion of said backing.

2. The transducer as claimed in claim 1 wherein said backing further comprises a backing formed of substantially the same material as said transducer.

3. The transducer as claimed in claim 2 wherein said transducer is formed of poled ceramic material and said backing is formed of unpoled ceramic material of the same type as said transducer.

4. The transducer as claimed in claim 1, 2 or 3 wherein said backing is shaped in the form of a wedge.

5. The transducer of claim 4 wherein said wedge has the shape of a cone.

6. The transducer of claim 5 wherein said cone is curved and tapered in the shape of a Wood's Horn.

7. The transducer as claimed in claim 1 wherein said sound absorbing means further comprises a tungsten loaded rubber.

8. The transducer as claimed in claim 1 or 7 wherein said sound absorbing means further comprises means embedding at least said wall portion of said backing in said sound absorbing means.

9. The transducer as claimed in any one of the preceding claims for use in borehole logging applications.

10. A method for attenuating sound from the back of such a transducer for decreasing the ring-down time of the transducer, comprising the steps of:
- absorbing substantially all the acoustic energy from the back of such an acoustical transducer in a tapered backing having a face portion and a wall portion, the face portion being acoustically coupled to the transducer, the backing having an acoustical impedance substantially the same as the transducer, and the taper of the backing terminating substantially in a line or point on the backing substantially opposite the face; and
- attenuating the sound in the backing with a sound absorber acoustically coupled to the wall portion of the backing.

11. The method as claimed in claim 10 using the transducer as claimed in any one of the claims 1 to 9.

12. Acoustical transducer provided with a sound attenuating backing for decreasing the ring-down time of the transducer substantially as described in the description with reference to the appended drawings.

13. Method for attenuating sound from the back of a transducer for decreasring the ring-down time of the transducer substantially as described in the description with reference to the appended drawings.

FIG.1

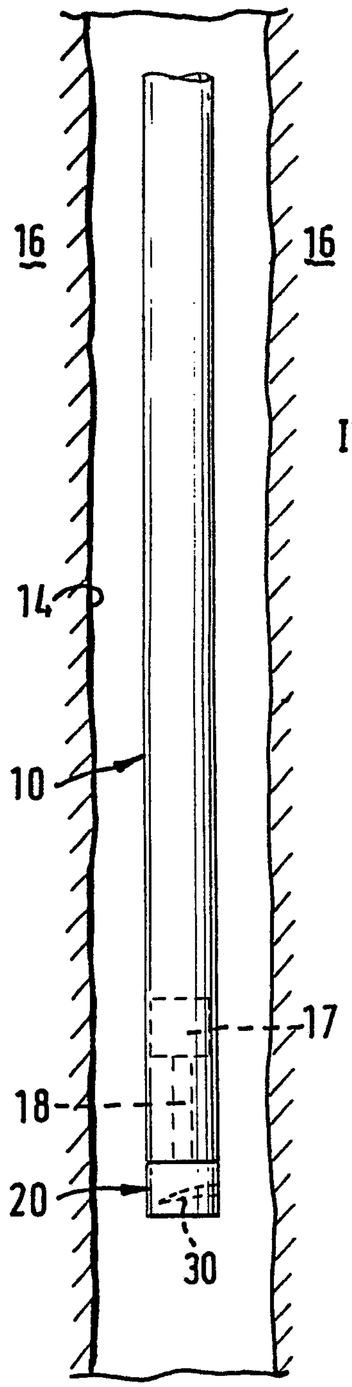

FIG.2

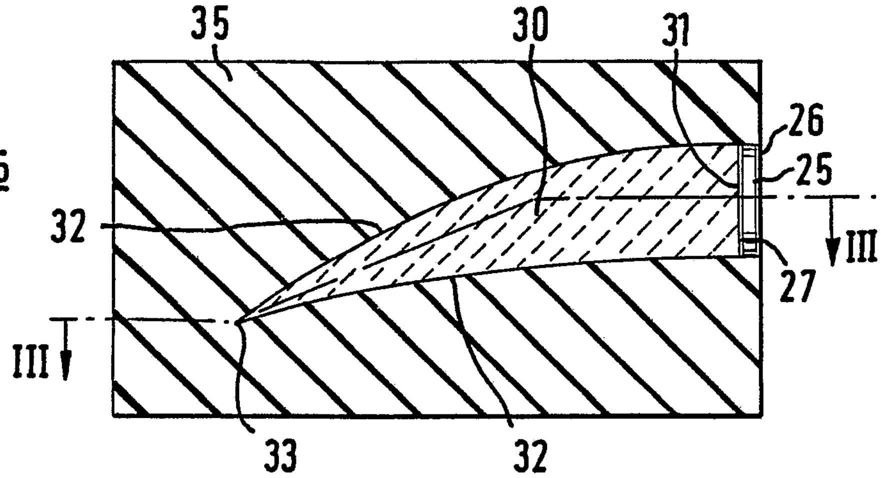

FIG.3

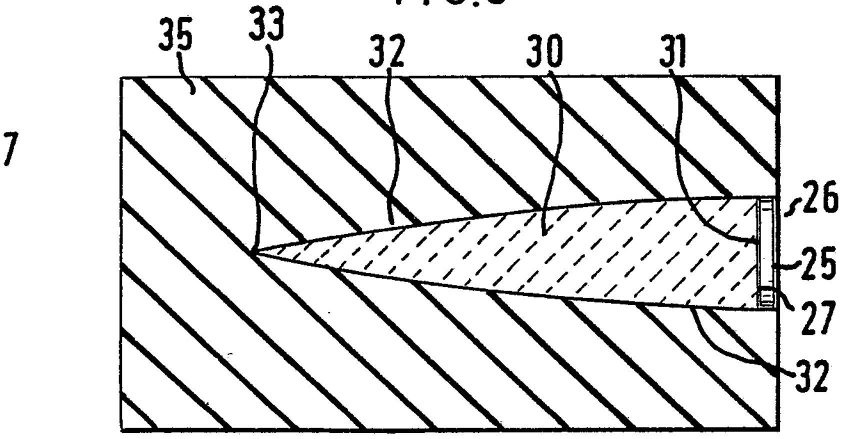

FIG.4