

# High signal-to-noise ratio wedges for oblique incidence in ultrasonic testing

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It is experimentally shown that ultrasonic transmission through a column of couplant, with a thin film, at the end, produces greater amplitudes than through a piece of acrylic with the same length. This suggests the use of a wedge that could yield a greater signal-to-noise ratio than that of commercial wedges involved in oblique incidence ultrasonic inspection. The suggestion has been pursued, and the effects: on a weld are presented.

*Keywords:* Oblique incidence; wedges; ultrasonics; transmission; reflection.

Se muestra experimentalmente que la transmisión de ultrasonido a través de una columna de acoplante, rematada con una película delgada, conduce a una amplitud mayor que aquella a través de una pieza de acrílico de la misma longitud. Esto sugiere la elaboración de una zapata que permita tener una razón señal-ruido mayor que aquella que proporcionan las zapatas comerciales utilizadas en la inspección con ultrasonido a incidencia oblicua. Siguiendo esta sugerencia se ha elaborado una zapata y se muestran los resultados de su uso en una placa soldada.

*Descriptores:* Incidencia oblicua; zapatas; ultrasonido; transmisión reflexión.

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## 1. Introduction

Oblique incidence in ultrasonic testing is widely used in the inspection of irregularly shaped pieces, difficult-to-reach places or when propagation along a specific direction in the test material is required. Also, it has been used to take advantage of the phenomenon known as mode conversion [1], which permits the generation and propagation of a shear or a surface mode by oblique incidence at an interface.

Ultrasound requires a medium to propagate and, thus, material testing relies on the use of couplants to transmit sound from the transducer to the test material. Although this requirement limits its applications, it has also led to intensive research and development of couplants, transducers and models to describe the interaction ultrasound-test material and, thus, provide a basis for analysis of the experimental results.

Ultrasound propagation through different media has been studied for a long time and discussed to a great extent by several authors [2]; of particular interest to this work is the attenuation of sound through solids and fluids. It has already been shown that attenuation is a function of frequency and of the elastic properties of the propagating medium; thus, ultrasound at a given frequency will travel a shorter distance in gases than in liquids or solids. Also, the higher the frequency the shorter the distance travelled in a given medium. As a result, air has not been used as a couplant until recently, when new air coupled transducers became available [3,4], although they are still frequency limited; there are specific applications [5] where conventional transducers and couplants are not suitable.

Liquids have traditionally been used as couplants in two modes, one by having the test piece and the transducer immersed in the couplant, and the other by using a thin film between the transducer and the test piece, the latter being

suitable mainly for pieces whose surface geometry allows for seating the transducer. Thus, oblique incidence is more easily maintained by immersion than by contact; in the former, it is simply achieved by orienting the axis of the transducer in order to have the proper angle with the normal to the surface of the test material, while the latter will require the appropriate wedge to help maintain the angle of incidence during the test.

The contact mode is usually preferred for on-site testing so that wedges are required; however, since ultrasonic inspection involves the analysis of the signal received, a large signal-to-noise ratio is desired. Efforts to increase such a ratio include focusing techniques, new materials for transducers,...etc., as the well as design and construction of wedges.

Although the construction of wedges dates back to the 1960's, the commercially available wedges are made of plexiglass, acrylic, lucite or similar materials; early attempts considered a couplant filled cavity with a neoprene rubber pad under the probe [6]. Such a design allows the deformation of the pad by applying pressure, so that it adapts to surface irregularities leading to the transmission of sound; however, the control of the motion and the angle of incidence may be lost if the deformation is exceeded. Also, there may be significant wearing due to dragging on the test surface, and the sensitivity may be limited due to the reverberation at the neoprene-test material interface.

The purpose of this work is to follow up the early attempts of the couplant-filled cavity wedge by analysing the transmitted signal through couplants, by themselves, and in conjunction with different materials. As a result, a selection of couplant and pad material will be made.

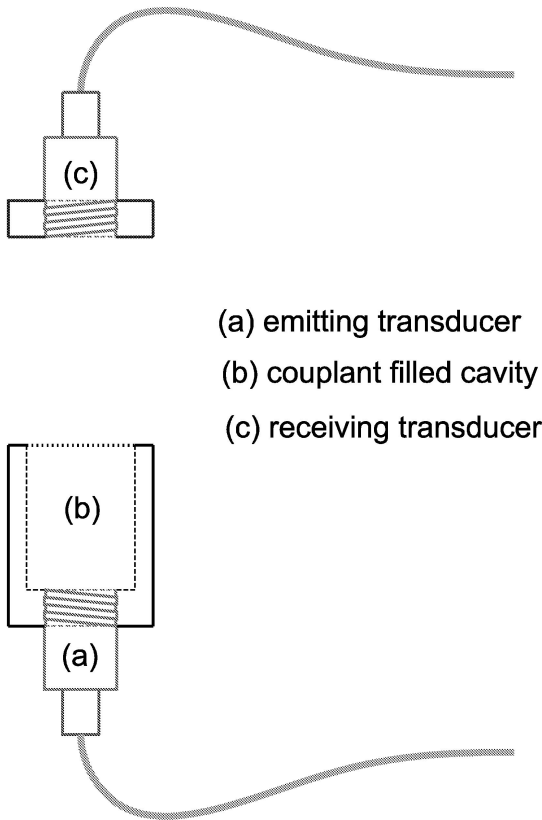


FIGURE 1. Schematics of cavity and transducers used to obtain the transmitted signals through couplants and couplants+materials.

The following section describes the couplant container used to perform the tests of the couplants: water, glycerine, and a commercial gel, alone; followed by a description of the test performed in conjunction with an overhead projector film, anti-wearing protective membrane, and acrylic.

Based upon the results of the above sections, materials for a wedge are proposed in Sec. 3, and its implementation for the inspection of welded plates is described, as well as the results obtained on a test plate. Finally, Sec. 4 summarizes and concludes on the results.

**2. Tests of couplants and materials**

Acoustic couplants differ in their bulk modulus of adiabatic compressibility, surface tension, and viscosity, among other factors [7]. Since their function is the transmission of sound, it is convenient that their absorption and attenuation coefficients be as small as possible, so that the power loss is kept to a minimum. Although absorption and attenuation manifest themselves in a decaying amplitude of a wave [8], the former also decreases the frequency components, so that the waveform is modified. In other words, during the passage of a wave through a medium, part of the wave energy may be converted into internal energy and, thus, the components of the outgoing wave may differ from those of the incoming one, so that a couplant may act as a filter. Therefore, the power spectrum for the acquired signals will also be obtained.

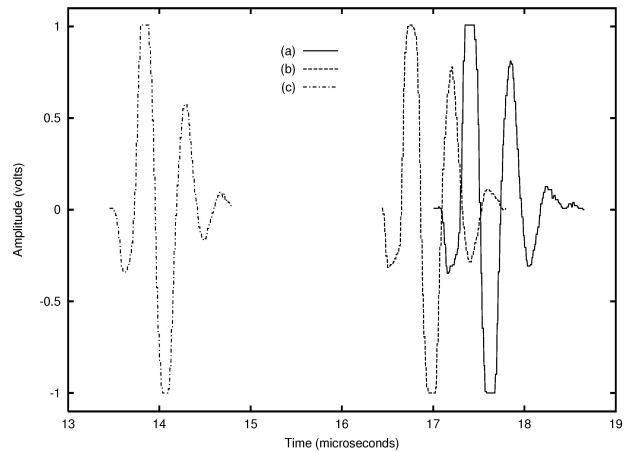


FIGURE 2. Comparison of amplitudes of transmitted signals through water (a), gel (b) and glycerin (c) alone.

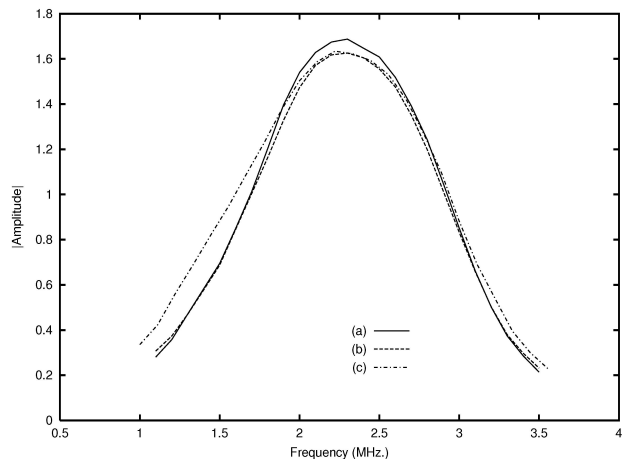


FIGURE 3. Comparison of power spectra of transmitted signals through water (a), gel (b) and glycerin (c).

The tested couplants were contained in a cylindrical cavity 19 mm in diameter and 25.4 mm long, bored lengthwise in a 32×25×25 mm acrylic prism, Fig. 1b. The axis of the cylinder was aligned with the axis of the ultrasonic transducer, which is screwed to the lower end, Fig. 1a; the other end was topped with the receiving transducer or with the tested materials, Fig. 1c. The receiving transducer is mounted on an aluminum plate 25 × 25 and 6.25 mm thick, with a hole in its center where the transducer is screwed in. This array allows for the contact of the couplant with the transducer and, at the same time, insures that the axes of the emitting and receiving transducers are aligned.

A personal computer based pulser-receiver board<sup>i</sup> was used to drive the transducers and a high speed analog-to-digital converter<sup>ii</sup> was used to be able to store the received signal on a hard disk, for post-processing.

All tests were carried out with a non-focused broadband contact transducer of central frequency at 2.25 MHz and 9.525 mm diameter<sup>iii</sup>, which is common in non-destructive inspection; the excitation parameters were fixed throughout

the tests and the gain was set in such a way that the amplitude of the transmitted signal, through water alone, was unity. The sampling rate was set at 62.5 MS/sec.

### 2.1. Couplants

The tested couplants were, in order of increasing viscosity, water, glycerin and a commercial gel<sup>tv</sup>. Only the transmitted signal was obtained, since reflection requires a surface, and for the couplants alone this would be the couplant-air interface; in general, however, this is of no interest due to the fact that the reflecting surface is that of the material under inspection. The transit time  $t$  of the ultrasound through the couplant column is shown in Fig. 2 for each of the test couplants, taking into account that the length of the couplant column is  $l = 25.4$  mm, then the speed of sound  $v = l/t$  in each of the couplants is estimated to be 1464 m/sec in water, 1516 m/sec in gel and 1835 m/sec in glycerin. As far as frequency components are concerned, they may be more clearly seen in the Fourier representation through the power spectrum, as shown in Fig. 3. In all cases, the peak frequency is between 2.2 and 2.3 MHz, which is around the central frequency of the transducer.

### 2.2. Couplants + Materials

The materials tested, a 0.127 mm thick overhead projector film, a 0.737 mm thick anti-wearing membrane<sup>v</sup> and a 25.4mm thick piece of acrylic, are used to cover the upper end of the couplant container, and they will be the reflecting or transmitting surfaces. The transmitted pulses are shown in Fig. 4 for the couplant-film combination, while Fig. 5 shows the results for the couplant-membrane combination. The preceding figures show that the transmitted pulses will be similar; however, the amplitudes are different for the film and membrane, for a given couplant. Thus, the presence of the film is negligible, but the membrane drops the amplitude by about 20%. These figures, together with Fig. 2, may be used to estimate the speed of sound in the film and the membrane at 1165 m/sec and 1844 m/sec, respectively.

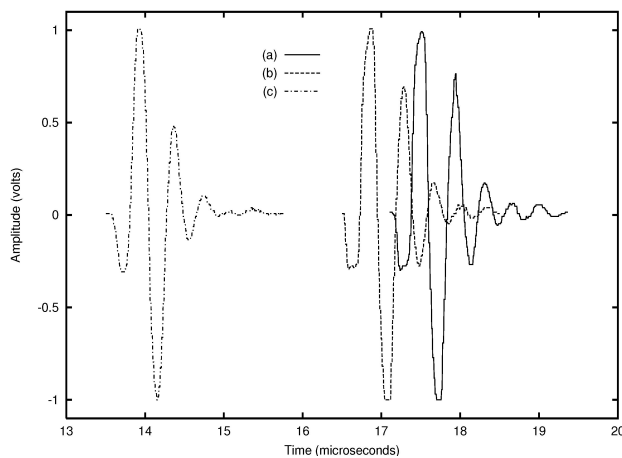


FIGURE 4. Comparison of amplitudes of transmitted signals through water (a), gel (b) or glycerin (c) + film combination.

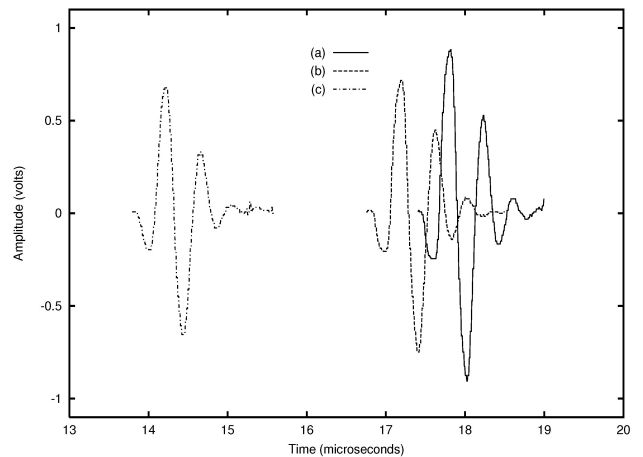


FIGURE 5. Comparison of amplitudes of transmitted signals through water (a), gel (b) or glycerin (c) + membrane combination.

It should be noted, however, that these values may have large associated uncertainties due to the small thickness of the film and the membrane; nevertheless, it is possible to estimate the wavelength,  $\lambda$ , using these values together with the frequency of the transducer, to be 0.517 mm and 0.819 mm. This indicates that the thickness of the film is of the order  $\lambda/4$ , while for the membrane it is about  $\lambda$ , which explains the observed difference amplitude.

Figure 6 includes the transmitted pulse through acrylic in the direct contact mode and shows that the amplitude in this mode is about 20% higher than that involving the couplant container; however, it should be noted that it is about 40% smaller than that obtained with the couplant-film combination. As before, this figure may be used to estimate the speed of sound in acrylic to be 2612 m/sec.

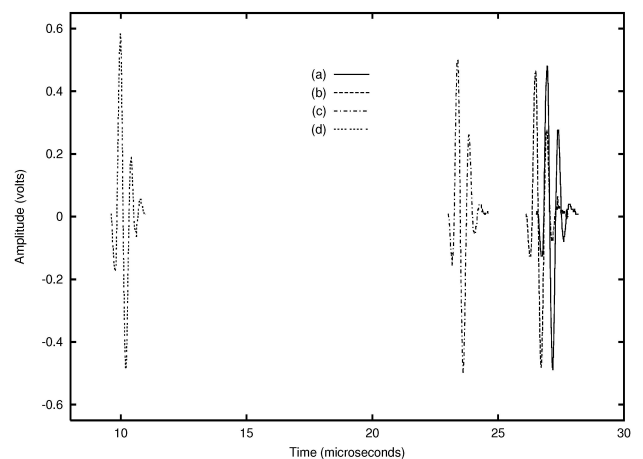


FIGURE 6. Comparison of amplitudes of transmitted signals through water (a), gel (b) or glycerin (c) + acrylic, including the direct contact mode (d).

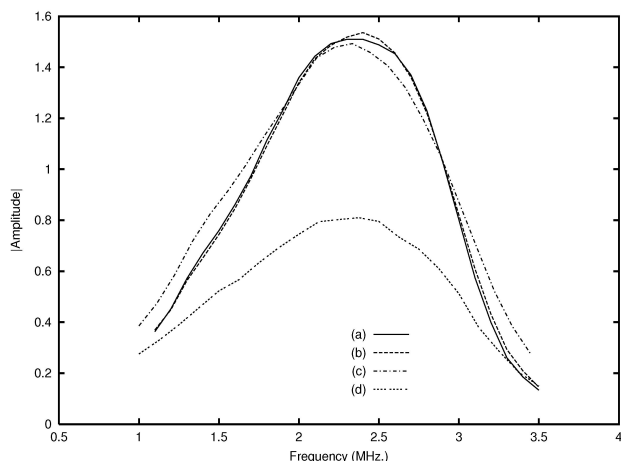


FIGURE 7. Comparison of power spectra of transmitted signals for water (a), gel (b) or glycerin (c) + film combination and acrylic (d) in the direct contact mode.

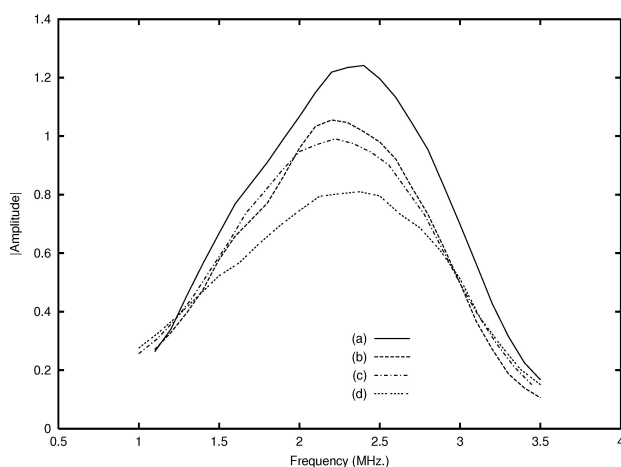


FIGURE 8. Comparison of power spectra of transmitted signals for water (a), gel (b) or glycerin (c) + membrane combination and acrylic (d) in the direct contact mode.

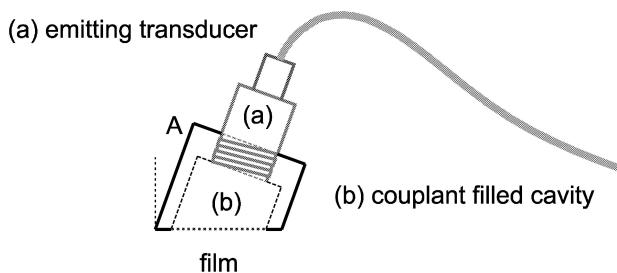


FIGURE 9. Schematics of the implemented wedge used to obtain the reflected signals from the edges of a carbon steel plate and the weld of plates.

### 3. Design and test of a wedge for oblique incidence

The preceding results suggest that a couplant, in combination with a film or a membrane, leads to a higher signal-to-noise ratio than acrylic alone. However, it is important to

note that, when the cavity is inverted, the film or the membrane will support the column of couplant; under such condition, the membrane deforms more than the film, indicating that the membrane has a rubber-like behavior. Furthermore, comparison of the power spectrum of the couplant-film and the couplant-membrane combination, Figs. 7 and 8, indicates that the couplant-film combination yields a larger transmitted amplitude. Therefore, the use of the water-film combination is proposed.

The proposed wedge consists of a cylindrical cavity bored along the axis of a commercial acrylic bar, Fig. 9b, with one end at a right angle to the axis and covered by the transducer, Fig. 9a. The other end of the cavity forms an angle with the axis of the acrylic bar and is covered by the film. The angle is determined according to Snell's law [7], so that the ultrasonic beam propagates along the desired direction through the test material upon refraction. It should be noted that face A of the acrylic bar should be properly finished so that possible reflections are not reflected back to the transducer. Also, the incidence angle is that between A and the normal to the surface, dotted line in Fig. 9. Two such cavities were constructed so that propagation takes place at 45° in carbon steel; one is to be used with a 9.525 mm diameter transducer while the other is for 12.7 mm diameter transducers. The former was used for top and bottom edge detection of a 6.35 mm thick steel plate, while the latter was used to detect inhomogenieties in a welded plate; in both cases, reflected signals are compared to those obtained using commercial wedges<sup>vi</sup>.

The results from the edge detection are shown in Fig. 10; in this case, the gain had to be increased, but was kept fixed, and the same for the test of both wedges; the sampling rate was also increased to 250 MS/sec. As before, this figure may be used to estimate the speed of the shear wave in the plate; if the commercial wedge data are used, then the estimate will be 3100 m/sec, while for the designed wedge it will be 3129 m/sec. It should be noted that the amplitude of the reflected signal, using the designed wedge, is around twice the corresponding amplitude using the commercial wedge, while the power spectrum shown in Fig. 11 covers the same frequency range but with different amplitudes.

A commercial flaw detector<sup>vii</sup> was used to test the other wedge on a 304.8 × 304.8 × 25.4 mm welded plate; this plate is the result of welding two 304.8 × 152.4 mm, 25.4 mm thick plates, along the 304.8 mm side, and has defects in two known localized regions. Although signals were obtained, with the designed and the commercial wedges, at eight points along the weld, only signals from two points are shown. Fig. 12 shows the signals, as provided on the display of the detector, corresponding to the commercial (a) and designed (b) wedges, respectively; both signals were obtained at the same point, in one of the regions with defects. Fig. 13 shows the signals obtained similarly in the other region, (a) corresponds to the commercial and (b) to the designed wedge, respectively. As before, all signals were obtained under the same excitation and gain parameters; they differ only in the

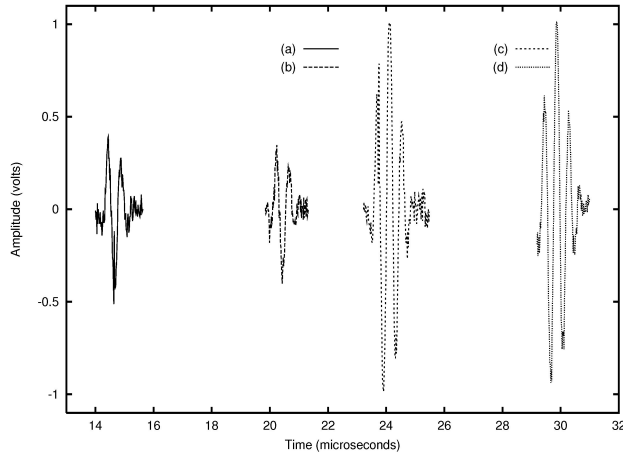


FIGURE 10. Signals reflected by the bottom and top edges of a 6.35 mm thick carbon steel plate, using a commercial (a,b) and the designed (c,a) wedges, respectively.

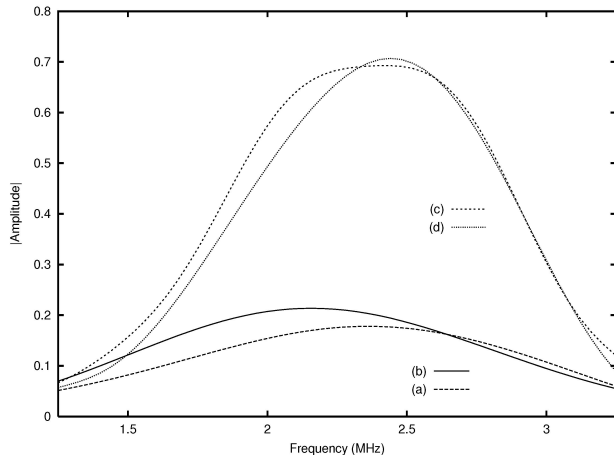


FIGURE 11. Power spectra of signals reflected by the bottom and top edges of a 6.35 mm thick carbon steel plate, using a commercial (a,b) and the designed (c,a) wedges, respectively.

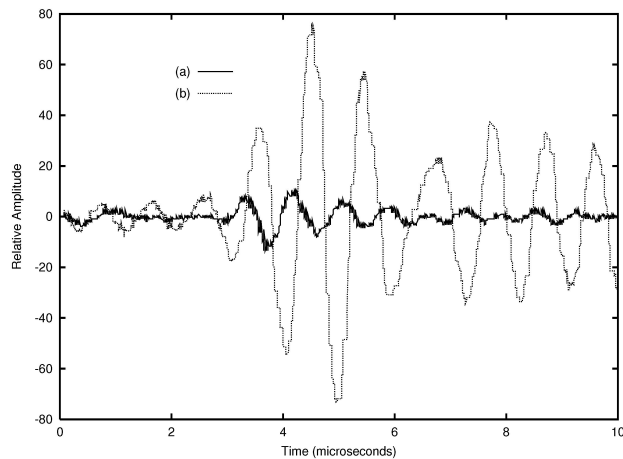


FIGURE 12. Signals reflected by a defect in a region of the weld, obtained at the same point by a commercial (a) and the designed (b) wedge.

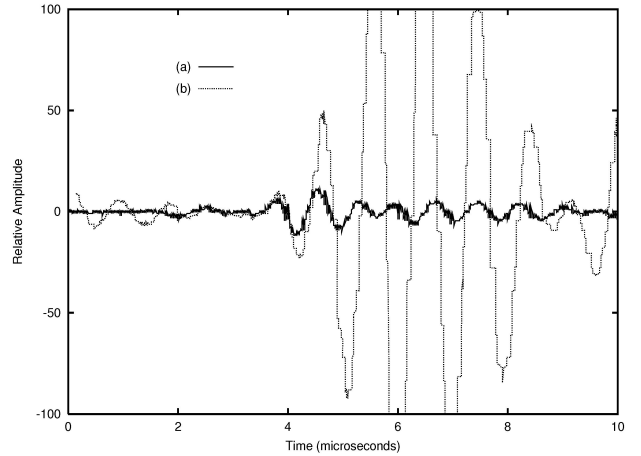


FIGURE 13. Signals reflected by a defect in another region of the weld, obtained at the same point by a commercial (a) and the designed (b) wedge.

gate start, since the difference in the speed of sound in each wedge must be accounted for.

#### 4. Conclusions

Based upon the preceding results, it may be concluded that

- The transmission amplitudes through couplants + film and couplants + membrane are larger than those through acrylic with the same ultrasonic path length; in particular, the combination water-film provides the largest amplitude,
- the wedge implemented shows an improved signal-to-noise ratio over that provided by a commercial wedge,
- some of the difficulties present in early designs are overcome with the use of the film, which, being less flexible than the membrane or the neoprene, will deform less under slight variations of the couplant pressure, so that the wedge will be more easily moved and the control of the incidence angle will not be lost, and
- the thickness of the film, being of the order  $\lambda/4$ , makes it acoustically transparent and the sensitivity is increased; however, this will set an upper limit for the frequency as well as its application to relatively smooth surfaces.

Although the results seem promising, further work, involving other frequencies as well as other angles of propagation, is required. In addition, the question on the temperature dependence of the speed of sound and the absorption in the couplant must be addressed.

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- iii* Panametrics, Ultrasonic transducer V549.
- iv* Sonotech Inc., Sonotrace Ultrasonic Couplant.
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