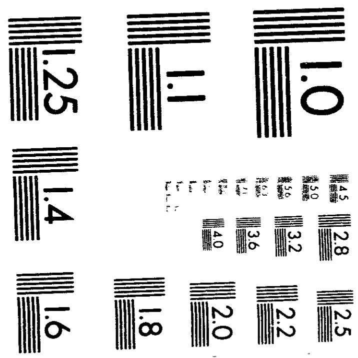

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834,747 CRACK DETECTION USING RESONANT ULTRASOUND SPECTROSCOPY

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CRACK DETECTION USING RESONANT ULTRASOUND SPECTROSCOPY

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BACKGROUND OF THE INVENTION

This invention relates to ultrasonic inspection and, more particularly, to ultrasonic resonance spectroscopy for detecting crack-like defects. This invention is the result of a contract with the Department of Energy (Contract No. W-7405-ENG-36).

Sound waves, i.e., ultrasonics, are used to perform a variety of nondestructive measurements for quality control in manufacturing processes and in detecting flaws and component characteristic changes arising from use of a component. One well known process uses echoes to locate crack-like defects at or below material surfaces, as well as internal cavities and flaws. Such processes require sensitive equipment for echo detection and experienced operators to interpret the echo results.

Yet another ultrasonic inspection technique uses ultrasonic resonance characteristics to provide information on features of a specimen. For example, U.S. Patent 4,428, 235, issued January 31, 1984, teaches a method for flaw characterization by comparing an ultrasonic resonance spectrum determined experimentally with a pattern obtained from a specimen being investigated. Four characteristic parameters are analyzed, namely (1) maximum spectrum strength, (2) center frequency, (3) mean value of frequency spacing between maxima in a frequency spectrum, and (4) standard deviation of the frequency spacing. These characteristics are used to determine changes in attributes of the specimen being examined. However, this technique requires that baseline or other reference information be known.

U.S. Patent 4,829,823, issued May 16, 1989, describes a defect detection system using ultrasonic resonances. A mathematical model is established using known resonance frequencies of one or more exemplary work pieces having acceptable known characteristics, e.g., the coefficients of elasticity, weight, localized defects, and the like. The resonance frequencies for subsequent work pieces are then measured around frequency locations corresponding to the resonance frequencies of the exemplary pieces. Using the mathematical model, the selected characteristics of the subsequent work piece can be calculated from shifts in the resonance frequencies and used as a measure of acceptance or rejection of the piece. Again, exemplary measurements are required in order to implement the ultrasonic inspection scheme.

The need for exemplary data is overcome by the present invention and crack detection is accomplished by ultrasonic resonance inspection of a completed work piece without the need for a known standard or "good" resonance pattern. Accordingly, it is an object of the present invention to provide ultrasonic flaw detection from resonance characteristics of a single object.

It is another object of the present invention to enable the detection of incipient flaws in a work piece without the need for comparative resonance spectrum data.

Additional objects, advantages and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

SUMMARY OF THE INVENTION

To achieve the foregoing and other objects, and in accordance with the purposes of the present invention, as embodied and broadly described herein, this invention may comprise a method for detecting crack-like flaws in a component using resonance ultrasound spectroscopy. A first ultrasonic resonance spectrum of a component is generated using a plurality of exciting frequencies with the component in a dry condition. The component is then wetted with a selected liquid effective to penetrate crack-like flaws and a second ultrasonic resonance spectrum of the component is generated from the plurality of exciting frequencies. Second harmonic frequency components in the first and second ultrasonic resonance spectra related to each one of the plurality of exciting frequencies are then determined and compared to ascertain the presence of crack-like flaws in the component.

In another characterization of the present invention, apparatus is provided for detecting crack-like flaws in an object using an ultrasonic resonance spectrum. Oscillator means generates from a plurality of exciting frequencies an ultrasonic resonance spectrum of an object. Heterodyne means then generates a second harmonic spectrum from the resonance spectrum where each second harmonic component is related to each one of the plurality of exciting frequencies. Recording means then records successive ones of the second harmonic spectrum to enable crack-like flaws in the object to be detected.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate an embodiment of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

FIGURE 1 is a block diagram schematic of a system for determining the second harmonic components in the frequency response of an object to an exciting frequency sweeping over a range of frequencies.

FIGURES 2A and 2B graphically depict the second harmonic components in dry and wet ultrasonic response spectra of an aluminum plate with a crack-like flaw.

FIGURES 3A and 3B graphically depict the second harmonic components in dry and wet ultrasonic response spectra of a commercial airplane part with a crack-like flaw.

DETAILED DESCRIPTION OF THE DRAWINGS

In accordance with the present invention, the presence of crack-like flaws in the surface of an object, e.g., stress and corrosion cracks, is determined by comparing the second harmonic components in the resonance response spectra from the component under at least two conditions that differently affect the second harmonic components of the response spectrum. This method can be used at any time in the life of an object and can be used with objects that have no prior resonant ultrasound spectrum.

Consider a solid object with a crack in the surface. The crack is essentially closed shut under conditions of no stress. When high-frequency ultrasound is applied to the object, pressure forces from the sound cause the crack to open and close slightly against air pressure. The resonance frequencies in this "dry" condition may be shifted from those obtained in an uncracked part, but no conclusions can be draw about crack-like defects unless a reference spectrum is available.

If the object is now wetted with a liquid effective to penetrate crack-like flaws, such as a volatile solvent or a wax, the cracks fill with the liquid and stay filled. The "wet" object then will exhibit a significant difference in both the first and second harmonic components of the resonance response spectrum. One change is that the ultrasonic attenuation of the first harmonic may become significantly larger with liquid-filled cracks vs. air-filled cracks. Thus, the object with crack-like defects will show slightly broadened resonances after the liquid is introduced.

Another property of the cracks is that during application of ultrasound, for each half-cycle of sound that produces tensile stress, the crack opens. For each half-cycle of sound producing compressive stress the crack slams shut, or tries to. Thus, a part with cracks exhibits a different response for each half cycle. If the cracks are filled with air, a non-symmetrical response is obtained since the response amplitude is limited in the closed direction. Second harmonic response components in the resonance response spectrum are then generated. If a liquid now fills the cracks, the liquid is essentially incompressible and stops the cracks from slamming shut, giving rise to a more symmetrical response, which reduces the second harmonic content of the resonance response spectrum. The second harmonic spectrum under wet and dry conditions can then be compared to detect small crack-like flaws in previously untested parts using resonant ultrasound techniques.

Referring first to Figure 1, there is shown in block diagram form a schematic for an apparatus for producing a record of the second harmonic frequency components of an ultrasonic response as a function of the exciting frequency. Sample 10 is ultrasonically excited by transducer 12 and the response is detected by transducer 14. Transducers 12 and 14 may be any one of a number of types of commercially available ultrasonic transducers. The excited response 42 is output through preamplifier 36 and amplifier 38 to mixer 28 and to one channel of oscilloscope 46. The recording device may be an oscilloscope, but may be a printer or a computer memory system that subsequently allows a display or other record to be created.

Transducer 12 is excited by excitation frequency oscillator, or synthesizer, 16 that outputs a frequency, f, controlled by computer 22. Synthesizer 16 may output a plurality of individual frequencies to excite sample 10 over a set of predetermined frequencies or may sweep the output frequency over a predetermined frequency range. The digital output commands and other data flow is along buses 20, 24, and 27, which are conventional commercial buses that comply with the standards set by industry standard IEEE 488.

Mixing frequency oscillator, or synthesizer, 26 is also controlled by computer 22 along bus 27. The output of mixing frequency synthesizer 26 is at least a frequency 2f for input to mixer 28. In a preferred embodiment, the output frequency from frequency synthesizer 26 is offset by a selected intermediate frequency (IF), e.g., 1 kHz, from the pure second harmonic frequency, 2f. This IF offset technique is conventional and provides for noise components only in a small bandwidth to greatly improve the signal-to-noise ratio and concomitant device sensitivity.

Mixer 28 is a superheterodyne type circuit with two inputs to be heterodyned: the output response of sample 10 from amplifier 38 and the output of frequency synthesizer 26 at, e.g., 2f+1kHz. It can be shown that the output from heterodyning the two signals includes a component at the IF frequency, i.e., 1kHz, having an amplitude related to the amplitude of the second harmonic frequency components in output signal 42 forming the second harmonic spectrum. The output signal from mixer 28 is input to a band pass filter 32 at the IF frequency, e.g., 1 kHz, to attenuate other frequency components. The filtered signal is input to absolute value circuit 34, whose output is a dc voltage functionally related to the amplitude of the second harmonic frequency component in the output frequencies from sample 10. The dc component from absolute value circuit 34 is input to digital voltmeter (DVM) 18, where the value may be digitized and input to computer 22 along bus 24.

The dc voltage from circuit 34 is also input to a second channel of oscilloscope 46 as a visual diagnostic. Computer 22 records input frequencies and response data to provide a record of second harmonic amplitude vs. response frequency. A comparison of the records between excitation of the dry component and the component after being wetted or otherwise coated with a liquid will clearly indicate the change in the second harmonic content of the two conditions to ascertain the existence of crack-like defects in the object.

Figures 2A and 2B graphically depict the application of resonance ultrasound spectroscopy according to the present invention to crack detection in an electron beam welded aluminum plate. The plate was welded to simulate a microscopic crack, with the crack being continuous across almost half the plate. Figure 2A depicts the second harmonic spectrum over a swept frequency range of 30-47 kHz. Several second harmonic peaks are readily observed. The plate was saturated with ethanol, all surface liquid was removed, and a second harmonic frequency spectrum was again generated over the same frequency range. Figure 2B graphically shows the resulting second harmonic spectrum with the substantial attenuation of second harmonic peaks as shown in Figure 2A. The attenuation of the second harmonic peaks is a sensitive indication of the presence of a crack.

Figures 3A and 3B graphically depict the ultrasound inspection results of an airplane wheel. Figure 3A is the second harmonic spectrum of the "dry" wheel and Figure 3B is the second harmonic spectrum of the "wet" wheel. The attenuation of second harmonic frequencies is readily apparent. The wheel was known to have at least one crack one-half inch long.

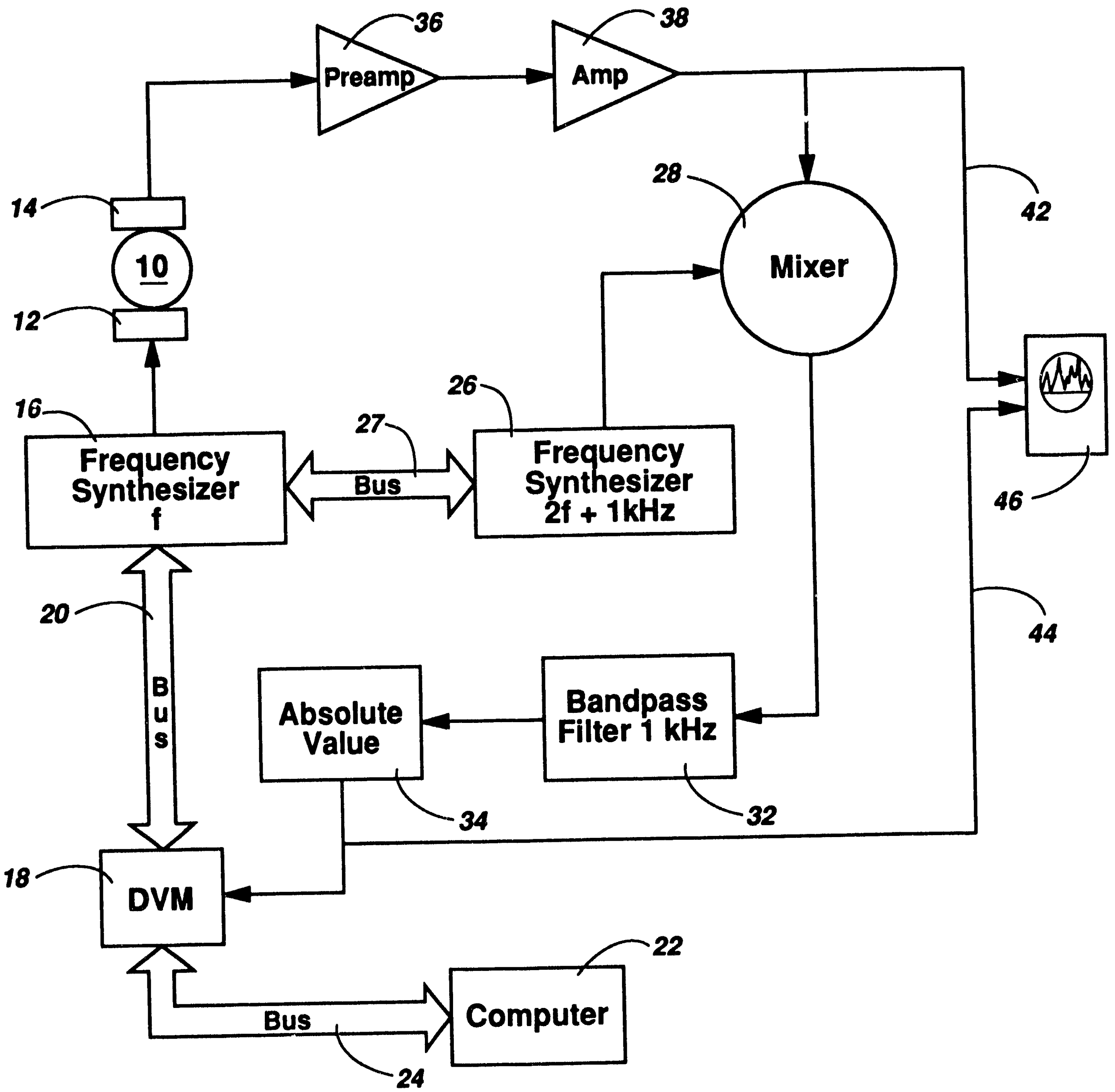
It is apparent from Figures 2A, 2B, 3A, and 3B that the second harmonic spectrum obtained according to the present invention allows the ready detection of crack-like flaws in components without the need for any reference spectrum other than the spectrum obtained with the part in a "dry" condition. The attenuation of second harmonic components in a flawed component after coating with a suitable liquid can be visually observed, e.g., on an oscilloscope or a plotted graph, or can be automatically detected, e.g., using a suitable software routine in a computer to locate and compare peaks in the second harmonic spectrum.

The method of the present invention can be applied with any technique that alters the asymmetry of the crack response to acoustic energy. For example, the second harmonic of the acoustic resonance response could be obtained under different temperature conditions. The expanded size of the crack at higher temperatures would provide a more symmetric response, i.e., attenuated second harmonic components. Likewise, the components might be placed under a strain to open the crack and prevent crack closing to attenuate at least some frequencies in the second harmonic response when a crack is present.

The foregoing description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

ABSTRACT

Method and apparatus are provided for detecting crack-like flaws in components. A plurality of exciting frequencies are generated and applied to a component in a dry condition to obtain a first ultrasonic spectrum of the component. The component is then wet with a selected liquid to penetrate any crack-like flaws in the component. The plurality of exciting frequencies are again applied to the component and a second ultrasonic spectrum of the component is obtained. The wet and dry ultrasonic spectra are then analyzed to determine the second harmonic components in each of the ultrasonic resonance spectra and the second harmonic components are compared to ascertain the presence of crack-like flaws in the component.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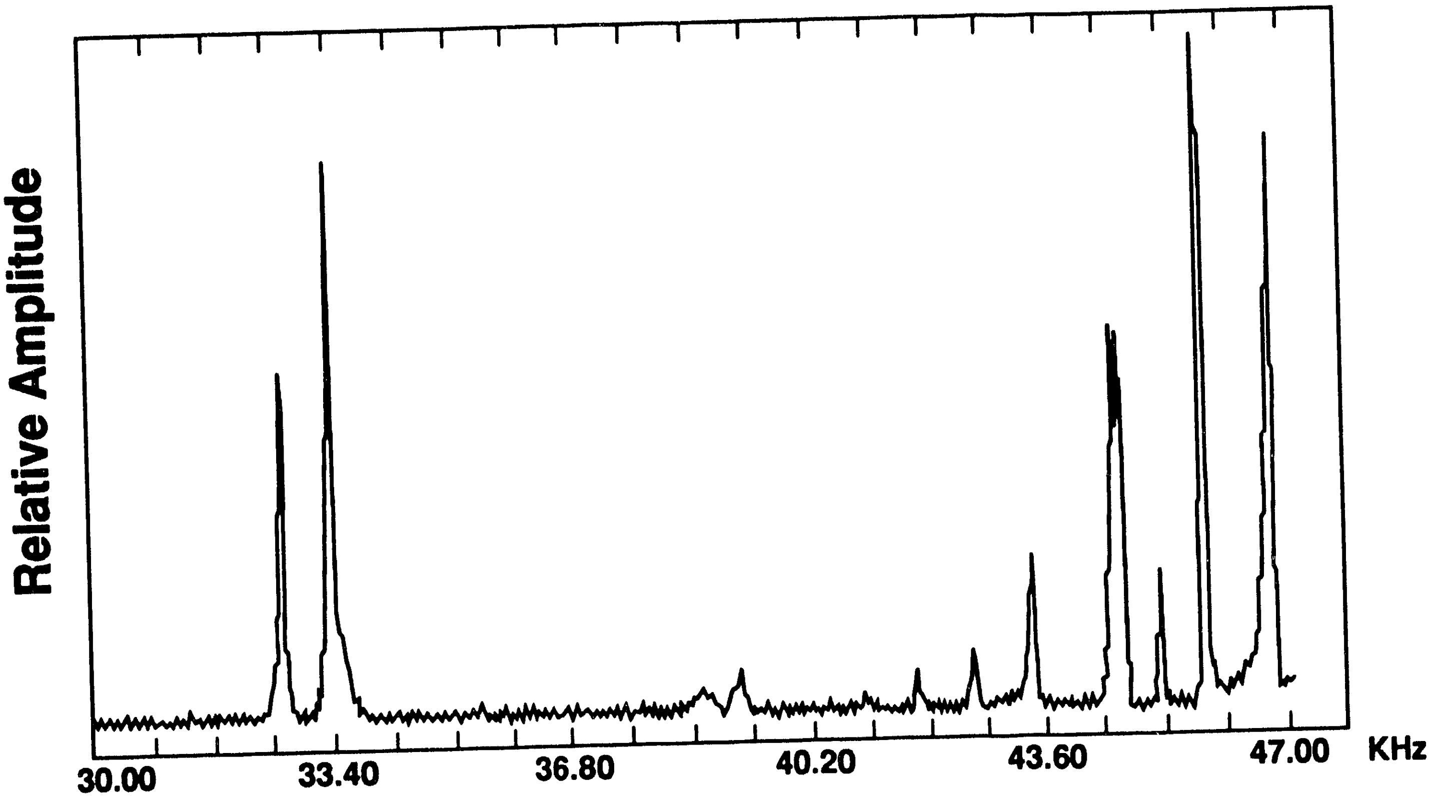
Preamp
38
Amp
28
Mixer
42
14
10
12
26
16
27
Frequency Synthesizer f
Bus
Frequency Synthesizer 2f + 1kHz
46
20
B u s
Absolute Value
Bandpass Filter 1 kHz
44
34
32
18
DVM
22
Bus
Computer
24

Fig. 1

Fig. 2A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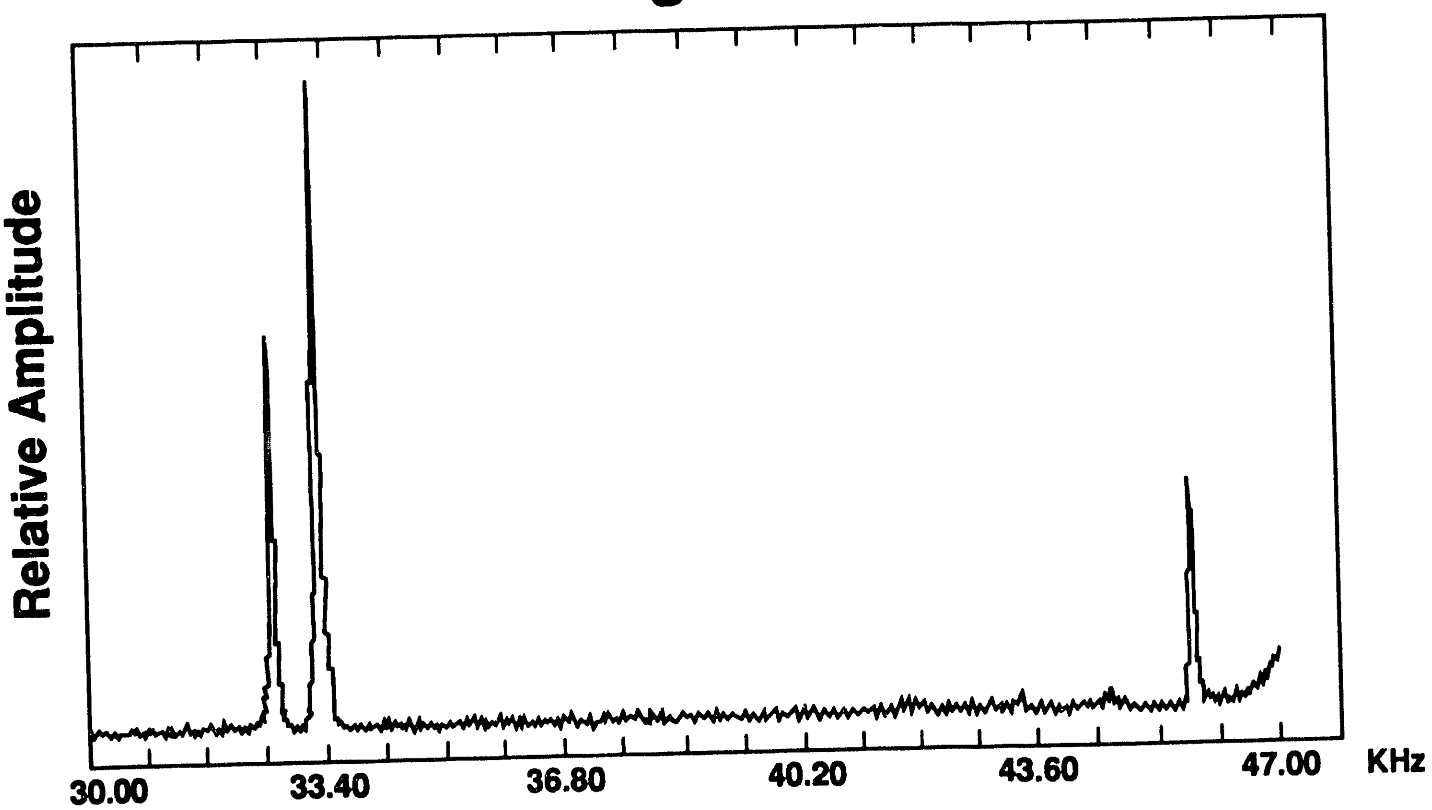
36.80
40.20
43.60
47.00
KHz

Fig. 2B


Relative Amplitude
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33.40
36.80
40.20
43.60
47.00
KHz

IS-12/91-6389

Fig. 3A

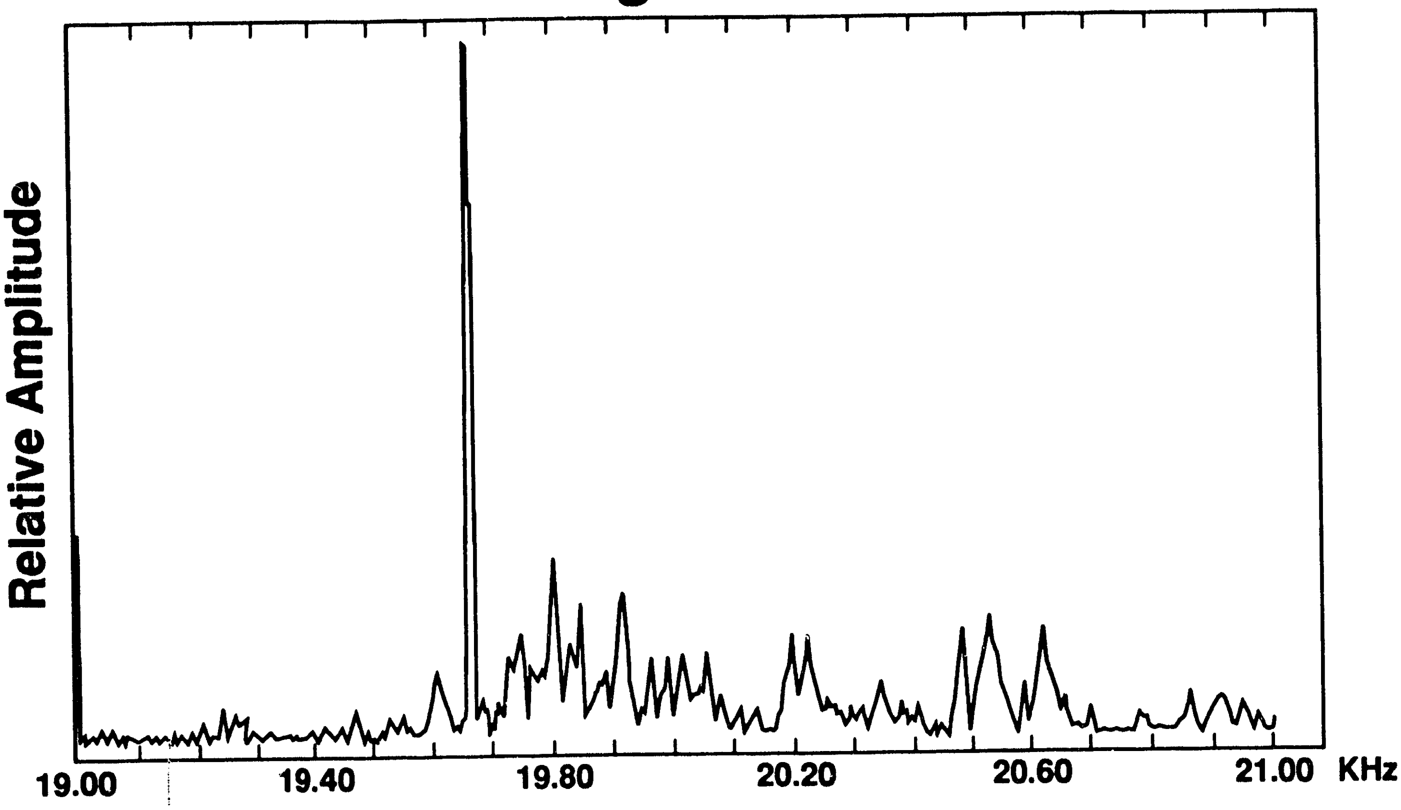
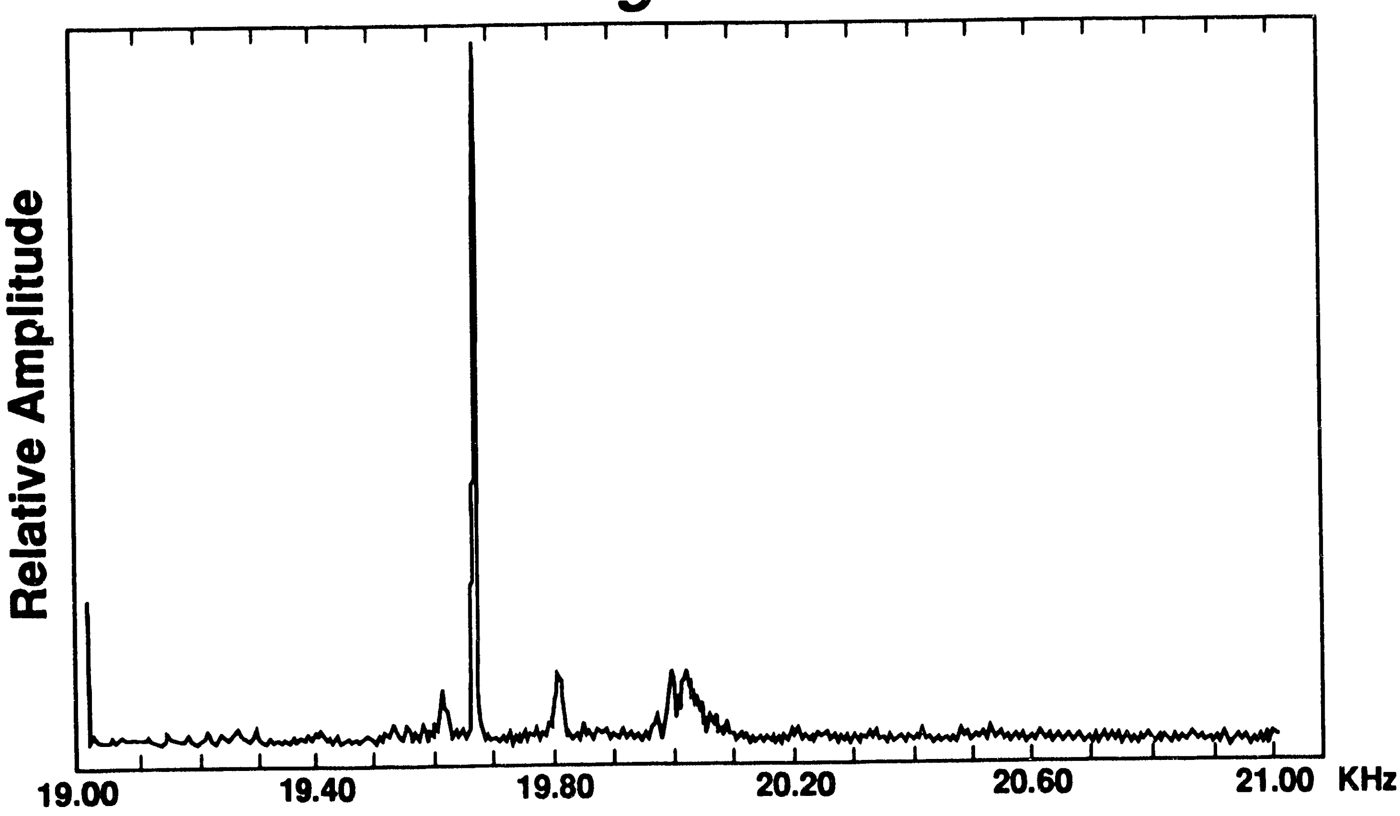


Fig. 3B



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