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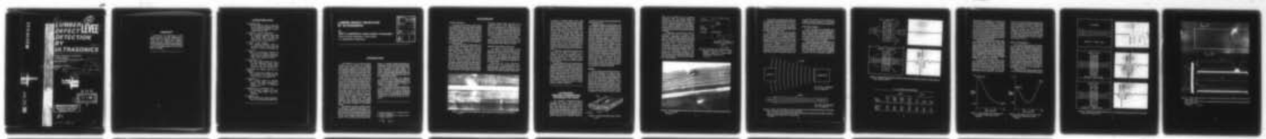

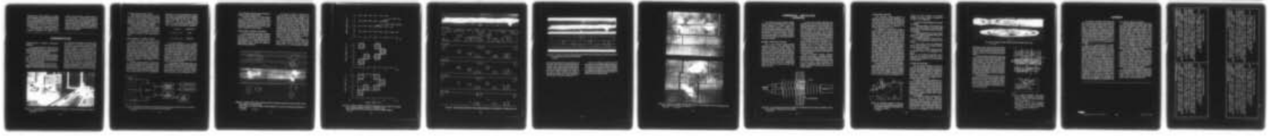

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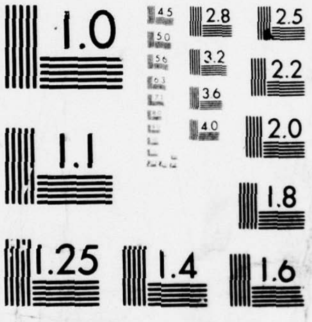

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LUMBER DEFECT DETECTION BY ULTRASONICS.

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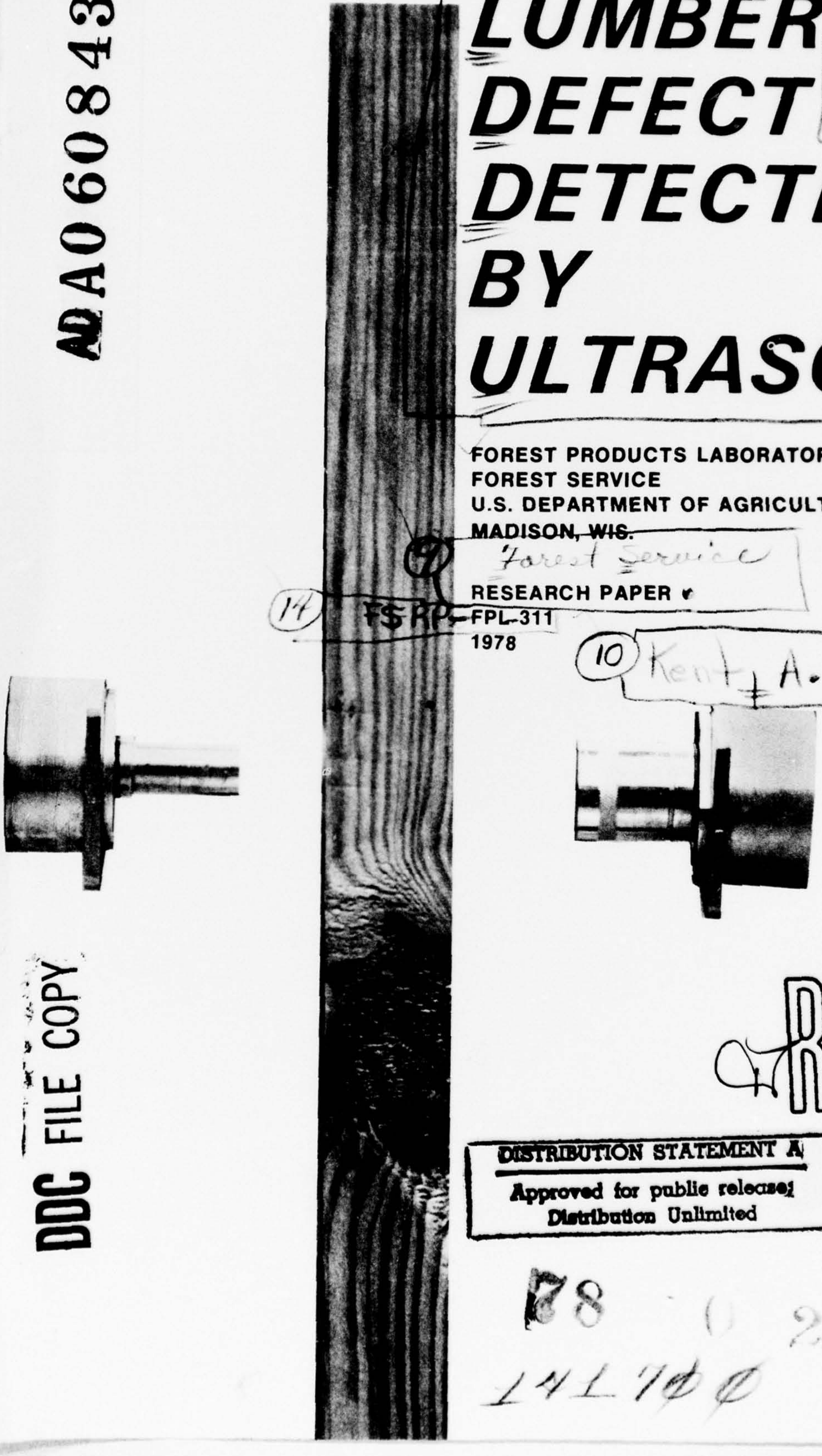

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ABSTRACT

Ultrasonics, the technology of high-frequency sound, has been developed as a viable means for locating most defects in lumber for use in digital form in decision-making computers. Ultrasonics has the potential for locating surface and internal defects in lumber of all species, green or dry, and rough sawn or surfaced.

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LUMBER DEFECT DETECTION BY ULTRASONICS

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INTRODUCTION

More efficient use of our Nation's timber resource can be realized by increasing product yield through improved processing techniques and equipment. At present, nearly all processing decisions in the wood industry are made and executed by people rather than by computers. A poor decision usually results in less product from the raw material and means that more timber must be removed from our forests to meet the wood product demand. With the objective of relieving the demand on our forests, the Forest Service has initiated research programs to increase utilization efficiencies through improved processing and decision-making techniques. The technology exists to make the difficult processing decisions correctly with a computer programed with carefully designed decision-making algorithms (2,3,5).[2] The computer can, however, only make these decisions when supplied with a complete description of the raw material quality in digital form accurately obtained at production speeds.

Any attempts to devise a lumber scanner for obtaining an adequate description of individual board quality for the computer must take into account the wide range of conditions germane to the wood material referred to as lumber. Such conditions as moisture content (green or dry), surface quality (rough sawn, planed, or sanded), species (hardwoods or softwoods), and point-of-manufacture (edger, cut-off saw, rip saw, etc.) have an effect on accurate recognition of lumber quality. Any lumber scanning technology developed, unless for a very specialized application, will have to be applicable to these various conditions of the lumber being scanned.

Generally, the known flaw detection techniques fall into two categories: those sensitive only to changes in surface qualities of the material, and those sensitive to internal, or subsurface, qualities as well.

For some lumber scanning applications, surface recognition alone will provide adequate information for making processing decisions. For most applications, significant improvements in product yield can be made if a description of internal quality can be obtained.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Numbers in parentheses refer to literature cited at the end of this report.

BACKGROUND

Surface Scanning

One approach to sensing surface quality requires that the defects be visually identified and tagged with a light-reflective or magnetic mark. The locations of these marks are then sensed by photoelectric sensing devices. A variation on this idea is to index the location of lumber defect areas into a computer using a manually positioned pointer system. Both of these approaches rely heavily on human ability (or inability) to recognize and mark defects at production speeds.

A popular approach to surface scanning without human involvement is the use of optical scanners to locate defects. Optical systems, electronic imitations of the human eye, create images dependent upon the amount of light from the wood surface that reflects back to a lens. Of particular importance in considering optical scanning techniques for lumber is that "What it sees is what you get." Optical systems can record superfluous data that have to be identified and removed from the meaningful data. For example, dark heartwood areas, dirt, and sticker and scuff marks usually have enough contrast in light reflection to be picked up as defects. Conversely, defects which have little or no contrast in color or light reflection, due to species characteristics or a rough-sawn surface, can be missed with this scanning system (fig. 1). The optical scanning techniques are proficient at locating defects that have a distinct dark appearance in contrast to adjacent clear wood, such as knots in pine lumber.

One reported optical technique is able to detect cracks and checks in lumber. The technique uses a laser as a light source and is being developed and tested by industry.

Internal (Subsurface) Scanning

The location of internal defects in wood products requires a sensing technique that penetrates the surface of wood. Microwaves, X-ray, and ultrasonics are "through-transmission" flaw-detection techniques that are used in various applications to locate internal flaws and are thought to be applicable for scanning lumber.

Microwave and X-ray.—Generally, microwave and X-ray flaw-detection techniques function by measuring the amount of electromagnetic radiation transferred through a material. The amount actually transferred is

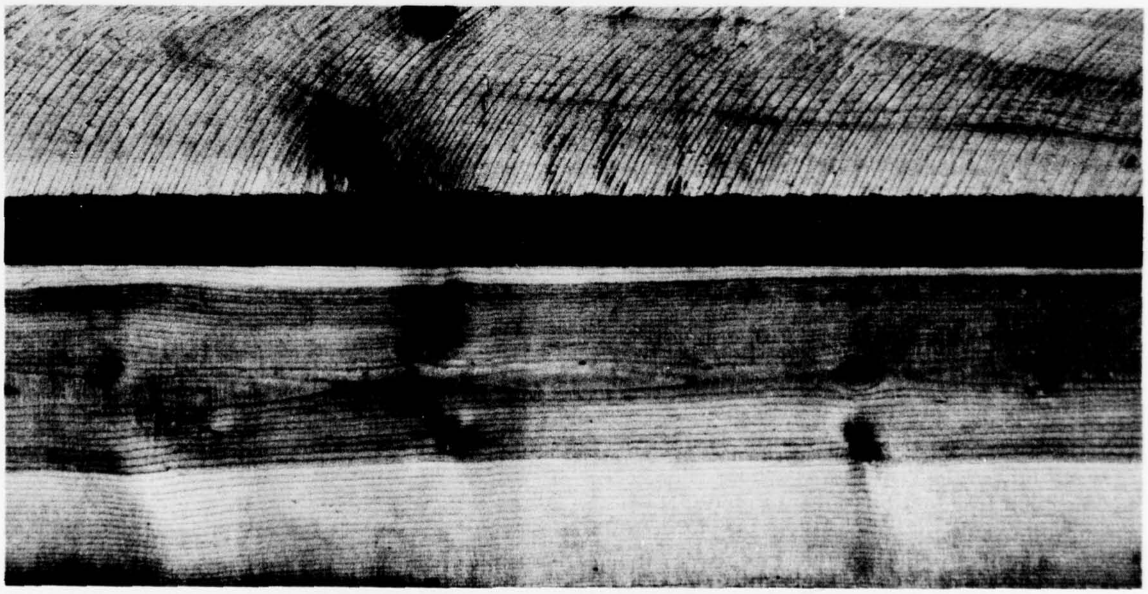

Figure 1.—Rough sawn hard maple board (top) and planed ponderosa pine board (bottom).
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a function of material density; thus a flaw associated with an excessive change in density can be detected. In applying these density-sensitive flaw-detection techniques to wood, some difficult problems are encountered. Flitches, fresh from the log, have a high, nonuniformly distributed moisture content. This moisture has a relatively high density that overshadows any smaller density variations that may be attributable to wood defects, thus limiting the techniques to scanning lumber that has been dried to a uniform moisture content. Furthermore, normal density differences between species would limit application to scanning one species per machine setting, or at best, species groups that have similar densities.

Ultrasonics.—Ultrasonics is a science that deals with the effects of vibrations of ultrasound and with the apparatus used to produce, measure, and record these waves (9). Ultrasound ("ultra" = beyond) is high-frequency sound beyond the audible range of human hearing.

Positive results from early experiments in measuring ultrasound velocity in wood showed significant differences in velocity in areas of localized steep grain. Wood is anisotropic with respect to sound, resulting in sound traveling faster along the grain than across the grain. Further research has led to the design and testing of an ultrasonic technique for sensing and locating defects in wood products (6,7,8). This research is based on the time it takes sound to travel through wood of varying moisture content and density.

ULTRASONIC THROUGH-TRANSMISSION TECHNIQUE FOR WOOD

The ultrasonic through-transmission technique for wood is aided by wood's anisotropy. Wood has three perpendicular axes: The longitudinal axis is parallel to the fiber (grain); the radial axis is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis is perpendicular to the grain but tangential to the growth rings (fig. 2). The velocity of sound in the wood is a property closely associated with this anisotropy (1,4).

Because the grain of clear wood is normally straight (parallel to the longitudinal axis of a piece of lumber) and defective wood is often associated with localized areas of distorted grain, the rate of sound travel across the grain of clear wood remains fairly constant for any given species, and the rate of sound travel through defective wood is significantly different. Continual designing, modifying, and testing of the ultrasonic technique has revealed that sufficient sound energy can be transmitted through wood to detect the grain changes associated with defects. A three-dimensional model of actual ultrasonic velocity measurements taken every ½-inch along and across a piece of softwood lumber shows (fig. 3) the correlation between grain direction and velocity of sound. Note the uniformity in the velocity data shown in relation to the clear, straight-grain areas of the board. Obtaining this "image" of the board from the sound velocity data provided the impetus to pursue an automated lumber scanning system that incorporates the ultrasonic technique.

Method

Sound velocities are calculated from transit time data obtained by a basic through-transmission technique transmitting sound through wood and measuring the elapsed time (fig. 4). An ultrasonic wave is created by shock exciting the transmitting transducer with a single pulse from the pulse generator. In this application, a 400-volt pulse of 1 μsec duration is used. When this pulse is initiated, a time interval counter for obtaining transit time starts running. The transmitted sound wave propagates through wood immersed in a water

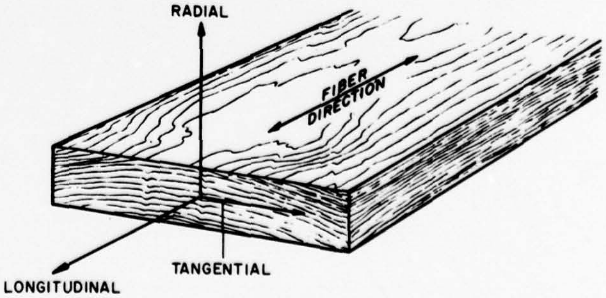

Figure 2.—Three perpendicular axes in wood.
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bath, and is picked up by a receiving transducer. When the receiver senses the sound wave, the time interval counter is stopped to get the transit time. The velocity of sound in wood can be obtained after measuring the distance between the transducers, measuring the thickness of the wood, and then subtracting the time to transmit sound through the water.

Transducers are devices that transform energy from one form to another. In this application, piezoelectric transducers were used to transform high-frequency electrical energy into high-frequency mechanical energy and back again. Frequencies usually associated with ultrasonic through-transmission techniques for sending sound through wood range from 150 kHz to 1000 kHz. At the lower frequencies (150-200 kHz), the size of the piezoelectric element in the transducer is 1.5 to 2 inches in diameter. With this size, and with the large beam angle of the sound created (fig. 5), flaws cannot be located with much precision.

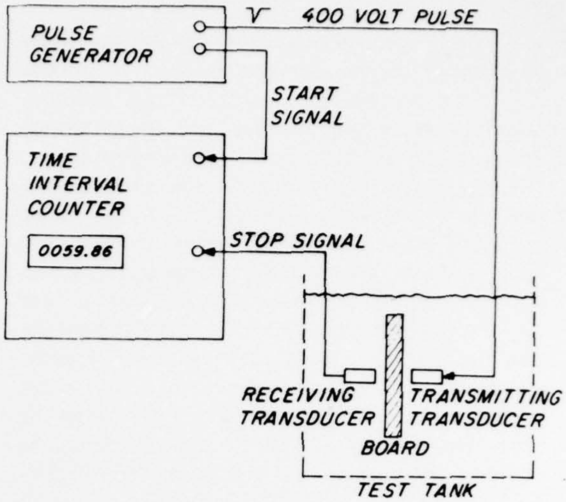

Figure 4.—Schematic of through-transmission ultrasonic technique used to make ultrasonic transit time measurements through wood. See figure 12.
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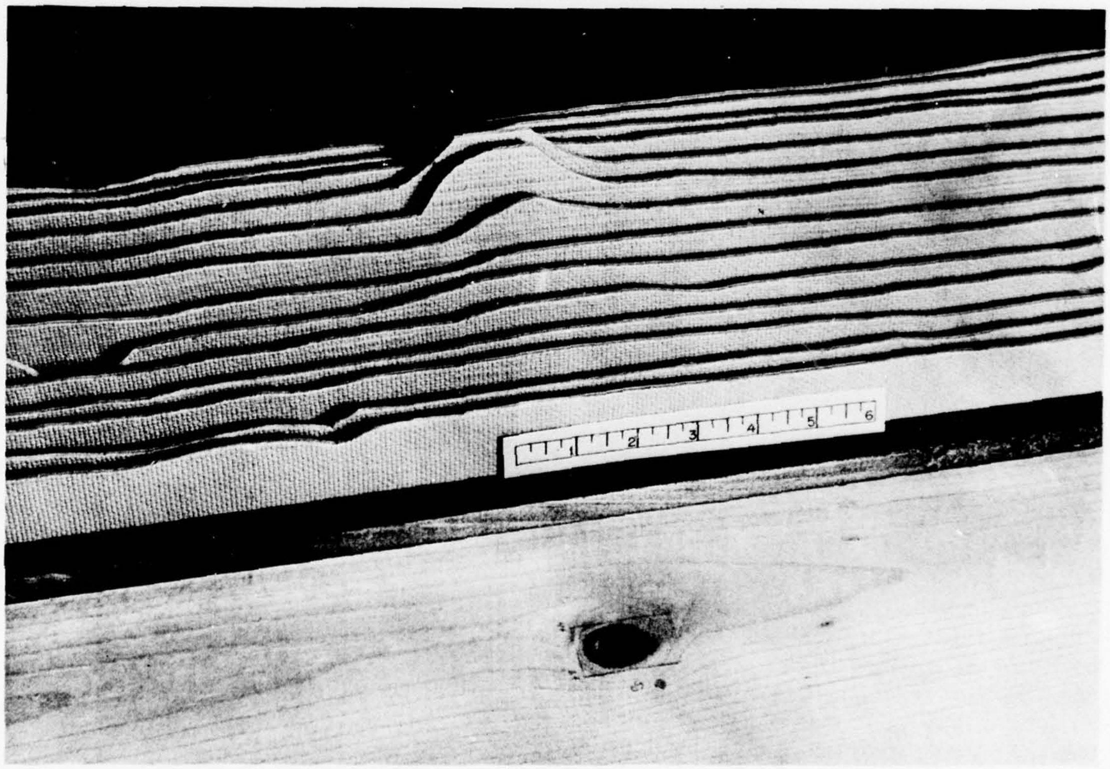

Figure 3.—Three-dimensional model of sound velocities and the respective board area showing clear wood and a defect.
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At the higher frequencies (500-1000 kHz), it is possible to get piezoelectric elements in the transducer as small as 0.5 to 1 inch in diameter. This smaller diameter and higher frequency means a smaller beam angle (fig. 5) and thus permits greater precision and better definition of defects in wood.

The water between the immersed board and the transducers is used as the ultrasonic couplant necessary to propagate sufficient sound energy into and out of the wood. This is based on the similarity of the specific acoustic impedances of water and wood, which results in very little reflection of sound at the wood/water boundaries. If the impedance values of two media are quite different, such as for air and wood, considerable sound energy is reflected at the wood/air interface (fig. 6). The water, as a couplant, makes good contact with a rough sawn surface of wood, as well as a sanded or planed surface—a phenomenon that broadens the potential field of application.

Preliminary Results

Sound velocities were calculated from transit time data taken on several species of clear, straight-grained wood samples (table 1). These samples were carefully prepared to provide the three perpendicular axes, and did not contain any known defects such as knots, crossgrain, decay, checks, or splits.

In these tests, sound velocities were 2 to 3 times faster longitudinally along the grain than radially or tangentially across the grain. Less difference was found between the tangential and radial directions, although radial velocities were consistently faster than tangential velocities. The sound velocities recorded in

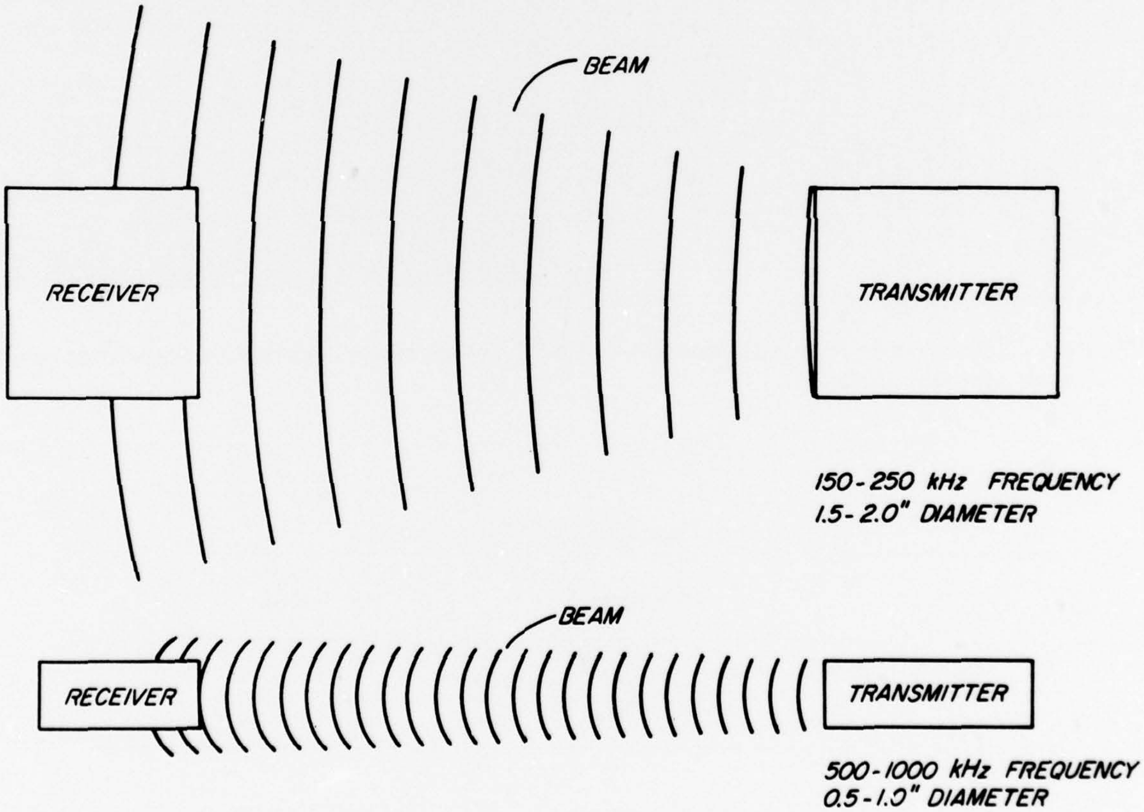

Figure 5.—Upper: The wide beam of sound is a result of the low transmitted frequency (150 to 250 kHz) and means poor resolution of a defect area.
Lower: The narrow beam of sound is a result of the high transmitted frequency (500 to 1000 kHz) and means good resolution of a defect area.
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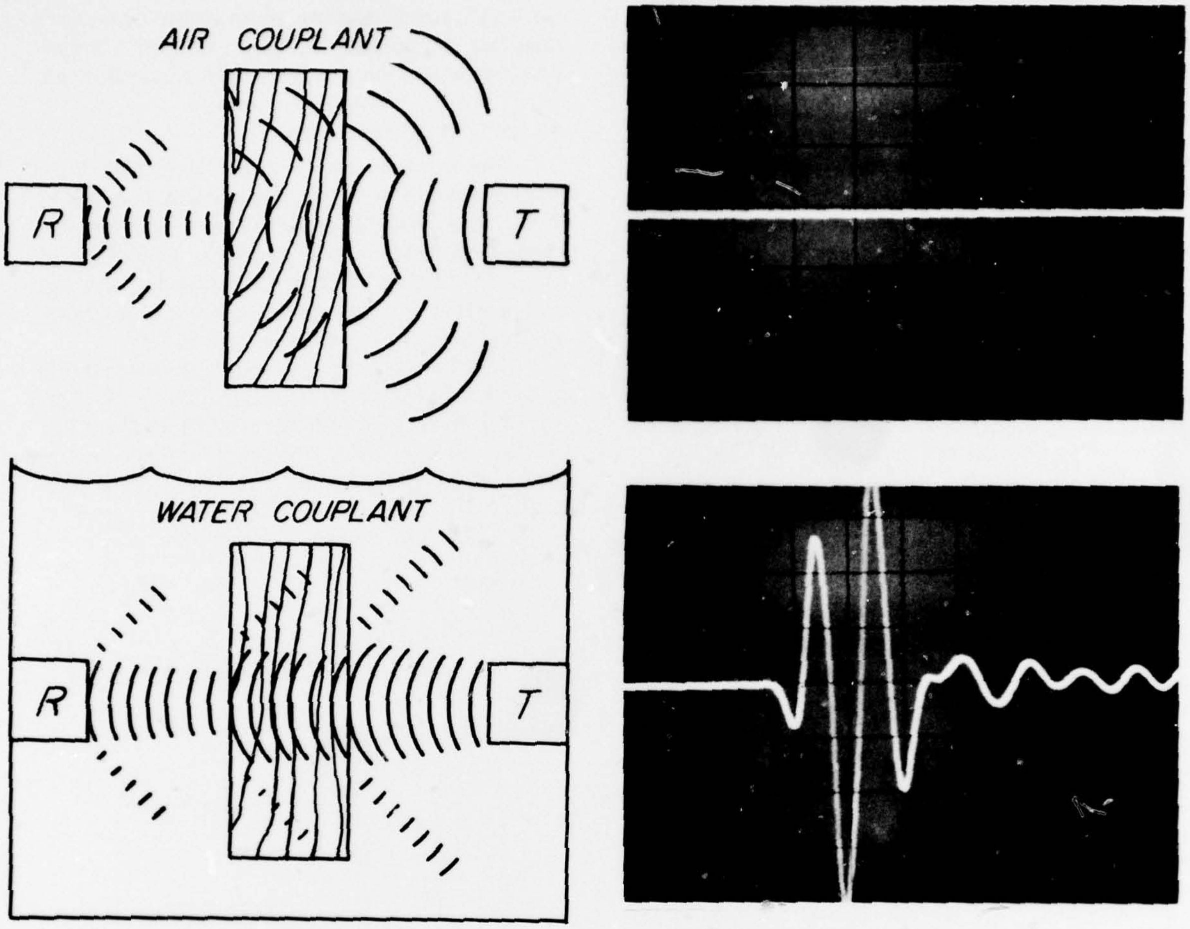

Figure 6.—Schematic and received waveforms showing sound reflection using air couplant (top) and water couplant (bottom).

Table 1.—Sound velocities for several wood species

	Softwood				Hardwood		
Sound propagation	Douglas-fir (dry)	Western red cedar (dry)	Eastern white pine (dry)	Ponderosa pine (green)	Beech (dry)	Hickory (green)	Red oak (green)
	m/sec						
Longitudinal	4350	5850	4350	4390	6610	5270	4110
Radial	1980	2160	2470	1620	1980	2250	2040
Tangential	1770	1980	1550	1460	1770	1680	1790

rotation from a longitudinal to a radial direction continually decrease (fig. 7). The same is true in moving from a longitudinal to a tangential direction. However, the velocities obtained in moving from a radial to a tangential direction do not change consistently but slow considerably about halfway through the rotation (fig. 8). These results are attributed to the cell structure of the wood with respect to the alinement of the sound path between the transmitting and receiving transducers.

When transmitting sound through water alone, through water and ¾-inch clear wood, and through water, wood, and a knot, the relative differences in the received ultrasonic signal wave form and its arrival time can be seen (fig. 9). The faster sound velocity through the wood than through water alone verifies that sound propagates through the cell wall structure. Similarly, the knot and the associated steep grain causes an increase in sound velocity as compared to clear wood.

To illustrate the principle, transit times were recorded from a ponderosa pine board along three selected scan lines (fig. 10) with data taken along each scan. One scan along line C to D is clear, straight-grained wood, one along line A to B is through a knot with associated localized steep grain, and another, line A to C, is across the width of the board to show the relationship between tangential and radial propagation of sound. The board was sawn after scanning to expose the grain pattern along each scan. The pronounced changes in the transit times associated with the localized steep grain around the knot can be clearly seen, along with the uniform transit time data recorded from the clear, straight-grained wood (fig. 10).

Other Considerations

The use of rolling transducers to contact the wood has been suggested to eliminate the water couplant and still have adequate coupling of the sound to the wood. Experience and investigation indicate that the rolling transducer covering needs to be wear resistant, and that the internal ultrasonic elements must be small enough for wood defect identification. The rolling transducer also requires good contact between the transducer's flexible cover and the material being scanned. If the material is rough-sawn lumber, then poor contact is unavoidable, thus limiting the usefulness of the rolling transducer.

Focusing of the ultrasonic beam produced by the transducers is possible and has been

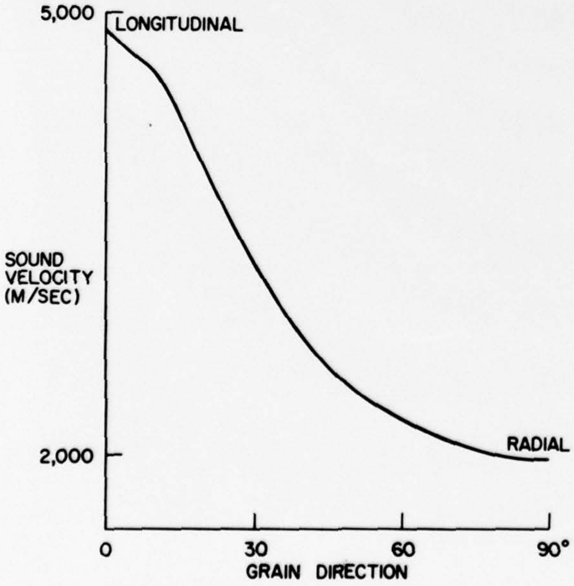

Figure 7.—The change in sound velocity from longitudinal to radial axis in wood.
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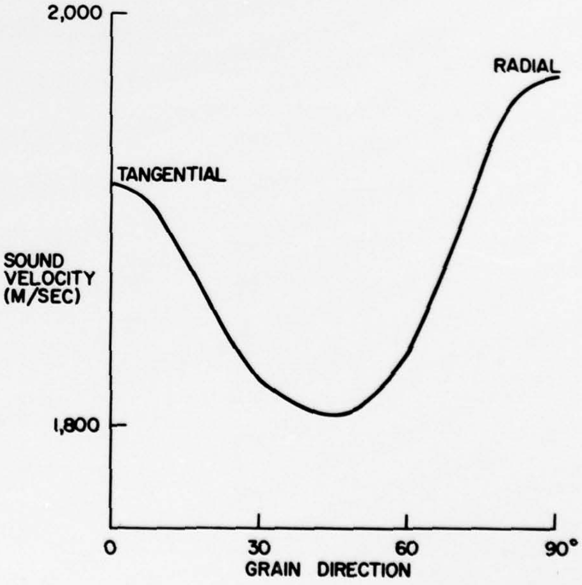

Figure 8.—The change in sound velocity from tangential to radial axis in wood.
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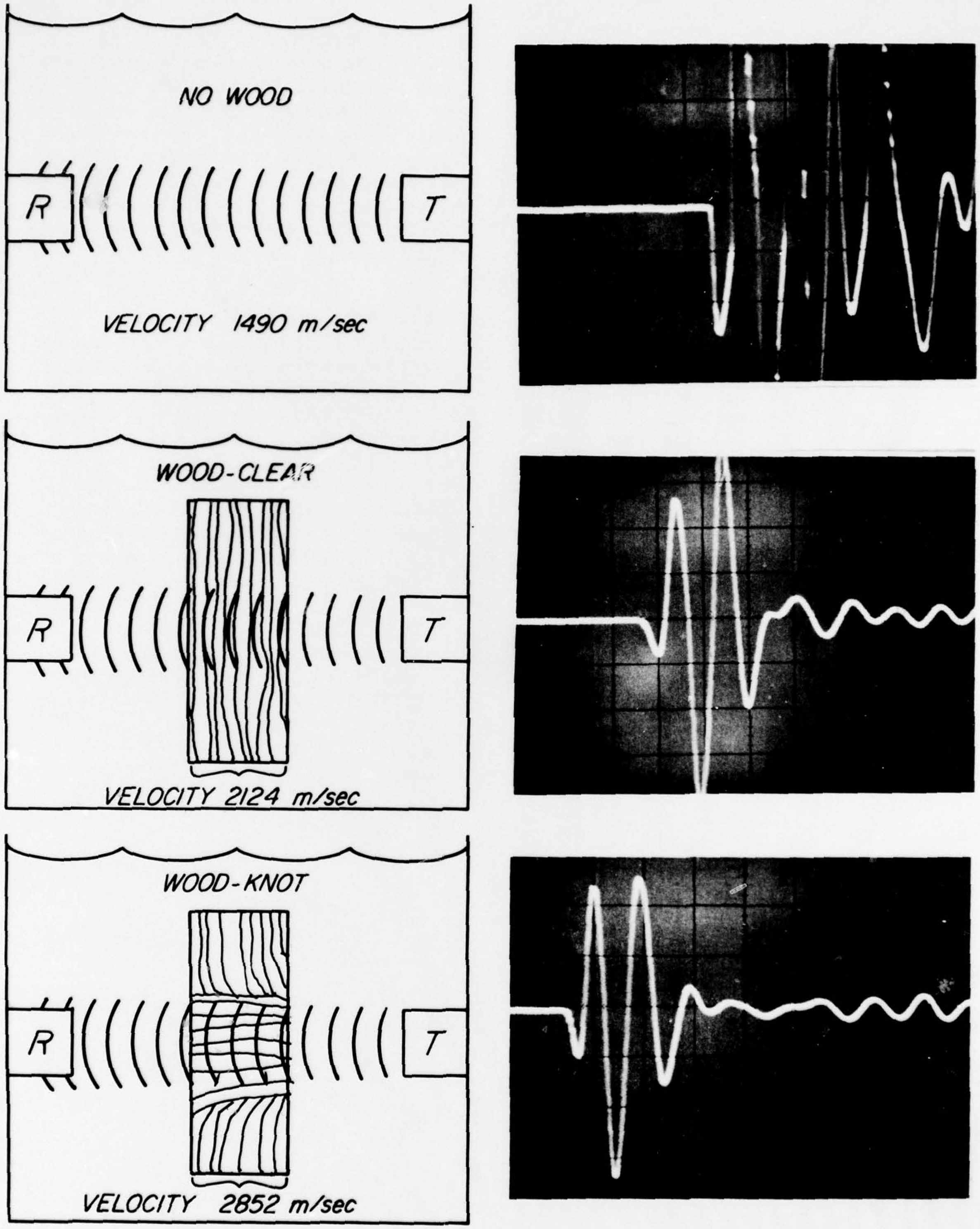

Figure 9.—Velocity and received waveforms of sound propagated through water alone, through clear wood, and through a knot.

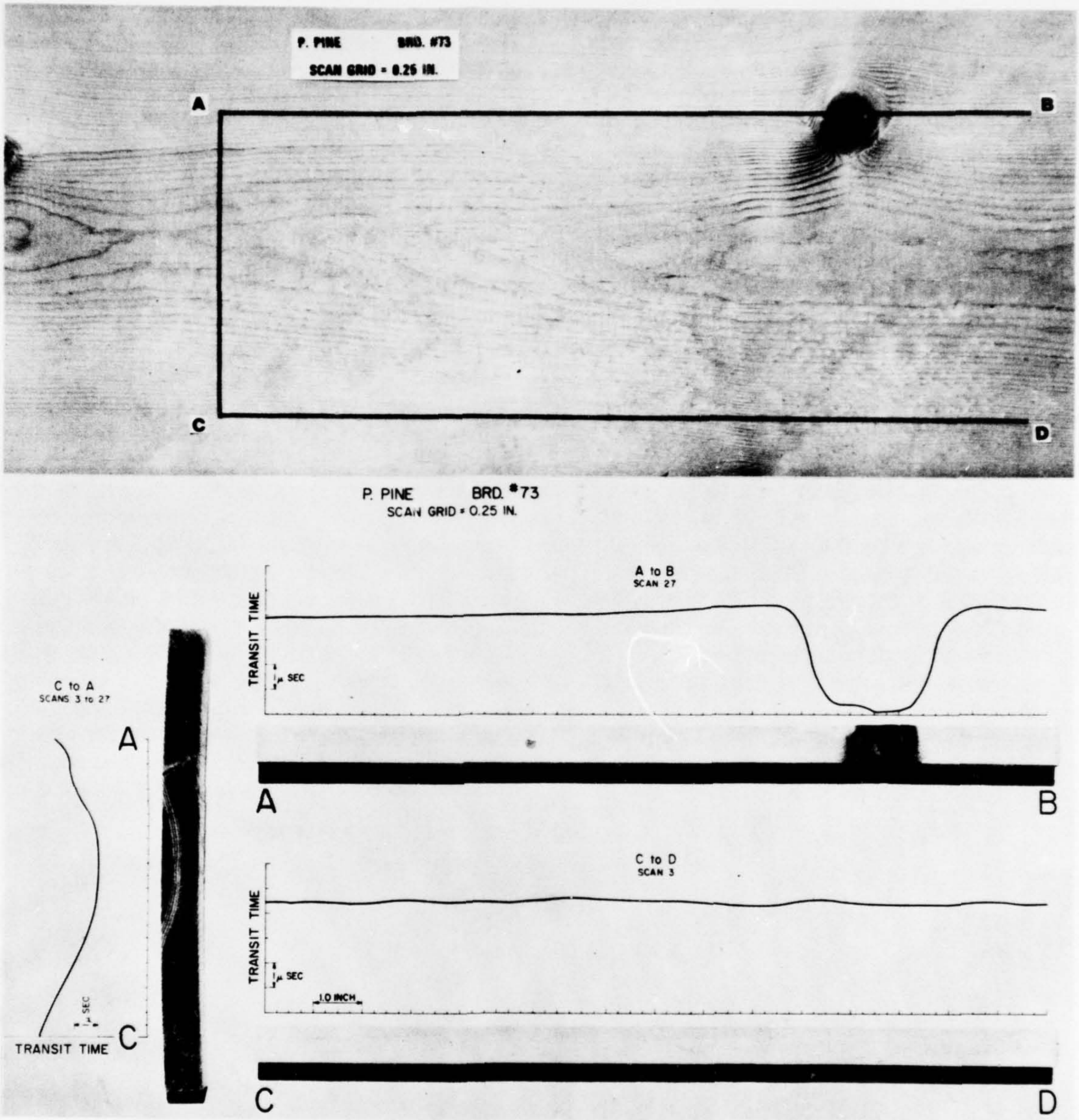

Figure 10.—Upper: Scanning paths on a ponderosa pine board through a defect (A to B) and through clear wood (C to D).

Lower: Edge view of wood and corresponding ultrasonic transit time data showing the relative changes that occur.

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considered as having potential for locating lumber defects, but has had limited investigation. It is understood that maintaining the correct distance between the transducer and the material (wood) is critical to the focal point of a focused beam of sound. Varying wood thicknesses make such a system unfeasible.

The piezoelectric crystal element in the ultrasonic transducers is usually barium titanite, lead metaniobate, or lead zirconate. In our experience, commercially available transducers made from lead metaniobate or lead zirconate have been adequate. When a specific application is developed, the potential exists for further refinement of the ultrasonic signal levels through improved design of the ultrasonic transducers.

EXPERIMENTATION

Experimental Lumber Scanning System

A computer-controlled lumber scanner, called a defectoscope (fig. 11), was built to test and demonstrate the principle of the ultrasonic lumber-defect detection technique.

This system was designed as a prototype to model the critical parameters associated with a commercial lumber scanning application, as well as to provide for positioning and control of the transducers.

Under direct computer control, X- and Y-stepping motors accurately move a pair of ultrasonic transducers along a board immersed in a water tank at speeds up to 50 lineal feet per minute. In this manner, transit time data are taken at regular intervals along and across a board, normally at ½-inch increments for testing purposes. The X-stepping motor controls the movement of the transducers along the length of a board with an accuracy of 1/200 inch. The Y-stepping motor controls the position of the transducers across the width of a board with an accuracy of 1/1600 inch. The carriage, driven by the X- and Y-stepping motors, firmly holds the transmitting and receiving transducers at a fixed distance apart. Various arrangements of multiple transducer assemblies can be mounted on this carriage

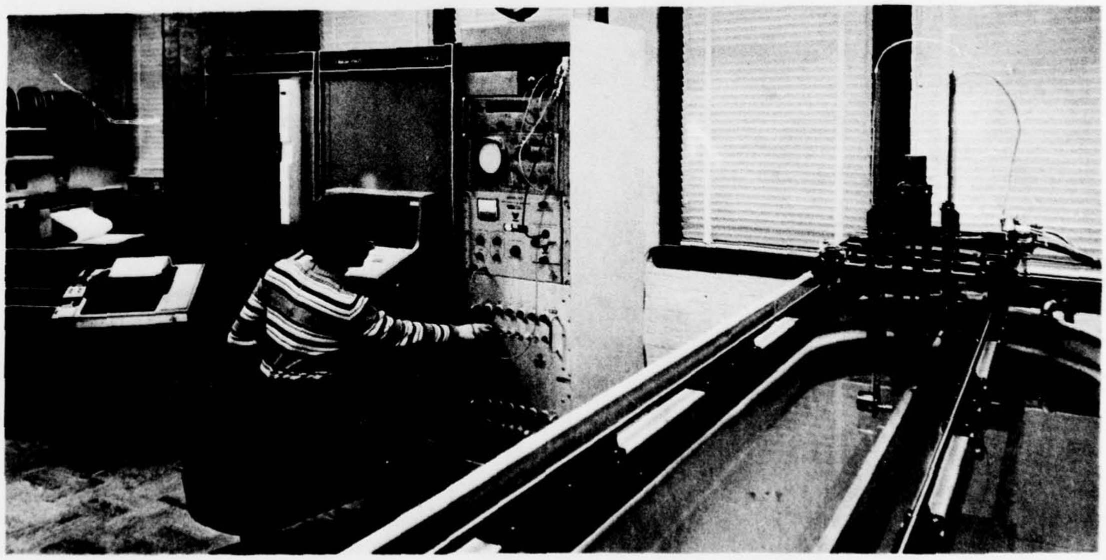

Figure 11.—The computer-controlled lumber scanning system for laboratory evaluation of ultrasonic lumber defect detection.

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for testing under computer control.

The computer, given scanning instructions by an operator via teletype, has complete control of the scanner, positioning the transducers, and collecting the transit time data (fig. 12). Data are stored on magnetic tape for analysis after scanning is complete.

A computer-controlled line plotter is connected to the system for output of the results obtained from the lumber scanner. The plotter will make X,Y pen movements in 0.01-inch increments at a speed of 400 increments/second.

Data Analysis for Defect Location

Transit time data from each board scanned are recorded to the nearest 0.01 sec and stored in the computer for analysis. A contour plot (fig. 13, upper) of transit time data, where each contour line represents equal values, shows the strong correlation between the visible grain pattern (fig. 13, center) of the board scanned, and the data. Knowing that this correlation did exist enabled the investigation of various methods of analyzing the data to obtain the location of the defects on the board (6,7).

The data analysis algorithm selected was designed to classify the board area scanned as being either defective or nondefective. Each area classified was a square centered on the scan line, and located between the data points (fig. 13, lower, and fig. 14). This mathematical description is a binary classification of each area made by comparing every two adjacent transit times along each scan line. If adjacent transit times differ by less than a preset difference, Δt, the area is designated as "clear." If the difference is equal to or greater than Δt, the area is classified as "defective."

Formula	Classification
$[t_i - t_{i+1}] < \Delta t$	"Clear"
$[t_i - t_{i+1}] \geq \Delta t$	"Defective"

The preset difference, Δt, is a variable dependent upon the defect resolution desired for a particular configuration of the ultrasonic apparatus at the time of scanning. Results of the analysis using different Δt's from 0.1 µsec to 0.9 µsec at increments of 0.2 µsec reveal the changes in classification of defect areas that occur over the range of Δt's (fig. 15). The Δt selected to get the best resolution is also affected by the distance between data points and/or transducer diameter.

This approach to processing transit time data separates those areas of the board that exhibit sharp changes in sound velocities from those areas that have gradual changes associated with normal, clear wood. Often, sharp changes in sound velocities do not oc-

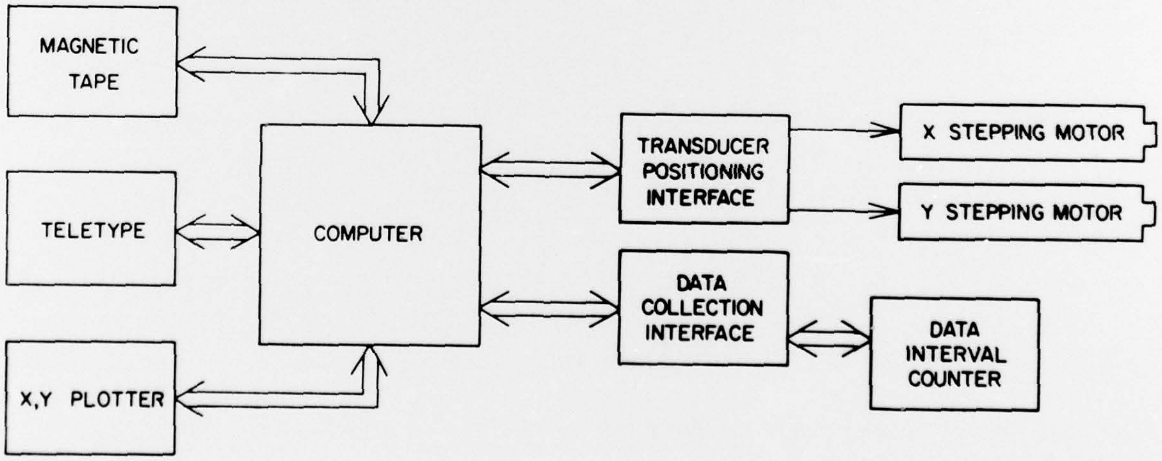

Figure 12.—Schematic of computer-controlled lumber scanning system showing lines of communication for transducer control and data collection. See figure 4.
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cur in the center of defects, giving the false impression these areas are clear.

A normal procedure for locating defects in a ¾-inch pine board is to use ½-inch-diameter, 1,000-kHz transducers positioned 4 inches apart, with data recorded every ½ inch along each scan and across the board. With this setup, a difference level (Δt) of 0.5 µsec is used to classify the board areas.

Using Defect Location Information

To demonstrate the application potential of having a two-dimensional model of defect locations in a computer, a sawing algorithm was designed which maximizes the percent clear area sawn from a board scanned by the defectoscope system using the ultrasonic defect sensing technique.

The sawing algorithm selected for demonstration simulates a finger-jointing operation producing wood moulding. It considers total board size, defect location, saw kerf, minumum length of usable clear cutting, and desired widths of clear cuttings. In this process, random-length clear cuttings are produced by first ripping the lumber into predetermined widths, and then crosscutting out the defects. All permutations of rip widths that occur from one edge of a board are considered. For each permutation, a "percent clear yield" solution is calculated, and compared to the previous best solution.

The best solution is plotted under computer control showing the board outline, the defect areas, and the rip and crosscut solutions (fig. 16). The undesirable localized

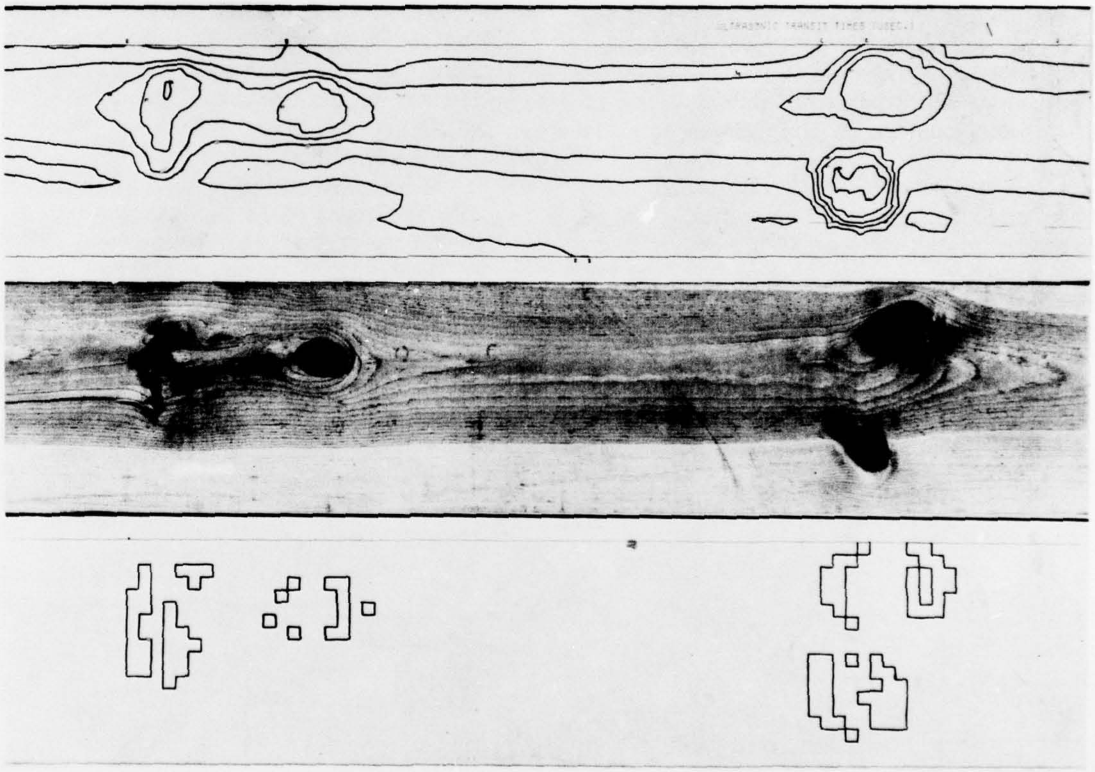

Figure 13.—Upper: Contour plot of ultrasonic transit time data, showing the close correlation to the grain pattern of this pine board.
Lower: Plot of the results of defect analysis designed to provide a mathematical description of this board.
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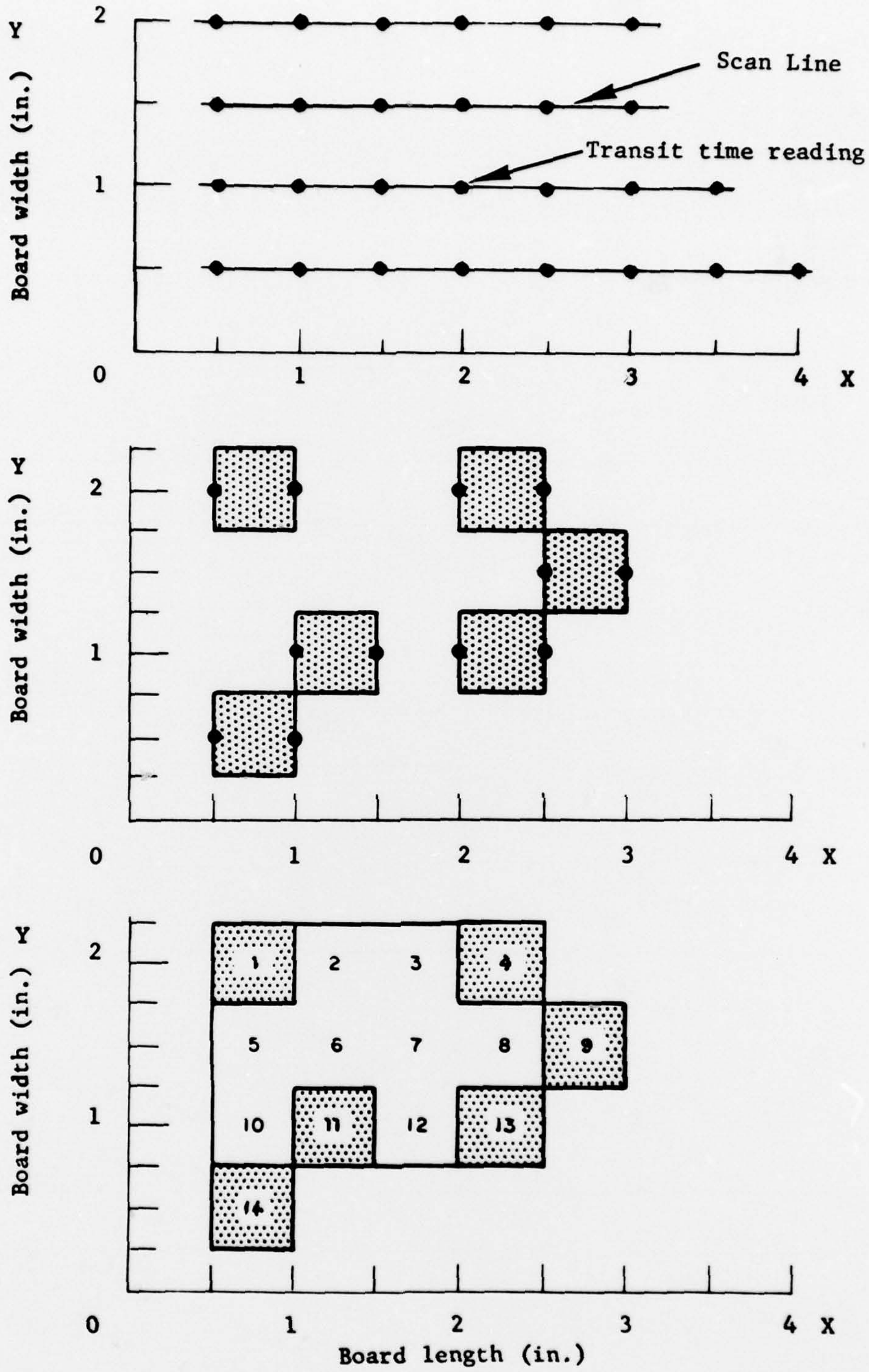

Figure 14.—Upper: Locations of transit time readings on scan lines form squares.
Center: Shaded squares represent six defective areas.
Lower: Defective areas are outlined to include unusable material.
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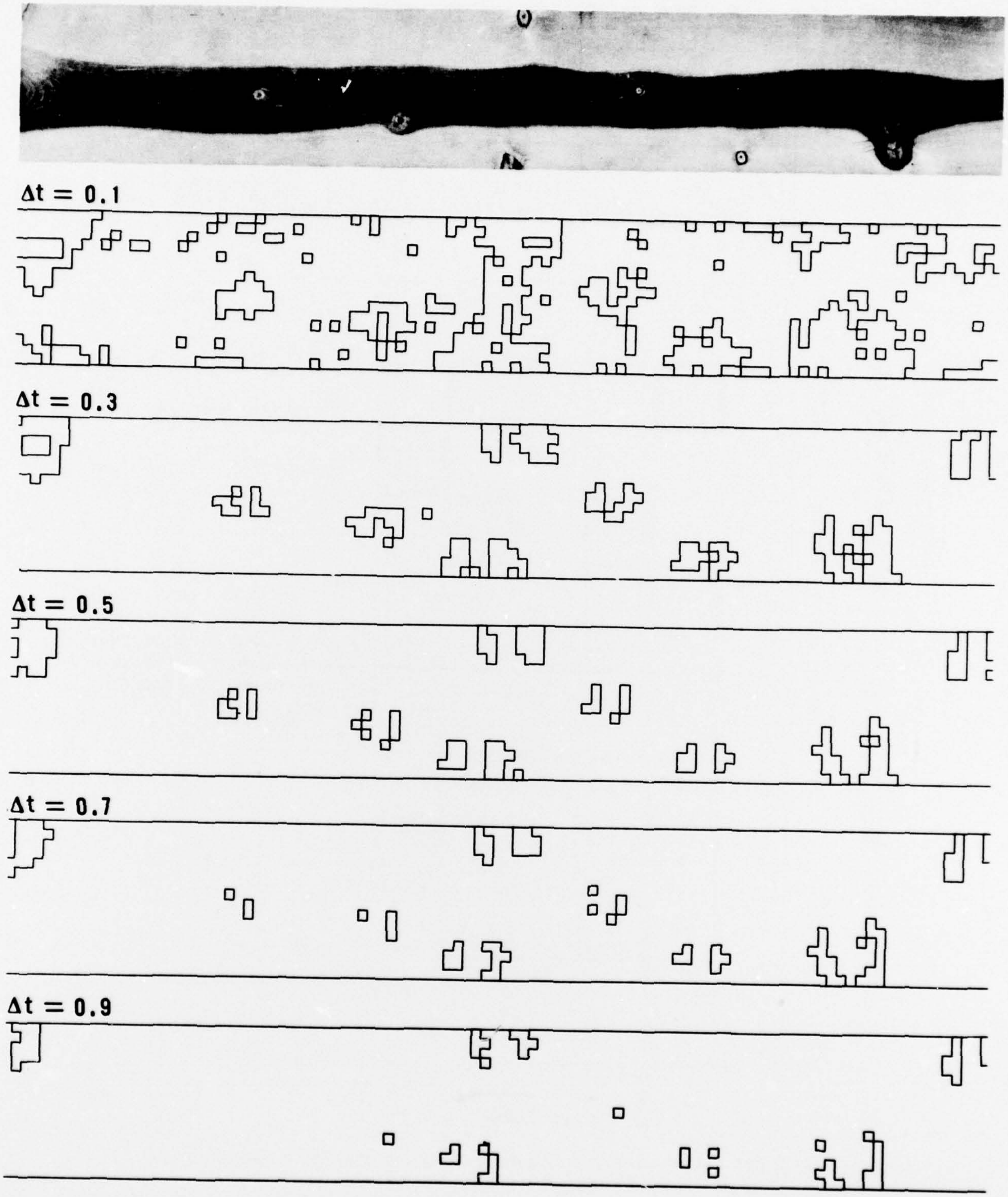

Figure 15.—Defect analysis results for various difference levels, Δt's, ranging from 0.1 μsec to 0.9 sec.

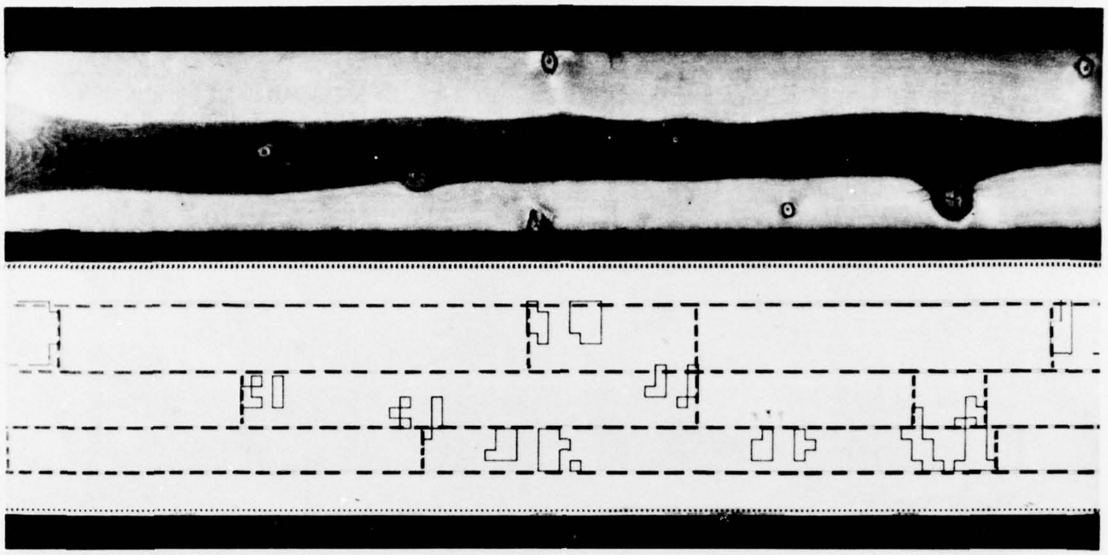

Figure 16.—A section of a board ultrasonically scanned showing the ripping and crosscutting solution to remove defects and obtain clear cuttings.
M 145 842

steep grain associated with most defects is not included in the ends of cuttings determined to be clear. After a board had been scanned for defects, it was ripped and then crosscut according to the computer's decision. An overlay of the actual defect locations was used to evaluate the results and make comparisons with the area removed by sawing (fig. 17).

Given the existing numerical control technology and the demonstrated capability of the ultrasonic lumber-defect detection system, it is assumed that saws could be numerically controlled by this system to do the actual sawing instead of the plotter drawing the board, its defects, and the sawing pattern.

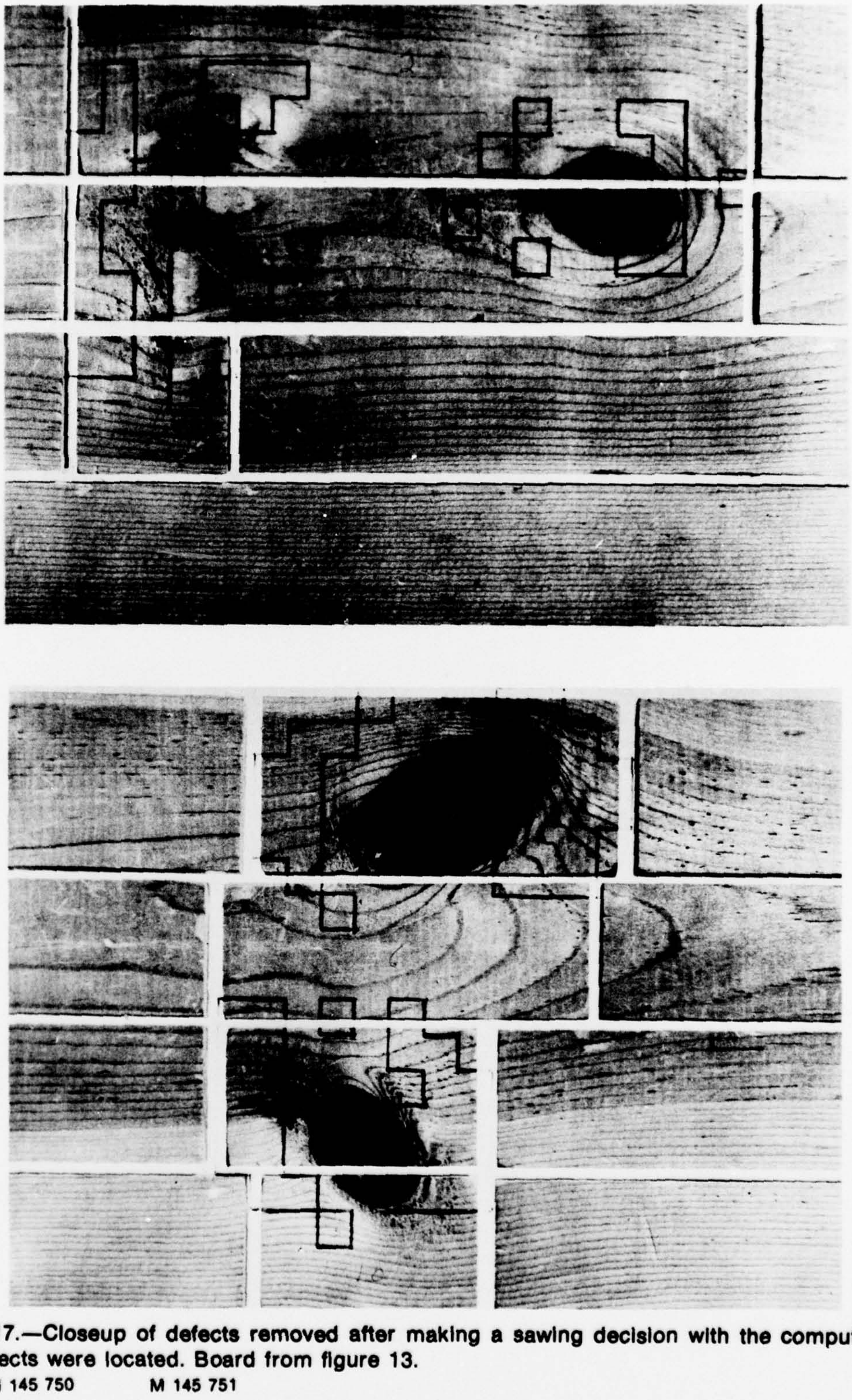

Figure 17.—Closeup of defects removed after making a sawing decision with the computer after defects were located. Board from figure 13.

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COMMERCIAL APPLICATION POTENTIAL

The ultrasonic lumber scanning system has profoundly demonstrated that a mathematical description of lumber quality can be electronically obtained in digital form and that processing decisions can be made by the computer with this information. However, this system is a laboratory device, not commercially applicable to an industrial situation that requires handling and scanning boards at production speeds.

Multiple Transducer Concept

Early in the ultrasonic defect sensing research program, it was determined that commercial application would require the ability to move the board past a bank of transducers, without the calculating, handling, and analyzing of large volumes of transit time data. For example, a 12-inch-wide, 16-foot-long board has 4,096 transit-time data-collection positions that amount to a rate of 25,600 data points per minute in scanning at 100 lineal feet per minute, or 153,600 data points per minute for scanning at 600 lineal feet per minute.

To avoid the problems associated with significant numbers of transit time data and making defect decisions in the computer, consideration was given to making a defect decision immediately upon receiving the sound pulse through the board. This entailed transmitting a sound pulse through the board and comparing its arrival times at two adjacent receiving transducers (fig. 18). The difference in arrival times was computed as clear ("go") or as defective ("no-go"). Efficiency is improved by transferring only one data bit indicating a "go" or "no-go" condition at every decision point on a board rather than transferring the 48 bits necessary in determining transit time data. Handling the single data bit is simpler and results in less electronic noise interference.

Electronic crosstalk between adjacent receiving transducers, a potential problem, was found to be manageable when the ½-inch-diameter receiving transducers were mounted on ¾-inch center. Tests comparing this method of obtaining defect location with the original comparison of transit time data show similar results.

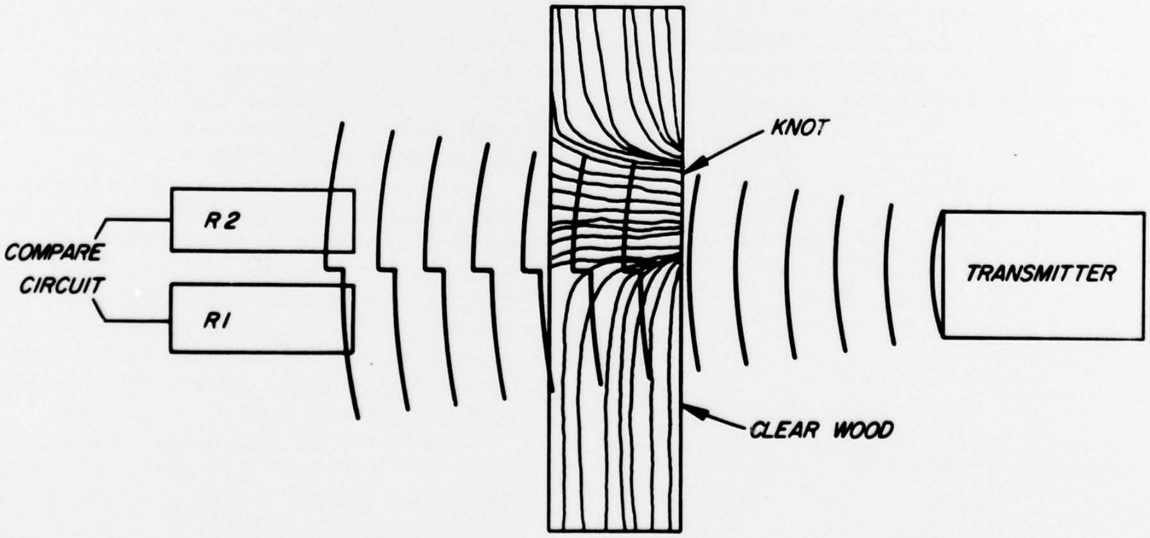

Figure 18.—Two transducers are used to receive the transmitted sound pulse for comparison of the sound velocity through wood at two points.
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Longitudinal Scanning

The Laboratory scanning system described here holds the board stationary in a water tank, while a single pair of transducers is moved back and forth along its length until all data are obtained. At this rate, a 12-inch-wide, 8-foot-long board is scanned in 4 minutes (about 120 bd. ft./hr.).

In designing a commercial ultrasonic lumber scanner, the initial approach was to have a bank of transducers covering the full width of the board, with the board moved lengthwise between the transducers. A tank long enough to accommodate lumber 16 feet long was considered to be impractical, and an alternative was sought. The alternative required a "water dam" arrangement to accommodate the necessary water couplant between the transmitting and receiving transducers. The last design for longitudinal scanning included a single water gate on the input end with the board moving upward at an angle (fig. 19). Water lost around the board at the input gate would be pumped back into the scanning tank. The scanning speed of this design was calculated to be less than 150 lineal feet per minute, or about 9,000 board feet per hour.

One of the difficult problems in the design of the longitudinal scanner was scanning unedged flitches (fig. 20). It was found that too much water would be lost due to the irregular profile and tapered edges. Another problem was the need to maintain longitudinal movement of the board past the transducers in a straight line. This is similar to the difficult problem of moving a board in a straight line through a rip or edger saw.

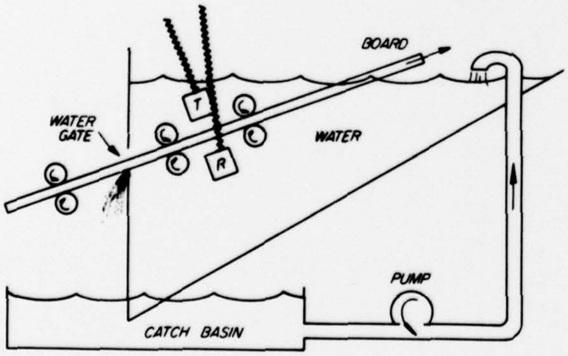

Figure 19.—Proposed method of scanning lumber moving longitudinally past a bank of ultrasonic transducers that spans the full width of a board.

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A number of disadvantages to this system are evident:

1. Scanning speed of 150 lineal feet per minute was only a fraction of the rate of 600 lineal feet per minute that would be required commercially.
2. There appeared to be no way to design around the problem of excessive water loss in scanning unedged flitches.
3. Excessive space would be required in a mill for the longitudinal movement of the lumber.
4. The system could not adequately resolve defect location in the width direction where it is most important.
5. Alinement of lumber passing through the scanner could not be adequately controlled.

When a new concept—transverse scanning—was conceived without the above limitations, the longitudinal scanning system was abandoned.

Transverse Scanning

The new concept, designed to overcome previous difficulties, involves moving the board transversely past ultrasonic transducers that span the full board length. This approach permits a slow scanning speed, allows the scanning of unedged boards, provides adequate defect resolution, and adapts well to present product flow rates.

The board transporting mechanism consists of opposing sets of chains that carry the boards into the water couplant and past a bank of transducer modules. The chain sets are staggered so the chain does not obstruct the transducers (fig. 21). The chain sets maintain equal pressure and constant speeds when transporting unedged boards and varying board thicknesses.

The transducer modules are designed to hold 17 half-inch-diameter receiving transducers spaced ¾ inch on center. Each module has a scanning path of 12 inches. By incorporating the comparative technique for locating defects, each module will provide 16 bits of "go" or "no-go" information. Alternate modules are staggered, with the end

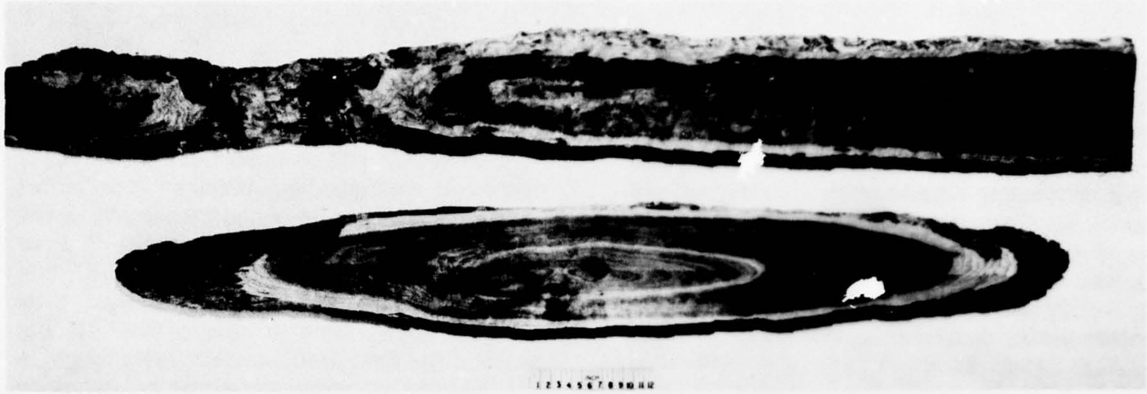

Figure 20.—Unedged lumber flitches as they are sawn from a log.
M 144 495

transducer of each module scanning the same path as the end transducer of the next module (fig. 21). The transmitting transducers will be directly opposed to the receiving transducer banks.

A scanning rate of 50 feet per minute will mean an actual product flow rate of 600 to 650 lineal feet per minute. Data, handled by a microprocessor, can be taken every 1/10-inch across the board width, giving excellent resolution to defect width. One concern with this approach is the large number of ultrasonic transducers necessasry to span the full board length. Simpler design, increased flexibility, and smaller space requirements are expected to offset this concern.

A board profile scanner using an optical technique and a board identification marking system are included in this scanner design. These functions, obtained before the board enters the water couplant, are necessary in addition to defect location to make and execute the sawing decisions.

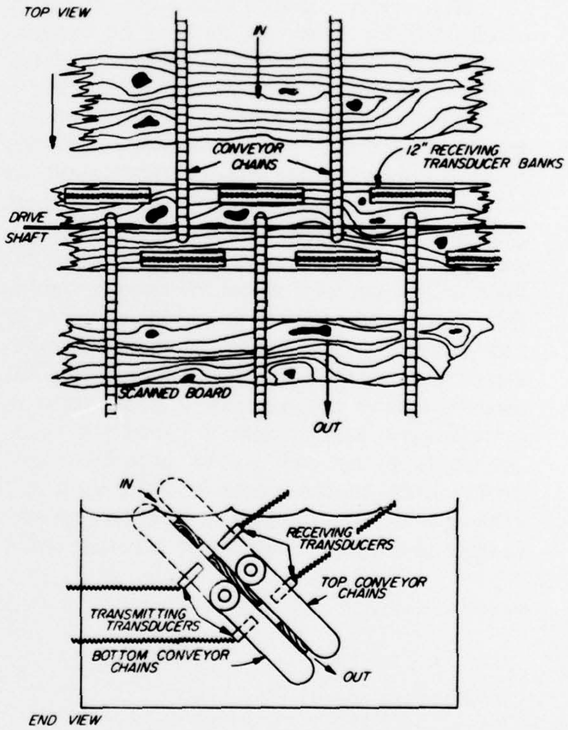

Figure 21.—Upper: Proposed 1-foot transducer modules arranged for 100 percent scan of a board and enabling handling with chain conveyors.
Lower: Side view of chain conveyors proposed for moving lumber sideways (transversely) into a tank of water and past the ultrasonic transducers.
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SUMMARY

The research reported in this paper has been aimed at eventual development and use of a production-type lumber scanner that will scan at production speeds. An ultrasonic system is now capable of describing lumber quality in digital form so a computer can make and carry out complex processing decisions to maximize conversion efficiency. The ultrasonic lumber-defect-detection system described in this report has been demonstrated to be a viable means for locating defects in lumber of all species, green or dry, and rough sawn or surfaced.

With any flaw-detection system developed for detecting defects in lumber, there will be detection errors; some from identifying too much area as defective, and some from missing defective areas. It is known that the ultrasonic technique, as developed, will not reliably locate all of the defects found in lumber. Defects such as cracks, splits, and grub and worm holes can be oriented in such a way that the sound waves are undisturbed by their existence, and therefore escape detection. Future refinements and improvements to the technology are expected to keep these errors to a minimum. Optical techniques for locating visible surface defects would seem to complement the ultrasonic technique quite successfully, as well as to provide board profile data to the computer. Through experience in this research, it is expected any lumber scanning system will incorporate more than one flaw-detection technique.

Research efforts have been intentionally aimed at distinguishing between clear areas and defect areas in wood. However, many decisions made in processing lumber involve permitting certain defects or blemishes in the product where they might enhance final product appearance or where they will not show in the final product. Being able to locate the defects will allow the computer to place them in an acceptable position at the time the processing decision is made. Additional research is necessary to determine if defects can be type classified so that certain ones, such as sound knots, can be excluded as defects in the processing decision.

Successful application of these reported research results will require a difficult but presumably possible conglomeration of disciplines to eventually realize a commercial lumber scanning system that will operate at production speeds. These talents include mechanical and electrical engineers along with interested personnel from the wood industry, machinery manufacturers, the computer industry, and the electronics industry.

Finally, it has been determined that sound can be successfully propagated through wood for detecting defects. In the future, ultrasonics could possibly lead to determining internal quality in logs, and making computerized, quality-based, log-sawing decisions.

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KEYWORDS: Wood anisotropy, sound velocity, through-transmission, transit time data, transmitters, water couplant, X-Y-grid, algorithm, longitudinal scanning, transverse scanning.

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