Detection of Defects in Red Oak Deckboards by Ultrasonic Scanning

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Abstract

Experiments were conducted to detect defects in red oak (*Quercus rubra*, L.) deckboards by ultrasonic scanning. Scanning of the deckboards was carried out with two rolling transducers in a pitch-catch arrangement with pallet parts moving between the transducers at 70 ft/m and 220 ft/m. Data were collected, stored and processed using LabView^{TM} software. The defects examined were sound and unsound knots, bark pockets, holes, decay, and wane. Three deckboard samples (fresh cut and unplaned condition) were scanned for each defect type. Defects were characterized on the basis of time of flight, pulse energy, and pulse duration of the received signals. Results demonstrated that defected wood can be distinguished from clear wood by observing the variation in received signals. Ultrasonic signal parameters are more sensitive to unsound knots, decay, bark pockets, holes, and wane, compared to sound knots. This study demonstrates the feasibility of on-line inspection of green (high moisture content) and rough (unplaned) red oak deckboards.

Keywords: Ultrasonic Scanning; Wood Defects; Rolling Transducer; Pallet; Deckboard; Non-destructive Testing

Introduction

Each year, over 400 million wooden pallets are manufactured in the USA, consuming 4.5 billion board feet of hardwood lumber (Bush et al. 1997). Typically, wooden pallets consist of two parts—stringers, the structural center members that support the load and deckboards, the top and bottom members that provide dimensional stability and products placement. There are many types of pallet designs depending on species, size, number, pallet use, and position of stringers or deckboards, but most pallets are produced from solid wood (lumber) or from the center cant material of logs. These cants have a high percentage of defects and have less market value for other solid wood products.

Knots, cross grain, bark pockets, insect holes, splits, decay, shake, wane, etc. are the most common defects found in pallet parts. The extent and severity of these defects often depend on wood species. High quality pallet parts produce high-grade pallets, which extends a pallet's life and promotes multiple use. Manual grading and sorting of pallet parts is a slow and inaccurate process depending on the individual skill of a grader. Moreover, the presence, location, and extent of defects in pallet parts are often difficult to determine accurately, making manual grading complicated. Schmoldt et al. (1993) also showed that increased pallet durability and performance imparts much greater value to carefully manufactured pallets.

Many researchers have examined a variety of ultrasonic parameters to detect defects in wood (McDonald 1980, Patton-Mallory and DeGoot 1990, Ross et al. 1992, Fuller et al. 1995, Niemz et al. 1999, Raczkowski et al. 1999, Karsulovic et al. 2000). These studies included both natural, as well as processing-related, wood defects and tested laboratory samples or surfaced lumber. In the pallet industry, however, the situation is quite different because pallet manufacturers use low quality, unsurfaced wood during manufacturing. This means that any pallet scanning system must work on parts shortly after cutting. Furthermore, simple ultrasonic propagation velocity may not be sufficient to detect most types of defects. Some defect types may not respond well to time-of-flight measurements, but may response to other ultrasonic parameters, e.g., peak amplitude, time to peak amplitude, centroid time, root mean square of the time domain, pulse length, insertion loss, frequency domain mode, frequency domain energy, etc. Recent reports by Halabe et al. (1993, 1994, 1996) showed that frequency domain analysis provides valuable information for detecting decay in wood. For the last few years, research has been conducted to develop an automated pallet part inspection system (Schmoldt et al. 1994, 1996, 1997, Kabir et al. 2000a, 2000b).

This paper presents some ultrasonic scanning results performed on oak deckboards containing various defects. These preliminary investigations are intended to discern which parameters are sensitive to which wood defects. Subsequently, a more thorough study will attempt to quantify how the selected set of ultrasonic parameters can accurately discriminate different defect types.

Methods and materials

Scanning equipment

The scanning apparatus was designed by the Ultrasonics Group, Forest Products Division, Perceptron, Inc. The system consists of in-fed and out-feed roll beds, two pinch rollers for part movement, and two rolling transducers which are mounted in an ultrasonic scanning ring. Perceptron provided the necessary electronics and software to control material movement, signal generation, and waveform capture and analysis. Data were collected, stored, and processed by LabView™ software modules. We can easily plot the data against board length for a single scan line. The desired resolution (number of waveform per inch) can be achieved by controlling roller speed and the number of pulses generated and received per second.

Data collection

Twenty oak deckboards—of varying lengths with an average thickness of 1/2 inch—were collected from a local sawmill. They were fresh cut and unplaned. The boards were placed into cold storage immediately to keep their moisture content near the fresh-cut level. Because moisture content above fiber saturation has little effect on ultrasonic propagation, we were able eliminate any sources of error due to moisture differences. A line was drawn on each board through a defect of interest and scanning was performed along the line through the specimen's thickness from face to face. Currently, only one scan line of data is obtained in a single pass through the systems. Multiple passes are required to scan a part completely and produce a 2-D image. Future versions of the scanning system will accommodate complete inspection of a part in one pass.

Defects examined here were unsound and sound knots, bark pockets, insect holes, decay, and wane. Boards were scanned with two scanning rates—10 waveforms/inch (70 ft/m roller speed) and 4 waveforms/inch (220 ft/m roller speed). Each board was scanned ten times for each defect type and scanning rate to check for scanning reliability. Measurements were carried out at 120 kHz transmitting frequency and received signals were sampled at 500 kHz. From three to five samples of each defect type were tested.

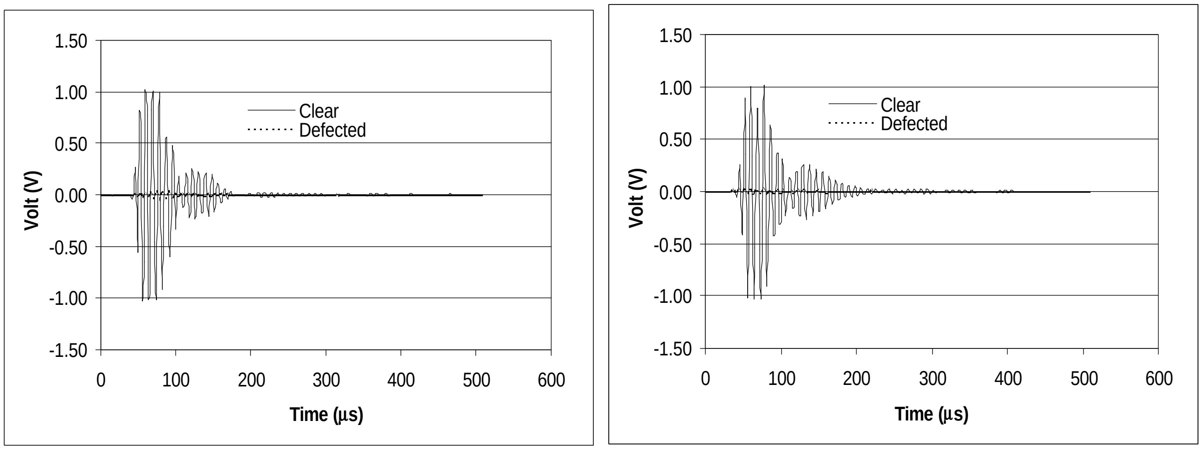
Six ultrasonic parameters—three involving time-of-flight, two involving ultrasound pulse energy, and one using ultrasound pulse duration—were measured for each defect type. More information regarding these ultrasonic parameters can be found in Kabir et al. (2000a). Parameters included pulse length (PL), time of flight-centroid (TOF-centroid), time of flight-energy (TOF-energy), time of flight-amplitude (TOF-amplitude), energy value (EV), and energy/pulse value (EPV). Each defect type was characterized using these parameters. Energy value (EV) is derived from the energy *E* [1], and is expressed in decibels (dB). By convention, this is a negative number, with lower signals (containing less energy) being more negative. The pulse length parameter (in units of microseconds) is simply the time for which the pulse is "on," and depends upon the transmitted ultrasound frequency. These two parameters, energy value and pulse length, can be combined to provide a single parameter, which is known as energy/pulse value (EPV). Again, because of the wide range of energy levels, EPV is also expressed on a logarithmic scale (in dB). TOF-energy is calculated as the time at which the energy integral [1] crosses a threshold value—as a percentage of the final (maximum) value. If the threshold value is, for instance, 40%, then TOF-energy is simply the time at which the integral value reaches 40% of the final value. Similarly, TOF-amplitude is the time at which the amplitude of the signal first reaches, for instance, 40% of the maximum amplitude. TOF-centroid is the time to the centroid of the time waveform, which is based on the ratio of the first- and zeroth order moments. No frequency domain parameters were calculated in this study.

$$E = \int v^2(t)dt \qquad [1]$$

Results and discussions

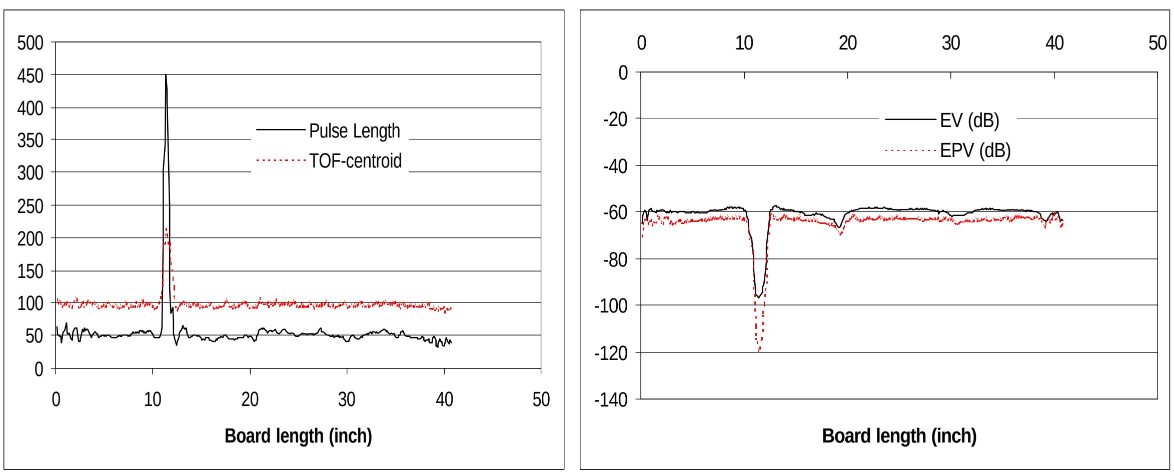
Examples of received ultrasonic signals through clear and defected oak deckboards are shown in Figures 1(a) and 1(b). The defected wood, i.e., unsound knot, or decay, reduces the strength—amplitude of the signal—to a substantial extent. Figure 2 illustrates scanning results through an unsound knot. It is clearly seen in this figure that the unsound knot can easily be detected by observing the abrupt signal change in the region of the defect. The defect's extend can also be assessed when the measurement parameters are plotted against board length.

Sound knots have less affect on ultrasonic signals (Figure 3). In fact, there is little change in value for all ultrasonic parameters. An earlier report on yellow-poplar deckboards also supports this finding (Kabir et al. 2000a). Nevertheless, previous studies (McDonald 1980, Schmoldt et al. 1996) have found reduced time of flight for sound knots when initial signal arrival was used for timing. This makes intuitive sense because a sound knot is effectively longitudinal transmission, which is nearly twice a fast as radial. Time of flight calculated for the centroid value, as was done here, may be less sensitive to sound knots than the initial arrival peak. However, we are further checking this result to ensure that all the calculations have been done correctly.



(a) (b)

Figure 1. *Received ultrasonic time-domain signal through clear and defected wood, (a) unsound knot, (b) decay.*



(a) (b)

Figure 2. U*ltrasonic measurements through an unsound knot, (a) Pulse length and time of flight-centroid, (b) Energy value and Energy /Pulse value. All parameters are plotted against board length.*

Figure 4 depicts the variation of ultrasonic signals due to decay. The parameters PL, TOF-centroid, TOF-amplitude, and TOF-energy increase in the decay region. Decay's effect on TOF-amplitude and TOF-energy is not as dramatic as PL and TOF-centroid. The parameters EV and EPV show sharp decreases (higher loss) in the vicinity of decay. Typically, decay has a similar effect as unsound knots because unsound knots contain some decayed wood.

To examine the repeatability and reliability of data collection, all boards were scanned ten times and coefficients of variation (CV%) were calculated. The CV% for a decay sample are presented in Figure

4(d). Low CV% values for most parameters suggest that data collection repeatability is acceptable, although high CV% values are obtained for PL. The high CV% values for PL may be occur for several reasons. First, PL may be more sensitive to a shifting data collection point that can occur with multiple scans of the same line. Second, decay regions often exhibit less homogeneity than other defect types. Third, the PL parameter seems to vary considerably even within clear wood regions—suggesting that the parameter is difficult to measure reliably.

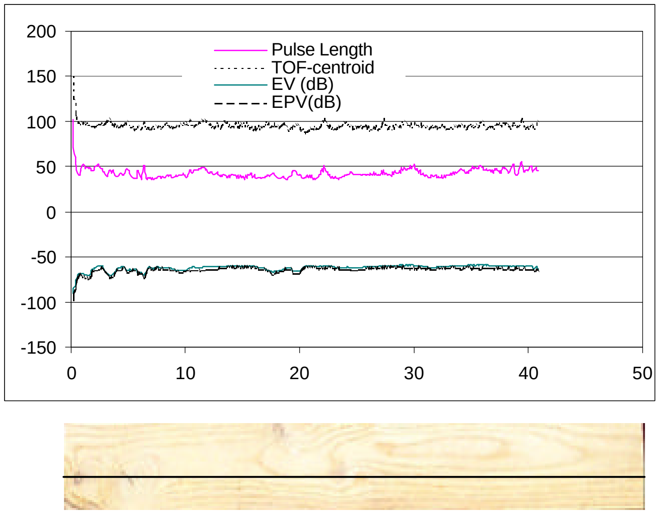


Figure 3. *The response of several ultrasonic parameters to the presence of a sound knot.*

Figures 5(a) and 5(b) depict the effect of a bark pocket defect on ultrasonic signals. All the ultrasonic parameters are greatly affected. This is entirely expected, as bark is very different from wood. Figure 5(c) compares the measurement of EPV at two scanning rates, 10 waveforms/inch and 4 waveforms/inch. It is obvious from this figure that scanning rate does not have much effect on ultrasonic measurements.

Ultrasonic scanning can also identify insect holes and wane as presented in Figures 6(a) and 6(b) respectively. Here, energy parameters are shown. Because wane can contain some bark, as well as exhibit missing wood, there seems to be less energy loss than with holes, bark pockets, decay, and unsound knots.

Conclusions

Sound and unsound knots, bark pockets, decay, holes, and wane in oak deckboards can be detected by non-destructive ultrasonic scanning. Several different ultrasonic parameters are required, however, for different defect types. Unsound knots, decay, bark pockets, and holes show a rapid change in ultrasonic signals near the defect region. Pulse length and time of flight exhibit an increasing trend (greater values) for most defects, whereas energy value and energy/pulse value show decreasing magnitudes. The scanning apparatus demonstrated good repeatability and reliability for data collection, as we obtained low coefficients of variation for repeated measurements. Furthermore, scanning rate has little effect on data collection, which suggests that scanning at relatively high industrial speeds is feasible.

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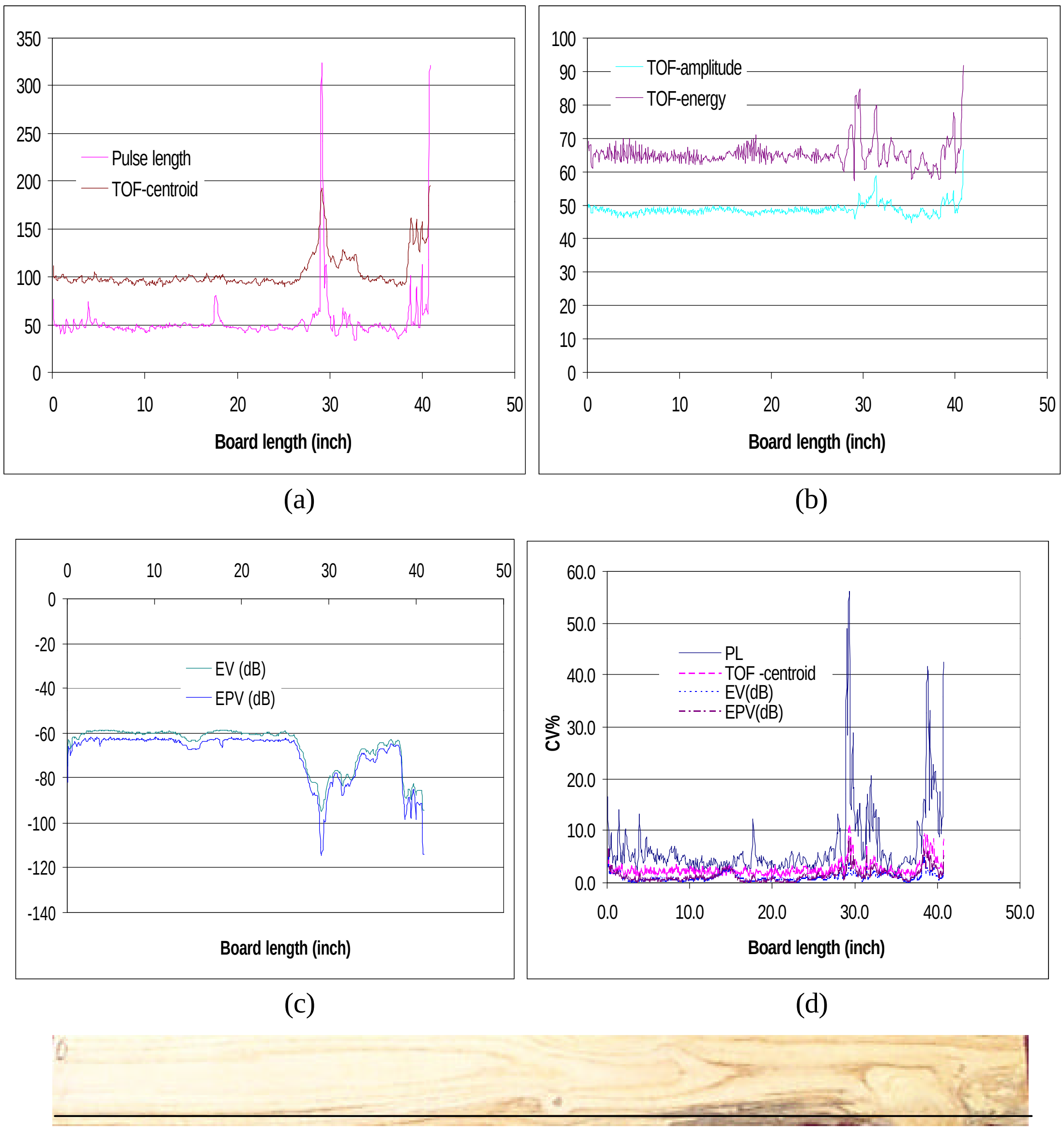


Figure 4. *The effect of decay on ultrasonic measurements (a, b, c), coefficients of variation (CV%) of ten repeated measurements (d).*

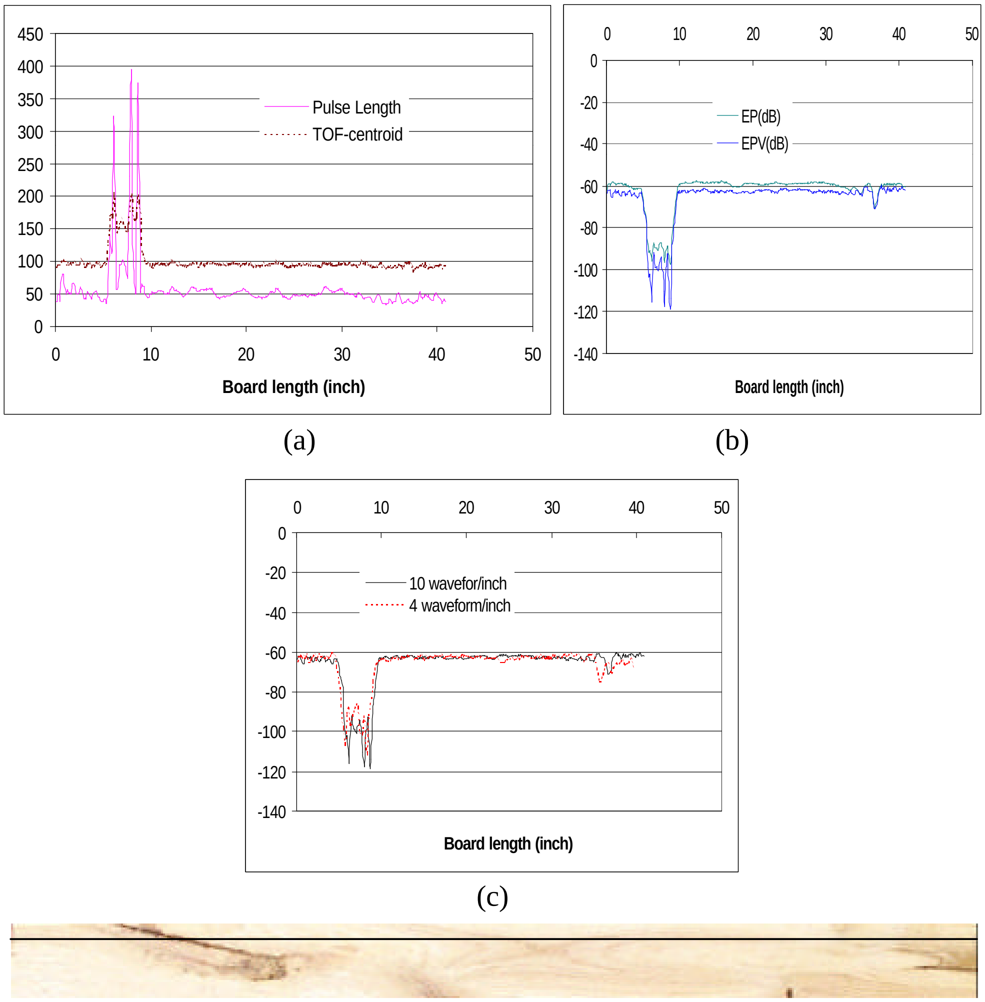


Figure 5. *Measured ultrasonic parameters through a bark pocket (a, b), the effect of scanning rate on EPV values (c).*

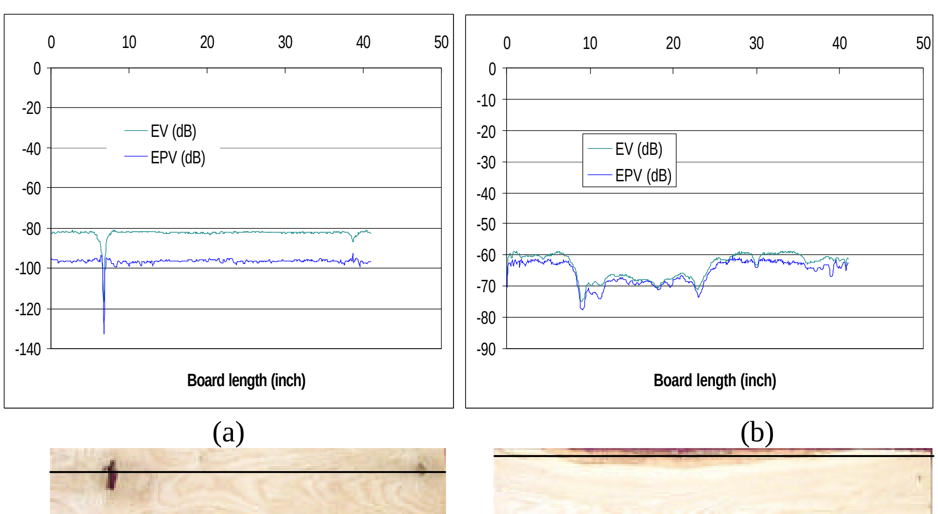
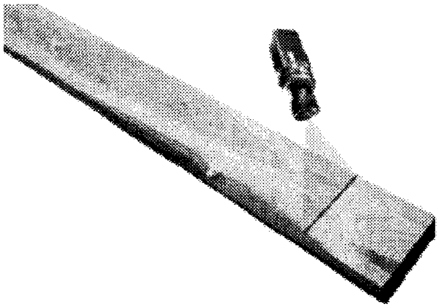


Figure 6. *Measured energy value and energy/pulse value, (a) through hole, (b) through wane.*



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