X-RAY SCANNING MACHINE FOR TREE-RING WIDTH AND DENSITY ANALYSES[1]

M. L. Parker
Department of the Environment, Canadian Forestry Service,
Western Forest Products Laboratory, Vancouver, British Columbia

and

L. A. Jozsa
Faculty of Forestry, University of British Columbia, Vancouver, British Columbia

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ABSTRACT

High-quality radiographs of wood samples can be produced for intra-ring specific gravity studies using an X-ray scanning machine. A hydraulic system is used to provide constant-speed and vibration-free motion for scanning tree-ring samples up to 4 feet [1.22 m] long. Stationary exposures can be made from distances of up to 7 feet [2.13 m]. Wood-sample preparation and X-ray film-processing techniques are described.

Additional keywords: in-motion radiography, X-ray densitometry, specific gravity, dendrochronology, wood density, annual growth increments.

INTRODUCTION

An X-ray scanning machine has been developed to produce radiographs of tree-ring samples that can be used to obtain accurate measurements of intra-ring specific gravity.[2] In-motion radiography is used to produce X-ray negatives of wood samples that are scanned on a densitometer described separately (Parker et al. 1973).

Previous research (Polge 1963, 1966; Echols 1970; Parker and Meleskie 1970) has demonstrated that high-quality radiographs of tree-ring samples are obtained only if the X-ray beam penetrates the wood sample in a direction parallel to the wood grain. This condition is approximated for short wood samples if the X-ray source is positioned a considerable distance from the specimen and film to reduce parallax distortions. However, the best results are obtained (particularly for long samples) if the wood specimen and film are scanned in a radial direction from one end to the other by a narrow X-ray beam. By this method radiation penetrates the wood in the desired direction irrespective of sample length.

The in-motion or scanning technique is used in industrial radiography to produce high-resolution radiographs of large items (Hopkins, no date). Experiments were conducted by Parker and Meleskie (1970) to produce radiographs of tree-ring samples by the in-motion technique. Echols (1970, 1971) has built several X-ray scanning machines for wood-quality studies and McNeely et al. (1973) also use the scanning technique to produce radiographs for tree-ring analysis.

The X-ray scanning machine described in this article has been in operation at the Western Forest Products Laboratory since

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[2] The unit of measure is g/cm^3. The terms "specific gravity" and "density" will be used interchangeably.

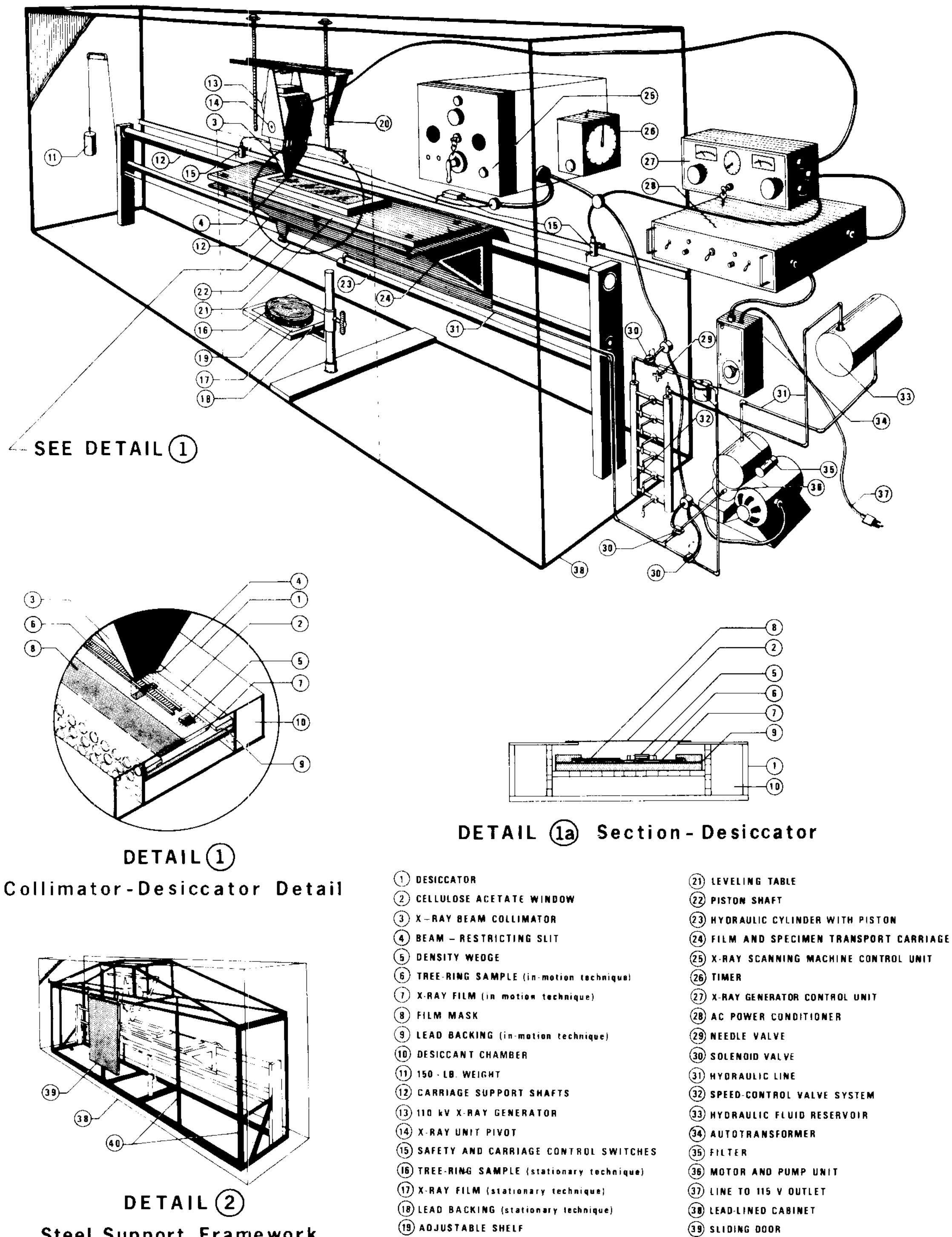

Fig. 1. X-ray scanning machine.

1971. Stable X-ray emission and constant scanning speed are required if radiographs of uniform background are to be produced by the in-motion technique. Constant-speed and vibration-free traversing of a wood sample and film under an X-ray beam is obtained by the use of a hydraulic system powered by a weight. The scanning speed is regulated by a series of valves that act as dampers in the hydraulic line.

A number of factors can affect the quality of X-ray negatives, such as fluctuation in supply voltage to the X-ray generator, size of beam-restricting slit, moisture content of wood, lack of uniformity in sample thickness, film-processing methods, and sample-preparation techniques. These factors were considered in the design and operation of the X-ray scanning machine described here.

X-RAY SCANNING MACHINE DESIGN

The X-ray scanning machine is designed for both in-motion and stationary radiography. It is shown in Fig. 1 with components numbered in parentheses below. In the scanning technique, a collimated beam of X-radiation (20 kVp and 2 mA) is emitted through a 0.33-inch-wide [8.38 mm] slit (4) onto the tree-ring samples (6), density calibration wedges made from plastics or paper (5), and the X-ray film (7) that are located 12.5 inches [31.75 cm] below the 0.33-mm focal spot of the X-ray generator (13), which is a 110 kVp unit with a 0.254-mm-thick beryllium window. The specimens, film, and desiccator (1) are supported by a 4-foot-long [1.22-m] carriage (24) that travels at a uniform speed beneath the X-ray unit. The X-ray generator and beam collimator (3) are normally positioned so that the X-ray beam is aligned perpendicularly to the top surface of the transport carriage, but the X-ray unit pivot (14) can be used as required to align the beam with the long axis of the longitudinal tracheids of conifers and vessels of angiosperms. A 150-pound [68-kg] weight (11) is used to move the carriage to which is fastened the piston of a hydraulic cylinder (23) that forces fluid through a constricted opening. The speed of the carriage during X-ray exposure is controlled by hydraulic valves with orifices of different sizes (32), and the normal scanning speed is 2 inches [5 cm] per minute. An electric motor and hydraulic pump unit (36) are used to return the carriage to the ready position. A large hydraulic-fluid reservoir (33), located above all other components of the hydraulic system, serves to keep air out of the lines (31) and dissipates heat generated in the fluid by the pump. An AC power conditioner (28) stabilizes voltage to the X-ray generator.

For the stationary technique, radiographs of tree-ring samples are made by positioning a wood specimen (16) on X-ray film (17) placed on the adjustable shelf (19) directly beneath the X-ray generator (13). Exposure distance is adjustable up to a distance of 7 feet [2.13 m]. For this technique, the X-ray beam collimator (3) is removed and the transport carriage (24) is positioned to one side, so that it does not obstruct the X-ray beam. Stationary exposures have been made on film up to 14 × 17 inches [36 × 43 cm] in size and with wood samples up to 5.5 inches [14 cm] thick. A typical exposure for an air-dry, 2-mm-thick sample would be 2 minutes at 20 kVp and 2 mA at a distance of 4 feet [1.22 m]. This method is used to make radiographs with large images showing relative variation in wood density, moisture content differences, location of extractives, areas of decay, etc., rather than the high resolution, narrow images of wood samples that are produced by the scanning technique for accurate density analysis.

Automatic operation for both the in-motion and stationary exposure techniques is obtained by use of the X-ray scanning-machine control unit (25). The solenoid valves (30) on the hydraulic lines, the safety and carriage control switches (15), the timer (26), the X-ray generator control unit (27), and motor and pump unit (36) are all operated from this central control unit. The X-ray generator and traversing system are enclosed in a light-tight and X-

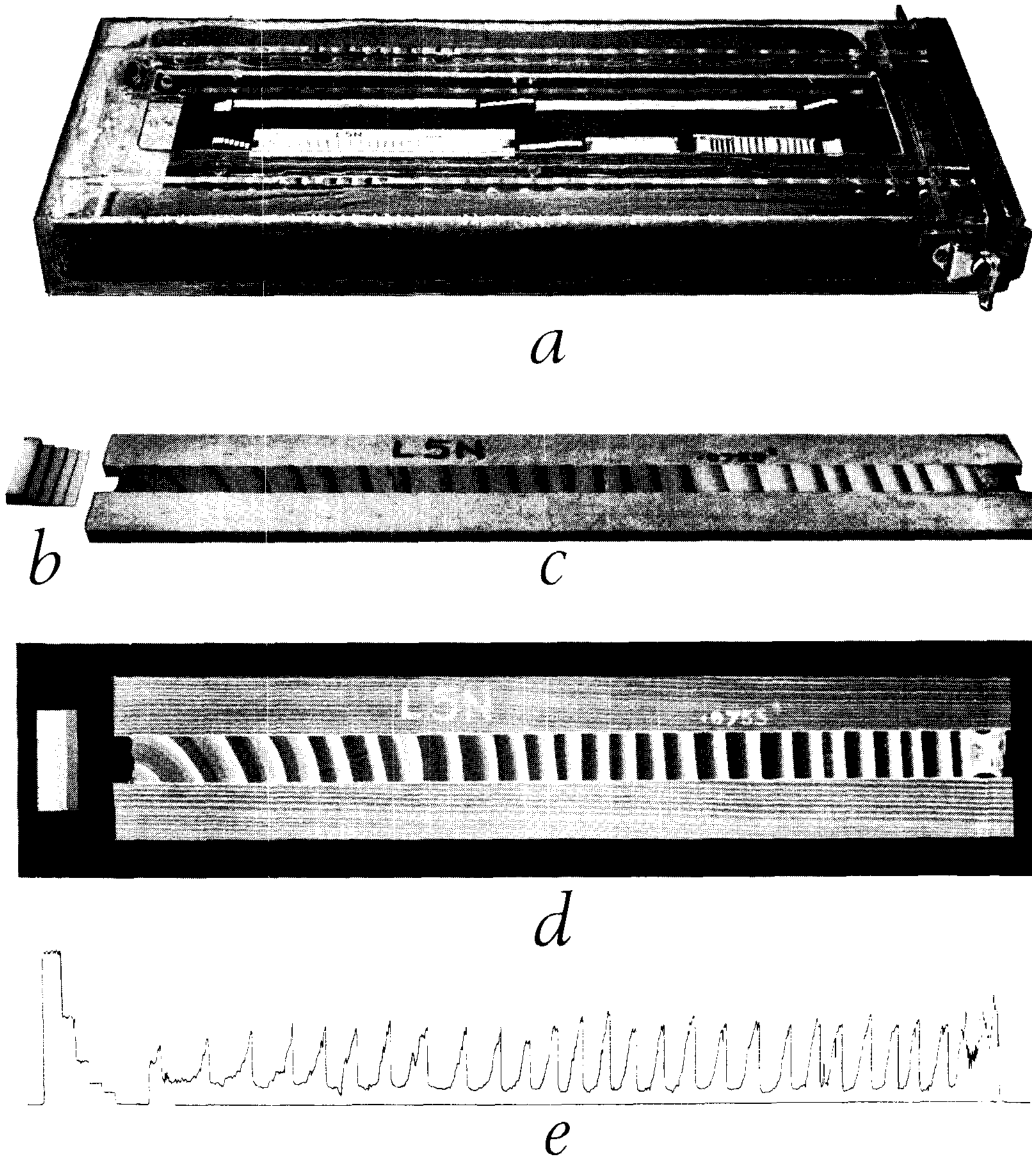

FIG. 2. *a*. Specimen desiccator used during X-ray exposure, *b*. stepped wedge of known density for calibration of wood specific gravity, *c*. mounted and surfaced tree-ring sample, *d*. X-ray negative (in-motion technique), *e*. tree-ring width-density plot.

ray opaque, lead-lined cabinet (38) with a sliding door (39).

SAMPLE PREPARATION

The techniques of field collection and mounting of tree-ring samples are those used by the Geological Survey of Canada (Parker 1970). Tree-ring specimens, consisting of wood blocks, 5-mm increment cores, or $\frac{5}{8}$-inch [1.6 cm] cores, are mounted between two sticks of wood (Fig. 2*c*) with the grain in the mounts aligned radially with respect to wood of the tree-ring sample. This mounting technique provides stability for surfacing, X-ray exposure, labelling, and storage of specimens. The mounted samples are fed between a pair of metal-slitting circular saws of a device constructed for this purpose (Kusec 1972). This method produces a specimen with the smooth surface and uniform thickness required for accurate determination of density. The prepared specimens are 2 mm thick (± 0.0025 mm within a sample and ± 0.005 mm between samples), transverse cross sections normally extending from the vicinity of the pith toward the bark (Fig. 2). The specimen identification number and thickness are recorded on the film by writing these numbers on the specimen mount with an X-ray opaque, lead-based paint before X-ray exposure.

A common procedure used by some laboratories using X-ray densitometry is to condition samples to 8 to 12% moisture content. We have decided to oven-dry samples after mounting and keep them in this condition during X-ray exposure. The reasons for this are: (a) Under different conditions of moisture content, there is differential shrinkage between earlywood and latewood, causing variant changes in volume that affect specific gravity; (b) It is difficult to maintain uniform conditions of humidity and temperature from day to day for moisture content conditions other than the oven-dry state; (c) If moisture is present in a tree-ring sample during X-ray exposure, it is difficult to determine the amount of radiation absorbed by water and the amount absorbed by wood. A desiccator was built to hold both a tree-ring sample and an X-ray film during exposure, in order to maintain oven-dry conditions (Figs. 1 and 2*a*).

FILM PROCESSING

Uniform X-ray film development is required to assure the accurate measurement of intra-ring density by X-ray densitometry. The Eastman Kodak Co. recommends gaseous-burst agitation to attain the most uniform development (Eastman Kodak Co. 1969). Large tanks were built to handle the three sizes of X-ray film used, which are 3½ × 17 inches [9 × 43 cm], 8 × 10 inches [20 × 25 cm], and 14 × 17 inches [36 × 43 cm]. A gaseous-burst agitator was built for the film-developing tank and connected to an automatically controlled nitrogen-burst system. Film-processing tanks are placed in a temperature-controlled waterjacket. A fine-grained, high-resolution, single-emulsion X-ray film is used. If double-emulsion film is used, an undesirable offset image will be produced if the X-ray generator is pivoted to accommodate those tree-ring samples with misaligned tracheids.

The X-ray negatives are examined on a light table with a low-power binocular microscope, and the years of the annual rings are annotated on the film.

SUMMARY

The X-ray scanning machine described in this paper was built to produce radiographs of tree-ring samples for densitometric analysis by both in-motion and stationary techniques. The advantage provided by the scanning technique is avoidance of the parallax effect by using a collimated beam of X-rays to penetrate the sample parallel to the longitudinal tracheids along the entire length of the specimen. Constant-speed and vibration-free traversing are provided by a hydraulic system. Stable X-ray emission is enhanced by the use of an AC power conditioner. Sample preparation and film processing techniques also are important considerations in the production of radiographs to be used for intra-ring specific gravity determination.

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Obituary

BROR L. GRONDAL

Dr. Bror L. Grondal, professor emeritus of Forestry at the University of Washington, widely known in forest products research, died 12 March 1974, at the age of 84. He served on the College of Forestry faculty from 1913 to 1959 after receiving his B.A. degree from Bethany College, Kansas, and his M.S.F. from the University of Washington. He received an honorary D.Sc. from Bethany. In 1950 he was named the outstanding University of Washington Forestry Alumnus of the Year, being cited as an authority on wood structure. He invented the opposed-fan dry kiln and was co-inventor of a chemical wood pulping process. The Red Cedar Shingle Bureau printed more than a million copies of his 100-page handbook on red cedar shingles.

Dr. Grondal was chairman of the committee that drafted the Articles of Association and By-laws to originate the Forest Products Research Society, and when that organization was founded in 1947 he was elected Past Chairman in lieu of the present office of Past President. He was active in Sigma Xi and was a past national president of Xi Sigma Pi, as well as being a charter member of the Society of Wood Science and Technology. He was also a life member of the Swedish Forestry Association.

He is survived by his wife, Florence Armstrong Grondal, a daughter, Mrs. D. J. Robbins, and a son, B. P. Grondal, all of Seattle.