G. S. C. TREE-RING SCANNING DENSITOMETER AND DATA ACQUISITION SYSTEM

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ABSTRACT

A tree-ring scanning densitometer and data acquisition system has been built by the Geological Survey of Canada to extract tree-ring density and tree-ring width data from dendrochronological specimens and X-ray negatives of specimens. The system produces tree-ring density plots, ring density and ring-width bar graphs, and printed and punch tape digital data. This prototype was built primarily from commercial pre-constructed electronic components, but a modified densitometer and other original-design units also were used in the construction.

INTRODUCTION

Climatically controlled annual ring-width variation has been the basis for tree-ring studies since the development of dendrochronology early in this century. These unique patterns of ring-widths have made possible the accurate dating of thousands of archaeological tree-ring specimens in the Southwestern United States and elsewhere. These patterns also have been fundamental to studies in dendroclimatology relating annual radial tree growth to climatic parameters. Although *ring-width* variation is the basis for dendrochronology, other features, such as false annual rings, percentage of latewood, transition of earlywood to latewood, and maximum density of latewood are useful for crossdating and climatic comparison. Only recently, however, have techniques of *tree-ring density* analysis been developed that present these characteristics in parctical graphic and quantitative form. Of particular value is the technique of using X-ray negatives of increment borings to produce densitometric plots of tree-ring series (Polge 1965a, 1965b, 1966) and the method of measuring wood density on a scanning microphotometer and automatically recording data on punched tape for computer analysis (Green and Worrall 1964; Green 1965).

This paper reports on the construction and use of the tree-ring scanning densitometer and data acquisition system developed at the Geological Survey of Canada to use this new and promising technique of density analysis. This prototype will record *both ring-width and ring density* data and present them in graphic and digital form. Density and ring-width values are obtained from X-ray negatives, and ring-width measurements can also be taken directly from the tree-ring specimens.

FORM OF THE DATA

The G. S. C. tree-ring scanning densitometer is designed to produce: (1) density plots, (2) ring-width measurements, (3) maximum density bar graphs, and (4) ring-width bar graphs (Fig. 1). The density plots presented in this paper are from X-ray negatives (Parker and Meleskie 1970) plotted by an X-Y recorder and are similar to those produced by Green and Worrall (1964) from radial scans of transverse microtome thin sections of wood samples and by Polge (1966) from scans of X-ray negatives. Radial distance is measured in .01 mm increments by a scan of the X-ray film from pith area toward the bark and recorded on the X-axis in an expanded scale. Film density

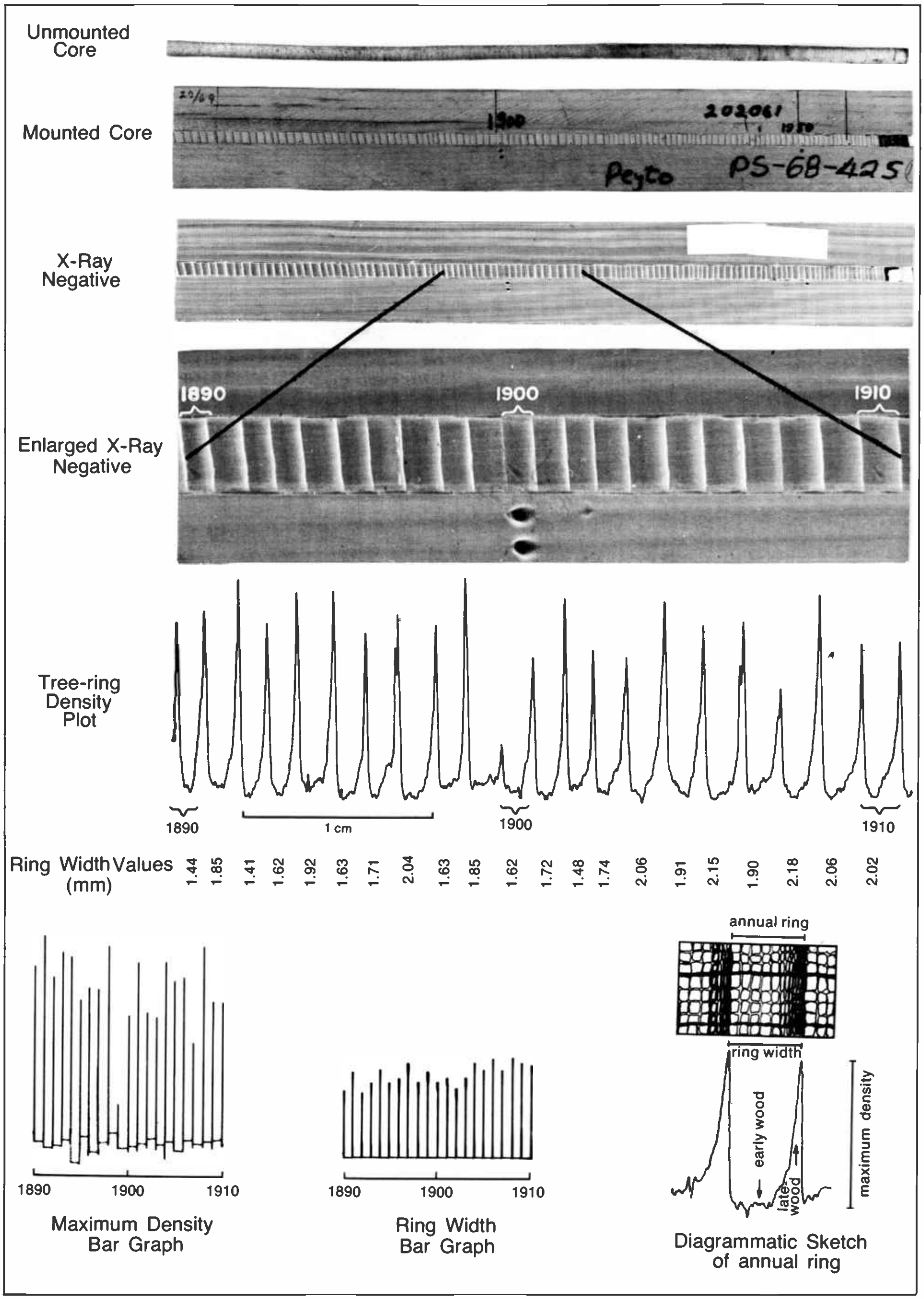

Fig. 1. Tree-Ring Width and Density Data from X-Ray of Increment Core

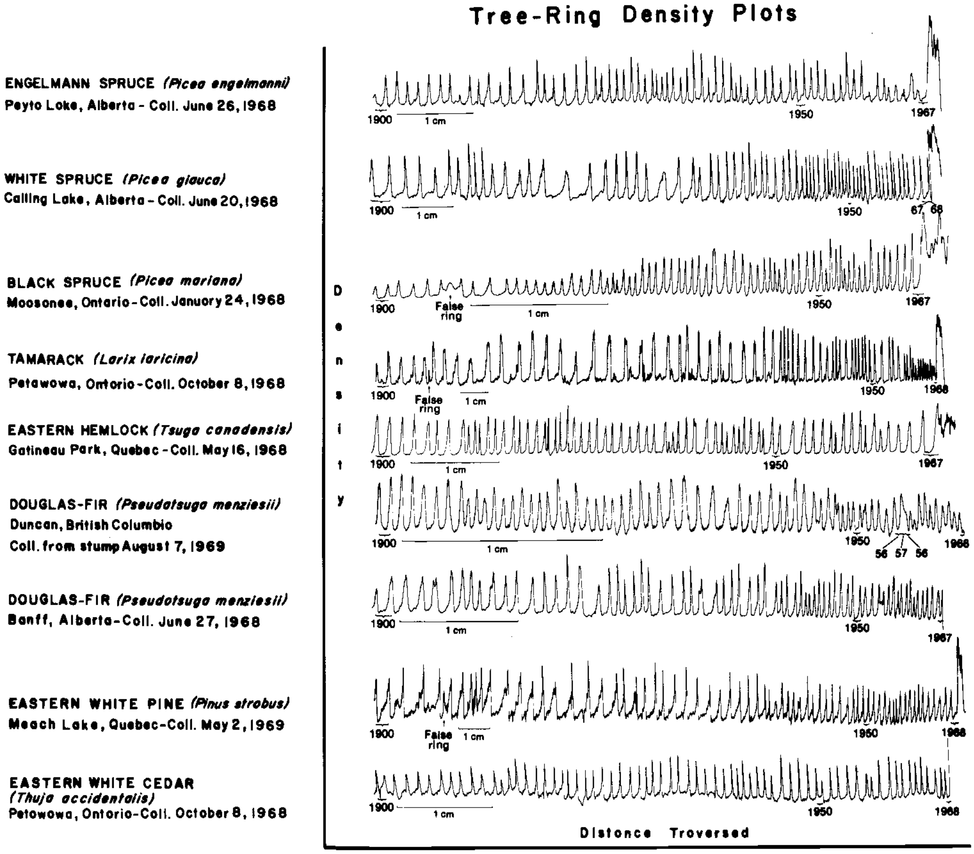

Fig. 2. Tree-Ring Density Plots

(representing wood density) is plotted as relative values on the Y-axis. Maximum plot amplitude indicates maximum wood density.

Annual ring-widths are measured between points of maximum density change on the X-ray negative. Ring-width measurements also are obtained from tree-ring specimens mounted on a carriage and viewed through a microscope with cross hair. Ring boundary positions are determined by the operator and the ring-width data are recorded automatically in printed form and on punched tape.

On the maximum density bar graph, the maximum annual latewood density is plotted on the Y-axis relative to fixed equal year increments on the X-axis. The X-axis is similarly plotted in equal year increments on the ring-width bar graph, but the Y-axis records annual ring-width values.

A number of density plots of tree-ring series of different species are presented to show the form of the data (Fig. 2). Some species exhibit much variation in latewood density and others are more variable in width of the rings. Crossdating between Engelmann spruce trees from the Peyto Lake area in Alberta is illustrated in three different ways: (1) by tree-ring density plots, (2) by ring-width bar graphs, and (3) by maximum density bar graphs (Fig. 3).

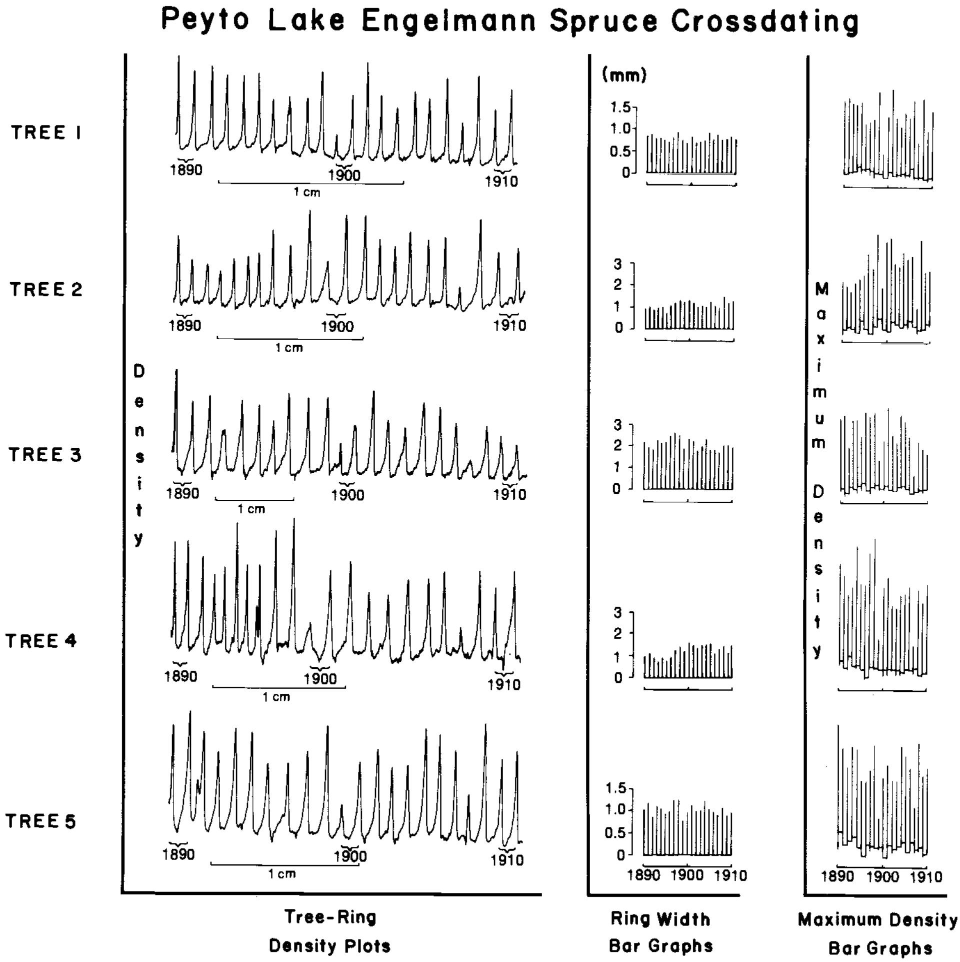

Fig. 3. Ring-Width and Density Crossdating

Design and Construction

Approach and Objectives

It is not economical to construct a complex electro-mechanical system in a small laboratory if comparable apparatus is available from a commercial firm with production line facilities. There is, however, a sound basis for building a system with modern electronic data handling units that can be tied into an existing instrument, such as a densitometer. This is especially true if a new form of data is discovered or developed, a form that cannot be handled by existing commercial instruments. The system to be described is based on these considerations and on the judgement that there are definite advantages in using X-ray negatives of tree-ring specimens for evaluation of annual rings and variations within seasonal growth (Parker and Meleskie 1970).

The negatives produced by X-ray techniques are similar to spectrographic films and can be viewed on most densitometers but need some instrument modification if graphs and digital data are required. Some form of digitized output for computer use is almost essential because of the quantity of data required for building tree-ring chronologies. A precision stepping motor can be used as a source of digitized output. This type of motor, with pulse synchronized to an electronic system, is more advanced and less costly than any comparable mechanical instrument with related gears and shaft-type translators. Modern data acquisition systems, whether computer based or made from separate modules, are reliable, compact, and easily modified to keep pace with future developments. Many manufacturers offer suitable equipment and will usually advise on interconnection between in-going and out-going signal devices.

Basic Units and Operation

Although all components of the system are interrelated, seven basic units are designated for simplicity in explaining its operation: (1) the scanning densitometer, (2) the ring-width measuring table, (3) the digital counter-scaler, (4) the electronic control system, (5) the remote hand-control unit, (6) the X-Y plotter, and (7) the teleprinter and paper tape recorder (Fig. 4). X-ray negatives scanned on the densitometer unit will produce density plots, density bar graphs, and ring-width bar graphs on the X-Y plotter, and ring-width values to be printed and punched by the teleprinter. The functions of start, stop, print, motor speed control, and year increment are controlled by the operator with the remote hand-control unit. Ring-width values are obtained from tree-ring specimens on the ring-width measuring table, also operated by the remote hand-control unit, and recorded on the teleprinter in digital form and as ring-width bar graphs on the X-Y plotter. Radial distances traversed, i. e., values in .01 mm units representing actual distance traversed on the X-ray film or tree-ring specimen, are displayed on the digital counter-scaler. The electronic control system integrates and converts data carrying signals and control signals between all components of the system.

The system, as a whole, permits a great deal of latitude in X-axis and Y-axis plotting scale and scanning speed. At the same time, it is very accurate and responds immediately to control commands.

The Modified Jarrell-Ash Densitometer

A Jarrell-Ash[1] densitometer, now out of production in its original form, has been partially dismantled and modified in the construction of the scanning densitometer and ring measuring table. A new film transport is used, consisting of a pulsed stepping motor with planetary reduction gear and belt drive to a transparent plastic cylinder, around which the X-ray negative is wrapped (Fig. 4*d*; Fig. 5*c*). The transparent cylinder encases the existing light projection arm of the densitometer, permitting the image on the film to be projected onto the original slit table with photoelectric cell beneath. The top part of the original instrument is removed for use as the specimen carriage on the ring-width measuring table, and is driven by the same type of pulsed motor (Fig. 4*a*; Fig. 5*a*).

The pulsed motor (several makes of which are available), driven by a translator unit, permits direct conversion of angular rotation into displayed digits on the electronic scaler-counter, which in turn, provides a binary coded decimal signal to perform any function that is associated with coded data acquisition. The motor has a 200 step function for 360 degrees of rotation, and the shaft to cylinder ratio plus a selected planetary gear provide suitable amount of film advance for one electrical pulse. This is the counting pulse of the scaler and in this system is designated for one hundredth part of a

[1] Brand names are given for information only, with no intention of endorsing any particular product.

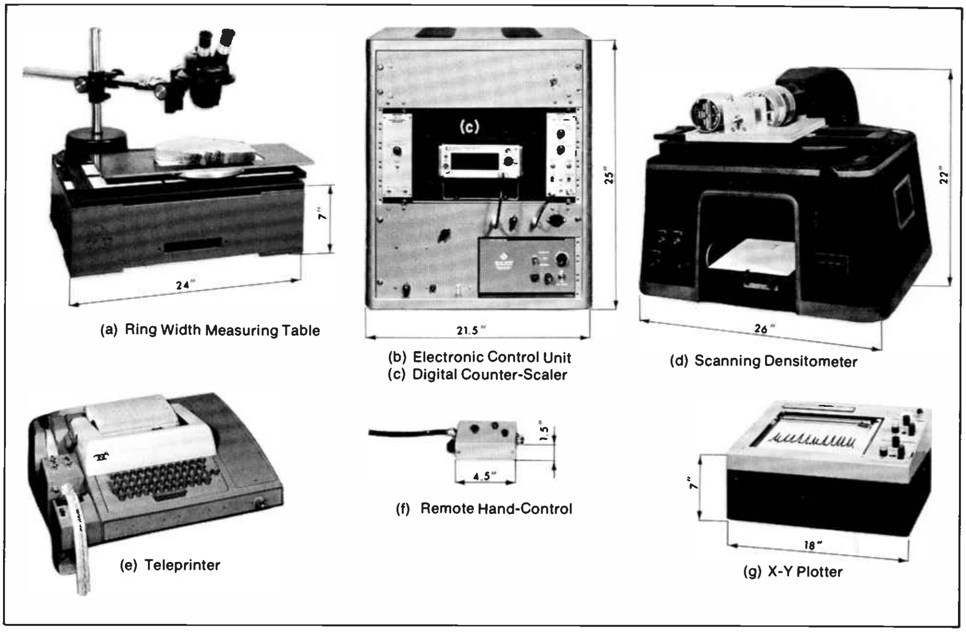

Fig. 4. Basic Units of the System

millimeter, i. e., actual film movement for one digit count. This is well within specification limits of the motor without requiring the use of a high precision unit. Reproducibility is excellent and a distance of 10 cm may be scanned with ±.02 mm. With a suitable belt drive between motor and cylinder, no backlash is present.

The rotating cylinder has the advantage over horizontal table drive in that the overall inertia of the drive system is minimized, permitting the full precision capability of the motor to be used. A table using the heavy steel castings of the original densitometer top has been made for use with heavy wood sections viewed under the microscope. It is working satisfactorily but would be improved by lighter construction to reduce momentum when stopped from fast traverse speeds.

The Electronic System For Control and Data Acquisition

There are two forms of signal information from the X-ray negative that the electronic system can use to transmit data: (1) the distance between chosen points on the line scan of the film surface, and (2) the variation in density within the thickness of the emulsion. The radial distance scanned is a direct function of the stepping motor and is predetermined by the gear ratio selected for one digit displayed by the counter. The only variable is time per step and this is controlled by the motor speed adjustment from approximately 4 to 300 steps per second. The signal is an electrical pulse.

A number of variables can affect the stability of the density information signal, for example the lamp source, the optical system, and the slit control, and these aspects of the basic densitometer design must be considered. In addition, the choice of film emulsion characteristics and the selection of the photosensitive device and its attendant amplifier are important. The density signal is in analog form.

The component parts of the electronic system are: (1) the stepping motors and translator drive (motor control) unit, (2) the logic circuits for digital and analog conversion, (3) the X-Y recorder, (4) the teleprinter and paper tape recorder with control units, (5) the D. C. power supply, and (6) the basic control units and cabinetry for the whole system (Fig. 5). All units can be purchased in complete form except the basic control, and this component can be constructed at moderate cost by one who is versed in logic control methods.

The stepping motors and translator have been described in the preceding section.

The digital counter-scaler has five digit capability plus an outlet in 8421 binary coded decimal (BCD) form to supply the conversion modules. It has an up-down count function to permit decrease in reading for reversal of film direction. This unit is provided with stop, start, and reset output facilities for remote control.

The digital and analog conversion modules are used to perform several functions. The distance-traversed signal, in digital form, from the stepping motor and translator drive unit is converted to an analog signal for X-Y recorder operation by way of the BCD of the scaler. The density signal, of analog origin, is fed directly to the X-Y plotter and may be converted into digital form if needed as output to the teleprinter. Preconstructed module boards that perform these functions are mounted in the basic control unit.

A simple X-Y recorder that plots on 8½ x 11 inch sheets is used in this system. The bar graphs are made using a digital to analog incrementer in the basic control unit. Any standard recorder of this type will accept the analog signals carrying distance and density information, but more elaborate instruments may be worth consideration. The use of

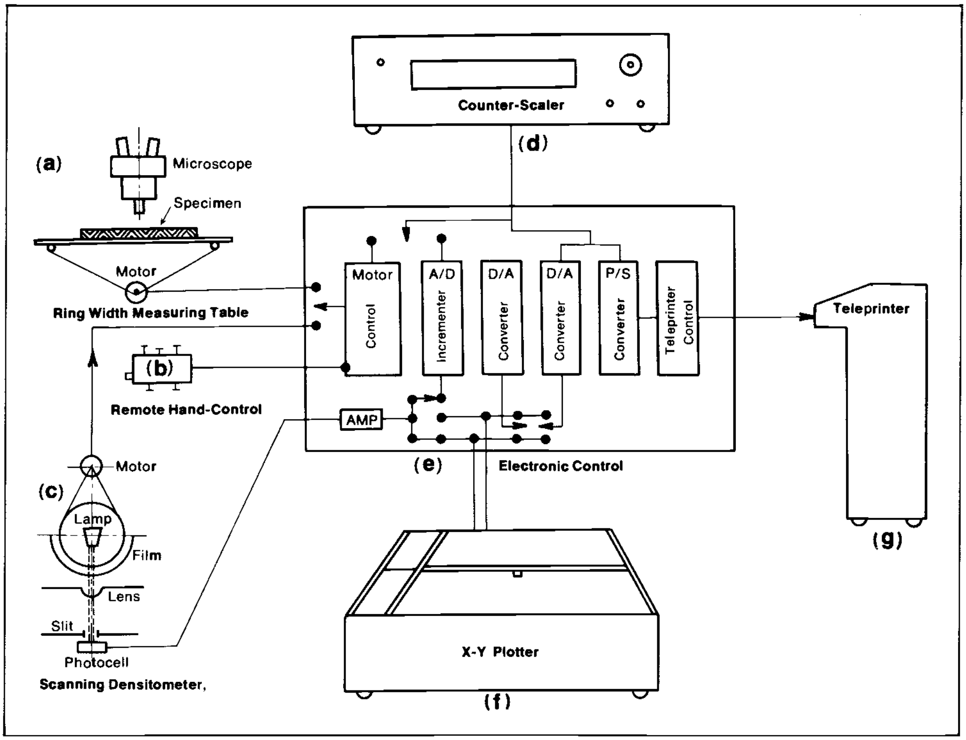

Fig. 5. Schematic Diagram of the System

Z-folded or continuous-roll paper would facilitate the production of the density and bar graph plots; plug-in time-base facilities also would be useful for bar graph plotting; and there are X-Y recorders that interface with computers for in-out signal transfer, making possible the plotting of computer processed data.

The teleprinter and paper tape recorder is a standard ASR 33 Teletype machine and is probably the least expensive recorder on the market for the facilities it offers. An external control is used that includes parallel to series conversion (for the BCD signal from the scaler) and a means for regulating character and line space. Several suppliers offer control units for Teletype machines.

The D. C. power supply is an independent unit, well regulated and with low ripple in order to supply the converters and operational amplifiers needed in the basic control unit.

The basic control unit receives the two information signals (density and distance-traversed) directly for processing by digital or analog conversion modules before being switched to read-out instruments. X-axis or Y-axis amplifiers may be selected for either signal, or one signal only may be selected for one axis while the other axis is fed incremental signals to produce bar graphs. The BCD information is fed into this unit from the scaler and out to the teleprinter and X-Y recorder. The control pulses for start, stop, print, reset, etc., are handled by this unit and cable access is provided for the remote hand-control unit permitting the operator to countermand the panel controls while viewing either the projected image on the scanning densitometer or the tree-ring specimen under the microscope on the ring-width measuring table. The main A. C. supply with fuse and bussed outlets for other units is included in this basic control unit and all of these components are mounted in a standard 19 inch rack-type cabinet (Fig. 4*b*; Fig 5*e*).

SUGGESTED MODIFICATIONS

The system, as described, has cost approximately $7,000 for all component parts except the original densitometer which was available at no cost. This figure does not include the labor involved in design and assembly. The present system is to be considered a prototype and anyone wishing to duplicate it may alternatively consider the use of a small digital control type computer, of which there are now many on the market for about $8,000 including teleprinter in-out control. A universal type interface board could be inserted into the computer to receive the information signals, and a pulsing motor drive board also could be incorporated. The only additional components needed would be the scanning densitometer, the ring-width measuring table, and the X-Y plotter. It would be relatively easy to program in machine language for all of the functions described in this paper.

A great deal could be done to improve the present densitometer aspect of the system by building a completely new optical system with balanced photocell light source designed to maintain constant light level. The slit and projection image could have a finer position indicator line to establish peak locations and also could have better shielding from extraneous light. The transparent cylinder could be mounted vertically for better access, and if it were made of glass it would not be as easily scratched as the plastic cylinder. A rotable slit holder would permit better alignment with the ring boundaries and the angle of rotation could be used to calculate the divergence of the actual scan from a desired scan that is perpendicular to the ring boundaries.

CONCLUSION

Use of tree-ring density information more than doubles the data that can be extracted from tree-ring series by techniques utilizing ring-widths alone. It has been demonstrated that ring density data relate to climatic factors (Polge 1965*b*), and therefore, can be used to supplement ring-width indices for dating and dendroclimatic analysis. The tree-ring scanning densitometer and data acquisition system built by the Geological Survey of Canada extracts width and density data from dendrochronological specimens and X-ray negatives of specimens, and converts these data into useful graphic and digital form. The system was built primarily from pre-constructed modules, and electronic rather than mechanical components were used whenever possible. The overall objective has been to develop a system that will extract both tree-ring width data, for which methods of analysis are well developed, and tree-ring density information, for which methods of analysis have not been developed, but may prove to be at least as important as ring-width data in the future development of dendrochronology.

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