RECTILINEAR SCANNER FOR DETERMINATION OF BONE MINERAL CONTENT

by

MASTER

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INTRODUCTION

A rectilinear scanner and the associated electronic control apparatus (Fig. 1) have been built for use in the photon absorptiometric determination of bone mineral content in vivo. Rectilinear scanning has the advantage of minimizing repositioning errors as compared to a single point determination or a single linear scan. It has been shown (1) that the reproducibility of measurements of bone mineral content of irregularly shaped bones, eg. the distal radius, can be improved from 5% to 2% by averaging three measurements at 3 mm intervals along the bone. The above experiments showed that it is apparently simpler to relocate an area rather than a single line when making measurements on irregularly shaped bones.

This rectilinear scanner was designed to scan a 15 cm x 15 cm area in a raster pattern with a continuous scanning speed of 2 mm/sec in the "y"-direction and variable stepping increments in the "x"-direction. The system has been built on an aluminum base 25 cm square and has a height of about 40 cm. Its weight is approximately 25 pounds including the table for limb support.

The electronic control apparatus includes an electronic timer, relays, and power supplies. This equipment is enclosed in a metal chassis with dimensions 10 in. x 6 in. x 3.5 in. deep. Interconnections between the control box and the scanner are made through a cable which plugs into a socket on the scanner base.

LINEAR SCANNING MECHANISM

The reversible, synchronous motor (see Parts List [P.L.] #1) used for scanning has an output shaft speed of 1 rpm and a torque of 100 in-oz. It is equipped with a planetary type clutch actuated by a 115 VAC relay. When the clutch is de-energized, the output shaft is free to rotate, permitting the scanner to be moved manually to any desired position.

The platform to which the source and detector holders are attached, the guide rods and their end supports, and the base plate to which these supports and the scanning motor are mounted will be termed the linear scanning system. Power is transmitted to the

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Fig. 1. Photograph of the rectilinear scanner and the control box. The end of scan bumpers on the source and detector platform and the limit switches on the guide-rod end supports can be seen (scale in cm.).

platform carrying the source and detector via a toothed belt attached to the platform and a geared pulley (P.L. #2). The platform, supported by ball bushings, travels along a parallel pair of hardened, stainless steel guide rods (P.L. #3) (Fig. 2). The geared pulley has a pitch diameter of 1.500 in. yielding a theoretical belt speed of 1.995 mm/sec. Measurements of the time elapsed in scanning a 10.00 cm (SD = .06 cm) path yielded scanning speeds of 1.997 mm/sec (SD = .012 mm/sec) in the forward direction and 2.002 mm/sec (SD = .013 mm/sec) in the reverse direction.

The limits of the scan are set at the desired end points by adjusting a pair of bumpers attached to the source and detector platform. These bumpers activate a set of limit switches fastened to the guide-rod end supports (Fig. 1). Depending on the settings selected on the control panel, either the direction of the scanning motor is reversed at the end of the path and the scanner moves back along the same line in the opposite direction or dynamic braking is applied to the scanning motor and the stepping sequence is initiated.

STEPPING MECHANISM

With the scanning motor stopped, power is applied to the stepping motor: a reversible, synchronous motor with 30 in-oz of torque and output shaft speeds of 30 or 60 rpm (P.L. #4). The stepping motor remains "on" for a time interval, set on the control panel, ranging from 1.1 to 17.1 seconds. Power is transmitted to a lead screw of 1.25 mm pitch via a toothed belt and a pair of geared pulleys (P.L. #5) (Fig. 3). The lead screw is threaded through a pair of bronze lead nuts attached to the base plate of the linear scanning system (Fig. 2). The rotation of the screw thus indexes the linear scanner by the pre-set distance. The scanning system is supported by the lead screw and a parallel, hardened, stainless steel shaft. The system is borne on the shaft by a ball bushing (P.L. #6). At the completion of the step, dynamic braking is applied to the stepping motor and removed from the scanning motor. The scanner then resumes its motion in the opposite direction.

ELECTRONIC CONTROLS

The "on" time of the stepping motor is determined by an electronic timer. A 60 Hz sinusoidal signal is fed to a Schmitt trigger which outputs a 60 Hz square wave. This signal is inputted to the clock of the first of eleven J-K flip-flops (P.L. #7). The Q output of this flip-flop is connected to the clock of the second and so on. Each of the flip-flops outputs a square wave with a period twice that of its input. The outputs of the last five flip-flops yield "on" times of 1.1, 2.1, 4.3, 8.5, and 17.1 seconds. The amplified output operates a relay which disconnects the power from the stepping motor. Dynamic braking is then applied to this motor thereby insuring that the

Fig. 2. Photograph of the linear scanning system showing the toothed belt, geared pulley, and guide rods. Also shown are the lead screw and nut used for the stepping motion.

Fig. 3. Shown here are the belt and geared pulleys for transmitting power to the lead and the aluminum table for limb support (scale in cm.).

step terminates without coasting. Stepping can be done in either direction with negligible difference between the length of steps for the two directions (see Table 1). Stepping is done at the 30 rpm speed. The 60 rpm speed is available for slewing to a desired starting position.

The control panel (Fig. 4) is divided into two sections plus the main power switch and neon pilot light. The section labelled "Scan Motor" includes three switches: scan-standby; forward reverse; and clutch, in-out. The "Scan-St'dby" switch supplies either 115 VAC, for scanning, or D.C., for braking, to the scanning motor. With the switch in the "St'dby" position the scanner is rigidly locked in place by the dynamic braking applied to the motor. The "F-R" switch operates a relay for reversing the direction of the scanning motor at any time during a scan. The "Clutch, In-Out" switch controls the relay on the scan motor which operates the clutch on its output shaft. With the clutch out the source and detector platform can be moved manually for easy positioning.

The controls for the step motor include the "No-Step" switch which de-activates the stepping electronics. With this switch in the "No-Step" position, the scanner will reverse at the end of each linear scan without stepping. The "30-60" switch controls a relay which selects either the 30 or 60 rpm speed of the stepping motor. There is also an "F-R" switch for reversing the direction of stepping. Limit switches attached to the linear scanner will also do this automatically when it comes to the end of the lead screw. The switch labelled " ∞ " is used to put the stepping motor into the slewing mode for arriving quickly at the desired starting position. Finally, a rotary switch labelled "Step-Length - 1, 2, 3, 4, 5" selects the length of step that the scanner will make at the end of a linear scan. The lengths of the steps are those given in Table 1.

PROPOSALS AND CONCLUSIONS

In contrast to the linear scanners made at Wisconsin (2,3) for which the scan path is within the guide-rod end supports the scan path of the rectilinear scanner is totally outside of the scanner mechanism. An aluminum table, 30 cm x 50 cm, has been attached to the scanner for supporting a subject's limb during the scan (Fig. 3). A section of the table-top somewhat greater than the maximum scanning area has been removed and the opening is surrounded by a one half inch wide shelf. It is intended that special holders for scanning the forearm, humerus, or os calcis, etc. will be designed to sit on this shelf and be fastened to the table, thus obviating the need for several special purpose scanners.

We eventually hope to obtain position information by installing linear potentiometers coupled to the scanning and stepping systems. Also suitable logic circuits can be designed to use this information to provide precise electronic settings for the limits of a scan.

Table 1.

<u>Step Number</u>	<u>Theoretical Step Length (mm)</u>	<u>Measured Forward Step Length (mm) $\pm$ S.D.</u>	<u>Measured Reverse Step Length (mm) $\pm$ S.D.</u>
1	0.669	0.715 $\pm$.069	0.712 $\pm$.062
2	1.331	1.377 $\pm$.052	1.378 $\pm$.051
3	2.669	2.714 $\pm$.047	2.715 $\pm$.052
4	5.331	5.37 $\pm$.10	5.380 $\pm$.083
5	10.669	10.728 $\pm$.029	10.739 $\pm$.037

Fig. 4. The control panel used to operate the scanner (scale in cm.).

Because this unit was designed to be versatile it is necessarily larger and heavier than a similar unit which might be designed for a specific application. Considerable savings in weight could be made by replacing the stepping motor with a manually activated stepping device. Various structural components could possibly be made of thinner material, or channeled and tubular elements could be used. A side-on photomultiplier tube and a radiation source mounted on a telescoping, hydraulically activated linear scanner could offer considerable size and weight savings.

PARTS LIST

1. Hurst Model AR-DA; 100 in.-oz. @ 1 rpm; Hurst Manufacturing Corp., Princeton, Indiana 47570.
2. Pic No. FA-189 "No-Slip" Positive Drive Belt and No. FC4-48 "No-Slip" Geared Pulley; Pic Design Corporation, P.O. Box 335, Benrus Center, Ridgefield, Conn. 06877.
3. Thomson Solid Stainless Steel 60 Case Hardened and Ground Shafts, 3/8 in. dia. x 10 in. long; and three of Thomson Precision Series A Ball Bushings, 3/8 in. bore, No. A-61014; Thomson Industries Inc., Manhasset, New York 11030.
4. Holtzer-Cabot Ser. No. MF 3810-1; Holtzer-Cabot Corp., Tri-Boro Industrial Park, North Attleboro, Mass. 02760.
5. Pic No. FA-95 "No-Slip" Positive Drive Belt and two of No. FC6-48 "No-Slip" Geared Pulleys (see #2).
6. Thomson Solid Stainless Steel 60 Case Hardened and Ground Shaft, 1/2 in. dia. x 10 in. long; and Thomson Precision Series A Ball Bushing No. A-81420, 1/2 in. bore (see #3).
7. Motorola Integrated Circuit No. MC 723 P; Motorola Inc., Chicago, Ill.

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3. Witt, R.M., Sorenson, J.A. and Cameron, J.R. An Improved Linear Bone Mineral Scanner. U.S. Atomic Energy Commission Report COO-1422-40 (August, 1968).

ACKNOWLEDGEMENT

This work is supported in part by the U.S. Atomic Energy Commission through Contract AT-(11-1)-1422.