Square Cants from Round Bolts Without Slabs or Sawdust

By

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FOR MAXIMUM EFFICIENCY A HEADrig for converting bark-free bolts into cants must (1) have a fast cycle time, (2) require minimum handling of bolts and refuse, and (3) convert the volume represented by slabs and kerf into a salable byproduct.

In an effort to satisfy these requirements, three headrig configurations were conceived. All have one feature in common—the bolt is centered between end dogs prior to machining. A bolt length of 100 inches was used for test purposes because this length was considered the maximum that could be clamped between end dogs without suffering excessive lateral deflection during machining. None of the headrigs make sawdust, they convert the entire volume outside the S4S cant into pulpable chips. One of the rigs is also capable of making flakes with dimensions approximating those of a postage stamp. All three headrigs were tested on green slash pine bolts. Gross and net cutterhead power requirements were measured with a recording wattmeter. Motion pictures were taken at speeds adequate to reveal the gross mechanism of chip formation.

The three designs create chips or flakes by distinctly different cutting actions: (1) end-milling with chip severance accomplished by cutting across the grain wth the knife edge at right angles to the grain, (2) peripheral milling with the knife edge perpendicular to the grain but traveling more or less parallel to the grain, and (3) cutting with a shaping lathe configuration in which the knife edge is parallel to the grain but moves perpendicular to the grain. The kinematics, force systems, and chip severance phenomena associated with these three cutting systems are explained in detail by Koch.[1]

[1] Koch, Peter. 1964. Wood machining Processes. Chapters 3, 4, and 12. The Ronald Press Company, New York. (In press.)

Results

The experimental setup for the end-milling configuration is illustrated in Figure 1. The path taken by each knife is shown in the inset.

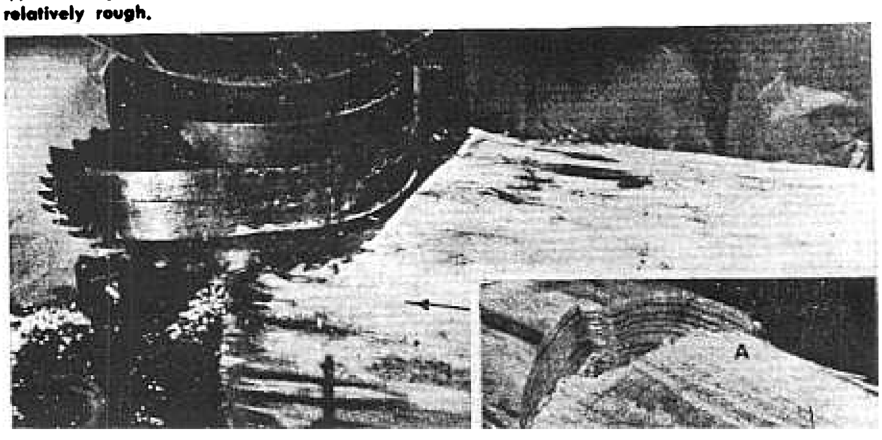
Resulting pulp chips are shown in Figure 2. Shear failures caused at the time of chip formation permit the gross chip to be broken readily into smaller chips of rather uniform thickness and precisely uniform length. Close examination of the chips discloses primary fiber failure at the cutting plane and secondary failures at a variable distance below the cutting plane. This phenomenon has been explored and explained by McKenzie.[2] These secondary failures probably would reduce pulp yields.

Net specific-cutting energy averaged 0.011 hp minute per cubic inch of wood removed. This is an average value for chip thicknesses of ½, ⅝, and ¾ inch. The green slash pine bolts averaged 86 percent moisture content and 0.58 in specific gravity (oven-dry volume and weight).

On production equipment, cutterheads would consist of two-knife cutting discs arranged in a staggered stack several inches high; the machine would have two heads, on opposite sides of the bolt. Spacing between the heads would determine size of the cant. After traveling between the opposed heads on the first pass, the bolt would index 90° about its long axis before returning between the cutters on the second and final pass prior to discharge. The heads would rotate at 3,600 rpm, and speed of bolt traverse would determine chip length.

[2] McKenzie, W. M. 1960. Fundamental aspects of the wood cutting process. For. Prod. J. 10(9) :447–456; and McKenzie, W. M. 1962. The relationship between the cutting properties of wood and its physical and mechanical properties. For. Prod. J. 12(6) : 287–294.

Figure 1.—Experimental setup for end-milling configuration of Koch Headrig. Green slash pine bolt measures 9 inches in diameter. Cutterhead equipped with two carbide-tipped knives turning at loaded speed of 62 rpm; rake angle 45°, sharpness angle 37½°, clearance angle 7½°, and cutting-circle diameter 11-1/16 inches. Traverse speed of bolt 62 inches per minute for ½-inch chip, 77½ inches per minute for ⅝-inch chip, and 93 inches per minute for ¾-inch chip. Inset shows contour of cut; splintering has occurred at point A, and surface is relatively rough.



The force exerted by each knife is enough to cause a maximum deflection of 5/16 inch at midspan of a 100-inch bolt 9 inches in diameter. This configuration also causes some undesirable splintering as the knife emerges from the cut (inset of Figure 1). Judicious arrangement of a thin scoring saw preceding the main cutter showed some promise of alleviating the situation. In Figure 1, a saw is attached to the end of the cutter. Tests were made with this saw removed, and the surfaces thus produced were not appreciably rougher.

High requirements of specific cutting energy, exertion of a large force normal to the longitudinal axis of the bolt, a tendency toward tearout at the corners of the cant, a rough surface on the cant, and formation of some fines are the principal disadvantages of the end-milling configuration. On the other hand, the cube-like chips are uniform and should pack well in a digester. It is probable that further research would lead to the development of an end-milling cutter that would minimize most, if not all, of the problems enumerated above.

The experimental setup for the peripheral-milling configuration is shown in Figure 3. The end-clamped, green, slash pine bolt has been previously shaped to leave a known volume of wood for removal in four successive passes at different feeds per knife. This was done to facilitate calculation of net specific-cutting energy. Cutterhead rotation and feed direction are arranged to effect climb-milling.

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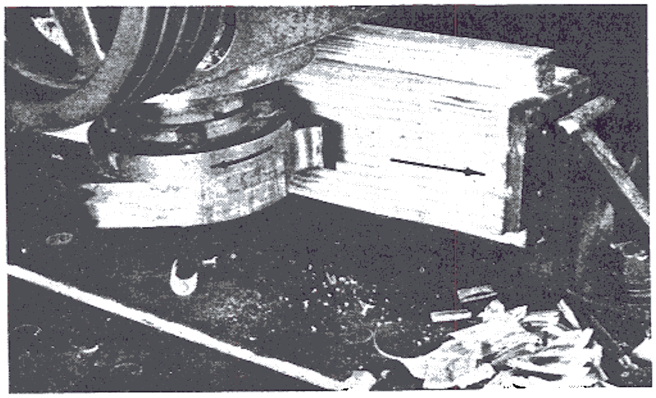


Figure 3.—Experimental setup for peripheral-milling configuration of Koch Headrig. Refer to Figure 1 for cutterhead specifications and feed speeds.

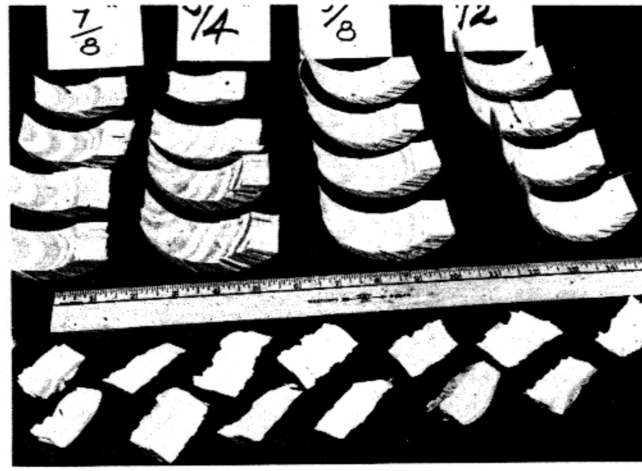


Figure 4.—Pulp chips (slash pine) from the configuration shown in Figure 3.

A production machine would require one pair of opposed sideheads rotating so as to effect climb-milling on the first pass of the bolt, and a second pair of opposed heads rotating in the opposite direction to climb-cut on the return pass. The heads, consisting of staggered 2-knife discs stacked to a height of 20 inches, would turn at 3,600 rpm. Thus the bolt would be completely machined in an initial pass followed by a 90° indexing and return.

Resulting pulp chips are shown in Figure 4. These chips were made at feeds per knife of ½, ⅝, ¾, and ⅞ inch; net specific cutting energy was, respectively, 0.0026, 0.0024, 0.0023, and 0.0020 hp minute per cubic inch of wood removed. The slash pine bolt averaged 84 percent moisture content and 0.56 specific gravity. Koch[3] explains why specific cutting energy decreases with increased chip size.

Shear failures caused at the time of chip formation permit the gross chip to be broken readily into smaller chips that closely approximate the conventional pulp chip in size and appearance. Virtually no fines are produced by this machining technique.

With this configuration, both specific-cutting energy and the force normal to the longitudinal axis of the bolt are greatly reduced. Maximum deflection at the midpoint of the illustrated bolt was less than 0.02 inch. Furthermore, normal forces from the paired cutterheads are self-canceling. The surfaces generated are accurate and moderately smooth, but reflect the effects of the large feeds per knife.

The experimental setup for the shaping-lathe configuration is shown in Figure 5. Rotational speed of the log is variable from approximately 2 through 14 rpm. The cutterhead spindle is fixed while the workpiece spindle oscillates under control of the cam to generate the shape of the cant (point A, Figure 5). The 6-knife cutterhead illustrated consists of three pairs of L-shaped knives, each pair set to track and cut flakes approximately 1-3/16 inch long. Thus, the entire head assembly illustrated makes a cut 3½ inches long. The bolt was scored in sections to permit measurement of power requirements or photographic analysis for nine cutting situations. The green slash pine bolt is 12¼ inches in diameter. The finished S4S cant dimension is 7⅞ inches square.

Flakes shown in Figure 6 are 0.016 inch thick (average) and 1-3/16 inches long. Flake thickness is controlled by adjusting the speed of the cutterhead

[3] *Op. cit.* See equations 6–81 through 6–87 and figure 6–25.

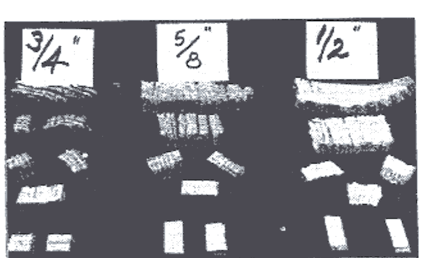


Table 1. — POWER REQUIREMENT AND FLAKE CHARACTERISTICS WHEN REDUCING ROUND, BARK-FREE, GREEN, SLASH PINE BOLTS TO S4S CANTS ON A SHAPING LATHE [1]

Log diameter (Inches)	Moisture content (Percent)	Specific gravity, oven-dry weight and volume	Cant size (Inches)	Rpm of bolt	Peripheral feed per knife on bolt circumference (Inches)	Net power (feed and cutting) per lineal inch of bolt length [2] (Hp)	Net specific power (feed and cutting) per cubic inch of wood removed [3] (Hp minutes)	Average thickness of oven-dry flakes (0.001 inch)	Range of flake thickness [4] (0.001 inch)
5½	106	0.58	3 by 4	1.82	0.0059	0.33	0.0154	8	4- 14
				4.0	.0129	.52	.0111	14	4- 29
				7.24	.0234	.85	.0100	18	5- 37
				10.33	.0334	.93	.0077	28	6- 60
				14.0	.0453	1.11	.0067	37	6- 75
12¼	104	.50	7⅞ by 7⅞	1.82	.0131	1.0	.0096	11	4- 21
				4.0	.0288	1.9	.0085	18	4- 30
				7.24	.0522	2.5	.0062	26	6- 52
				10.33	.0744	3.3	.0057	40	8-119
				14.0	Cam would not stay in contact with followers at 14 rpm.				

[1]Up-milling 13-inch diameter cutterhead rotates at 2,675 rpm. Two knives tracking, rake angle 45 degrees, sharpness angle 30 degrees, clearance angle 15 degrees.

[2]Gross hp m nus idling hp. These values are approximate inasmuch as they represent peaks rather than averages recorded on the wattmeter. Because the wattmeter requires a certain time to react and accurately record a maximum, and because load duration was sometimes short, some peaks are probably understated.

[3]Net cross sectional area of wood removed: 11¾ square inches from the 5½ inch bolt, and 56 square inches from the 12¼ inch bolt.

[4]Flake thickness varies because of knife path (up-milling), cam-induced workpiece oscillation, imperfect tracking of knives (could be emedied by jointing), and tearout.

(or bolt). Flake length is controlled by the length of the cutting edge on individual knives, or by suitably placed scoring knives.

Specific-cutting energy, including feed energy, averaged 0.009 hp minute per cubic inch of wood removed when data from two bolts and all flake thicknesses were grouped (Table 1). The green slash pine bolts averaged 105 percent moisture content and 0.54 specific gravity. Specific-cutting energy in this configuration is reduced because of the cutting direction in relation to the grain, but it is increased because of the relatively thin chips (Figure 6). Cutting forces normal to the bolt can be reduced to a nominal value by proper design of the knives. A production machine would have a cutterhead extending the full length of the 100-inch bolt.

This configuration produces an accurately sized cant with a superior surface and sharp, well-defined corners. By modifying the shape of the cam it is possible to produce cylindrical fence posts, cants with chamfered corners, or other desired polygonal shapes. The flakes have dimensions suitable for the manufacture of flakeboards with superior mechanical properties. At some sacrifice of surface quality on the cants, the headrig probably can also produce pulp chips with a minimum amount of damage to individual fibers. From this point of view, the headrig might be superior to the conventional pulpchipping machine, which characteristically causes some end-bruising of each chip.

The shaping lathe has the advantage that the bolt need not be traversed but need only be revolved once about its longitudinal axis. A single cutterhead is required. The cutterhead exerts nominal force normal to the cutting plane, although the force tangent to the cutting plane may be sufficient to cause deflection on bolts of small diameter.

With all of the foregoing thoughts in mind, preliminary designs for production equipment were made only on the peripheral-milling and shaping-lathe configurations.

Production Capabilities

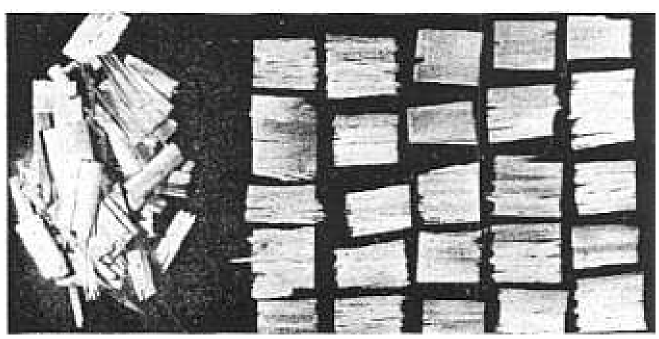
In order to assess the production capabilities of these designs, it is assumed that the available boltwood measures 100 inches long and averages 8½ to 9 inches in diameter inside bark at mid-length (i.e., large enough to yield a wane-free cant slightly larger than 4 by 6 or 5 by 5 inches).

If the headrig can produce five cants per minute for 360 minutes out of a 480-minute shift, the per-shift production of green S4S cants will be 2,500 cubic feet and boltwood consumption will be 73 cords or 1,800 bolts. It is assumed that there are 75 cubic feet of solid wood in a standard cord (128 cubic feet) of 100-inch, rough, southern pine bolts. Approximately 2.2 cubic feet of bark-free roundwood are required to make 1 cubic foot of S4S, wane-free, green cant.

It is also assumed that the green bolts (after barking) average 100 percent moisture content and that the green weight of the bark-free boltwood is 62.4 pounds per cubic foot. It follows that approximately 94 tons

Figure 5.—Experimental setup for shaping-lathe configuration of Koch Headrig. Refer to Table 1 for description of cutterhead.

Figure 6.—Typical slash pine flakes from the configuration shown in Figure 5.



(green-weight basis) of pulp chips (or flakes for flakeboard) will be produced per 8-hour shift. In addition, the barker will remove 20 to 25 tons of green bark per 8-hour shift.

Two alternative headrig configurations were analyzed. Both are entirely automatic from the time the bolt is delivered to the log deck until the S4S cant is removed by forklift from the sorter behind the headrig. The degree of closure of the charging jaws automatically measures bolt diameter and starts a sequence of actions that controls the charging, setworks, discharge, and sorting mechanisms. A sawyer stands by to observe the action, override the automatic setworks if necessary, recycle to eliminate wane, and take action in the event of mechanical trouble. Bolt diameter determines cant size. The program instructions may be changed as desired. For example, 8½-inch-diameter bolts may be machined into 4¼- by 6-inch cants one day and into 5¼- by 5.4-inch cants on the next.

The peripheral-milling configuration (Figures 3 and 7) is designed to accept a bolt having a minimum diameter of 4½ inches and convert it into a 2 by 4, but 4¼ by 3 inches probably will be a more likely minimum practical cant size. Charging and sorting layouts are illustrated in Figure 8. It is believed that one forklift operator can offbear 4-foot-wide tiers of cants from the sorter, place stickers, and build 4-foot by 4-foot packages of cants for delivery to the subsequent manufacturing station.

The shaping lathe configuration (Figures 5 and 9) is principally designed to make cants 4¼ by 3 inches and larger, but it will accept bolts of 3- and 4-inch minimum diameter for conversion into round fence posts. The charging, discharging, and sorting mechanisms are diagrammed in Figure 10.

Price of the headrig equipment (not installed), complete with automatic controls, log deck, charging equipment, headrig, discharge chains, and 15-place sorter, is estimated at $130,000 for the peripheral-milling layout and $120,000 for the shaping-lathe. Knives and grinding room equipment require additional sums.

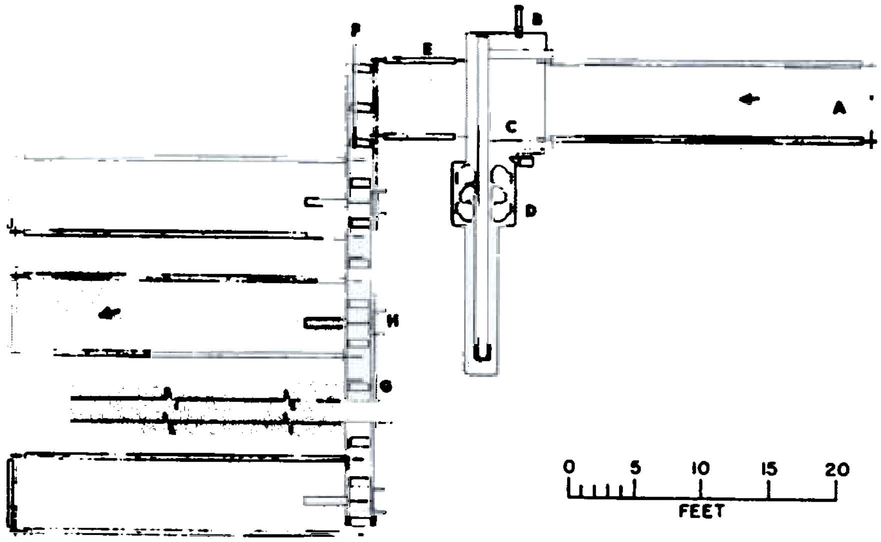


Figure 8.—Flow plan for peripheral-milling configuration of Koch Headrig. Sequential automatic operations are listed below.

Details for Figure 7

A. Charging jaws close symmetrically and center bolt in two planes.

B. Traverse ways for charging jaws permit centered bolt to be moved into line with the end dogs of the carriage.

C. Overhead track (with matching track below) to carry end dogs that grip the bolt on both ends. Carriage traversed at constant speed (according to desired chip length) by motor-driven ball screw.

D. Opposed pair of 2-knife, 20-inch-high, 14-inch cutting circle, 65 hp chipping heads turning at 3,450 rpm. This pair cuts only on the first pass and rotation is such that climb-milling is achieved.

E. Opposed pair of 12-knife, 15 hp jointer heads set 1/64-inch inside chipping heads D and F in order to put a well-planed final surface on the cant.

F. Chipping heads same as D but rotating in the opposite direction to climb-cut on the return pass. (Note: Cutterheads D, E, and F are mounted in two opposed assemblies so that cant size can be controlled by an automatic setworks.)

G. Chip outlet hoods. The few shavings made by jointer heads E must be separately exhausted.

H. End dogs (narrow enough to pass between cutterheads when in their most closed position).

I. Turning tongs to rotate partially machined bolt after initial pass. Only center pins of end dogs remain engaged during 90° rotation.

Notes: Bolt length, 100 ± 2 inches; bolt diameter, 4½-inch minimum and 24-inch maximum; S4S cant size, 3- by 4¼-inch through 12- by 12-inch; cycle rate, 5 cants per minute; chip length, ½, ⅝, or ¾ inch as specified

Details for Figure 8

Charger Cycle:

1. Bark-free bolt proceeds down the log deck (A) and drops into the charger. Not shown, but necessary, is a bolt spacing and indexing device to make sure that bolts are delivered to the charger singly and in proper attitude.
2. Cylinder (B) pushes bolt against stop to position one end.
3. Clamps of bolt charger (C) close symmetrically and center bolt in two planes.
4. Degree of closure of charging clamps, acting in concert with program instructions relating S4S cant size to bolt diameter, puts information into the memory system to control setworks and sorter mechanisms.
5. The charger assembly (with bolt) advances until its centerline coincides with the centerline of the carriage.

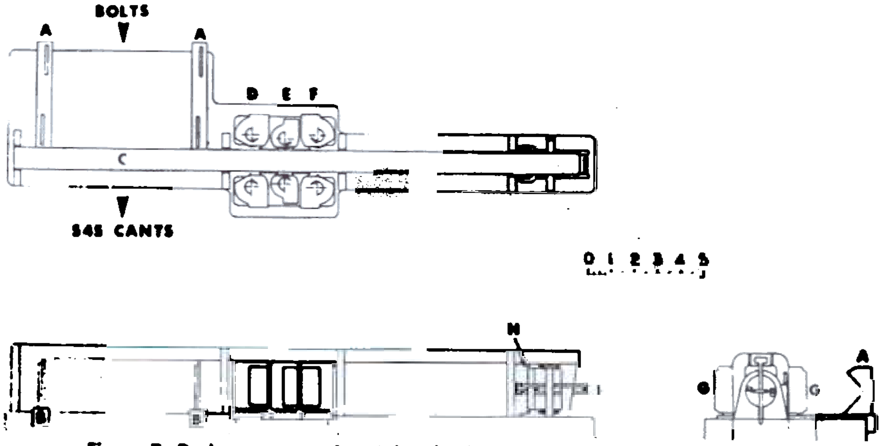


Figure 7. Design concept of peripheral-milling configuration of Koch Headrig. Details for points A through I are listed above.

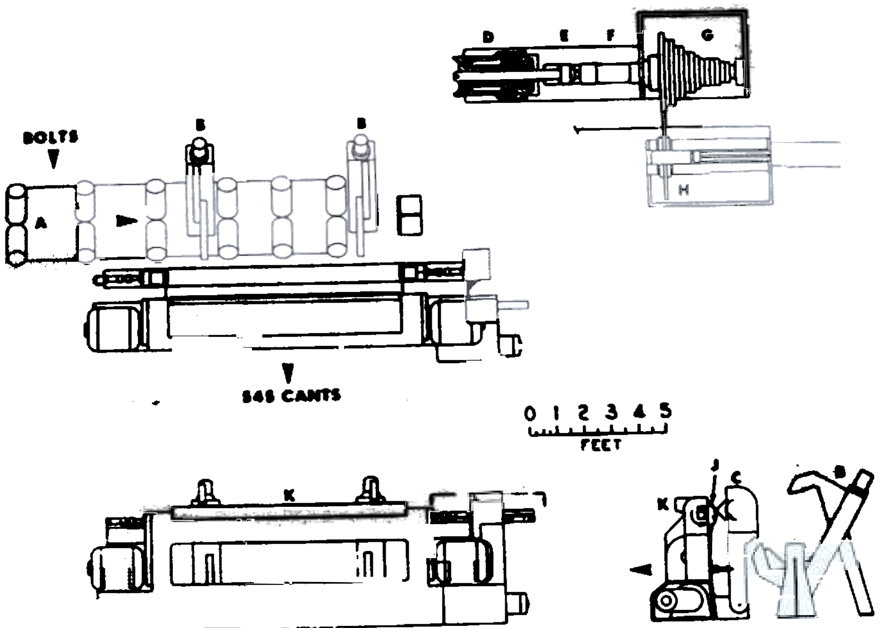


Figure 9.—Design concept of shaping-lathe configuration of Koch Headrig. Details for points A through K are listed below.

6. End clamps on carriage engage and the automatic setworks positions cutterhead clusters (D).
7. Charger clamps release.

Headrig cycle:

8. Carriage makes constant-speed forward stroke.
9. When the carriage clears the charger clamps, the charger retracts and picks up another bolt.
10. At the end of the forward stroke, the turner grips the finished surfaces on one end of the bolt.
11. The carriage end clamps release the outermost dogs, but do not free the center pin from the bolt.
12. The turner rotates the bolt 90° (by rack and pinion) and at the same time the setworks repositions cutterhead clusters (D).
13. The end dogs are reset and the turner releases the bolt.
14. The carriage completes its return stroke and discharges the S4S cant, and the cycle repeats.

Sorter cycle:

15. As the charger moves to the carriage centerline with a new bolt, the finished and discharged S4S cant is pushed onto the sorter receiving chains (E), and proceeds to roll case (F).
16. The proper sorter stop, (G) for example, is energized by the memory system.
17. Ejector (H) is energized and the cant is pushed off onto the accumulation chains (I).
18. Cants proceed to end of chains (I) to be picked up in tiers and stacked in stickered packages by a forklift truck.

Details for Figure 9

A. Vee-rolls to feed bolt endwise into charging jaws.
B. Charging jaws close symmetrically to center bolt in two planes.
C. Work-holding arm pivots to center line of charger and picks up bolt.
D. Detail of variable-speed, power-driven (5 hp) retractable chuck.
E. Hydraulic cylinder for engaging entire housing on large bolts.
F. Cylinder for engaging only center pin on small bolts.
G. Cams (one duplicating each desired shape of cant or post).
H. Cam follower having same diameter as cutterhead.
I. Positioning device to locate cam follower in relation to cams (remotely and automatically controlled with 15 positions).
J. 104-inch-long cutterhead with six jointed knives driven by a pair of 150 hp motors (one at either end) at 2,880 rpm. Cutting circle is 13 inches in diameter.
K. Exhaust hood for flakes.

Notes: Bolt length 100 ± 2 inches; bolt diameter, 3 inches minimum and 24 inches maximum, S4S cant size, 3- by 4¼-inch through 12- by 12-inch (also 3- and 4-inch round fence posts); cycle rate, 5 cants per minute; flake thickness and length as desired (0.015-inch thick and 1 inch long, for example).

Details for Figure 10

1. Bark-free bolt moves down bolt deck (A) and drops into vee-rollers (B).
2. Vee-rollers move bolt against stop (C).
3. Charger jaws (D) close symmetrically to center bolt in two planes.
4. Degree of closure of charging clamps, acting in concert with program instructions relating S4S cant size (and desired flake thickness) to bolt diameter, feeds the memory system to control cam positioner, retractable chuck selection, rpm of workpiece spindle, and sorter mechanisms.
5. Work-holding arm pivots to centerline of charger and bolt is end-dogged with suitable chuck.
6. Cam follower is positioned over proper cam to produce S4S cant as programmed.
7. Charger clamps open and bolt begins to rotate at programmed rpm.
8. Workholding arm pivots to machining position and comes under control of the proper cam.
9. Charger picks up another bolt.
10. Bolt in work-holding arm makes one revolution and machining is complete.
11. Work-holding spindle stops rotating, cant is dropped onto receiving chains (E), and cycle repeats.
12. Sorter cycle same as in Figure 8.

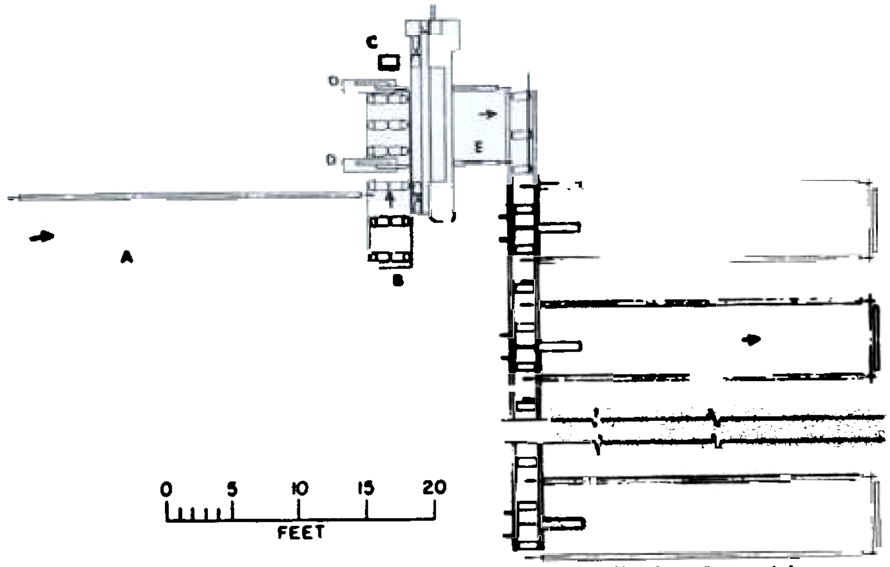


Figure 10.—Flow plan for shaping-lathe configuration of Koch Headrig. Sequential operations are listed below.