Precision grinding to produce more accurate corrugating rolls

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ABSTRACT: The accuracy of the flutes on the corrugating roll has a profound effect on productivity and box strength. This report describes the technology used to precision-grind the corrugating rolls required for high-speed manufacture of high-quality board.

KEYWORDS: Accuracy, continuous process, corrugated boards, corrugated machines, flutes, grinding, precision, rolls, specifications.

Several manufacturers are producing corrugated board at average speeds of over 275 m/min (900 ft/min) and at top speeds approaching 380 m/min (1250 ft/min). Operating speed and roll life are chief among the demanding requirements for today's corrugating rolls, which are manufactured in the A-, B-, C-, and E-flute configurations.

Metal shaping

What is the most efficient roughing method to remove the metal from a corrugating roll to form the profile of the flutes? The conventional method of removing metal is with single-point planers or the multifluted cutters used in gear hobbers and milling machines. The planer or hobbing machine, running at economical feeds and speeds, will provide flute forms to accuracies on the order of 0.05 mm (0.002 in.) per flute profile pitch and depth when cutting metals ranging from tool steel to high-speed steel to tungsten carbide.

Using appropriate abrasives, running at efficient feeds and speeds, and using suitable amounts of coolant, machine manufacturers equipped with massive grinding-machine bases can efficiently remove metal and produce components with flat surfaces or intricate contours.

Extended life

Manufacturers of corrugating rolls have found that roll life is extended by using hardened rolls (up to 60–64 Rockwell C) or by chrome-plating or laser-hardening the flute tips. The use of abrasive raw materials in the production of corrugated board reduces corrugating-roll life and can compromise the integrity of its flute configurations. Abrasive materials also can damage the roll by causing flute tips to break away in the high-speed corrugating process.

Hardened corrugating rolls cannot be machined by normal metal-removing processes. They must be ground to provide the accuracy required for the flute configuration.

Geometry

The greater the accuracy of the mate between the top and bottom corrugating rolls, the better is the meshing of the flute contours and the higher is the corrugator operating speed. Historically, grinding has been the final step in providing the finished form of the mating parts of the corrugating rolls. Hardened corrugating rolls are finish ground to closer and closer accuracies. For instance, crowning accuracies of ± 0.0001-in. variance from theoretical are possible. This accuracy was unheard of 10 years ago.

Continuous-dress, creep-feed grinding

Substantial cost reduction and quality improvements now are made in the manufacture of corrugating rolls by a new continuous-dress, creep-feed grinder (**Fig. 1**). Creep feed means that the flutes are initially formed by one pass of the corrugating roll under a precision-dressed grinding wheel with the table and roll moving at 600 mm/min (24 in./min). After all the flutes have been ground, an additional "spark-out" pass, at a table speed of 24 m/min (79 ft/min), provides 0.03 mm (0.001 in.) depth of stock removal for the final-finish grind cycle. The time needed to grind a corrugating roll with B-flute configuration from a solid core is 9.5 hours.

Specifications for rolls that can be machined with the continuous-dress, creep-feed roll grinder are given in **Table I.**

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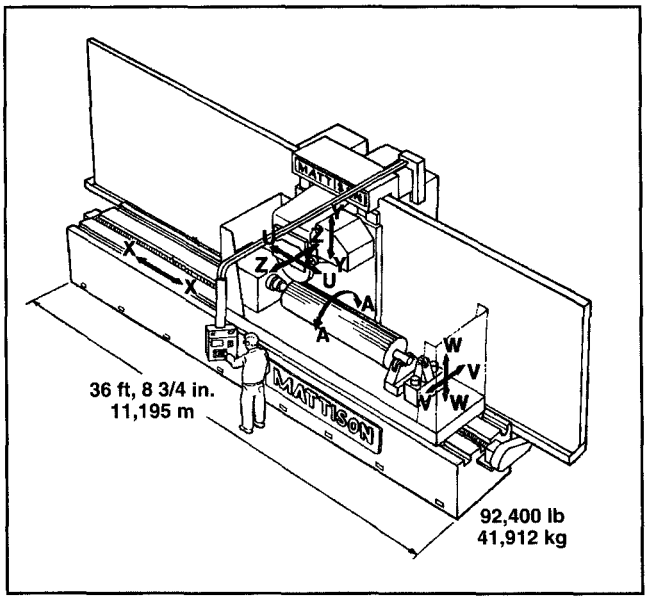
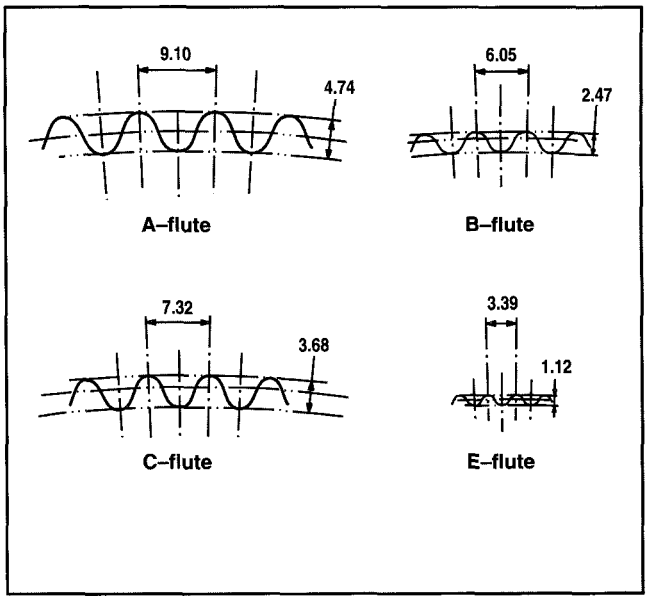
1. Schematics of the 42-metric-ton, CNC (computer numerical control), continuous-dress, creep-feed, corrugating-roll grinder showing the movements of the various axes



2. Calculated dimensions for the major flute forms. All dimensions shown are metric and for reference only, since diameter of roll and number of flutes determine specific dimensions.



I. Specifications for corrugating rolls machined in continuous-dress, creep-feed roll grinders*

Roll dimensions, mm	
Outside diameter	302.77
Crown	0.515
Number of flutes	156
Flute dimensions, mm	
Depth	2.6
Length	2515
Pitch	6.094

*Fabricator speeds: creep-feed rough grind = 0.6 m/min; finish grind = 24 m/min; grinding-wheel = 2400 m/min

The basic dimensions for the major flute configurations are shown in **Fig. 2.** The accuracies that can be achieved with continuous-dress, creep-feed roll grinding are illustrated in **Fig. 3** and discussed under the following subheadings.

Flute-to-flute spacing

As seen in Fig. 3A, flute-to-flute spacing—measured from the outside diameter using gauge pins in the flute forms—will be accurate within 0.005 mm (0.0002 in.) of the true calculated pitch for 90% of all flutes. Over three flutes, accuracy will be within 0.010 mm (0.0004 in.). Spacing will be accurate within 0.02 mm (0.0008 in.), cumulative, for all spacings on a 360° circle for a 305-mm-diam. (12 in.) roll.

Cumulative indexing error

Figure 3B shows that the maximum cumulative indexing error over 360° (one full turn) of the fixture will be within ± 0.010 mm (0.0004 in.) from the true calculated spacing on a 305-mm-diam. (12 in.) roll. The tooth-to-tooth index variation will not vary more than ± 0.005 mm (0.0002 in.).

Flute-form depth

Figure 3C shows that flute-form depth, as indicated by an optical comparator, will be within a total error envelope of 0.013 mm (0.0005 in.).

Profile error

Figure 3D shows that profile error of any one flute will be ± 0.006 mm (0.00025 in.) from the true calculated profile as shown by the optical comparator.

Roll-diameter ends

Figure 3E shows that roll-diameter ends, measured at the tooth tops, will be within 0.015 mm (0.0006 in.).

Cylindricality

Cylindricality of the entire linear flute length, measured at 200-mm increments from the center line of the corrugating roll, will be ± 0.005 mm (0.0002 in.).

Lead error

Lead error, measured by a laser measuring instrument, will be ± 0.01 mm (0.0004 in.).

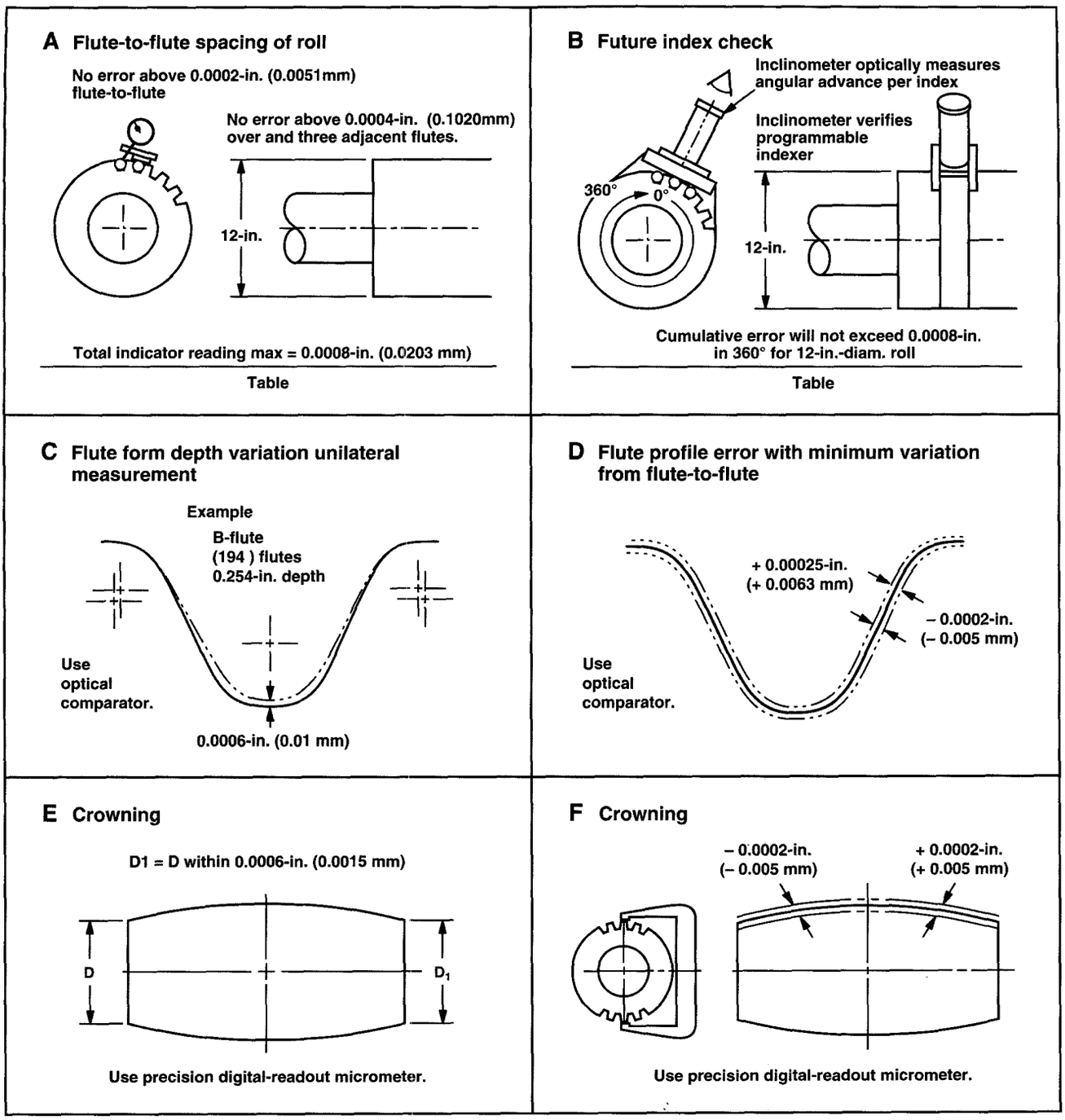
Crowning

Figure 3F shows that the crowning profile will be within ± 0.0025 mm (0.0001 in.) of the theoretical crowning profile.

Machine-tool control criteria

With the metal-removing problem settled by abrasives, the precision required by manufacturers of corrugating rolls demands state-of-the-art technology: computer numerical control (CNC). Heidenhain incremental rotary encoders are used for precision indexing to provide correct rotary spac-

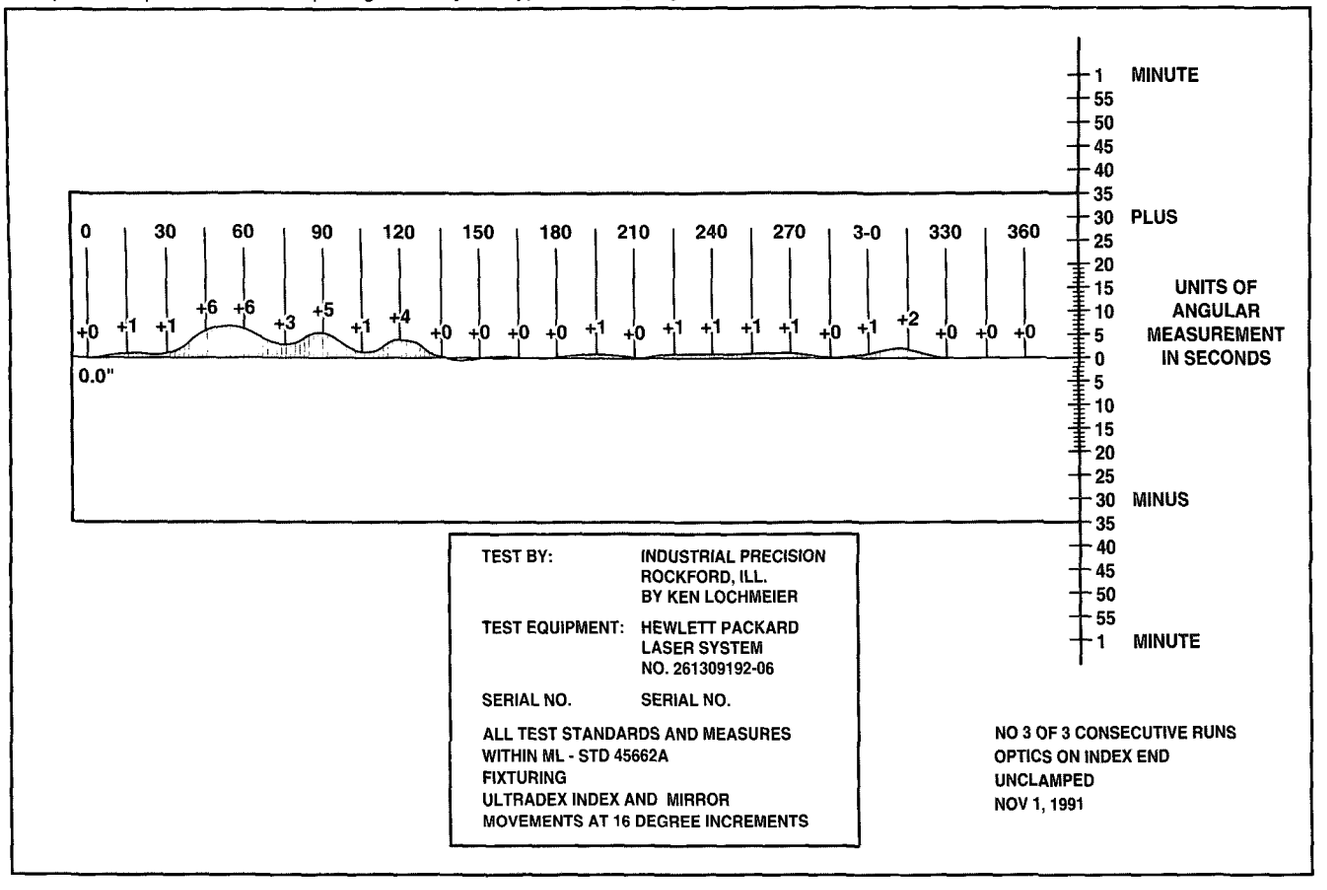
3. Finished-roll inspection accuracies possible with continuous-dress, creep-feed grinding of corrugating rolls



ing of the flutes. Linear scales with digital readouts for table feeds and speeds provide the ultimate accuracy. The creep-feed grinder, the indexing fixture that locates and holds the corrugating roll, and the two different types of grinding-wheel dressers all demand a control that can command movements on nine different axes. Included are wheel-size sensing to enable the grinding wheels to accelerate in revolutions per minute, as the wheel wears in diameter, to correct for constant surface feet per minute on the outside diameter of the grinding wheel. The various axes are shown in Fig. 1. The arrows indicate the direction of movement for the various components.

Experience shows that users want a CNC control that will save time and money in every step of the process. The control does not need to be programmed in the office. It can be programmed on the shop floor by the

4. Inspection report of the index-spacing accuracy of a typical corrugating-roll form or profile



operator. If the operator has previously set a program to grind a specific flute form in the corrugating roll, he or she can reprogram for a different form in approximately 15 min. The CNC also can be programmed so that one operator can operate two corrugating-roll grinders simultaneously.

The marriage of the CNC control to the corrugating-roll indexer has been accomplished by using a rotary encoder with a servomotor. The CNC control can maneuver nine separate axes. There is two-axis simultaneous control of the table motion and grinding-head feed to provide accurate crowning. Additional features include circular interpolation, incremental programming, tape format, mirror image, 9-in. cathode-ray-tube screen, English/metric conversion, and constant surface-feet-per-minute control of the grinding wheel. The CNC control can store many different flute-form programs and provide instant manual data input for flute or program changes. The CNC also provides absolute crowning for both right-hand and left-hand motion of the table, allowing indexing of the roll at the end of each table stroke.

The Mattison-designed indexer centers one end of the corrugating-roll journal. The indexer has a worm-gear drive powered by a servomotor that receives its instructions from the CNC control and incremental rotary encoder, which has a resolution of 360,000 steps per revolution and provides an accuracy of 0.001°. A braking method is applied to the rotary encoder to eliminate hunting. An inspection report for flute spacing is shown in **Fig. 4**.

Many people familiar with manufacturing precision processes are surprised at the accuracies that manufacturing science has produced in conjunction with the CNC control. The precision process includes fixtures, automatic wheel dressing (dressing 0.0001 mm from the grinding wheel per revolution), and indexing the corrugating roll between cuts with the accuracies listed in Fig. 3.

The CNC control provides the opportunity for constant precision. It usually takes four years of apprenticeship to make an all-around machinist ready for highly skilled metal-working operations. When the average machinist leaves a company, the skills learned on the job leave with the machinist. With the CNC corrugating-roll grinder, the skill stays because it is built into the creep-feed grinder control system. Another machinist can learn to program the CNC control in a very short time.

Machine stamina

Creep-feed grinders require rigidity, mass, and correct balancing of wheels and spindles. Mass is an important inhibitor of vibration, which has an

adverse effect on finish, correct geometry, and tolerances.

To maintain the accuracy of the flute profile and finish by creep-feed grinding, the grinding machine must be very stable, rigid, and capable of moving very heavy loads. The corrugating-roll fixtures, plus the corrugating roll, weigh up to 15,400 kg (7,000 lb) while sitting on a machine table that weighs 28,600 kg (13,000 lb). The machine table must be reversed in direction many times (up to 1300 cycles) per corrugating roll.

Energy

Total grinding effort for any grinding process consists of three parts: cutting, plowing, and rubbing. The cutting energy is usually only 10% of the total. However, continuous dressing keeps the grinding wheel sharp and drastically cuts the amount of energy consumed by plowing and rubbing and helps maintain the metallurgical balance, which can be altered by thermal increases and burning.

We solved the problem of high energy costs by using a molding material on the reciprocating table called Moglice. This material reduces the coefficient of friction of iron upon iron from 0.2 to 0.05, a 75% reduction of friction. A huge ball screw has been developed for moving the grinder table at continuous speeds up to 23.0 m (75 ft) per minute.

A lead screw, with an Acme thread and nut, has very high friction coefficients. Ball screws can reduce this friction in precision machine tools up to 90%. The low coefficients of friction of the slides and ball screws on the creep-feed grinder save much electrical energy.

Wheel dresser

The grinding-wheel dressers are designed to be controlled and adjusted by the CNC control. During the grinding operation the quality of the corrugating roll is the first consideration. The second consideration is how many corrugating rolls can be produced by the rotary, diamond-wheel dresser. In recent months, there has been significant development with improving the life of diamond dressing rolls used in head-mounted dressers. During the roughing operations, the grinding wheel is continuously dressed every revolution. The CNC control is programmed to feed the rotary, diamond dressing roll into the grinding wheel a distance of 0.0001 mm (0.000004 in.) per grinding-wheel revolution.

The rotary, diamond dressing roll should operate at peripheral speeds approaching the grinding-wheel speed. Ideally this is 80% of the peripheral grinding-wheel speed. Speeds for diamond rolls of 100–150 mm (4–6 in.) in diameter are in the range of 3000 rpm to 4500 rpm.

Wheel speeds and specifications, table feeds, number of passes, proper root mean square finish, multiple tolerances, and programming techniques are proprietary information established by each individual manufacturer of corrugating rolls. Research has shown that by continuously dressing a grinding wheel using an overhead diamond roll dresser, the stock removal rate of the process can be increased by a factor of more than 10 times that of conventional grinding. The various tolerances for profile, spacing inspection, and crowning are shown in Fig. 3.

Operator awareness

Although a machinist easily can be taught to program the CNC control in a very short time, there are additional skills the operator must provide from previous manufacturing experience. A two-week school is provided for thorough training of machinists from firms that own or have ordered a CNC corrugating-roll grinder. The class does not exceed five students at a time.

One of the most important attitudes that machine operators should command, especially those not familiar with creep-feed grinding, is the significance of every element in the process. For instance, can the operator check the geometry of the flute? Does the operator know how to use an optical comparator and make a template, 50x magnification, to check the flute contour? This kind of information is necessary to check the accuracy of the machine.

Coolant technology

Improvements in manufacturing science have developed systems to provide water coolant or oil coolant at 570 L/min (150 gal/min) under 689 kPa (100 psi) pressure.

Summary

High-quality corrugating rolls are manufactured with the aid of massive machine and fixture elements, nine-axes CNC control, and rotary encoders. Continuous-dress, creep-feed grinding will remove large volumes of stock very quickly, maintaining accurate form profiles independent of the length of the corrugating roll. The benefits and advantages of continuous-dress, creep-feed grinding are high productivity, the ability to grind difficult alloy steel, the elimination of milling and hobbing equipment, more accurate retention of form profile, and excellent surface finish. ■

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