MACHINE STRESS RATING

with the

CLT CONTINUOUS LUMBER TESTER

by

Friend K. Bechtel   Metriguard Inc. Pullman WA

Presented to the

MACHINE STRESS GRADING SEMINAR

Sponsored by

Maritime Forest Ranger School

R.R. No. 10
Fredericton, N.B.
CANADA E3B 6H6

Any of the following engineers at Metriguard Inc. would be pleased to receive your questions or comments about this material.

James D. Logan, President
Friend K. Bechtel, V.P. & Dir. of Res.
James R. Allen, Manager of Engineering
Ray L. Fry, Project Engineer
Daniel A. Uskoski, Project Engineer
R. Ken Byers, Project Engineer

Metriguard Inc.
S.E. 1120 Latah Street
P.O. Box 399
Pullman WA 99163 USA
Phone   (509)332-7526
Facsimile (509)332-0485

MACHINE STRESS RATING

with the

CLT CONTINUOUS LUMBER TESTER

by

Friend K. Bechtel   Metriguard Inc.
Pullman WA   October 15, 1990

INTRODUCTION

The CLT Continuous Lumber Tester is responsible for most of the Machine Stress Rated lumber production in North America and is becoming known in Australia and New Zealand as the machine of choice there as well. The CLT had its beginnings in the early 1960s, with first MSR output from a production line machine in 1962. Since then, some major improvements in CLT design, construction and application have occurred. The present day CLT is widely known as the world's fastest and most accurate production line machine for measurement of flatwise bending modulus of elasticity (E).

The property, E, is important in describing how much a piece of lumber deflects under load, in determining how much load a long thin timber can take under column loading before buckling and in estimating the strength of lumber. The measurement of E allows lumber to be sold in MSR grades. MSR lumber is worth more to the user because of additional reliability in its structural design values, reduced waste and greater consistency.

In this paper, we discuss how the CLT works, some of its features which have benefitted MSR producers and some of the improvements that have been made to keep the CLT at the forefront of production line measurement of E.

Because of its speed, ruggedness, accuracy, maintainability and ease of operation, the CLT is the most cost effective machine available anywhere for the production of MSR lumber.

HOW THE CLT WORKS

The CLT measures the flatwise bending modulus of elasticity of lumber by averaging the forces required first to bend the lumber downward and then upward in successive 48 inch (1219 mm) bending test spans. Constant deflections reduce inertial problems which are evident in alternative machines that sense deflections produced from constant forces. The two-span arrangement compensates for bow and kink which exist to some extent in almost every piece of lumber. Three clamp roller sections isolate the bending spans from each other and from gravity overhang and vibration effects outside the bending test spans.

In North America, the E category of each piece of lumber is determined from both Average E and Low Point E. Average E is the average of the measurements over the length of the lumber, and Low Point E is the minimum of these numbers. The color of an ink spray mark automatically applied to the lumber as it exits the CLT identifies the E category of each piece.

The machine speed is specified to 1200 ft/min (366 m/min), but some CLTs are running successfully at 1550 ft/min (472 m/min). A small gap end-to-end between pieces is required so that photosensors can detect the ends of the pieces.

The following description of CLT design features explains why the CLT is successful at high speeds.

CLT Infeed

Lumber is presented to the CLT endwise with the wide face horizontal and centered laterally to the centerline of the machine. The elevation of the lumber is adjusted so the lumber is centered for entry between the first pair of clamp rollers. Feeding of lumber into the CLT is improved if the lumber enters at a slight angle (1.12 degrees) downward relative to the CLT. This angle can be accomplished either by tilting the infeed downward or by tilting the CLT upward. The 1.12 degree infeed angle causes the lumber to be aligned with the entry trajectory forced on the lumber by the first CLT clamp roller section.

Constant Deflection

Flatwise bending E of lumber can be measured by bending it and measuring the forces and deflections. Two natural alternatives to consider in implementing this idea are, first, to apply a constant force and measure the deflection or, second, to apply a constant deflection and measure the force. In practice, the application of a constant force involves moving, i.e. accelerating, masses as the deflection changes with changing E in the piece. Inertial effects from the accelerating masses cause inaccuracies which become greater as speed increases.

Because of the inertial effects, the CLT uses the second approach and measures the force required to achieve a constant deflection. One bending test span of a CLT is illustrated in Figure 1. Clamp rollers at the ends of the test span isolate the measurement from effects outside the span such as whip of the lumber ends. Assuming that the CLT is leveled, the clamp rollers clamp the lumber at each end of the test span at angles of 1.12 degrees relative to the horizontal plane. With this arrangement and with the load roller deflecting a uniform piece of lumber by about 5/16 inch (7.95 mm) at span center, the clamp rollers will apply zero moment at the ends of the test span, i.e., the deflection angle at the span ends equals the clamp roller angle.

Calibration of the deflection amount is achieved with two aluminum test bars, a long bar which engages all of the rollers in the test span and a short bar which engages just the load roller and the four clamp rollers nearest the load roller. The deflection amount is adjusted until the force at the load roller is the same for either test bar. At that condition, the net moment effect from the clamp rollers is zero.

With the fixed geometry of Figure 1, inertial effects from the clamp rollers and the load roller are minimized. This is a key feature allowing the CLT to function accurately at very high speeds.

Two Bending Test Spans

The CLT includes two bending test spans with geometry as shown in Figure 2. In the first test span, the lumber is bent downward, and in the second, it is bent upward. "Compensated E" which is an average of the downward and upward measurements at each point along the length is thus largely independent of bow and kink in the lumber. Clamp rollers at the trailing end of the first test span perform double duty and serve also as clamp rollers at the leading end of the second test span.

Figure 3 taken from Logan [1985] illustrates this process of combining measurements from the two test spans and eliminating by superposition the effects of deviations from straightness in the lumber. Note that the signal from the first test span is delayed prior to averaging it with the signal from the second test span. The time delay is equal to the time required for lumber to move from the first to the second test span.

Averaging measurements from oppositely oriented deflections to obtain Compensated E is of great importance in making the result independent of lumber deviations from straightness.

Average E and Low Point E

The Compensated E measurement is processed in the CLT electronic unit to obtain the "Average E" over the length of lumber and also the lowest value "Low Point E" along the length. Figure 3 illustrates how Average E and Low Point E are obtained from the Compensated E signal.

In North America, both Average E and Low Point E are used to obtain the E category and define an ink spray color mark which is automatically applied to the lumber. Figure 4 illustrates how the CLT logic system works in defining E categories, or "machine grades", from both Average E and Low Point E. Each measured piece of lumber can be plotted as a point in two-dimensional space where the abscissa is Average E and the ordinate is Low Point E. For a piece of lumber to qualify for a given E category, the Average E and Low Point E measurements for that piece must exceed independently selected thresholds respectively for Average E and Low Point E. In Figure 4, we see that these thresholds form regions in the two-dimensional space for each category. The 45 degree line is part of the boundaries because it is not possible for Low Point E to be larger than Average E, and hence no points can occur above the 45 degree line.

MSR lumber, produced against a given set of Average E and Low Point E thresholds and subjected to visual override scrutiny in the determination of MSR grade, must pass certification and must survive the daily, on-site quality control checks that are part of North American MSR grading rules established by the various grading agencies (Logan [1990]). Determination of thresholds is based on experience. Initially, they are set relatively high, so that the MSR lumber will pass certification. The rules allow small adjustments of thresholds downward toward less conservative positions as quality control records indicate. There is general agreement that Average E thresholds are most important for controlling the bending E requirements and Low Point E thresholds are most important for controlling the strength requirements of the grades. Typically, Low Point E thresholds are set to values that are approximately 80% of the Average E thresholds.

In Australia and New Zealand where MSR practices grew up around different machinery not capable of providing Average E measurements, only Low Point E is used. There, the E category ink marks, determined by Low Point E thresholds alone, are often applied on an incremental basis along the length of each piece of lumber produced. At high CLT speeds, this requires a high-speed controller and ink spray marking system.

<u>**Processing and Control**</u>

Processing and control of the CLT is directed by photosensors which detect when the second bending test span is covered by lumber. When the photosensors detect that the second bending test span is covered, they direct the Average E and Low Point E computations to begin operating on the Compensated E signal. When the photosensors detect the trailing end of the piece, the Average E and Low Point E values are compared with thresholds, E category is determined and an ink spray mark is applied to the end of the piece. Then, the system is reset and awaits a signal from the photosensors that the next piece has covered the second bending test span.

The system is designed with a calibrated voltage source and sequencing clock so that passage of lumber through the machine can be simulated. This built-in test feature allows much of the electronic unit to be checked out and calibrated without the machine operating.

Figure 5 is a diagram illustrating interconnections of the CLT mechanical system and the electronic processing and control system.

FEATURES AND BENEFITS

In this section, we review briefly the distinguishing features of the CLT and the benefits these features provide to the producer of MSR lumber.

Constant Deflection

The constant deflection feature of the CLT largely eliminates inertial effects which can be caused if masses in the machine accelerate. The benefit is more accurate measurement at much higher speeds.

Two Bending Test Spans

Bending the lumber both upward and downward in successive bending test spans and then averaging the results yields a value called "Compensated E". Compensated E is independent of bow and kink in the lumber. Most lumber has some bow and kink, and these anomalies greatly affect the measured E if they are not compensated for. The benefit of compensating for bow and kink is a more accurate E measurement and, consequently, improved high-grade yield.

Isolated Bending Test Spans

The CLT with its multiple clamp roller design at the ends of its two test spans isolates the bending measurement in each span from the effects of bending moments created by the other test span or by any motion of the lumber outside the test spans including whip of the ends of the lumber as it progresses through the machine. Accuracy and repeatability is improved, and speeds can be much higher when the bending test spans are properly isolated from external effects.

Flatwise Feeding

Lumber is fed to the CLT on the flat. Flatwise feeding is easier and more economical than edgewise feeding, and it allows the machine to be located much closer to the planer.

Rugged, Reliable and Long-Lived

The CLT has a history of long, trouble-free operation with low maintenance. This makes the CLT a valuable long-term investment for its owners.

High Speed

The high speed capability of the CLT allows it to keep up with the fastest of the high-speed planers. This eliminates the need for extra material handling and presorting operations which are sometimes necessary to select candidate stock for slower equipment. The CLT is ideally suited to provide the first sorting operation. Measurement performance at high speed is a primary feature of the CLT and is one of the reasons for the low per-unit costs of MSR production when the CLT is used.

Repeatable Measurements

Obtaining the same measurement results for multiple passes of the same piece of lumber through the CLT gives confidence in the results. Repeatability is a strong point of the CLT and makes the CLT consistently correlate well with accurate off-line measurements of E. Figure 6 is the result of tests made by Metriguard in 1978 comparing the CLT Average E with the E as measured by a Metriguard Model 3300 Transverse Vibration E Computer. The coefficient of determination is $R^2 = 0.976$. The same tests performed today probably would yield an even better correlation because of the improved precision of today's CLTs. A repeatability test of the most recent CLT put into production is illustrative. Thirty pieces of lumber were passed through the CLT twice, and Figure 7 is a scatter plot of the result. The ordinate is Low Point E, and the abscissa is Average E. The plotting symbol for each piece is its piece number. This symbol is shown twice representing the two passes through the machine. It is clear from Figure 7 that for some pieces (1, 3, 12, 18, 19, 22, 23 and 28) there is no distinguishable difference between the two passes, and the others are very close, both in Average E and in Low Point E.

With a machine that is repeatable, the grade thresholds can be finely tuned for more precise sorting, improved high grade yields and greater profits.

Easily Understood, Calibrated, Operated and Maintained

This feature allows the CLT to be introduced to the production line and operated usually with the same people as before. It is necessary that someone be identified to take overall responsibility for quality control.

The CLT electronic unit is designed with replaceable, plug-in printed circuit modules, which simplifies trouble-shooting, repair and upgrading. Most MSR producers keep a set of spare printed circuit modules on hand so that problems can be resolved with minimal downtime. Factory stock backup is also maintained.

History of Successful and Profitable Performance

The record achieved by the present CLT and its predecessors over many years in North America is evidence that the CLT produces MSR lumber at lowest per-unit cost of any machine in existence. Ince [1979] analyzed the costs of producing MSR lumber, and Figure 8 is taken from his paper. Although conditions have changed since then, Ince's analysis is still valuable, and this figure is still representative of the costs of producing MSR lumber. At 120 MMfbm throughput, Ince's cost figures ranged between $0.96 and $1.34 per Mfbm throughput. These costs included variable costs, overhead, working capital, taxes, depreciation and facility investment cost plus return on investment. Investment and return costs were amortized over a seven-year planning period. Ince did not include any added sorting, inventory or marketing costs.

The increased value of the product mix from an MSR production facility has been in the range of $10 to $20 and higher per Mfbm applied to the entire throughput. It is clear that if even $10 can be achieved with, for example, $2 cost, the result is $8 per Mfbm improvement in profit. At 100 MMfbm per year throughput, the result is an $800,000 increase in annual profit.

Excellent profits have been shown with much less production, e.g. in the 20 MMfbm range. For those entering the MSR business, calculations of estimated profits must be done on an individual case-by-case basis.

CLT IMPROVEMENTS

The following is a list of some of the more important recent improvements to the CLT and the benefits they provide. It is important to know that every CLT in existence is capable of being upgraded to new standards with these improvements.

Tighter Specifications on Roller Eccentricity

A new means of attaching the 24 clamp rollers to their shafts allows more stringent eccentricity standards to be applied to the rollers. The new standard is Total Indicated Runout (TIR) of no more than 0.002 inch (0.05 mm) at any axial location on any of the CLT rollers. This improvement has resulted in much better measurement repeatability.

Adaptive Synchronization of Computer Control System to Machine Speed

Although the CLT performs best when it is going at constant speed, small changes in speed can cause changes in the optimum amount of time delay for the E signal from the first bending section. Addition of a tachometer signal from the machine hardware now controls the electronic delay and optimally synchronizes it with the machine. The result is a more accurate overlay and averaging of the signals from the first and second bending sections, according to the method of Figure 3. Thus, the accuracy of the Compensated E signal is improved. This feature also allows the use of variable speed drives or simply changing the machine speed from time to time without the necessity of recalibrating the electronic unit.

Inertial Compensation

The CLT design inherently minimizes inertial effects by avoiding use of accelerating machine masses. However, there is some acceleration, particularly at very high speeds. Most of this is caused by small movements against the air clamping system in the second bending test span as lumber enters and exits the span. As the clamp rollers move downward slightly to accept the lumber, they cause accelerations in the load roller and mounting assembly which, in the second bending section, is slung from the clamp roller assembly frames. This produces an inertial component of signal not caused by bending forces on the lumber. Stops on the clamp assembly frames can be adjusted to minimize the acceleration and hence the inertial component of signal. To further reduce the inertial effects, we have introduced an inertial compensation system that subtracts a measurement of the inertial effect from the measured E signal. Recently, we have discovered and patented a new method for even more completely removing inertial effects. It is important to know that, at today's high production speeds, problems which were not apparent at lower speeds have solutions. The CLT is ahead of the speed requirements, and the new inertial compensation methods will push the CLT capabilities further in the future.

Improvements in Load Roller Assembly Design

Improvements in load roller design have been made primarily for ease of maintenance. For example, a new external adjusting means provides for adjusting the preload in one of the sets of bearings in the load roller assembly. This set of bearings, which allows the load roller to have a rotational degree of freedom about a longitudinal axis for tracking twist in the lumber, previously required disassembly and selection of shims for proper adjustment.

A further improvement allows a second set of bearings, the spindle bearings, to be adjusted for preload without disassembly. This design has not yet been released for new machines and requires more testing, but we expect it to be a major improvement in maintenance ease.

Finally, the attachment of the load roller assembly to the CLT frame uses a third set of bearings which require adjustment for zero free play. Over time, these bearings are prone to failure from a condition known as false brinelling. A new flexure coupling, Figure 9, has been developed, tested and patented. The flexures are available as replacements for the bearings, and we anticipate that they will soon become standard on all new CLTs. The flexures eliminate the bearing adjustment and false brinelling failure problems. In addition, they eliminate the need for a null spring required with the bearing design to support the load roller assembly against gravity and provide a preload to a force measuring load cell. The null spring has been a minor source of annoyance because its support in the load roller assembly occasionally creates friction losses and small discrepancies in repeatability during calibration.

Roller Trash Guards

Steel trash guards, Figure 10, have been mounted to the machine at locations where clamp rollers can carry chips and other debris into spaces between the rollers and frame members. Use of the trash guards has eliminated a source of downtime from roller jam-ups. There are a total of 12 of these trash guards on each machine.

Updated Printed Circuit Modules

Numerous changes have been made to the printed circuit modules used in the CLT electronic unit. As new parts become available and old parts become obsolete, opportunities for new features, better stability and greater accuracy can be exploited by redesigning these modules. Each new version of a printed circuit module is capable of performing all the functions of the old modules and usually also has additional capabilities. New modules are completely functional in the older machines as plug-in replacements.

Optional High-Speed Spray Marking System

The requirements of Australia and New Zealand have led to the development of a high-speed spray marking system, Figure 11. This system is capable of identifying the E category of lumber incrementally along the length of each piece and spray marking it incrementally according to its local E category.

The high-speed spray marking system is believed to have merit in other spray marking applications in planer mills and sawmills as well as for completely different industrial applications.

SUMMARY AND CONCLUSIONS

The CLT has a long record of success in accurately and profitably sorting lumber for modulus of elasticity in high-speed MSR production facilities. Features built into the machine have been tested and modified as required to perform the intended job. A continuing stream of improvements has kept the CLT ahead of the speed requirements of even the fastest of the new planer mills, and new improvements now in testing are pushing these speeds even higher.

Economic analyses clearly point in the direction of speed and accuracy for the lowest per-unit costs of producing MSR lumber. Better than all these analyses is first-hand contact with those who have used the CLT for MSR production. We think you will find that MSR producers who use the CLT are pleased with the CLT, its performance and its contribution to their sales and profits.

REFERENCES

Ince, Peter J., "Cost of Grading Lumber by The Machine-Stress-Rating Process," Forest Products Journal, Vol. 29, No. 10, October 1979.

Logan, James D., "Machine Stress Rating in North America," Forest Products Research International, CSIR, Pretoria, South Africa, April 22-26, 1985.

Logan, James D., "Getting Started with Machine Stress Rating," Proceedings, Sawmill Technology for the 1990's, Forintek Canada Corp., June 1990.

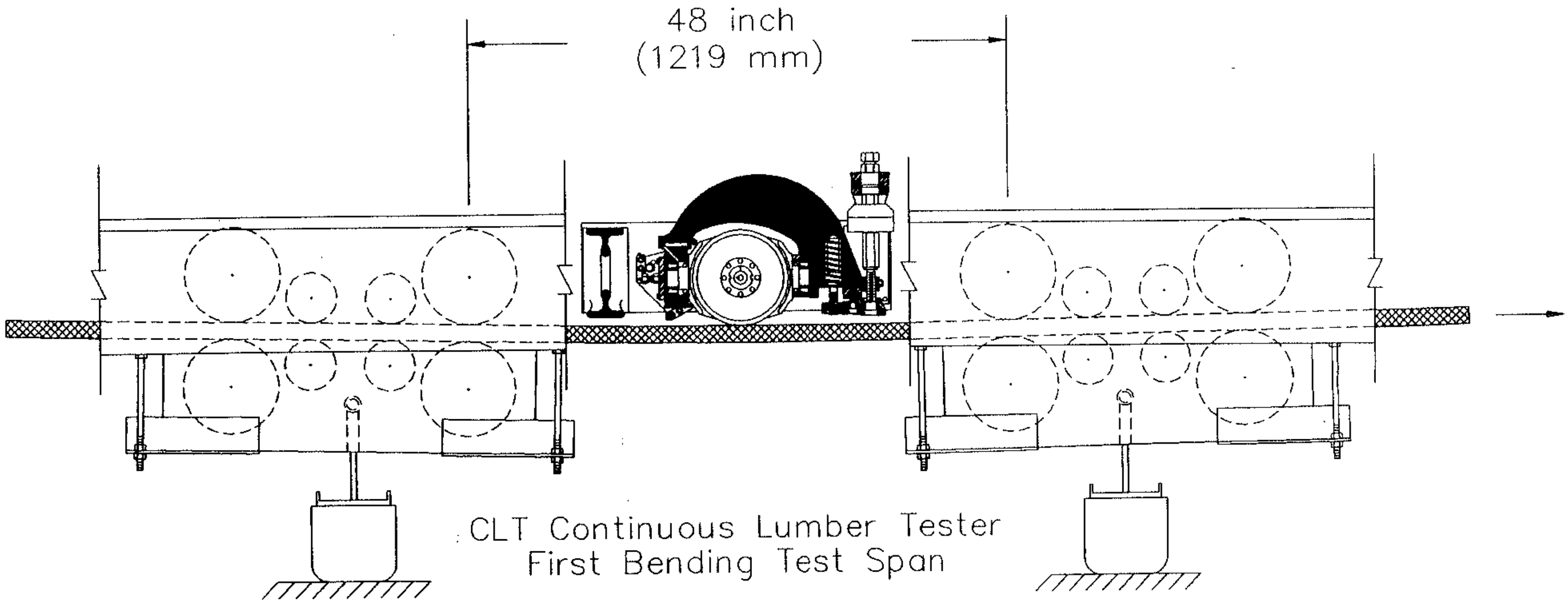

Figure 1. **The first bending section in the CLT consists of clamp rollers at each end of the test span and a load roller at the center. The first set of clamp rollers guides the lumber at a 1.12 degree downward angle into the test span and the second guides it out, at a 1.12 degree upward angle. The clamp rollers isolate the test span from external moments on the lumber.** With a calibrated deflection at the center of the span, the moment restraint of the clamp rollers does not contribute to the force on the load roller for a uniform piece of lumber.

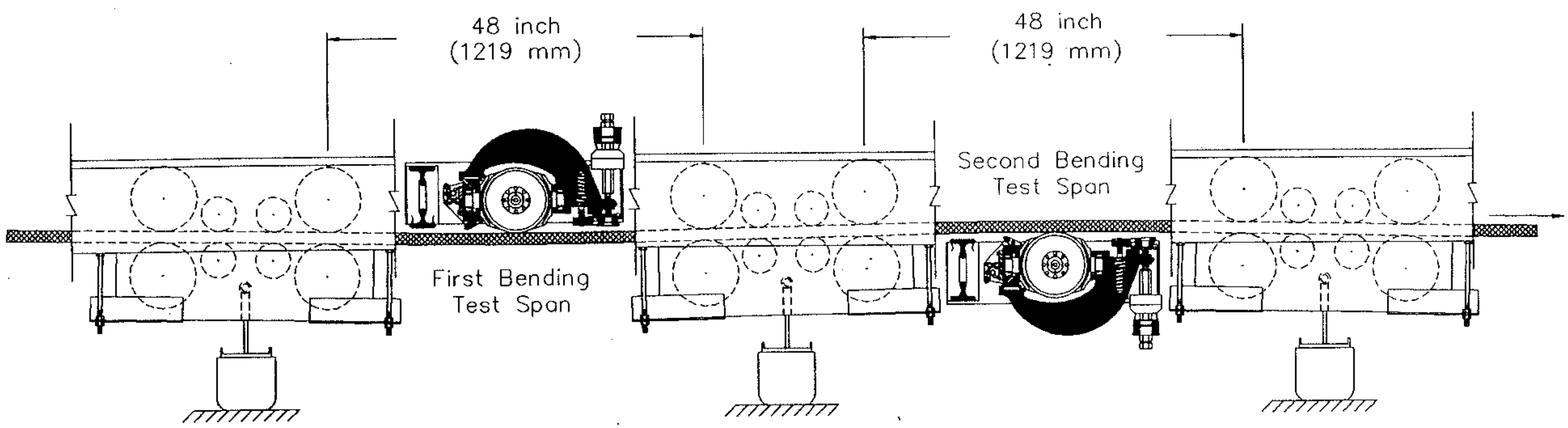

Figure 2. The CLT implements two bending test spans, the second immediately following the first. The exit clamp rollers from the first span serve as the entry clamp rollers to the second. In the first span, the lumber is bent downward, and in the second it is bent upward. Lumber enters and exits the CLT a downward angle of 1.12 degrees relative to the CLT longitudinal axis. This is a fall of 2.35 inch in 10 feet of run (59.7 mm in 3.05 m). For best operation, the lumber infeed is adjusted so the angle of lumber entering is aligned downward by 1.12 degrees relative to the CLT. This angle can be accomplished either by adjusting the infeed angle or by tilting the CLT.

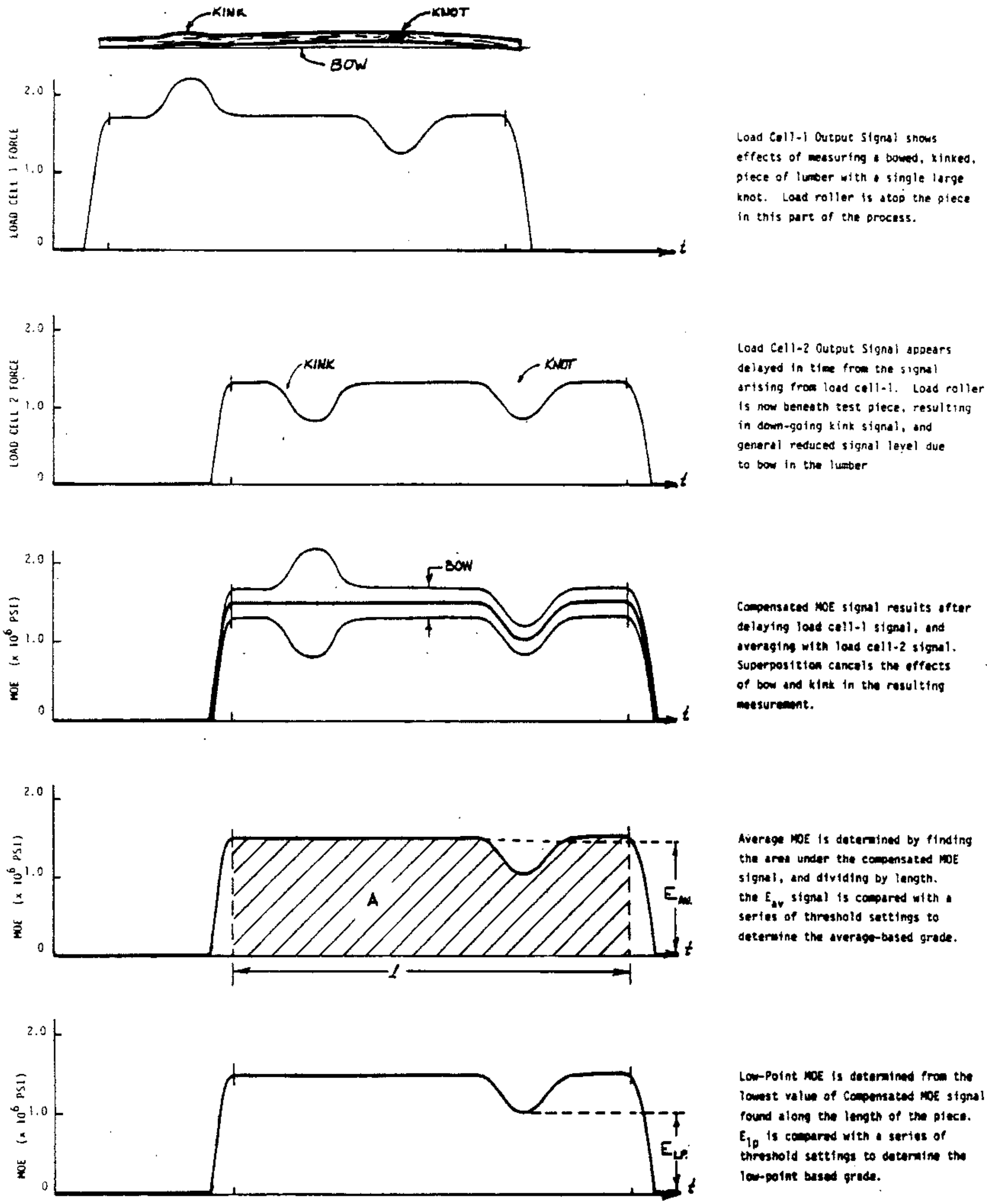

Figure 3. The CLT averages the forces required to bend the lumber both down and up at each point along the piece. From this average signal, called Compensated E, the average and lowest values over the length, called Average E and Low Point E, are obtained.

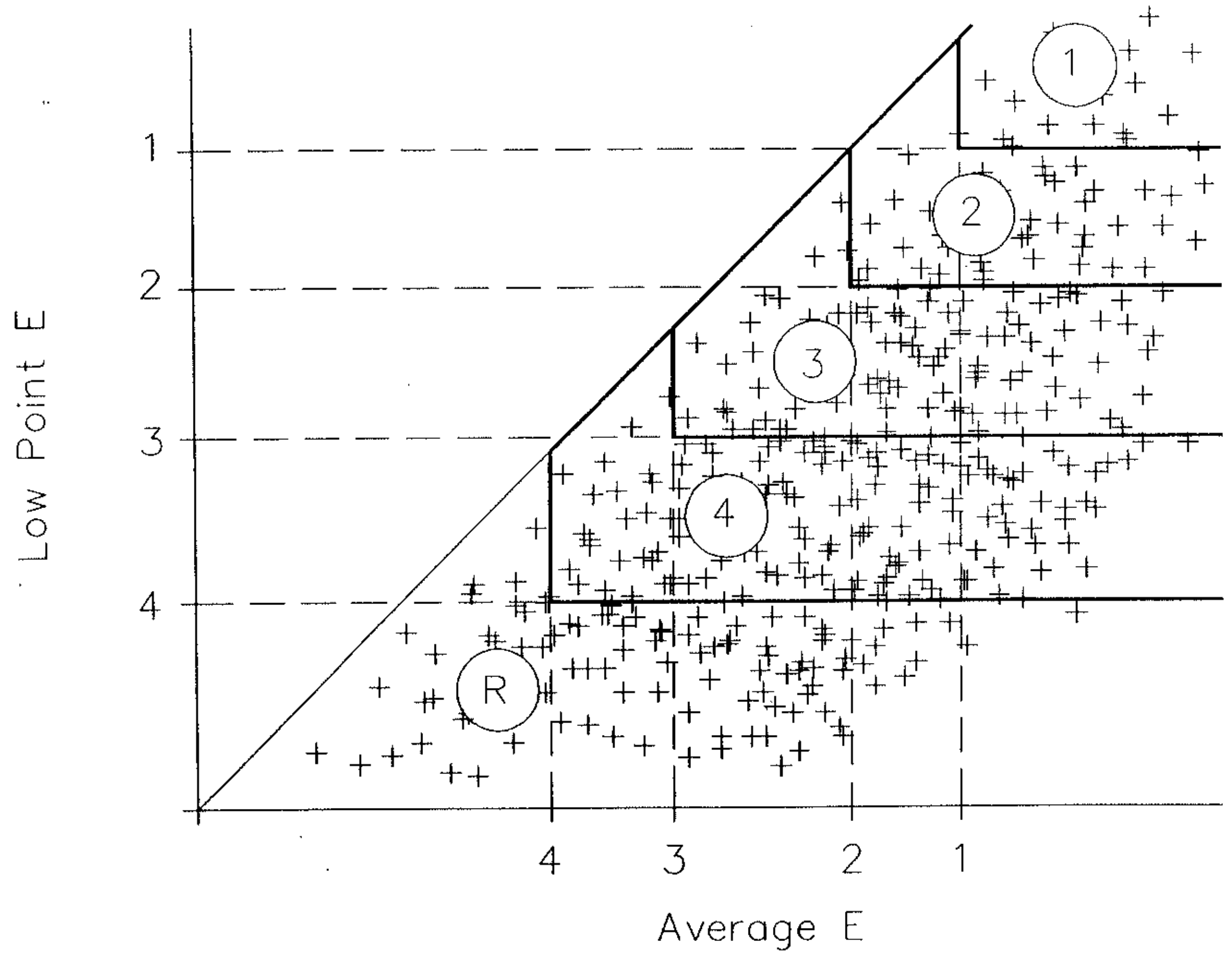

Figure 4. Average and Low Point E measurements for a piece of lumber are used to determine the E category for that piece. The categorization logic is evident if the piece of lumber is represented by a point in two-dimensional space. Here, each point represents the Average and Low Point E values for a piece of lumber. The boundaries splitting the space into four E categories and one residual category are shown in terms of Average E and Low Point E thresholds.

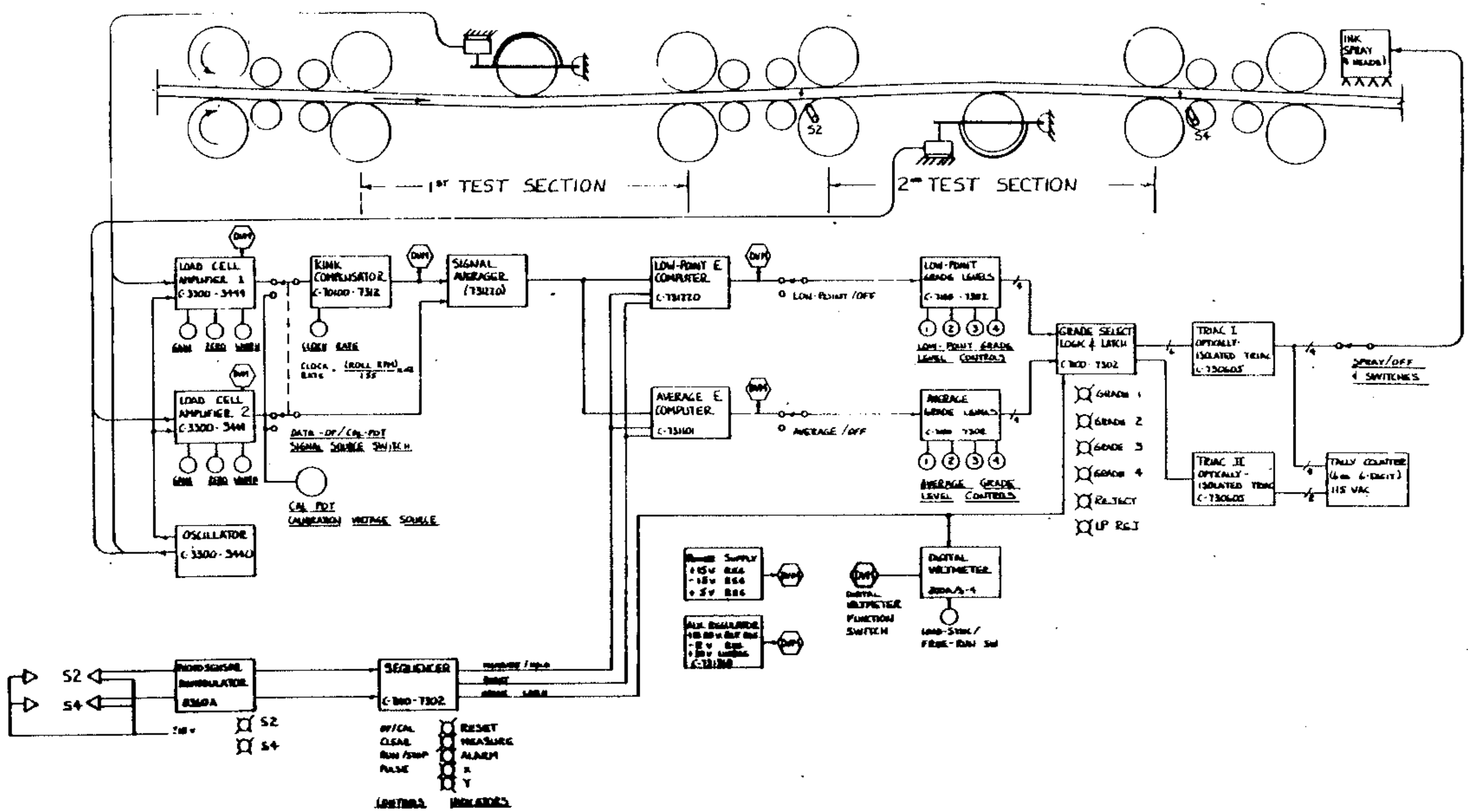

Figure 5. The CLT signal processing consists of modules which function to perform specific tasks. Calibrating methods are built-in so that an operator can calibrate and verify performance of the modules without lumber passing through the system.

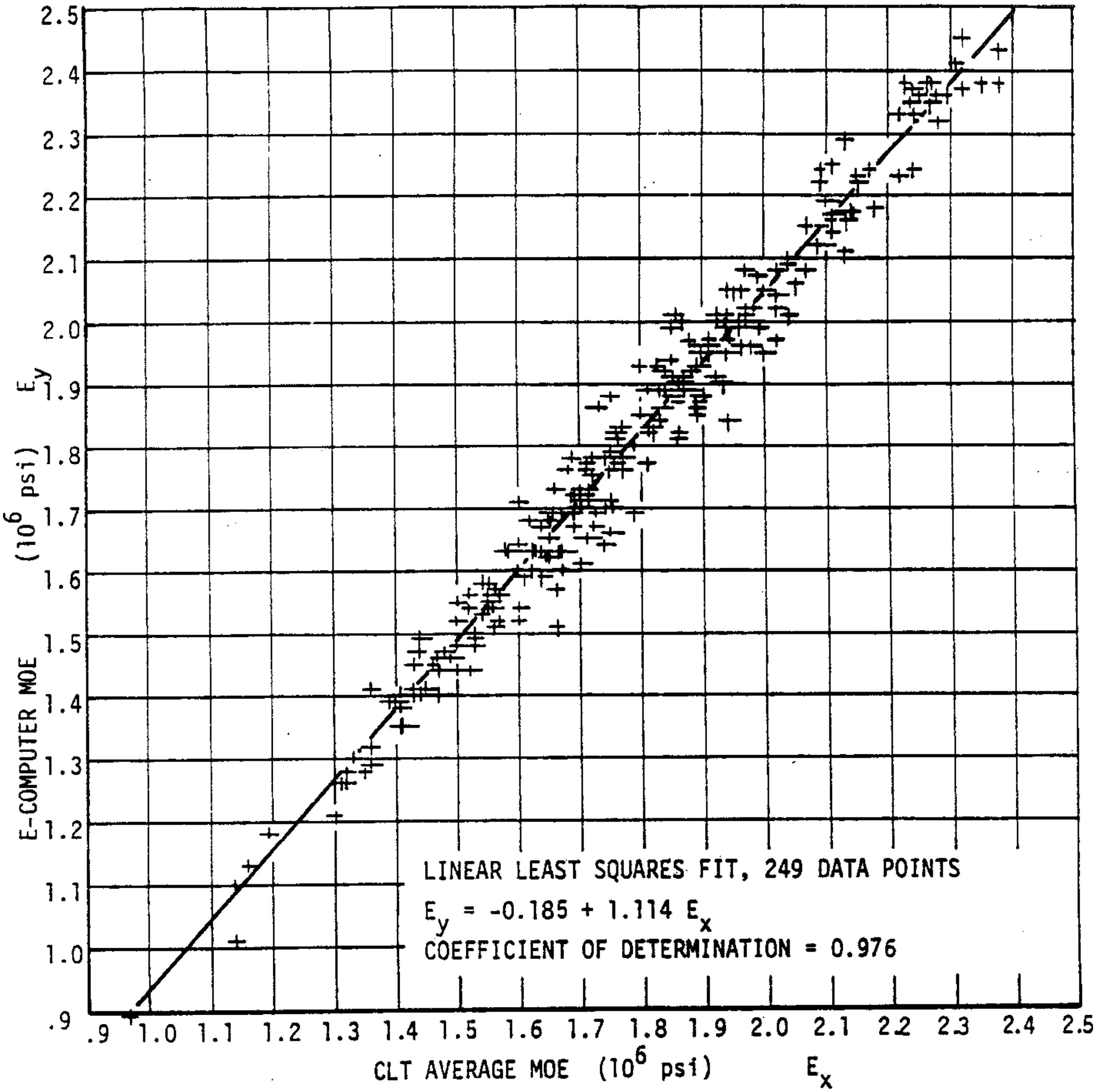

Figure 6. The flatwise bending E from a Metriguard Model 3300 E-Computer correlates very well with the CLT Average E measurement. Both measurements are flatwise averages over the length of lumber tested, although the weighting of points into the averages is not identical. This data shows the excellent correlation between the CLT and off-line measurements of E. Improvements in the CLT measurement precision since 1978, when these data were taken, likely would increase the correlation even further.

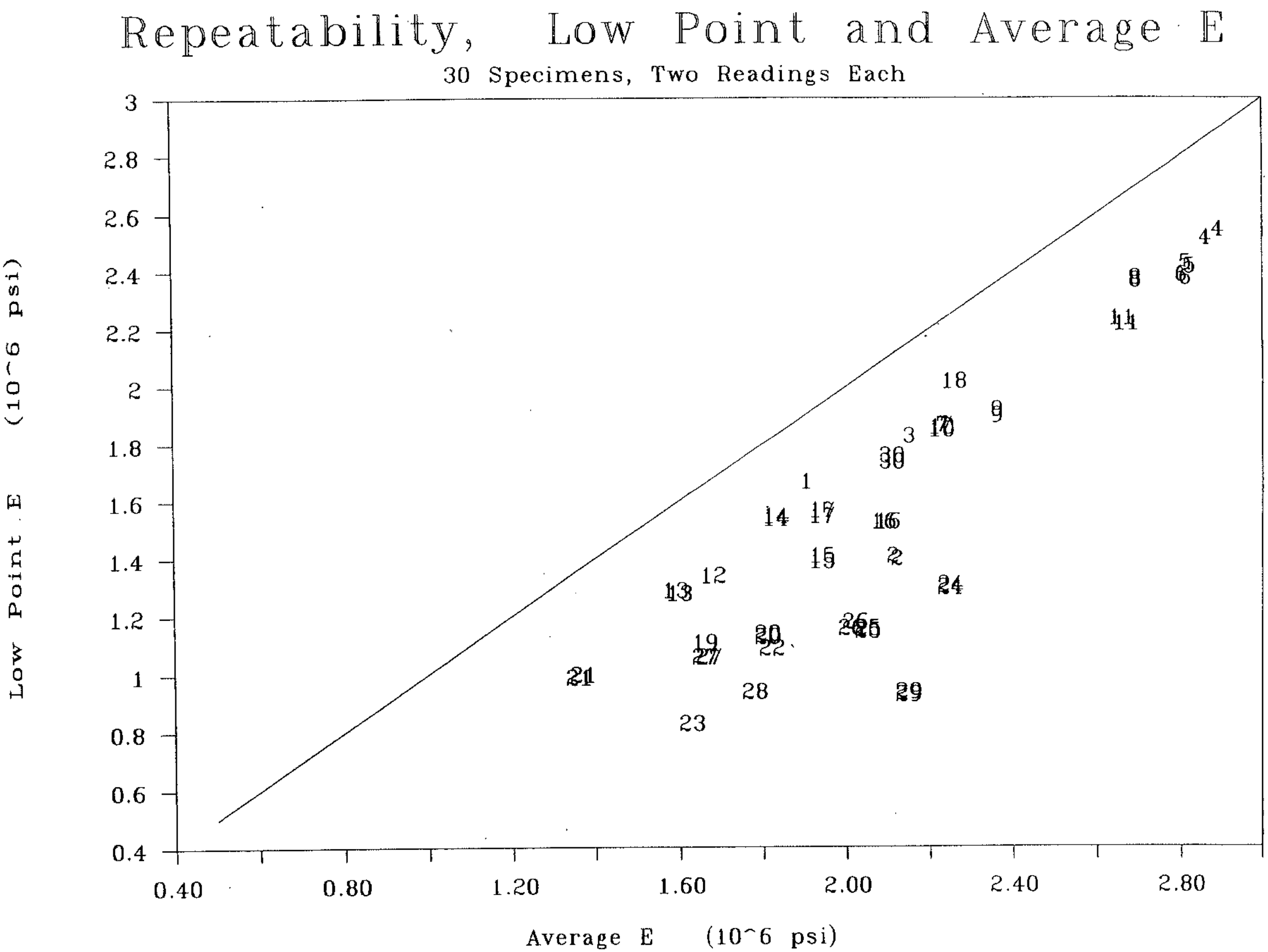

Figure 7. Thirty pieces of lumber measured twice by a CLT can give almost identical results both for Average E and for Low Point E. This test of a CLT recently put into service illustrates what a high degree of precision can achieve in production line measurement performance. For several of the pieces no detectable differences are evident in measured values between the first and second runs through the CLT.

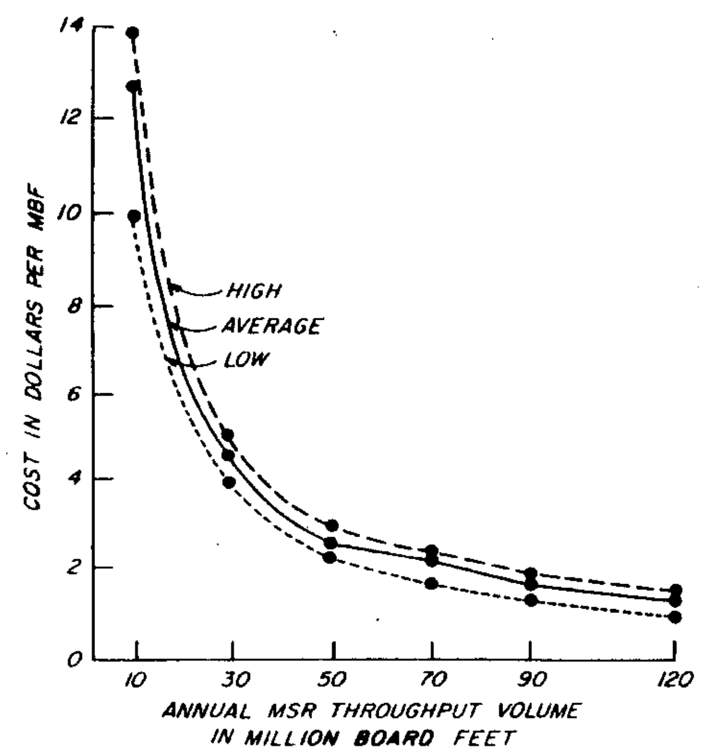

Figure 8. The costs of producing MSR lumber can be very low. This graph from a 1979 study, gives a range of costs per Mfbm plotted against annual production throughput.

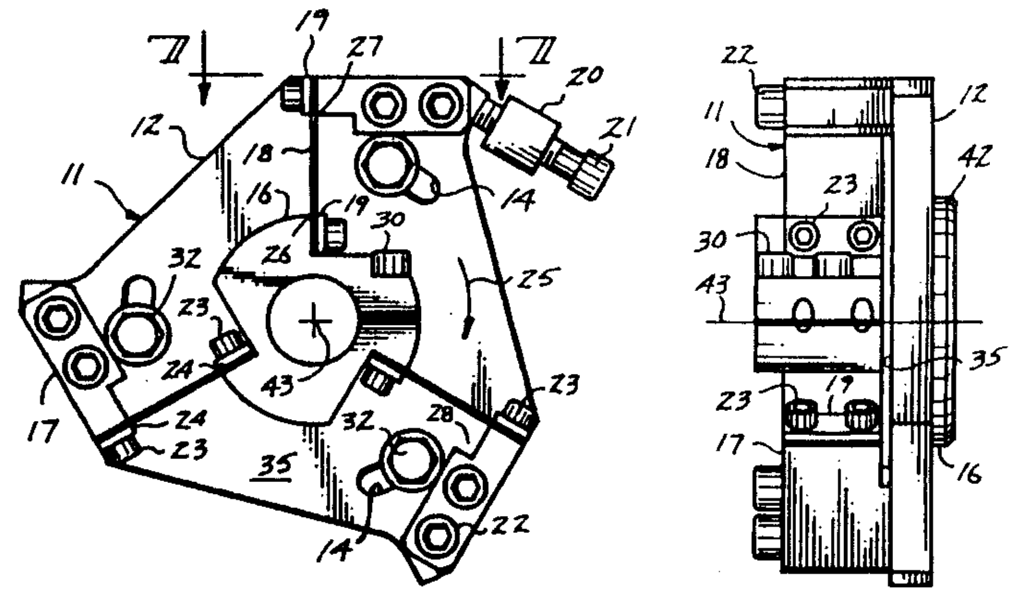

Figure 9. Patented flexure couplings will soon replace a pair of bearings which mount the load roller assembly to the CLT frame. False brinelling wear and bearing free play are maintenance problems which the flexure couplings solve. They also make the null spring in the first load roller assembly unnecessary. Removal of the null spring removes a source of minor repeatability difficulties that have been observed on occasion.

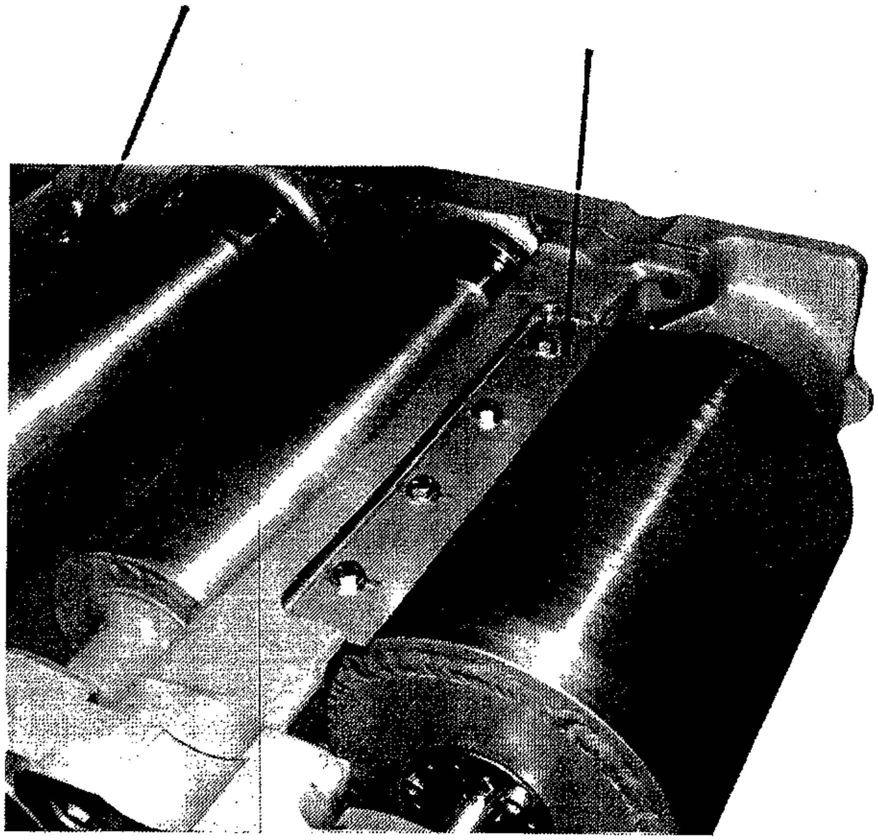

Figure 10. Clamp roller jam-ups are no longer a maintenance problem when these trash guards are installed. Present on all remanufactured and new machines for several years now, these guards eliminate the problem of trash and debris being carried by the rollers into the small spaces between the frame members and the rollers.

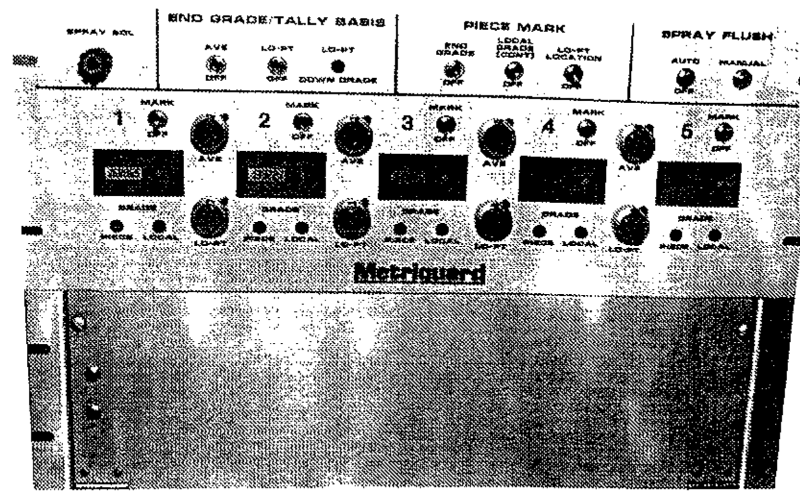

Figure 11. Incrementally spray marking lumber moving past ink spray nozzles at high speeds is a challenge solved by Metriguard's high-speed spray marking system. Particularly in Australia and New Zealand, this system has found application with the CLT. The system is believed to have other applications as well, where high speed control and application of an ink spray mark is required.