Measurement of Wood Pole Strength
Polux® a New Non-Destructive Inspection Method

By: Edward Ezer Ph.D. Eng.
Senior Member IEEE

Abstract – Wood pole structures make up a large part of utility transmission and distribution networks. Loading on in-service poles is increasing sometimes beyond design limits due to additional attachments of Fiber Optics and Cable TV and more violent weather. The paper describes a new technology Polux that can provide Asset Managers with reliable objective pole strength data to support maintenance and capital expenditure decisions.

The instrument integrates the groundline measurement of fiber strength and moisture content of a pole with six other parameters: species, knots, circumference, height, age and mechanical damage to calculate the Moment of Rupture (MOR) at groundline. This MOR compares directly with the ANSI value to derive a percentage loss of strength from new. Correlation of this technology with actual pole breaking tests is better than $r = 0.8$.

I. Introduction

The deregulation of the utility industry in North America is forcing utilities to compete for customers. To improve their competitive edge, utilities are cutting unnecessary costs, reducing staff and capital budgets, while attempting to improve reliability. The need to increase customer satisfaction and decrease liability claims is leading utilities to develop comprehensive information technology based asset management programs. These programs incorporate customer cost-of-service interruption as a major component of service reliability statistics. All such programs require objective reliable data on the condition of the utilities’ infrastructure to support maintenance and capital expenditure decisions.

Wood pole structures make up a large part of utility transmission and distribution networks. An estimate of the number of poles presently in use in North America is 150 million. Inspecting and treating these poles in a timely manner is essential to maintaining system integrity and getting the most service life from this infrastructure. In most utilities’ service territories, loading of poles is actually increasing as the same pole is being used to carry more cables and attachments for new cable TV and Optical communications services. While physical loading of poles is being increased, more violent storms are putting to question the standard wind loading data that was used to design existing utility pole lines.

A practical objective method for wood pole strength evaluation did not exist until now. The new Polux® technology is the first practical method that provides utilities with reliable objective pole strength data for use in asset management decisions.

II. Current Practices

Visual inspection and grading of new wood poles by suppliers often place utilities in the unenviable position of buying a product that carries no guarantee of performance nor does it have a reliable strength value when installed.

The National Electric Safety Code NESC (Ref 3) requires that a pole be rejected when 33% of its strength is lost. As new poles do not have a strength rating utilities use the nominal strength values given in the ANSI specifications for each species of wood poles (Ref1). These values carry a variance of almost 20%. Limited knowledge of the condition of the pole at the time of installation and when the pole is in service, has resulted in excessive and costly replacement and re-treatment of poles, in most cases too early and too often.

The most common methods of wood pole inspection continue to be either visual or “sound and bore” techniques performed by utility linemen or external contractors. Unfortunately, these tests are subjective and have been shown to be unreliable. They often result in poles being prematurely rejected, or more importantly, leave inadequate or hazardous poles in service.
Subjective assessments are sometimes accompanied by objective measurements using expensive and time-consuming sonic, X-ray or NMR methods. The more objective inspection techniques currently available are expensive and often too complicated for widespread use. More important, the strength measurement derived from their result does not correlate convincingly with the actual strength of the pole when the latter is tested to destruction.

A recent review of both objective and a subjective methods of pole testing “Performance of Utility Pole Strength Prediction Techniques” (Ref. 4) concluded that “None of the methods applied in the study had sufficient correlation with Pine pole breaking strength to support their acceptance as a highly reliable technique for selecting poles for replacement”. The author suggests that a “useful correlation threshold should be in excess of $r = 0.7$, (1.0 being the maximum)”.

### III. Wood Aging Process

Wood remains the material of choice for use in poles because of its many inherent advantages, which include climability, weight, dielectric properties and environmental acceptability. From the utilities’ perspective, poles made of wood are the most economical to install and maintain when compared to all other materials over a forty or fifty year cycle.

Like any other material a wood pole starts deteriorating almost from the moment it is installed. Sometimes decay is present in the original tree or can start early due to bad application of the pole preservative treatment. Obviously good quality control by the manufacturer is important to ensure that the tree selection is good and that the initial preservative treatment is well applied in order to arrest or reduce the deterioration in the first number of years. However, weathering, leaching, and the biological degradation of the preservative will reduce its effectiveness as time passes and decay will begin to deteriorate the pole. This process could go on for 40 years or more before it begins to compromise the load carrying capacity of the pole.

Decay of wood structures most often occurs at the ground level because the four elements necessary for the decay organisms are present there. These are: moisture, oxygen, food supply (wood), and temperature ($20^\circ$ to $30^\circ$ Celsius). Most of the moisture is present due to the capillary action of the fibers drawing water upwards from the bottom of the pole to a few inches above ground where it begins to dissipate into the atmosphere. The result is a cone of wetness near the groundline. Oxygen in most soil types is present in sufficient quantities to support decay for only the first 18” below groundline. Hence the groundline area of 18” below to 6” above the ground is the most likely area for initial decay to occur (Ref.4).

Although some poles may decay above ground due to insect infestation, woodpecker or mechanical damage, such decay can be visually noticed and the utility can quickly correct the problem.

Studies have shown that **the most common reason for pole failure is groundline decay.**

### IV. Variables that affect Pole Strength Measurement

Two main factors affect the overall strength of the pole:

1. The composite strength of the natural components that form the pole.
2. The decay, if any, that reduces this natural strength of the pole.

Furthermore, the ability of the pole to resist the bending moment resulting from wind loads is calculated as:

$$
\text{Moment} = \text{Constant} \times \text{fiberstress} \times \text{Circumference}^3
$$

Hence the bending strength is proportional to fiber stress and to the cube of the circumference of the pole. Almost 80% to 90% of the bending capacity in a typical utility pole is developed in the outer 2 to 3 inches of the shell. The center portion of a pole adds very little to its bending strength (Ref.3).

### V. Structure Strength of a Pole

A wood pole is not a homogeneous mass of fibers. The pole must be looked at as a composite
structure formed from longitudinal wood fibers, which are compressed and expanded in “rings” according to the species and its growth pattern. Growth rings and their number per inch of circumference are the most important parameter in determining the density of the wood; hence the circumference of the pole and a physical measure of the wood fiber density is crucial in arriving at an estimate for the strength of the pole. Within this composite wood structure knots are present where tree branches grew. These knots can influence the strength of the structure depending on their size and on the species of wood. The whole structure has also water present in various degrees depending on the age of the wood and its location in the soil. This water is either present due to the remaining sap of the tree or is there from biodegradation of the wood.

The height of the pole is also a factor in calculating the loading requirements. Statistically, taller trees grew faster and hence have fewer rings per inch of diameter than shorter trees, therefore taller poles (>50 ft) have weaker nominal fiber stress values. This is recognized in the ANSI specs for wood poles. The scarcity of high quality trees and recent trends to accelerate tree growth reduces the nominal strength values of most species. This reduction in nominal strength values for most species of poles used by utilities has not yet been recognized in the ANSI specs for wood poles. The average nominal strength for new poles at about 20% below the values given by ANSI.

What this means to utilities is that when they are replacing older poles with new ones of the same class the newer poles will be almost 20% weaker than anticipated; a big factor to take into consideration when designing new lines or when increasing the loading on existing lines.

VI. Effect of decay on pole strength

In general, wood poles have not been found to lose strength from factors other than biodegradation (decay) or physical damage. Decay that destroys the outer shell of a pole rapidly reduces the bending strength. A 13% reduction in circumference caused by decay reduces the bending strength by 34%. Conversely, the impact on bending strength from internal decay is much less. For example, typical distribution sized poles that are hollow except for 2 inches of sound shell will theoretically retain 80% to 90% of their original bending strength (Ref.3). The magnitude of reduction in bending strength due to internal decay is much less than from shell rot. Consequently, measurement of fiber stress in the outer shell is a major factor to consider when evaluating currently available instruments for wood pole inspection.

Another factor to be evaluated along with the wood fiber stress is the moisture content of the wood. This is initially high when the pole is new and decreases during the first few years after installation to an equilibrium level as the pole dries out naturally. This level remains the same thereafter for a sound pole but rises at the groundline as decay increases. Hence the age of the pole must be taken into consideration when using moisture content as an indicator of pole decay. Initial moisture content is attributable to the amount of sap in the wood and can be ignored, but the presence of high levels of moisture in older poles is almost certainly attributable to biodegradation. Different species have different levels of moisture content at equilibrium. The pole surface moisture content varies continuously depending on the weather and location of the pole in the ground and must not be confused with interior moisture content. Therefore, an objective weather independent pole strength measurement cannot use pole surface condition as an indicator of the overall condition of the pole.

Other variables that affect the pole strength are knots, age (for some species more than others), and circumference.

Any reliable estimate of the strength of a wood pole must therefore take as many of the variables that influence the wood structure strength into consideration as is practical.

VII. Polux® Technology Background

The Swiss Federal Institute of Technology which houses the world’s largest wood structures institute (IBOIS) developed the Polux® System of wood pole inspection in Europe. The six year research and development program was sponsored by the French power company Electricité de France (EDF), in cooperation with the Swiss Power companies and the Institute (Ref 5,6). The Polux® inspection system has been adopted by some of the largest utilities in the
North American calibration of the instrument began in October 1995 and was followed by calibration and validation testing in October 1996 (Ref 7), Oct. 1998, and Oct. 99 at the Hydro-Quebec and Bell Canada joint test facility in Montreal, Canada. In these validation tests over 250 poles of the most common species used by utilities in North America were measured and then subjected to destructive bending tests in order to determine their actual remaining strength. An extremely high correlation of the instrument readings with the pole strength (correlation coefficient r > 0.8) was obtained which proved that the instrument can be operated in North America with a very high degree of confidence. (Hydro-Quebec HydroTech Winter 1996, vol. 11, No. 1).

The Polux® inspection device uses two special insulated probes that are driven into the pole at the groundline, the most vulnerable point where decay is most likely to be present. These special insulated probes, about 2.5 inches in length and 1/8 inches diameter, are used to simultaneously measure two critical properties of the pole. The first is the insertion force taken by the double probes from a constant depth of 2in. inside the wood. This measure is taken through a force sensor connected to the base of the probes. The second, taken between the tips of the probes at the same 2-inch depth, is the moisture content inside the pole. The two-inch depth where the measurements are taken is in the critical strength bearing outer shell of the pole.

The probes are capable of measuring moisture content well beyond the fiber saturation point which is important in the assessment of advanced decay in the pole. As the penetration resistance in wood is affected by the moisture content of the wood fibers, the simultaneous measurement of both hardness and moisture content enables Polux® to distinguish between good wood which is humid and hard to penetrate, and rotten wood which is also humid but offers little or no resistance to probe penetration.

Normally two measurements are taken on each pole at diametrically opposite points for increased reliability. The average of these two measurements constitutes a complete reading. These measurements are neither affected by daily
fluctuations (e.g. rain or weather conditions) in the surface condition of the pole, nor by its surface treatment (preservative).

Decay below ground or core decay causes loss of fiber strength in the groundline section of the pole. The penetration resistance of the probes at the groundline readily picks up manifestation of such decay where the Polux® test is performed. Polux®’s readings correlate significantly with the actual strength of the pole when the pole is stressed to destruction Fig.(1). The accuracy of the Polux® residual strength calculations is to within ±15%. Such tests were performed at independent pole research and testing facilities.

In addition to the measurements of hardness and moisture content, the hand-held computer associated with the instrument integrates five other pole variables that contribute to wood strength into the multi-variate pole strength analysis; species, circumference, height, knots, age and mechanical damage. Visual factors such as insect or pole top or surface decay are also noted. The results of the inspection - pole strength which is “Moment of Rupture” (MOR) at the groundline, minimum remaining life, and all other pole attributes - are calculated in the hand held computer and tabulated in an Excel based spreadsheet for eventual retrieval.

In addition to the measurements of hardness and moisture content, the hand-held computer associated with the instrument integrates five other pole variables that contribute to wood strength into the multi-variate pole strength analysis; species, circumference, height, knots, age and mechanical damage. Visual factors such as insect or pole top or surface decay are also noted. The results of the inspection - pole strength which is “Moment of Rupture” (MOR) at the groundline, minimum remaining life, and all other pole attributes - are calculated in the hand held computer and tabulated in an Excel based spreadsheet for eventual retrieval.

IX. Advantages of the Polux® NDE Wood pole inspection System

The Polux® wood pole inspection system offers many advantages over other wood pole inspection methods. These are:

- The Polux® test is a direct measure of fiber strength and moisture content 2 inches inside the pole. This measurement in the strength bearing part of the pole is not dependent on the surface condition of the pole. Surface wetness due to rain, minor surface damage due to weathering or the pole preservative treatment does not affect the Polux® reading.

- Polux®’s measurements of residual pole strength are objective and repeatable, and are not dependent the interpretations of the individuals carrying out the measurements.
• The Polux® measurement integrates many variables in the calculation of the pole strength; probe penetration resistance, knots, moisture content, pole age, circumference, height, species, and mechanical damage. Each of these variables has a bearing on the residual strength of the pole.

• The Polux® system is manufactured to ISO 9002 standards which ensures that all the instruments have a high degree of quality control and that the reading of one instrument is the same as any other. It also ensures that the instruments are calibrated at a regular frequency to rigid standards so that the user is assured of the repeatability of the measurements between instruments. This quality control is very important when many instruments are being deployed in the field over a long period of time.

• The Polux® system is the only wood pole strength measuring system accepted and certified ISO 9002 by an Electric utility. Electricité De France, the French National Power Company (the largest Power company in the world) has certified Polux® as its only acceptable wood pole strength measuring system.

• The Polux® system is designed for exterior use and is sufficiently water, humidity, and temperature resistant to withstand the harsh environments where poles are often located. In addition, the Polux® instrument performs its own self diagnostic test each time it takes a reading, and will not function if it detects any internal malfunctions.

X. Utility Benefits from using the Polux® System

Electric utilities use the National Electric Safety Code (NESC) as a starting point for designing Transmission and Distribution lines. The NESC specifies the minimum required strength the pole must have according to government regulation. The NESC does not specify the method to be used for determining the material strength at the time of replacement. This decision has been left to the judgment of the engineer. The NESC code limit requires that a pole be rejected when 33% of its “section modulus” (hence its strength) is lost. Due to the major limitations of the inspection methods presently utilized, and the absence of a good method to evaluate pole strength, poles are often rejected when they might still have adequate strength. Worse still, unsafe poles with interior decay might not be rejected using existing inspection methods. Similarly, in wood pole line designs, pole-loading criteria are based on ANSI values of strength for each species of wood. Since poles are only visually graded when new, they have a large coefficient of variation. Therefore it is very possible that a pole may be at the lower end of the designated strength even when newly installed.

• Direct measurement of strength of in-service poles with a good non-destructive evaluation (NDE) technique provides the utilities with a pole management program where decisions are driven by reliable objective data. The pole strength database developed with the new NDE instrument Polux will identify weaker poles and will allow for more informed decisions on when to replace, retreat, or strengthen such poles. Pole maintenance budgets can therefore be directed to the most pressing needs for improving system reliability.

• Many utilities automatically inspect and retreat poles after 10 or 15 years in the ground. Suppliers of poles, on the other hand, quote twenty or even more years before the poles need to be treated. Retreatment of a pole might delay the onset of decay but it will not increase the strength of the pole if it is already decayed. A database of life and decay patterns of each pole species could save the utilities considerable pole line maintenance costs by eliminating unnecessary inspections as well as re-treatments in the early life of the wood poles.

• More accurate wood pole assessment with this device would also result in a more ecologically sound approach to wood pole management by reducing costly retreatment with chemicals that eventually leach into the soil around the base of the pole.

• Development of long-term trend patterns will provide sound basis for new strategies on cost-effective pole selection, placement, re-inspection, and maintenance.

In summary:
Objective reliable pole condition measurement with a proven non-destructive technology such as Polux® will permit utilities to develop minimal risk pole management and
replacement strategies while optimizing replacement and re-treatment budgets.

XI. References: