IN FIELD NON DESTRUCTIVE TESTS FOR WOODEN POLES FOR THE SECURITY AND THE MAINTENANCE OF THE OVERHEAD POWER LINES

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INTRODUCTION

Wooden poles designed to support electricity- and telephone overhead lines have been used since the introduction of the cables on the market, about a hundred years ago. As an industrial product, the pole design has fairly developed. Improved impregnation methods have prolonged their lifetime to between 30 and 50 years. Still, the pole lifetime is very variable and might be shorter or much longer.
The number of in-service overhead wooden poles within the EU corresponds in average to 1 pole per 2 persons, more in the Nordic countries. This fact makes a strategy for network management necessary, with the following targets:

- *Fulfill required security for linesman staff*
- *Guarantee the reliability of the network*
- *Satisfactory organization and an optimization of maintenance, repairing and replacements*
- *Extension of the poles life time.*

OVERHEAD POLES AND IMPORTANT PROPERTIES

The properties of the overhead pole, especially the mechanical resistance, vary considerably from one pole to the other.
Traditionally, visual inspections are made to avoid the use of damaged or affected poles. But this is not enough to determine whether the pole is reliable. A damaged pole can be very strong and a visually perfect one can be very weak. Therefore, guidelines have been put up, where pole stresses caused by wind on the poles should not exceed specified values. The latter ones are based on a nominal bending strength and a security factor of 2,5 - 3,0. In Switzerland e.g., the admitted maximum value for bending stress is 45/3 N/mm^2. The traditional verification made at the ground level, can be expressed [1]:

$$D_b^3 = \frac{FL \cdot 32}{\sigma_{adm} \cdot \pi} \qquad (1)$$

D_b = min. diameter at the ground line
Φ= αππλιεδ φορχε ατ τηε πολε τιπ
Λ= πολε λενγτη αβοϖε τηε γρουνδ λινε
σ_{adm} = αδμιττεδ βενδινγ στρεσσ

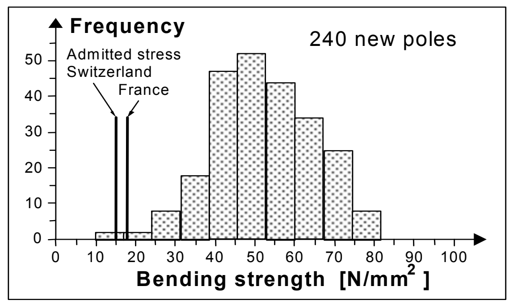

Fig.1 Statistical distribution of bending strength for tested new poles (admitted maximum stress value in comparison).

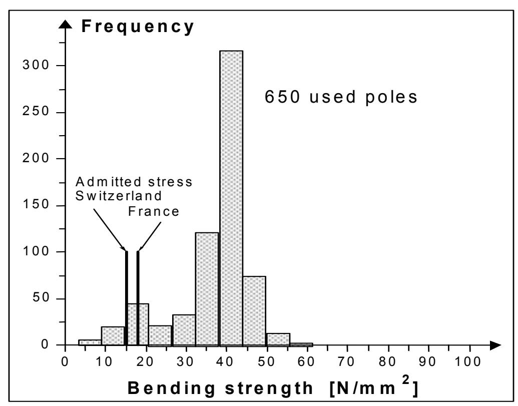

Fig.2 Statistical distribution of residual bending strength for tested used poles (admitted maximum stress value in comparison)

Figure 1 shows that some of the used tested poles do not respect the threefold security against failure. Still, seen over a large number of poles (e.g. along a line) the security factor will be approximately 3.
This general statistical approach does not consider the individual pole strength, but is based on the admitted maximum stress value.
The figures 1-4 give an insight in the statistical distribution of different parameters for some pole samples. The results have contributed to the development of the Polux® technology.

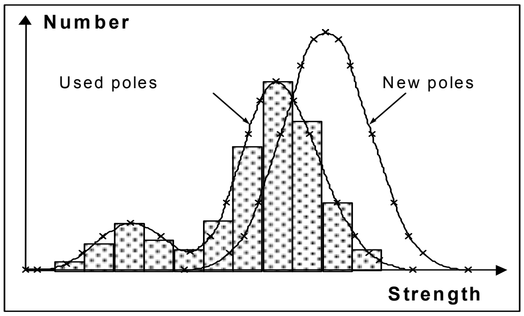

Fig.3 Comparison between new and used poles. Statistical distribution of residual bending strength for used poles with respect to normal ageing and to abnormal attacks. The last mentioned phenomenon is characterized by a side-maximum to the left.

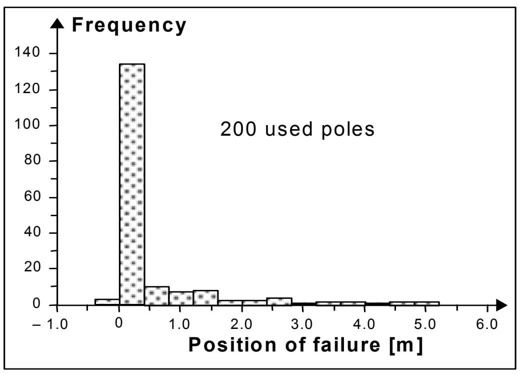

Fig.4 Position of failure section related to ground level (=0). The actual sample comprises 200 used poles.

AGEING AND RELIABILITY

Despite chemical treatment (impregnation), the poles lose a part of their mechanical resistance with time, through ageing processes. Those can be of two kinds. The first one is due to variations in mechanical solicitation (wind and snow) or humidity (alternating drying and humidifying). The altering effects of these processes extend over a period of 5 years approximately. This is the phase called *normal altering*.

Type two, on the other hand is an *abnormal altering* phase and is due to biological attacks. The latter one affects 8 to 15% of the poles during the first 30 years in operation. The biological influence succeeds to get through the chemical protection and the mechanical resistance can abruptly decrease. Beside the last mentioned altering, observations where made on wood fiber decomposition, that seems to be dependent on age, variations in humidity and type of chemical treatment. A reason to this could be a slow oxydation process that lowers the mechanical resistance. Thus, this abnormal ageing process can occur where no biological decay is found.

Other local types of abnormal altering mechanisms can also contribute to a higher exchange rate of poles. Examples are mechanical damage by vehicles or woodpeckers.

The statistical ageing process for 650 poles is shown in Figure 2. The sample has been randomly chosen, independent on age from 10 years old to 60 years old. The Figures 3 highlights the evolution from the new wooden poles to the in-service ones. Apparently, the normal ageing process displaces the resistance distribution curve to the left. Moreover, a side maximum can be seen to the left, indicating a concentration of abnormal influence.

VARIABLES IN NON DESTRUCTIVE TESTINGS

Below, the critical residual mechanical resistance is examined (original resistance in non-affected conditions – resistance reduction due to ageing and/or decay) at the ground level. Even though pole failure has been registered higher up along the pole, it occurs statistically to 90% at this point which is the reason that the resistance evaluation (the test) is made there. The 10 remaining percent can mostly be detected by visual inspection, which is always a complementary part of the Polux®- technology.

If the visual inspection has not indicated weak sections above the ground level, the position for the failure section is very probably the ground level ±20cm (fig.4).

In consequence to the above mentioned, the development of the Polux® testing procedure focus on the pole at the ground level. This has given concrete results by examination of the local density on one hand, by means of the so called Pilodyn method (fig.5), the humidity quote on the other hand. Wood with a high humidity quote underlines a presence of biological decay. The wood fibers are then damaged and the residual mechanical resistance is lowered (fig.6). The most significant values for overhead wooden poles in Switzerland occur in a section 5cm above ground, which reinforce the hypothesis that biological decay statistically attacks the part of the pole above the ground line and not bellow. This concerns poles treated with creosote as different metallic salts. For reimpregnated (painted) poles, the conditions are more complex, since humidity transport plays a certain role.

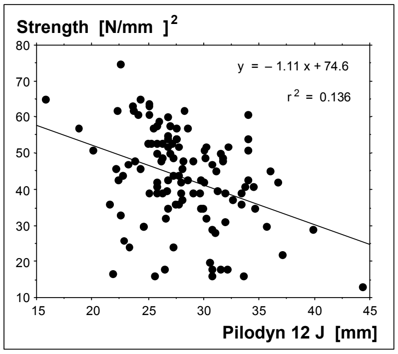

Fig. 5 Correlation between Pilodyn measurements and failure strength at cantilever bend loading. The actual sample comprises 200 used poles.

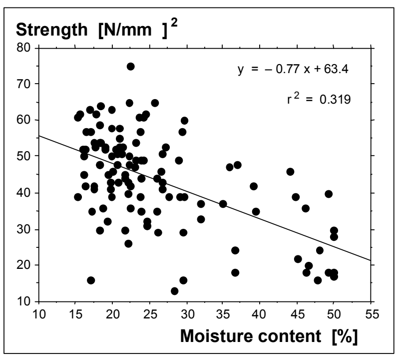

Fig. 6 Correlation, based on 200 used poles, between values from moisture measurement (Gann, average values from 4 measurements at +5cm level above ground = level of embedment +5cm) and cantilever bending failure stress.

Outgoing from the combination of the two variables density and humidity, the residual mechanical resistance can be evaluated with satisfactory exactness (which would be not possible with the two variables separately). A concept has been developed, where two electrodes are pressed into the pole at which humidity and pressing force are measured simultaneously. This is the principle for the test device Polux®. While the Pilodyn method uses a point to determine the local dynamical density over a distance of 20-25mm, Polux® uses a force sensor that instantly measures the almost static force required to press two electrodes into the pole base at a depth of 40mm. The humidity is recorded at the same time. This technique reduces the risk of wood crack formation. Beyond humidity and density, several years of research and development have resulted in auxiliary parameters to further increase the exactness of the Polux® analysis. Fig.9 shows results achieved by Polux® measurements for a group of poles. The coefficient of correlation between the failure load estimated by non destructive testing (Polux®) and the real breaking loads, (achieved by destructive testing), r^2 = 0.7, corresponds to a standard deviation of ± 15%. Compare with fig.9 (without taking any notice to the Polux® security scale, represented by hatched surfaces): Polux® calibration: Actual residual failure strength against residual failure strength estimated by Polux®.

THE TEST DEVICE POLUX®

The basic idea in the development of the Polux® device consists in a combination of density- and moisture content measurements. After testing and evaluation of the first prototypes the guidelines could be put up for the development of a more sophisticated product. Hereby special importance has been given to user-friendliness and fast analyzing results. This has resulted in a portable and waterproofed instrument, with about a minute between measurement and analyzed result giving the residual strength and a security diagnosis (see figure 8). Polux® total weight, with all basic equipment, packed in its rucksack is only 8,5kg, despite its shock-resistance and reliability.
In the following, the principles of the Polux® security and lifetime aspects as well as measurements will be presented according to a more detailed scheme.

POLUX® SECURITY SCALE

The inspection of poles with the Polux® device is made at the ground level, perpendicular to the line direction and if possible in the prevailing wind direction. The recorded values from these measurements are transmitted in real time into classified reliability. A two color screen (green and red) shows the results*:

- ***Red***: R < 18.3 N/mm². The pole is very weaken and should not be climbed without a special security arrangement for stability and/or support. To be changed!
- ***Flashing red***: 18.3 < R < 23.0N/mm² (15 x 1.53). The pole is certainly weaken but has a higher residual bending strength than specified in the standards. The pole can be then kept in the line. But because of this low value and the risks of next degradations, the next test on this pole must be near. Ascent needs precautions. Next test in 3 years.
- ***Flashing Green***: 23.0 < R < 28.0N/mm² (15 x 1.87). The weakest pole in this group is to 80% probability stronger than 18.3N/mm², the best to 99%. The designation ”good” can be done for these poles. Next test in 5 years.

- ***Green***: The probability for poles from this group, to have values < 15N/mm², i.e. with risk for maintenance staff, is lower than 1%. The poles are in very good condition. <u>10 years</u>.

Fig.8 Pole inspection with Polux® connected to the handheld computer Psion

Polux® evaluation of *residual strength* is done according to the equation 2:

$$R = k_1 D + k_2 H + k_3 + \varepsilon \quad (2)$$

R Pole residual bending strength in N/mm².

D Density, measured by Polux® thanks to the two probes.

H Moisture content, measured by Polux®, between the probes, 40mm within the pole.

$k_{1,2,3}$ Factors of correlation, depending on impregnation, species, salt solutions, etc.

ε Statistical error of the model.

This evaluation procedure has been compared and calibrated to destructive testing for ultimate bending strength. To a large extent is has been carried out in laboratory at the Institute for Wood Constructions at the EPFL, Lausanne (CH), according to the Cantilever technique. Fig.9 shows this calibration and the scattering of the test. The graph also shows the security classes by the green and the red patterns indicating the reliability for the Polux® adjustment. In addition, to get the adjustment more accurate, Polux® defines two transition areas (flashing green and flashing red). The positioning of these zones has been calculated by Polux® with the pole in the class with the smallest diameter. In reality it implies, that the security for larger poles is greater than mentioned under "Polux®'s security scale".

*depending on national codes
here: examples from France

POLUX® EXPECTED LIFE TIME

Polux® evaluation of residual life time can be deducted from the formula of the calculation of the residual strength and associated security classes (equ.2). Nevertheless, concerning life-time (i.e. advised inspection period), the measured moisture content has been given extra weight, since it reflects the risk of biological attacks.

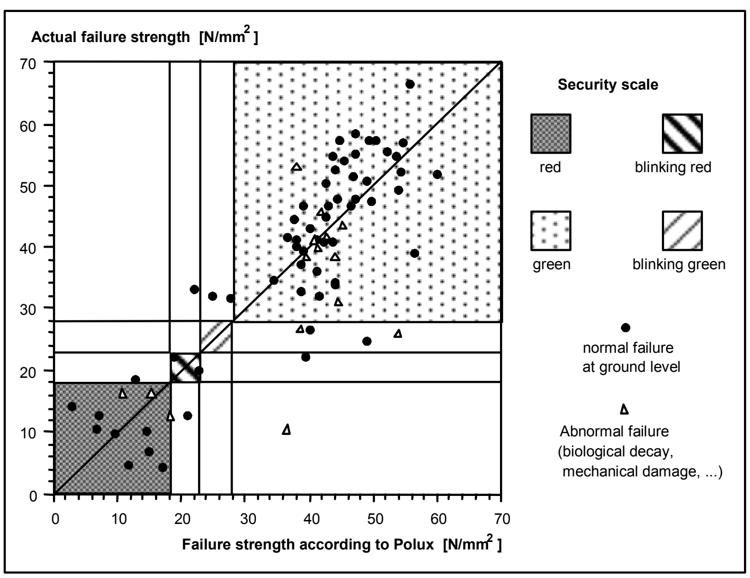

Fig. 9 : Correlation between the predicted bending strength given by Polux and the real bending strength. Definition of the classes of security according to the national standards.

With the help of this scheme, an image of the "health" distribution for a pole sample, e.g. along a line, can be obtained [2]. Naturally, the Polux® device also enables analyses at an "individual" level, pole by pole. This is of special interest for poles that not have been assigned "red" in the security classification, i.e. the poles being a matter of judgment with respect to priority for exchange or maintenance.

STATISTICAL EVALUATION WITH THE SOFTWARE K-STORE®

All data collected by Polux® with the in-field tests can be further worked up, completed and evaluated. The Polux® instrument has been equipped with a memory that automatically stores tested data in a database-register. During field tests, the user can give complementary information (e.g. pole designation special observations or remarks) with the help of a handheld computer. Linked to Polux® , the observations and the results of the device allow a multivariate analysis and a global management of the line. Polux® can afterwards at the office, be directly connected to a PC by a serial port of type RS 232. The transferred information (in basic form) comprises, eventual type of wood treatment, pole designation and test results. The software K-Store®, treats these data, to present the information in a user-friendly way. K-Store® can for instance give the test results for a line in graphical form and this for calculated pole residual strength (see fig. 10a) as well as advises on time until next test campaign, depending on the speed of biological decay (see fig. 10b). With access to this information network managers can concentrate on the most urgent zones to be maintained or where poles have to be changed [3]. Hence, for one pole sample that turns out to be in good condition it can be motivated to put off next scheduled test campaign, whereas for one in bad shape it can be an economical matter whether all or some should be changed.
Finally, where two or several earlier test campaigns have been carried out, the test series enable a mutual comparison and tendencies can be analyzed concerning decay mechanisms.

In this way geographical or pure historical tendencies might be exposed (i.e. decay affected origin tree), but also the effect of different chemical pole treatments.

PICUS

This software, installed on a handheld computer (see fig. 8), completes Polux® and K-Store® in a user-friendly way. The program enables a data collection and a display in field, next to the poles. The program integrates actual quality codes in order to make immediate in-field decisions possible about security for the cables, isolators, etc... Thanks to Picus®, the Polux® - technology can be personally adapted to meet any requirements i.e. that of wood types, chemical treatments, climate conditions, pole quality etc.
Moreover, the additional information given by the inspection staff with the help of Picus®, increases the accuracy of the Polux® technology and opens a wide range of possibilities for a global management thanks to its compatibility with GPS and SIG integrated systems.

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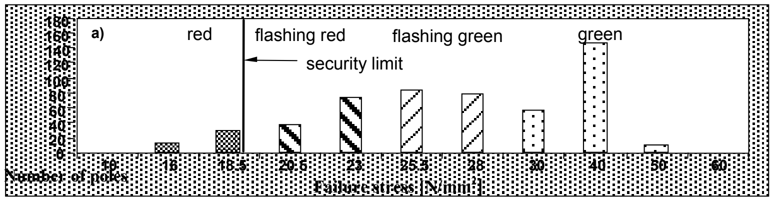
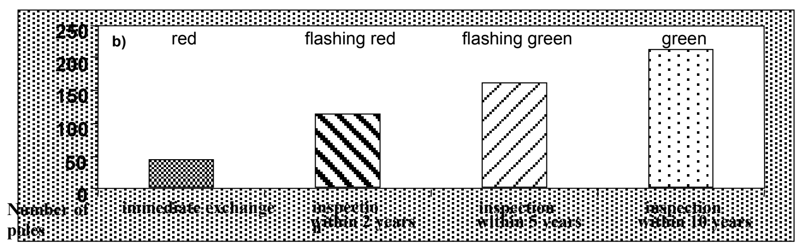


	number of poles	[%] per group	average stress per group [N/mm²]	average security factor per group
red	45	8	16,7	0,9
blinking red	115	21	21,1	1,2
blinking green	163	30	25,5	1,4
blinking green	215	40	32,7	1,8
total	**538**	**100**	**26,7**	**1,5**



Date for network installation (average value)	1977
Date for installation of the oldest pole	1929
Date for installation of the youngest pole	1995

	Number of poles	[%] per group
Immediate exchange	45	8
Inspection within 2 years	115	21
Inspection within 5 years	163	30
Inspection within 10 years	215	40
total	**538**	**100**

Fig 10 Results from statistical evaluation with K-Store® sofware. The essential security aspects (a) and the estimated lifetime/advised inspection period (b) are shown in the two graphics above, with the statistical network values in table form.