Controlled Ageing of High Voltage Pylons

Peter Polák, Martin Kasenčák, Jakub Porubčan, Michal Novoveský, Vladimír Piussi
First Welding Company Inc.
Slovakia

Abstract—**This contribution is dedicated to issues of long term safe service of high-voltage pylons, which are during service loaded by variable loading with simultaneous acting of external environment. There were proved the procedures ensuring that the limit state will not occur during the period of technical life and the service will be safe for a long time. A draft of diagnostic procedures was elaborated. The maintenance and repair procedures, assuring the safety of service until next inspection are planned on the basis of application of analytic methods of dynamic fracture mechanics. Controlled ageing allows to save high economic values at spending considerable lower costs for inspection and maintenance.**

Keywords-pylons; controlled ageing; residual life; risk based inspection

I. INTRODUCTION

The construction of high-voltage lines transmitting 110 kV, 220 kV and 400 kV started in Europe in the 40-ties of the past century. Most of original pylons are in service till present days. Replacement is actually performed only for the reason of pylon breakdowns.

II. LOADING OF PYLONS

The construction of high-voltage lines transmitting 110 kV, 220 kV and 400 kV started in Europe in the 40-ties of the past century. Most of original pylons are in service till present days. Replacement is actually performed only for the reason of pylon breakdowns. Pylons are loaded by random loading processes. Breakdowns usually occur due to icing, strong side wind and/or by combination of both. Gusty wind causes the galloping of ropes. In general, four types of dynamic loading occur which are caused by unfavourable weather conditions. These are: aeolic oscillations of ropes, galloping oscillation of ropes, dynamic impact at shedding of ice from the rope and detachment of whirls on the pylons and insulators. Danger of sudden breakdown occurs at resonance, when the loading frequency is equal as the own frequency of pylons. Breakdown of one pylon used to be the initiator of the so-called domino effect - a progressive breakdown of greater number of pylons.

A. Response to External Loading

The rate and dynamics of external loading cause a response in the critical points of structure by damage cumulation. In the first phases this is an event without visible signs on material surface, when the incubation phase of fatigue failure on the level of structure and substructure (crystals) takes place, mainly by growth in density of dislocations. This stage of development of fatigue cracks is usually affected by the stress concentration from notches and also by residual stresses, mainly in the zone of welded joints. After incubation stage of fatigue process, the stage of fatigue crack growth follows. The damage process terminates by rupture of the remaining cross section. In case of existence of surface defects (crack, lack of fusion, cold lap, etc,) the incubation phase is abandoned and the entire process of fatigue consists only in the fatigue crack growth.

By the Griffith - Irwin (1957) theory, the main criterion for fracture of a structure and/or its part consists in attainment of the critical crack size a_c . At this size of crack, the limit state would occur by mechanism of brittle or mixed brittle-ductile fracture. Regarding the fact that fracture occurrence should be avoided, the admissible crack size must be smaller than the critical. The structures dynamically loaded in service may be loaded either by high-cycle fatigue, strain (low- cycle) fatigue or by irregular fatigue loading. Theoretical background for determining the growth rate of fatigue cracks is sufficiently mastered at present. For crack growth rate at high cycle fatigue, the Paris - Erdogan's (1936) relationship is used, whereas for the strain fatigue the Manson - Coffin's (1954) relationship is applied and at irregular fatigue, the cumulative hypotheses are employed, whereas the most widely used seems to be the Palmgren - Miner's (1945) criterion in conjunction with Wohler's (1860) curve [1].

Present direction in the field of design, manufacture, service, repairs and liquidation of structures is governed by the approaches making use of the theoretical and practical knowledge of the „Fitness For Service - FFS" approach. Documents from this field are accessible on the web site: www.eurofitnet.org.

Application of this theory in fabrication and service of metallic structures is schematically shown in Table 1.

The limit state may occur from several reasons, for example from the material loss of the bulk structure, caused by corrosion. Material degradation may occur due to ageing, distortion of crossbars and due to defect growth by fatigue process, most often by loading caused by the sharp atmospheric influences.

TABLE I. MODULES OF FITNESS FOR SERVICE" APPROACH.

Safety and service reliability	Structure design	Structure fabrication	Assessment during life	Analysis of limit states
Information needed for assessment	Information about service during life	Rate and type of loading	Mechanical properties of material	Extraordinary effects
Possible failure modes	Fracture (brittle, ductile)	Distortion (plastic collapse)	Fatigue	Corrosion
Integrity criteria	Critical defect size	Residual life	Categorisation	Passportisation
Application	Creation of databases	Utilisation of databases	Controlled ageing	Economic studies

B. *Risk based Inspection*

At present, there are many important high-voltage lines in the age, when the life of pylons is approaching and/or it has already reached the design life. Therefore it is necessary first of all to eliminate in maximum possible measure the dangerous states and risks leading to possible formation of limit state in pylons and at the same time to secure the diagnostics of all pylons older than 40 years.

Repairs and maintenance of pylons are mostly performed just by partial interventions, either of greater or smaller extent and these are performed on the basis of empiric professional judgements. The advances suitable for assessment and continuous diagnostic monitoring of real technical state of pylons during their life has not been developed nor introduced up to now. Any relevant progression for determination of residual life, that would be generally accepted and binding, were elaborated. Since there is considerable disunity in opinions how to proceed in individual cases, it is necessary to elaborate a knowledge-based solution of diagnostics, procedures for maintenance and repairs as well as for replacement of pylons and/or entire lines.

Optimum solution of maintenance and repairs supposes determination of suitable inspection intervals. Their determination follows from the analysis of damage risks (Risk Based Inspection - RBI) [2], as shown in Fig.1. The structure must be capable to tolerate the failures formed between the two inspection intervals. Thus, in spite of existence and growth of damage caused by corrosion and/or dynamic loading, the structure must be safe and functional up to the next planned inspection. Determination of interval of diagnostic inspections directly depends on the admissible probability of failure.

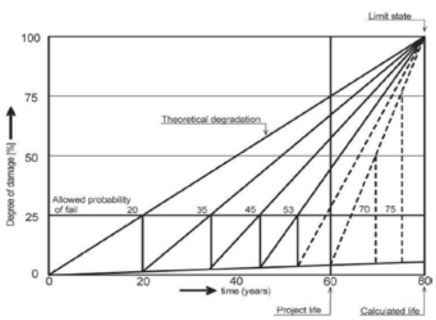

FIGURE I. INTERVALS OF STRUCTURE INSPECTION BY THE RISK BASED INSPECTION THEORY.

III. SYSTEM OF DIAGNOSTIC MEASUREMENTS

Diagnostics is destined for an objective determination of factual state of pylon material from the viewpoint of its damage during the service. Modern non-destructive and destructive diagnostic methods used for determination of factual stage of pylon damage allow to obtain a complex picture about the internal and external defects in the critical cross sections, as well as the measure of material damage due to ageing. The scheme of system is shown in Table 2.

TABLE II. THE SYSTEM OF DIAGNOSTIC MEASUREMENTS.

<table>
<tr><td colspan="7">Diagnosed subject</td></tr>
<tr><td>Material sampling</td><td>General visual inspection</td><td colspan="5">Direct NDT inspection</td></tr>
<tr><td>Mechanical tests</td><td>Surface corrosion
UTT</td><td colspan="5">Inspection of critical points</td></tr>
<tr><td>Metallographic studies</td><td>State of surface protection
ET</td><td>VT</td><td>UT</td><td>ET</td><td>MT</td><td>PT</td></tr>
<tr><td>Chemical analysis</td><td>Distortion of crossbars</td><td colspan="5">Residual stresses</td></tr>
<tr><td>Transition temperature</td><td>State of bases</td><td colspan="5">Local hardness</td></tr>
<tr><td colspan="7">Results of diagnostics</td></tr>
<tr><td colspan="7">Proposal for maintenance and repairs</td></tr>
</table>

A. *Life of Pylons*

The diagnostics grasps the actual state in damage of individual pylons. Based on assessment criteria, the extent of damage is assessed in five degrees, whereas the first degree represents a non-damaged pylon and the fifth degree represent a pylon in emergency condition. The intermediates comprise: slightly, moderately and considerably damaged pylon. The damage degrees are schematically shown in Fig. 2. The damage process of steel structure of pylons progresses in the course of life separately in its individual components (corrosion, ageing, defect growth, distortions of crossbars etc.) but the resultant effect of damage is represented summarily. The degradation process is governed by actual physical and chemical laws, which allow to predict their expected further development, as also seen in Fig.2.

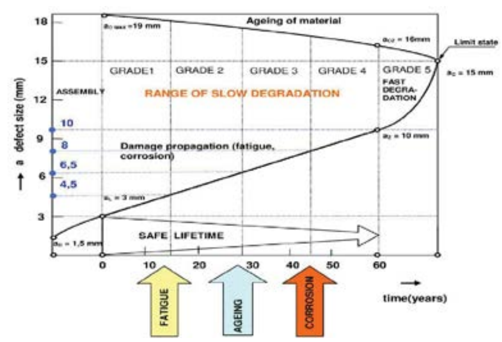

FIGURE II. THE COURSE OF LIFE AND THE DEGREES OF PYLON DAMAGE.

Thus, a real possibility to determine the supposed residual life of pylon structure is created. The individual degradation effect preserve certain specific features, therefore it is necessary to analyse the individual degradation effects separately [3]. The residual life may be determined for each individual pylon, however it is recommended to determine it just for the most damaged pylon in each section.

B. *Residual Life*

Residual life generally depends on the state in structure damage, on acceptable damage size and on the supposed service conditions in the course of time form diagnostics performance till the end of safe life. Four significant modes of damage may occur on pylon structures which alter during the course of life and affect the residual life of a pylon: material ageing [3], corrosion [4], fatigue crack growth [1], distortion of crossbars.

Determination of supposed residual life is an engineering problem, which solution consists in a unimpeachable estimation of time during which the pylons may be utilised at met requirements for service safety. Residual life of pylons is thus considered till termination of a safe service and not up to reaching the emergency (limit) state. Each of the mentioned damage modes may separately cause the termination of service period, due to exceeding the critical damage size (CDS). The time courses of assessment properties can be obtained on the basis of long-term monitoring of individual damage modes. This allows to achieve the life function of studied property. At individual damage modes, attention should be mainly paid to the following two issues:

- course of the life function at individual damage modes,

- critical degree of degradation (CDS) of an actual damage.

Regarding the fact that the development of individual damage modes, as well as the admissible degree of degradation mutually differ, since they are of different physical or chemical essence, it is necessary to approach to individual damage modes separately.

IV. Controlled Ageing

Integrity of pylons must be ensured continually. The quality systems have introduced the principle of responsibility of manufacturer and operator for the safety of product, in our case the lines of high-voltage during the entire period of their technical life. This requirement may be ensured by the method of controlled ageing of pylons. Principle of controlled ageing consists in the fact that a complex diagnostics with subsequent maintenance (eventually also repairs) of all defective points is performed in the intervals defined in advance [5]. After such action the structure gets to its „initial" state. However, the material degradation caused by ageing will remain a permanent change that cannot be removed. These intervals are determined by the RBI (risk based inspection) method, as shown in Fig. 3.

Controlled ageing has a direct effect upon two most important performance criteria, namely the service reliability and Life Cycle Cost (LCC). However, also time of safe service is prolonged. On the side of expenditures, the costs for diagnostics, maintenance and repairs are involved, whereas on the side of savings a prolonged time of safe life of pylons is obtained. Practice have shown, that the cost for controlled ageing are considerable lower, than the savings obtained by prolonged time of safe service with postponing of new investment.

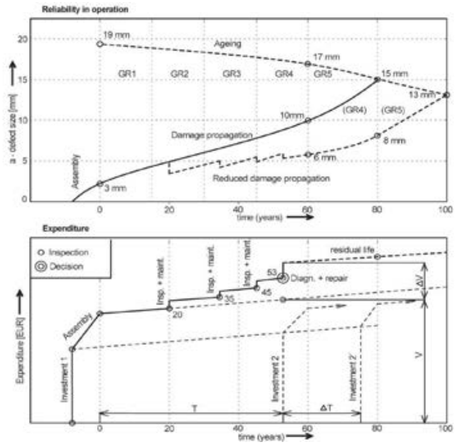

FIGURE III. THE COURSE OF CONTROLLED AGEING AND DATA ANALYSIS.

A. *Passportisation and Database of Pylons*

Precondition for introduction of system of controlled ageing consists in creation of passportisation of pylons. Each pylon has its passport with given all basic data necessary for further analyses in the course of life, as shown in Table 3.

TABLE III. MAIN DATA IN PASSPORT.

Fabrication and putting to service	External effects in the region of location	Realised repairs and maintenance
Locality (map)	Temperature range, icing zone	Replacement of crossbars or other parts (splice bars etc.)
Line designation	Band of precipitation	Replacement of accessories
Pylon designation	Band of wind speed	Replacement of ropes
Drawing documentation	Maximum windstorm degree in the region	Replacement of insulators
Static calculation - standard	Landslides	Renewal of paints
Date of pylon erection	Seismic effects	Removal of scrub, soil
Date of putting into service	Area of infestation – industry	Repair of foundations
Pylon material	Area of infestation – chemistry	Other repairs
Used joints: welds/bolts	Other effects	Other maintenance
Filler metal	Notes	Notes
Other data		

Individual lines were put into service at different time. It is quite apparent that all input data will not be available for the older line sections. However, this is by no means an obstacle for creation of databases of actual present state. A database is actually a defined set of passports with all relevant data for performing the analyses of actual state and plan of maintenance, repairs and/or reconstruction. All tests and measurements must be performed by an authorised institution. Database is continually completed with all data connected with the service of pylons, as the results of occurring during the line life, realised maintenance and so on.

V. Discussion and Conclusions

Research of life of pylons in high-voltage lines has shown the possibilities for realisation of repairs, maintenance and replacement on the basis of scientific approach [6]. In some cases of loading of carrying pylons it is necessary to perform also other non-standard tests, as for example fatigue tests, tests of crack growth rate, determination of fracture toughness, tensometric (strain rate) measurements, rigidity measurements and detection of resonance frequency of a pylon. In order to assure the service reliability, as well as the optimum economical usage of transmission system, it is advisable to elaborate and implement the program of controlled ageing of transmission system. This will then allow to monitor and assess the effect of service and degradation processes on individual components of transmission line, to observe the trends in changes of their state and to accept early the precaution measures for removing and/or moderating the causes of ageing. The program of controlling ageing is one of preconditions allowing to prolong the residual life of transmission system. Finally it must be emphasised that determination of residual life is neither cheap nor simple. This supposes introduction of a system for observing the „life" of pylons starting with design up to discarding from service (decommissioning).

ACKNOWLEDGEMENTS

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