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Neural Network Precept Diagnosis on Petrochemical Pipelines for Quality Maintenance

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Abstract

Pipeline tubes are part of vital mechanical systems largely used in petrochemical industries. They serve to transport natural gases or liquids. They are cylindrical tubes and are submitted to the risks of corrosion due to high PH concentrations of the transported liquids in addition to fatigue cracks. Due to the nature of their function, they are subject to the alternation of pressure-depression along the time, initiating therefore in the tubes' body micro-cracks that can propagate abruptly to lead to failure by fatigue. On to the diagnostic study for the issue the development of this prognostic process employing neural network for such systems bounds to the scope of quality maintenance.

Keywords: Percept, Simulated results, Fluid Mechanics

1. Introduction

The pipelines tubes are manufactured as cylindrical tubes of radius R and thickness e. The failure by fatigue is caused by the fluctuation of pressure-depression along the time t ($0 \leq P \leq P_0$). These pipelines are unfortunately usually designed for ultimate limits states (resistance).To be more realistic, a prognostic model is proposed here based on analytic laws of degradation by fatigue (Paris' law) in addition to the cumulative law of damage (Miner's law).This prognostic model is crucial in petrochemical industries for the reason of favorable economic and availability consequences on the exploitation cost .

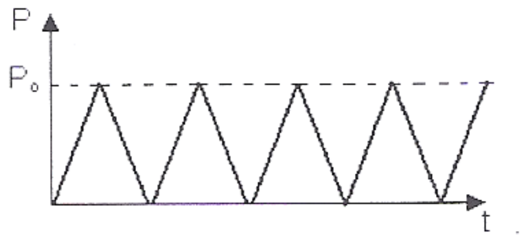


Fig. 1: Internal pressure diagram.

2. Paris Law

The Paris' law allows determining the propagation speed of the cracks *da/ dN* at the time of their detection: $\frac{da}{dN} = C.(\Delta K)^m$ where *a* is the crack length, *N* is the number of cycles, *C* and *m* are the Paris constants, and ΔK is the stress intensity factor.

We can distinguish:

- The long cracks that obey to Paris law
- The short cracks that serve to decrease the speed of propagation

- The short physical cracks that serve to increase the speed of propagation

The law can be written also as : $\log\left(\dfrac{da}{dN}\right) = \log C + m \log(\Delta K)$

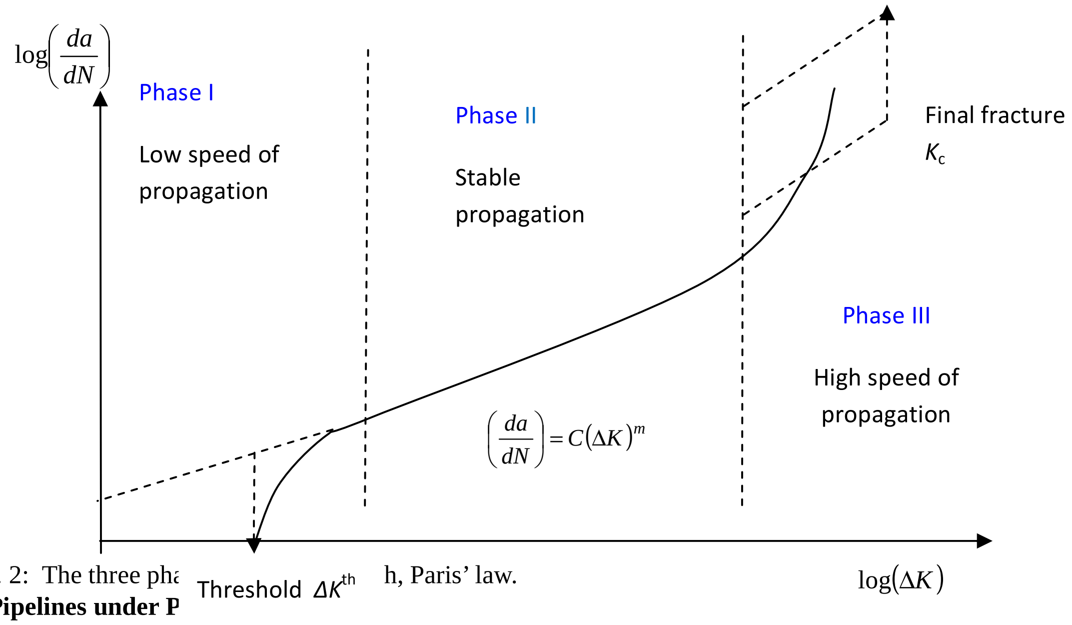
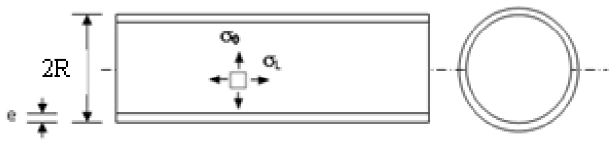


Fig. 2: The three pha h, Paris' law.

3. Pipelines under P

A tube is considered thin when its thickness is of the order of one tenth of its radius: e ≤R/10

Fig. 3: Cylindrical pipelines



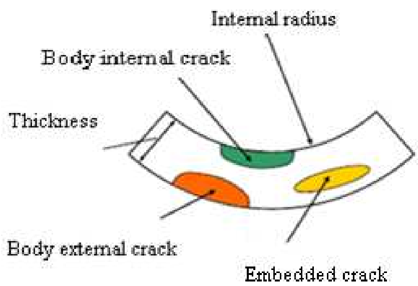
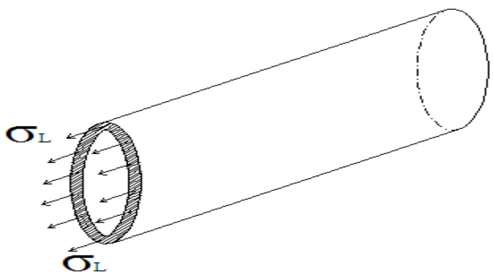


Fig. 4: Stress type distribution

4. State of Stresses

Te tubes are cylindrical shells of revolution. when thin tubes of radius r and of thickness e are under internal pressure p, the state of stresses is membrane-like under bending loads. the membrane stresses are circumferential (hoop stress) σ_θ and longitudinal stresses (axial stress) σ_L



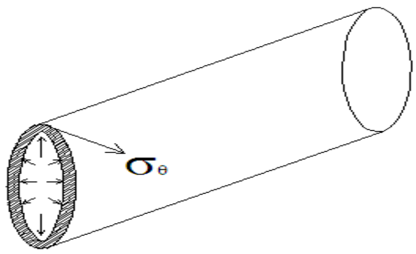


Fig. 5: Axial stresses and Hoop stresses in cylindrical pipelines

These stresses are given by: $$\begin{cases} \sigma_\theta = \dfrac{P\,R}{e} \\ \sigma_L = \dfrac{P\,R}{2\,e} \end{cases}$$

The critical cracks are those which are perpendicular to maximal stresses σ_θ, that means longitudinal cracks which are parallel to the axis of the tube. A crack is of depth *a* or of length *a*, if we measure in the direction of the tube thickness e. Normally the ratio a/e is within the following range: $0.1 \le a/e \le 0.99$

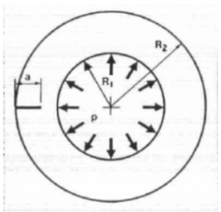
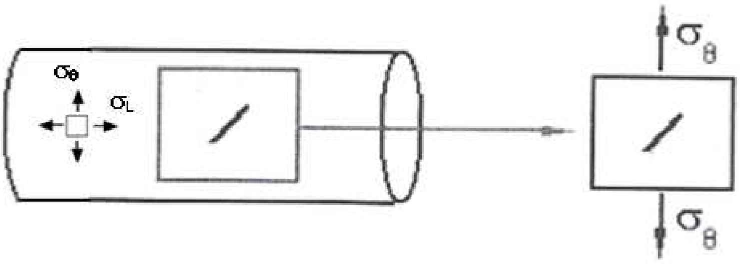


Fig. 6: Crack length in radial view



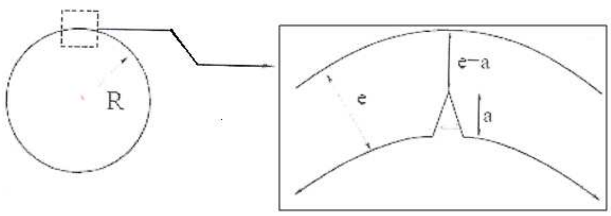


Fig. 7: Cracked pipeline section

The stress intensity factor K_I represents the effect of stress concentration in the presence of a flat crack.

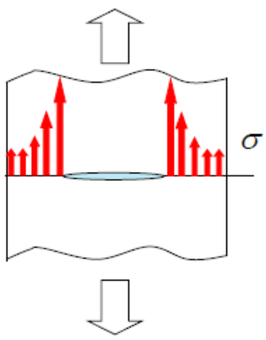


Fig. 8: Non-uniform distribution of stresses near the crack

The stress intensity factor is given [6] by:

$$K_I = y(a) \times \sqrt{\pi a}\, \sigma_\theta$$

$$\Rightarrow K_I = 0.6 \times g(a) \times \sqrt{\pi a} \times P.\frac{R}{e} \leq K_{IC}$$

with $Y(a) = 0.6 \times g(a)$: is the geometric factor ;

$$g(a) = \frac{1 + 2\left(\frac{a}{e}\right)}{\left(1 - \frac{a}{e}\right)^{\frac{3}{2}}}$$

K_{IC} : is the d is given by:

$$K_{IC} = \sqrt{\frac{J_{IC} \cdot E}{1 - (\nu)^2}}$$

Note that the factor K_I must not exceed the value of K_{IC} .

$$K_{IC} = \sqrt{\frac{J_{IC} \cdot E}{1 - (\nu)^2}}$$

5. Proposed Percept Model

Consider a pipeline of radius R = 240 mm and of thickness e = 8 mm transporting natural gases, the parameters related to materials and to the environment are taken as being equal to

: [5] m= 3 et $C = \varepsilon = 5.2.10^{-13}$

The length of the crack is denoted by a with an initial value $a_0 = 0.2$ mm $a_0 \leq a \leq a_N = \frac{e}{8} \Rightarrow \frac{e}{a_N} = 8$

We have to respect the following ratio:

$$0.1 \leq \frac{a}{e} \leq 0.99 \Rightarrow 1.01 \leq \frac{e}{a} \leq 10$$

Take a similar form to $\frac{da}{dN}$ as $\dot{a} = \varepsilon \phi_1(a) \phi_2(p)$

with: $\varepsilon = C$; $\phi_1(a) = \left(Y(a)\sqrt{\pi a}\right)^m$; $p = \Delta\sigma$ and $\phi_2(p) = p^m = (\Delta\sigma)^m$

The initial damage is: $a(0) = a_0$

A recurrent form of crack length gives:

$$a_i = \varepsilon \phi_1(a_{i-1}) \phi_2(p_i) + a_{i-1}$$

And the corresponding degradation is given by:

$$D_i = D_{i-1} + \eta \phi_1(D_{i-1}) \phi_2(p_i)$$

$$\text{for } m = 3 \Rightarrow \phi_2(p_i) = p_i^3 = (\Delta\sigma_{\theta i})^3$$

$$\text{Morevor } \eta = \frac{\varepsilon}{a_N - a_0}$$

We define the damage fraction by: $d_j = \dfrac{da_j}{a_N - a_0}$

Therefore, we get the cumulated total damage: $D_i = \sum_{j=1}^{i} d_j = \sum_{j=1}^{i} \dfrac{da_j}{a_N - a_0} = \dfrac{\sum_{j=1}^{i} da_j}{a_N - a_0} = \dfrac{a_i}{a_N - a_0}$

We can easily prove that: $D_N = \sum_{j=1}^{N} d_j = 1$

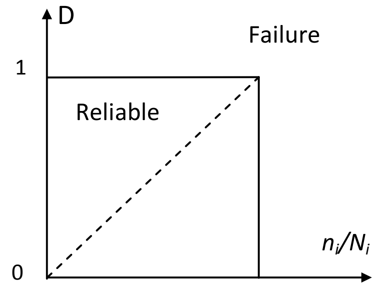


Fig. 9: Miner's law of damage

$$
\begin{aligned}
&\text{where:}\\
&0 \le n \le N, \quad a_0 \le a \le a_N;\\
&D_0 \le D \le 1 = D_N; \quad D_N = \sum_{j=1}^{N} d_j = 1\\
&D_0 = \frac{a_0}{a_N - a_0} \Rightarrow a_0 = \frac{D_0 a_N}{1 + D_0}
\end{aligned}
$$

$$
\begin{aligned}
&\text{The other sequences are:}\\
&D_0 = \frac{a_0}{a_N - a_0}\\
&D_1 = \frac{a_1}{a_N - a_0}\\
&D_2 = \frac{a_2}{a_N - a_0}\\
&\vdots\\
&D_n = \frac{a_n}{a_N - a_0}
\end{aligned}
$$

6. Percept simulation of levels

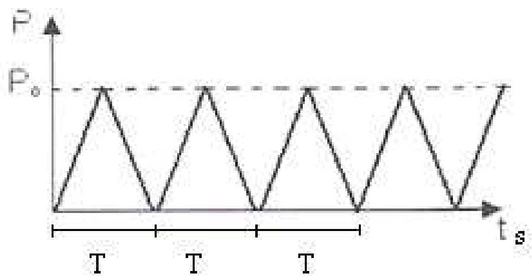


Fig. 10: Triangular simulation of internal pressure

Table :1 Statistical Characteristics of Each Pressure Mode

Pressure mode	**Mean of p_i ($\bar{p}_i$ in MPa)**	**C.o.v. of p_i in %**	**Law**
High (mode 1)	8	10 %	Triangular
Middle (mode 2)	5	10%	Triangular
Low (mode 3)	3	10%	Triangular

We study three levels of maximal pressures in pipelines which are: 3 MPa, 5 MPa, and 8 MPa that are repeated within a specific interval of time T=8 hours. At each level, we deduce the degradation trajectory *D* in terms of time or in terms of the number of cycles *N*.
The failure by fatigue is obtained for a certain critical number of cycles: pressure-depression or for a certain time period. Therefore, the lifetime of the pipeline for each level of maximal pressure is deduced at *D*=1.

7. Results and Discussion on Simulation

The Monte Carlo one level percept simulations for 1000 times for the pipeline system and under the 3 modes of internal pressure (high, middle and low) gives the degradation trajectory which are represented in the following 3 figures.

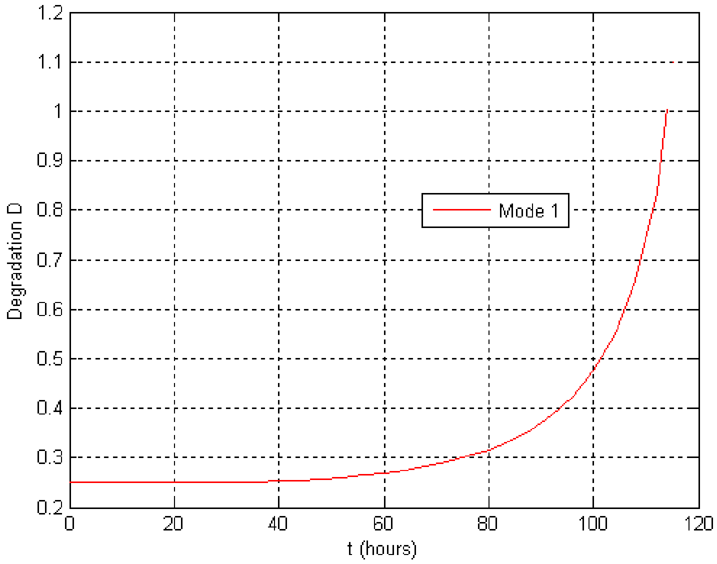


Fig. 11: Degradation evolution for mode 1

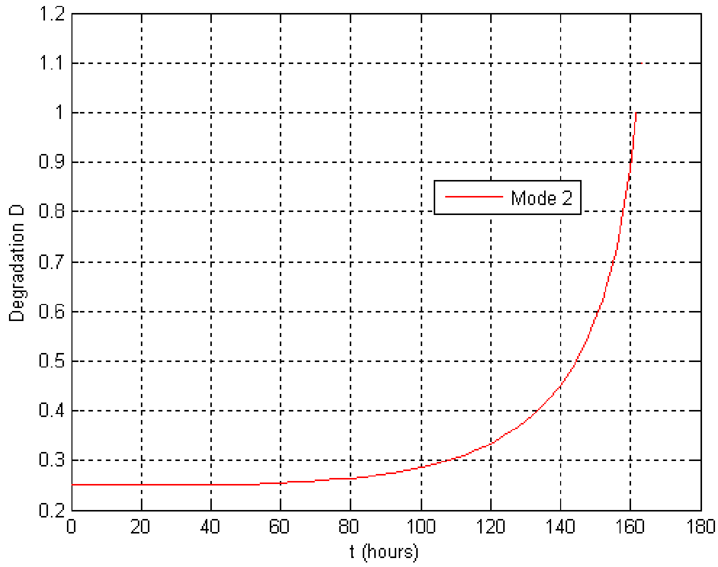
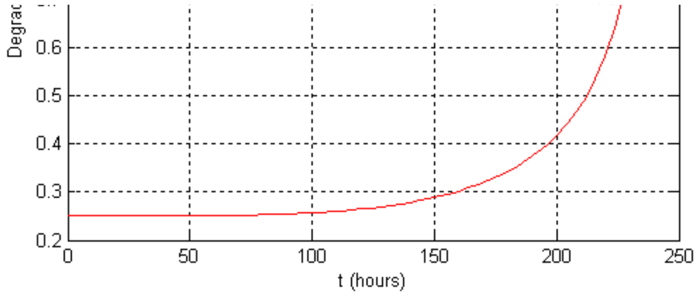


Fig. 12: Degradation evolution for mode 2



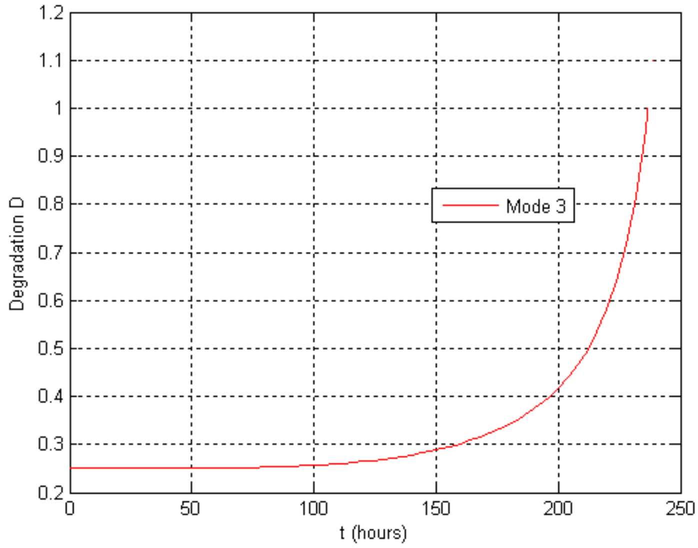


Fig. 13: Degradation evolution for mode 3

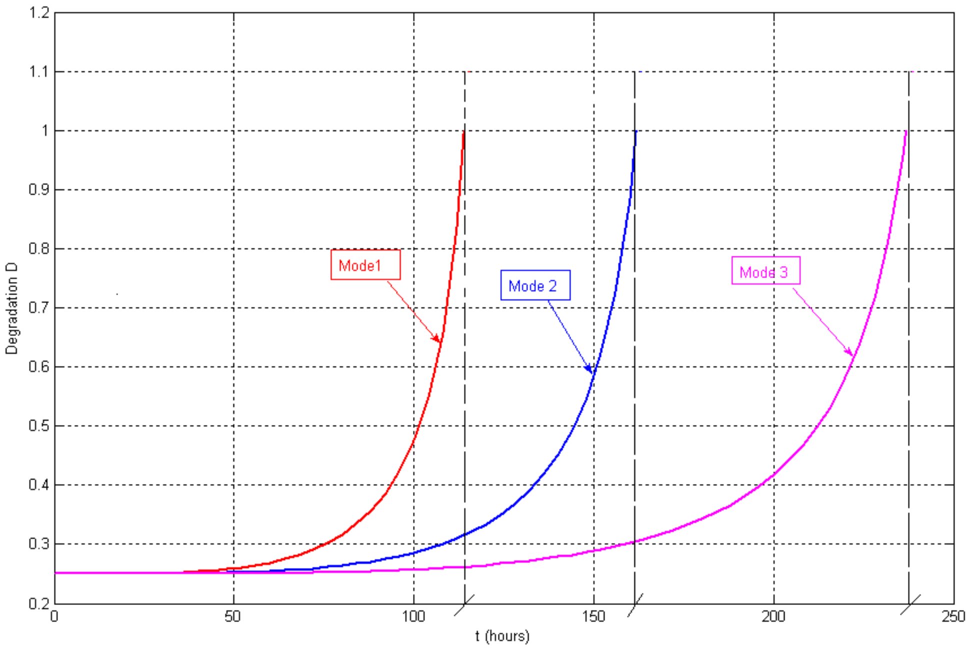


Fig. 14: Degradation evolution for All three modes

We deduce from the percept interrogation that the pipeline lifetime is nearly 115 hours for mode 1 (high pressure), nearly 160 hours for mode 2 (middle pressure), and nearly 240 hours for mode 3 (low pressure). From these curves, we can see that our prognostic model, using analytic laws, gives the remaining lifetime of pipelines at any instant.

8. Conclusion and Scope for Future Work

The percept neural network sustains in predicting the life time effectiveness on field efficiency for the radial pipelines by which the user is able to read the rear and bear happenings on fluid mechanics in industries. The study also helps in predicting the sustainability feature of turbines in heavy alloy plants which could be scope for the work in future.

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