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Evaluation and Control of the reliability of Weld Joints in Petroleum Products Transportation Pipelines

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The economic performance of petroleum products transport companies is dependent on the reliability of their equipment. Ruptures of the weld joints of petroleum products carriage pipelines have major consequences at the human, environmental and economic levels. Weld joints are potential sites of dangerous cracks. The management of reliability of weld joints in pipelines is useful to integrate the quality planning and risks throughout their life cycle and to systematically track their characteristics all along their life cycles. The use in situ of inspection results from non-destructive control techniques is an essential component of evaluation and control of reliability of pipes in their function. It requires calculation methods and tools to assist in the decision-making in support of inspection and repair campaigns. It is in this context that the present study was conducted, which is a contribution to the efforts of methodological assessment of the reliability of petroleum products transport pipelines.

1. Introduction

In transporting petroleum products over ever growing long distances, pipelines cross deserts, mountains, swamps, rivers and seas. These are translated into strains and stresses that produce complex and severe working conditions on pipe welded joints whose bearing capacity depends on the heterogeneity of the mechanical properties of different areas of the joint and on the quality of the seam amongst others. The bearing capacity of pipe welds decreases even more in the presence of concentration of stresses and deformations which in their turn depend on the presence of technological defects associated with the seam form and assemblies.

The need to deal with increasingly larger consumption worldwide has led to convey, store, and refine more oil, gas, and finished products. One way of achieving this is to increase pipe dimensions with subsequent decrease in reliability but this may be balanced by pipe thickness increase or by the choice of another material (Abdelbaki et al, 2014). Furthermore and for economic reasons, in order to transport the finished products, successive pumping is used. Successive pumping or "batching" consists of shipping the products separately in a given order by the same pipeline. These products are either different fuels, or crude oil and condensate. One of the problems related to successive pumping is the instability of the operating parameters of successive pumping stations such as the discharge pressure, which depends on the number of cycles of successive pumping, sequences of cargo and transported products properties (Genot, 1980). The pressure changes occurring during start-up and stopping of the pumps or the pumping stations are also significant.

So the flow of the fluid in the pipe periodically goes from steady regime with a constant pressure to a non-permanent regime that gives rise to dynamic loads. The pipelines operation practice confirms the fact that cyclic loading caused by unsteady flow regimes lead to the formation of fatigue cracks in the welded joints and which is completed by a sudden fracture. Pipelines fractures, although scarce, have disastrous consequences, affecting human life, property and environment. It is therefore useful to develop support elements for decision making based on monitoring of the behaviour of pipeline welds. The phenomenon of fatigue is a slow process which introduces many uncertainties and requires inspections to prevent the risk

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of rupture (Goyet and Maroni, 1996). The reliability mode must therefore incorporate the results of pipelines inspection with their quality in order to better assess the damage.
The results of the inspections in situ serve, among other things, to control and forecast the reliability of pipelines in operation (Weiswerler, 1987). Then, it becomes necessary to first define the reliability of controlled welding joints, taking into account various defects that may exist or arise and loads to whom they are subjected.
For the detection of defects in welded joints non-destructive control is used (Baldev et al, 2000). Defective welded joints are repaired or replaced so that all of the pipeline welded joints are considered to be reliable and meet the requirements of international standards (Bouzid et al, 2005). However, currently, there is in fact no non-destructive testing method of control guaranteeing with 100 % fidelity the detection of weld defects in pipeline transporting petroleum products. That is why there is always a certain probability of missed defects including those who pose danger to the integrity of welds. These, in effect lead to failure of the pipe and practically determine the reliability of the welded joints. Thus, the use of inspection results in situ from non-destructive monitoring techniques is an important component of the procedure of evaluation and control of the reliability of welded joints in their operation. The additional information collected at the time of the inspection, concerning the evolution of damage, is used to update the reliability of welded joints. It is in this context that this contribution was developed.

2. Study approach

The reliability of welded joints subjected to regular inspections and repairs, depends only on the number of defects undetected during control. The reliability Q of a welded joint of a pipeline in service is given by the Eq(3) (Dacunha and Duflot,1994).

$$Q = 1 - H_0 \tag{1}$$

Where H_0 - the failure probability of a welded joint

$$H_0 = 1 - exp\left[- K(a^*) \times \frac{1- P_\propto(a^*)}{P_\propto(a^*)}\right] \tag{2}$$

a^* is the critical dimension of a given default type :

$$K(a^*) = \mu(a^*) \times P_\alpha(a^*) \tag{3}$$

$\mu(a^*)$ is the arithmetic mean of the number of defects, of a given type whose size is greater or equal to a^***.**

$P_\alpha(a^*)$ is the probability of detection of a given type defect whose dimension is greater than or equal to a^*

The probability $P_\alpha(a^*)$ depends on the detection probability $P^*(a)$ of a defect of dimension **a**, located at a place of control and also on the distribution of defects according to their dimensions:

$$P_\alpha(a^*) = \frac{1}{1-F(a^*)} \times \int_{a^*}^{\infty} P^*(a^*) \times P(x)dx \tag{4}$$

With: $F(a^*)$ distribution function of defects of size a^*

$P(x) = \frac{dF(a)}{da}$ density of distribution of defects according to their size

$$P^*(a) = \begin{cases} 0 \; for \; a \ll a_0 \\ 1 - exp[-\lambda(a - a_0)] \; for \; a > a_0 \end{cases} \tag{5}$$

Where: a_0 Threshold of detection of the dimensions of the considered default,

λ experimentally determined parameter for each type of defects

During operation, defects whose dimensions have not reached the threshold values, grow and after a given time, will reach critical dimensions (Cataldo and Diligent, 2010).

Consider that at the time $t = t_0$, there is one single failure to dimension **a**. This defect can be detected by the control to a certain probability, or missed, with probability $1 - P_\propto(t)$.
Residual lifetime T is determined as the extension of the operation after the check, during which the size of the default grows up to the critical value is a^*.
It is then determined, as being the root of the Eq(6):

$$a(T) = a^* \tag{6}$$

For a fixed value a^*, the residual lifetime T is a random quantity. This is related to the stochastic relationship $a(t)$. The probability of failure according to the residual life span criterion is determined as the probability of satisfying the inequality : $a(t) > a^*$

$$H_T(t) = P\{a(t) > a^*\} \tag{7}$$

Finally, taking into account the probability of failure at the time of control t_0, the failure probability will then be at the time: $t > t_0$

$$H(t) = H_0 + H_T(t) \tag{8}$$

For known distribution laws of $P_a(a,t)$ et $P_{a^*}(a^*)$, we will have:

$$H_T(t) = \iint_{D[a,t,a^*]} P_a\,(a,t) \times P_{a^*}(a^*).\,da^*.\,da \tag{9}$$

The of integration domain $[a,t,a^*]$, is defined by the inequality $a(t) > a^*$
and the expression (9) takes the following form:

$$H_T(t) = \int_{-\infty}^{\infty}\left[P_a(a,t)\int_{-\infty}^{a} P_{a^*}(a^*)da^*\right]da = \int_{-\infty}^{\infty} P_a\,(a,t) \times F_{a^*}(l)\,dl \tag{10}$$

3. Results and discussion:

The control plan flow chart structure of the reliability of the multi-product pipelines weld joints is presented in Figure 1.

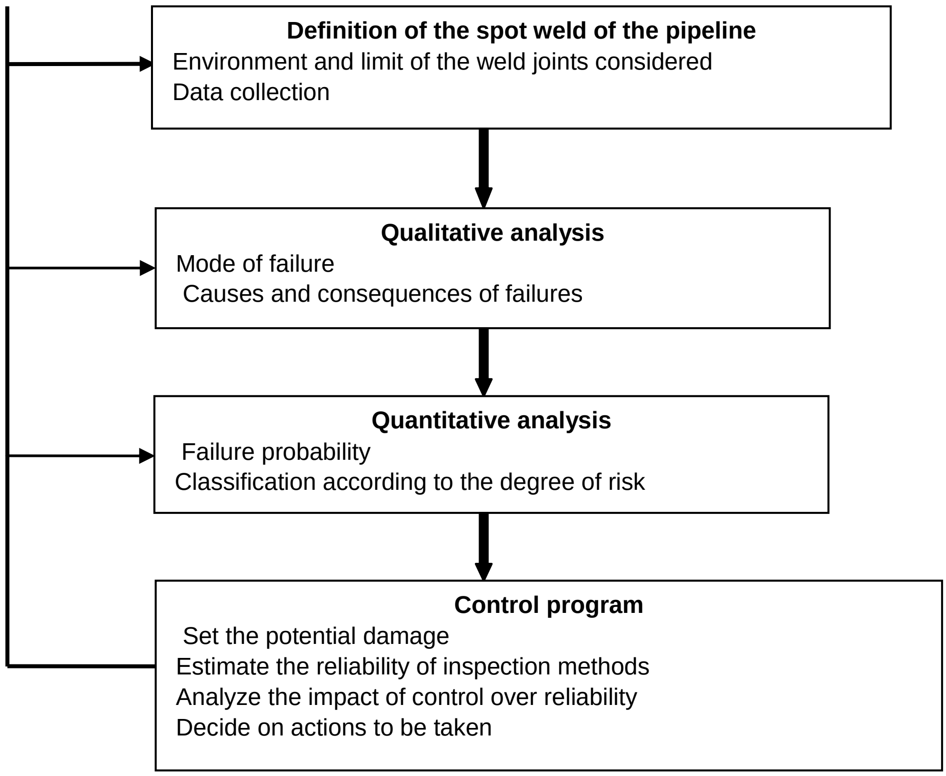

Figure 1: Flow chart of the reliability checking plan for the weld joint

Inspections of the welded joints of petroleum products transporting pipelines pipe assemblies are imperfect. This is why the probabilistic framework is used to define the defect detection probability. Its calibration is done on a statistical basis

Technical performance of non-destructive testing process of welded joints in pipes, are observed from a double perspective decision angle, namely: the presence of a defect (detection capability) and the extent of the defect (measuring capability of the crack depth or length). The defect detection probability is estimated from knowledge of the detection threshold deducted from the inspection techniques inter-calibration. The inter-calibration procedure used consists of manufacturing welded tubular assemblies and recreating defects similar to those cracks observed in-situ using fatigue testing (Forsyth et al., 2000). In this respect, the numbers of good and bad discoveries have been measured by class of defects (dimension and typology), and the observed probability of good detection was calculated. The results are presented in Figures 2 and 3.

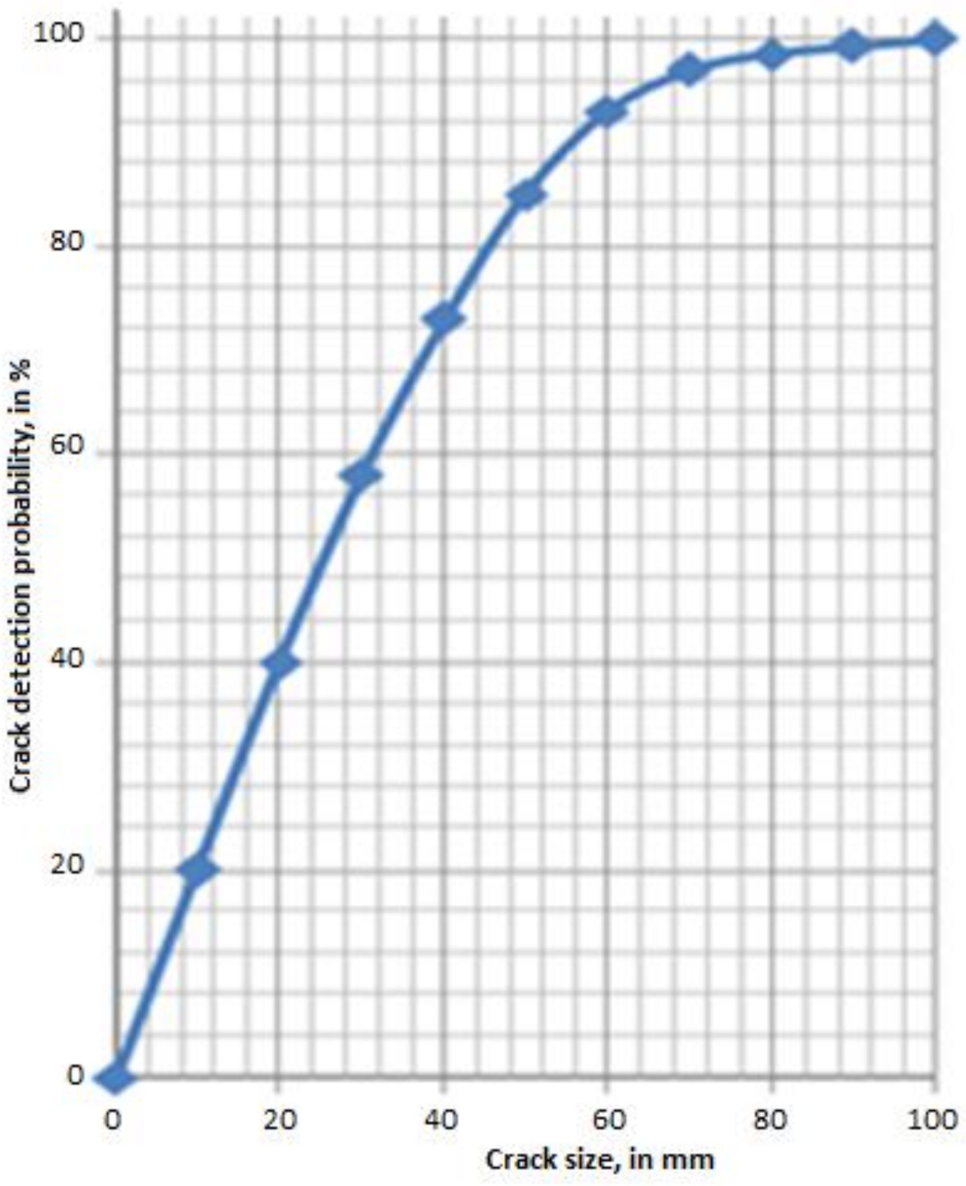

Figure 2: Integral probability of detecting cracks according to their size

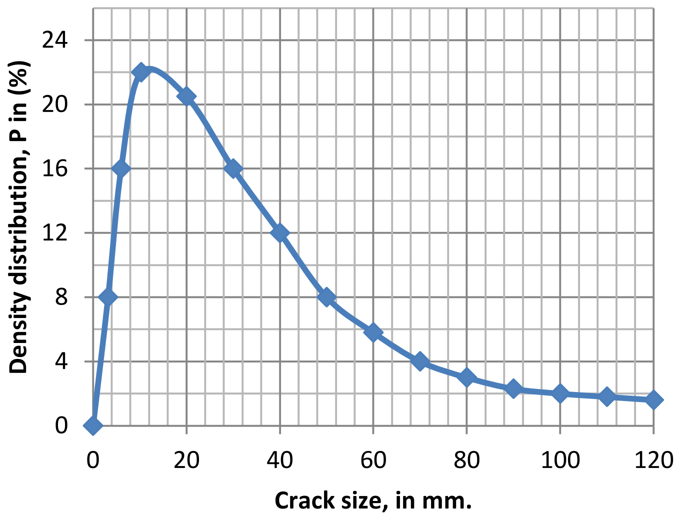

Figure 3: Density of distribution of defects according to their size

The re-evaluation of the failure probability of welded joints is then made on the basis of the results of their periodic inspections.
The results of the study of the dependence of the failure probability of a welded joint on the basis of the initial length of the crack and the periodicity of inspections are presented in Figure 4 below.

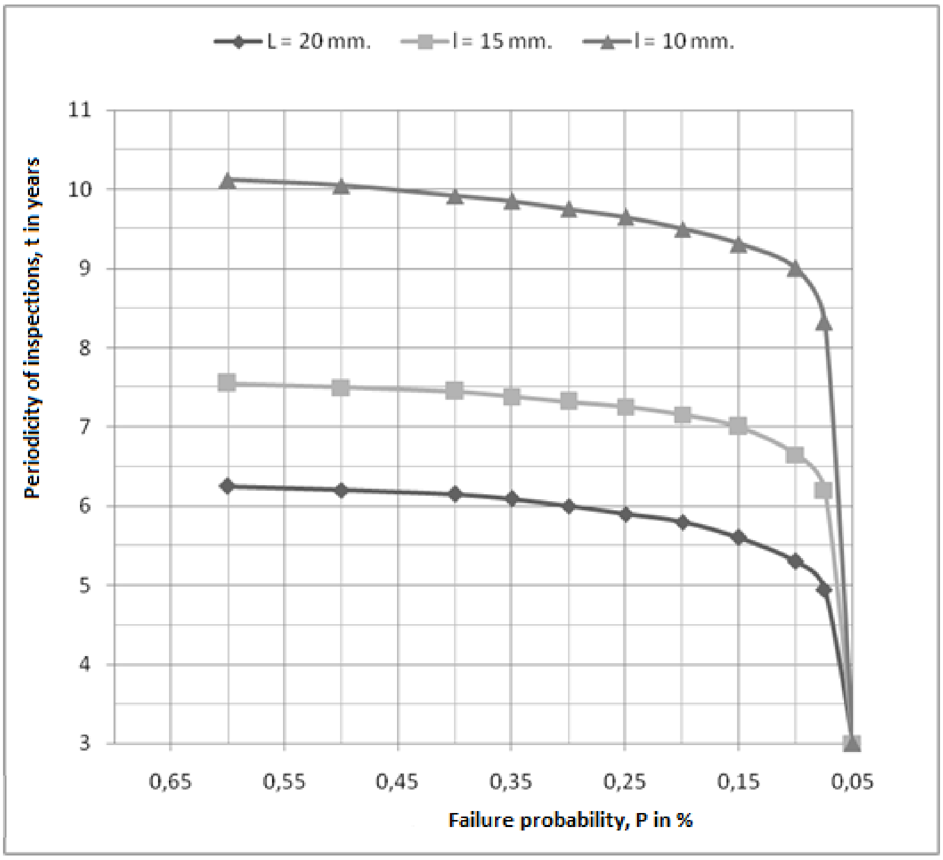

Figure 4: Dependence of the failure probability of a weld joint in terms of initial crack length and inspections periodicity (t)

4. Conclusion

One of the influential causes on the reliability of operation of petroleum products transporting pipelines is the state of welded joints of the pipes. The welded joints are sites, in which fatigue cracks appear and spread. The amount of failures resulting from the defects of welded joints, reaches 60 % of the probable causes. Maintaining a high level of reliability of the petroleum products transporting pipelines, requires the improvement of the non-destructive testing methods, providing more reliable information on the technical condition of the welded joints of pipes Assembly.

The planning of inspections, contributes significantly to the reduction of the failure probability of welded joints subjected to dynamic loads. Changes in the failure probability for various cases influence the decisions taken concerning the planning of maintenance operations. In addition, the benefit acquired from the planning of inspections is clear, since it allows quantifying the level of damage accumulated in the welded joints in a more realistic manner and providing a better measure of reliability.

On the basis of obtained results, a maintenance policy is set based on a reliability criterion based on the control quality of welds of the considered pipeline. In this case the control intervals are regular, but the quality of control of welding joints is adjusted in such a way that the required minimum reliability is respected.

References

Abdelbaki N., Gaceb M., Bouali E., Bettayeb M., Bouzid R. 2014, Reliability approach to the choice of dimensions and materials of tubes used in hydrocarbons transport networks, Chemical Engineering Transactions, 39, 1339-1344.

Baldev R., Subramanian C.V., Jayakumar T., 2000, Non-destructive testing of welds, Narosa Publishing House, New Delhi.

Bouzid R., Bouali E., Gaceb M., 2005, Analysis of cracks evaluation standards in welded joints of pipelines, Welding in the world, 49, 492 – 495.

Cataldo G., Diligent O., 2010, A method for testing pipeline welds using phased arrays, World Intellectual Property Organisation, WO 2010 09 72 69.

Dacunha D., Duflot M., 1994, Probability and Statistics, Masson, France (in French).

Forsyth D.S., Abbas F., Leemas D.V., Mcrae K.I., 2000, Development of POD form In-service NDI data, Review of Progree in Quantitative Nondestructive Evaluation, 19, 2167 - 2174.

Genot V., 1980, Transport of liquid and gaseous hydrocarbons by pipeline, Technip, Frence (in French).

Goyet J., Maroni A., 1996, Optimal inspection and repair planning, An application with a sensitivity study using of fatigue of welded components and structures, Senlis, France.

Weiswerler F.J., 1987, Non-destructive testing of large diameter pipe for oil and gas transmission lines, Ed. V.C.H.