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Advanced Assessment of Pipeline Anomalies using an Anfis Model and 3D Data processing

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ADVANCED ASSESMENT OF PIPELINE ANOMALIES USING AN ANFIS MODEL AND 3D DATA PROCESSING

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Abstract

ENAGAS, in collaboration with the CIME (Structural Materials Research Center*;* Technical University of Madrid - UPM) and the University of Cantabria (UC), has developed a powerful IT tool for assessment of gas pipeline's anomalies (dents, dents+corrosion, dents affecting ductile girth welds or seam welds, dents associated to mechanical damage, injurious mechanical damage with concurrent visible indentation, ripples in pipe surface, metal loss due to corrosion, crack-like flaws, etc.) and for the analysis and assessment of pipeline life extension (metal loss due to corrosion, fatigue crack growth and crack growth due to SCC). It is based on main international recognized standards (ASME B31.8, ASME B31G, API 579-1/ASME FFS-1, BS 7910, NG-18, ISO 12747, etc.). It includes a module for processing geometric data from any commercial 3D scanning tools, by means of which Level 2 & 3 evaluations of multiple types of anomalies can performed. Furthermore, for the corrosion assessment has been developed an adaptive neuro-fuzzy model (ANFIS) with learning capacity from real data gathered in inspection campaigns.

Keywords: Pipeline; Corrosion; FFS; 3D scanning; Fuzzy logic; ANFIS

Introduction

It is necessary to ensure the integrity of equipment and facilities to rationalise the decision-making and to prevent that the replace/repair actions are implemented automatically.

A comprehensive approach to integrity assessment management involves the compliance with five strategic milestones: Reliability in operations in the periods between inspections, maximize the time between consecutive inspection periods, maximize the remaining life of the facilities, optimize inspection stop intervals, and optimal distribution between investments in capital expenditures (CapEx) and operating expenditures (OpEx).

A Fitness-For-Service (FFS) assessment must be carried out using some internationally accepted integrity standard and the design code originally used for the equipment and facilities (ASME B31.8; ASME B31.8S; ASME B31G; API 579-1/ASME FFS-1).

The result of an FFS evaluation shall attend to one or more of the following questions: Acceptable sizes of areas with corrosion/erosion and rates of progression of damage, acceptable sizes of dents, crevices and ovalizations, acceptable crack sizes and propagation velocity, estimation of the remaining life, operating limits that guarantee integrity and other measures to mitigate risks, improvements in design, manufacture and maintenance, and adequate NDT for each anomaly.

In addition, the result of an FFS assessment can become an input to design a Risk Based Inspection (RBI) system, to decide continue operating without taking actions, the optimal interval between inspections, how to monitor the anomaly and frequency, when should be done the repair/replacement, review the operating conditions, and to decide if the design should be modified or the if materials used should be improved.

The end goal is to integrate the approach of the FFS technologies with the RBI and the NDT, to be able to demonstrate the integrity of facilities and equipment, as well as the evolution throughout their service life when they are affected by one or more mechanical damage.

If this integration is properly executed, the company can obtain significant savings in the operation of its facilities, as well as increasing levels of safety and reliability.

Some transmission system operators (TSO) have established its own anomaly evaluation procedures, identifying which are the main typologies, like dents, dents+mechanical damage, sharp dents (associated or not to visible mechanical damage: indentation, etc.), dents that affect welds (ductile girth or seam welds), corrosion, dents+corrosion, ripples and cracks.

There are different commercial solutions, but some TSO have developed its own specific tools to increase the capacities of those commercial software and to attend their real needs. In such way, this report presents the investigation and development of specific IT tools done by CIME and ENAGAS, for assessment of gas pipeline's anomalies and the analysis and assessment of pipeline life extension, including a 3D data processing and a an innovative adaptive neuro-fuzzy model (ANFIS) with learning capacity from real data gathered in inspection campaigns.

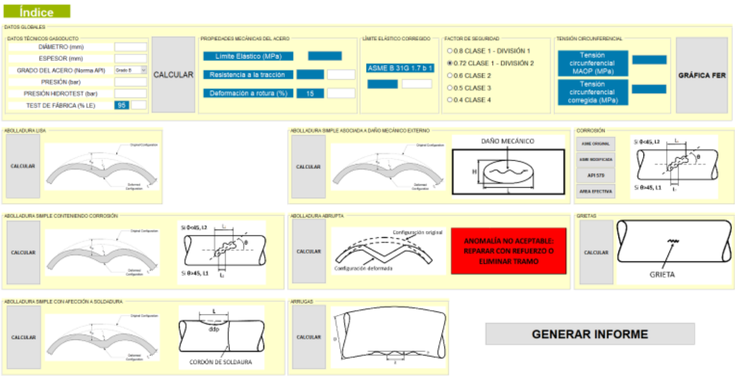

Figure 1. EVANOGAS (ENAGAS-CIME).

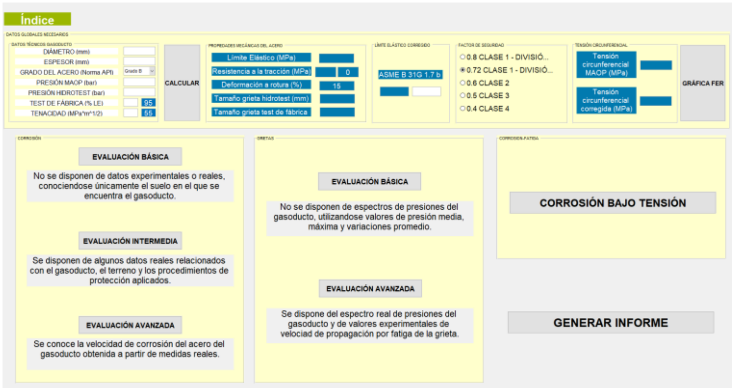

Figure 2. EVIREGAS (ENAGAS-CIME).

3D scanning of pipe defects

Sometimes, the evaluation of anomalies is limited by the fragmentary information that we have about their morphology and dimensions. The Level 1 and Level 2 evaluation procedures included in the different application standards (API 579-1 / ASME FFS-1, BS 7910, NG-18, etc.) use approximations that try to cover the lack of data on the configuration of the anomaly.

The Level 3 evaluation allows to undertake more detailed and reliable calculations on the behaviour of a real anomaly, but provided that the precise starting information is available, both on the geometry of the anomaly, as well as on the properties of the materials and the conditions of operation.

In this sense, the new 3D scanning equipment allows to exhaustively characterize the morphology of the anomalies found during the NDT inspection. The digitization of the geometry allows to know the precise information that is needed to carry out the calculations that guarantee the structural integrity of the gas pipeline.

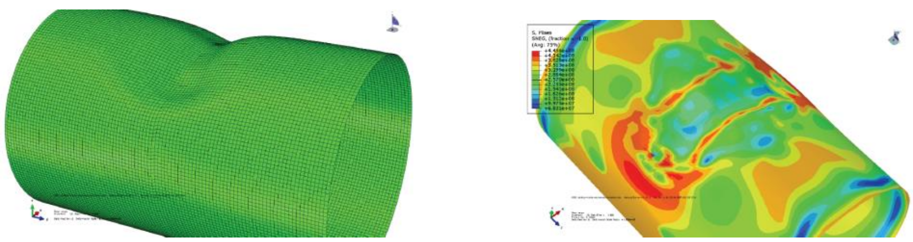

Figure 3. 3D image and FEM of pipe defect.

For an appropriate assessment of anomalies it is essential to determine the most accurate geometry. Mechanical instrumentation were used in the past, but usually there was a slight uncertainty in the geometrical measurements made on the defects, which only allowed to do Level 1 assessment.

Nowadays, there are advanced technologies for 3D mapping, like those based on structured light or laser, through which the level of evaluation can be significantly increased.

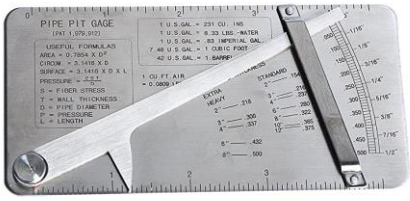

Figure 4. Pipe pit gage.

Figure 5. 3D structured light scanner

Once the physical information (the anomaly) of an object has been captured, with the required guarantees for precision and repeatability, it is possible to store it digitally and send it to the computer, to be processed using the appropriate evaluation software.

In this regard, it is possible the joint use of 3D scanners with specific software developed for the assessment of different types of geometrical anomalies in a pipeline/equipment/structures, and for evaluating the life extension in case of corrosion.

The type of analysis that can be obtained with the joint use of 3D scanners and that software can extend to both corrosion problems and mechanical damage. In the case of corrosion, it is possible to capture with high resolution areas with loss of wall thickness due to corrosion, using high processing speeds and with automatic pitting detection.

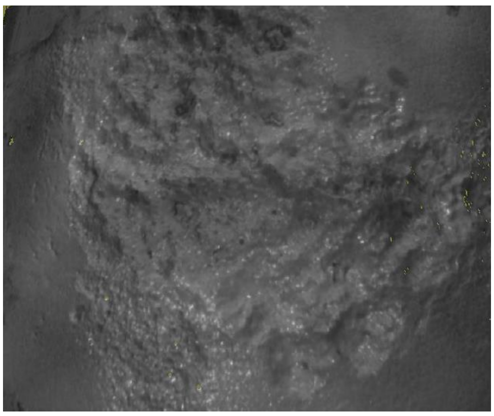

Figure 6. 3D scan corrosion area.

Using the real geometry of the gas pipeline, the real dimensions of the anomaly can be precisely defined, automatically applying the interaction rules to determine an effective anomaly size. Subsequently, the geometry is exported as a mesh that is directly usable by finite element programs (FEM) for a Level 3 evaluation of that found anomalies. In this way, the estimated collapse pressure and the possibility of perforation in any of the pits found can be calculated.

The selection of a Level for analysis depends on multiple factors, but by using 3D toolbox up to Level 3 can be performed.

On the other hand, in the case of mechanical damage, it is possible to obtain and organize high resolution graphic images and generate an automatic meshing of the entire affected area. With any surface finish, fast processing of the information generated is possible. Automatic detection of the extent and depth of the mechanically damaged area allows 2D sections, and determine the maximum depth of the anomaly.

The geometry can be exported to 3D design programs, to make additional measurements, be exploited to the last consequences and, finally, obtain 2D profiles of serial cuts in both directions.

In addition, wrinkles formed on the external surface during (cold) bending operations can be captured by 3D scanning for their subsequent analysis using the software tools developed.

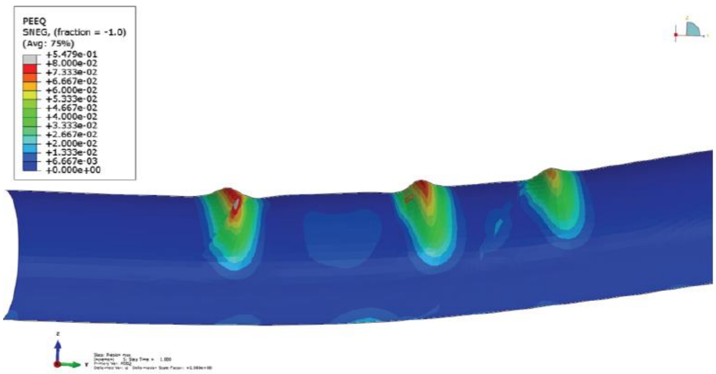

Figure 7. FEM model of wrinkles in H-SAW pipe, obtained from 3D scanning

The methodology developed and implemented by CIME and ENAGAS comprises a number of steps shown below:

1. Geometry capture of anomalies by 3D scanning.

   Some techniques can be used, but structured light has been used for the development of the IT tool described in this paper.

2. Treatment of the generated point cloud and interpolation of the associated surface. This treatment is done in four steps:

   - Importing the 3D scanning.

   - Realignment.

   - Delaunay triangulation.

   - Creation of a surface.

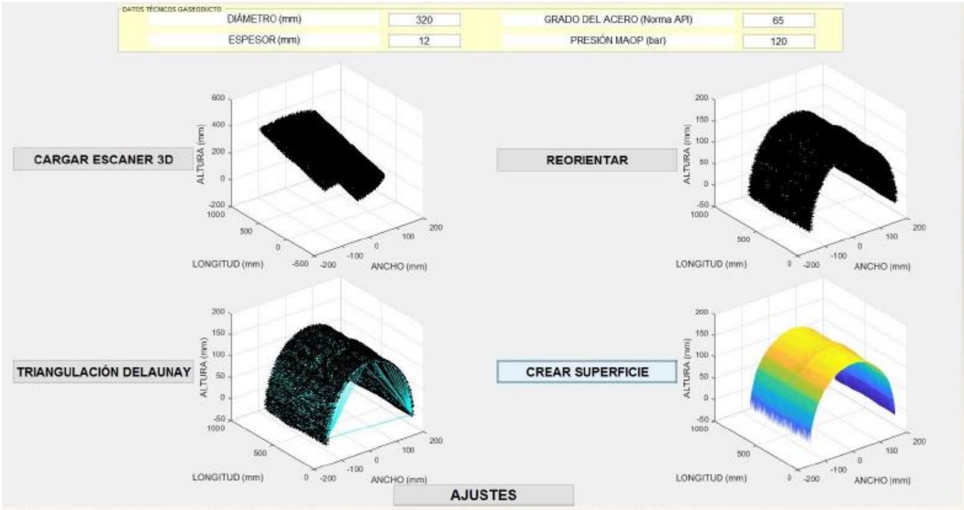

Figure 8. SCANGAS. 3D data processing module.

Additionally, some adjusts shall be applied, obtaining essential information of the real anomaly:

- Development of the 3D surface.
- Longitudinal depth profile.
- Top view of the longitudinal depth profile.
- Transverse depth profile.
- Top view of the transverse depth profile

By introducing the required adjust and sensibility, can proceed to determine the accurate geometric parameters of the anomaly.

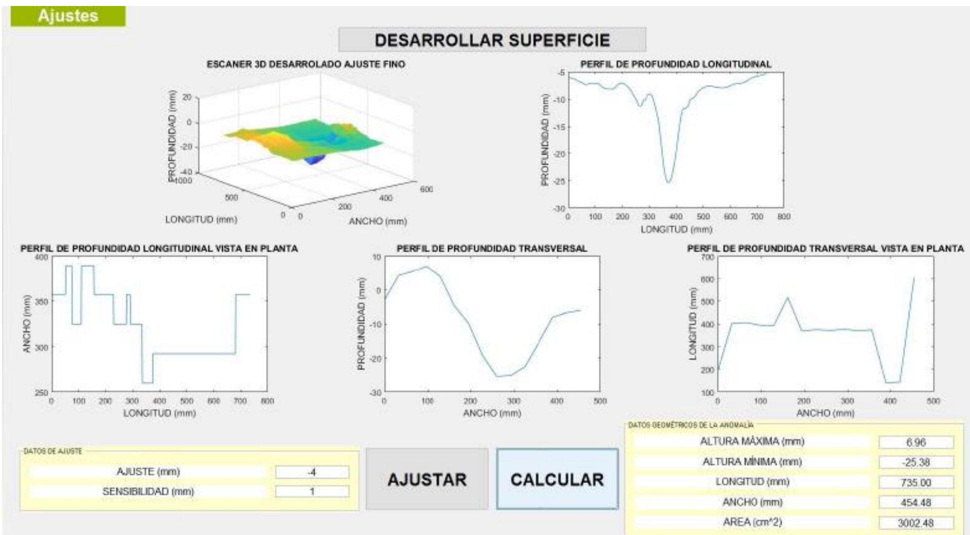

Figure 9. SCANGAS. Surface development and adjusts.

3. Export of the geometry to the software programs developed for the evaluation of the anomalies (i.e., EVANOGAS and EVIREGAS).
4. Generation of automatic meshing for the application of the finite element calculation method.
5. Calculation and analysis of the results.
6. Level 3 evaluation of the significance of the anomaly in relation to the structural integrity of the gas pipeline.

ANFIS for improve the corrosion prediction. Case study

Fuzzy logic is based on the use of variables that are neither totally true nor totally false, that is, whose values lie somewhere between two possible extreme values. Therefore, Fuzzy logic will allow to work with intermediate values within a scale. In this way, one can work with imprecise or poorly defined information.

The main objective of the developed ANFIS IT tool (ANFIGAS) is to provide projections of the external corrosion rate in gas pipelines, providing the necessary information to perform the necessary calculations for determining the remaining life of the gas pipelines operated by the TSO, using the Corrosion assessment IT tool already in service (i.e EVIREGAS), and supporting the decisions needed for the maintenance and the management of the structural integrity of the facilities.

The ANFIS system does not substitute the conventional corrosion assessment tools based on well recognized standards, but complements them by providing more precise information on corrosion rate that can be expected to occur in the pipeline, based on a number of critical parameters. So, the integration of the ANFIS tool is quite useful.

The research and works carried out by CIME have allowed integrating, in a single and open tool, the modules for the evaluation of discontinuities, remaining life and 3D scanning together with the application of an ANFIS System.

As case study, let’s consider a corrosion area located in a pipeline after NDT inspection.

From the scanning and treatment of the 3D images we obtain a surface. As a first step, the main data will be entered into the gas pipeline: diameter, nominal thickness, steel grade (according to API 5L), MAOP, and additionally, two representative data of the point where the anomaly was detected: gas pipeline identification and the kilometre point (KP).

It is recommended collecting all the input data, so that the model can provide the better estimation of the corrosion rate.

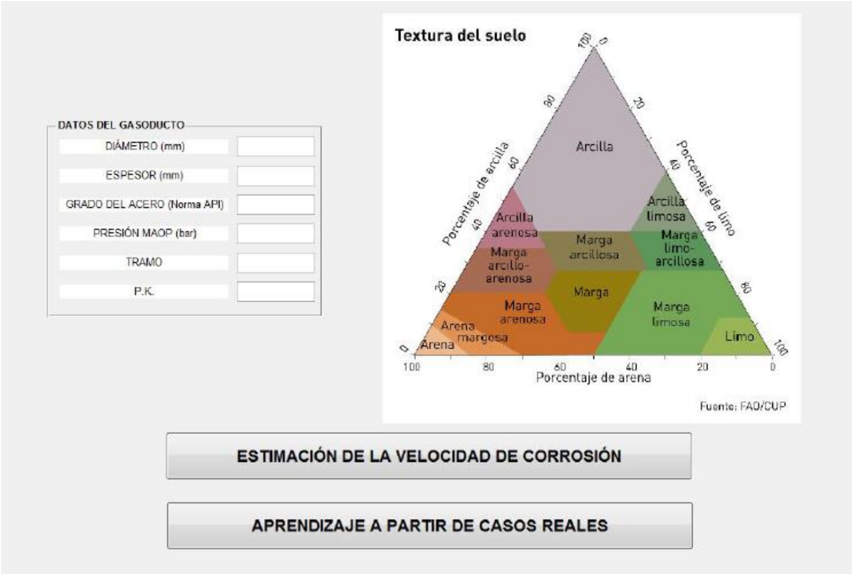

Figure 10. ANFIGAS data entry screen.

From here two possibilities arise. On the one hand, obtaining an estimated value of the corrosion rate from the significant variables. On the other hand, the possibility of training the “expert system” by learning from real cases.

The first one (obtaining the corrosion rate), is determined from the following input parameters: type of soil, type and condition of the coating, soil pH, resistivity, content of clay fines, sulfate concentration, chlorides concentration, cathodic protection information and temperature.

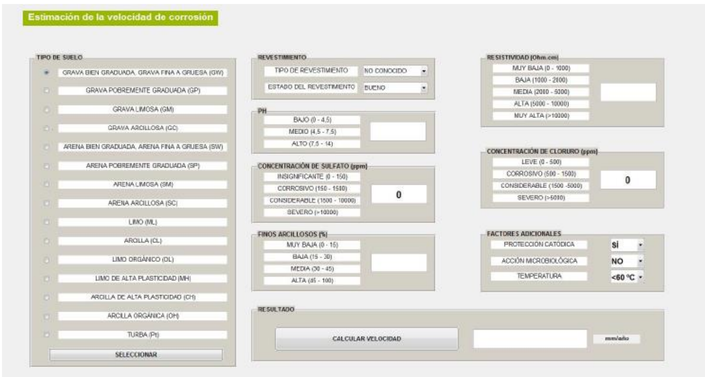

Figure 11. ANFIGAS. Specific input data for corrosion rate calculation.

ANFIGAS will start working with the entered variables and will estimate a corrosion rate (expressed as a loss of wall thickness in mm/year) based on its fuzzy inference engine.

But apart from this, it is possible to train the “expert system” by introducing real cases, where the value of all the variables is known and there is also a real measure of the corrosion rate. By pushing “Learning” button, ANFIGAS will start a new window for uploading the necessary information (Figure 12).

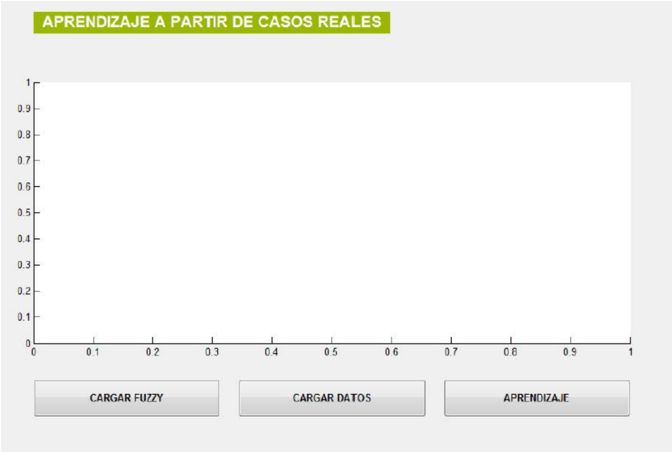

Figure 12. ANFIGAS. Training screen.

Clicking “Load Fuzzy”, the software will load the fuzzy inference engine on which it is going to work to improve its predictions. Each time a training session is carried out, an improved model is obtained, capable of making more adjusted predictions to the real values actually measured in specific cases.

If you click again “Load Fuzzy” button, the program will take the data of the real cases available and use it to train the expert system. These data will be arranged in an Excel sheet with a fixed format.

Finally, if click on “Learn button”, the software will apply a hybrid learning method based on a neural network programmed within the application. Iteration after iteration, the error between the predictions made by the fuzzy inference engine and the real measurements will be reduced, showing the loaded data and the predictions made in the graph (Figure 13).

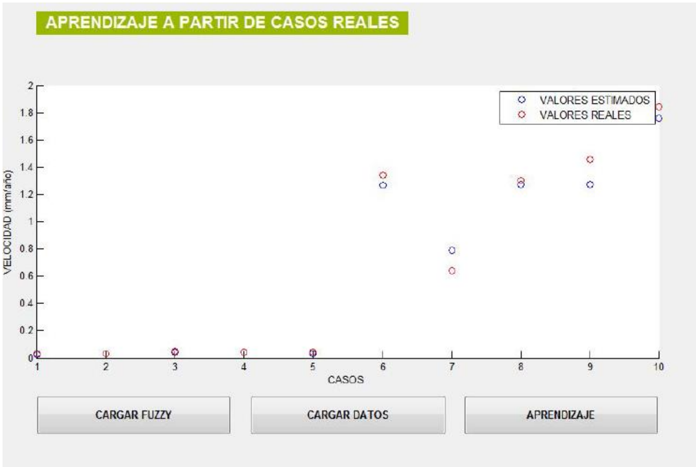

Figure 13. ANFIGAS. Comparison between training values and estimates made.

Conclusions

This paper has presented the advantages of a joint use of 3D scanners with specific software developed for the assessment of different types of geometrical anomalies in a pipeline/equipment/structures, and for evaluating the life extension in case of corrosion. In this regard, a neuro-fuzzy expert system (ANFIGAS) has been developed for estimating the corrosion rate of buried pipes, incorporating the possibility of learning from real cases.

As a practical case, both the 3D scanning and the expert system software can be applied to obtain the exact dimensions of an anomaly (dent, ripple, corrosion, etc.) and evaluate the (external) corrosion rate of a buried pipe. The ANIGAS software allows to predict a corrosion rate but also to learn from real cases and improve the implemented model for doing better predictions.