A fuzzy approach to leak detection in liquid pipelines

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Abstract: This paper presents a leak detection technique based on fuzzy logic. The developed system is connected via OPC protocol to a pipeline simulator for testing purposes. The model represents a real pipeline operated by Petrobras Transportes. In order to assess its performance, leaks are simulated, as well as operational maneuvers that usually cause leak detection systems to generate false alarms.

Keywords: leak detection, fuzzy logic, opc, simulation

1. INTRODUCTION

Leak detection is a major concern in oil industry. Among the many techniques found in the literature, industry still makes use of the more conservative ones, while novel techniques are not sufficiently exploited by software developers.

The selection of a leak detection system depends on a variety of factors such as pipe and products characteristics, instrumentation, communication capabilities, including the data acquisition system, thermal insulation, if present, burial depth, operating temperature, background noise and operating conditions [1]. Due to economic reasons and in some cases vandalism, instrumentation is only available at pipeline ends. Uncertainties from instrumentation, pipeline characteristics and fluid characteristics affect the sensibility to leak detection [2]. Performance metrics and classification of methods [3] provide some guidance to the industry on the selection criteria. Other types of classification can be found in [4]. Regarding internal leak detection techniques, [5] provide a useful coverage. Leak detection scenarios can be one of the following types: shut-in condition, flowing condition and flowing or shut-in condition with slack line[1]. Most of leak detection systems do not work under slack line condition. The proposed work applies to flowing pipelines without slack line condition.

A technique solely based on fuzzy logic for leak detection and localization can be found in [6]. The system is composed of two fuzzy systems, one for state recognition and the other for leak detection. As the state of the pipeline is important for the detection of leaks, the output of the first fuzzy system is also an input to the second one. The system presented here acts in a similar way but consists of only one fuzzy system for both state recognition and leak detection.

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[1] Slack line is a condition where the pipeline absolute internal pressure is below the steam pressure of the product at any point of the pipe. At this point the product begins to evaporate.

2. METHODOLOGY

2.1. Leak detection principles

The problem of leak detection is depicted in Figure 1, which shows the steady state of a leak. The system should detect leaks before this steady state is reached.

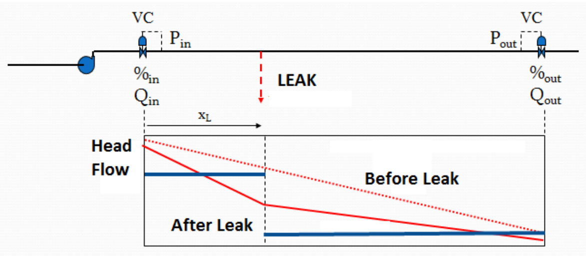

Figure 1. Pipeline signature

The dotted red line is the hydraulic gradient without any leaks while the continuous red line is the same hydraulic gradient after a leak occurrence. The blue line is the flow after the leak.

A hydraulic commercial simulator was used in this study. It allows the simulation of leaks and of operational conditions, as changes in control valves or any other actions operators may take in a real pipeline operation. Some leak detection systems, including the popular mass balance system, do not handle well transients arising from operators' actions, usually resulting in false alarms.

2.2. System description

The main idea behind the present work can be seen in Figure 2. The hydraulic simulator SPS® is arranged in such a way that some leaks occur in different positions, as shown in 3. The system, developed in Matlab, communicates with the simulator via an OPC protocol [7].

The fuzzy system has four inputs and one output, as shown in Figure 4. The inputs are: (1) the difference between flows from the inlet and outlet of the pipeline, (2) verification if the pipeline is in shut-in or flowing, (3) pressure gradient of inlet, (4) pressure gradient of the outlet.

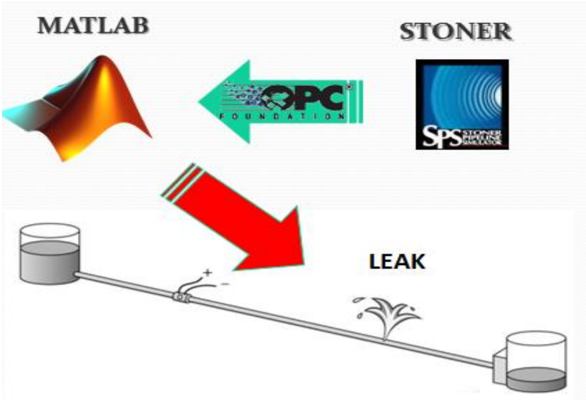

Figure 2. Leak detection scheme

The minimum operator is used for combining rules antecedents and for implication; the maximum is used for rule aggregation and defuzzification is performed through the Mean of Maxima method. Membership functions for the input variables are shown in Figure 5, where the bottom left and right figures are the pressure gradient of inlet and outlet respectively.

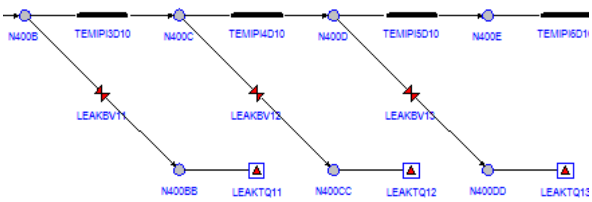

Figure 3. Leak simulation in different positions

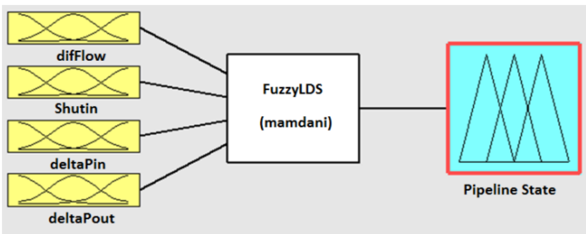

Figure 4. Fuzzy System structure

Output membership functions can be seen in Figure 5. They correspond to six linguistic terms representing the states of the pipeline.

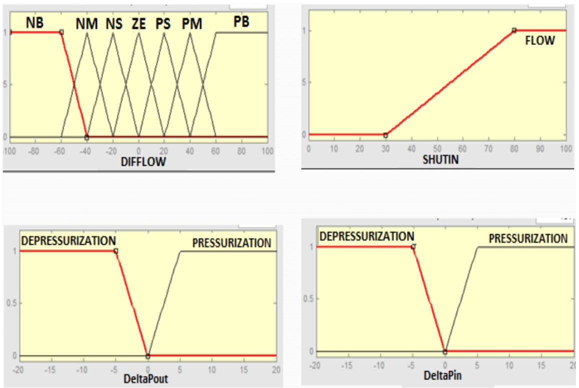

Figure 5. Input membership functions

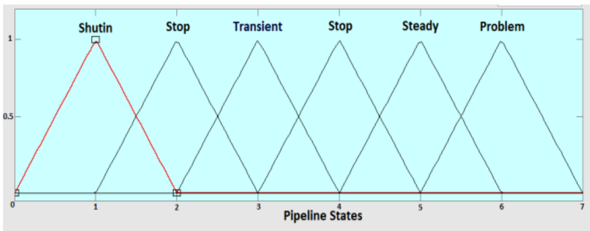

Figure 6. Output membership functions

The system has 22 rules, built on the basis of the first author's experience as an automation engineer at Transpetro national operational control center.

The architecture of the developed system is shown in Erro! Fonte de referência não encontrada.. The two blocks on the left are responsible for the OPC communication. The first two variables inside the OPC Read block are flow, one for each end of the pipe, while the last two are subtracted from their past values, represented by a first order delay.

Once the pressure gradient has been calculated, they are both multiplied by scaling factors. These may vary depending on the OPC acquisition time. If it is too small, the magnitude of the pressure gradients may also be too small; they must then be scaled to a more representative value. If the acquisition time is higher, the factor may have to be reduced. The variables are then fed into the fuzzy logic controller, the output of which indicates the pipeline state.

Tuning can be performed either by adjusting scaling factors or by changing fuzzy sets supports, for example.

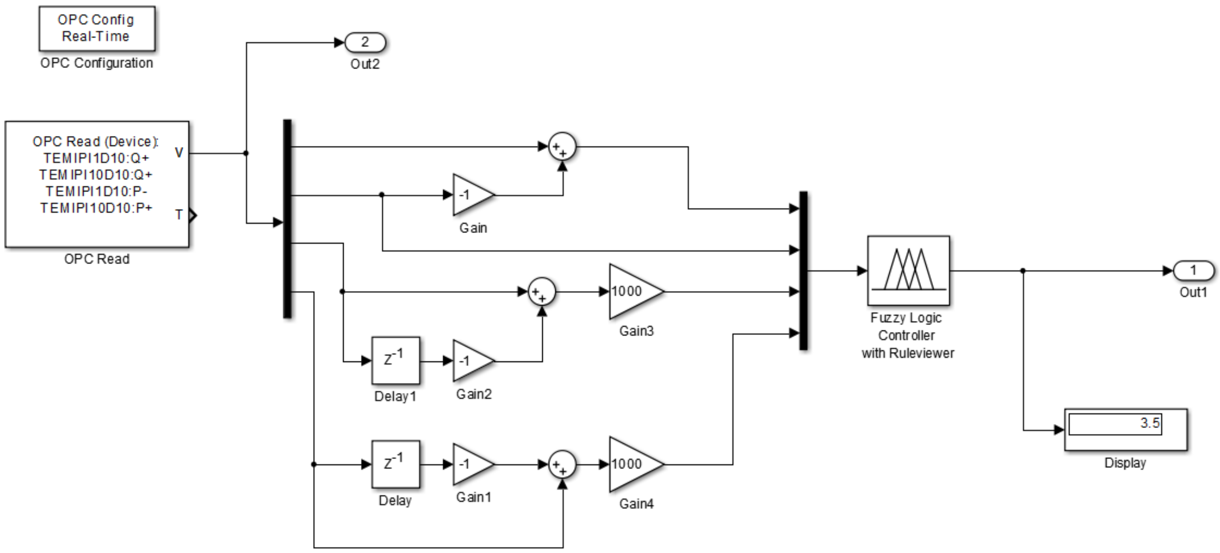

Figure 7. System architecture

3. RESULTS

The model represents a real pipeline 225 km long and with an external diameter of 10 inches. The initial condition (0) was steady state flowing and the pipe was filled with diesel. Some conditions were created in order to test the fuzzy system. In test 1, it was verified if the system was able to detect the shut-in condition. The second test considered the pipeline in flowing steady state. The third test considered a leakage. The fourth test verified the system's behavior in the presence of usual transients some common scenarios were simulated, like depressurization by closing the outlet control valve or due to pump shutdown. The system generated no false alarms when submitted to all those scenarios, as shown in Table 1.

Table 1. Tests Results

Test	Response
0	TRUE POSITIVE
1	TRUE POSITIVE
2	TRUE POSITIVE
3	TRUE POSITIVE
4	TRUE POSITIVE

4. CONCLUSIONS

Many other tests may be conducted from this point, as, for example, inserting noise in the model. One important issue is acquisition time. During tests the system was not performing well with regard to pressures: sometimes their values were zero, which led to oscillation between states. This was fixed by increasing the acquisition time from one second to three seconds.

Some technique for identifying the leak position should be used together with the detection technique presented here. In order to be used in a practical way, the system will have be developed in a standalone version and equipped with capabilities of offline acquisition to help tuning.

5. REFERENCES

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