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Measurement of the Response of Pipeline Insulating Joint to the Passage of Pipeline Inspection Gauge

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Abstract: Measurement of the dynamical response of pipeline insulating joint to the passage of Pipeline Inspection Gauge (PIG). Deformation and acceleration on the surface of gas pipeline were measured in situ. The influence of the PIG sudden stop on the state of stress in the insulating joint was evaluated.

Keywords: Pipeline Insulating Joint; Pipeline Inspection Gauge; Stress Analysis.

1 Introduction

One of the main tools of the inspection of buried pipelines is the PIG (Pipeline Inspection Gauge) which is used for the detection of defects. The inspection gauge is introduced into the pipeline and moves inside propelled by the flowing medium. Weight of the PIG of 1000 mm diameter is about 2000 kg and its velocity is in range (1–5) mm/s. In the course of the long-time practice there has arisen a suspicion that the passage of PIG through the pipeline can cause the damage to the pipeline insulating joints which are the components of cathodic corrosion protection system. The aim of our research was to determine whether the disruptions of joints may occur as the consequence of acting force and vibration load caused by the passage of the PIG. The literature survey reveals very few numbers of publications dealing with the dynamic characteristics and the associated vibratory motion of the inspection tool. The similar problem is discussed in article [1].

2 Experiment

The experimental measurements were performed on the selected insulating joint which was a part of a pipeline located near frequently used railway line because railway traffic can also be taken into consideration as a potential source of additional loading of a pipeline. The soil covering the joint was removed and the measuring sensors were placed to selected points M1 – M5 (Fig. 1). Increasing number of measuring point indicates the direction of PIG passage. At the points M2, M4, M5 the 3D accelerometers were attached. At the points M1, M2 and M5 the strain gauges were placed in axial and in hoop direction. At the point M3 the laser triangulation displacement sensor (LTDS) was placed and was used for measurement of the change of distance between two parts of the joint (see Fig. 2 and 3). It can be seen that the joint flange did not move.

The range of amplitudes and frequencies of the expected vibrations was not known in advance. Therefore, two types of accelerometers were chosen: capacitance sensors suitable for lower frequencies and intensities of vibrations, and piezoelectric sensors for higher frequencies and amplitudes.

The PIG arrived at the velocity of approximately 2 mm/s and stopped in the middle of the insulation joint for about 10 seconds due to the increased frictional force in the area of the narrowed profile of the joint. Then it started again with speed of about 3.5 mm/s. The record of velocity from the PIG internal measuring unit is on the Fig. 4. When the PIG reached the insulation joint its velocity decreased rapidly and the PIG even stopped for several seconds. During the time when the PIG was stopping the rustle caused by friction between the plastic collars of the piston and the inner surface of the joint was audible but there was not any obvious impact. There are plastic rings on the body of the PIG which slide along the walls of the pipe therefore a collision between the rigid parts of the piston and the pipe or the joint is very unlikely.

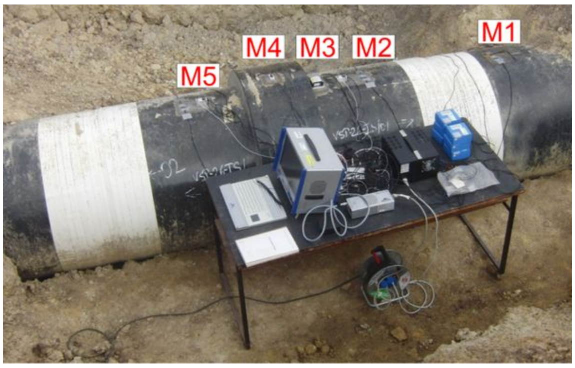

Fig. 1: The insulating joint with sensors.

Fig. 2: Laser triangulation displacement sensor.

The PIG stop caused a rapid pressure change in the gas flow and led to the increase of pressure difference between front and back of PIG. After the PIG started to move again it reached a higher velocity before it settle on an initial value. The velocity reached by the PIG immediately after the restart can be quite higher in comparison with the gas velocity. Vibrations and increase of stress in pipeline are the result of a local rise of pressure in the pipeline due to the piston stop that caused a hydrodynamic shock.

The response of the strain gauge and the accelerometer to the restart of piston is on Fig. 5 and 6 where x is the axial direction and y is the hoop direction of gauge. The stop of the piston excited the response in the strain gauges at points M1 and M2 only. All six strain gauges responded to the restart of piston as it can be seen on Fig. 7 and 8. The evaluation of measurement showed a dramatic response of the two strain gauges at M1 (placed on the pipe in front of the joint) to the stop of piston, which almost 5 times exceeded the measured data at points M2 and M5 (placed on the joint).

3 Stress Evaluation

The response of strain gauges in axial and circumferential direction at M1 was the most significant because they are in the place with the thinnest wall. The gauges were glued on the surface of gas pipe deformed by the current working inner pressure which was around 5 MPa. The axial and circumferential over-stresses evaluated from the measured strains must be added to stresses caused by the working pressure. The over-stresses are calculated using the relations for biaxial state of stress:

$$\sigma_t = \frac{E}{1-\nu^2}(\varepsilon_t + \nu\varepsilon_a), \sigma_a = \frac{E}{1-\nu^2}(\varepsilon_a + \nu\varepsilon_t). \tag{1}$$

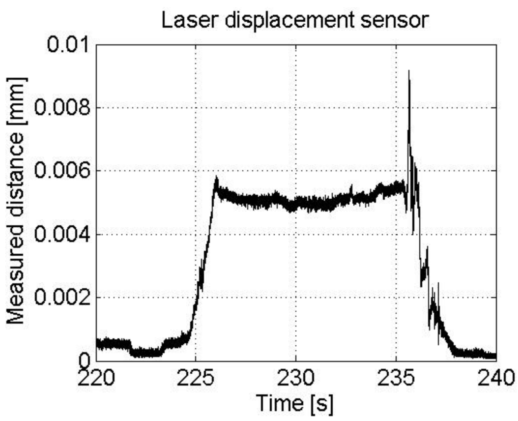

Fig. 3: Change of distance measured by LTDS.

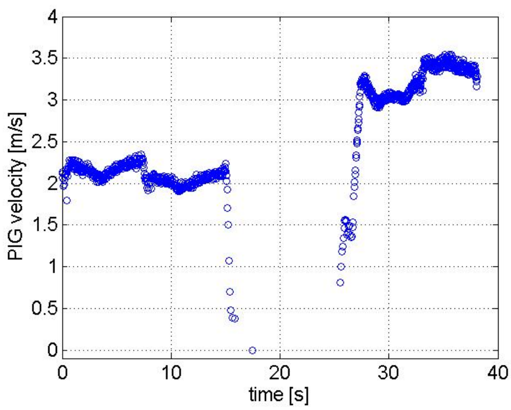

Fig. 4: Measured PIG velocity.

The resulting values of axial and hoop over-stress for the place M1 and M2 are on Fig. 9 and 10. The radius of the gas pipe is 500 mm and its wall thickness is 11.4 mm so it can be considered as thin-walled tube. In this case it is assumed that the circumferential stress is approximately constant throughout the wall thickness. Assuming operating pressure p = 5 MPa then the circumferential stress in the pipe is $\sigma_t = pr/t$ = 219 MPa and

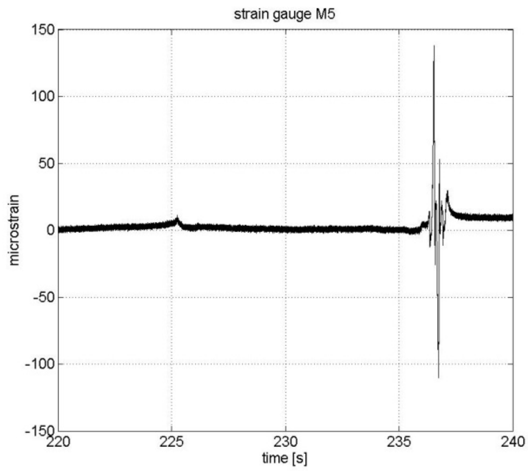

Fig. 5: Strain gauge at M5 – restart of PIG.

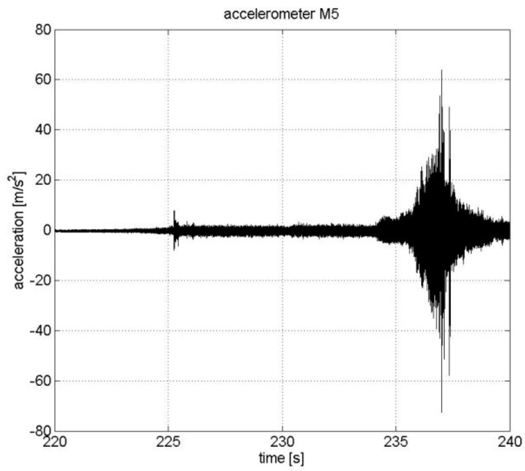

Fig. 6: Piezo accelerometer at M5 – restart of PIG.

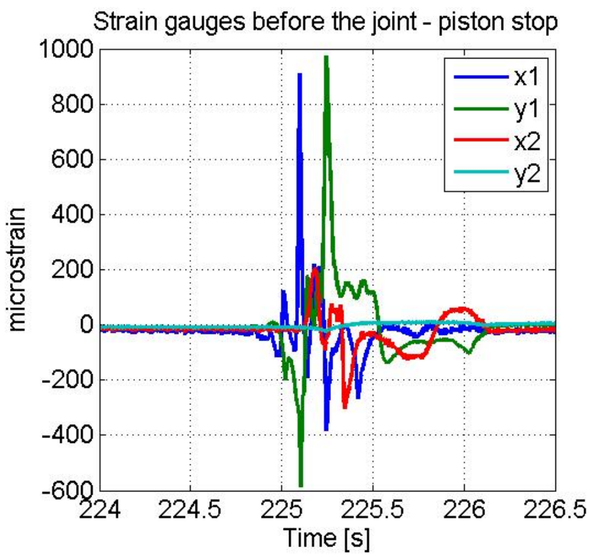

Fig. 7: Response of strain gauges to the PIG stop.

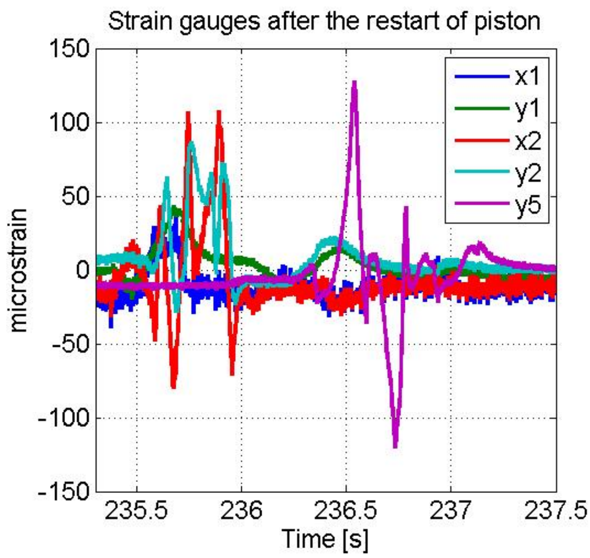

Fig. 8: Response of strain gauges to PIG restart.

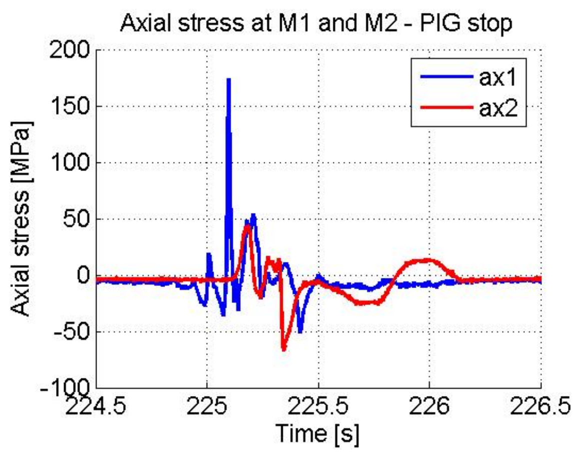

Fig. 9: Axial over-stress in course of PIG stop.

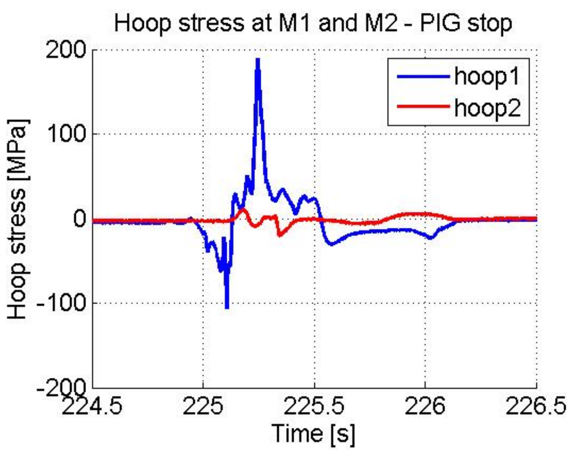

Fig. 10: Hoop over-stress in course of PIG stop.

the axial stress is $\sigma_a = \mu\sigma_t = 66$ MPa. Then the over-stresses due to the PIG stop are of the same magnitude as the stresses due to the working pressure. Maximum total HMH equivalent stress in the pipe was around 380 MPa at the moment of the PIG stop. The material of the pipe is the steel X70API5L whose yield limit is 483 MPa. The safety factor 1.3 is quite low.

4 Conclusion

All installed sensors responded to the passage of the PIG. The stop of the inspection piston caused an immediate increase of gas pressure in the pipeline and the short-term peaks of the gas pipe deformations and the pipe vibrations of high frequency and with low amplitude that lasted for a very short time. This caused corresponding peaks of additional stress. The analysis of stress in the pipe and in the insulation joint showed that the stresses did not exceed the strength of the pipe or joint material. The data of the laser distance sensor indicated that there was not a significant shift between the joint parts. No damage was obvious from visual inspection of external joint surface. The analysis of frequency response of accelerometers also showed that the frequencies were high and that there was a rapid decline of vibrations. It can be stated that the passage of the PIG did not cause any damage to the insulating joint.

References

[1] M. Durali, A. Fazeli, M. Ayimi, Investigation of Dynamics and Vibration of a Three Unit Pig in Oil and Gas Pipelines, in proc.: Proceedings of IMECE 2008 ASME International Mechanical Engineering Congress and Exposition (2008), 2008, Boston, Massachusetts, USA.