Evaluation of Depth and Profile of Surface Longitudinal Cracks and their Growth in DN300 High Pressure Pipeline

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Abstract: In an operated DN300 high pressure pipeline, crack-like defects were detected by internal inspection methods. The pipeline section could not be therefore further operated without detailed and careful evaluation of its safety and reliability. Several meters long section of the pipeline was taken out from ground for the purpose of experimental laboratory evaluation of the damage extent. Magnetic defectoscopy confirmed an existence of numerous distinct indications of longitudinal defects. Methodology of measurement of depth of these cracks was proposed using direct current potential drop (DCPD) method. An experimental calibration dependence of potentials on crack depth and shape was evaluated in laboratory. Precision limits of the DCPD method being used in this specific case are discussed in the paper, particularly considering inclined shape of the cracks. Results are related to actual crack depth values and their inclination evaluated by metallographic method.

Keywords: high pressure pipeline; crack-like defect; DCPD method; crack depth.

1 Introduction

Natural-gas pipeline accidents mostly result in major damage to buildings and other constructions located not only nearby but also quite far away and often put a lot of people in danger of injury or death. Such crashes are almost always connected with enormous material and financial damages. Therefore, safety and reliability management of high pressure gas pipelines is one of the most important issues for the operators. If damage to the pipeline is detected, such pipeline sections can no more be operated as long as safety and reliability is not confirmed on the basis of comprehensive theoretical and experimental evaluation.

In one of DN300 high pressure pipelines in Czech Republic, crack-like defects were detected. Several meters long section of the pipeline was taken out from ground for the purpose of experimental laboratory evaluation of the damage extent followed by high pressure fatigue test and test to rupture. One of the important points to be evaluated was, whether the cracks are stable or grow during the tests.

The only possibility to evaluate the crack growth was to use indirect methods of measurement of their depth. As there have been many years experience with DCPD method of crack measurement (e.g. [1-3]), it was decided to explore possibilities and conditions of its use for this specific case of longitudinal cracks in pipe. Note that the DCPD method is particularly suitable for measurement of cracks in laboratory specimens. As far as pipes are concerned, it can be used with a high precision for transversal cracks. In both cases, theoretical calibration curves can be computed and used with high precision. This does not, however, concern longitudinal cracks. when it is practically impossible to reach homogeneous direct current field in the crack area, which is a fundamental condition for using the analytical calibration. Therefore, experimental calibration had to be carried out, dedicated for the specific pipe section of specific dimensions.

2 Experimental Programme

Section of the pipe with no NDT indications, i.e. probably no cracks was used for the experimental calibration. 60 mm long longitudinal line was indicated on the pipe surface and at its centre, row of five electrodes was spot welded to the pipe surface in perpendicular direction. Two electrodes near the line, at the distance 5 mm from the line were used for measurement of potential V(a) on crack, the third electrode located at the distance 10 mm from one of the potential electrodes measured reference potential Vref and two fairly thick outside electrodes, at distance 20 mm from the nearest potential electrode, served as the direct current source. After measurement of initial value of the potentials V(a) / Vref, which was close to ideal ratio 1, artificial crack was modeled by thin gradual cuts do depth with surface length 60 mm. Position of the electrodes and cutting procedure are shown in Fig. 1.

Besides experimental measurement of the potential dependence on crack depth, modified analytical calibration curve based on Johnson´s formula [5] according to [1-3] was calculated for fictive values of specimen width W = 10 mm, which corresponded to pipe wall thickness.

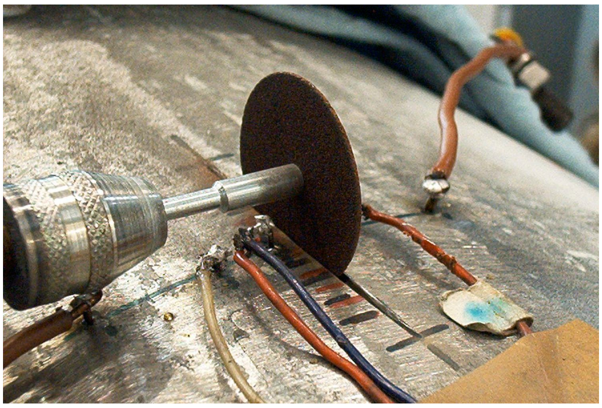


Fig. 1: Modelling of crack by cutting with potential measurement

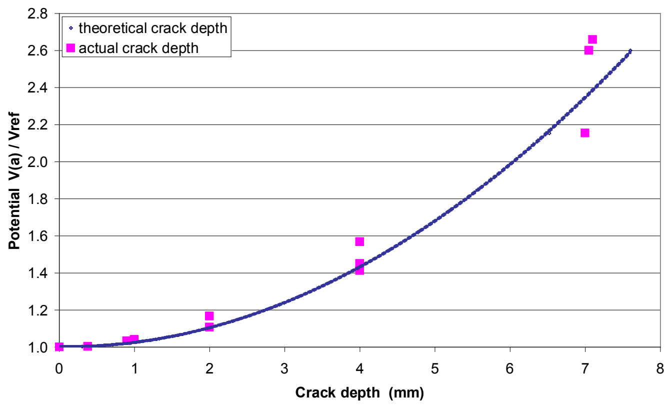


Fig. 2: Analytical calibration curve and points of experimental measurement

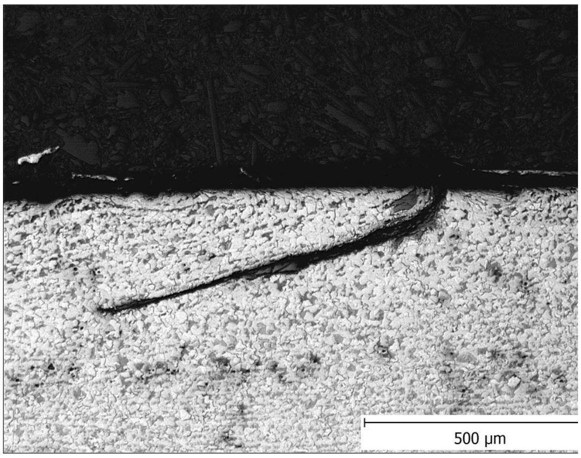
3 Results and Discussion

The calculated calibration curve with experimentally measured points is shown in Fig. 2. The results were very promising, because in spite of that the direct current field was not homogeneous near the crack area, results indicated that for the first approximation, the calculated curve could be used. The agreement between the analytical curve and experimental points was particularly good for the case that the depth was not constant along all the 60 mm surface length but was maximum in the crack centre and gradually decreased to its ends, approximately according to parabolic dependence. If the depth was constant along the whole crack length, the potential ratio V(a) / Vref was slightly higher than the calculated curve and on the contrary, if crack depth decreased to its ends linearly, then the points were bellow the curve.

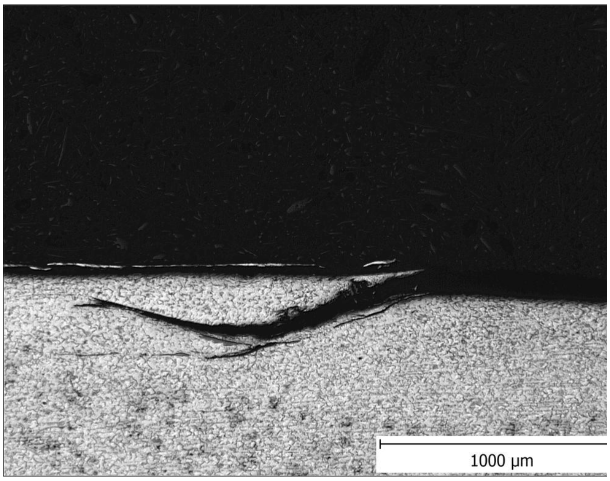
In the second step, the DCPD method was verified on actual NDT indications of cracks in the pipe section, with typical surface length between 40 mm and 100 mm, sometimes even more. Electrodes were spot welded to the surface near four crack indications Nos. 2, 4, 12 and 25 in the same way and distances like during the experimental calibration. Measured potentials were recalculated to crack depths using the analytical curve in Fig. 2. The calculated values corresponded sequentially to depths 1.30 mm, 0 mm (actually negative value, which is nonsense), 2.17 mm and 1.60 mm. Then the pipe was sectioned and metallographical cuts perpendicular to the cracks in their centres were prepared.

The metallographical examination provided surprising results. The most important was the fact that practically all crack or crack-like defects were considerably inclined – Fig. 3. Some of them were in fact subsurface defects almost parallel to the pipe surface. Crack No. 4 was even curved back to the surface, so its maximum depth was not coincident with its tip – Fig. 3 b. Note that the selected cracks corresponded to the strongest NDT indications, as shown in Fig. 3 e, f.

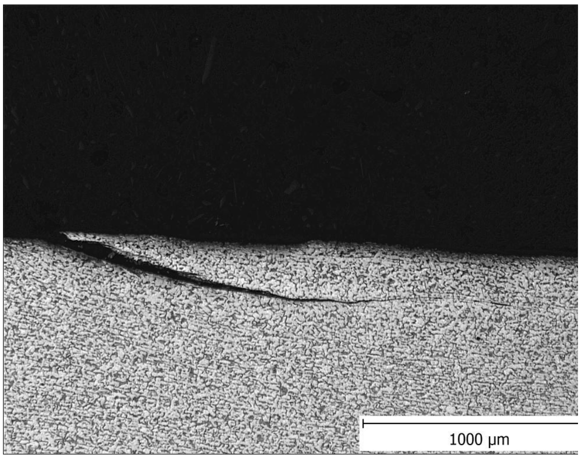
Both values of crack length and depth were evaluated from the cuts in Fig. 3 and were correlated with calculated depth values from the DCPD measurement using the analytical calibration curve in Fig. 2. The results were much less encouraging than in case of the previous calibration with the artificial longitudinal radial cut. The comparison is in Table 2, dimensions are in mm.



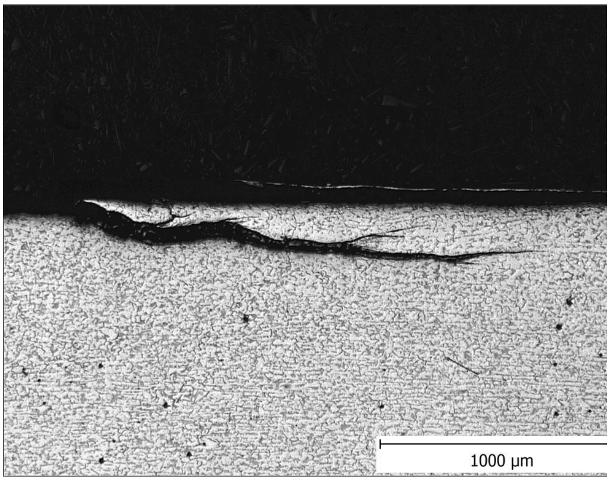
a) crack No. 2



b) crack No. 4



c) crack No. 12



d) crack No. 25

e) NDT indication No. 12

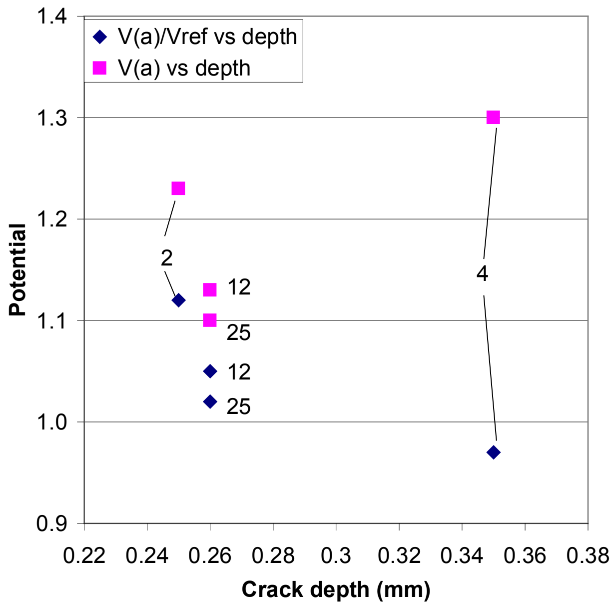
f) NDT indication No. 25

Fig. 3: Cracks in cross section metallographical cuts and NDT surface indications of selected cracks: a) No. 2, b) No. 4, c) No. 12, d) No.25, e) indication No. 15, f) indication No. 25

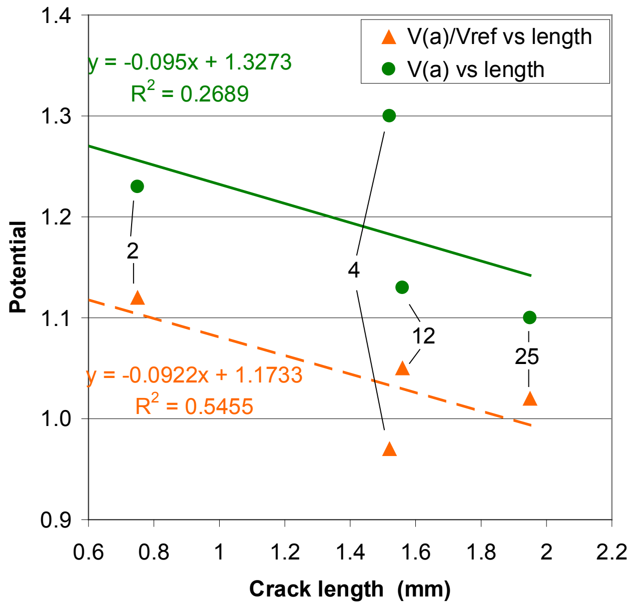
In the next step, the measured potentials were plotted against values of crack depth and crack length, respectively, with the aim to try to explain the unusual an unexpected results. Individual values of the potential V(a) and also values of the ratio V(a) / Vref were plotted in the diagrams in Fig. 4.

Tab. 2: Actual dimensions of the cracks with calculated depths

Crack No.	Actual depth	Calculated depth	Actual length	Crack No.	Actual depth	Calculated depth	Actual length
2	0.25	1.30	0.75	12	0.26	2.17	1.56
4	0.35	0.00	1.52	25	0.26	1.60	1.95



a) measured potentials V(a)/Vref and V(a), respectively, as dependence on crack depth



b) measured potentials V(a)/Vref and V(a), respectively, as dependence on crack length

Fig. 4: Dependence of potential ratio V(a) / Vref and pure V(a) on depth and length of cracks

It follows from Table 2 and Fig. 4 that there is no reasonable agreement between actual and calculated values of crack depth, respectively. There is even no meaningful agreement between potential V(a) or potential ratio V(a) / Vref on either crack depth or crack length. On the contrary, the potentials have a decreasing tendency with increasing crack length – Fig. 4b, which seems to be more or less absurd. There is, however, a reasonable explanation: The strong inclination of the cracks causes a kind of potential shadow on the crack side in the direction of inclination resulting in lower measured values. The shadow is the higher the crack is longer and so, measured potentials are inversely related to the length of strongly inclined cracks.

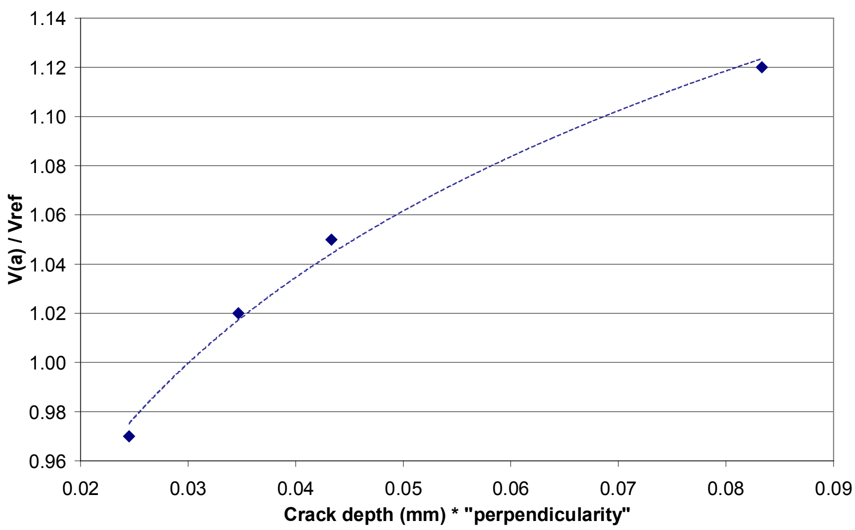


Fig. 5: Potential ratio V(a) / Vref was plotted against crack depth multiplied by “crack perpendicularity”

Another attempt was made to achieve a reasonable relationship between crack dimensions and measured potentials, namely introducing a parameter called “crack perpendicularity”, defined as ratio of crack depth to its length. It is evident that such ratio equals one for ideally perpendicular crack. When actual crack depth values were multiplied by this parameter and measured potential ratio V(a) / Vref was plotted against these values, a reasonable diagram was obtained – Fig. 5, with a logarithmic dependence. More experimental points would be, however, needed to make fairly general conclusions.

The very different bahaviour of DCPD potential measurement on the inclined cracks in the pipe can also be distinctly shown in another diagram – Fig. 6, where the first part of the analytical calculated calibration curve is shown together with actual potential measurement, ratios V(a) / Vref, carried out on the crack modelled by cutting in exactly radial direction, i.e. with no inclination. The agreement is very good. On the contrary, the same V(a) / Vref values evaluated on the inclined real defects not only do not agree with the theoretical curve, but have even opposite slope.

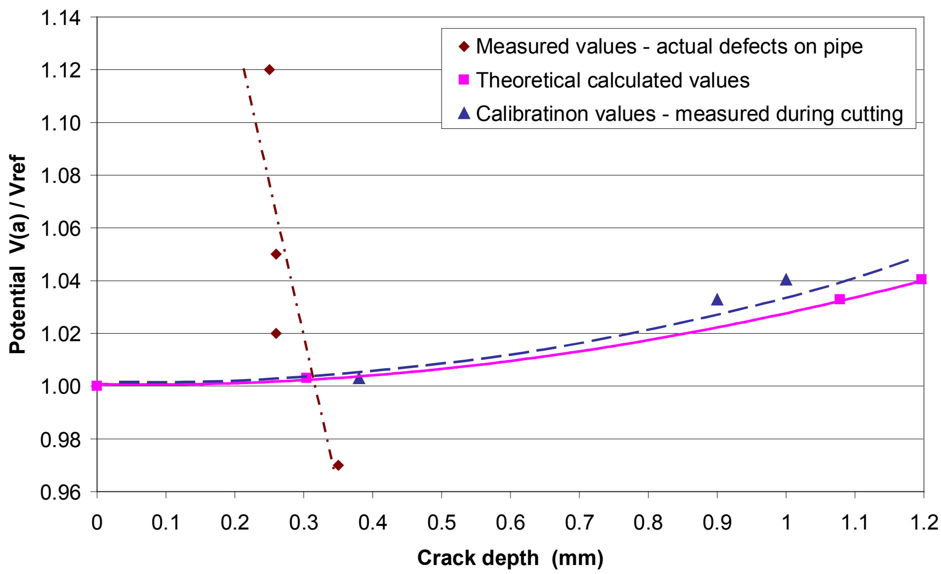


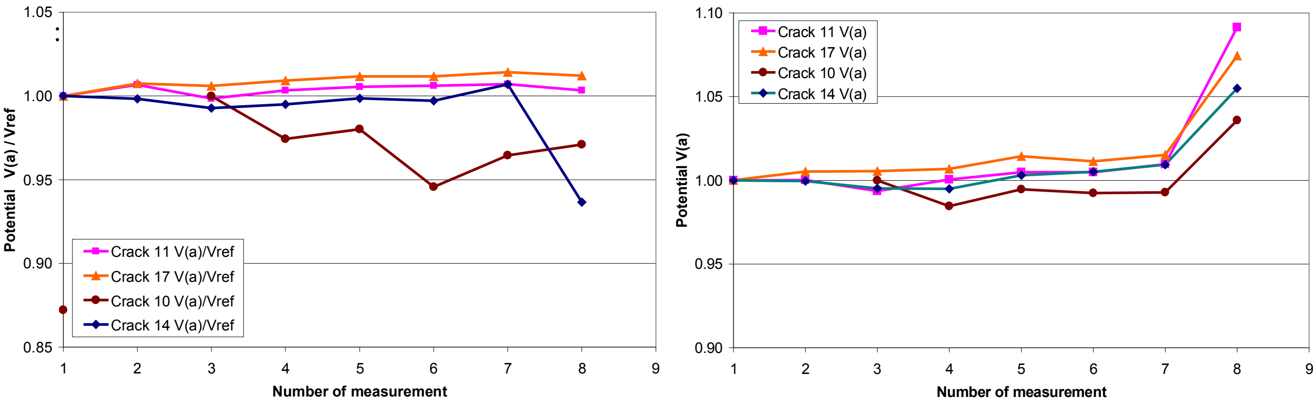
Fig. 6: Potential ratio V(a) / Vref was plotted against crack depth multiplied by “crack perpendicularity”

It also should be pointed out that measured potential, more exactly potential ratio is affected by important fact, whether the reference electrode is placed in the direction of the crack inclination or at the opposite side of the crack. In this work, it was quite probably in the direction of inclination, but not sure. Another comment concerns a possibility to calculate potential field near crack of any shape and dimensions by resolving the relevant Laplace equation using numerical methods, which is, however, very complicated and time consuming task.

4 Application of DCPD Measurement during Pipe Pressure Tests

The DCPD method was eventually used for measurement of possible crack length changes of actual cracks in the pipe during pressure cycle induced fatigue crack growth assessment and during static pressure test to failure, however with the reservation about low precision of absolute crack depth assessment. For variously inclined cracks the method can only be used for assessment of occurrence of crack increments during tests.

DCPD measurement was performed near four defects with most distinct NDT indications Nos. 11, 17, 10 and 14. The configuration of the electrodes was the same as in case of previous calibration and measurement, just the distance of current electrodes was slightly higher, approximately 100 mm from the nearest potential electrode. The pipe section was loaded by internal pressure, namely fatigue loading between zero and maximum service pressure to 1200 cycles followed by static test to failure. Results are shown in Fig. 7, where measurements Nos. 1 – 8 correspond sequentially to the following conditions: 1 – initial measurement, 2 – 1 cycle, 3 – 200 cycles, 4 – 1000 cycles, 5 – 1200 cycles, 6 – static loading to 12.5 MPa, 7 – static loading to 24.9 MPa and 8 – 34 MPa just before failure.



a) V(a) / Vref values during pipe pressure test   b) values of pure V(a) during pipe pressure test

Fig. 7: Application of DCPD measurement on four selected cracks during pressure cycle induced fatigue test and static pressure test to failure

Results in Fig. 7 confirm that some changes of the potentials, at least quite minor occurred on all of the four defects. In spite of the fact that measurement of reference potential in standard situations increases stability and self-consistence of the method, in this specific case, measurement of pure V(a) values provides more reasonable information, namely increasing tendency of the potential values. Note that in the cases of strongly inclined cracks, increased internal pressure may result in better contact between fracture surfaces and eventually in slight decrease of the measured values. However, this concerns not only pure potentials V(a) but also potentials Vref. It is the reason why the values in Fig. 7 b are considerably more consistent than those in Fig. 7 a. It looks that the most important changes occurred at the end of fatigue loading stage. This indicates that a kind of fatigue growth of the defects occurred. However, as far as the last strong increase of the potentials V(a) is concerned, it can be connected to the overall plastic deformation before final failure rather than growth of corresponding cracks.

5 Conclusions

The main results of the work aimed at exploration and verification of possibilities to use DCPD method, successfully being used for exact measurement of crack length and growth in laboratory specimens and several components, for measurement of depth and growth of longitudinal cracks in pipes during internal pressure induced fatigue and static tests can be summarised as follows:

- In case of the specific configuration of the potential and current electrodes, the method can not only be used for a rough assessment of crack occurrence and growth, but even analytical calibration curve based on the Johnson´s formula is applicable with quite high degree of accuracy.
- Actual existing crack in the assessed pipe section were substantially inclined, which strongly complicated application of the method for exact measurement. In such case, the use of method can be considered for rough assessment of crack existence and its growth, more or less from the qualitative viewpoint only.
- The method applied to measurement of actual indications during pipe fatigue test and static test to failure provided useful information about changes of the character of the defects. The main changes concerned last stages of the fatigue loading and static loading before failure. On the other hand, the changes could concern not only actual crack growth, but also contact conditions between the fracture surfaces.

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