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MODELLING OF BEHAVIOUR OF SPIRAL WELD OF HIGH-PRESSURE GAS PIPELINES

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ABSTRACT: *The local effects of notches in the form of long cuttings on the development of deformations in the wall of a spiral welded pipeline were modelled in the course of the hydraulic strength tests of hp gas pipelines. The influence of notches and the spiral weld on the pipe state of stress were investigated experimentally together with the numerical simulation of the behaviour of pipes with defects by means of the application of the ANSYS programme. The research has demonstrated that if the material is not too damaged by fatigue and is not considerably heterogeneous and weakened by microcracks in the structure, it is possible to accept very deep weakening of the pipe wall.*

KEYWORDS: high-pressure pipeline, spiral weld, notch, yield point, stress hardening, computation modelling

1 INTRODUCTION

The high-pressure (hp) gas pipelines of the Czech national gas supply network were constructed in about 1960 and their operation life was over 30 years. Such pipelines represent in the Czech Republic more than 20% of the total length. The material of the pipes of the national gas supply network is ferritic perlitic carbon steel of good plastic properties, i.e. yield point/strength ratio R_e/R_m is from 0,65 to 0,78 and ultimate strength R_m = 380 MPa to 550 MPa. The ageing of the gas pipelines manifests itself by degradation processes of the steel of the pipes, the origin of corrosion defects and the generation of local fields of very high stress levels in the pipe walls. The present hp gas pipeline system used older pipelines with PN 25 as well as the new pipelines PN 40. Their interconnecting often means that the new pipelines have to be operated at PN 25 because they are connected with older gas pipelines. During the last ten or more years were realised several research programmes that had to find out and describe faults caused by corrosion, fatigue or a less suitable foregoing construction technology. The objective of our research was to find crucial data about strength and residual life of hp pipelines of the national gas supply network after long-term operation and to enable an output increase by changing the operational pressure from 2,5 MPa to 3,5 MPa together with achieving a necessary amount of operational reliability.

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The assessment of the reliability of operating pipelines necessitates the knowledge of the actual stress and strain magnitudes in the pipe wall. The real magnitudes of these quantities often differ significantly from theoretical values computed in the design of a hp pipeline of ideal dimensions and properties. A plenty hp pipelines after a long-term of operation shows different faults. These faults cause higher concentrations of stress in such a way that at specific local areas the plastic strain limit is reached and often exceeded. Corrosion damage, the deviations from circularity, local variations of wall thickness, geometric imperfections in welded joints and other inaccuracies of the pipeline form due to its production and placing in the ground play their role in the stress state of the pipeline. The local effective values of total stresses in pipeline operation in sensitive wall places of the real pipe may lie even above yield point. Therefore the strength computation based on the values of stresses produced in the wall of an ideal pipeline by the internal operating pressure is not conclusive.

The hp gas pipelines were assembled of welded, mainly spirally, pipes. The manufacturing and assembly welded joints of high-pressure pipelines of the national gas distribution network represent an enormous length and may influence considerably the stress state of the pipes and their deformation processes in the course of operation. In most cases the steel is of good plastic qualities, considerable yield point and the ability to hardening by plastic deformations. According to experience defects of various types originate of the pipelines. One of the defect types may be a notch in the form longitudinal cutting which originates either by an external physical interference in the course of construction or by corrosion in the course of pipeline operation. Because the environs of the manufacturing spiral weld of the hp pipeline often become the decisive for the origin of the pipe degradation, the influence of cracks in the form of notches on the deformation development in the wall of a spiral welded pipeline was modelled in the course of experimental research of boundary conditions of hp gas pipelines.

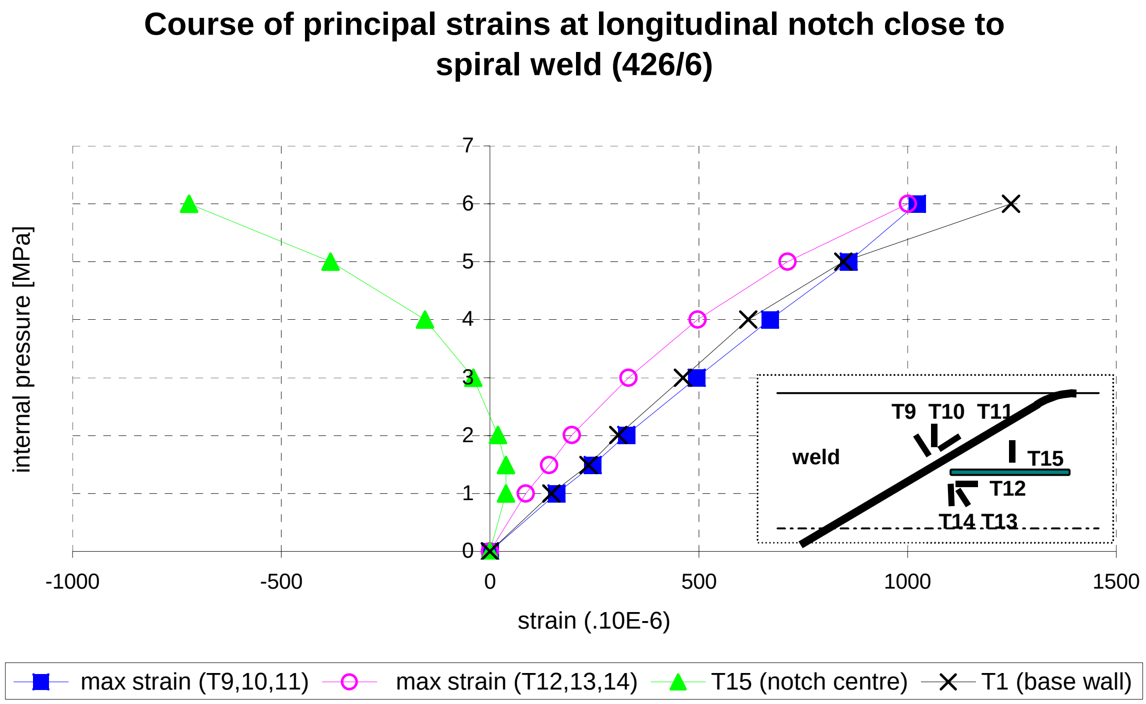

Fig. 1

2 EXPERIMENTAL MODELLING

The processes of degradation of hp gas pipelines are often connected with defects of longitudinal, spiral as well as transverse production welds. However, it is necessary to bear in mind that in engineering practice the real pipes combine these local effects with additional stresses; also influence of internal stresses in the proximity of welded joints must be taken into account.

In the course of experimental research (Jíra et al 1996) 6 pressure vessels made of spiral welded pipes of different diameter and wall thickness were subjected to hydraulic strength tests. The walls of the vessels were provided with models of various actual defects which may originate in pipeline operation. One of the types of artificial defects consisted in deep cuttings some 100 mm long the depths of which corresponded with 2/3 of wall thickness. The cuttings were made with curved run-out to ensure a continuous transition to full wall thickness. The purpose of these measurements was to obtain information on conditions of strain and origin and development in the place defects and on the influence of the spiral weld on the origin and propagation of damage. The cuttings were located in three positions. The longitudinal notch situated in the plain pipe wall between the spiral welds was taken as a basis of comparison. Further two notches were located in the immediate proximity of the spiral weld, one in the longitudinal direction (Fig. 1) the other parallelly with the spiral weld (Fig. 2).

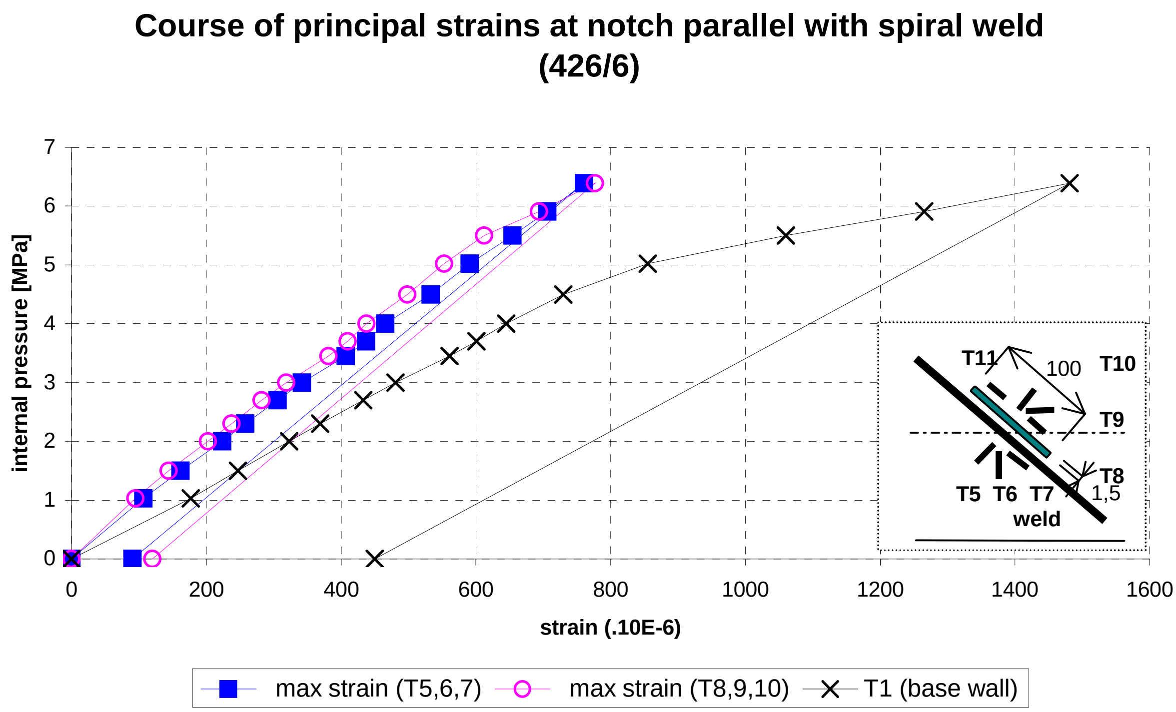

Fig. 2

It is obvious that in case of pipes produced in good quality the spiral weld stiffens the cylindrical shell of the pressure vessel. The results of strain gauge measurements have shown that hp pipeline loading to operating level produces stresses in the environs of spiral welds. This points to a local and often fast transition to the region of plastic deformations which differs substantially from the ideal idea of an infinite cylindrical shell of circular pipeline cross section in the welded joints. In the measurements by means of strain gauge rosettes in the close proximity of the spiral weld also computed directions of principal stresses differed.

This is due to both the complex stress field and the deviations from the geometry in the environs of welded joints and to weld super-elevation. In the course of load application by internal pressure the principal axes rotate in a complex manner due to the local development of plastic deformations. After successive equalization of geometric imperfections and the reduction of the magnitude of natural stresses the axes of principal strains rotate practically to the circumferential and longitudinal direction in the way observed in the base wall material at a sufficient distance from spiral weld.

The influence of cuttings did not manifest itself as effectively as it had been assumed. Longitudinal cutting or the cutting parallel with the spiral weld do not influence significantly the stiffening effect of the spiral weld at the beginning, as *Emax* at the defect side and the side defect free weld have approximately the same history. The deformation in the place of the defect is only slightly greater, as actually a marked deformation takes place in the cutting ligament, where the whole deformation process takes place. The failure took place in the place of cuttings by their opening and the disruption of the weakened ligament. During this destructions the crack did not develop beyond the length of the cutting. However, the edges of the notch were visibly buckled. While the longitudinal cutting in the pipe wall was four times as wide as initially, the width of the cutting parallel with the spiral weld increased only twice and mildly decreased again after load relief. This confirms the stiffening and positive effect of the spiral weld. The concentration notch effect of the cutting has not manifested itself at all. This low sensitivity to the notch effect will manifest probably in all cases when the material has sufficient plastic reserve.

All experiments have shown that in spite of considerable thickness reduction in the places of cuttings the experimentally ascertained bearing capacity of the damaged pipe is higher than initially expected. The longitudinal defect in the base wall failed when 65% of the actual pipe strength have been reached. The longitudinal cutting in the proximity of the spiral weld at ruptured at 80% and the cutting parallel with spiral weld close to 90% of the real strength of the tested pipes.

In respect of the transition from elastic to plastic deformation there are considerable anomalies which cannot be explained by the difference between uniaxial stress of the test sample and the biaxial stress of the ideal cylindrical shell of the hp pipeline. Plastic deformation due to natural stresses appears earlier under overload, but develops gradually without noticeable transition from the upper to the lower yield point like in the tensile test bar. An analysis of the form of deformation in the environs of welded joints points to the fact that residual stressses even in case of pipelines subjected to the prescribed standard pressure test at the beginning can be within the range of 1/3 of the yield point.

3 COMPUTATIONAL MODELLING

The local defect is the greatest danger for failure of the pipe wall. The notches can originate in the places of damaged pipeline insulation and are concentrated on limited pipe surface, but attains considerable depth and length. We used the programme ANSYS (Jíra, Jírová, Micka 1998) for the numerical analysis of the stress field and deformation process inside the notch and in the vicinity of it and the spiral weld. The environs of the cutting was modelled by 3D section in the shape of the cylindrical parallelogram. The notch had a constant width and its bottom was elliptical curved. For node definition an automatic meshing with smaller node distance in the vicinity of points located on the edge of a cutting was used. The boundary conditions were defined with the use of symmetry. An isoparametric spatial element SOLID95 consisting of 20 nodes was used for the solution of the given problem. The material was considered as being in elastic-plastic region with linear hardening.

Stiffening effect of spiral weld

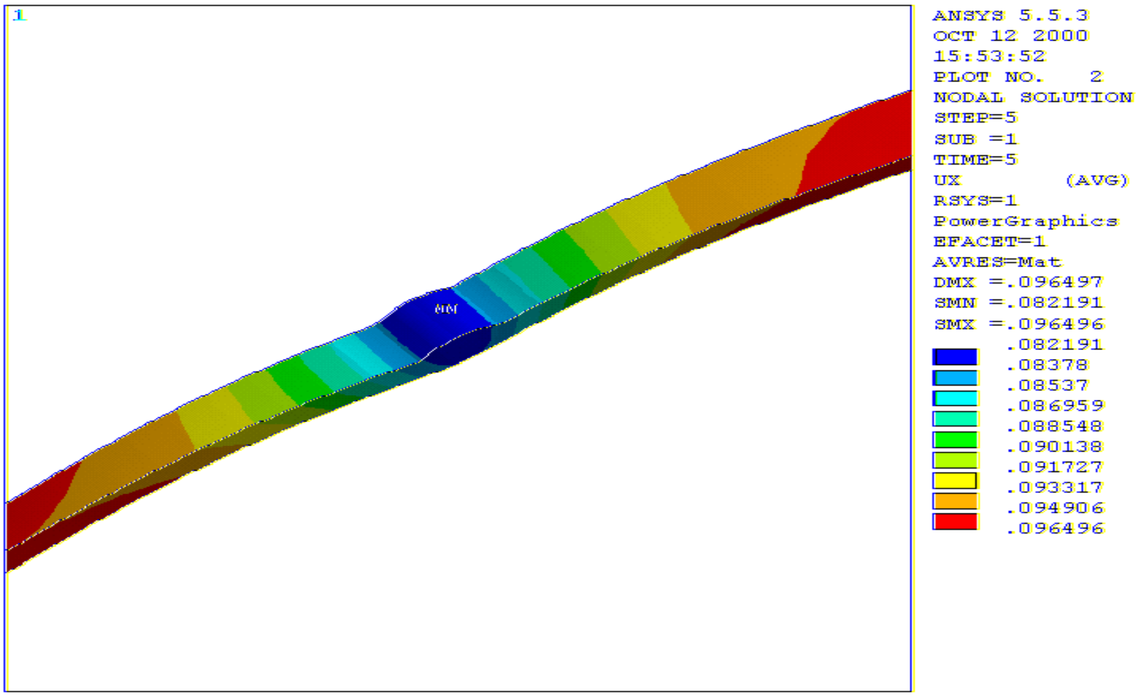

Fig. 3

The computation proved the stiffening effect of the spiral weld on the deformation of the pipe wall (Fig. 3). The fields of stress or strain and directions of principal stresses in the vicinity of the notch were the result of the computational modelling. The elastic-plastic model of notch enabled to discover the local process of the plastic deformation. During the service internal pressure 4 MPa the small plastic zone can be created in the transition from a spiral weld to base material (Fig. 4) and which can be an initiation of fracture. For the determination of the reparative overpressure (Gajdoš et al. 2000) during the piping rehabilitation it is important to know the characteristic sizes of the notches and the corresponding coefficients K of the stress concentration. The task was solved experimentally together with the numerical simulation of the notch behaviour. The outputs can be plotted graphically or it is possible to make a print of the displacement and stress in all points of the FEM network. The values of the local maximal stresses in the bottom or at the periphery of the notch can be determined and the coefficients *K* of the stress concentration can be determined by comparison with the average membrane stresses.

4 CONCLUSION

Under repeated loading an increase of the threshold of origin of plastic deformations or, in other words, strengthening, takes place even in case of notches. The failure took place in the cuttings by their opening and the rupture of the weakened cutting ligament. In case longitudinal notch the crack width was 4 times as large as the original width and in case of the notch parallel with the spiral weld only twice as large, a fact due to the stiffening effect of the weld along the whole cutting length.

The experiments have shown that the defect in the form of a cutting is more dangerous, if located in the direction of the lengthwise axis of the pipeline. Its strength is approximately 8-10% lower than the strength of the notch situated parallelly with the spiral weld, but 15% higher than the strength of a notch situated longitudinally in the pipe wall in the area between the spiral welds. A parallel notch, in spite of its great depth, is less dangerous than expected, as it attains as many as 90% of the theoretical strength of the pipe.

Plastic zone on spiral weld edge

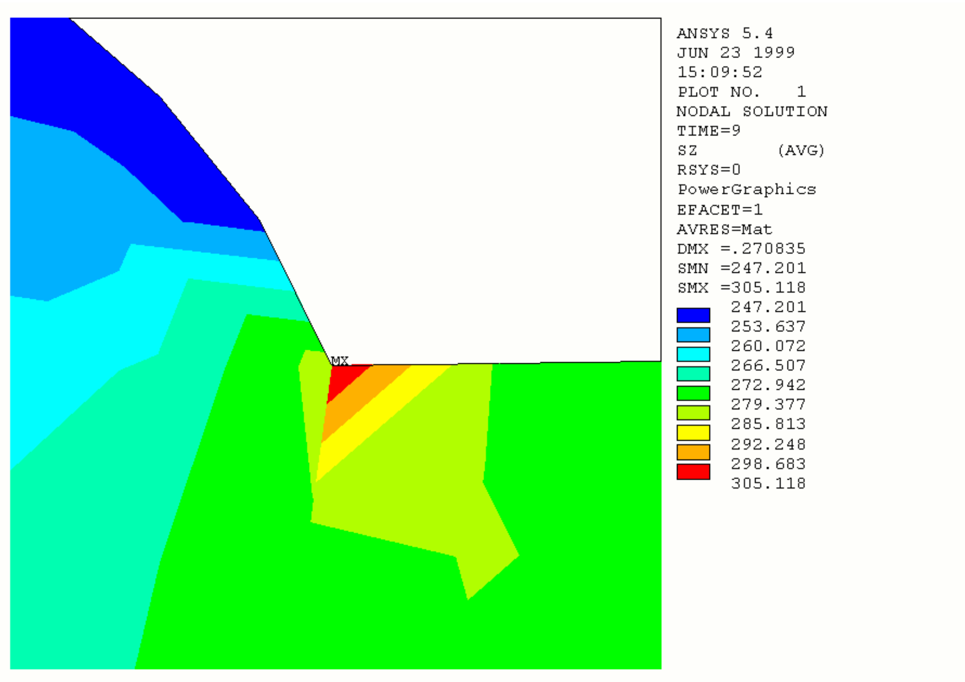

Fig. 4

We have studied the reliability of hp pipelines weakened by the notches. The research has demonstrated that if the material is not too damaged by fatigue and is not considerably heterogeneous and weakened by microcracks in the structure, it is possible to accept very deep weakening of the pipe wall. According to the size of the local wall weakening the limit depths of the cuttings have been determined, so that a reliable residual service life can be determined for different pipeline sizes and pressures, provided we know the speed of wall corrosion loss.

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