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Non-destructive Testing and Repair of Pipelines

SEVENTH FRAMEWORK PROGRAMME

Springer

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Preface

Transmission pipeline systems have supreme significance for an effective functioning of the petroleum industry, providing European market with energy resources: crude oil, natural gas, liquid petroleum products, and liquefied natural or petroleum gas. Taking into account the long life of such pipeline networks and the present situation, with over 20% of the large-diameter pipelines having exhausted their lifetime, an important task at the present moment becomes safeguarding the reliability for these transmission systems. In such a context, pipeline maintenance activities (comprising inspection and repair) are very important. Many studies have proven that among the main reasons of steel pipeline failures are the volumetric surface defects (VSDs, also named local metal loss defects), generated by corrosion and/or erosion processes and by this way considerably decreasing the pipeline strength and expected lifetime.

The present book is devoted to a provision of efficient and safe operations of transmission pipelines by improvement of existing and development of new methods for the detection (by means of non-destructive techniques, based on low-frequency ultrasonic testing with directional waves) and repair (using advanced composite materials systems) of VSDs, generated in the pipelines. These studies are performed in order to bring the efficiency of damaged sections up to the level of the undamaged pipeline. The combination of both research directions mentioned above is, in our opinion, important since the increased technological opportunities of long-range ultrasonic testing promote a more efficient application of composite repair technologies, which are developed taking into account an assessment of the stress–strain state in the VSD areas of in-service repaired pipelines.

The activities of transporting petroleum, natural gas and petroleum products are services that must be provided continuously. As a consequence, the present-day maintenance strategies require that the inspection and technological repair procedures normally used should be applied without removing the pipelines from service. In such conditions, the pipe repair systems, based on composite materials (that are analysed in the present book), are more and more often used, because they have a good economic efficiency. They considerably increase the remaining life of the repaired pipelines and they do not require welding operations (implied by using another repair methods, which require special precautions, when performed on pipelines under pressure).

In order to ensure efficient and safe operation of existing transmission pipelines, operating companies routinely inspect the pipes. The methods normally used to such a purpose, like for instance "smart pigs", are sufficiently expensive, require significant reconstruction and have, in some cases, an insufficient sensitivity. As an alternative, the application of long-range ultrasonic testing and phased array technologies, studied in Chapter "Long-Range Ultrasonic and Phased Array Technologies", contributes to the increase of the functional capability of non-destructive testing, namely range of test, defect detection, positioning and sizing capabilities.

Aiming at the development of recommendations for an application of the long-range ultrasonic and phased array technologies for pipeline diagnostics, different types of generated and received guided ultrasonic waves, their interaction with discontinuities and directional properties of ultrasonic antenna array are analysed. An accurate characterisation of damaged area detected in the transmission pipeline by the long-range ultrasonic waves is carried out using the wavelet transform and inverse techniques. The vibration-based damage detection (VBDD) techniques, based on the changes in the dynamic characteristics of a structure caused by the defect, are also analysed for steel pipeline systems. The localization of impact damage in thin-walled composite structure using variance-based continuous wavelet transform technique is investigated, and the defects identification method in pipeline systems, based on a combination of finite element method and artificial neural networks, is proposed.

The methods for the assessment of the pipeline areas, requiring maintenance works, are performed. The remaining strength of a transmission pipeline on which VSDs have been detected (using the results of non-destructive testing) are analysed and compared in Chapter "T- and L-Types of Long-Range Guided Waves for Defect Detection", with the help of several case studies. The VSDs are characterised, the criteria and procedures, defined by the norms presently used, are discussed, focusing on the assessment of the remaining strength factor and residual life of damaged pipelines. The procedures for the evaluation of the possible interaction between several adjacent VSDs are also discussed and compared.

Different types of materials (polymeric fillers, fibre reinforced materials and polymeric adhesives) are studied in Chapter "Directional Properties of Ultrasonic Antenna Array" in their application to advanced composite repair systems. After reviewing the properties of such materials, the methods of enhancing the strength of adhesion interaction between the composite wrap/sleeve, used for repair and the steel pipe, are analysed. The mechanical properties of composite materials are characterised by both fracture methods (used to determine also dynamic characteristics) and non-destructive techniques (impulse excitation and inverse technique, based on low-frequency vibrations, laser-induced ultrasound, used to define elastic properties), demonstrating the efficiency of the developed procedures and the reliability of the obtained results.

The existing technologies using advanced polymeric composite materials systems for the reinforcement of pipelines with VSDs are analysed and compared in Chapter "Interaction of Low-Frequency Guided Waves with Discontinuities", using information from the manufacturers of such repair systems, the pipeline operating companies and the experience of the authors. The technologies, based on composite materials, used for pipelines coating to ensure their protection against corrosion, are also present, together with repair methods for such coatings. The design methods, applied for the definition of the characteristic dimensions (thickness and length) of the composite wraps/sleeves, used in the repair systems, are also compared and a new design procedure is proposed by the authors.

Many standards dealing with the composite repair systems are based on simplified approaches and do not take into account the complex stress–strain state in the damaged areas. Consequently, several analytical and numerical procedures, presented in Chapter "Vibration-Based Damage Detection of Steel Pipeline Systems", are developed for the detailed assessment of the stress–strain state in the repaired VSD areas. The recovery, by applying advanced composite repair systems, of the carrying capacity of pipeline sections with local corrosion damage is also analysed, using the finite elements method, considering also the case of pipes with two interacting VSDs. Several analytical models, developed to model the contact interaction between the steel pipe and the composite wrap, are also described. An optimisation methodology, based on the planning of experiments and response surface technique, is developed for the composite repair systems considerably reducing the required computational expenses.

An experimental programme (comprising full-scale hydraulic tests of pipes under inner pressure, up to bursting), developed and performed by the authors, aiming at studying the reinforcement effects of a repair system using composite materials for a damaged transmission pipeline, is described in Chapter "Localization of Impact Damage in Thin-Walled Composite Structure Using Variance-Based Continuous Wavelet Transform". Validation of the developed numerical models and estimation of the composite repair efficiency is made, based on the results of such a programme.

The topics discussed and the solutions formulated in this book will be interesting and useful for a wide audience, namely for students and researchers studying and developing effective non-destructive techniques and advanced composite materials repair systems for transmission pipelines, as well as for the providers or manufacturers of the components of such techniques and repair systems and for the engineers designing, planning and executing maintenance activities for different pipelines belonging to the transmission systems of hydrocarbons or of other fluids.

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