Topics in Safety, Risk, Reliability and Quality

Volume 30

More information about this series at http://www.springer.com/series/6653

Sviatoslav Timashev · Anna Bushinskaya

Diagnostics and Reliability of Pipeline Systems

Springer

Sviatoslav Timashev
Russian Academy of Sciences
Ural Federal University
Yekaterinburg
Russia

Anna Bushinskaya
Russian Academy of Sciences
Ural Federal University
Yekaterinburg
Russia

ISSN 1566-0443 ISSN 2215-0285 (electronic)
Topics in Safety, Risk, Reliability and Quality
ISBN 978-3-319-25305-3 ISBN 978-3-319-25307-7 (eBook)
DOI 10.1007/978-3-319-25307-7

Library of Congress Control Number: 2015957225

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer International Publishing AG Switzerland

To my wife, Shirley Timashev, and our grandchildren Nikita, Sophia, Stanislav, Vladislav, Brittany, Jessica, Christina, Caroline, and little rascal Daniel;

—Sviatoslav Timashev

To my parents, Nadezhda Melgunova and Victor Bushinskiy.

—Anna Bushinskaya

Preface

The motivation for writing book was to provide a comprehensive analysis of all aspects of integrity and safety of pipeline systems to the extent required for practical application. The book sums up ideas expressed in numerous articles penned individually and as a team by both authors, and although most of them went through double-review filters and were published in the proceedings of major international conferences and journals, they remain difficult to access. A distinctive feature of this book is its interdisciplinary approach to the solution of individual cases and of the whole imperative problem. The proposed solutions of fundamental problems have been designed, in addition to following the logic of a particular research discipline development, with specific requirements of the pipeline industry in mind. Another very important characteristic of this book is that the interdisciplinary problem discussed here has been studied as a sequence of interdependent problems from various fields of knowledge and engineering disciplines, and resolved using a task chain approach, when the solution output of the first problem is an input for the next problem, etc., until the output of the last problem produces the ultimate solution for the whole problem.

The book brings to light some of the most relevant and not yet resolved safety and integrity problems of pipeline systems, which are vital systems not only for the petroleum industry and the fuel and power sector in general, but also for any other modern industry sector.

A specific feature of all solutions in the area of new diagnostic tools for in-line inspection (ILI) development is their highly confidential nature, particularly for data analysis algorithms. Every firm carefully protects its processes, rarely disclosing what particular parameters of their technology are used as the essential variables, which is a requirement under the umbrella API 1163 (ILI Qualification Standard), and what the values are of these parameters. Published papers do not disclose the solution approach used, describing bare bone results, which cannot be verified or replicated, since there is no full description of the algorithms used in the analysis. Apart from competition and commercial secret protection, there are multiple other reasons for this situation. Without dwelling on them, we should point out that the international API 1163 standard recommends establishing strategic partnerships between the pipeline companies and the diagnostic service providers (DSP), which, if need be, could act in concert on many issues of mutual interest.

From our long-standing experience of delivering lectures on the topic of this book to pipeline industry professionals from more than 30 countries worldwide, we are more than well aware of the certain skepticism with regard to (and even in some cases, total rejection of) the applicability of probabilistic methods when solving practical problems of pipeline systems safety and integrity management. This is due to many factors, which include existing knowledge gaps in the specialists' training and the need to change the decision makers' mentality. On the other hand, there is also insufficiently transparent presentation by researchers and scientists of the real and clear advantages offered by application of a probabilistic approach. The authors express their hope that this book will be helpful in closing this gap at least partially.

Pipeline systems (PS) are an almost ideal generalized type of a critical infrastructure computational model. In this connection, we believe that the methodological approaches outlined in the book to problem solving in the areas of diagnostics, monitoring, integrity, residual strength assessment, failure probability (reliability), maintenance, and safety of pipeline systems are of a general nature, and could be utilized for assessing other types of infrastructures.

This book, with decades of research behind it, is nevertheless, the result of a sequence of serendipity and lucky events. It started with Keith Leewis, Ph.D., (Canada/USA, Pipeline Research Council International-PRCI), who invited the first author to be a member of the API Work Group 1163, which wrote over several years, the API 1163 Standard, published in 2004, and is now the foremost desktop manual of every pipeline operator and ILI services vendor. When working in the WG 1163, the author was involved in discussions with other members of the group, comprised of top American and Canadian professionals from the pipeline transportation industry, research institutions, regulatory bodies, and academia and he learned immensely from them about the current pipeline problems (as they were seen in the West), and how they should be solved. By that time this author had a 15+ year experience of solving the same practical problems for the Soviet/Russian oil and gas pipeline industry, which has assets predominantly in West Siberia's Far North. This provided a unique opportunity to see the problem simultaneously from both sides; i.e., from a broadest possible viewpoint and to develop some innovative solutions. Members of the WG 1163 from whom the first author got the most valuable feedback include Tom Bubenik (USA), Guy Desjardins (Canada), and Bernie Selig (USA).

The second major event was when B.J. Lowe of *Clarion* (Houston, Texas) and John N. Tiratsoo of *Tiratsoo Technical* (UK, Australia) invited the first author to create for pipeline professionals intensive short courses on *Reliability based management of pipeline integrity and safety*, and *Analysis of ILI data for creating optimal integrity management plans*. By preparing and delivering these courses in the Americas and Eurasia, and receiving feedback from audiences from over 30 countries, we attained further insight into the complex socio-technological problem of pipelines operation.

Several years later, Prof. Andrew Palmer (UK, Singapore), one of the world's leading scientists in pipeline design, construction, and operation, invited the first author to participate in the research team of the Intergovernmental Panel on Climate Change (IPCC), WMO UN, to work on the problem of CO_2 capture and sequestration by means of extracting it from the atmosphere and then transporting the liquefied or compressed gas by tankers or pipelines, respectively, for depositing it on the ocean bottom, or deep in the Earth's mantle rock formations. Our work for IPCC unexpectedly won the collective Nobel Peace prize of the year 2007 (the second half of the prize went to Vice-President Al Gore).

The fourth and crowning event happened, when Prof. Adrian Gheorghe of the *Old Dominion University*, Virginia, USA, acclaimed specialist in the field of critical infrastructure theory (he coined it as *infranomics*), became acquainted with the results of many years of fundamental and applied research, obtained by the *Science & Engineering Center* "*Reliability and Safety of Large Systems and Machines*" Ural branch Russian Academy of Sciences on the problem of diagnostics and reliability of pipeline systems as critical infrastructures, initiated writing this monograph, which sums up the above efforts. In this regard we would like to express our sincere gratitude and acknowledgment to Prof. A. Gheorghe, who made this possible.

Although there are only two authors of the book, we thank all of our colleagues with whom numerous papers were published in peer reviewed journals and presented at most prestigious conferences in Calgary, Osaka, Rio de Janeiro, Amsterdam, Moscow, Bahrain, New York, Houston, Yekaterinburg, Krasnoyarsk, Liverpool, to name a few. Their names are cited in the list of references of this book, but it is our privilege to mention them here: Candidates of Sciences Margarita G. Malyukova (who also helped writing Chap. 7), Ludmila V. Poluyan (who lent a hand in writing Sects. 1.4, 5.3 and 8.3) Doctors of Science Alexander B. Kuzmin, Alexander N. Tyrsin and Alexander Chernyavski; Ph.D. students Zhanna V. Yurchuk, Vitaly V. Kuznetsov, Tatyana A. Makarova, Irina S. Solovyeva, Maria A. Gretskikh. In the fast changing work environment time is a very important, even crucial, asset. We are extremely grateful to Tatyana V. Govorukhina, Tatyana G. Kovalchuk, Irina G. Nikulina, and Sergey N. Shubin, who spent precious time in helping to compile the manuscript.

The authors are happy to extend their sincere and deep gratitude to Tom Morrison (Canada), Tomas Beuker (FRG, Switzerland), Francisco Caleyo (Ph.D., Mexico), Alphonso Lester, Ph.D. (both of Mexico), who graciously shared with us their vision on the ILI data analysis and interpretation, and to all professionals who provided data on defects measurements in real-life pipelines, located in three continents—Europe, Middle East, Asia, and North America—which made it possible to perform verification of the theoretical results obtained by the authors, in real-life environments. In this connection we are sincerely grateful to the late Rem I. Vyakhirev, Dr. of Sci., (CEO, JSC Gasprom, Russia), and A.D. Sedykh, Cand. Science (Chief of R&D Department, JSC Gasprom), who supported our research efforts related to reliability of gas compressor stations piping and equipment, and to the late V.N. Chepursky, Cand. Science (JSC Sibnefteprovod, Tyumen, Russia) for engaging the authors in the practical work of assessing reliability and remaining life of oil pipelines, which operate in the permafrost of Western Siberia; Yu.V. Lisin, Dr. of Sci., (Vice-President of *JSC "AK Transneft"*, Russia), for inspiring a number of research tasks; E.S. Vasin, Dr. Sci. (*JSC TDC "Diascan"*, *JSC "AK Transneft"*), Candidates of Science, G.A. Zhukova, (ZAO Moscow *NPO "Spectr"*); V.E. Loskutov, B.E. Patramansky, S.E. Popov (all from *ZAO NPO "Spetsneftegas"*, Yekaterinburg), V.I. Stolypin (*JSC "Gazprom Dobycha Orenburg"*), as well as to ILI technology specialists Phillip Hoyt, Ph.D., USA; Martin Phillips, Ph.D., USA; Kamal Ben Amara, Ph.D. (Qatar), Mark Susich (BP, Alaska). The results obtained on the basis of statistical data made available by them have been used for successful solution of a number of applied problems in the interests of *JSC Gasprom*, *TDC "Diascan," ZAO NPO "Spetsneftegas," JSC "Gazprom Dobycha Orenburg,"* as well as for a number of other companies. Parts of these results have been used in this book.

The book will be useful to experts and professionals in the area of diagnostics, monitoring, maintenance, reliability, and safety of critical infrastructures, and, primarily, to decision makers—persons responsible for various types of pipeline operations. It will also be useful to diagnostic service vendors, ILI tool developers, and designers, specialists in the area of operational and environmental safety, as well as researchers, Ph.D. candidates, and graduate students majoring in respective fields. Some parts of the book are currently used as a manual by the postgraduates of the Civil Engineering Institute of the Ural Federal University.

The exciting task of writing this book was divided in the following way: Preface, Introduction, Chap. 1, Sects. 3.3, 3.4.1, 3.4.2, 3.8, 3.9 of Chap. 3, Chap. 4, Chap. 7, and Conclusions were written by the first author; the rest of the book is a result of joint effort. I feel it necessary to say that it was a pleasure to work with my co-author, Dr. Anna V. Bushinskaya, my former Ph.D. student, whom I consider highly talented and unbelievably dedicated to science. I wait with awed anticipation to see what mark she will leave in the branch of science in which she is working.

We are indebted to the Springer team Nathalie Jacobs, Cynthia Feenstra, Albert Paap, and our toughest editors, an enthusiastic, professional, and supportive team, especially, Edwin Beschler, Sharmila Rajesh, who made all efforts to make the book up to the highest standards, concise, and easily readable. We also want to thank all those specialists whose names we do not know, but nevertheless appreciate their efforts very much.

For readers' convenience a list of abbreviations is provided in duplicate. One of the copies may be removed from the book for easy reference during reading.

Despite all our efforts to the contrary, the book may still contain some errors. The authors would be sincerely grateful to attentive readers who may point them out to us.

Chautauqua Sviatoslav Timashev
August 2015

Contents

About the Authors

Sviatoslav Timashev is the founder of the well-known Ural school of scientific thought “Safety of critical infrastructures and territories,” Doctor of technical sciences, Distinguished scientist of Russia, Merited Educator of the Russian Federation, Principal Scientist and Scientific Director, Science and Engineering Center “Reliability and Safety of Large Systems and Machines” Ural Branch, Russian Academy of Sciences; Professor and Director of the Research Lab and Master’s Program “Safety of Critical Infrastructures and Territories,” Ural Federal University (UrFU). Both institutions are in Yekaterinburg.

S. Timashev authored and co-authored 28 books and over 420 papers, and holds 16 patents in the field of diagnostics and monitoring systems.

He is licensed by the Russian Federal Agency for Ecological, Industrial and Nuclear Safety as the highest category expert in safety of oil and gas infrastructures. He is a specialist in stochastic stability and dynamics, diagnostics, monitoring, residual lifetime, maintenance, reliability, and safety of critical infrastructures, including pipeline systems.

S. Timashev is a member of the Russian Federation academy on quality problems, Washington Academy of Sciences Fellow; Fulbright Academy of Science and Technology member, as well as member of ASME, SRA, SARMA, MAA, and ACS. S.A. Timashev is charter member of the International Association on Structural Safety and Reliability (IASSAR) and the PIPE institute for professional pipeline engineers (UK). He is also member of the Work Group of the API 1163 Standard on in-line inspection quality. Professor S. Timashev is editorial board member of several international journals, including “Machinery Science Problems and Reliability of Machines,” “Emergency Situations and Safety Problems” (both Russia), “Structural Safety” (USA), “Pipeline Engineering” (UK), “Condition Monitoring And Diagnostic Engineering Management—COMADEM” (UK), “Journal of Risk Analysis and Crisis Reduction” (China). He also provides international consulting services and delivers intensive short courses on "Risk Based Management of Pipeline Integrity and Safety" and on "In-Line Inspection Data Analysis for Optimizing Integrity Management Plans" for pipeline specialists and engineers of 26 countries (up to date) of Australia, Asia, Africa, Europe, North and South America.

He is also an Institutional Co-recipient (as a member of the IPCC WMO UN international team of researchers) of the Nobel Peace Prize, 2007, for developing methods and means of CO_2 sequestration from the Earth's atmosphere and depositing it in deep rock formations and on the seabed (including the use of pipeline technology).

Anna Bushinskaya Candidate of Science, Leading research fellow of the Science and Engineering Center "Reliability and Safety of Large Systems and Machines" Ural Branch, Russian Academy of Sciences, and Associate Professor of the Ural Federal University (UrFU). Both institutions are in Yekaterinburg. She specializes in the field of statistical analysis of ILI data, integrity, reliability, residual lifetime, and predictive maintenance of pipeline systems. She is the author and co-author of one book (to date) and over 50 peer reviewed papers.

Nomenclature

AIC	Additional inspection control
AM	Adapted method
ANOVA	Analysis of variances
APR	Accident probability reduction
ASEP	Accidence sequence evaluation program
ASME	American society of mechanical engineers
BN	Bayesian network
BP	Burst (failure) pressure
BR	Building regulations
BS	building standard
CA	Corrosion allowance
CAP	Current accident probability
CCO	Critical crack opening
CCS	Corrosion control strategies
CD	Crack detection
CDF	Cumulative distribution function
CGR	Crack growth rate
CI	Critical infrastructure
CL	Confidence level
CLT	Central limit theorem
CM	Corrosion monitoring
CR	Corrosion rate
CS	Corrosion samples
DC	Decision criterion
DEM	Differential equations method
DEMC	Differential equation and Monte Carlo (method)
DM	Decision maker
DP	Design pressure
DSP	Diagnostic service providers
DV	Deterministic value
E/FTA	Event/fault tree analysis

ECP	Electrochemical protection
EMAT	Electromagnetic acoustic transducer
ER	Electrical resistance
ERP	Electric resistivity probes
EST	Engineering schools of thought
ET	Event tree
EVs	Essential variables
FD	False detection
FGE	Full group of events
FI	False identification
FND	False non-detection
FSA	Full statistical analysis
FTD	Fault tree diagram
G-C	Gram-Charlier's series
G-C-E	Gram-Charlier-Edgeworth (series or method)
GCS	Gas compressor stations
GLSM	Generalized least squares method
HE	Human errors
HF	Human factor
HIC	Hydrogen induced cracking
HPF	Hazardous production facility
IC	Implementation costs
IDP	Inherent detection probability
ILI	Inline inspection
IMPs	Integrity management plans
IPOD	Inherent probability of detection
IPS	Integral score parameter
ISM	Important sampling method
LPR	Linear polarization resistance
LSF	Limit state function
LSM	Least square method
MC	Monte Carlo (method)
MEs	Measurement errors
MFL	Magnetic flux leakage
MIs	Measurement instruments
MLE	Maximum-likelihood estimation
MMSES	Man–machine–structures–environment system
MPs	Main pipelines
MS	Measurement system
MSOP	Maximum safe operating pressure
NDE	Non-destructive quantitative evaluation
NDT	Non-destructive control technique
NNLS	Nonnegative least squares (method)
OP	Operating pressure
OPS	Oil pumping stations

OSD	Operating-stress design
PBMP	Pure birth Markov process
PDMP	Pure death Markov process
PIG	Pipeline inspection gage
PILIT	Perfect ILI tool
POD	Probability of detection
POF	Probability of failure
PPTS	Pipeline performance tracking system
PS	Pipeline system
QHRA	Quantitative human reliability analysis
R&R	Repeatability and reproducibility (measurement system)
RBI	Risk-based inspection
RDs	Regulatory documents
RF	Random function
RL	Regression line
ROC	Receiver operating characteristic
RVs	Random variables
S/F	Success/failure
SA	Sensitivity analysis
SC	Stress corrosion
SCC	Stress corrosion cracking
SDE	System of differential equations
SDs	Standard deviations
SF	Safety factor
SIF	Stress intensity factor
SIs	Strategic infrastructures
SLS	Surface of limit states
SMOP	Safe maximum operating pressure
SSS	Stress–strain state
THERP	Technique of human error rate prediction
TI	True identification
TMFL	Transverse magnetic flux leakage
TPD	Third-party damage
TS	Tensile strength
UPAP	Ultimate permissible (desirable) accident probability
UT	Ultrasound type/technique
VA	Variance analysis
VF	Variation factor
VI	Verification instrument
VIC	Visual inspection control
WC	Weight contribution
WLC	Weight loss coupons
WM	Wall thickness measurement
YS	Yield strength