The Rules for Hydraulic Transient Design Analysis

- Guide for Designers and Manufacturers
- Recommendations for Investors and Managers

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9. Oil Pipelines, 10. Liquid Gas Pipelines, 11. Fluid Transportation,
12. Long Distance Conduits, 13. Irrigation Systems, 14. Water Cooling Systems,
15. Draining Systems, 16. Coal Transportation 17. Control hydraulic systems,
18. Oil systems, 19. Liquid Gas Systems

What the Experts Said

More "What the Experts Said" see APPENDIX 2

Peter Dörfler[1]
Hydro Adviser LLC, Zürich

I went through the draft and there are many interesting cases I didn't know. Readers will learn a lot. I only have some doubts about the effect for decision making – it is not an easy task to avoid all kinds of mistakes.

Dr Peter Dörfler
Consulting engineer
Hydro adviser LLC, Zürich[2]

Timothy J. Welch
Hydropower Program Manager, U.S. Department of Energy

Hydropower has provided 10% of U.S. electricity generation and 85% of cumulative U.S. renewable power generation over the past 65 years. The Energy Department supports the position that the nation's water resources can be harnessed responsibly to contribute environmentally sustainable, reliable, and cost-competitive renewable electricity to the national grid**. It also supports ongoing research and work like yours to realize the full potential benefits of hydropower.**

Timothy J. Welch

Prof. Dr. Yongguang Cheng
State Key Laboratory of Water Resources and Hydropower

Prof Cheng read the manuscript and filled the review questionnaire. He suggested that the book can be published by Springer after some improvements in expressions.

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People's Republic of China

[1] Author of the book (Dörfler et al, 2013)

[2] Hydro adviser LLC is a specialized company in Zurich (CH); owned by Dr. Peter Doerfler. (LLC - Limited liability company)

The Rules to Hydraulic Transient Design Analysis

- Guide for Designers and Managers
- Recommendations for Investors and Managers

The most important crucial advice

MAKE IT SAFE

Fluid Dynamics Is Same Everywhere

Hydroelectric Systems
Hydroelectric Plants
Pump-Turbine Storage Plants
Pump Storage Plants
All Hydraulic Systems
Nuclear Plants
Air Vessels
Water Distribution Systems
Oil Pipelines
Auxiliary Hydraulic Systems
Fluid Transportations
Liquid Gas Systems

This book has two chapters:

Chapter 1 rules for investors, managers and executives decision makers

This Chapter is published for the first time.

Chapter 2 helpful guide to experts involved in designs of new hydraulic plants, or upgrading and modernisation of old plants and systems in operation.

ASME Hydro Power Technical Committee has reviewed in 2009 Pejovic's Chapter 12 Hydraulic Transients and Hydraulic Vibrations for the new edition of The Guide to Hydropower Mechanical Design, ASME Hydro Power Technical Committee, HCI Publications, 1996[3]. Here this Chapter is further updated.

Stanislav Pejovic, P.E., PhD, is an independent consultant in Missisauga, Ontario, Canada. He is a recognized, widely published expert in the analysis and of hydrro turbines and associated systems, specializing in hydraulic transient and vibration analysis and in model- and field-testing hydraulic machinery. A contributor to The Guide to Hydropower Mechanical Design, Dr. Pejovic initated Chapter 12 "Hydraulic Transients" and prepared the chapter's first draft.

Understanding the Effects of Draft Tube Vortex Core Resonance

Hydro Review Worldwide September 2000

[3] This new edition is not yet published

Smarter Investment and Design – Less Trouble

All experts face the dilemma about where to draw the line between the effort of achieving a better design and when to implement a project. Although premature implementation often leads to expensive maintenance and operational problems, seeking perfection leads to costly and delayed projects. The challenge of making such decisions in complex energy systems is further complicated by extensive overlap of technologies, by broad design experience and knowledge requirements, and by the ever-present social and economic dimensions. The question of how to achieve the best balance between design and operation is specifically considered for several well-known hydroelectric plants, (Grand Coulee, Niagara Falls, Richard B Russell, Iron Gates 2, Jenpeg, Bajina Basta, Zvornik, The USA, Canada, Serbia, Bosnia and Herzegovina) along with reflections on how this knowledge can best be transferred to less experienced designers. Any hydroelectric installation, as a rule, should be designed using several stages. At each stage, the entire project documentation should be reviewed by independent reviewers selected and nominated by official authorities. The organized multidisciplinary transfer of experience is a priority task to be undertaken by the universities and electricity sector in Ontario, Canada and worldwide. There is a clear need to plan, finance and implement various long-term initiatives; it is urgent that decisions to address this be made now.

Slightly adjusted text from the article:

Knowledge Transfer with Intention to Improve
Design While Reducing Operational Expenses

Maricic Tihomir, Karney W. Bryan, Pejovic Stanislav

This work was supported in part by Ontario Power Generation
and University of Toronto. Manuscript received March, 23th, 2009.

Our Experience in Hydraulic Transients and Vibrations

A trend towards larger and more powerful units and complex networks has been a characteristic for the recent designs of hydraulic systems. This fact, together with high construction, equipment and labour costs, stresses the need for a more rational design of new plants. The components of systems should be strained as close to the allowable limits as possible, without endangering the safety of the structures. This goal can be achieved only with a reliable knowledge of possible loads in the whole system. The most dangerous stresses are those provoked by pressure surges and vibrations, especially if the resonance appears which the worst case is. Maximum pressures during transient operations, such as rapid closing down, opening-up, equipment breakdowns, earthquakes, etc., may destroy pipelines, valves or some other parts and cause considerable damage and sometimes even loss of human lives. The sound design of a new plant is impossible without a complete analysis of these transients. This knowledge also helps in preventing resonance in the existing systems, thus avoiding serious risks and damage to the plants. In such a way, the reliability of the project may be increased, and the operating and maintenance costs significantly reduced.

The analysis of transients is rather a complex and time consuming task, each case introducing some original problems. Our experience, gathered on several plants, where safety of the plant was in danger of destruction or could have been endangered by hydraulic oscillations and waterhammer surges, are described.

CASE STUDIES – OUR EXPERIENCE IN HYDRAULIC TRANSIENTS AND VIBRATIONS

Bryan Karney, Aleksandar Gajic, Stanislav Pejovic

International Conference on Case Studies in Hydraulic Systems - CSHS'03,

Proceedings of the International Conference on CSHS03, Belgrade, 2003

Current Affair:
Perspectives on Electricity Policy for Ontario

Technologies are interlinked and must be continually transferred and elaborated in order to work; innovations are disparate if they are blocked by continuous gaps in our mutual conveyance of knowledge.

This is a critical time for concerted action to renew the mechanisms of policy debate and formulation on energy policy for Ontario.

Last Chapter last Paragraph last sentence in the book:

Current Affair:

Perspectives on Electricity Policy for Ontario,

Editors:

Reeve D., Dewees D.N., Karney B.W.,

University of Toronto Press, 2010.

Authors

Stanislav Pejovic, Prof., PhD, ICC Expert, P. Eng. International Chamber of Commerce (ICC) expert in ICC Arbitration. He was Professor, Head of Hydraulic Energy Dept., and Chair and Member of the Board of the Institute of Mechanical Engineering at the University of Belgrade. He has been a Part time Professor at the University of Toronto and Ryerson University, Toronto since 2002. At the University of Toronto he taught a new course for the first time in North America: "Design of Hydro and Wind Electric Plants" (2008 and 2009). He designed the highest head pump storage plant Bajina Basta in Serbia. At that time the highest head plat in the World.

Prof. Pejovic was elected with the greatest number of votes, as an applicant for membership of the Serbian Academy of Sciences and Arts by secret vote organized among Professors of Mechanical Engineering at the University of Belgrade.

He is an Award winner for 2006 "Honoris Causa" of National Ethnic Press and Media Council of Canada. Dr. Pejovic is a licensed Professional Engineer in the Province of Ontario.

Dr. Pejovic is a professor in hydraulic energy and hydraulic machinery, lecturing on specialized subjects related to energy, design of power plants, thermodynamics, physics, fluid mechanics, and hydraulic transient analysis (water hammer, vibrations, hydraulic vibrations, stability, resonance in technical systems and human blood vessels). He is a member of the IAHR (International Association for Hydraulic Research) Committee on Hydraulic Machinery and Systems (old name Section Committee on Hydraulic Machinery and Cavitation), a member of ASME (American Society of Mechanical Engineers) Hydro Power Technical Committee and a member of The International Editorial Committee for Book Series on Hydraulic Machinery.

Prof. Pejovic has acted as a consultant on design, construction, site and model tests of a great number of pump, pump storage and hydro power plants and undertaken computer simulation of the transient and hydraulic vibration of several systems. Some of these include Monitoring of Radioactivity in Effluent and Environment (Ontario, Canada), Bajina Basta Pumped Storage Power Plant (Serbia), Lisina Storage Pumps, Big Hanaford Combined Cycle Plant, Water Cooling System (USA), Cooling Water System of Thermal Power Plant, Obrenovac (Serbia), Cooling System, PPN (Pillaiperumalnallur) Combined Cycle Power Plant (India), and Water Distribution System of Belgrade. Prof. Pejovic is the author of books on hydraulic transients and vibrations: "Guidelines to Hydraulic Transient Analysis" with Dr. A.P. Boldy, and Dr. Obradovic, "Guidelines to Hydraulic Transient Analysis of Pumping Systems" and "Hydraulic Transients of ASME Guide for Mechanical Design of Hydroelectric Plants".

Supported by Alexander von Humboldt Foundation, Prof. Pejovic spent two years in Germany at the University of Braunschweig, and the University of Hannover.

Aleksandar Đ. Gajić, Prof. Dr. is full member of the Academy of Engineering Sciences of Serbia, Professor at the University of Belgrade, visiting researcher or evaluator professor at Institute of Fluid Science, Tohoku University, Sendai, Japan and University Politechnica Timisoara, Romania as well as University Chalmers, Goetheborg, Sweden. He was a member of the Executive Committee International Association for Hydraulic Research, Section for Hydraulic Machinery and Cavitation between 1996 and 2008.

He was the State Secretary in Ministry for Education, Science and Technological Development and Special Advisor to the Minister of Mining and Energy. He is member of Supervisory Board of Electric Power Industry of Serbia (EPS). He was also President of Governing Board of "Belgrade Waterworks", and Thermo Power Plants "N. Tesla".

At the University of Belgrade Prof. Gajic was Head of the Department for Hydraulic Machinery and Energy Systems; the President of the Council and taught 7 under graduate courses and 6 post-graduate courses. He is member of the Council of Faculty for Architecture, and worked part time at several Universities in Serbia, Montenegro, and Macedonia.

Prof. Gajić has been involved in several research and engineering organizations; he has been a member of the Institution of Diagnostic Engineers - sect. Experts-International Directory, president of Yugoslav (Serbian) Institution for Standardization - Commission for Hydraulic Machinery, committee member of Yugoslav (Serbian) Association for Hydraulic Research. He has also been a member of IEC-TC4, International Electrical Commission, Technical Committee - Hydraulic Turbines, Vice-chairman of the 15-th IAHR Symposium, Belgrade, 1990, and Chairman of the Int. conf. "Case Studies in Hydraulic Systems", held in Belgrade, 2003 and IAHR WG Meeting Cavitation and Dynamic Problems in Hydraulic Machinery and Systems, Belgrade, 2011. and Chairman of International Conference Energy and Ecology Industry, Belgrade, 2018.

He was a member of the Editorial Board of the international journal "FME Transactions".

The research interest of prof. Gajić has been in the domain of flow in hydraulic machinery and systems, hydraulic transient regimes, rationalization and optimal exploitation of the multifunctional water supply and hydropower systems; development of methods for reliability and availability of hydro power plants. He has developed numerical programs, and experimental methods for field tests, resulting with increasing of power output from 6 x 174 MW to 6 x 210 MW in HPP "Iron Gate I", Serbia and from 245 MW to 305 MW in HPP "Perucica", Montenegro. He participated in designing of equipment for hydro- and thermo power plants in former Yugoslavia, Iraq, Iran, Jordan, and Cyprus PSPP Bajina Basta, HPP Pirot, HPP Bocac, HPP Podsused, HPP Sv. Petka, HPP Bekhme, HPP Hadfitha. He has designed and tested pumps for chemical and petrochemical industry.

Prof. Gajić is author of more than 10 university books, 24 textbooks, over 160 papers (in Serbian, English and Russian), published in journals, and over 200 research Reports. He has chaired 21 national or regional research projects, financed by Serbian authorities. He has been team member in 30 research studies. He has about 100 citations.

Reviewers:

Springer International Publishing AG.

Springer reviewed this manuscript under the title

Hydraulic Transient Design Analysis: A Guide for Investors, Designers, Manufacturers and Managers in 2017 and accepted to be printed in the series SpringerBriefs in Applied Science and Technology.

American Society of Mechanical Engineers - ASME
Hydro Power Technical Committee – HPTC

HPTC has reviewed in 2009 the updated Pejovic's Chapter 12 Hydraulic Transients and Hydraulic Vibrations for the new edition of The Guide to Hydropower Mechanical Design. In this book it is further updated as a helpful guide to experts involved with designs of new hydraulic plants, or upgrade and modernisation of old plants and systems in operation. This book is not yet published.

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General Preface

SMALL HYDRAULIC SYSTEMS

EVERYTHING PRESENTED IN THIS BOOK RELATES TO ALL HYDRAULIC SYSTEMS. THE ENTIRE ANALYSIS OF THE TRANSIENTS AND HYDRAULIC VIBRATIONS IS VERY COMPLEX; THEREFORE IT IS NOT NORMALLY RECOMMENDED FOR SMALL SYSTEMS SINCE IT IS TOO EXPENSIVE. IT IS VERY IMPORTANT TO SELECT APPROPRIATE TRANSIENT PROCESSES AND TO ANALYSE ONLY THEM. THERE IS NO UNIVERSAL PROCEDURE WHICH APPLIES TO ALL THE VARIOUS SYSTEMS. THEREFORE, IT IS HIGHLY RECOMMENDED TO UTILIZE THE ASSISTANCE OF EXPERIENCED EXPERTS WHO ARE DEALING WITH HYDRAULIC TRANSIENTS, VIBRATIONS AND SYSTEM STABILITY, IN ORDER TO SOLVE EACH PROBLEM. IF THAT IS NOT DONE, THE PROBABILITY OF AN ACCIDENT OR INCIDENT OCCURRING WILL BE VERY HIGH.

ALL HYDRAULIC SYSTEMS

THE MAJORITY OF THESE RULES FOR HYDRAULIC TRANSIENTS CAN BE RELATED TO ALL (WATER, LIQUID GASS, OIL AND ANY OTHER FLUID SYSTEMS) HYDRAULIC SYSTEMS WHICH ARE ALSO SENSITIVE TO HYDRAULIC VIBRATION AND WAVE SHOCKS. THE ELASTICITY OF FLUID AND PIPING COULD HAVE A DOMINANT INFLUENCE IN STABILITY ANALYSIS.

APLIED HYDRAULIC TRANSIENTS, HYDRAULICS, FLUID MECHANICS

AS HYDRAULIC TRANSIENT AND VIBRATION ANALYSES ARE SIMPLIFIED APPLIED FLUID MECHANICS FOR PRACTICAL APPLICATIONS, COMPUTATIONAL FLUID DYNAMICS (CFD) AND OTHER SOLUTIONS ONLY ROUGHLY DESCRIBE THE FLOW. THEREFORE, ALL CALCULATIONS MUST BE CAREFULLY VERIFIED ON SITE.

Preface

In appreciating the great importance of hydraulic transients and vibrations The Electric Power Industry of Serbia (EPS), (former Yugoslavia) supported the studies (1) Guidelines to Hydraulic Transient Analysis and Measurements in Auxiliary Pump Systems of Hydro and Thermal Power Plants, and (2) Guidelines to Hydraulic Transients Calculations in Hydro Power Installations undertaken by Professor S. Pejovic. (3) The book "Guidelines to Hydraulic Transient Analysis", Pejovic S., Boldy A.P., Obradovic D., Technical Press, 1987 presents results of the second study. (4) The book "Guidelines to Hydraulic Transient Analysis of Pumping Systems", Pejovic S., Boldy A.P., P & B Press, 1992 presents additional results of all and to all studies.

The Author of this book, a contributor to the (5) Guide to Hydropower Mechanical Design, HCI Publications, 1997 prepared Chapter 12 Hydraulic Transients.

ASME Hydro Power Technical Committee has reviewed in 2009 the updated Pejovic's (6) Chapter 12 Hydraulic Transients and Hydraulic Vibrations for the new edition of The Guide to Hydropower Mechanical Design. This book is not yet published.

The (7) Chapter 2 in this book is further update of all above listed books as a helpful guide to experts involved with designs of new hydraulic plants, or upgrade and modernisation of old plants and systems in operation.

Taking part in the International Chamber of Commerce arbitration has been among others a source of new sensitive skill at the point of decision makers as well as technical design process and construction of hydro plants

Chapter 1 is new. Rules in it advise investors and decision makers how to ensure a safe design.

This book relating to hydraulic systems is also based on the authors' books, studies, articles, and experience gathered from analysing hydraulic transients for a great variety of systems and plants.

The objective of this book is to give parallel instructions for all types of hydraulic systems including small ones which may require a number of protecting devices for preventing high pressure fluctuation due to water hammer and vibrations. Beside the data obtained by experience from working on many systems for hydro units, many sources of data are given in the literature.

These rules are intended for experts, managers, decision makers, engineers and staff in design, construction, exploitation, investigation or maintenance of different systems and auxiliary hydraulic systems of hydro, thermal and nuclear power plants, as well as for investors and equipment manufacturers of these systems. The purpose is to point out the great importance of transients - hydraulic water hammer and hydraulic vibrations - and their influence on safety and economical construction of the hydro units and to help all participants in the exploitation and maintenance of such systems.

A well performed analysis of transient regimes might be very fruitful; it can ensure the safety of the plant, eliminate or attenuate operational problems, and prevent serious damage.   We do hope that this book will help others to achieve their ends.

All readers and users of this book are asked to address their suggestions and comments, as well as the list of mistakes, so the next edition would be more complete, up to date and of the highest quality.

Toronto/Belgrade   Authors

2018

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Symbols

a	celerity or velocity of propagation – wave speed
A	valve area
GD^2	polar moment of inertia, usually given as MD^2 (GD^2, WR^2)
g	acceleration of gravity
H_L	head loss
H_{st}	static head
h_s	suction head
I	polar moment of inertia
K	flow coefficient for the valve / surge tank
K_{in}	flow coefficient, flow into surge tank
K_{out}	flow coefficient, flow out of surge tank
L	permitted length of tailrace tunnel
M	torque (T)
M_{11}	unit torque (T_{11})
MD^2	polar moment of inertia, usually given as MD^2 (GD^2, WR^2)
n	speed of revolution
n_{11}	unit speed
P	power
Q	flow, discharge
Q_{11}	unit discharge
Q_{st}	flow into surge tank (> 0); or flow out of surge tank (< 0)
T	torque (M)
T_{11}	unit torque (M_{11})
T_f	minimum closure time from fully open position
T_{f0}	minimum opening time(s) from closed (y = 0) to full open (y = 1)
T_h	cushioning time(s)
T_q	servomotor dead time(s)
T_s	closing time of guide vanes
T_z	total closure time(s)
T_w	water starting time

T'_f	time when cushion starts, time from fully open position
Y	relative servomotor stroke
y	relative servomotor stroke
y_o	partial opening
y_h	transition position
v_0	flow velocity in the tailrace tunnel
V	velocity
V_o	initial flow velocity
v_{dt}	water speed at the runner outlet - the draft tube cone inlet
WR^2	polar moment of inertia, usually given as MD^2 (GD^2, WR^2)
ΔH	increase in head
ΔV	change in flow velocity
β	runner blade inclination
ζ	head loss coefficient
ω	angular speed

Abbreviations

ASME	American Society of Mechanical Engineers
CD	Computer Disk
CFD	Computational Fluid Dynamics
CSHS	Case Studies in Hydraulic Systems
GD^2	moment of inertia, usually given as MD^2 (GD^2, WR^2)
GHG	Green House Gas
HPP	Hydroelectric Power Plant
HPTC	Hydro Power Technical Committee
LLC	Limited Liability Company
l/s	liters per second
masl	meters above sea level
MD^2	polar moment of inertia, usually given as MD^2 (GD^2, WR^2)
MW	megawatt
mm/s:	millimeter per second
mWC	meters of water column
m^3/s	cubic meter per second
NIS	Naftna Industrija Srbije – Oil Industry of Serbia
PEO	Professional Engineers Ontario
PSHP	Pump Storage Hydroelectric Plant
r/min:	revolution per minute
rpm	revolution per minute
Q	Discharge in m^3/s
Tm^2	Ton square meter
UofT	University of Toronto
WR^2	polar moment of inertia, usually given as MD^2 (GD^2, WR^2)
Δh:	hydraulic loss or overpressure