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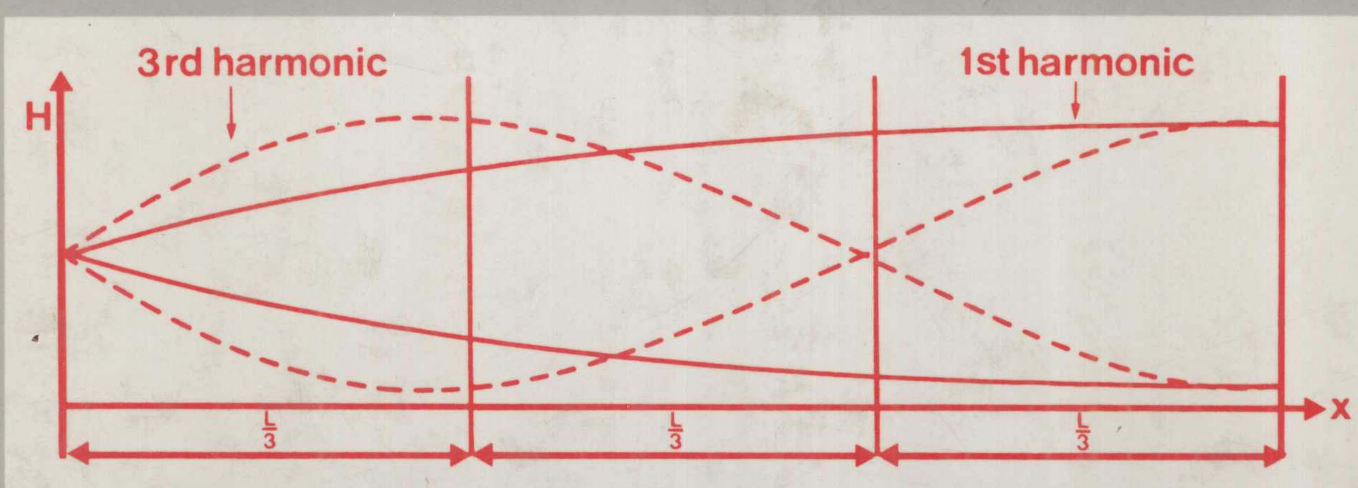

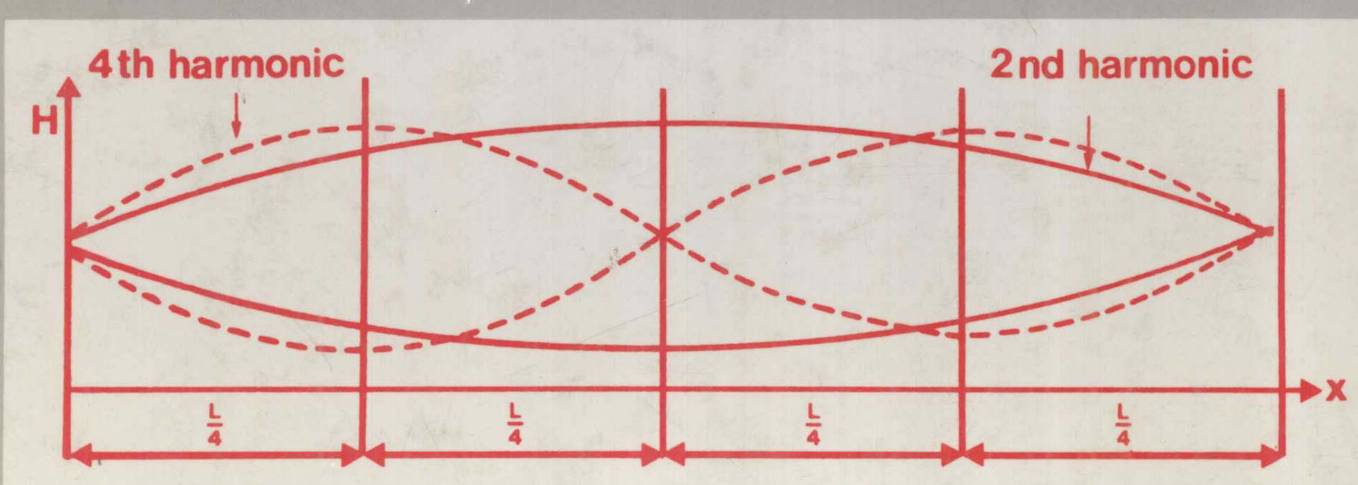

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Published by
Gower Technical Press Ltd.,
Gower House,
Croft Road,
Aldershot,
Hants. GU11 3HR,
England.

Gower Publishing Company,
Old Post Road,
Brookfield,
Vermont 05036,
U.S.A.

British Library Cataloguing in Publication Data

Pejović, S.
Guidelines to hydraulic transient analysis.
1. Hydraulic machinery 2. Water hammer
3. Water–power electric plants
I. Title II. Boldy, A.P. III. Obradović, D.
621.31'2134 TJ844

Library of Congress Cataloguing in Publication Data

Pejović, S.
Guidelines to hydraulic transient analysis.

Bibliography: p.
Includes index.
1. Hydraulic transient. 2. Hydroelectric power plants – Safety measures.
I. Boldy, A.P., II. Obradović, D. III. Title.
TC174.P36 1987 621.31'2134 86–31925

ISBN 0 291 39723 9

Printed and bound in Great Britain by Dotesios(Printers)Limited,
Bradford-on-Avon,Wiltshire

Preface

The aim of this book is to assist engineers who are responsible for the design, construction, commissioning and operation of hydroelectric power plants; it does not explain the philosophy of transient flow or present methods for the analysis of such phenomena. The book is intended as a handbook, assisting engineers to determine the main parameters for a proposed installation, to define the necessary data for, and scope of, the transient analysis, to select the most dangerous cases and to draw the correct conclusions.

The information presented in this book is important for large and small hydro power plants and pumping systems. Analysis of hydraulic transients and hydraulic vibrations is a very time consuming and expensive activity. It is therefore important in the case of small power plants that only the most critical transients are selected and analysed. Unfortunately, it is quite impossible to prescribe rules which will apply in every conceivable case, at least for the time being. Therefore the analysis of transients and vibrations for small power plants should be given to the experienced engineers.

The potential dangers for hydro plants due to transient phenomena are discussed in Chapter 1 together with the principles, and devices for pressure surge and hydraulic vibration protection. (Some accidents resulting from transient phenomena is included to show the significance and potential dangers for hydro plants).

The main elements of hydro power plants, for the transient flow analysis, are described in Chapter 2. Characterisitic steady state regimes are defined. Characteristic parameters of transient flow analysis are explained in Chapter 3.

Chapter 4 contains a brief description of turbine governors with important parameters listed. Various regulating devices are mentioned, and the opening–up closing–down modes are explained in detail, stressing the important parameters (maximum seed of servomotor piston, for instance).

Chapter 5 deals with input data necessary for the analysis of transient regimes in hydro power plants. The extent of investigations on a small–scale model is specified in some cases. Other data, needed for the analysis on the level of feasibility study and/or general design, are also listed there.

Various transient regimes are classified in Chapter 6. There are normal cases which the plant has to withstand without difficulties, then emergency cases, when no substantial damage should occur in the plant, and lastly catastrophic cases when some damage cannot be prevented.

Computational runs which should be performed in the analysis are listed in Chapter 7. Parameters of the analysis are discussed and the minimum output specified.

Measurements and investigations performed during the various phases are discussed in Chapter 8.

The recommended range of main parameters are discussed in Chapter 9. Some guidelines for protection against water–hammer are also given in Chapter 10.

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. The authors do hope that this book will help other engineers to achieve their ends.

The authors welcome comments, opinions, and suggestions from colleagues regarding the material presented in this book. All contributions will be carefully evaluated and where appropriate incorporated in the next edition. Please address any contributions to:

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Notation

A	m^2	flow area characteristic area of hydraulic machine ($\pi D^2/4$)
A_t	m^2	cross–sectional area of tunnel
A_{st}	m^2	cross–sectional area of surge tank
A_r	m^2	effective tunnel area
a	ms^{-1}	velocity of pressure wave (wavespeed)
a_o	m	wicket gates opening
b_p	–	permanent speed droop
c	ms^{-1}	flow velocity
c_o	ms^{-1}	initial flow velocity
D	m	characteristic diameter of hydraulic machine runner
F_a	N	axial hydraulic thrust
F_{11}	–	unit axial hydraulic thrust (Fa/D^2H)
f	Hz	frequency
f_{th}	Hz	theoretical natural frequency
g	ms^{-2}	gravitational acceleration
H	m	head
H_o	m	rated head
H_L	m	head loss
h	–	dimensionless head (H/Ho)
I	kgm^2	inertia of rotating parts ($MD^2/4$)

K	–	valve flow coefficient
K_{st}	$m^{-5}s^{2}$	surge tank throttle flow coefficient
L	m	length of a tunnel or penstock
L_e	m	equivalent length of a tunnel or penstock
M	Nm	torque
M_o	Nm	rated torque
M_{11}	–	unit torque (M/D^3H)
m	–	dimensionless torque (M/M_o)
MD^2	kgm^2	polar moment of inertia of rotating parts (4I)
n	min^{-1}	speed of rotation
n_o	min^{-1}	rated speed of rotation
n_{11}	–	unit speed ($nD/\sqrt{H}$)
P	W	power
P_g	W	generator power
P_h	W	hydraulic power
P_ℓ	W	power loss
P_m	W	motor input power
p	Pa	pressure
p_s	Pa	design pressure for piston
Q	m^3s^{-1}	volumatic flow rate (discharge)
Q_o	m^3s^{-1}	steady state volumetric flow rate
Q_{11}	–	unit discharge ($Q/D^2\sqrt{H}$)
T_a	s	unit starting time
T_f	s	servomotor closing time corresponding to maximum servomotor velocity
T_f^H	s	reduced servomotor closure time
T_f^ω	s	extended servomotor closure time
T_{fo}	s	minimum opening time of servomotor
T_h	s	time for decelerated closure of wicket gates
T_q	s	servomotor dead time
T_r	s	penstock reflection time
T_{st}	s	period of mass oscillation
T_{th}	s	theoretical period of first harmonic
T_{vf}	s	minimum time of valve closure

T_{vh}	s	valve cushioning time
T_{vq}	s	valve dead time
T_{vz}	s	total valve closure time
T_w	s	water starting time
T_z	s	total servomotor closure time
t	s	time
u	–	dimensionless displacement of spool valve
u	ms^{-1}	peripheral speed of the runner ($\omega D/2$)
V	m^3	volume
x	m	distance (measured along pipe axis)
x_i	–	relative change in speed ($(n - n_o)/n_o$)
x_{ir}	–	overspeed protection setting
x_{ist}	–	dimensionless manual speed setting
x_r	mm	displacement of spool valve
Y	mm	displacement of main servomotor of turbomachine
Y_o	mm	reference value of Y
Y_h	mm	reference position of the servomotor piston, from which the motion of the piston is decelerated
Y_m	mm	maximum displacement of the main servomotor piston
y	–	dimensionless displacement of main servomotor (Y/Y_o)
β	–	runner blade angle
ΔH	m	amplitude of pressure surge
Δ_h	–	relative amplitude of pressure surge ($\Delta H/H_o$)
Δh_{per}	–	value of Δh corresponding to 'perfect' closure mode of wicket gates
Δp	Pa	pressure difference acting on servomotor piston
Δt	s	time increment
Δt_e	s	equivalent delay time of a governor
Δx	m	distance increment
Δz	m	elevation increment
$\epsilon_{\Delta h}$	–	perfection coefficient
ζ	–	coefficient of head loss

ρ	kg m^{-3}	mass density
σ_F	–	axial force coefficient
τ	–	torque coefficient
τ	s	half period of pipe (2L/a)
φ	–	flow coefficient
ψ	–	energy coefficient
ω	–	angular velocity

Acknowledgements

This book is based on a study of transient phenomena undertaken by Professor S. Pejovic at the request of the Association of Power Industry, Belgrade, Yugoslavia and presented in an interim report[15] (in Serbo Croation) to the Association. The Association has given permission for the publication of some of these results in this book.

The editing of this book was supported by an Academic Travel Grant provided by The British Council and The Association for International Scientific, Educational, Cultural and Technological collaboration of Serbia.

The authors are indebted to Assistant Professor A. Gajic, Faculty of Mechanical Engineering University of Belgrade, for his careful reading of the text and many useful comments, to Mr. Nebojsa Vrhovac who prepared the drawing and Mrs. J. Carrington who typed the final manuscript.

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