

# Contents

<b>1 Basic Concepts</b>	1
1.1 Hill Charts, Operating Modes, and Parameters	1
1.2 Amplitudes and Spectra	7
1.3 Pulsation Phenomena in Pipes and Plants	12
1.4 Hydraulic Resonance	18
1.5 Hydraulic Instability	23
1.6 Mechanical Assessment of Components	27
References	30
<b>2 Low-Frequency Phenomena in Swirling Flow</b>	33
2.1 Swirling Flows in Pipes, Vortex Breakdown Phenomena	33
2.1.1 Basic Observations	33
2.1.2 Early Research	34
2.2 Draft Tube Vortex Phenomena	35
2.2.1 Partial-Load Vortex: Forced Oscillation (Half-Load Surge)	36
2.2.2 Random pulsation at Very Low Load	40
2.2.3 Partial-Load Vortex: Two Threads (Twin Vortex)	41
2.2.4 Low Partial-Load: Self-Excited Oscillation	41
2.2.5 Upper Partial-Load Vortex: The “80 % Pulsation”	43
2.2.6 Instability of the Helix Flow Pattern	44
2.2.7 Self-Excited Oscillation at High Load (Full-Load Surge)	45
2.2.8 Full-Load Vortex: Forced Oscillation	48
2.2.9 System Response	48
2.2.10 Mechanical Effects	48
2.2.11 Peculiarities of Francis and Other Turbine Types	50
2.2.12 Prediction and Assessment	52
2.2.13 Countermeasures	54

2.3	Runner Inter Blade Vortex . . . . .	56
2.3.1	Physical Mechanism . . . . .	56
2.3.2	Prediction, Features, Diagnosis . . . . .	56
2.3.3	Operation Range Affected . . . . .	57
2.3.4	Detrimental Effects . . . . .	57
2.3.5	Countermeasures . . . . .	59
2.4	Vortex Breakdown: Other Locations . . . . .	59
2.4.1	Penstock Manifold . . . . .	59
2.4.2	Kaplan Hub . . . . .	61
2.4.3	Draft Tube Fin Tip Vortex . . . . .	62
	References . . . . .	64
<b>3</b>	<b>Periodic Effects of Runner-Casing Interaction . . . . .</b>	<b>69</b>
3.1	General Properties of Unsteady Blade Row Interaction . . . . .	69
3.2	Oscillation at Runner Frequency . . . . .	71
3.2.1	Unbalance of Runner . . . . .	71
3.2.2	Asymmetry of Casing . . . . .	72
3.3	Blade Interaction in Reaction Machines . . . . .	75
3.3.1	Flow Phenomena Involved . . . . .	75
3.3.2	Mechanical Effects . . . . .	79
3.3.3	Influence of Design, Countermeasures . . . . .	81
3.3.4	Numerical Simulation. . . . .	83
3.4	Axial Machines . . . . .	84
3.4.1	Wake Effects from Wicket Gates . . . . .	84
3.4.2	Excitation of Axial Vibration . . . . .	85
3.4.3	Runner Blade Passage on Axial Machine Discharge Ring . . . . .	86
3.5	Bucket Passage in Pelton Turbines . . . . .	87
3.5.1	Physical Background . . . . .	87
3.5.2	Mechanical Effects . . . . .	90
3.5.3	Numerical Simulation of Jet Impact. . . . .	92
3.5.4	Influence of Design Parameters. . . . .	93
3.6	Pressure Wave Interference in the Spiral Casing . . . . .	98
3.6.1	Mechanical Effects . . . . .	105
3.6.2	Possibilities for Mitigation . . . . .	105
	References . . . . .	108
<b>4</b>	<b>High-Frequency Vortex Phenomena . . . . .</b>	<b>111</b>
4.1	Von Kármán Vortex Street . . . . .	111
4.1.1	Basic Flow Mechanism . . . . .	111
4.1.2	Turbine Components Affected by Vortex Streets. . . . .	113
4.1.3	Related Design Practice . . . . .	116
4.1.4	Numerical Flow Simulation . . . . .	118

4.2	Flow Turbulence . . . . .	120
4.2.1	Physical Background and Properties. . . . .	120
4.2.2	Operating Conditions and Turbulence Level . . . . .	121
4.2.3	Transient Operation . . . . .	123
4.2.4	Numerical Flow Simulation . . . . .	124
	References . . . . .	125
<b>5</b>	<b>Cavitation-Related Phenomena . . . . .</b>	<b>129</b>
5.1	Dynamics of Cavitation Bubbles and Clouds . . . . .	129
5.2	Flow Situations Prone to Cavitation. . . . .	131
5.3	Cavitation Damage . . . . .	132
5.4	Other Mechanical Effects . . . . .	135
5.4.1	Vibration and Noise. . . . .	135
5.4.2	Increased Compressibility of Flow. . . . .	135
5.4.3	Pressure Shocks. . . . .	136
5.4.4	Cavitation-Induced Instability . . . . .	138
5.5	Countermeasures . . . . .	138
5.6	Numerical Flow Simulation . . . . .	138
5.6.1	Cavitation Modeling . . . . .	139
	References . . . . .	141
<b>6</b>	<b>Stability-Related Unsteady Phenomena . . . . .</b>	<b>143</b>
6.1	Gap Flow Effects . . . . .	143
6.1.1	Basic Mechanism. . . . .	143
6.1.2	Destabilizing Labyrinth . . . . .	145
6.1.3	Crown/Band Chamber Effects . . . . .	145
6.2	Flutter of Guide Vanes. . . . .	148
6.3	Penstock Auto-Oscillation: The 'Leaking Seal' Effect . . . . .	149
6.3.1	Basic Mechanism. . . . .	149
6.3.2	Characteristic Features . . . . .	150
6.3.3	Countermeasures . . . . .	151
6.4	Pump and Pump-Turbine Instabilities. . . . .	151
6.4.1	Pump Instability due to Excessive Head. . . . .	151
6.4.2	Pump Turbine Instability due to S-Shaped Characteristics. . . . .	153
6.4.3	Numerical Simulation. . . . .	155
6.4.4	Rotating Stall in Pump Turbines, Turbine Brake Quadrant . . . . .	156
6.4.5	Pump Turbine Instability Influenced by Hysteresis . . . .	158
6.4.6	Precautions Recommended for Commissioning . . . . .	159
	References . . . . .	160

<b>7</b>	<b>Model Tests, Techniques, and Results</b>	163
7.1	Similarity Considerations	163
7.2	Francis Turbine Model Tests	166
7.2.1	Pressure Pulsation	166
7.2.2	Aeration Pressure	177
7.2.3	System Studies	181
7.3	Pump Turbine Model Tests	185
7.3.1	Pressure Pulsation	185
7.3.2	Guide Vane Torque	187
7.3.3	Runner Forces	190
7.4	Axial Turbine Model Tests	193
7.4.1	Bulb Turbine Tests	193
7.4.2	Vertical Kaplan Turbine Tests	194
7.4.3	Vertical Fixed-Blade Turbine Tests	197
	References	197
<b>8</b>	<b>Selected Field Experience</b>	199
8.1	Francis Turbine with Forced Oscillation at High Load	199
8.2	Francis Turbine with Self-Excited Oscillation at High Load	203
8.3	Pump-Turbine Pulsation and Instability at Speed-No Load	207
8.3.1	Penstock Vibration and High-Frequency Pulsation	207
8.3.2	Instability at Speed-No Load	209
8.3.3	Medium-Frequency Pulsation	211
8.4	Von Kármán vortex in Propeller Turbine Stay Vanes	213
8.4.1	Cracking of Stay Vanes	213
8.4.2	Analysis and Corrective Measures	214
8.4.3	Later Development	215
8.5	Vertical Kaplan Turbine with Disturbed Intake Flow	219
8.5.1	Noise at High Load	220
8.5.2	Root Cause Analysis	221
8.5.3	Possible Solution	223
	References	224
<b>9</b>	<b>Practical Guidelines</b>	225
9.1	Planning and Design	225
9.1.1	Influence of Plant Parameters	225
9.1.2	Selection of Unit Data	226
9.1.3	Pulsation and Vibration Guarantees	227
9.1.4	Resonance and Other Kinds of Trouble	228
9.1.5	Good Design Practice	230
9.2	Model Testing	230
9.2.1	Test Conditions	230
9.2.2	Scope of Testing	231
9.2.3	Interpretation	231

9.3	Field Testing . . . . .	232
9.3.1	Measurement of Pressure Pulsations. . . . .	232
9.3.2	Vibration measurements . . . . .	234
9.4	Troubleshooting. . . . .	235
	References . . . . .	236
<b>Index</b>	. . . . .	<b>239</b>

<http://www.springer.com/978-1-4471-4251-5>

Flow-Induced Pulsation and Vibration in Hydroelectric  
Machinery

Engineer's Guidebook for Planning, Design and  
Troubleshooting

Dörfler, P.; Sick, M.; Coutu, A.

2013, XXIV, 244 p., Hardcover

ISBN: 978-1-4471-4251-5