

American National Standard for  
**Rotodynamic Pumps**  
for Design and Application

Sponsor  
**Hydraulic Institute**  
[www.Pumps.org](http://www.Pumps.org)

Approved February 1, 2019  
**American National Standards Institute, Inc.**

This is a preview. Click here to purchase the full publication.

# American National Standard

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus and other criteria for approval have been met by the standards developer.

Consensus is established when, in the judgement of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation of any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretations should be addressed to the secretariat or sponsor whose name appears on the title page of this standard.

**CAUTION NOTICE:** This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken periodically to reaffirm, revise, or withdraw this standard. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute.

Published By

**Hydraulic Institute**  
**6 Campus Drive, First Floor North**  
**Parsippany, NJ 07054-4406**  
**[www.Pumps.org](http://www.Pumps.org)**

Copyright © 2019 Hydraulic Institute  
All rights reserved.

No part of this publication may be reproduced in any form,  
in an electronic retrieval system or otherwise, without prior  
written permission of the publisher.

Printed in the United States of America  
ISBN 978-1-935762-81-2



Recycled  
paper

This is a preview. Click here to purchase the full publication.

## Contents

	Page
Foreword . . . . .	xiii
14.3 Rotodynamic pump design and application. . . . .	1
14.3.1 Introduction . . . . .	1
14.3.1.1 Purpose . . . . .	1
14.3.1.2 Scope . . . . .	1
14.3.1.3 Preferred terms, units, and symbols for pump applications . . . . .	2
14.3.2 Rotodynamic pump classifications. . . . .	5
14.3.2.1 Pump types . . . . .	5
14.3.3 Performance. . . . .	20
14.3.3.1 Characteristic curves . . . . .	20
14.3.3.2 Pump and system curve interaction . . . . .	21
14.3.3.3 Typical curve shape . . . . .	22
14.3.3.4 Predicting pump performance after speed of rotation or impeller diameter change. . . . .	28
14.3.3.5 Variable-speed drives. . . . .	33
14.3.4 Applications . . . . .	34
14.3.4.1 Pump selection process . . . . .	34
14.3.4.2 Continuous, intermittent, and cyclic service . . . . .	37
14.3.4.3 System pressure limitation . . . . .	37
14.3.4.4 Operation away from the best efficiency point . . . . .	38
14.3.4.5 Liquid temperature rise in a rotodynamic pump . . . . .	40
14.3.4.6 Pump priming . . . . .	45
14.3.4.7 Viscosity . . . . .	46
14.3.4.8 Two-phase flow . . . . .	46
14.3.4.9 Solids . . . . .	51
14.3.4.10 NPSHA considerations for temperature and elevation . . . . .	51
14.3.4.11 Application considerations – viscous liquids . . . . .	56
14.3.4.12 Special axial flow pump application considerations – siphon system . . . . .	58
14.3.4.13 Intake . . . . .	58
14.3.4.14 Self-primer features . . . . .	61
14.3.4.15 Losses . . . . .	63
14.3.4.16 Start-up and shut-down . . . . .	65
14.3.4.17 Pump and motor speed torque curves . . . . .	67
14.3.4.18 Discharge valve position for start-up . . . . .	72

This is a preview. Click here to purchase the full publication.

14.3.4.19	Shut-down .....	73
14.3.4.20	Self-priming pumps, start-up and shut-down considerations (valve position) .....	74
14.3.4.21	Reverse runaway speed.....	74
14.3.4.22	Water hammer (hydraulic shock) .....	74
14.3.4.23	Vibration/dynamics.....	75
14.3.4.24	Sound.....	75
14.3.5	Hydraulic features .....	78
14.3.5.1	Specific speed .....	78
14.3.5.2	Impeller configurations .....	81
14.3.5.3	Casing design.....	84
14.3.5.4	Hydraulic loading .....	88
14.3.6	Mechanical features.....	119
14.3.6.1	Casing design.....	119
14.3.6.2	Column design (vertical pumps).....	119
14.3.6.3	Discharge head (structural element) .....	122
14.3.6.4	Rotor shaft design .....	126
14.3.6.5	Design of vertical lineshaft .....	136
Appendix A	Introduction to general applications.....	141
A.1	General service applications .....	141
Appendix B	Special effects pumps .....	151
B.1	Introduction .....	151
B.2	Regenerative turbine pumps .....	151
B.3	Pitot tube pumps .....	156
B.4	Vortex pumps.....	162
B.5	Screw centrifugal pump.....	164
B.6	High-speed pumps .....	167
B.7	Vertically suspended sump pumps .....	170
Appendix C	Materials .....	179
C.1	Materials of construction .....	179
Appendix D	Seals .....	186
D.1	Seals .....	186
D.2	Shaft seals.....	186
D.3	Bearing housing sealing .....	193
Appendix E	Bearings .....	197
E.1	Introduction .....	197
E.2	Bearings .....	197

This is a preview. Click here to purchase the full publication.

E.3	Bearing life . . . . .	203
E.4	Lubricant life . . . . .	206
E.5	Handling and installation damage . . . . .	206
E.6	Shipping damage . . . . .	207
E.7	Minimum loading requirements . . . . .	207
E.8	Cage fractures . . . . .	207
E.9	Electric arcing . . . . .	207
E.10	Sleeve bearing life . . . . .	207
Appendix F	Lubrications systems . . . . .	208
F.1	Lubricant types . . . . .	208
F.2	Quantity and quality of lubrication . . . . .	209
Appendix G	Couplings . . . . .	217
G.1	Types of couplings . . . . .	217
G.2	Speed limitations . . . . .	221
G.3	Equipment alignment . . . . .	221
Appendix H	Baseplates and foundations . . . . .	222
H.1	Introduction . . . . .	222
H.2	Seismic analysis . . . . .	222
H.3	Foundation and anchorage for horizontal pumps . . . . .	223
H.4	Baseplates – introduction . . . . .	224
H.5	Foundation and anchorage for vertical pumps . . . . .	239
H.6	Mounting plate (integral to discharge head) . . . . .	240
Appendix I	Drivers . . . . .	242
I.1	Introduction . . . . .	242
I.2	Electric motors . . . . .	242
I.3	Engines . . . . .	255
I.4	Steam turbine . . . . .	263
I.5	Gears . . . . .	263
I.6	Deceleration devices . . . . .	263
Appendix J	Monitoring and controls . . . . .	264
J.1	Introduction . . . . .	264
J.2	Monitoring frequency . . . . .	264
J.3	Control limits . . . . .	264
J.4	Appendix contents ANSI/HI 9.6.5 . . . . .	265
Appendix K	Index . . . . .	267

## Figures

14.3.2 — Overhung pump types and classifications .....	5
14.3.2.1.1a — OH0 pump .....	5
14.3.2.1.1b — OH1 pump .....	6
14.3.2.1.1c — OH1h pump .....	6
14.3.2.1.1d — OH2 pump .....	6
14.3.2.1.1e — OH3 pump .....	6
14.3.2.1.1f — OH4 pump.....	7
14.3.2.1.1g — OH5 pump .....	7
14.3.2.1.1h — OH5g pump .....	7
14.3.2.1.1i — OH6 pump.....	8
14.3.2.1.1j — OH7 pump.....	8
14.3.2.1.1k — OH7h pump .....	8
14.3.2.1.1l — OH8, OH8b pumps .....	9
14.3.2.1.1.1a — OH1i pump .....	9
14.3.2.1.1.1b — OH2i pump .....	10
14.3.2.1.1.1c — OH3i pump .....	10
14.3.2.1.1.1d — OH4i pump .....	10
14.3.2.1.1.1e — OH5i pump .....	11
14.3.2.1.1.1f — OH7i pump.....	11
14.3.2.1.1.1g — OH13i pump .....	12
14.3.2.1.1.2a — OH7j pump .....	12
14.3.2.1.1.2b — OH1j pump .....	12
14.3.2.1.1.2c — OH13j pump .....	12
14.3.2.1.2a — BB1 pump .....	13
14.3.2.1.2b — BB2 pump .....	13
14.3.2.1.2c — BB3 pump .....	13
14.3.2.1.2d — BB4 pump .....	14
14.3.2.1.2e — BB5 pump .....	14
14.3.2.1.3a — VS0 pump .....	14
14.3.2.1.3b — VS1 pump .....	15
14.3.2.1.3c — VS2 pump.....	15
14.3.2.1.3d — VS3 pump .....	15
14.3.2.1.3e — VS4 pump .....	16
14.3.2.1.3f — VS5 pump .....	16

14.3.2.1.3g — VS6 pump .....	16
14.3.2.1.3h — VS7 pump .....	17
14.3.2.1.3j — VS8 pump .....	17
14.3.2.1.1.1h — VS4i pump.....	17
14.3.2.1.1.1i — VS5i pump .....	18
14.3.2.1.4a — RT1 pump: overhung, close-coupled, side channel design .....	18
14.3.2.1.4b — RT2 pump: overhung, close-coupled, peripheral design .....	18
14.3.2.1.4c — RT3 pump: between-bearing, flexibly coupled, side channel design .....	19
14.3.2.1.4d — RT4 pump: between-bearing, flexibly coupled, peripheral design .....	19
14.3.2.1.5 — OHOD Pitot tube pump.....	19
14.3.2.1.6.1a — Closed coupled circulator CP1 .....	20
14.3.2.1.6.1b — Closed coupled circulator CP2 .....	20
14.3.2.1.6.2 — Flexibly coupled circulator pumps CP3.....	20
14.3.3.1.1 — $n_s$ examples .....	21
14.3.3.2 — Simple system and pump performance curves.....	21
14.3.3.2.1 — Operating point .....	22
14.3.3.3.1 — Typical system curve shape .....	22
14.3.3.3.2 — Head versus rate of flow of various specific speed pumps .....	23
14.3.3.3.2.4a — Test curve with dip.....	24
14.3.3.3.2.4b — Dip occurring at trimming of Impeller .....	24
14.3.3.3.2.4c — Dip occurring with increase in pitch angle.....	24
14.3.3.3.2.5 — Dip with hysteresis .....	25
14.3.3.3.3 — Power versus rate of flow of various specific speed pumps.....	25
14.3.3.3.4 — Efficiency vs Rate of Flow for various specific speed pumps.....	26
14.3.3.3.5a — NPSH3 vs Rate of Flow for various specific speed pumps .....	26
14.3.3.3.5b — Datum elevation for various pump designs at eye of first-stage impeller.....	27
14.3.3.4a — Impeller with straight outside diameter .....	29
14.3.3.4b — Impeller with angled outside diameter .....	29
14.3.3.4c — Diameter reduction of a radial diffuser pump .....	29
14.3.3.4 — Vane overlap, radial flow impeller .....	31
14.3.3.4.1 — Mixed flow impeller trim .....	31
14.3.3.4.2a — Typical axial flow pump impeller chord angle .....	32
14.3.3.5.1a — Power consumption by discharge throttling .....	33
14.3.3.5.1b — Power consumption using a VSD.....	33
14.3.3.5.1c — Potential savings flat pump curve.....	34

14.3.3.5.1d — Potential savings steep pump curve .....	34
14.3.4.1.1.1a — Series operation .....	35
14.3.4.1.1.1b — Pumps operating in series .....	35
14.3.4.1.1.3 — Pumps operating in parallel .....	36
14.3.4.1.1.3.1 — H (Q) of different pumps in parallel operation .....	37
14.3.4.4.1 — Typical preferred operating region .....	38
14.3.4.8.1 — Two-phase pumping applications.....	46
14.3.4.8.2 — Effect of gas on pump performance.....	47
14.3.4.8.2.1a — Venting the eye of the impeller .....	48
14.3.4.8.2.1b — Top suction impeller .....	49
14.3.4.8.2.2a — Self-priming pump — construction industry .....	49
14.3.4.8.2.2b — Self-priming pump — chemical industry .....	50
14.3.4.8.2.2c — Helico-axial multiphase pump.....	50
14.3.4.10.5a — NPSHR reduction for pumps handling hydrocarbon liquids and high-temperature water (metric units) .....	55
14.3.4.10.5b — NPSHR reduction for pumps handling hydrocarbon liquids and high-temperature water (US customary units) .....	56
14.3.4.12 — Siphon system .....	58
14.3.4.13 — Inlet configurations .....	59
14.3.4.13.1 — Suction cans (barrels) with vents.....	60
14.3.4.14 — Typical self-priming installation .....	61
14.3.4.16a — Torque versus speed template (metric units) .....	67
14.3.4.16b — Torque versus speed template (US customary units).....	68
14.3.4.17a — Torque curve .....	68
14.3.4.17b — Plotting torque versus speed (metric units).....	71
14.3.4.17c — Plotting torque versus speed (US customary units) .....	72
14.3.4.18.1 — Axial pump with low system head .....	73
14.3.4.24.2a — Combining sound pressure .....	77
14.3.4.24.2b — dBA correction for impeller trim and percent BEP operation .....	77
14.3.5.1 — General impeller types .....	79
14.3.5.1.1.2 — Single suction impeller .....	80
14.3.5.1.1.3 — Single-stage, horizontal, double suction pump .....	80
14.3.5.2.1 — Enclosed impeller.....	81
14.3.5.2.2a — Open impeller.....	82
14.3.5.2.2b — Semi-open impeller with a full back shroud .....	82
14.3.5.2.2c — Semi-open impeller with a scalloped back shroud .....	82

14.3.5.2.3 — Typical Barske impeller .....	83
14.3.5.2.4 — Typical vortex impellers .....	83
14.3.5.2.5a — Inducer, end suction pump.....	84
14.3.5.2.5b — Inducer, vertically suspended pump .....	84
14.3.5.3.1 — Single volute casing.....	85
14.3.5.3.2 — Double volute casing .....	85
14.3.5.3.3 — Circular (concentric) casing .....	85
14.3.5.3.4 — Diffuser casing .....	86
14.3.5.3.7 — Typical bowl and stage casing .....	86
14.3.5.3.8 — Self-primer casing .....	87
14.3.5.3.9 — Double suction casing – horizontal split case .....	87
14.3.5.3.10 — Double suction casing – vertically suspended.....	88
14.3.5.4.1.1.1 — Approximate boundaries of radial thrust direction, single volute pump .....	89
14.3.5.4.2a — Radial thrust factor for single volute with various specific speeds .....	91
14.3.5.4.2b — Radial thrust factor for double volute with various specific speeds .....	91
14.3.5.4.2c — Sketch to illustrate $D_2$ and $b_2$ .....	91
14.3.5.4.2d — Radial thrust factor for circular (concentric) casing typical for specific speed 20 (1000) .....	92
14.3.5.4.3.2.1 — Typical thrust profile .....	94
14.3.5.4.3.2.4 — Alternate thrust balancing methods .....	95
14.3.5.4.3.3.1a — Pressure distribution on enclosed impeller .....	96
14.3.5.4.3.3.1b — Enclosed impeller thrust factors for various specific speeds .....	98
14.3.5.4.3.3.1c — Average values of $K_{Bal}$ , pressure reduction factor as a function of total balance hole area and rear wear ring clearance area .....	99
14.3.5.4.3.3.1d — Enclosed impeller with plain back shroud .....	99
14.3.5.4.3.3.1e — Impeller with back ring .....	102
14.3.5.4.3.3.2 — Cross section of semiopen impeller showing diameter locations.....	107
14.3.5.4.3.3.3 — Axial impeller dimensions .....	108
14.3.5.4.3.3.4a — Enclosed impeller plain top shroud, vertically suspended pump .....	109
14.3.5.4.3.3.4b — Semiopen impeller, vertically suspended pump.....	109
14.3.5.4.3.3.4c — Enclosed impeller with back ring and balance holes, vertically suspended pump.....	110
14.3.5.4.3.3.4d — Enclosed end of shaft at suction .....	110
14.3.5.4.3.3.4e — Shaft sleeve through packing or mechanical seal .....	110
14.3.5.4.3.3.4f — Shaft sleeve through pressure breakdown bushing .....	111
14.3.5.4.3.3.5 — Experimental thrust coefficient $C^{1.2}$ .....	112
14.3.5.4.3.3.7 — Axial thrust versus rate of flow curves .....	117

This is a preview. Click here to purchase the full publication.

14.3.6.2.3a — Open lineshaft .....	121
14.3.6.2.3b — Enclosed lineshaft .....	121
14.3.6.3.2 — Cast discharge head .....	123
14.3.6.3.3 — Fabricated discharge head .....	123
14.3.6.3.4 — Subsurface discharge head .....	124
14.3.6.3.5 — Separate discharge types VS4 and VS5 .....	125
14.3.6.3.9a — Internal seal arrangement .....	126
14.3.6.3.9b — Special seal arrangement .....	127
14.3.6.4.1.1 — Horizontal, between-bearings, axially split, multistage pump .....	128
14.3.6.4.2.1 — Overhung impeller .....	129
14.3.6.4.2.2 — Between-bearings, single-stage pump .....	130
A.1 — Turbine characteristics .....	143
A.2 — Turbine performance .....	145
A.3 — Dry-pit pump overhung flexibly coupled vertical end suction .....	146
A.4 — Dry-pit pump overhung, close-coupled, vertical end suction .....	146
A.5 — Dry-pit pump overhung, foot-mounted, flexibly coupled, horizontal, end suction .....	147
A.6 — Self-priming pump construction industry .....	149
A.7 — Self-priming pump chemical industry .....	150
B.1 — Regenerative turbine pump types and classifications .....	151
B.2 — Regenerative turbine – impeller between bearings – two stage .....	152
B.3 — Regenerative turbine flow path .....	153
B.4 — Regenerative turbine pump performance .....	155
B.5 — Pitot tube pump .....	157
B.6 — Pitot tube pump rotating assembly (1) .....	158
B.7 — Pitot tube pump performance .....	161
B.8 — Vortex pump .....	163
B.9 — Screw centrifugal pump .....	164
B.10 — Screw centrifugal pump impeller .....	165
B.11 — High-solidity (left) versus low-solidity (right) straight radial vane impeller common in high-speed pumps .....	168
B.12 — Tailpipe and float control .....	172
B.13 — Rate of flow versus minimum submergence .....	173
B.14 — Schematic showing vaporproof/pressurized design .....	175
B.15 — Lubrication cleanliness .....	176
B.16 — Nozzle loads .....	176

D.1 — Stuffing box without lantern ring .....	186
D.2 — Stuffing box with lantern ring .....	187
D.3 — Mechanical seal classification by arrangement .....	187
D.4 — Mechanical seal classification by design .....	188
D.5 — Mechanical seal classification by construction .....	188
D.6 — Seal chamber for external component seal .....	191
D.7 — Seal chamber for internal cartridge seal .....	192
D.8 — Types of bearing housing shaft seals .....	193
D.9 — Lip seal .....	194
D.10 — Lip seal with secondary V-ring .....	195
D.11 — Bearing isolator .....	196
E.1 — Cylindrical-type radial journal (sleeve) bearing .....	201
E.2 — Pivot-shoe-type thrust bearing feed lubrication .....	201
E.3 — Pivot-shoe-type thrust bearing – complete with shaft-driven oil pump arranged for force-feed lubrication .....	201
E.4 — Type OH arrangement .....	202
E.5 — Type BB arrangement .....	202
E.6 — Vertical turbine pumps .....	203
F.1 — Oil bath lubrication system with constant level oiler .....	212
F.2 — Slinger ring installation using a bearing cartridge for ease of installation .....	213
F.3 — Typical oil mist bearing construction .....	214
F.4 — Dry-start running times at different shaft speeds when applied to PTFE bearings .....	215
F.5 — Conversion example from enclosed line shaft vertical pump (left) to open line shaft (right) .....	216
G.1 — Head shaft coupling, rigid style, for hollow-shaft motor .....	220
G.2 — Flanged adjustable coupling, rigid style .....	221
G.3 — Flanged adjustable spacer coupling, rigid style .....	221
H.1 — Typical horizontal pump anchor bolt, leveling jack bolt, and grout design .....	224
H.2 — Grouted baseplate, fabricated steel .....	226
H.3 — Grouted baseplate, cast iron .....	227
H.4 — Nongrout baseplate .....	228
H.5 — Pregrouted baseplate .....	228
H.6 — Soleplate .....	229
H.7 — Freestanding baseplate .....	230
H.8 — Baseplate mounting springs with slide bearing .....	230
H.9 — ASME B73.1 pump and baseplate .....	231