

# **Pulsation and Vibration Control in Positive Displacement Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services**

API RECOMMENDED PRACTICE 688  
FIRST EDITION, APRIL 2012

REAFFIRMED, JULY 2021



American  
Petroleum  
Institute

## Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Classified areas may vary depending on the location, conditions, equipment, and substances involved in any given situation. Users of this Recommended Practice should consult with the appropriate authorities having jurisdiction.

Users of this Recommended Practice should rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

## Foreword

This document is intended to describe, discuss and clarify the design of pulsation and vibration control for positive displacement machinery systems used for services in the petroleum, petrochemical and natural gas industries. The original focus of this document was to provide insight on the many changes to the pulsation and vibration material in the Clause 7.9 of the 5th Edition of API 618 for reciprocating compressors only. Due to industry interest, the scope of this document has been expanded to include other types of positive displacement equipment (such as pumps and screw compressors). However, due to publication schedules, these other types of positive displacement equipment will be addressed in future editions.

This document is not intended to be an all-inclusive source of information for this complex subject. Rather, it is offered as an introduction to the major aspects of pulsation and vibration control for positive displacement machinery addressed during a typical system design. A significant amount of the material has been extracted from documents previously published by the contributors. The different design philosophies of the various contributors are consolidated in this document to help users understand the choices available and make informed decisions about what is appropriate for their application. While the theory is generally applicable to all types of positive displacement machinery, the text in this edition will frequently refer specifically to reciprocating compressors.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Shall: As used in a standard, "shall" denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, "should" denotes a recommendation or that which is advised but not required in order to conform to the specification.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Currently in preview, click buy full version

## Contents

Page

### Part 1: Pulsation and Vibration Control Fundamentals for Positive Displacement Machinery

1	Scope	1
2	Terms and Definitions	1
3	Fundamentals of Pulsation and Mechanical Vibration Theory	3
3.1	Overview of Pulsation Concepts	4
3.2	Overview of Mechanical Concepts	35
4	Fundamentals of Modeling	66
4.1	Overview of Acoustic Modeling	66
4.2	Overview of Mechanical Modeling	73
4.3	Concurrent Acoustical and Mechanical Design	73
4.4	Design Philosophies For Varying Degrees Of Acoustic And Mechanical Control	74
4.5	Design Approach and Philosophy Selection Guidelines	76
5	Flow Measurement	78
5.1	Introduction	78
5.2	Flow Measurement by Measuring Differential Pressure (DP) - Orifice Plate, Nozzle, and Venturi	80
5.3	Flow Measurement by Turbine Flowmeters	80
5.4	Flow Measurement by Vortex Flowmeters	80
5.5	Flow measurement by ultrasonic flowmeters	81
5.6	Flow Measurement by Coriolis Flowmeters	82
5.7	References	82
6	Results Reporting Guidelines	83
6.1	Scope	83
6.2	Results	83
7	Field testing	89
7.1	Confirmation that Design Requirements Have Been Met	89
7.2	Vibration Problems	89
7.3	Excessive Pressure Drop	90
7.4	Premature Valve Failure	90
7.5	Driver Overload	90
7.6	Failure to Deliver Expected Flow	90
8	Valve Dynamic Performance Analysis	90
8.1	The VLPA Model	90
8.2	Valve Reliability and Efficiency	91
8.3	Application Of Analysis Results To Valve Selection	91
8.4	Valve Dynamics Analysis Report	93
Figures		
1	Piston Motion and Velocity for a Slider Crank Mechanism	5
2	Single Acting Compressor Cylinder with Rod Length/Stroke = $\infty$ and No Valve Losses	5
3	Symmetrical, Double Acting Compressor Cylinder with Rod Length/Stroke = $\infty$ and No Valve Losses	6

## Contents

Page

4	Unsymmetrical, Double Acting Compressor Cylinder with Rod Length/Stroke = 5 and No Valve Losses	6
5	Traveling Wave in Infinite Length Pipe	7
6	Mode Shapes of Half Wave Responses	7
7	Mode Shapes of Quarter Wave Responses	8
9	Reducer with Dynamic Forces	10
8	Elbow with Dynamic Forces	10
10	Tee with Dynamic Forces	11
12	Pulsation Suppression Device with Dynamic Forces	12
11	Elbow with Dynamic Forces	12
13	Shaking Force for Sample Pulsation Damper	13
14	Shaking Force for Sample Pipe Lateral	14
15	Head End (HE) Pressure-Volume Card	15
16	Ideal (Adiabatic) PV Diagrams	16
17	Valve Losses	21
18	Losses Due to Pulsation	21
19	Losses Due to Pressure Drop	22
20	Effect of Clearance Volume, Condition 1	23
21	Effect of Clearance Volume, Condition 2	24
22	Effect of Clearance Volume, Condition 3	25
23	Effect of Suction Temperature, Condition 4	26
24	Effect of Suction Temperature, Condition 5	27
25	Effect of Suction Pressure, Condition 6	28
26	Effect of Suction Pressure, Condition 7	29
27	Pump Cavitation	31
28	Pump Cavitation Field Data	32
29	Components of Pump Section Head	33
30	Amplification Factor for Various Damping Ratios	38
31	Effect of Separation Margin from Mechanical Natural Frequency on Amplification Factor	39
32	Common Piping Configurations	40
33	Non-dimensional Piping Shaking Force Guideline	42
34	API 618 Design Vibration Guideline	45
35	Non-dimensional Pulsation Suppression Device Shaking Force Guideline	47
36	Example of Inertial Cylinder Pressure Force versus Crank Angle and Frequency Spectrum	48
37	Example of Rod Loads Due to Gas Force, Inertial Force and Combined Rod Load	49
38	Conceptual Guidelines for Vent and Drain Piping Valve Supports	49
39	Conceptual Guidelines for Vent and Drain Piping Valve Supports	50
40	Conceptual Guidelines for Vent and Drain Piping Valve Supports	50
41	Frequency Factors for Idealized Pipe Spans and Bends (1st and 2nd Natural Frequencies)	53
42	Frequency Factor ( $I$ ) versus Ratio ( $L/h$ ) for Uniform U-Bend	54
43	Concentrated Weight-Correction Factors for Ideal Piping Spans ( $P$ = Concentrated Load, $W$ = Weight per Unit Length)	55
44	Typical Compressor Flange Deflections	56
45	Plot of a Pipe System	57
47	Typical Branch Connection Finite Element Model	58

## Contents

	Page	
46	Lowest Mode Shape . . . . .	58
48	Example of a Partial Finite Element Model of a Compressor . . . . .	59
49	Typical Dynamically Fixed Clamps . . . . .	60
50	Example of a Hold Down Type Support with no Allowance for Thermal Displacement in the Vertical Direction. . . . .	62
51	Example of a Spring Hold Down Type Support which Allows Thermal Motion in the Vertical Direction . . . . .	63
52	Allowable Shaking Forces per API 618, 5th Edition . . . . .	65
53	Example of Pipe and Support Configurations . . . . .	67
54	Lumped Acoustic Model. . . . .	70
55	Analogous Electrical Model . . . . .	71
56	Electronic Analog for One Pipe Section (Simplified Version without Flow Resistance) . . . . .	71
57	Measuring Flow Expressed a Change of the Vortex Frequency . . . . .	81
58	Compressor Configuration. . . . .	85
59	Cylinder Nozzle Pulsation (Predicted vs. Guideline). . . . .	85
60	Pulsation Suppression Device Line-Side Pulsation (Predicted vs. Guideline) . . . . .	86
61	Pulsation Suppression Device Shaking Force (Predicted vs. Guideline). . . . .	86
62	Compressor System Finite Element Model with Test Points . . . . .	87
63	Typical Display of Valve Motion versus Crank Angle, Cylinder Pressure versus Volume and Analysis Results Table . . . . .	92
<b>Tables</b>		
1	Frequency Factors for Various Pipe and Support Arrangements . . . . .	44
2	Example of a Maximum Span Table for 25 ft . . . . .	55
3	Effect of Pipe Support Structures on Mechanical Natural Frequencies . . . . .	57
4	Generic Piping Shaking Force Criterion from Clause 7.9 of the 5th Edition of API 618 . . . . .	64
5	Generic Piping Shaking Force Criterion from Clause 7.9 of the 5th Edition of API — Based on Pipe Size . . . . .	4
6	Overview of Pulsation Impact on various Flowmeters . . . . .	79
7	Compressor Geometry . . . . .	84
8	Operating Conditions . . . . .	84
9	Gas Composition. . . . .	85
10	Lowest Mode Shape and Mechanical Natural Frequency. . . . .	88
11	Recommended Design Results for Cylinder Stretch Load Case. . . . .	88
12	Expected Results. . . . .	88

## Contents

	Page
<b>Part 2: Reciprocating Compressors</b>	
<b>1 General</b> .....	<b>4</b>
<b>2 Comments On API 618, 5th Edition, Clause 7.9 – Pulsation and Vibration Control</b> .....	<b>94</b>
<b>API 618 Annex M (informative) Design Approach Work Process Flowcharts</b> .....	<b>113</b>
<b>API 618 Annex N (informative) Guideline for Compressor Gas Piping Design and Preperation for an Acoustic Simulation Analysis</b> .....	<b>116</b>
<b>API 618 Annex O (informative) Guidelines for Sizing Low Pass Acoustic Filters</b> .....	<b>119</b>
<b>API 618 Annex P (informative) Piping and Pulsation Supression Device Shaking Force Guidelines</b> .....	<b>122</b>
<b>Figures</b>	
<b>618-4 Piping Design Vibration at Discrete Frequencies 108</b>	
<b>M-1 Design Approach 1</b> .....	<b>113</b>
<b>M-2 Design Approach 2</b> .....	<b>114</b>
<b>M-3 Design Approach 3</b> .....	<b>115</b>
<b>O-1 Nonsymmetrical Filter</b> .....	<b>119</b>
<b>P-1 Non-dimensional Piping Shaking Force Guidelines</b> .....	<b>123</b>
<b>P-2 Non-dimensional Pulsation Supression Device Shaking Force Guidelines</b> .....	<b>123</b>
<b>P-3 Shaking Forces along the Piping Axis</b> .....	<b>124</b>
<b>P-4 Shaking Forces along the Pulsation Supression Device Axis</b> .....	<b>124</b>
<b>P-5 Examples of Shaking Force Restraints</b> .....	<b>126</b>
<b>Tables</b>	
<b>618-6 Design Approach Selection 97</b>	
<b>N-1 Compressor Data Required for Acoustic Simulation</b> .....	<b>118</b>
<b>P-1 Cylinder Assembly Weights Possibly Requiring Strengthening</b> .....	<b>127</b>

# Pulsation and Vibration Control in Positive Displacement Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services

## Part 1: Pulsation and Vibration Control Fundamentals for Positive Displacement Machinery

### 1 Scope

The purpose of this document is to provide guidance on the application of pulsation and vibration control requirements found in the API purchasing specifications for positive displacement machinery. The fundamentals of pulsation and piping system analysis are presented in this Part.

The text begins with an overview of the fundamentals of pulsation and mechanical theory in Section 3. The intent of Section 3 is to introduce terminology and define the elements of the analysis process. Section 4 begins with a discussion of the acoustic and mechanical modeling techniques associated with the different design philosophies, which emphasize either pulsation or mechanical control, and concludes with a discussion on the appropriate selection of a Design Approach and Philosophy. Section 5 discusses the effects of pulsation on the accuracy of various types of flow measurement devices. Section 6 summarizes the requirements for documenting study results. Section 7 offers guidance on the performance of field testing to validate the results of the design process and to troubleshoot pulsation or vibration problems. Finally, methodologies for conducting a dynamic analysis of the compressor or pump valve performance are described in Section 8. The material in this Part is generally applicable to all types of positive displacement machinery.

Part 2 deals specifically with reciprocating compressors and provides commentary regarding each paragraph of Clause 7.9 of API 618, 5th Edition. It is the intent of the API Subcommittee on Mechanical Equipment that similar material be provided on reciprocating pumps and screw compressors in future editions.

### 2 Terms and Definitions

For the purposes of this document, the following definitions apply.

#### 2.1

##### **acoustic simulation**

Process whereby the one-dimensional acoustic characteristics of fluids, and the reciprocating compressor dynamic flow influence on these characteristics, are modeled taking into account the fluid properties, the compressor model and the connected vessels and piping, and other equipment. The model is based upon the governing mathematical equations (motion, continuity, etc.). The simulation should allow for determination of pressure/flow modulations at any point in the piping model resulting from any generalized compressor excitation. (Refer also to 2.2, 2.4, 2.9, 2.13, 2.16, and 2.18.)

#### 2.2

##### **active analysis**

Portion of an acoustic simulation in which the pressure pulsation amplitudes due to imposed compressor(s) operation for the anticipated loading, speed range and state conditions are predicted. (Refer to 2.1.)

#### 2.3

##### **amplification factor**

Measure of acoustic or vibration sensitivity to excitation when the frequency of the excitation source is coincident with or near an acoustic or mechanical natural frequency. A high amplification factor ( $AF > 10$ ) indicates that vibration during operation near a natural frequency could be excessive. A low amplification factor (e.g.  $AF < 5$ ) indicates that the system is not as sensitive to excitation when operating in the vicinity of the associated acoustic or mechanical