

American National Standard for

Controlled-Volume Metering Pumps

for Nomenclature, Definitions,
Application, and Operation



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First Floor North
Parsippany, New Jersey
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Sponsor
Hydraulic Institute, Inc.
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Approved August 12, 2013
American National Standards Institute, Inc.

American National Standard

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Published By

**Hydraulic Institute, Inc.
6 Campus Drive, First Floor North
Parsippany, NJ 07054-4406**

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Printed in the United States of America

ISBN 978-1-935762-09-6



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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Institute are to promote the continued growth and well-being of pump users and pump manufacturers and further the interests of the public in such matters as are involved in manufacturing, engineering, distribution, safety, transportation, and other problems of the industry, and to this end, among other things:

- a) To develop and publish standards for pumps;
- b) To collect and disseminate information of value to its members and to the public;
- c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;
- d) To increase the amount and to improve the quality of pump service to the public;
- e) To support educational and research activities;
- f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of Standards

- 1) Hydraulic Institute Standards are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser and/or the user and to assist the purchaser, in selecting and obtaining the proper product for a particular need.
- 2) Use of Hydraulic Institute Standards is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the Standards.

Definition of a Standard of the Hydraulic Institute

Quoting from Article XV, Standards, of the By-Laws of the Institute, Section B:

"An Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing, and service for which designed."

Comments from users

Comments from users of this standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this standard may be sent to the Technical Director of the Hydraulic Institute. The inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of an Institute Standard or an answer provided by the Institute to a question such as indicated above, the point in question shall be sent in writing to the Technical Director of the Hydraulic Institute, who shall initiate the appeals process.

Revisions

The standards of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards are reaffirmed using the ANSI canvass procedure.

Scope

This standard is for controlled-volume metering pumps, which are reciprocating power pumps used to accurately displace a predetermined volume of liquid in a specified time period. It includes types and nomenclature;

definitions; design and application; and installation, operation, and maintenance. This standard does not apply to accessory items, such as piping, tubing, fittings, or instrumentation or pump drivers.

Units of measurement

Metric units of measurement are predominantly used, and, where appropriate, US customary equivalents appear in brackets following the metric units. Charts, graphs, and sample calculations are shown in both metric and US units.

Consensus for this standard was achieved by use of the canvass method

The following organizations, recognized as having an interest in the standardization of controlled-volume metering pumps, were contacted prior to the approval of this standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

ARCADIS

Colfax Fluid Handling

Kemet Inc.

MWH Americas, Inc.

Neptune Chemical Pump Co., Inc.

Working group committee members

Although this standard was processed and approved for submittal to ANSI by the canvass method, the committee met many times to facilitate its development. At the time it was developed, the committee had the following members:

Chair – Don Weidemann, Neptune Chemical Pump Co., Inc

Vice-chair – James Casey, Milton Roy Americas

Committee Members

Gary Cornell

Aaron Hinchliffe

Doug Purdy

Peter Timpanelli

Company

Blacoh Fluid Controls, Inc.

Iwaki America Incorporated

Wanner Engineering, Inc.

LEWA, Inc.

Alternates:

Joel Higbee

Dennis Ruis

Milton Roy Americas

Iwaki America Incorporated

7 Controlled-volume metering pumps

7.0 General description of controlled-volume metering pumps

Controlled-volume metering pumps (also known as *metering pumps*, *proportioning pumps*, *chemical injection/feed pumps*, or *dosing pumps*) are reciprocating positive displacement pumps typically used for the injection of chemical additives, proportional blending of multiple components, or metered transfer of a single liquid. These types of pumps are used in applications requiring highly accurate, repeatable, and adjustable rate of flow.

The rate of flow of a controlled-volume pump is a function of the cross-sectional area of the plunger or piston, or displacement of the diaphragm; the stroke length; and the stroking speed. The pumping action is created by a reciprocating piston and controlled by suction and discharge check valves. The rate of flow is adjusted by changing the stroke length and/or the stroking speed.

Controlled-volume metering pumps are characterized by their ability to meet specific performance requirements concerning steady state accuracy, repeatability, and linearity.

7.1 Types and nomenclature

Because controlled-volume metering pumps are employed in a number of different environments and applications, several types have been developed with different liquid ends and drive and control mechanisms. The basic elements of the pumps are the driver, stroke-length adjustment, pumphead, and the gearbox. These are shown in Figure 7.1, which illustrates the general arrangement of these elements and how they are combined to form a controlled-volume metering pump. Detailed descriptions of these elements follow below.

7.1.1 Construction characteristics of controlled-volume metering pumps

NOTE: The following definitions and illustrations represent typical construction characteristics of controlled-volume metering pumps but do not necessarily represent recommended designs. Variations in design may exist without violating the intent of this standard.

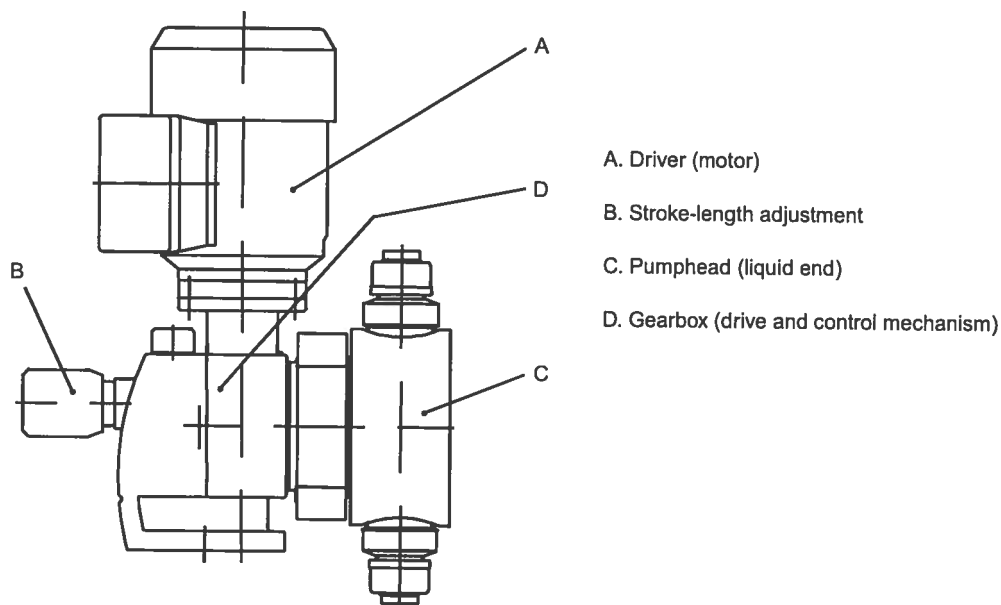


Figure 7.1 — Basic elements of a controlled-volume metering pump

Liquid end

- Plunger
- Piston
- Mechanical coupled disc diaphragm
- Hydraulic coupled disc diaphragm
- Hydraulic coupled tubular diaphragm
- Hydraulic coupled conical diaphragm

Drive and control mechanisms

- Electromagnetic drive (solenoid)
- Reciprocating air/gas drive
- Motor driven,¹ variable speed
- Motor driven,¹ mechanical lost motion
- Motor driven,¹ hydraulic lost motion
- Motor driven,¹ variable eccentric (non-lost-motion)

7.1.2 Description of liquid ends

The pump liquid end assembly (also called the *reagent head assembly*, *pumphead*, or *wet end*) includes all parts that contain or are in direct contact with the liquid being pumped.

7.1.2.1 Plunger

A plunger liquid end (see Figure 7.1.2.1) contains a reciprocating plunger in direct contact with the liquid being displaced. It uses packing within a stuffing box or seals to restrict leakage. This design is not inherently leak free. The plunger design allows for lower required “minimum suction head,” limited only by the vapor pressure of the liquid, and this design can be used in high-pressure applications. In operation the process liquid is admitted through the suction check valve as the plunger moves away from the wet end. As the plunger moves towards the wet end, the suction check valve closes and the discharge check valve opens discharging liquid.

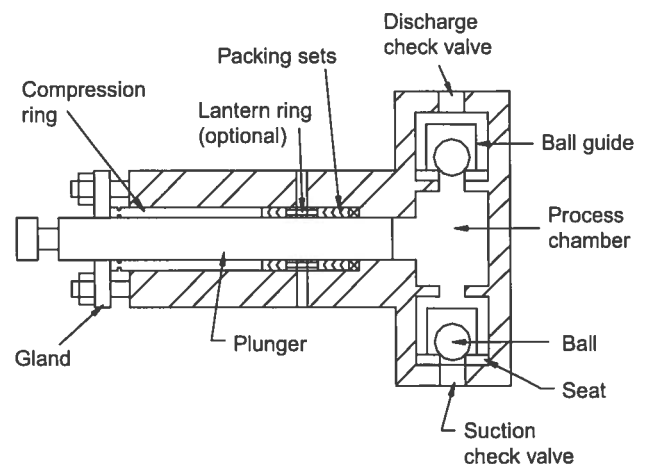


Figure 7.1.2.1 — Plunger pump

¹ Motor driven is understood to include electric, pneumatic, hydraulic turbine, or hydraulic motors.

7.1.2.2 Piston

A piston liquid end (see Figure 7.1.2.2) contains a reciprocating piston in direct contact with the liquid being displaced. It uses packing or seals located on the piston to restrict leakage. This design is not inherently leak free. The piston design allows for lower required “minimum suction head,” limited only by the vapor pressure of the liquid, and can be used in high-pressure applications. In operation the process liquid is admitted through the suction check valve as the piston moves backwards. As the piston moves to the front, the suction check valve closes and the discharge check valve opens discharging liquid.

7.1.2.3 Mechanically coupled disc diaphragm

A mechanically coupled disc diaphragm liquid end (see Figure 7.1.2.3) contains a flexible, round diaphragm, clamped at the periphery, that is in direct contact with the process liquid being displaced. This type of design is inherently leak free. The diaphragm material is typically a fluoropolymer, elastomer, or fluoropolymer-elastomer composite. A connecting rod is connected directly to the diaphragm. The diaphragm is not pressure balanced as the process pressure is acting on one side of the diaphragm and atmospheric pressure is acting on the other side. This results in higher stress levels in the diaphragm and therefore these pumps are typically used for lower pressure applications. In operation the process liquid is admitted through the suction check valve as the diaphragm/connecting rod assembly moves away from the wet end. As the diaphragm/connecting rod assembly moves towards the wet end, the suction check valve closes and the discharge check valve opens discharging liquid.

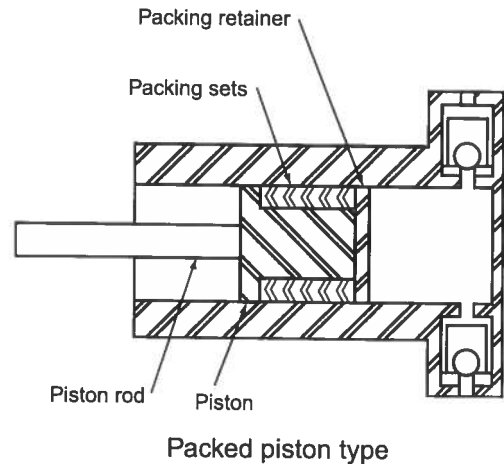


Figure 7.1.2.2 — Piston pump

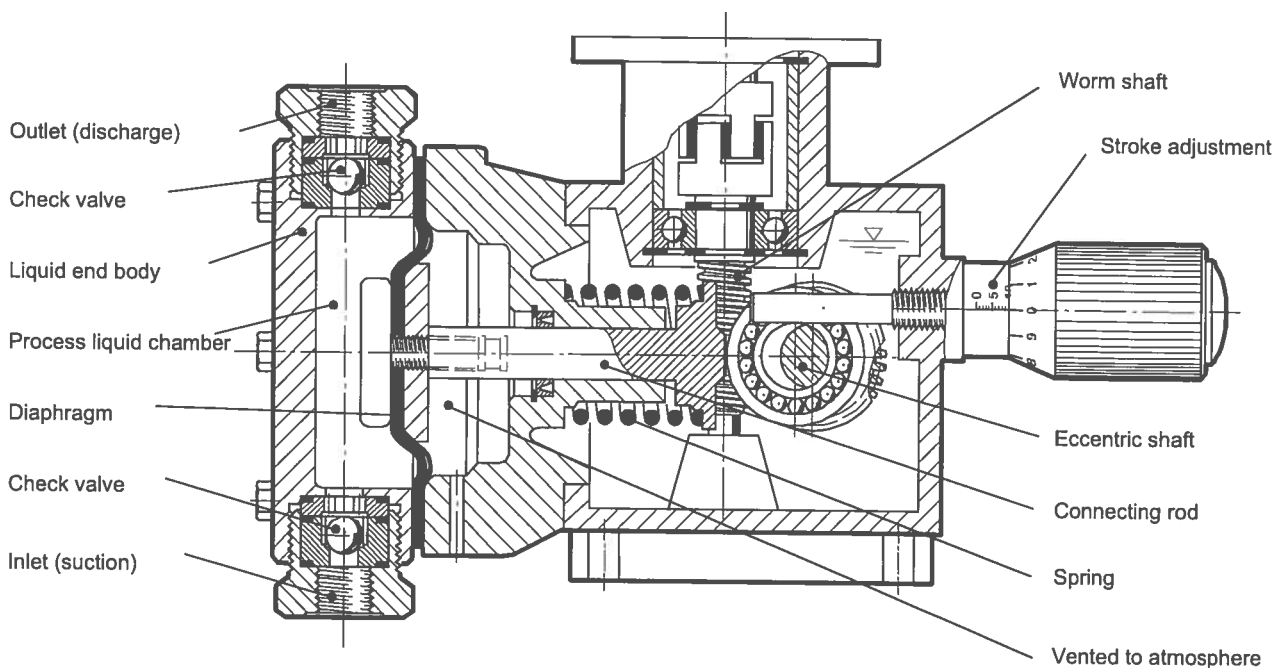


Figure 7.1.2.3 — Mechanically coupled disc diaphragm

7.1.2.4 Hydraulic coupled disc diaphragm

A hydraulic coupled disc diaphragm liquid end (Figure 7.1.2.4a) contains a flexible, single or double configuration diaphragm, clamped at the periphery, and is in direct contact with the process liquid being displaced. This type of liquid end design is inherently leak free. The diaphragm material is typically a fluoropolymer, elastomer, or fluoropolymer-elastomer composite. Liquid end designs featuring flexible metallic diaphragms are available and used in applications where severe operating conditions prohibit the use of fluoropolymer or other elastomers.

In operation, the diaphragm is moved by a hydraulic fluid, which is displaced by a reciprocating plunger or piston. The stresses in the diaphragm are minimal, as the process pressure acting on one side of the diaphragm is balanced by the hydraulic pressure acting on the opposite side. The process liquid is admitted through the suction check valve as the diaphragm moves towards the wet end, the suction check valve closes and the discharge check valve opens discharging liquid. Liquid end designs of this type may include provisions such as contour plates, springs, or diaphragm positioning hydraulic control valves (Figure 7.1.2.4b) to ensure the diaphragm does not move beyond its elastic limits.

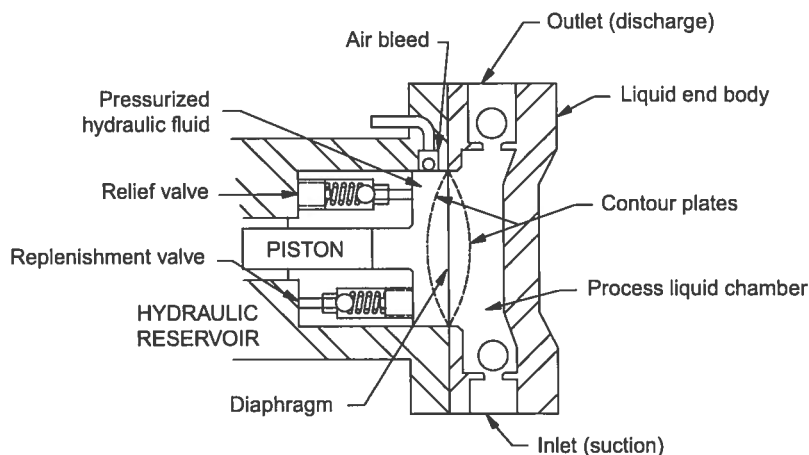


Figure 7.1.2.4a — Hydraulic disc with contour plates

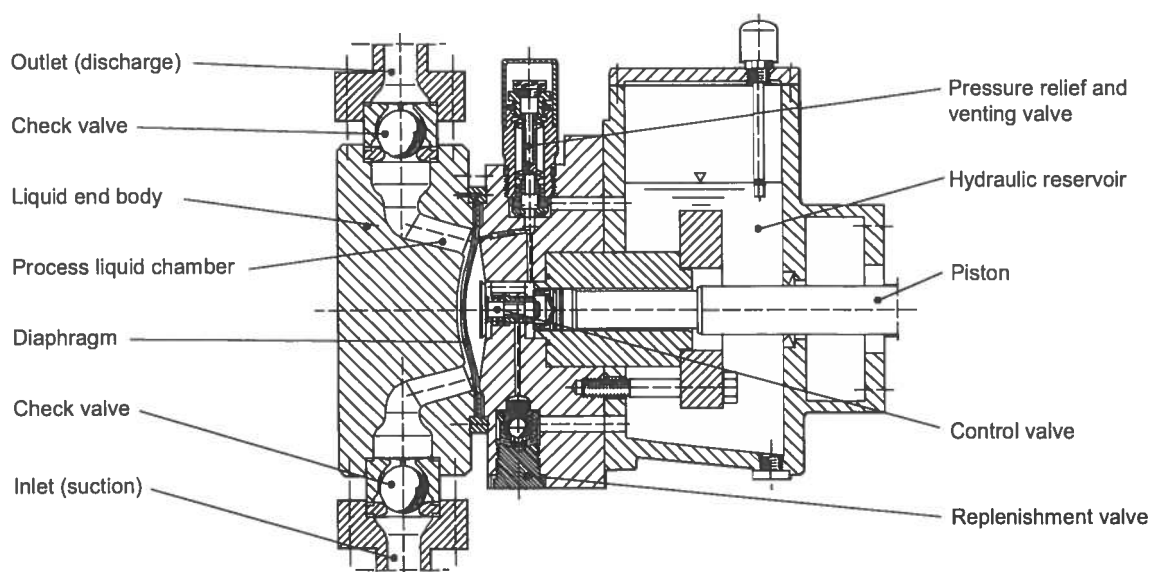


Figure 7.1.2.4b — Hydraulic disc with diaphragm positioning valve

7.1.2.5 Hydraulic coupled tubular diaphragm

A hydraulic coupled tubular diaphragm liquid end (see Figure 7.1.2.5) contains a flexible tube, clamped at both ends, that is in direct contact with the process liquid being displaced. This type of liquid end design is inherently leak free. The diaphragm material is either PFA or an elastomer. These liquid ends are typically used for viscous liquids or slurries. In operation, the plunger moves rearward and, through hydraulic coupling, expands the tube admitting liquid into the tube's cavity through the suction check valve. As the plunger moves towards the wet end, the hydraulic fluid constricts the tube moving the process liquid through the discharge check valve. A disc diaphragm constrained by contour plates may be used in series hydraulically. This disc diaphragm is used to ensure that the tube operates within its elastic limits.

7.1.2.6 Hydraulic coupled conical diaphragm

A hydraulic coupled conical diaphragm liquid end (see Figure 7.1.2.6) contains a flexible conical diaphragm, clamped at the periphery, that is in direct contact with the process liquid being displaced. This type of liquid end design is inherently leak free. The diaphragm material is an elastomer. In operation, the plunger moves away from the wet end and process liquid is admitted through the suction check valve. As the plunger moves towards the wet end, the discharge check valve opens, allowing the process liquid to discharge and the conical diaphragm expands, storing elastomeric energy to return it to its original position.

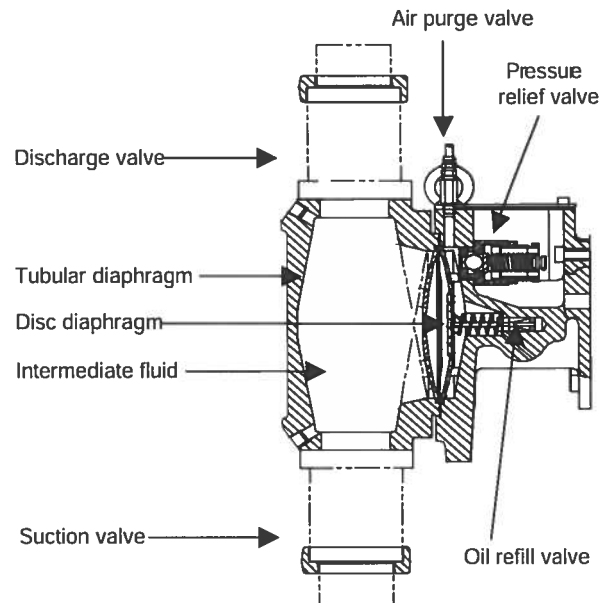


Figure 7.1.2.5 — Hydraulic tubular diaphragm

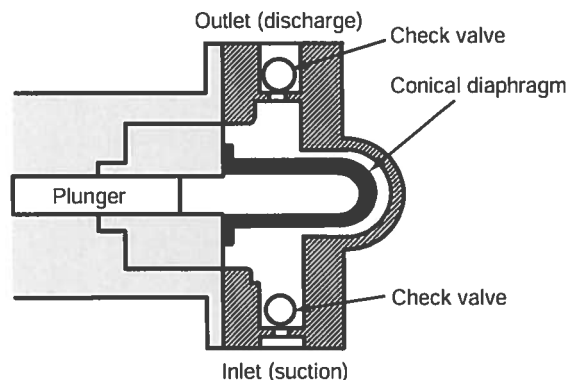


Figure 7.1.2.6 — Hydraulic conical diaphragm

7.1.3 Drive and control mechanisms

The drive and control mechanism is typically located between the driver and the liquid end. Its purpose is to create reciprocating motion of a piston, plunger, or push rod at a controlled frequency (stroke rate). As a controlled-volume metering pump, its secondary purpose is to allow controlled variation of the stroke length by means of its inherent stroke adjustment control mechanism (except in the case of the fixed stroke-length design, see Section 7.1.3.3).

7.1.3.1 Electromagnetic drive (solenoid)

The electromagnetic drive (see Figure 7.1.3.1) employs an electromagnet that, when pulsed, generates a linear motion transmitted to the liquid end. Each pulse results in one discharge stroke of the pump. The flow is controlled by changing the rate of pulses to the electromagnet and/or by varying the stroke length. These pumps can be run indefinitely in the stalled condition without damage to the pump or most systems. Typically used in lower flow and lower pressure applications. This type of design is inherently leak free.

7.1.3.2 Reciprocating air drive

Reciprocating air drives (Figure 7.1.3.2) use an air cylinder to transmit linear motion to the liquid end. The flow is controlled by changing the pulse rate of the air entering and leaving the cylinder, changing the displacement by adjusting a physical stop, or by changing the rate of flow of air supplied to the air cylinder. These drives can be run indefinitely in the stalled condition without damage to the pump or pumping system. Most designs can be powered by air or other gases.

7.1.3.3 Fixed stroke-length drives

The stroke length is constant in a fixed stroke-length drive (see Figure 7.1.3.3). The stroking speed is changed to vary the flow. As the velocity and acceleration of the mechanisms used are typically sinusoidal (see Figure 7.3.1b), the resulting velocity and acceleration of the process liquid is also sinusoidal. Unlike the lost-motion drives, volume per stroke remains constant and flow rate is changed by speed adjustment.

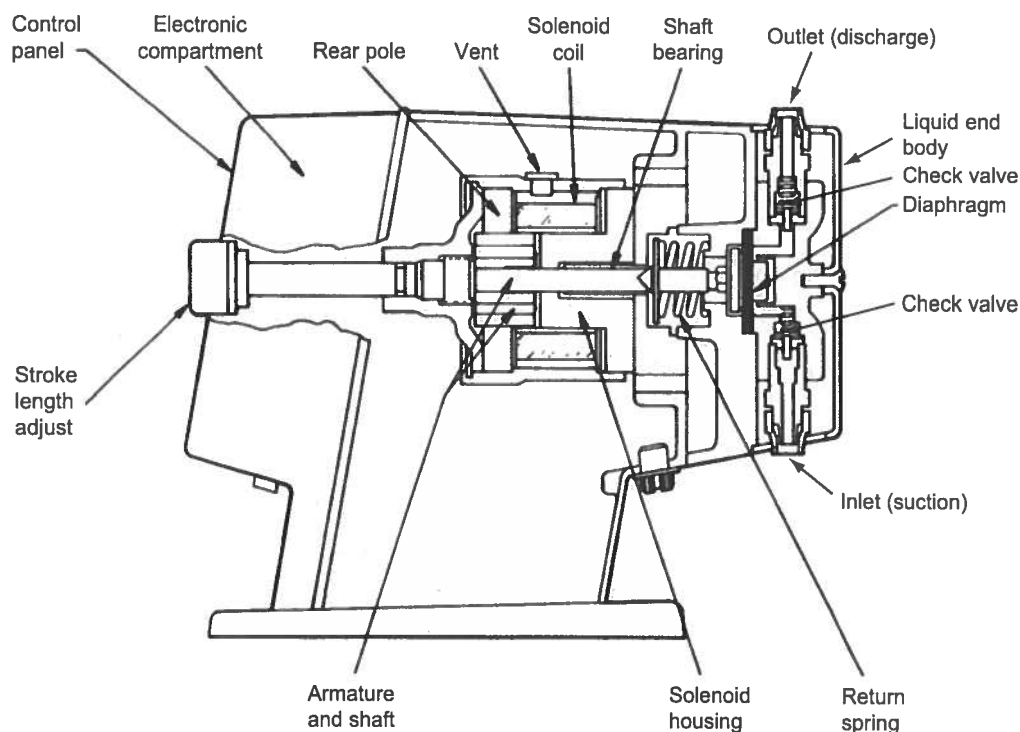


Figure 7.1.3.1 — Electromagnetic drive

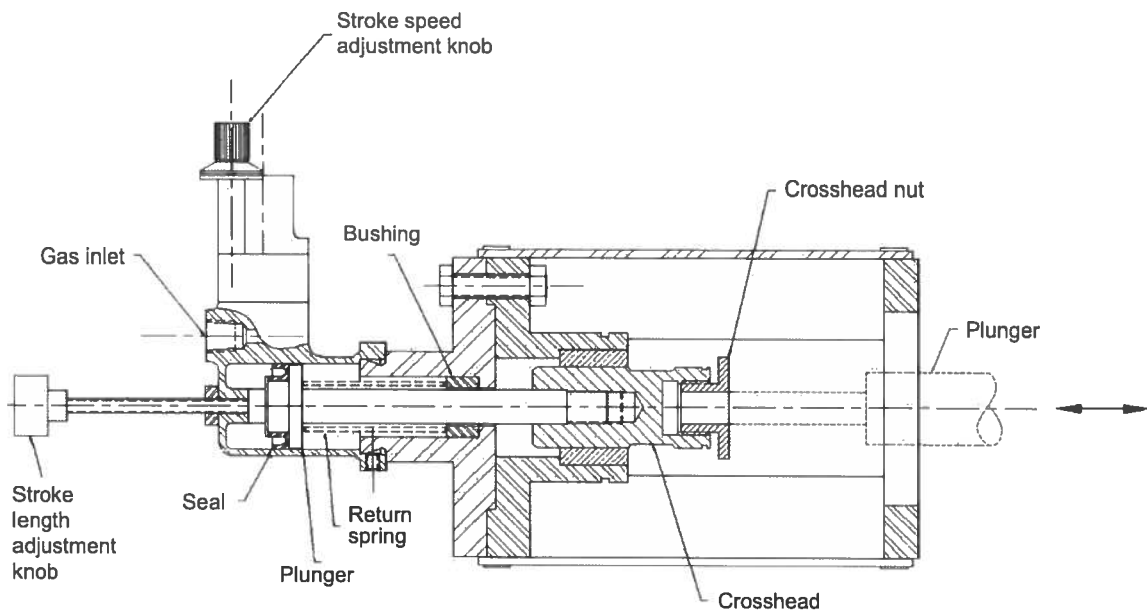


Figure 7.1.3.2 — Reciprocating air drive

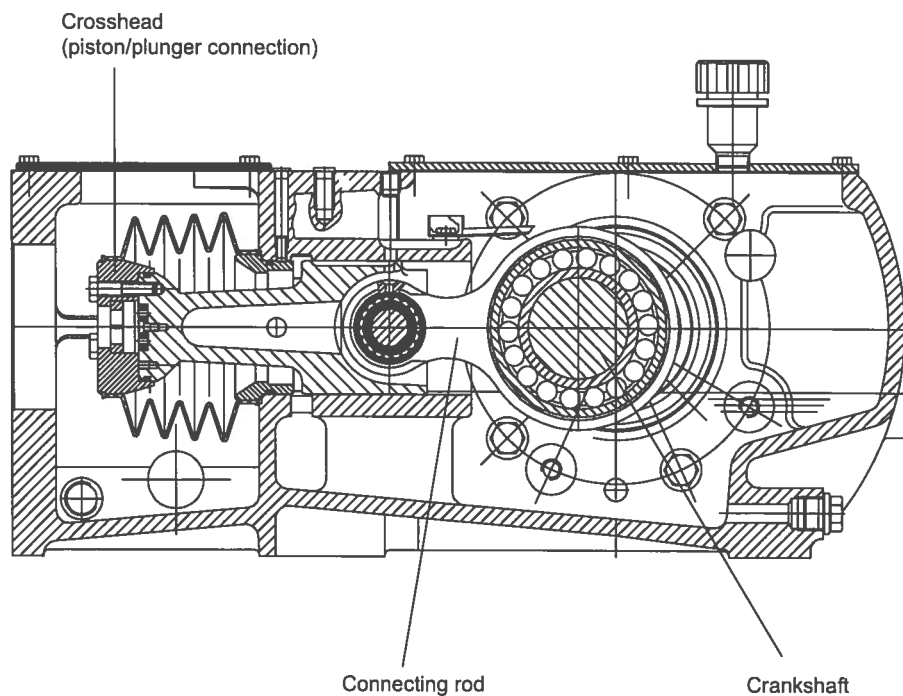


Figure 7.1.3.3 — Fixed stroke-length drive

7.1.3.4 Mechanical lost-motion drives

Mechanical lost-motion drives (Figure 7.1.3.4) have adjustable mechanical stops limiting the stroke length of the piston, plunger, or push rod to some portion of the total stroke. Rate of flow is controlled by the adjustment of the stop. These pumps are normally used at lower rates of flow. Figure 7.1.2.3 also illustrates the construction of a mechanical lost-motion drive in conjunction with a mechanically coupled diaphragm liquid end.

7.1.3.5 Hydraulic lost-motion drives

Hydraulic lost-motion drives (see Figure 7.1.3.5) use a constant mechanical stroke length to pump hydraulic fluid to actuate a diaphragm. To adjust the rate of flow, a portion of the hydraulic fluid is bypassed so it imparts less motion to the diaphragm. These pumps are typically used at lower rates of flow.

7.1.3.6 Variable stroke-length drive mechanisms (non-lost-motion drive)

For typical design configurations, the effective radius of the crank arm is adjustable, varying the stroke length of the piston. The velocity and acceleration of the flow remains sinusoidal, but the volume per stroke can be reduced throughout the adjustment range. Sinusoidal output is similar to fixed stroke-length drives except that there is a mechanical means to change the effective stroke length, which changes the volume per stroke. Therefore, these non-lost-motion drives (see Figure 7.1.3.6) tend to be used in higher flow applications or when long pipe runs are required.

7.1.4 Nomenclature

The nomenclature and definitions in these standards were prepared to provide a means for identifying the various pump components covered by these standards and to serve as a common language for all who deal with this type of equipment.

7.1.4.1 Automatically controlled

The mechanism for varying the pump rate of flow is controlled by an external electronic or pneumatic signal. The external signal may control the stroke length and/or input speed to the pump.

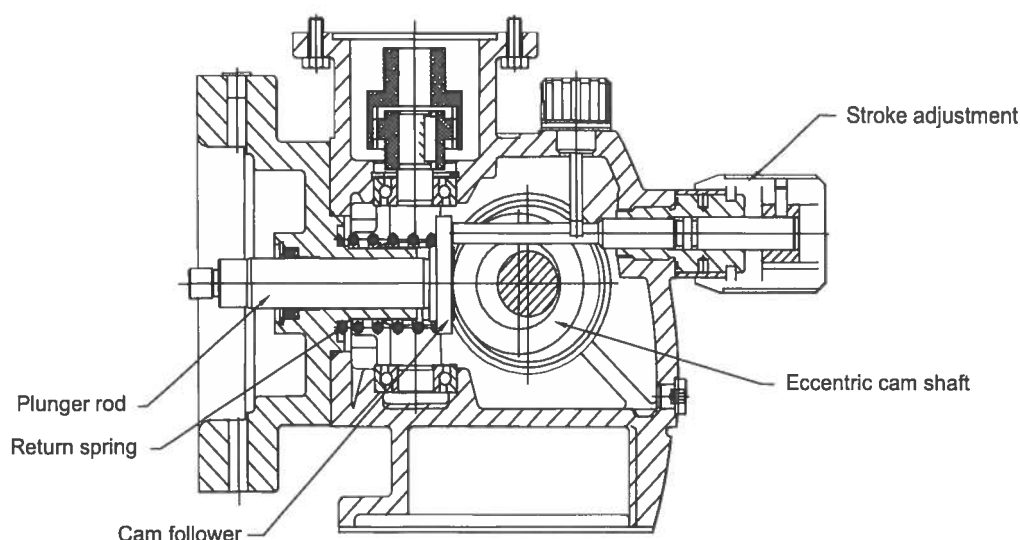


Figure 7.1.3.4 — Mechanical lost-motion drive

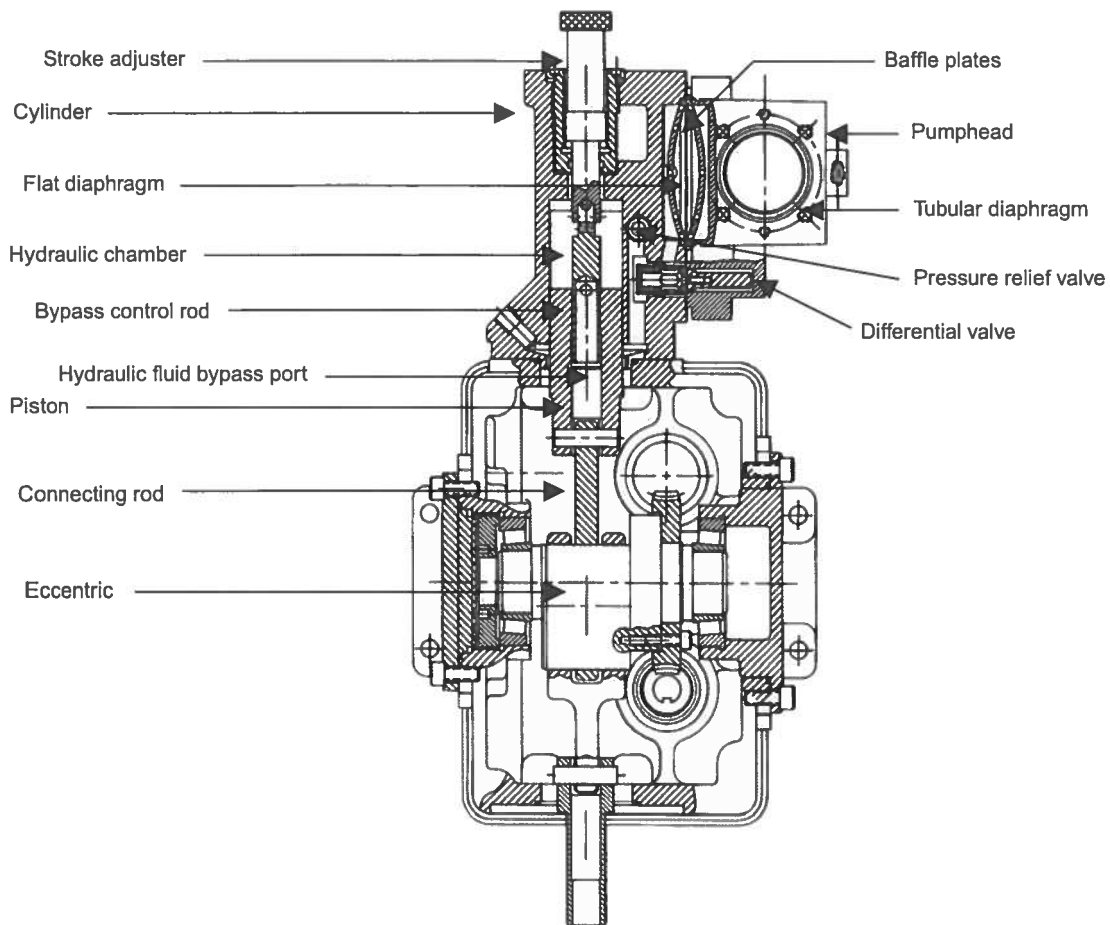


Figure 7.1.3.5 — Hydraulic lost-motion drive

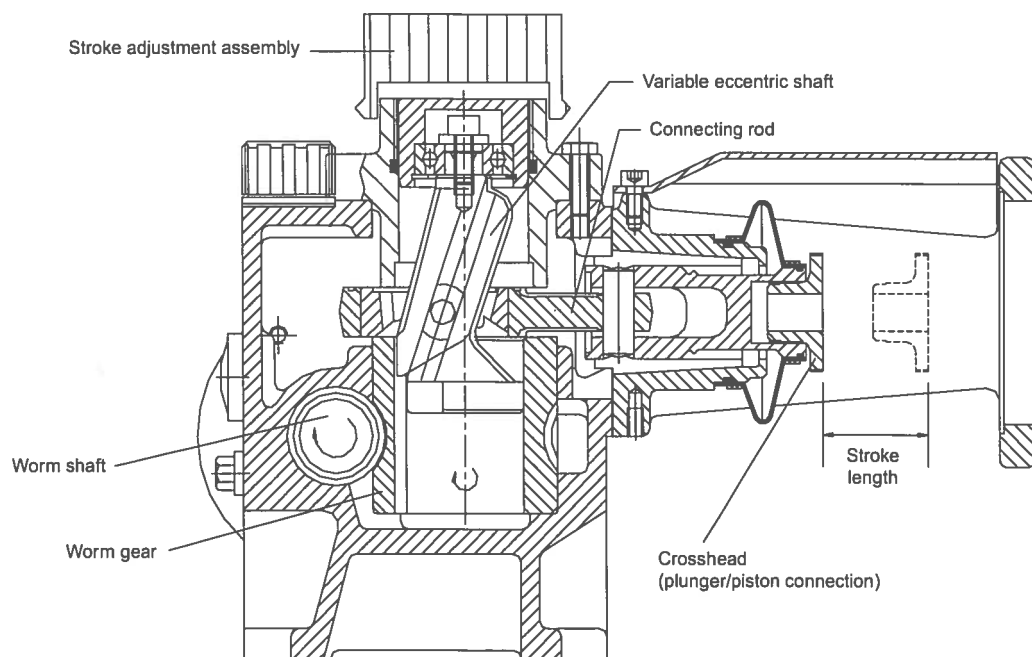


Figure 7.1.3.6 — Variable stroke-length drive (non-lost-motion)

7.1.4.2 Check valves

A controlled-volume pump uses suction and discharge check valves to produce directional flow of process liquid in the liquid head assembly. Various configurations of check valves are available for specific applications.

7.1.4.3 Diaphragm hydraulic system

Hydraulically actuated diaphragm pumps require hydraulic valves for proper operation. These valves are used to relieve, replenish, and/or bleed the hydraulic systems.

7.1.4.4 Diaphragm leak detection

Diaphragm leak detection systems are sensing systems that detect if a diaphragm has been compromised. These systems may detect reactions in barrier fluid, mechanical degradation of a diaphragm, changes in pressure/vacuum between diaphragms, or direct leakage of the process liquid by external means.

7.1.4.5 Diaphragms

Diaphragms provide isolation of the various liquids encountered in a diaphragm pump. To perform adequately, they should be of sufficient thickness and of appropriate material to minimize degradation from, or permeation of, the specified process liquid. Many diaphragm materials and configurations exist, but all perform the same basic function.

7.1.4.6 Liquid end assembly

The pump liquid end assembly (also called the *reagent head assembly* or *wet end*) includes all parts that contain the liquid being pumped.

7.1.4.7 Manually controlled

The mechanism for varying the pump rate of flow is manually adjusted.

7.1.4.8 Multiple diaphragm

A multiple diaphragm design uses two or more diaphragms operating in unison to provide redundant process liquid isolation. The diaphragms may be of similar or different design but must be synchronized to provide proper accuracy.

7.1.4.9 Simplex pump

Simplex pumps consist of a single liquid end and a single driver.

7.1.4.10 Multiplex pump

Multiplex pumps contain two or more liquid ends with the same or different capacities, powered by the same driver.

7.1.4.11 Remotely mounted liquid end

Most applications use liquid ends mounted directly to the drive mechanism. However, for extreme temperature services or a highly contaminating or explosive process, remotely mounted liquid heads may be specified to isolate the drive and/or control mechanisms.

7.2 Definitions

The purpose of this section is to define terms used in pump specification and applications. Symbols, terms, and units are shown in Tables 7.2a and 7.2b.

7.2.1 Accuracy and performance

The compound definition of metering performance, composed of steady state accuracy, linearity, and repeatability.

7.2.2 Accuracy, steady state

Steady state accuracy is the variation in rate of flow over a specified period of time, under fixed pump and system conditions, expressed as a percent of the maximum calibrated rate of flow. Steady state accuracy applies over a defined turndown ratio.

7.2.3 Capacity, rate of flow

7.2.3.1 Capacity, adjustment

The rate of flow produced by a reciprocating, controlled-volume metering pump may be controlled by varying stroke length (displacement per stroke) and/or the stroke speed (reciprocation rate or frequency).

7.2.3.2 Capacity, rate of flow (Q)

The rate of flow of a pump is the total volume throughput per unit of time at suction conditions. It assumes no entrained gases at the stated operating conditions. The term *capacity* is also used.

7.2.3.3 Capacity, design rate of flow (Q_D)

The design quantity of liquid delivered per unit of time at the maximum capacity settings and a given set of operating conditions specified by the manufacturer.

7.2.3.4 Capacity, actual rate of flow (Q_R)

The actual quantity of liquid delivered under installed conditions.

7.2.4 Displacement (D)

The volume swept by the piston or plunger in one stroke.

For single-acting pumps: $D = AL$

Where:

D = Displacement, in cubic centimeters (cubic inches)

A = Piston or plunger area, in square centimeters (square inches)

L = Stroke length, in millimeters (inches)

$$D = \frac{ALM}{10}$$

7.2.5 Efficiency, mechanical

The ratio of the pump power output to the pump power input, expressed as a percent.

7.2.6 Efficiency, volumetric

The ratio of the actual pump delivery per stroke to theoretical displacement, expressed as a percent.

7.2.7 Linearity

Linearity is an expression of maximum deviation (plus or minus) of a series of measured rates of flow versus capacity setting points to corresponding points on a theoretical straight line drawn through the points on a graph. The straight line is determined by the "least squares fit" method, applied to the measured points, obtained during a pump calibration test. Linearity is expressed as percent of maximum calibrated rate of flow. See Figure 7.3.1c.

7.2.8 Net positive suction head available (NPSHA)/Net positive inlet pressure available (NPIPA)

NPIPA is the total absolute suction pressure available from the system, determined at the pump suction nozzle, less the absolute vapor pressure of the liquid at pumping temperature.

$$\text{NPIPA} = p_{sa} - p_{vp}, \text{ in kPa (psi)}$$

Where:

$$p_{sa} = \text{total suction pressure} + \text{barometric pressure} = p_s + p_b, \text{ in kPa (psi)}$$

$$p_{vp} = \text{vapor pressure of the liquid at the temperature being pumped, in kPa (psi)}$$

or

$$\text{NPIPA} = p_s + p_b - p_{vp}, \text{ in kPa (psi)}$$

Where:

$$\text{(Metric units)} \quad p_s = p_{gs} + p_v + \frac{Z_s}{0.102}, \text{ in kPa}$$

$$\text{(US customary units)} \quad p_s = p_{gs} + p_v + \frac{Z_s}{2.31}, \text{ in psi}$$

NPIPA is determined at the centerline of the pump suction nozzle.

NPSHA is the same concept expressed in units of meters (feet) of process fluid.

7.2.9 Net positive inlet pressure required (NPIPR)/Net positive suction head required (NPSHR)

Net positive inlet pressure required (NPIPR) is the amount of suction pressure required by the pump to obtain satisfactory volumetric efficiency and minimize the effects of cavitation. This is usually when there is no more than 3% reduction in flow rate (capacity) from the pump at any air inlet pressure and total head condition on the pump curve. The pump manufacturer determines by test the net positive inlet pressure required by the pump at the specified operating conditions.

NPSHR is the same concept expressed in units of meters (feet) of process fluid.

7.2.10 Power, pump input

The mechanical power delivered to the pump input shaft at the specified operating conditions. Input power required is a function of the calculated pump output power and the manufacturer's stated efficiency.

7.2.11 Power, pump output power (hydraulic horsepower)

The hydraulic power imparted to the liquid by the pump at the specified operating conditions.

7.2.12 Pressure, acceleration (P_{acc})

Liquid in the suction and discharge piping of controlled-volume metering pumps has to be accelerated because flow varies from zero to peak with each stroke. This results in alternate pressure drops and surges. The instantaneous pressure drop required to accelerate the mass of liquid in the suction line, or the instantaneous pressure rise required to accelerate the mass of liquid in the discharge, is referred to as *acceleration pressure*.

7.2.13 Pressure, differential

The difference between discharge pressure and suction pressure at a given set of operating conditions.

7.2.14 Pressure, discharge (p_d)

The liquid pressure at the pump discharge port.

7.2.15 Pressure, discharge, rated

The required discharge pressure of the pump at specified operating conditions.

7.2.16 Pressure, friction loss (p_f)

The loss of pressure energy in a liquid due to friction as it flows through pipe, fittings, instrumentation, and equipment.

7.2.17 Pressure, suction (p_s)

The liquid pressure at the pump suction port.

7.2.18 Pressure, suction, maximum allowable ($p_{s\ max}$)

The maximum continuous suction pressure for which the manufacturer designed the pump at a given set of operating conditions specified by the manufacturer.

7.2.19 Pressure, suction, minimum allowable (MASP)

The minimum allowable pressure in absolute units at the pump inlet. This is governed by hydraulic considerations of the refill valve and is usually applicable to hydraulically actuated diaphragm-type pumps. It is determined by the pump manufacturer.

7.2.20 Pressure, total system discharge

The pressure the pump must generate to overcome system conditions. It is the sum of injection point pressure, static head resulting from discharge elevation, pipeline and component friction losses, and liquid acceleration losses.

7.2.21 Repeatability

Flow repeatability is rate of flow variation, expressed as a percent of maximum calibrated rate of flow, resulting from an excursion from a rate of flow set point followed by a return to that set point.

7.2.22 Slip (S)

Slip of a reciprocating pump is the loss of flow rate, expressed as a fraction or percent of displacement, due to leaks past the valves (including backflow through the valves caused by delayed closing) and past double-acting pistons. Slip does not include liquid compressibility or leaks from the liquid end.

7.2.23 Stroke length (L)

The length of complete movement of a piston, plunger, or mechanical diaphragm in one direction. Stroke length is typically expressed in millimeters (inches).

7.2.24 Stroke speed (n)

The number of strokes per unit of time. Stroke speed is typically expressed in strokes per minute (spm) or revolutions per minute (rpm).

7.2.25 Stroke speed, maximum allowable

The highest stroke speed at which the manufacturer's design will permit accurate metering under a given set of operating conditions.

7.2.26 Stroke speed, minimum allowable

The lowest stroke speed at which the manufacturer's design will permit accurate metering under a given set of operating conditions.

7.2.27 Suction, flooded

Under flooded suction conditions, the pressure at the inlet of the pump is always greater than or equal to 1 atmosphere while the pump is operating.

7.2.28 Suction lift, static

Under suction lift conditions, the pressure at the inlet of the pump is less than 1 atmosphere while the liquid is at rest. Suction lift may be thought of as "negative" static suction head.

7.2.29 Suction lift, total

The difference between the absolute operating inlet pressure at the pump inlet port centerline and atmospheric pressure. It is the sum of suction system frictional losses and the static suction lift.

7.2.30 Temperature, maximum rated (t_{max})

The maximum continuous temperature for which the manufacturer has designed the equipment when handling the specified liquid at the specified pressure.

7.2.31 Temperature, minimum rated (t_{min})

The minimum continuous temperature for which the manufacturer has designed the equipment when handling the specified liquid at the specified pressure.

7.2.32 Turndown ratio

Turndown ratio is the maximum rate of flow divided by the minimum rate of flow that can be obtained while maintaining the specified steady state accuracy, linearity, and repeatability.

Table 7.2a — Symbols

Symbol	Term	Metric unit	Abbreviation	US Customary unit	Abbreviation	Conversion factor ^a
A	Area of piston/plunger	square centimeter	cm ²	square inch	in ²	6.45
β (beta)	Meter or orifice ratio	dimensionless	—	dimensionless	—	1
C	Coefficient for acceleration head	dimensionless	—	dimensionless	—	1
d	Diameter	millimeter	mm	inch	in	25.4
D	Displacement	cubic centimeter	cm ³	cubic inches	in ³	16.39
Δ (delta)	Difference	dimensionless	—	dimensionless	—	1
η (eta)	Efficiency	percent	%	percent	%	1
g	Gravitational acceleration	meter/second squared	m/s ²	foot/second squared	ft/s ²	0.3048
γ (gamma)	Specific weight	newton/cubic meter	N/m ³	pound/cubic foot	lb/ft ³	0.0064
h	Head	meter	m	foot	ft	0.3048
L	Stroke length	millimeter	mm	inch	in	25.4
M	Number of pistons	dimensionless	—	dimensionless	—	1
n	Speed	stroke/minute	spm	stroke/minute	spm	1
NPIPA	Net positive inlet pressure available	bar absolute	bara	pound/square inch absolute	psia	0.0689
NPIPR	Net positive inlet pressure required	bar absolute	bara	pound/square inch absolute	psia	0.0689
NPSHA	Net positive suction head available	meter absolute	m	foot	ft	0.3048
NPSHR	Net positive suction head required	meter	m	foot	ft	0.3048
ν (nu)	Viscosity, kinematic	meter squared/second	m ² /s	centistoke	cSt	10 ⁶
π	pi = 3.1416	dimensionless	—	dimensionless	—	1
p	Pressure	bar	bar	pound/square inch	psi	0.0689
P	Power	kilowatt	kW	horsepower	hp	0.7457
Q	Rate of flow (capacity)	liter/hour	L/h	US gallon/hour	gph	3.7854
ρ (rho)	Density	kilogram/cubic meter	kg/m ³	pound mass/cubic foot	lbm/ft ³	16.02
s	Specific gravity	dimensionless	—	dimensionless	—	1
S	Slip	percent	%	percent	%	1
t	Temperature	degree Celsius	°C	degree Fahrenheit	°F	(°F–32) × 5/9
τ (tau)	Torque	newton-meter	N·m	pound-foot	lb-ft	1.356
μ (mu)	Viscosity, absolute	centipoise	cP	centipoise	cP	1
v	Velocity	meter/second	m/s	foot/second	ft/s	0.3048
V	Specific volume	cubic meter/kilogram	m ³ /kg	cubic foot/pound	ft ³ /lb	0.0624
x	Exponent	none	none	none	none	1
Z	Elevation gauge distance above or below datum	meter	m	foot	ft	0.3048

^a Conversion factor × US customary units = metric units (except temperature).

Table 7.2b — Subscripts

Subscript	Term	Subscript	Term
a	Absolute	ni	Net Inlet
A	Actual	o	Outlet
acc	Acceleration	oa	Overall
b	Barometric	p	Pump
c	Piston or plunger	s	Suction
d	Discharge	t	Theoretical
D	Design	Δ (delta)	Differential
drv	Driver	v	Velocity
g	Gauge	V	Volume
H	Total head	vp	Vapor pressure
i	Inlet	w	Hydraulic or water
max	Maximum	x	Exponent
min	Minimum	1	Test condition
mot	Motor	2	Specific condition

7.3 Application of controlled-volume metering pumps

7.3.1 Typical uses and industries

Controlled-volume metering pumps are used in many industrial and municipal applications. They are used where the process requirements and/or cost of the chemical additives dictate accuracy, consistency, and repeatability. In general, most applications can be categorized as one of the following:

- Single-point injection, used for:
pH adjustment; boiler feed treatment; process additive injection
- Controlled transfer, used for:
reactor feed; point-to-point transfer; filling operations
- Multistream proportioning, blending and mixing, used for:
resin blending; mayonnaise production; continuous dye addition

The controlled-volume metering pumps are used in a wide range of industries, including the following:

- Agriculture
- Boiler and cooling water treatment
- Chemical and petrochemical processing
- Food and beverage processing

- Gas odorization
- Mining and ore extraction
- Oil and gas production and transmission
- Personal care products
- Pharmaceuticals
- Potable water treatment
- Power generation
- Pulp and paper
- Textiles
- Wastewater treatment

7.3.2 General principles

The pumping action is developed by a reciprocating piston. This reciprocating motion develops a flow profile represented by a sine wave. Actual rate of flow is determined by the following formula:

$$\text{Rate of flow} = \text{Displacement} \times \text{Cycles per unit of time} \times \text{Volumetric efficiency}$$

Figure 7.3.1a illustrates how the rate of flow from a reciprocating, controlled-volume metering pump is minimally affected by changes in discharge pressure.

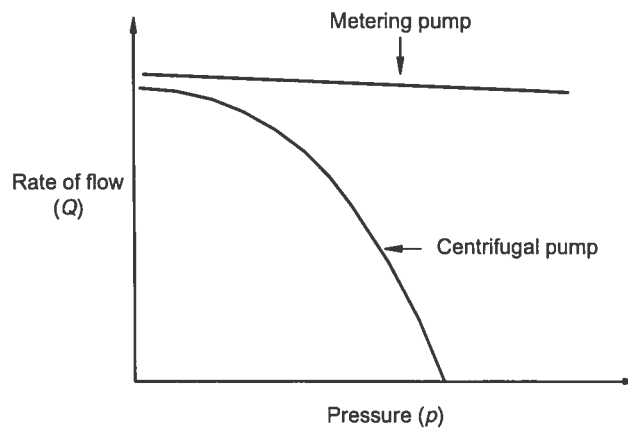


Figure 7.3.1a — Rate of flow versus pressure

Figure 7.3.1b illustrates how the average flow from a reciprocating controlled-volume metering pump is determined over several complete cycles.

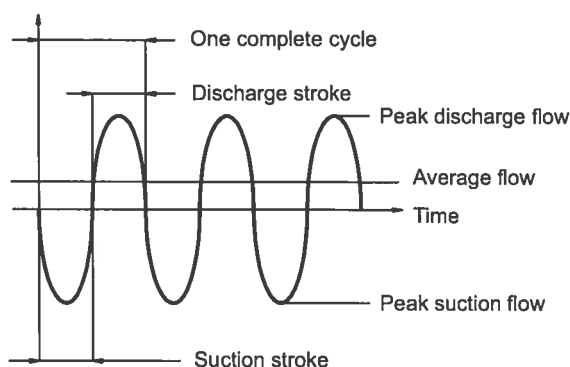


Figure 7.3.1b — Flow profile for reciprocating pump

Figure 7.3.1c shows rate of flow versus stroke-length setting for a controlled-volume metering pump at a given pressure and stroking speed. The curve is linear. The curve is not necessarily proportional in that 50% stroke setting may not equal 50% flow. This is because the curve may not pass through zero on both axes simultaneously. By measuring flow at two rate-of-flow settings, plotting both points, and drawing a straight line through them, other rates of flow versus stroke length settings can be accurately predicted.

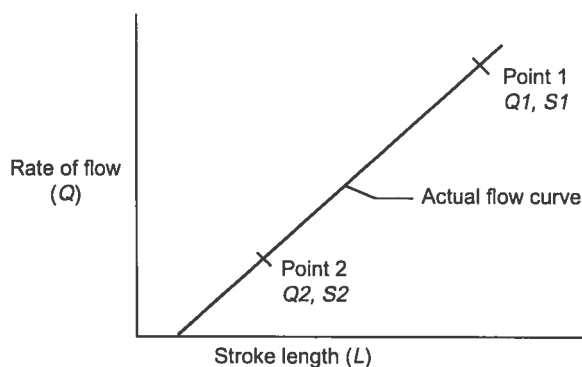


Figure 7.3.1c — Actual flow curve, rate of flow versus stroke length

Figure 7.3.1d illustrates the relationship between the theoretical and actual rate of flow of a controlled-volume metering pump. The difference between the theoretical and actual curves represents the volumetric efficiency (VE) as defined in Section 7.2.6.

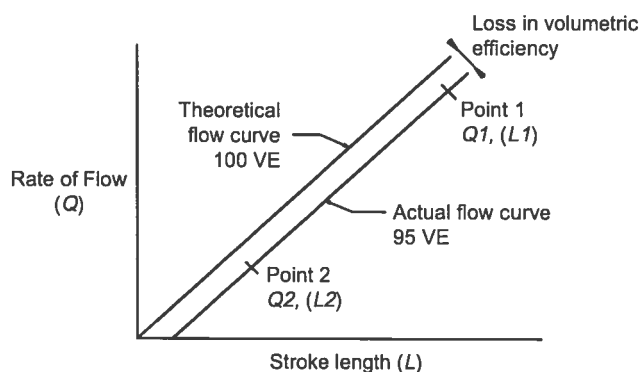


Figure 7.3.1d — Theoretical and actual flow curve, rate of flow versus stroke length

7.3.3 Sizing and selection

The manufacturer requires the following information to ensure the proper selection and operation of the controlled-volume metering pump.

7.3.3.1 Application data requirements

To begin the process of selecting the appropriate pump and its configuration, the end user must furnish detailed information regarding its process requirements, such as:

- Minimum, maximum, and normal operating rate of flow
- Minimum, maximum, and normal operating temperature
- Minimum, maximum, and normal operating suction pressure
- Minimum, maximum, and normal operating discharge pressure
- Material compatibility at process conditions
- Required accuracy and performance
- Basic liquid properties at operating conditions (viscosity, vapor pressure, solids characteristics, temperature, specific gravity)
- Special liquid properties (toxicity, flammability, reactivity, rheology)
- Utilities available, operational environment, and area classification
- Type of pump (refer to Section 7.1)
- Type of driver
- System control requirements
- System piping configuration and requirements

The criteria listed above is required by the manufacturer to select a pump that best meets the end user's needs.

7.3.3.2 Rate of flow and turndown

Controlled-volume metering pumps with stroke-length adjustment typically have a rate-of-flow (capacity) adjustment range between 10 and 100% of rated flow, expressed as a turndown ratio of 10:1. Below the stated turndown, accuracy cannot be guaranteed. The pump should be sized such that the entire flow range falls between 10 and 100 percent of the pump rate of flow.

Controlled-volume metering pumps may also use stroke frequency adjustment with turndown ratio dependent on the stroking speed of the pump and turndown capability of the driver.

Greater turndown range can be achieved in some applications by using both stroke-length adjustment and driver speed control when maximum rate of flow is greater than 10 times minimum flow. Extended turndown range must be confirmed with the pump manufacturer.

For optimal performance and most economical operation, a pump should be sized to operate at the top 30% of its rated flow rate. Operation in this range promotes the highest accuracy.

7.3.3.3 Materials of construction

The materials used in the construction of a controlled-volume metering pump must be compatible with the liquid being pumped. This includes all wetted components of the liquid end, such as seals, gaskets, diaphragms, and elastomers. The effects of corrosion, erosion, and reactivity at operating conditions must be considered when selecting or specifying equipment.

7.3.3.4 Environment

Special protection or material may be required if the pump is exposed to temperature extremes, high humidity, high salt content, or ultraviolet light (sun). Corrosive atmospheres may indicate a need for a special finish or coating. The purchaser/end user must know the area classification of the intended installation. Hazardous environments, including fumes or combustible dust, will affect pump, driver, accessory, and control configuration.

7.3.3.5 Choice of driver

The purchaser/end user may select electric motor, air/pneumatic or gas motor, or internal combustion engine, etc., depending on the application, the utilities available, and environmental concerns.

7.3.3.6 Control methods

- Manual adjustment of speed and/or stroke length
- Automatic adjustment of stroke length by electronic or pneumatic input signal
- Automatic adjustment of stroke speed by use of variable-speed drive, variable air pressure, or other means

7.3.3.7 Optional pump features

Accessory options are available for special applications, including, but not limited to:

- Gas vent valves to purge the liquid head when handling chemicals that off-gas
- Double diaphragms with leak detection systems; used where contamination of the process liquid must be prevented or when pumping hazardous or toxic chemicals and even the remote chance of leakage must be prevented
- Impulse/stroke counters
- Pressure and temperature sensors

7.3.4 System components

After pump selection, the balance of the installation must be defined. Plan the entire installation from the supply tank to the injection point and consider the necessary accessories. The manufacturers have experience in selecting and sizing the components associated with metering pump installations and can assist with selection of these components.

7.3.4.1 Suction piping

Suction pipe systems must be designed to satisfy the NPIP (NPSH) requirements of the pump. As a general rule, the pump should be located as close to the liquid supply as possible. An inlet stabilizer or standpipe may be mounted in the suction line, near the pump, to improve the suction inlet condition to the pump (i.e., increase NPIPA [NPSHA]).

- When appropriate, a "Y" strainer or similar device should be installed in the suction line to prevent particles from clogging the pump check valves
- A calibration column installed in the suction line, near the pump, will provide a means to verify pump output under actual operating conditions
- As an option, a flush line can be added to facilitate cleaning

7.3.4.2 Discharge piping

Discharge piping systems must be designed to accommodate peak flow and pressure conditions. System components typically used in discharge line design include:

- Safety relief valve – to protect pump, piping, and components.
- Backpressure valve – to provide necessary pressure to ensure proper pump check valve operation and to prevent siphoning when pumping to a low discharge pressure or when the differential between suction and discharge pressure is not sufficient.
- Pulsation dampener – to minimize flow and pressure variations in the discharge piping, if required.
- Pressure gauge and snubbers (or diaphragm seal for viscous, corrosive chemicals or slurries) to monitor the pump operation. Gauge block and test valves may or may not be desirable depending on application. A gauge test valve may also be used as a vent for ease of start-up.
- Injection check valve – installed at the injection point provides separation of the chemical and the fluid into which the chemical is injected. Addition of an injection quill at the injection point aids in more rapidly dispersing the injected chemical into a process stream.
- Other valves to consider – priming, isolating, draining, sampling, and flushing.

7.4 Installation, operation, and maintenance

With proper installation, care, and regular maintenance, controlled-volume metering pumps will operate satisfactorily for many years. The following paragraphs discuss the general principles that must be considered to ensure trouble-free operation.

Controlled-volume metering pumps are built in a wide variety of designs for many different services. The manufacturer's instruction book furnished with each pump should be carefully studied and followed as there may be specific requirements of a particular application that cannot be covered in a general discussion.

7.4.1 Safety

The following precautions should be taken when working with controlled-volume metering pumps to ensure safety of personnel:

- Follow all safety requirements per operating instructions, codes, and regulations.
- Electrical power should be turned off. All valves to liquid end should be closed and the liquid end drained.

CAUTION: Care should be taken to dispose of toxic or flammable liquids or vapors properly.

- The work area should be kept clear and all unnecessary items removed.
- All lifting devices should be checked for condition and weight limits before using.
- Before dismantling, assembling, or performing maintenance on the pump, the proper tools, correct parts, and manufacturer's instruction book shall be reviewed and available for consultation.
- Eye protection and appropriate protective gear must be worn.

7.4.2 Storage

All controlled-volume metering pumps are inspected and protected against corrosion for the period of shipment and installation only.

If the pump is not to be installed at once, then the pump and parts, such as packing, special wrenches, etc., should be stored in a clean, dry location, free from temperature extremes, in an approximately level position. Coat all machined surfaces with heavy, noncorrosive preservative. Inspect frequently to see that the surfaces are free of corrosion. Renew the preservative when necessary. Before putting unit into operation, inspect and clean thoroughly.

When it is known that a pump will be in storage or taken out of service for more than three months, such as for a relocation, plant shutdown, etc., follow manufacturer's instructions. Inspect periodically for possible leakage. In severe storage conditions, such as salt-laden marine environments or subfreezing temperatures, consult the manufacturer for a recommendation or for additional procedures.

7.4.3 Location of pump

Locate the pump as close to the liquid supply as possible. The location should be clean, protected from seepage or flood, and have adequate clearance to facilitate any repair, maintenance, or inspection activity.

7.4.4 Foundation

Depending on size and weight, controlled-volume pumps can be located on the floor or supporting structure. The purchaser/end user should consider ease of access for maintenance and the recommendations of the manufacturer.

7.4.5 Installation

Most pumps are aligned with the driver before leaving the factory. It is important the entire pump be properly supported and leveled. Use care not to spring the pump out of alignment when fastening it to the foundation. Alignment must be rechecked after piping has been completely installed.

7.4.5.1 Piping

Pipes must line up naturally. They must not be pulled into place with flange bolts, as this may force the pump out of alignment. Pipes should be supported independently of the pump so as to produce minimum strain on the pump.

7.4.5.2 Forces and moments

The most desirable arrangement is one in which suction and discharge piping line up naturally with the respective pump connections. When this is done, no force or moment is exerted on the pump that could result in stresses in the pump or its foundation. Thermal expansion, when handling hot or cold liquids, must also be considered. When the piping tends to expand or contract, it exerts a force and often a twist (torque or moment) on the point of restraint, such as the pump piping connection. Pipe strains are a common cause of process leakage, misalignment, hot bearings, worn couplings, and vibration. When requested by the purchaser/end user, the pump manufacturer shall advise the maximum allowable forces and moments that may be applied to the pump connections.

Variations in flow and pressure, changes in direction of flow, cavitation, worn pistons, pump valves, etc., all contribute to piping vibration. Therefore, suction and discharge piping must be rigidly fixed in all directions and not just lightly strapped down. Flush, clean, and blow out all piping before connecting to the pump. Use pipe dope and tape sparingly on male threads only.

7.4.5.3 Flanges and fittings

Flange fittings, unions, and flexible connectors should be located close to the pump in all pipelines, so as to facilitate removal of the pump. Alignment must be rechecked after suction and discharge piping have been bolted to the pump for testing the effect of piping strains. When handling hot or extremely cold liquids, disconnect the nozzle flanges after the unit has been in service to check the direction in which the piping expansion is acting. Correct for strain effect as required to obtain true flange alignment.

7.4.5.4 Priming

Controlled-volume metering pumps operating with a flooded suction will typically self-prime. Under suction-lift conditions, controlled-volume metering pumps are not necessarily self-priming and must be purged or may require a foot valve installed at the base of the suction pipe. Providing a vent port in the discharge piping makes some pumps self-priming at a reasonable suction lift. Other suction-lift installations may require priming by filling the pumphead chamber and suction pipe with liquid.

7.4.5.5 Safety relief valve

A safety relief valve should be installed in the discharge piping of a controlled-volume metering pump to protect the pump and system piping from overpressure. Pressure relief valve installation should be in accordance with local end user requirements or applicable code.

The final set pressure must be below the lowest rated working pressure component in the discharge system. The relief valve must be set sufficiently above the operating discharge pressure to prevent opening due to the discharge pressure peak. This causes decreased output rate of flow from the pump and diminished relief valve life.

NOTE: Hydraulically coupled diaphragm pumps are provided with internal hydraulic relief valves. These valves are designed to protect the pump drive mechanism and driver only. Do not use this internal valve for system protection.

7.4.5.6 Drive alignment after piping installation

After the piping has been installed, the pump and driver alignment should be checked again and corrected as required.

7.4.5.7 Gaskets, pipe dope, and pipe tape

The gaskets, pipe dope, and pipe tape used in the system piping are exposed to the same conditions of high or low temperatures, pH values, etc., as the pump wetted parts. Careful selection is necessary to avoid joint failure and the air and liquid leaks that follow.

CAUTION: Care must be taken to prevent any of these materials from contaminating the suction line, and fouling the pump check valves.

7.4.5.8 Flexible coupling

Controlled-volume metering pumps may use high-speed/low-torque or low-speed/high-torque flexible couplings. Proper alignment of coupling and driver is critical for satisfactory operation. Consult and follow the manufacturer's recommendations.

7.4.5.9 Lubrication

The power ends of controlled-volume metering pumps may use pressure, splash, or gravity lubrication. Grease-fed lubrication is also used. It is very important that the manufacturer's specific instructions or nameplate data be carefully followed as to choice of oil and the frequency of lubricant changes. The oil must be checked periodically for contamination.

7.4.6 Inspection

The pump should be inspected regularly. Leaky valves should be corrected as soon as they are discovered. Most pump troubles can be traced to worn valves, packing, rods, plungers, or bushings; grooved liners; improper suction conditions; or to faulty conditions outside the pump itself. There is no substitute for regular, thorough preventive maintenance. Table 7.4.6 provides guidelines for troubleshooting some of the most common conditions encountered in controlled-volume metering pump installations.

Table 7.4.6 — Locating trouble: controlled-volume metering pumps

Trouble	Possible Cause	Remedy
Pump rate of flow too low or no flow	Liquid end air-bound	Vent liquid cylinder and/or diaphragm chamber.
	Hydraulically coupled system vapor-bound	Allow pump to operate at low pressure through bypass valve to eliminate vapor.
	Dirty or worn check valves	Clean or replace check valve balls (or poppet parts) and seats.
	Restricted or clogged suction line	Clean suction strainer. Blow down suction line. If this trouble occurs often, use larger size strainer.
	Excessive suction lift	Decrease suction lift condition.
	Insufficient suction head	Increase suction pipe diameter and/or decrease length. Check NPIPA calculation. Consider use of suction stabilizer if necessary.
	Leaking pressure relief valve (internal or external)	Replace or reset relief valve. Measure discharge pressure spike.
	Incorrect pump setting	Increase stroke length or stroke speed.
	Restricted diaphragm support holes	Clean.
	Liquid viscosity too high	Reconfirm NPIPA vs. NPIPR. Review pump/check valve selection.
	Cavitation occurring	Reconfirm NPIPA vs. NPIPR.
Pump rate of flow too high	Insufficient discharge pressure or low differential pressure	Install backpressure valve to provide higher discharge/differential pressure.
	High liquid inertia due to suction acceleration	Use pulsation dampener to absorb pipe hammer. Or install backpressure valve to provide higher discharge/differential pressure.
	Incorrect pump setting	Decrease stroke length or stroke speed.

Table 7.4.6 — Locating trouble: controlled-volume metering pumps (continued)

Trouble	Possible Cause	Remedy
Speed reducer (gearbox) overheating (see manufacturer's instruction book for guideline)	Low oil level Too viscous or too much oil Dirty, contaminated oil (water or process contaminated) Excessive load caused by high operating pressure or high packing friction Bearings dirty or worn	Fill to proper level. Fill to proper level with correct viscosity and grade. Replace oil with fresh per instruction book. Reduce pressure. Check packing condition. Clean or replace. Flush and replace oil.
Overheating, pumphead housing (liquid end)	Low oil level Internal hydraulic relief valve is bypassing (for hydraulically coupled diaphragm pumps) Oil viscosity or level too high Excessive operating pressure	Fill to proper level. Check discharge pressure vs. set pressure of internal relief valve. Check condition of relief valve. Measure discharge pressure spikes if any. Fill to proper level with correct viscosity and grade per instruction book. Review pump selection.
Failure to start	Electrical/pneumatic circuit open	Correct electrical/pneumatic problem. Consult manufacturer's instruction book.
Pump stops (no mechanical motion)	Electrical/pneumatic circuit fault (circuit tripped) Pump internal mechanical problem Control system shut down the pump	Correct electrical/pneumatic problem. Inspect the pump. Consult manufacturer's instruction book. Check external control inputs.
Excessive or unusual noise during operation	Cylinder only partially filled during suction stroke Worn parts Cylinder packing too tight Relief valve bypassing (relieving)	Clean suction strainer. Blow down suction line. Inspect internals and replace bearings or other worn parts. Check packing gland. Inspect relief valve and check discharge pressure.
Leaking gland packing	Packing worn Plunger scored	Replace. Replace.

Source: Hydraulic Institute, 6 Campus Drive, First Floor North, Parsippany, NJ 07054-4406.

Appendix A

Index

This appendix is not part of this standard, but is presented to help the user with terms referenced in the standard.

Note: an f. indicates a figure, and a t. indicates a table.

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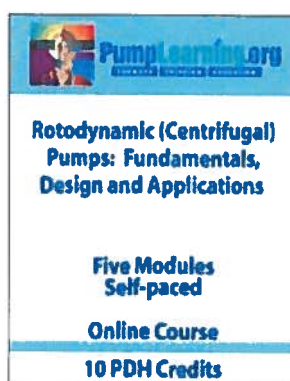
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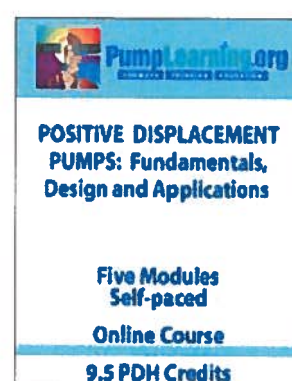
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