**Basic Accumulator Terms**

<table>
<thead>
<tr>
<th>Term</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precharge pressure</td>
<td>( p_0 )</td>
<td>Gas volume</td>
</tr>
<tr>
<td>Working pressure</td>
<td>( p_1 )</td>
<td>Gas volume</td>
</tr>
<tr>
<td>Working pressure</td>
<td>( p_2 )</td>
<td>Gas volume</td>
</tr>
<tr>
<td>Precharge ambient</td>
<td>( T_{p0} )</td>
<td>Gas volume</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>( T_1 )</td>
<td>Gas volume</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>( T_2 )</td>
<td>Gas volume</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
V_0 &= \text{Effective gas volume of the accumulator (this an internal net volume)} \\
V_1 &= \text{Gas volume at } p_1 \\
V_2 &= \text{Gas volume at } p_2 \\
T_0 &= \text{Temperature at precharging} \\
T_1 &= \text{Minimum ambient temperature} \\
T_2 &= \text{Maximum ambient temperature}
\end{align*}
\]

**Accumulator Operational Sequence Steps**

**Bladder**

1. The bladder accumulator is precharged with nitrogen to system design specified precharge pressure prior to accumulator installation.
   - The expanded, pressurized bladder causes the fluid port poppet to close, preventing the bladder from extruding into the fluid port.
   - No fluid is inside the accumulator at this step until the accumulator is installed in the hydraulic system and the system pressure becomes greater than the precharge pressure, \( p_0 \).
   - Once the system working fluid pressure becomes greater than \( p_0 \), the poppet will open and the bladder will begin to compress.

2. The accumulator is installed in the hydraulic system and the fluid is increased to the maximum working system pressure, \( p_1 \). This is often called “charging” the accumulator.
   - At \( p_1 \), the gas volume in the bladder accumulator is \( V_1 \).
   - At this step the maximum amount of fluid possible for a particular system pressure range is inside the accumulator and the fluid is compressing the bladder and nitrogen gas to smallest gas volume.

3. During operation, the minimum working system pressure, \( p_{min} \), is reached and the gas volume is now \( V_2 \). This is often called “discharging” the accumulator.
   - \( V_1 \) is the maximum gas volume during hydraulic system operation and correlates to the smallest possible fluid volume inside the accumulator during system operation.
   - The amount of fluid that is expelled, or supplied, to the hydraulic system is \( \Delta V \), where \( \Delta V = V_1 - V_2 \).
   - A small amount of fluid should remain inside the accumulator at \( p_{min} \), in order to prevent the bladder from rubbing or chaffing against the fluid port poppet which will cause bladder damage.
   - Therefore the precharge pressure, \( p_0 \), should always be slightly lower than the minimum working system pressure, \( p_{min} \).

**Diaphragm**

1. The diaphragm accumulator is precharged with nitrogen to system design specified precharge pressure prior to accumulator installation.
   - The expanded, pressurized diaphragm causes the integral poppet in the diaphragm to close over the fluid port opening, preventing the diaphragm from extruding into the fluid port.
   - No fluid is inside the accumulator at this step until the accumulator is installed in the hydraulic system and the system pressure becomes greater than the precharge pressure, \( p_0 \).
   - Once the system working fluid pressure becomes greater than \( p_0 \), the diaphragm and integral poppet will begin to compress and cause the integral poppet to move away from the fluid port opening.

2. The accumulator is installed in the hydraulic system and the fluid is increased to the maximum working system pressure, \( p_1 \). This is often called “charging” the accumulator.
   - At \( p_1 \), the gas volume in the diaphragm accumulator is \( V_1 \).
   - At this step the maximum amount of fluid possible for a particular system pressure range is inside the accumulator and the fluid is compressing the diaphragm and nitrogen gas to smallest gas volume.

3. During operation, the minimum working system pressure, \( p_{min} \), is reached and the gas volume is now \( V_2 \). This is often called “discharging” the accumulator.
   - \( p_1 \) is the maximum gas volume during hydraulic system operation and correlates to the smallest possible fluid volume inside the accumulator during system operation.
   - The amount of fluid that is expelled, or supplied, to the hydraulic system is \( \Delta V \), where \( \Delta V = V_1 - V_2 \).
   - A small amount of fluid should remain inside the accumulator at \( p_{min} \), in order to prevent the diaphragm from rubbing or chaffing against the shell which will cause diaphragm damage.
   - Therefore the precharge pressure, \( p_0 \), should always be slightly lower than the minimum working system pressure, \( p_{min} \).

**Piston**

1. The Piston accumulator is precharged with nitrogen to system design specified precharge pressure prior to accumulator installation.
   - The pressurized nitrogen will cause the piston to move completely over to the fluid port side.
   - No fluid is inside the accumulator at this step until the accumulator is installed in the hydraulic system and the system pressure becomes greater than the precharge pressure, \( p_0 \).
   - Once the system working fluid pressure becomes greater than \( p_0 \), the fluid pressure will begin to compress the gas by overcoming the precharge pressure, and cause piston to move away from the fluid port opening.

2. The accumulator is installed in the hydraulic system and the fluid is increased to the maximum working system pressure, \( p_1 \). This is often called “charging” the accumulator.
   - At \( p_1 \), the gas volume in the piston accumulator is \( V_1 \).
   - At this step the maximum amount of fluid possible for a particular system pressure range is inside the accumulator and the fluid is exerting force on the piston and compressing nitrogen gas to the smallest gas volume.

3. During operation, the minimum working system pressure, \( p_{min} \), is reached and the gas volume is now \( V_2 \). This is often called “discharging” the accumulator.
   - \( p_1 \) is the maximum gas volume during hydraulic system operation and correlates to the smallest possible fluid volume inside the accumulator during system operation.
   - The amount of fluid that is expelled, or supplied, to the hydraulic system is \( \Delta V \), where \( \Delta V = V_1 - V_2 \).
   - A small amount of fluid should remain inside the accumulator at \( p_{min} \), in order to prevent the piston from impacting the end cap for any system cycle.
   - Therefore the precharge pressure, \( p_0 \), should always be slightly lower than the minimum working system pressure, \( p_{min} \).
Accumulators

Bladder

Diaphragm

Piston

Precharge Recommendations

For energy storage:
\[ p_0 = 0.9 \times p_1 \]
\[ p_1 = \text{minimum working pressure} \]

For shock absorption:
\[ p_0 = (0.6 \text{ to } 0.9) \times p_m \]
\[ p_m = \text{median working pressure at free flow} \]

For pulsation dampening:
\[ p_0 = (0.6 \text{ to } 0.8) \times p_m \]
\[ p_m = \text{median working pressure} \]

Temperature Effect

Due to the Ideal Gas Laws, the precharge pressure of an accumulator is affected by the ambient temperature of the accumulator’s operating environment. Given the constant volume of an accumulator shell when the temperature rises, the gas pressure will increase and conversely as the temperature goes lower, the gas pressure decreases. This temperature effect on precharge gas pressure will affect operation of the accumulator in a hydraulic fluid system. Therefore it is critical to consider the precharge pressure at \( T_a \), maximum ambient temperature, and \( T_e \), the minimum ambient temperature, when sizing an accumulator to ensure that the accumulator is sized large enough to operate properly over the entire operating ambient temperature range. The formula below describes the ambient temperature and precharge pressure relationship to any temperature. Refer to the sizing example on page 95 to see how the formula is applied in the sizing calculation process.

Fahrenheit
\[ p_{0_{T_0}} = p_{0_{T_x}} \times \frac{T_0 + 460}{T_x + 460} \]
\[ T_0 = \text{precharge temperature in °F} \]
\[ T_x = \text{actual ambient operating temperature in °F, where } T_1 \leq T_x \leq T_2 \]
\[ p_{0_{T_0}} = \text{gas precharge pressure at precharge ambient temperature} \]
\[ p_{0_{T_x}} = \text{gas precharge pressure at maximum ambient operating temperature, where } T_x \text{ is } T_1 \leq T_x \leq T_2 \]

Celsius
\[ p_{0_{T_0}} = p_{0_{T_x}} \times \frac{T_0 + 273}{T_x + 273} \]
\[ T_0 = \text{precharge temperature in °C} \]
\[ T_x = \text{maximum operating temperature in °C, where } T_1 \leq T_x \leq T_2 \]
\[ p_{0_{T_0}} = \text{gas precharge pressure at precharge ambient temperature} \]
\[ p_{0_{T_x}} = \text{gas precharge pressure at maximum ambient operating temperature, where } T_x \text{ is } T_1 \leq T_x \leq T_2 \]
**Gas Behavior**

The compression and expansion processes taking place in hydro-pneumatic accumulators are governed by the general gas laws. The following applies for ideal gases:

\[ p_1 \times V_1^n = p_2 \times V_2^n \]

where the time related change of state is represented by the polytropic exponent “n”. For slow gas expansion and compression processes which occur almost isothermally, the polytropic exponent can be assumed to be \( n = 1 \).

For rapid processes, the adiabatic change of state can be calculated using \( n = k = 1.4 \) (for nitrogen as a diatomic gas).

For pressures above 3000 psi the real gas behavior deviates considerably from the ideal one, which reduces the effective fluid volume \( \Delta V \). In such cases a correction is made which takes into account an adiabatic exponent \( k \) even greater than 1.4; \( n > 1.4 \). By using the following formulas, the required gas volume \( V_0 \) can be calculated for various calculations.

For low pressure applications of less than 150 psi absolute gas pressures must always be used in the formulas.

**Calculation Formulas**

**polytropic:**

\[ V_i = \frac{\Delta V}{(\frac{p_i}{p_0})^\frac{1}{n} - (\frac{p_i}{p_0})} \]

**isothermal:**

\[ V_i = \frac{\Delta V}{p_0, (T_1) - (-p_0, (T_1))} \]

**adiabatic:**

\[ V_i = \frac{p_0, (T_1)^{n \cdot 0.714}}{p_0} - \frac{p_0, (T_1)^{n \cdot 0.714}}{p_0} \]

Correction factors to take into account the real gas behavior:

For isothermal change of condition:

\[ V_{0,real} = C_i \times V_{0,ideal} \text{ or } \Delta V_{real} = \Delta V_{ideal} \times C_i \]

for adiabatic change of condition:

\[ V_{0,real} = C_i \times V_{0,ideal} \text{ or } \Delta V_{real} = \Delta V_{ideal} \times C_i \]

The \( C_i \) and \( C_a \) can be determined from the following Correction factor graphs.

Calculate the ratio of Max/Min pressure, \( p_0/p_1 \).

On the graph find the intersection of \( p_0/p_1 \) and the maximum working system pressure \( p_0 \), which is shown as a curve on the graphs for either an isothermal or adiabatic change of condition.

Project the intersection point to the Y-axis to determine the appropriate correction factor, \( C_i \) or \( C_a \).

**Sizing Example**

An additional operation is to be added to an existing machine which requires 1.35 gallons of oil in 2.5 seconds for optimal operation. The system must operate between 3000 psi and 1500 psi. The operating ambient temperature range is 75 to 120°F.

The machine’s hydraulic fluid pump is sufficient to fully recharge the accumulator in the 8 second machine dwell time. Total machine cycle time = 10.5s.

**Given:**

- maximum system working pressure \( p_0 = 3000 \text{ psi} \)
- minimum system working pressure \( p_1 = 1500 \text{ psi} \)
- required fluid volume of the system \( \Delta V = 1.35 \text{ gallons} \)
- maximum ambient operating temperature \( T_1 = 120^\circ F \)
- minimum ambient operating temperature \( T_2 = 75^\circ F \)

**Determine the following:**

Necessary accumulator size, taking into account the real gas behavior by using correction factors

Calculate gas precharge pressure \( p_0 \) at 68°F (\( T_0 \))

Select accumulator size and type

**Solution:**

Since it is a rapid process, the change of condition of the gas can be assumed to be adiabatic.

1. Calculation for the required ideal gas volume:
   a) gas precharge pressure at \( T_1 \):
   \[ p_0@T_1 = 0.9 \times p_0 = 0.9 \times 1500 = 1350 \text{ psi} \]
   b) gas precharge pressure at \( T_1 \):
   \[ p_0@T_1 = 1350 \text{ psi} \times \frac{T_1 + 460}{T_0 + 460} = 1245 \text{ psi} \]
   c) ideal gas volume:
   \[ V_{0,ideal} = \frac{\Delta V}{\frac{p_0, (T_1)}{p_1} - \frac{p_0, (T_1)}{p_0}} \times \frac{1465}{1500} = 3.95 \text{ gals.} \]

2. Calculation for the required real gas volume:
   a) Determine the adiabatic correction factor, \( C_a \)
   \[ \frac{p_0}{p_1} = 2 \]

   From the correction factor for adiabatic change condition graph, using the 3000psi curve:
   \[ C_a = 1.16 \]

   b) Real gas volume:
   \[ V_{0,real} = C_a \times V_{0,ideal} = 1.16 \times 3.95 \text{ gal.} \] = 4.6 gal.

3. Select actual accumulator size by rounding up to nearest nominal size accumulator listed in catalog:

   Selected size: 5 Gallon = 20 Liter

4. Calculation of gas precharge pressure \( p_0 \) at 68°F:
   \[ p_0@T_1 = \frac{p_0@T_0 \times T_1}{T_0} = 1350 \text{ psi} \times \frac{T_1 + 460}{T_0 + 460} = 1230 \text{ psi} \]

3. Selected: Size 20 (5 gallon)

**Recommended Model:** SB330-20A1/112S-210C, Precharged to 1230 psi at 68°F
Pulsation Dampeners & Suction Flow Stabilizers

On the suction and pressure side of piston pumps almost identical conditions regarding non-uniformity of the flow rate occur. Therefore, the same formulas for determining the effective gas volume are used for calculating the dampener size. That in the end two totally different dampener types are used is due to the different acceleration and pressure ratios on the two sides.

Not only is the gas volume \( V_0 \) a decisive factor but also the connection size of the pump has to be taken into account when selecting the pulsation dampener. In order to avoid additional cross section changes which represent reflection points for vibrations, and also to keep pressure drops to a reasonable level, the connection cross section of the dampener has to be the same as the pipe line.

The gas volume \( V_0 \) of the dampener is determined with the aid of the formula for adiabatic changes of state.

A simulation of the pressure performance can be carried out by means of a computer program for real pipe line conditions.

**Formulas**

\[
V_0 (l) = \frac{\Delta V}{0.695 \times \left[ 1 - \frac{100}{100 + x} \right]^{0.714}}
\]

\[
X (\%\) = \frac{100}{\left( 1 - \frac{V}{0.695 \times V_0} \right)^{1.4} - 100}
\]

\[
\Delta V (l) = k \cdot q
\]

\[
X (\%) = \frac{\hat{p} - p_m}{p_m} \times 100 = \frac{\hat{p} - p_m}{p_m} \times 100
\]

\( V_0 \) = required gas volume

\( \Delta V \) = fluctuating fluid volume

\( q(l) \) = stroke volume per cylinder

\( p_m \) = residual pulsations

\( \hat{p} \) = max. working pressure

\( \hat{p} \) = min. working pressure

\( p_m \) = pump flow rate or pressure in the suction line

\( z \) = No. of compressions / effective cylinders per revolution

\( k \) = Coefficient of cyclic variation of the pump

**Calculation Example**

Parameters:
- Single acting 3-plunger pump
- piston diameter: 2.36 inches (60 mm)
- piston stroke: 3.15 (80 mm)
- rpm: 370
- flow rate: 64.44 gpm (244 l/min.)
- operating temp.: 68°F (20°C)
- operating pressure:
  - pressure side: 3625 psi (250 bar)
  - suction side: 58 psi (4 bar)

Required:
- Suction flow stabilizer for a residual pulsation of ± 2.5%
- Pulsation dampener for a residual pulsation of 0.5%

**Solution:**

a) Determination of required suction flow stabilizer

\[
V_0 (in^3) = \frac{0.13 \cdot (2.36^2 \times \pi)}{4} \cdot 3.15
\]

\[
0.695 \left[ 1 - \frac{100}{100 + 2.5} \right]^{0.714}
\]

**Selected:** SB 330-4 (see table on page 19)

b) Determination of required pulsation dampener

\[
V_0 (in^3) = \frac{0.13 \cdot (2.36^2 \times \pi)}{4} \cdot 3.15
\]

\[
0.695 \left[ 1 - \frac{100}{100 + 0.5} \right]^{0.714}
\]

**Selected:** SB 330 P-20 (see table on page 61)
# Energy Storage Form

<table>
<thead>
<tr>
<th>Field</th>
<th>Information</th>
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</thead>
<tbody>
<tr>
<td>Name</td>
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<td>Zip</td>
</tr>
<tr>
<td>Phone</td>
<td>Phone</td>
</tr>
<tr>
<td>Fax</td>
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</table>

**Operation of Pump**

- [ ] Continuous Operation
- [ ] Emergency Operation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Maximum Operating Pressure (P2)</td>
<td>PSI</td>
</tr>
<tr>
<td>Minimum Operating Pressure (P1)</td>
<td>PSI</td>
</tr>
<tr>
<td>Precharge Pressure at 68°F (20°C) (P0)</td>
<td>PSI</td>
</tr>
<tr>
<td>Temperature Range of Environment (T)</td>
<td>°F</td>
</tr>
<tr>
<td>Temperature Range of Fluid or System (TF)</td>
<td>°F</td>
</tr>
<tr>
<td>Pump Flow Rate (QP)</td>
<td>GPM</td>
</tr>
<tr>
<td>Total Cycle Time of System (TE)</td>
<td>Sec.</td>
</tr>
<tr>
<td>Number of Actuators (cylinders, etc.) (NV)</td>
<td></td>
</tr>
</tbody>
</table>

**Actuator Time Schedule and Flow**

- QVi = Required Actuator Flow (GPM)
- Ei = Actuator Start Time
- Ai = Actuator Shut Down Time

<table>
<thead>
<tr>
<th>Actuator</th>
<th>Time</th>
<th>Flow</th>
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</thead>
<tbody>
<tr>
<td>Actuator 1</td>
<td>E1</td>
<td>Q1</td>
</tr>
<tr>
<td>Actuator 2</td>
<td>E2</td>
<td>Q2</td>
</tr>
<tr>
<td>Actuator 3</td>
<td>E3</td>
<td>Q3</td>
</tr>
<tr>
<td>Actuator 4</td>
<td>E4</td>
<td>Q4</td>
</tr>
<tr>
<td>Actuator 5</td>
<td>E5</td>
<td>Q5</td>
</tr>
</tbody>
</table>

**Fluid**

Please attach any special requirements or drawings to the fax or e-mail.

**Required Mounting Orientation**

**Country of Final Installation**

(for country codes please see page 2)

**Required Quantity**

<table>
<thead>
<tr>
<th>Annual Usage</th>
<th>Target Price</th>
<th>Competitor</th>
<th>Quantity</th>
</tr>
</thead>
</table>

**Additional Remarks**
**Shock Applications Form**

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
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<tbody>
<tr>
<td>Company</td>
<td>E-mail</td>
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<tr>
<td>Phone</td>
<td>State</td>
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<tr>
<td></td>
<td>Zip</td>
</tr>
<tr>
<td>Phone</td>
<td>Fax</td>
</tr>
</tbody>
</table>

*Please attach any special requirements or drawings to the fax or e-mail.*

**What is the source of the shock?** *(i.e. valve closing, pump start, or other - please describe)*

**At the instance the shock occurs what is the...**

- Flow rate: __________ GPM
- Normal Operating Pressure: __________ PSI; Maximum Spike Pressure: __________ PSI
- The system's maximum allowable design pressure: __________ PSI

Information is required on all piping from the shock source to the anticipated location of the shock absorber *(accumulator)*.

Please continue to answer the following:
- Total Number of pipes: __________ *(up to 10 pipes)*

**Starting at the shock source, please answer the following:**

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Inner Diameter (inches)</th>
<th>Length (feet)</th>
<th>Pipe</th>
<th>Inner Diameter (inches)</th>
<th>Length (feet)</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>4</td>
<td></td>
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<td>5</td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If the vertical height from the shock source to the anticipated location of the shock absorber is greater than 10 feet please state this distance.

*Vertical Height: __________ feet*

**Fluid**

**Required Mounting Orientation**

**Country of Final Installation** *(for country codes please see page 2)*

**Required Quantity**

<table>
<thead>
<tr>
<th>Annual Usage</th>
<th>Target Price</th>
<th>Competitor</th>
<th>Quantity</th>
</tr>
</thead>
</table>

**Additional Remarks**
# Pulsation Dampening Form

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td>E-mail</td>
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<tr>
<td>Address</td>
<td></td>
</tr>
<tr>
<td>Phone</td>
<td>State</td>
</tr>
<tr>
<td>Phone</td>
<td>Zip</td>
</tr>
</tbody>
</table>

**Please attach any special requirements or drawings to the fax or e-mail.**

## What type of pump is causing the pulsation?  
Please name or describe (ie piston pump, gear pump, etc.)

## What is the...
- **Flow rate:** \_\_\_\_\_ GPM
- **Pump:** \_\_\_\_\_ RPM
- **Pump Piston Diameter:** \_\_\_\_\_ (inches)
- **Pump Piston Stroke:** \_\_\_\_\_ (inches)
- **Number of Rotating Elements:** \_\_\_\_\_ (3 piston, 13 tooth gear, etc)
- **Operating Pressure:** \_\_\_\_\_ psi
- **The system's maximum allowable pressure:** \_\_\_\_\_ psi

**Line Size where pulsation dampener will be fitted into:** ____________________________  
*(The I.D. of the line is what is really required)*

**Note:** A pulsation dampener should be always be installed as close to the pulsation source as possible to optimize its performance. A pulsation dampener should never be placed greater than 10 ft away from the pulsation source.

## Fluid

## Required Mounting Orientation

## Country of Final Installation  *(for country codes please see page 2)*

## Required Quantity

<table>
<thead>
<tr>
<th>Annual Usage</th>
<th>Target Price</th>
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<th>Quantity</th>
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## Additional Remarks