UNDERSTANDING HOW PULSATION ACCUMULATORS WORK

J. C. Wachel and S. M. Price
Engineering Dynamics Incorporated
San Antonio, Texas

ABSTRACT

Pulsation accumulators are used in reciprocating pump installations to reduce pump manifold pulsations and to attenuate pulsations transmitted into the piping. The pump and piping system form a complex acoustical system which has many acoustical and mechanical natural frequencies and the potential for high vibration and component failure problems. Many times the pulsation characteristics of the system are not calculated prior to installation, and an accumulator is selected based on pressure and flow rate criteria. In some cases, this is acceptable as can be attested by the numerous installations that are installed and have operated successfully without problems. However, many installations do experience high vibrations, piping and component failures, cavitation in the suction manifold, and generally poor reliability. These problems are often the result of the failure to consider the system's acoustical characteristics when selecting an accumulator.

The effects of several different types of accumulators in a three pump parallel system were studied using a digital computer program which models the pulsation characteristics of pump and compressor systems. Detailed computer analyses were performed on bladder gas-charged appendage and flow-through accumulators, the non-bladder, flow-through, gas-charged accumulators, and all-liquid Helmholtz filters. These results indicate that the off-the-shelf accumulators can be effective in some cases, but can combine with the particular acoustical characteristics of the system to amplify pulsations in other cases. In addition, the interaction between the individual pumps in a parallel installation can cause severe amplification of the pulsations. Guidelines are presented for the selection of pulsation filters for pump systems and the type of analyses that should be performed in the design stage.

INTRODUCTION

Many reciprocating pump installations suffer problems that cause increased maintenance and unreliable operation. Typical problems encountered are high vibrations of the piping and pump and/or failures in the piping, valves, crossheads, connecting rods, crankshafts, and working barrels. Many of these problems can be caused by high pulsation levels.

High pulsations are caused by the interaction of the excitation energy from the pump with the acoustical natural frequencies of the system. The pump and its suction and discharge piping system form a complex acoustical system and will have numerous acoustical natural frequencies. A reciprocating pump generates pulsations at integer multiples of the pump speed; however, outside of the pump manifold the harmonics with significant energy content will generally be at the plunger frequency and its multiples.

Vibration of the piping and pump is caused by pulsation-induced shaking forces which are a function of the pulsation amplitude and the flow area of the piping. Whenever there is a coincidence of the excitation harmonics with the acoustical natural frequencies of the system, amplification of the pulsations occur and excessive vibrations can be induced. Amplification factors are typically 10–40 for pulsation resonances and 10–20 for mechanical resonances. If the mechanical resonance coincides with an acoustical resonance, a combined amplification factor of 800 could occur.

Many pump systems are designed without consideration of the system acoustical pulsation characteristics and no accumulators or acoustical filters are installed.[1] These systems can encounter severe vibrations and failure problems immediately after startup. When excessive vibrations and failures occur, the piping system is typically modified by the addition of accumulators to reduce the pulsations. The accumulator is generally chosen on the basis of the system pressure and the flow rate; however, this may not be sufficient. Hence, the accumulator is sometimes successful in reducing the pulsations and other times it is not. When the selected accumulator does not reduce the pulsations, another brand or type is selected and it may or may not work properly.

[1]The terms accumulator, dampener, damper, filter, stabilizer, and desurger are used in the industry to describe devices that are used to control pulsations. In this paper the term accumulator will be used to describe such devices.

It is possible to calculate the effectiveness of any given accumulator in the design stage or for a modification to an existing installation [1,2]. Using a digital computer model which has this capability, the pulsations at any point in a piping system can be predicted. This allows the engineer to design the piping system to minimize the pulsations and the shaking forces.

It is difficult to predict the exact effects of accumulators on the pulsation response of systems without a means of analysis, such as the computer program mentioned above. A parametric analysis of a typical system showing the effects of different types of accumulators can provide insight into the system characteristics. This paper will discuss the results of an acoustic analysis of a reciprocating triplex pump system with various accumulators. The pump system studied has three pumps operating in parallel. The effects of the accumulators on the discharge system will be discussed; however, the understanding of the acoustical effects will also be applicable to the suction system.

In order to understand how the accumulator affects the acoustical characteristics of the system, it is necessary to understand how an acoustical wave is propagated. Acoustic pulsations travel at speed of sound in the fluid which, for most liquids, is from 3000 to 5000 feet per second. For the normal frequency range of pump pulsations, it is possible to use plane wave acoustic theory to describe the acoustical standing wave patterns since the pipe diameters are small compared to the wave length of the acoustic wave. The wave length of an acoustical wave is the speed of sound divided by the frequency. The frequencies of interest in pump installations are generally less than 300 Hz. Therefore, the wave lengths are greater than 10 feet. Low frequency harmonics which have the highest energy have wave lengths of 100 feet or more. The acoustical properties of systems having piping with diameters of less than 10 feet can therefore be accurately calculated using plane wave theory.

One important facet of the problem is the relationship between the acoustic speed of sound and the flow velocity of the fluid. The pulsations (acoustic waves) generated from the pump travel with a velocity of 3000–5000 feet per second and typical flow velocities are less than 50 feet per second. Thus the flow velocity will have little or no effect on the acoustical characteristics of the system. The flow velocity can be neglected and the understanding of the effects of the accumulator based on the acoustic wave alone.

TYPES OF ACCUMULATORS

There are several different types of accumulators and acoustical filters which are used to control pulsations in pump systems. Miller [3] described over 30 different kinds, although from an acoustic standpoint, the devices can be divided into the following categories:

1. Appendage accumulator with gas-filled bladder or diaphragm
2. Appendage accumulator with diverter and gas-filled bladder or diaphragm
3. Flow-through accumulator with gas-filled bladder/diaphragm or gas blanket
4. Resistive accumulator (pressure drop) devices
5. Acoustical filters (Helmholtz type)

The acoustical characteristics and the effects of the various types of accumulator on pulsations will be discussed.

Appendage With Gas-Filled Bladder

Accumulators that are mounted on the piping through a tee type installation are called appendage or side branch accumulators. Figure 1 shows sketches of the different accumulators. The gas-filled bladder or diaphragm is separated from the flow by a throat or neck from the pipe flow and a volume of liquid beneath the elastic member (Figure 1a and 1b).

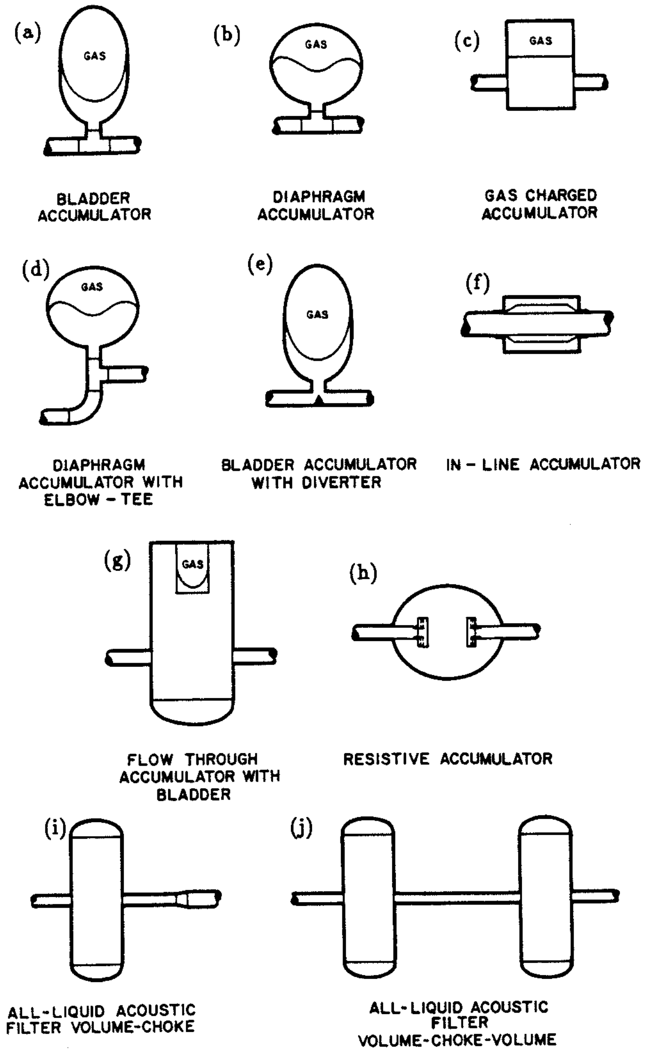

Fig. 1 Accumulator Types

Acoustically, the appendage accumulator consists of a throat or neck, equivalent to a short length of small diameter pipe, a volume of liquid in contact with the bladder or diaphragm, the elastic spring and mass properties of bladder or diaphragm, and the compliance of the gas volume confined in the bladder. Note that acoustically the bladder and the diaphragm accumulators are identical, in so far as the influence on the acoustical response is concerned. Accumulators are quite effective in many installations since the compliance of the gas above the bladder/diaphragm is equivalent to a large liquid volume. The equivalent liquid volume of a gas volume can be obtained by multiplying the gas volume by the ratio of the liquid to gas density and the speed of sound squared. For many liquid systems, this ratio is near 10000. Therefore a small gas volume can be equivalent to a large liquid surge volume. Due to the geometry of the accumulators (e.g. the throat or neck) these devices are usually more effective at low frequencies than at high frequencies.

A mechanical (electrical) analogy can be derived to help understand the dynamics of accumulators. The throat acts as a mass (inductance) and the volume acts as a spring (capacitor) to provide a resonance frequency. Above this frequency the accumulator will lose much of its effectiveness. For most accumulator designs, this acoustic natural frequency will be less than 100 Hz.

The effective liquid volume is very sensitive to the gas volume, since it multiplied by approximately 10000. Therefore, the gas volume must be constantly checked to ensure that the accumulator is properly charged. Although recommendations vary between manufacturers, a general rule of thumb is that the bladder/diaphragm is charged to 50 percent to 70 percent of the line pressure. The gas is typically injected into the bladder while the system is depressured; however, when the system is pressurized the gas volume will be reduced.

The effective gas volume changes with the steady-state line pressure. Mechanical constraints that support the bladder can interfere with the bladder, causing it to become ineffective. The mass and stiffness properties of the bladder can also influence the acoustical characteristics of the accumulator.

Appendage With Gas-Filled Bladder And Diverter

Accumulator manufacturers have recognized that the appendage type devices have limited frequency response capabilities and have experimentally determined that improved high frequency attenuation could be achieved by the use of a diverter which, according to the sales literature, causes the steady state flow to be "diverted" directly into the accumulator, thus improving the attenuation characteristics at the higher frequencies (Figure 1e). Experimental data has been collected to verify the claims [3].

The authors believe that the improved attenuation of the diverter type appendage accumulators is due to a different acoustical phenomenon and is not related to the diverting of the steady state flow into the accumulator. As discussed earlier, the acoustic wave travels at the speed of sound which is approximately 100 times the flow velocity, thus the effect of the flow velocity is negligible. The additional attenuation of the diverter accumulator is a function of the additional pressure drop of the diverter and the flow velocity vector does not significantly affect the results. Some additional turbulence may be created by the swirling but its primary influence is in the pressure drop.

Therefore, to model the diverter, an acoustical resistive element is added to the accumulator system model (Table 1). The acoustical analyses will show that the diverter does improve the acoustical attenuation at specific frequencies, but is accomplished by the pressure drop (damping) and not for the reasons normally presented in some of the sales literature.

Table 1: Analogies of Dynamic System Components

Mechanical	Electrical	Acoustical
Mass	Inductor	Choke
Spring	Capacitor	Volume
Dashpot	Resistor	ΔP

Some appendage accumulator manufacturers recommend that their accumulator be installed in the discharge system with an elbow and tee arrangement such that the steady state flow vector is directly into the appendage accumulator (Figure 1d). This configuration has been tested by the manufacturer and, under certain conditions, was shown to have increased attenuation. Improvements in attenuation obtained by this configuration are attributable to additional pressure drop at the elbow and the tee and not due to the direction of the flow vector. Experimental data may show that, at some speeds, the attenuation is increased; however, this design is undesirable since the addition of the elbow and tee introduces two additional shaking forces in the system [4]. Good design practices would eliminate all unnecessary bends in the piping system.

Flow-Through

The appendage type of accumulator attenuates pulsations, but is limited in its frequency response due to the effect of the throat. Improvements in the acoustic attenuation of accumulators can be achieved by the elimination of the throat. By using a flow-through filter with a gas-filled bladder/diaphragm or using a gas blanket over the liquid without a separating membrane (Figures 1f and 1g), the throat effects can be minimized and a broader frequency range of attenuation can be obtained.

One disadvantage of the gas blanket design (Figure 1c) is that the gas may be absorbed by the liquid and constant maintenance must be expended to ensure that the accumulator is properly charged. This is also a disadvantage of the gas-filled bladder/diaphragm accumulator since the gas charge must be checked periodically.

Resistive (Pressure Drop) Devices

In addition to the accumulators discussed above, resistive devices are used to attenuate pulsations in some piping systems. These accumulators typically will have small volumes, such as a small sphere; however, the major acoustical attenuation is achieved by forcing the flow through small diameter pipes which causes considerable pressure drop (Figure 1h). These devices can be effective for certain system modes (usually high frequency). Some sales literature claim a phenomenon called the fluid flywheel effect which is dependent upon the direction of the fluid flow. Again the velocity of the acoustic wave is so large compared to the steady state velocity that this effect is nearly non-existent, except for increased turbulent pressure drop.

Orifices and restriction perforations are also used to achieve attenuation of pulsations and can be quite effective if they are properly placed. Resistive type elements generally work best when they are installed at locations of maximum acoustic particle velocity (at acoustical standing wave pressure nodes).

Acoustical Filters (Helmholtz Type)

Acoustical reactive filters (Figures 1i and 1j) which are based upon low pass filter theory have been successfully used for many years. With the improvements in the acoustical modeling capabilities for pump systems, such filters can be optimized to achieve the maximum attenuation with a minimum of pressure drop [1]. The analogous relationship between low pass filters in electrical circuits and piping acoustics was discussed by Ludwig [5] and Hicks [6]. As summarized in Table 1, the liquid volume is analogous to a capacitor and the choke tube is analogous to an inductance. The filter design is based upon the acoustic natural frequency (commonly called the Helmholtz frequency) of the choke tube and the volume. The Helmholtz frequency is usually set at one-half the plunger frequency and the bottle and choke sizes are determined from the allowable pressure drop.

Acoustic filters (commonly called all-liquid filters since there is no need for gas volumes) can be designed with a choke tube and either one or two volumes. The added volume increases the Helmholtz natural frequency, but increases the attenuation as a function of frequency.

SYSTEM EFFECTS

Most pulsation problems are caused by a system problem caused by the complex acoustical system consisting of the pump and piping. If no accumulator or filter is in the system, the system will have numerous acoustic natural frequencies and mode shapes. If an accumulator or filter is introduced into the system, there will be a new set of acoustical natural frequencies and mode shapes. Depending on the location of the acoustic resonances and the plunger frequencies, the system may or may not have problems. This is one of the main reasons that a particular type or brand of accumulator will work in one system and not in another.

When an accumulator or filter is installed near the discharge or suction flange, an acoustical quarter-wave natural frequency is introduced. This quarter-wave mode has the maximum pulsation amplitude at the closed end of the pump manifold and a minimum pulsation amplitude at the entrance to the accumulator. An estimate of this acoustical natural frequency can be made using a simplified system which employs a constant diameter pipe from the end of the manifold to the entrance of the accumulator. The natural frequency would be equal to the speed of sound divided by 4 times the length from the end of the manifold to the entrance of the accumulator. This frequency, generally from 50–300 Hz, has been described by some investigators as an acceleration head frequency [3].

The acceleration head concept used on the suction system to calculate the required net positive suction head is an attempt to explain pulsations by a static phenomenon and is not needed if an accurate model of the pump and piping is used to predict the pulsations. If accumulators are used on the suction and discharge systems, each will have a resonant quarter-wave acoustical natural frequency determined by the acoustical length from the end of the manifold to the entrance of the accumulator and is not related to the acceleration head.

The quarter-wave mode resonances will normally be excited by the higher plunger harmonics and cause high pulsations in the suction and discharge manifolds. High pulsations in the suction manifold can cause cavitation since the negative peak of the pulsations subtract from the steady state pressure. If the instantaneous pressure drops below the fluid vapor pressure, cavitation occurs. Cavitation in the suction system and high pulsations in the discharge manifold can cause failures of valves, crossheads, connecting rods, the crankshaft, and bearings. As discussed by Wachel [1], this mode can be controlled through the use of an orifice at the pump flange or at the entrance to the accumulator.

ANALYSIS OF A TYPICAL SYSTEM

To evaluate the performance of various design configurations of pulsation accumulators, a simple piping system was analyzed with several accumulator designs, and with acoustic filters. Failures of the accumulators (bladder ruptures, over or under pressures, etc.) were also simulated.

Piping System Description

The pump piping system, shown in Figure 2 , is typical of many pump facilities and consists of three triplex reciprocating pumps operating in parallel. The pumps are piped into a common header, which continues with a single line into the pipeline. The upper-case letters at various points in Figure 2 indicate points where system pulsations were computed. For the purposes of this paper, only the test points relevant to the particular point being emphasized will be shown. In addition, the discharge side of this system was considered to be independent of the suction system[2].

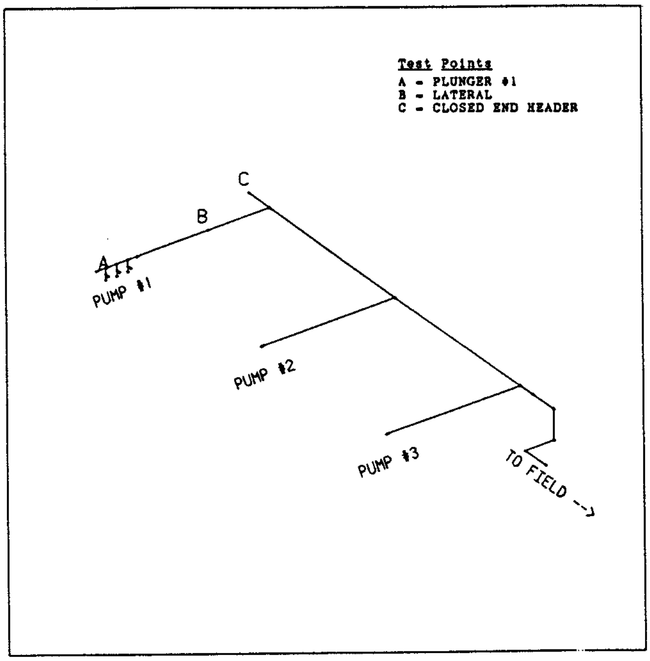

Fig. 2 Typical Pump/Piping Discharge System

Each of the pumps have 3.5 inch diameter plungers and a stroke of 5 inches, and operates at a constant speed of 308 rpm. The total output from each pump is 192 gpm of water at 1000 psia. The speed of sound in pure water at operating temperature is 4860 feet per second. To account for variations in water purity and temperature, the pulsation calculations were made for a ±15% variation in speed of sound. For clarity, this variation appears on the pulsation plots as a variation in pump operating speed.

The results of the acoustic analysis of the piping system with no acoustic treatment are shown in Figure 3. The vertical axis of each plot is independently scaled so that the frequency of the acoustical resonances can be noted. Several acoustic modes are present in the system that cause resonant pulsation levels of 15–30 psi peak to peak. Significant "cross-talk" is also apparent. Cross-talk is caused by acoustic modes that involve more than a single pump, and therefore can transmit energy from one pump to another. The complex pressure waves at most locations in the piping can have peak to peak (p–p) modulations as great as 60 psi, and can be 100 psi at the pump plunger face. A 6 inch pipe in this system could experience shaking forces of 1700 pounds, peak to peak. The necessary pipe clamps required to hold these force levels would be substantial.

[2] During the idealized pumping process, either the suction or discharge valve is closed. The acoustical properties of the discharge side are therefore effectively isolated from the suction side. Reference [4] provides more details concerning the acoustical modeling procedures used for this document.

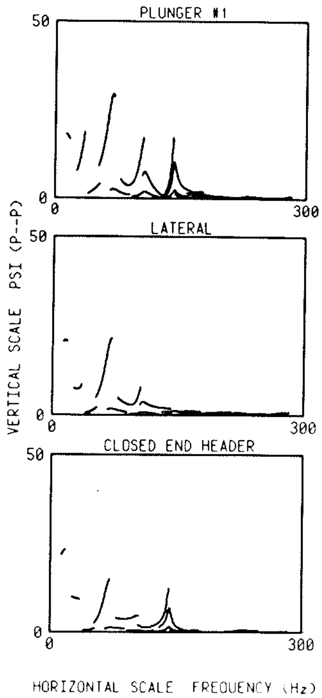

Fig. 3 No Pulsation Treatment

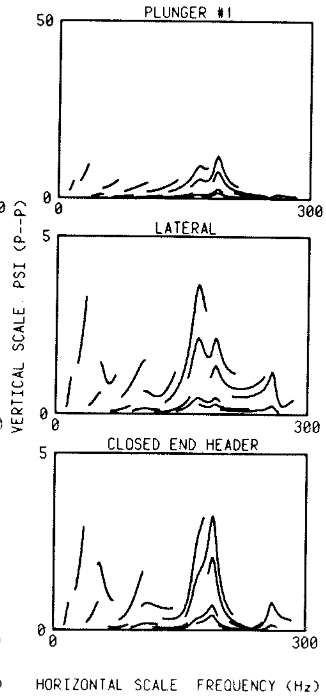

Fig. 4 Tee Installation

By adding a pulsation accumulator device, these pulsations and shaking forces can be reduced to more reasonable levels. The job of the piping designer is to choose a device that will adequately protect the piping and the pump. As will be shown, selection of a device without regard to the system acoustics and all operational parameters can result in a system that is worse than if no pulsation dampener was used.

Investigation of Accumulator Design

This study will begin with the appendage accumulators and their derivatives. Several different configurations will be studied to investigate the design limitations of each, as well as the acoustical phenomenon responsible for their operation. Flow-through devices will be investigated, followed by resistive devices. Finally, acoustic filters (sometimes called all-liquid filters) will be investigated.

Appendage Accumulators The acoustic elements of a typical appendage accumulator consist of a gas volume, a liquid volume, and one or more "neck" elements. The major acoustic effect is due to the gas volume which is typically confined in a bladder or diaphragm. Since the compliance of the gas (a measure of its softness) is roughly 10000 times greater than the compliance of the liquid, the additional liquid volume in the accumulator has little effect on the system acoustic natural frequencies and mode shapes. The throat area provides some inductance and consequently has a large effect on the performance of the accumulator.

The discharge system was analyzed with a bladder type appendage accumulator at each pump. The accumulators were installed using a pipe tee, as close to the discharge flange as possible (within one foot). The calculated pulsation levels at the plunger face, lateral and header piping are shown in Figure 4. Overall pulsation levels in the piping have been significantly reduced. (Note that the vertical scale is 5 psi full scale.) However, pulsations levels at the pump plunger face were only slightly reduced, due primarily to the creation of an acoustic quarter-wave resonant mode at 190 Hz between the closed end of the pump manifold and the accumulator. Note that system pulsation levels at low frequency have been reduced; however, some new high frequency modes have been created. The inductance of the accumulator neck combines with the compliance of the gas volume to reduce the effectiveness of the appendage accumulators at high frequency.

A general "good design" practice is to locate the accumulator as closely as possible to the pump discharge flange. As the distance between the end of the pump manifold and the accumulator increases, the "manifold resonance" frequency (quarter-wave) decreases. The higher energy content of the lower orders of pump speed will create a higher amplitude response at this resonance[3]. Since the manifold resonance has a pressure node at the accumulator, it can be controlled effectively with the additions of some damping at the accumulator.

Table 1 indicates that acoustic damping can be obtained with a pressure drop. Orifice plates are an effective means for introducing a pressure drop. They are also inexpensive to produce and can be easily added to systems in the design phase or after completion. Therefore, a five psi pressure drop orifice was simulated in the system model at the discharge flange of the pump. The amplitude of the response at the manifold resonance was reduced by 25%. Pulsation levels elsewhere in the system remained essentially constant (Figure 5).

Devices, such as a diverter plate, that introduce pressure drop at the accumulator (Figure 1e), also reduce resonant pulsation levels in the manifold. Introducing bends (elbow and tee) in the piping upstream of the accumulator will also provide some pressure drop (Figure 1d). An analysis of such an installation showed that the added pipe length between the pump and the accumulator decreased the frequency of the quarter wave resonance from 190 Hz to 155 Hz. The higher pulsation energies present at lower frequency tended to offset the damping effect from the pressure drop, and the peak calculated pulsation amplitude at the quarter wave resonance increased from 12 to 17 psi p–p. The analyses showed that while some improvements can be obtained at certain pump speeds (the quarter wave resonance may move so that the excitation frequency is on the flank of the resonance, and not the peak) pulsation levels in general will be higher (Figure 6). The results obtained with a straight section of pipe, an orifice plate at the flange, and the accumulator as presented in Figure 4 gave lower pulsations.

Effect of Gas-Filled Bladder Volume One disadvantage of appendage accumulators is that, if the bladder fails, the system is without pulsation control. Severe pulsations can result, causing pump and piping damage. Another potentially troublesome characteristic is that the effectiveness of the accumulator can be quite sensitive to changes in the gas volumes. As line pressures change, the volume of gas in the bladder changes, possibly altering system performance. In some cases, the system can be worse than if the accumulator were not present. To illustrate this point, the system was analyzed with a varying amount of gas volume in one of the accumulators.

[3] This phenomenon can cause pulsation levels in the manifold of a quintuplex pump to be higher than those in a triplex pump, even though the generated pulsation energy of a quintuplex pump is lower than that of the triplex pump.

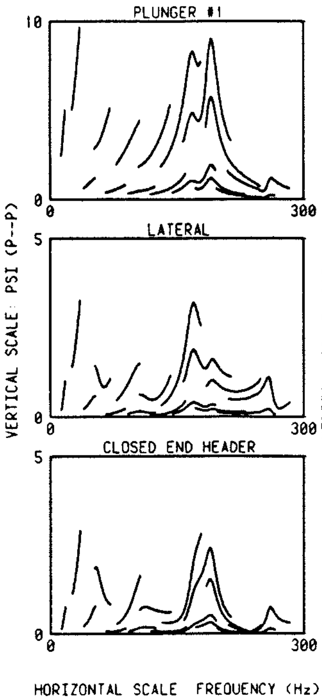

Fig. 5 With 5 psi Orifice

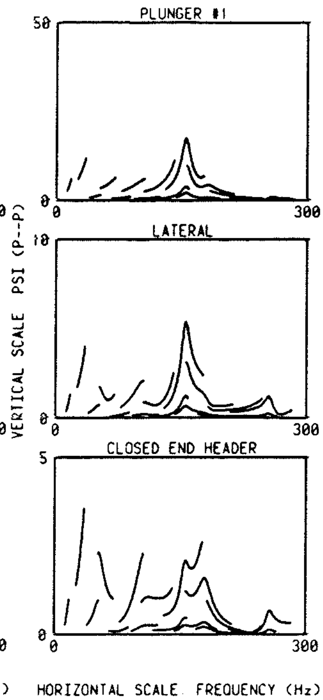

Fig. 6 Elbow-Tee Installation

The normal gas volume for this accumulator is 231 in^3. The system was analyzed for gas volumes of 200, 100, 50, 25, 5 and 0 cubic inches and the results are given in Table 2. As the gas volume decreased, a low frequency acoustic mode below the plunger frequency increased. The mode was a function of the distance between the accumulators of the three pumps. As this acoustic mode frequency increased, it moved through the plunger frequency. The pulsation amplitudes due to the first 3 harmonics of plunger frequency (higher harmonics were not significantly affected) at the plunger face, lateral, and header are listed in Table 2 for various gas volumes.

Table 2: Effects of Various Gas Volumes

Gas Volume Accumulator 1 (231 in^3)	Gas Volume Accumulators 2 & 3	Pulsations Test Point (psi p–p) Plunger Face	Lateral	Header
0	0	75	40	40
231	231	15	5	5
200	231	12	4	3
100	231	9	5	4
50	231	25	25	22
25	231	300	275	190
5	231	200	190	160
0	231	160	150	140

When all the accumulators on all three pumps were equally charged and the gas volume reduced, the pulsations did not get any higher than the system without accumulators.

Neck Area Appendage accumulators typically have a small diameter section of pipe at their entrance. This narrow neck or throat area acoustically acts like a mass in a mechanical spring-mass system to limit its high frequency response. The pressure drop associated with the neck will provide some damping.

This effect was analyzed by changing the diameter of the neck (Figure 7). A comparison of the high frequency responses of the original system (Figure 4) with the accumulator to that in Figure 7 shows that the larger the diameter of the neck, the more effective the accumulator is in reducing the pulsations.

Flow-Through Accumulators

An alternative design to appendage accumulators is the flow-through accumulator (Figure 1f and 1g). Their primary advantage is that they have no neck restriction. Some devices have additional liquid volume which can provide some pulsation control in case of a bladder failure. Flow-through accumulators (Figure 1g) are somewhat larger for a given gas volume than are the appendage accumulators and may be more expensive, depending upon the services. The bladder must be supported by various measures, such as cages, cans and internal cords. A comparison of the results of Figure 8 to Figure 4 shows that the pulsations transmitted to the lateral piping from the pump to the header are lower since the attenuation at the higher frequencies is improved. The flow-through accumulator has characteristics very similar to the appendage accumulator with no neck.

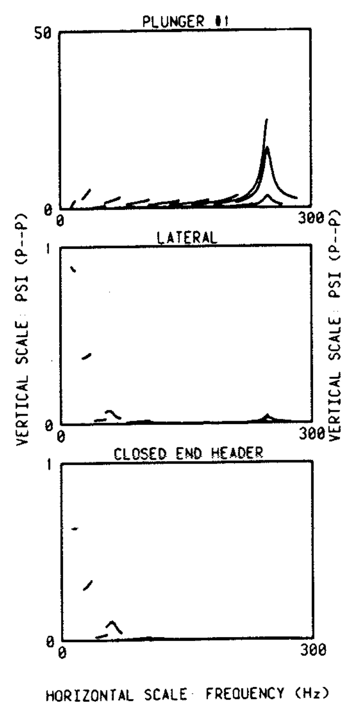

Fig. 7 Neck Enlarged

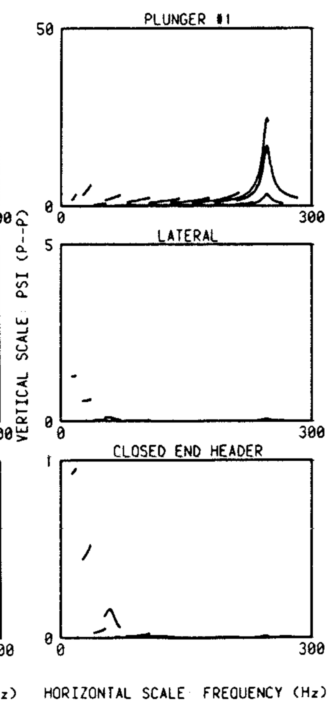

Fig. 8 Flow-Through

Resistance Devices

Apart from orifice plates and other flow restriction devices is a class of pulsation accumulators that provide a large resistance and a small liquid volume (Figure 1h). These accumulators usually have so little liquid volume that they can be considered almost entirely as resistance (damping). Therefore, they are most effective when placed at a dynamic pressure node (high dynamic particle velocity).

Figure 9 shows the pulsations calculated for the system with a resistance device at the pump discharge flange. To illustrate the effect of the volume, compare the results of Figure 9 to Figure 10 with the volume removed from the model. A mode at 65 Hz, and another at 135 Hz are affected slightly. With the volume removed from the model, the 65 Hz mode is not noticeably affected, and the mode at 135 Hz is only affected slightly. This behavior indicates that the majority of the attenuation effect is attributable to damping (pressure drop). Since these devices are usually installed at the pump flange, there are usually very few system acoustic modes that can be attenuated by these devices. The pulsations with this accumulator for the system are not significantly better than the system without treatment (Figure 3).

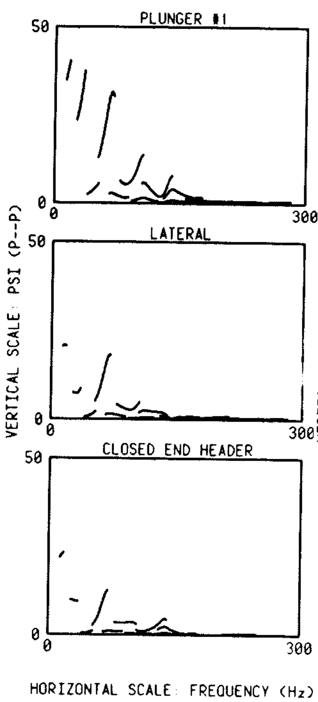

Fig. 9 Resistance Device

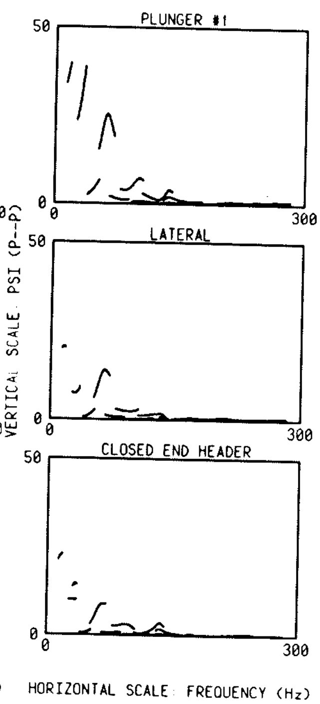

Fig. 10 Resistance Device — No Volume

Acoustic Filters

A properly designed acoustic filter is able to attenuate pulsation energy over a wide frequency range. Acoustic filters are relatively immune to changes in line pressure and once installed, require little, if any, maintenance. However, these filters are generally much larger in size and may have an initial cost higher than off-the-shelf accumulators.

An acoustic filter consists of a choke (a mass element), one or more volumes (spring element), and usually an orifice plate (a damping element) (Figures 1i and 1j). To design an acoustic filter, a cut-off frequency is selected (usually one-half the plunger frequency), and pipe sizes are selected based on the allowable pressure drop, local site requirements, and cost.

A volume-choke filter was designed and analyzed for this system. The final filter design consisted of a 7-foot-long bottle with an inside diameter of 35 inches and a 4-foot-long choke tube with an inside diameter of 1.5 inch. A 10 psi orifice was simulated at the pump flange to attenuate the quarter-wave resonance. As shown in Figure 11, maximum pulsations (obtained by the superposition of all harmonics) are calculated to be less than 5 psi in the piping, and less than 10 psi at the plunger face. The acoustic filter attenuates the high frequency excitation such that, outside the choke tubes, only the first two harmonics of plunger frequency are transmitted. In the pump manifold, other orders are present. Greater attenuation was obtained using a volume-choke-volume filter (Figure 12). As shown in Figure 13 the attenuation of the volume-choke-volume filter can almost be matched by the volume-choke filter by reducing the inside diameter of the choke to 1 inch. Experience has shown that two volumes are seldom needed in liquid systems. By reducing the diameter of the choke tube, the Helmholtz natural frequency will be lowered since the choke tube acoustical mass increases as the diameter is decreased. The attenuation at a selected frequency will be increased as the Helmholtz frequency is lowered.

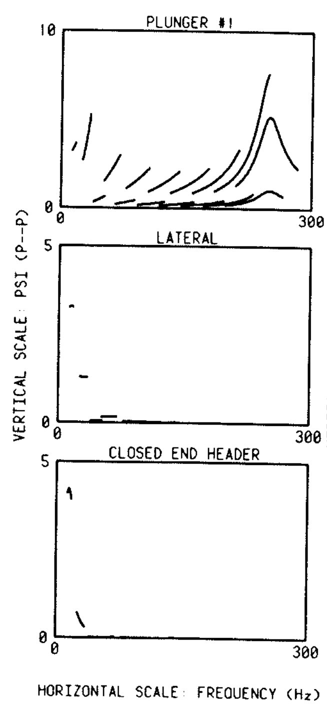

Fig. 11 ALF-VC—7′× 35″ID w/ 4′× 1.5″choke

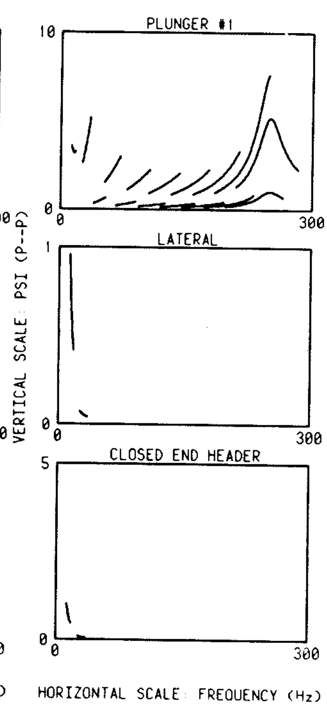

Fig. 12 ALF-VCV—2–7′× 35″ID w/ 4′× 1.5″choke

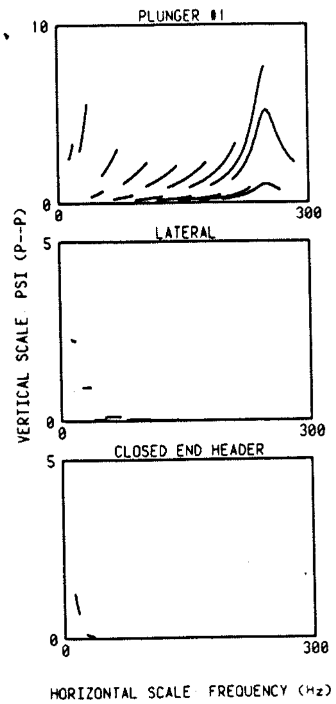

Fig. 13 ALF-VC—7′× 35″ID w/ 4′× 1″choke

CONCLUSIONS

Detailed modeling of a typical pump piping system was performed to develop a basic understanding of the acoustic behavior of accumulators used in such systems. Based upon the calculations and the application of acoustic theory, the following conclusions can be made.

1. Accurate calculations of the pulsations at any point in a pump or compressor piping system can be made with computer programs which can simulate the acoustical characteristics of all the acoustical elements in a piping system. Through the use of such programs, it is possible to study the effects of small changes in the acoustical system, such as changing the accumulator characteristics.

2. The introduction of an accumulator near the flanges of the suction or discharge manifold creates a new acoustical system. One major resonance that is introduced is a natural frequency which is a function of the distance from the end of the manifold to the entrance of the accumulator and the speed of sound in the fluid. This natural frequency will be excited by the higher plunger harmonics and can cause numerous problems.

3. The majority of cavitation problems on suction systems are caused by this acoustical mode since most systems have some kind of accumulator near the pump flange. Using the digital computer program, the onset of cavitation can be accurately calculated and the need for a charge pump properly evaluated.

4. The quarter-wave manifold resonances can be attenuated with properly sized orifice plates near the pump or accumulator flanges.

5. Accumulators with gas-filled bladder/diaphragm designs can be effective for low frequencies in simple systems.

6. Accumulators with gas charges are sensitive to the gas volume and therefore, should be checked on a regular basis to ensure that the system is working properly.

7. In multi-pump systems, the units can interact with each other to create severe problems if each of the accumulators with gas charges are not identical. If only one of the accumulators looses its gas charge, the pulsations in all the pumps can be affected.

8. The frequency response of the gas-filled bladder/diaphragm accumulators is limited by the throat dimensions, i.e., the larger the throat diameter the more effective the accumulator.

9. The flow-through, gas-filled, or gas blanket accumulators have improved frequency response since the throat restriction is removed.

10. All-liquid acoustic low pass filters (Helmholtz type) can be designed to achieve nearly any desired attenuation. The filter design is based on the Helmholtz frequency and the allowable pressure drop. All-liquid filters are not sensitive to system pressures since the speed of sound for most liquids does not change significantly with pressure. The attenuation of the filter is increased as the frequency increases; therefore, such designs; will work over large speed ranges.

11. Pumps and their piping systems should be analyzed for their pulsation characteristics before they are built to prevent problems before they occur. For example, a significant number of piping failures reported to the Nuclear Regulatory Committee (NRC) by the nuclear plant operators have occurred in their reciprocating charge pumps [7]. If these systems were properly analyzed in the design stage, most of these failures could have been eliminated.

Unit Conversions
1 psi = 6.895 KPa
1 in = 0.0254 m
1 ft = 0.3048 m
1 in^3 = 1.64×10^{-5} m^3

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