

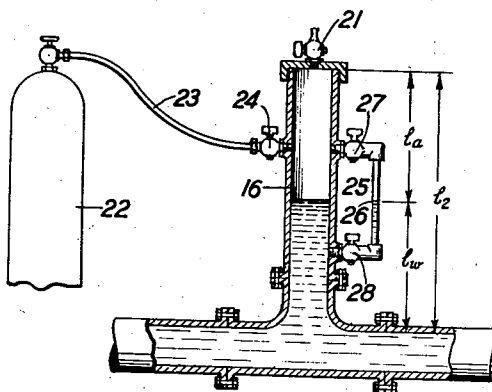
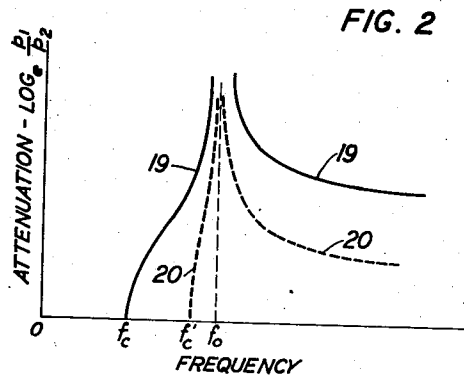
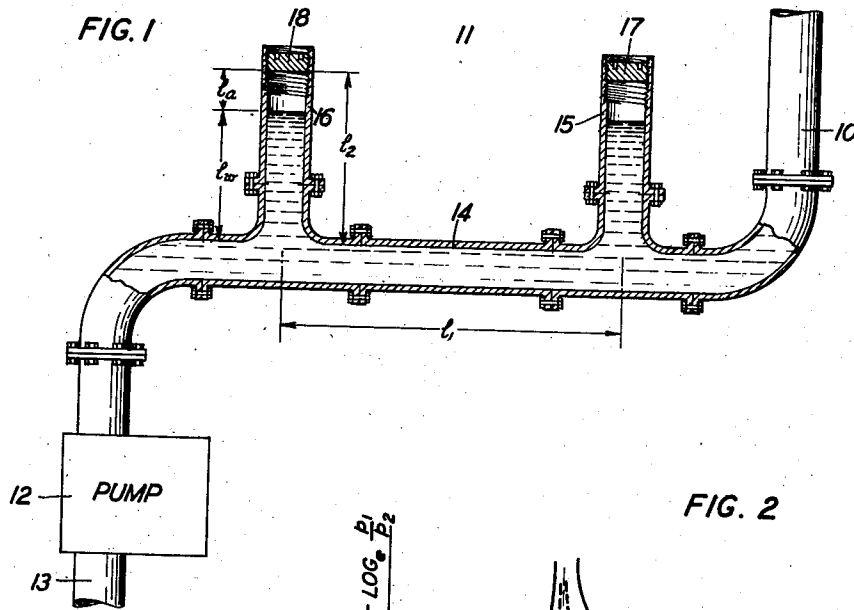
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FLUID TRANSMISSION

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FLUID TRANSMISSION

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This invention relates to fluid transmission and more particularly to arrangements for suppressing fluid pulsations in the pipes of a distribution or supply system.

An object of the invention is to prevent vibrations of the pipes of a fluid distribution system due to periodic pressure pulsations of a supply pump connected thereto.

Another object is to obtain a smooth steady flow of a fluid in a supply system.

In the water supply systems of high buildings distribution throughout the building is generally from a gravity tank on the roof to which the water is pumped through vertical risers connected to the supply mains. Where centrifugal pumps are used the impeller blades induce in the water periodic pressure variations of a relatively high frequency which may be in the audible range. These pressure variations tend to set the riser pipes into vibration which may be imparted to the floors and walls of the buildings and produce an audible disturbance of objectionable loudness.

In accordance with this invention, a vibration filter is associated with the supply pipe of a fluid distribution system, preferably at a point close to the supply pump or other source of pressure waves, the filter being so designed that pressure waves of the objectionable frequency are strongly attenuated while the steady flow of the fluid is not impeded.

A feature of the invention is the use in the filter of resonant vibration absorbing means tuned to the disturbing frequency. Other features will appear from the following detailed description and from the attached drawing, of which:

Fig. 1 shows an embodiment of the invention in a water supply system;

Fig. 2 represents attenuation characteristics to which reference is made in explaining the invention; and

Fig. 3 illustrates a modified form of the invention.

In the system of Fig. 1, a riser pipe 10 is connected through the device 11, which constitutes a vibration filter, and a pump 12, to a water supply main 13. The filter 11 comprises essentially a horizontal pipe section 14 in the main supply line and two closed vertical branches 15 and 16 at the ends of the horizontal section. The length of the branch pipes 15 and 16 is determined, as hereinafter explained, so that when the riser 10 is filled with water, the entrapped air and the water column in a branch constitutes a system resonant

at the pulsation frequency. For example, if the pump is of the centrifugal type having four blades and rotating at 1800 revolutions per minute, the pulse frequency to which the branches should be resonant would be 120 cycles per second.

The resonant branches act as absorbers of the pressure pulses and in combination with the inertia of the water in the pipe section 14 produce an attenuation of the pulses which is large at all frequencies above a certain lower limit and is particularly great in the neighborhood of the resonance frequency.

The amount of air in each of the branch pipes corresponds to the whole internal volume of the branch at atmospheric pressure. As the system becomes filled, a certain amount of water is forced into the branches under the head in the riser 10 and the air is thus compressed to a smaller volume determined, ultimately, by the height of the riser. The head of water in the riser thus determines the elasticity, or resistance to compression, of the entrapped air and also the mass of water in a branch. If the branch is of uniform sectional area it follows that its length for a desired resonance frequency will be determined by the water head or pressure. In the filter shown in Fig. 1, the side branches are closed at their outer ends by threaded plugs 17 and 18 by means of which some adjustment of the length, and therefore of the resonance frequency can be effected.

The theory of the action of the filter under regular periodic pulses is greatly simplified by making use of the concept of impedance. It is well known that when any body or system is subjected to a periodic force of sinusoidal variation, the resulting motion of the body or system after it has settled down to a steady state has also a sinusoidal variation of the same frequency as the applied force. At the instants of application and removal of the force transient vibratory motions of other frequencies may occur but these are generally damped out in a very short time. The steady state velocity of motion is proportional to the magnitude of the applied force and the ratio of the force to the velocity is termed the impedance of the body or system. For sinusoidal variations the "root mean square" values of the force and velocity are generally used in determining this ratio.

In systems of the type shown in Fig. 1, it is convenient to take as the force the pressure intensity in the water and as the velocity the rate of volumetric flow across the sections of the pipes. The force tending to produce the vibratory disturb-

ances in the system is, of course, the pressure variation which is superimposed upon the normal water pressure by the pump impeller blades. The impedance thus defined is termed acoustic impedance since oscillations of the system are of the same type as when sound waves are propagated through the water. For a further discussion of acoustic impedance, reference is made to an article by W. P. Mason, The approximate networks of acoustic filters, Bell System Technical Journal, Vol. IX, No. 2, April, 1930.

The velocity at any point in a system may or may not be in phase with the pressure variations. If the system is incapable of storing energy by virtue of its elasticity or its inertia but dissipates it as heat, the velocity will be in phase with the pressure. In the system of Fig. 1 energy dissipation in the filter is practically negligible and the velocities in general are out of phase with the pressures.

Consider now the acoustic impedances of the different portions of the system of Fig. 1. If l_1 denotes the length of the connecting pipe between the centres of the branches and S_1 its cross-sectional area, the impedance Z_1 of this section may be shown to be

$$Z_1 = j\omega \rho l_1 / S_1 \quad (1)$$

where ρ denotes the density of the water, ω is equal to 2π times frequency, and j is the vector operator

$$\sqrt{-1}$$

The operator j in Equation (1) indicates that the impedance is such that the velocity will be 90° out of phase with the applied force and will lag behind the force.

The side branches have a length l_2 part of which, l_w is filled with water and part, l_a , is filled with air under pressure. If the cross-sectional area be denoted by S_2 the impedances Z_w and Z_a of the water and air portions, respectively, may be shown to be

$$Z_w = j\omega \rho l_w / S_2 \quad (2)$$

and

$$Z_a = -j \frac{P\gamma}{\omega l_a S_2} \quad (3)$$

where P is the steady pressure of the enclosed air and γ is the adiabatic constant for air, its value being approximately 1.4. The negative sign in Equation 3 indicates that the velocity in the impedance Z_a will lead the force in phase by an angle of 90° .

The total impedance Z_2 of each side branch is the sum of Z_a and Z_w , or

$$Z_2 = j\omega \rho l_w / S_2 - j \frac{P\gamma}{\omega l_a S_2} \quad (4)$$

Equation 4 indicates that the impedance Z_2 will be zero, that is, the branch will be resonant, when

$$l_a l_w = \frac{P\gamma}{\rho \omega^2} \quad (5)$$

If the resonance frequency is assigned this gives a value for the product $l_a l_w$. The value of l_a may be determined from the fact that at normal atmospheric pressure, the air will occupy the whole length of the side branch. Hence,

$$l_a = \frac{P\gamma}{P l_w} \quad (6)$$

where P_0 denotes normal atmospheric pressure. Further, since

$$l_w = l_2 - l_a = l_2 \left(1 - \frac{P_0}{P}\right)$$

it follows from Equation 5 that, for resonance at an assigned frequency $\omega_0 + 2\pi$ the required length l_2 is given by

$$l_2 = \frac{\frac{P}{P_0} \frac{P\gamma}{1 - \frac{P_0}{P}}}{\omega_0^2} \quad (7)$$

The pressure P is equal to the atmospheric pressure plus the pressure due to the head of water in the riser.

The effect of the filter in reducing the intensity of the pressure pulses may be arrived at approximately by considering first the pressure attenuation in a filter made up of an infinite number of sections such as shown in Fig. 1 connected end for end. In such a filter, the side branches would have twice the cross-sectional area of those in Fig. 1 and half the impedance. Since the sections are all alike the percentage diminution of pressure would be the same in each. Consequently, the relationship between the pressure p_1 at the input of any section and the pressure p_2 at its output may be written in the form

$$\frac{p_1}{p_2} = e^T, \text{ or } \log_e \frac{p_1}{p_2} = T \quad (8)$$

where e is the base of the Napierian logarithms. The quantity T thus defined is termed the propagation constant per section of the filter; it may be evaluated in terms of Z_1 and Z_2 by the equation

$$T = 2 \sin h^{-1} \sqrt{\frac{Z_1}{2Z_2}} \quad (9)$$

which in combination with Equation 8 gives

$$\log_e \frac{p_1}{p_2} = 2 \sin h^{-1} \sqrt{\frac{Z_1}{2Z_2}} \quad (10)$$

Since Equation 10 represents the pressure attenuation per section in an infinitely extended filter, it will not apply exactly to a short filter system such as shown in Fig. 1 due to the difference in the termination conditions. However, for frequencies above a critical frequency which lies below the side branch resonance, the error is found to be of little consequence. This critical frequency is determined by the condition

$$Z_1 + 2Z_2 = 0 \quad (11)$$

which evidently corresponds to the resonance of the connecting branch and the two side branches connected in series and isolated from the remainder of the system. It is desirable that the critical frequency defined by Equation 11 should be well below the resonance frequency of the side branches since this insures a large degree of attenuation at all frequencies above the critical frequency. This can be achieved by making the inertia effect of the connecting branch large and the side branch impedances small relatively thereto. The advantages of these proportions are illustrated by the curves of Fig. 2 which show the relative attenuations at different frequencies obtained in two different cases. Curve 19 shows the attenuation according to Equation 10 when the critical frequency f_c is about half the side branch resonance frequency f_0 and curve 20 shows the attenuation when the critical frequency has a value about 85 per cent of the resonance frequency.

At frequencies below the critical frequency the curves indicate that the attenuation is zero. Actually the filter is capable of transmitting vibrations in this range with little or no attenuation. The system is analogous to an electrical broad-band filter of the type described in U. S. Patent 1,227,113 issued May 22, 1917 to G. A. Campbell, the theory of which is discussed at length in the Bell System Technical Journal, vol. 1, Number 2, November 1922, pp. 1-32.

In the practical design of the filter of Fig. 1, it is convenient to make the connecting branch 14 of about the same diameter as the main supply line to avoid increasing the frictional load on the pump. The condition that the impedance Z_1 of this branch should be large in comparison with that of the side branches requires that the length l_1 should be great and that the cross-sectional areas of the side branches should also be as large as possible. These requirements follow at once from Equations 1 and 4. Practically there are limits to the extent to which these dimensions can be increased. Due to the elasticity of the water, the pressure pulses have a definite wave length in the pipes equal to the velocity of sound in water divided by the frequency. If the length l_1 is much greater than one quarter of the wave length of the disturbing frequency, Equation 1 will cease to be accurate and the performance of the filter will be vitiated. For example, if the pulse frequency is 120 cycles per second the length l_1 should preferably not exceed 280 centimeters. The side branch areas are limited by the size of the opening that can be made in the side of the main pipe which, for circular section pipes, limits the side branch area to that of the main pipe.

In the foregoing discussion, it has been assumed that the amount of air in each side branch of the filter is determined by the quantity which will just fill the whole length l_2 at normal atmospheric pressure. In practical designs this may lead to a ratio of l_a to l_w which is very large or very small, depending upon the head of water in the riser pipe and the frequency of resonance ω_0 . If there is a great disparity between the lengths l_a and l_w then a small change in one of the volumes represented, such, for example, as might be caused by the absorption of part of the air by the water, will produce a disproportionate change in the resonance frequency ω_0 . It may be shown mathematically that in order to keep the side branch resonance most stable with variations in l_a and l_w the condition to be fulfilled is that the volume of air shall be equal to the volume of water, or

$$l_a = l_w = \frac{l_2}{2} \quad (12)$$

Substituting this value for l_a and l_w in Equation (5) gives

$$l_2^2 = \frac{4P\gamma}{\rho\omega_0^2} \quad (13)$$

from which the length of the side branch is determined in terms of the pressure of the air, the adiabatic constant for air, the density of the water and the frequency of resonance.

If the length l_2 is fixed in accordance with Equation (13) then it will be necessary to provide means for letting out part of the entrapped air

or for introducing additional air, whichever may be required, in order to adjust the volume of air to equal the volume of water in the side branch. Fig. 3 shows a modified form of the invention in which provision is made for varying the volume of air represented by l_a . A stopcock 21 is provided at the top of the side branch 16 for valving off air when the volume is too large. A tank 22 contains air under pressure which may be introduced into the side branch through a feed line 23, under the control of a valve 24. The pressure of the air in the tank must, of course, exceed the pressure P of the air in the side branch. A gauge 25 is provided for the purpose of finding the level of the water. The desired level may be marked on the gauge glass, as shown at 26. If the water level is below this mark, air is let out through stopcock 21, and if above, additional air is admitted through valve 24. When the proper level is reached stopcocks 21, 24, 27 and 28 are closed. Thereafter, the water level should be checked periodically and air added as required to compensate for that absorbed by the water.

What is claimed is:

1. In a water supply system comprising a main conduit and a pump for maintaining water pressure therein, means for suppressing pulsations of the water pressure due to the pump comprising a pair of side branches in said conduit adapted to retain entrapped air when the conduit is filled with water, the dimensions of said side branches being proportioned with respect to the normal water pressure to produce resonance in each of said branches at the pulsation frequency of said pump, and the separation of said branches being approximately equal to one quarter the wave length of the pressure waves corresponding to the pulsation frequency.

2. In a hydraulic system comprising a pipe line subject to periodic pressure impulses, an elongated chamber of uniform cross-sectional area communicating with said pipe line, means for supplying a gaseous medium under pressure to said chamber, means for valving off excess quantities of said gaseous medium, and means for indicating when the volume of liquid in said chamber is equal to the volume of gas in said chamber, the length of said chamber being proportioned with respect to the normal fluid pressure to be resonant at the frequency of said periodic pressure impulses when the volume of liquid in said chamber equals the volume of gas in said chamber.

3. In a water supply system comprising a main conduit and a pump for maintaining water pressure therein, means for suppressing pulsations of the water pressure due to the pump comprising a side branch having unrestricted communication with said conduit, said branch having a closed end and containing a column of water having thereabove a cushion of air, and said cushion being adapted by variations in volume to accommodate differences of pressure in said column of water incident to the operation of the pump, wherein said volumes of air and water may be so proportioned as to produce resonance in said branch at the pulsation frequency of said pump.

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