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STUDY OF A RESONATOR MODEL FOR ATTENUATION OF PRESSURE WAVES IN THE PRESENCE OF PULSATING FLOW ORIFICE PLATE.

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Abstract. *Several hydraulic installations have pulsating flows; however, in many of them the pressure waves must be damped or even eliminated. When considerations of a project, such as space limitations and the material causes the acoustic response of system performance to degrade and / or create excessive noise, the solution may be add a resonator system, improving its answer. In hydraulic systems, it is common to find facilities, resonators in series, which substantially reduce the problems associated with pressure pulses of high frequency, whether caused by pulsatile pumps feature for quick closing valves or sudden changes in direction or speed of flow.*
In the present paper, an experimental study of the behavior of the Helmholtz resonator and the resonator in series in a hydraulic system in which the flow of oil shipped by a bomb has spread contrary to sense pressure waves was performed. The experimental study of pulsating flow in pipes of a hydraulic bench for each type of resonator and the results showed that the installation of any of the resonators studied significantly alters the response of the system. The operation of the hydraulic system without the resonator is presented the results with those obtained after installation of the resonators in the hydraulic bench to then be compared. From this comparison is obtained absorption coefficient of pressure waves in the system with resonators. The most significant results were obtained with the installation of the resonator in series in the system. To this resonator, it was found that the position of the neck / or restrictions at the entrance at the output of the resonator changes the behavior of the system. The resonator in series with the neck at the entrance of the flow of oil greatly reduces the amplitude of pressure waves throughout the system, both upstream and downstream thereof. The resonator with the neck in the incoming waves of pressure changes little pressure waves upstream and downstream, the amplitude of pressure waves is greatly reduced at frequencies above the cutoff frequency, which is why it is characterized by filter type low pass. The results showed that the behavior of the Helmholtz resonator, the hydraulic system significantly affects system response. For the hydraulic bench, it follows that the resonator in series with the hydraulic system and with the neck at the entrance of pressure waves studied was the only devices that best met, since the changes of the response system downstream of the resonator not were significant , and the output of the resonator, pressure waves are strongly damped . Thus it is possible a pulsating flow through the bottom hole of the stock flow and flow " almost " permanent through the upper orifice plate .

Keywords: *resonator in series, helmholts resonator, pulsating flow, pressure waves*

1. INTRODUCTION

Much of the hydraulic installations have a pulsating flow, with pressure waves, which must be eliminated or just damped. In this case, the acoustic resonators and filters are used to control noise, especially for noise attenuation of discrete frequencies (pure tone) in industrial processes, vehicle exhaustion, among others. The acoustic characteristics of the reactive silencers are determined only by their geometric shape, being designed to allow the fluid to go through it, strongly reducing their noise energy (KINSLER, 1982).

The principle of these silencers is based on the reflection of the waves at the source, which means that the waves, while passing through the silencer, have a significant change in their acoustic impedance, which it is altered for a very high or a very low value. Then a small amount of energy propagates through the silencer and most of it is reflected back to the source. These silencers can be found at low cost and present low pressure drop regarding the loaded fluid (TANG, 1973; GORIN, 1987; GERGES, 1992).

The Helmholtz resonator is a simple and ideal device for control of acoustic systems that can be used on side vents in ducts or on the sides of an indoor environment and is mostly used to neutralize sound waves at low frequencies (ALSTER, 1972; TANG, 1973; GERGES, 1992; KELA, 2009). An application example is the internal combustion engine intake systems that are designed so that the acoustic response emphasizes the engine performance, increasing fuel economy and reducing emissions (ORTWING, 2005; VIERSMA, 1980). The Helmholtz resonators are widely used in pneumatic systems, but there are few studies of their use in hydraulic systems.

Specifically for hydraulic systems, it is common to find installations that have resonators in series in the system that substantially reduce the problems associated with high-frequency pressure pulses, whether caused by pumps with pulsatile characteristics, by quick closing a valve or sudden flow direction or velocity changes.

2. METODOLOGY

2.1. Helmholtz resonator

When designing an acoustic system, a Helmholtz resonator is often used to modify its acoustic response. The Helmholtz resonator basically consists in a cavity with a small opening through which the fluid contained within will come into contact with the fluid of the system or the environment.

When the dimensions of the cavity of an acoustic system are small compared to the wavelength, the movement of the middle of the system is analogous to a mechanical system with one degree of freedom, which has a set of mechanical elements: mass, stiffness and damping. The Helmholtz resonator consists of a enclosed recipient with volume V, communicating with the external environment through a small opening area S, radius "A" and length "L", Fig. 1 (TANG, 1973; GERGES, 1992).

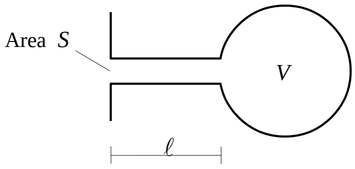

Figure1.Basic Helmholtz resonator.

The functioning of the resonator is based on the reflection of the waves to the source, i.e. when passing through the muffler, find a change of acoustic impedance to a very low value. Then a small amount of energy propagates through the resonator and most of the energy is reflected back to the source (GERGES, 1992). It is defined as impedance the magnitude which opposes the system movement. Inertia is a tendency to not modify the kinetic state of the system and the impedance is the tendency to eliminate movement (NEPOMUCENO, 1968).

In order to obtain the resonance frequency of the Helmholtz resonator, it is first necessary to assume that the wavelength of the vibration is much greater than the linear dimensions of the resonator neck. Also, it must be assumed that any pressure disturbance within the cavity propagates in reversible and adiabatic conditions, and the movement of fluid within the resonators neck is lossless (ALSTER, 1972; TANG, 1973; GERGES, 1992;).

Figure 2 shows that when a sound wave with the same resonance frequency of the resonator enters through the point C, the impedance at point A is zero and there is no pressure amplitude. So, no sound will be transmitted to the D output of the tube (KELA, 2009).

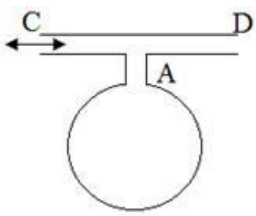

Figure 2. Closed tube with Helmholtz resonators in the side opening.

2.2. Resonator in series

In addition to the Helmholtz resonator, other types of cavities may also be used for pressure waves attenuation in fluids. The most common model for this type of filter consists of a cavity with a neck diameter lower than the systems tubes, but installed in series in the hydraulic system, Fig.3.

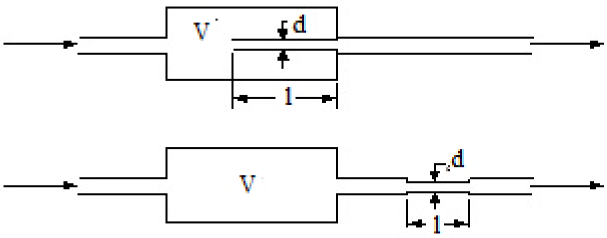

Figure 3. Physical arrangements for the acoustic filter in series in the installation.

Differently from the Helmholtz resonator, the resonator in series in the installation behaves as a low pass filter. The frequency at which the resonator starts absorbing the waves is called the cut-off frequency, and is given by (ERNEST, 1960; DICKEY, 1996), Eq. (1):

$$f_c = \frac{c}{2} \frac{d}{\sqrt{\pi l' V}} \tag{1}$$

Where: c = speed of sound in liquids (m/s); d = diameter of the neck (m); l′ = neck length (m); V = volume (m).

When designing a filter, the diameter and length of the neck should be chosen in order to do not generate excessive pressure drop in the hydraulic flow. The cut-off frequency must be calculated in order that the lowest frequency to be absorbed is higher than the cut-off frequency (ERNEST, 1960; DICKEY, 1996), Eq. (2):

$$f_0 = \frac{1}{2} f_c = \frac{c}{4} \frac{d}{\sqrt{\pi l' V}} = \frac{c}{2\pi} \sqrt{\frac{S}{l' V}} \tag{2}$$

Using $S = \frac{\pi d}{4}$ on Eq. (3).

It is observed that the resonance frequency for the resonator in series in the hydraulic installation is the same for the Helmholtz resonator, but the attenuation of pressure waves will only occur at frequencies above the cut-off frequency f_c.

2.3. Design of the resonator

The flow bench under study is intended for flow measurement analysis in pulsating flows and has two orifice plates: one on the upper pipe for measuring the flow in steady state and the other in the lower pipe for measuring pulsating flow. Between these two plates, there is a pressure pulse generator, Fig.4.

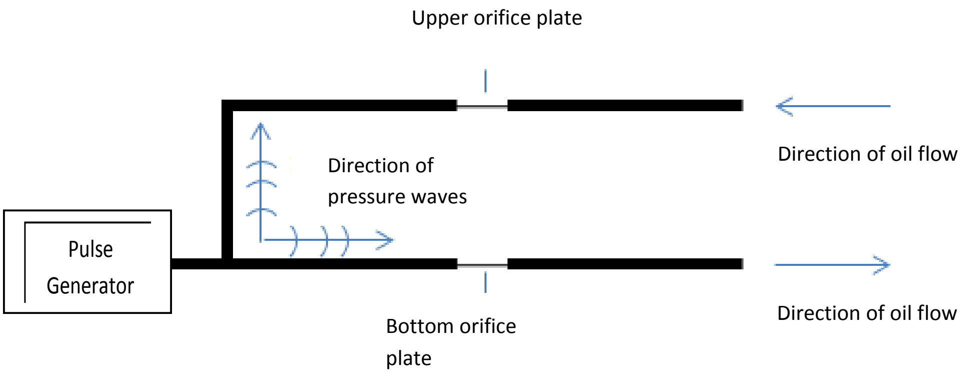

Figure 4. Scheme of hydraulic installation of the flow bench.

In figure 4, it is observed that the pressure waves created by the pulse generator are propagated in the lower tubes with the same direction of the hydraulic oil flow. In the upper tubes the waves propagates in the opposite direction.

Therefore, the problem is to create a device between the upper and lower pipes that reduces or eliminates the pressure waves that propagates towards the upper orifice plate, maintaining a constant pressure in the measuring system. In order to solve this issue, it was decided to install a resonator in the system between the two orifice plates considering its efficiency of noise attenuation, operational simplicity and the ease and low cost of construction of these devices.

The study will therefore be based on the physical model of the resonator, basically consisting of a cavity and a small opening (neck) which will be in contact with the fluid of the hydraulic system. Both the Helmholtz resonator and the resonator in series will be analyzed and tested on this bench in order to select the one that better attenuates the flow pressure waves. Due to the geometrical and functional similarity of the Helmholtz resonator and the low pass filter type resonator (in series), the same cavity was used for testing on both devices.

To perform the experimental tests, it is recommended to do it over a wide period of frequencies. In order to do so, using the greatest possible volume of the cavity, the neck length can be variated from about 0.2 m to 2.0 m.

With these values, it is possible to work with the resonator resonance frequency in a range of approximately 11.62 Hz to 80.50 Hz.

2.4. Analysis of the series resonator and the Helmholtz resonator in the hydraulic system

The Helmholtz resonator is a device quite used to attenuate acoustic waves in gaseous mediums, but there are only few studies of its application in liquid mediums.

The resonator in series in the installation is already used in hydraulic systems, but it was found no bibliography with data regarding its use for pressure waves propagating in the opposite direction to the hydraulic oil flow. Thus, there are two different configurations being studied, which can completely alter the operation of the resonator: the first is the placement of the neck / restriction in the oil flow inlet and the second is the placement of that neck / restriction on the incoming pressure waves. In this study, the two neck positioning settings for analyzing the functionality of them will be checked.

The functioning of the hydraulic system without the resonator will be presented and, subsequently, these results will be compared with the results of the system with the series resonator and the Helmholtz resonator. This comparison shows the influence of the resonators installation on the system operation. The upstream pressure waves and downstream of the resonator will be compared in order to obtain the curve of the absorption coefficient of the pressure waves in the system for the both resonators.

For the hydraulic system without the resonator, a pressure transducer in the system input (TES-SR), a transducer with the pulse generator (TGP) and another near the bottom orifice plate (TPOI) are necessary.

The figure 5 illustrates the hydraulic bench without the resonator and the arrangement of the pressure transducers.

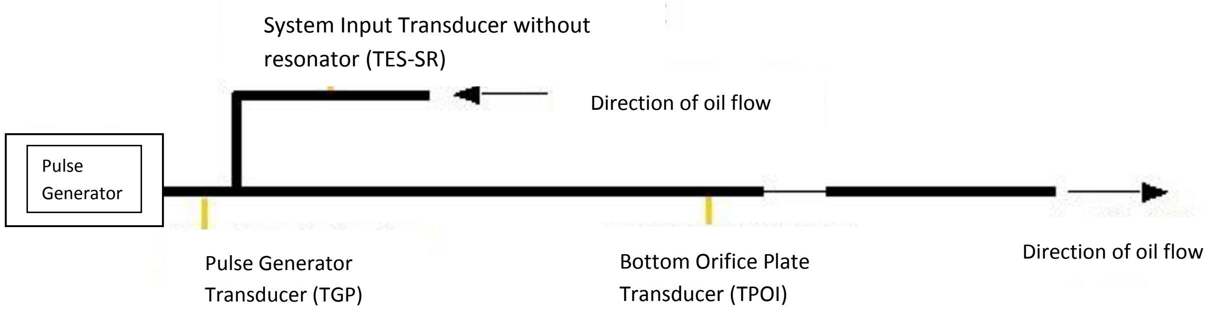

Figure 5. Hydraulic bench installation diagram with the main pressure reading points - assembly without the resonator.

2.5. Analysis of the hydraulic system without the resonator

After several measurements, it is calculated, for each frequency, the value of the amplitude of the wave pressure in the system input without a resonator (TES-SR). The Figure 6 illustrates, in three pressure levels in the system, the variation of the wave amplitude in the frequency domain curves.

Whichever is the level of pressure in the system, Figure 6 shows that the shape of the amplitude variation curve with the frequency is maintained although it is changing its position.

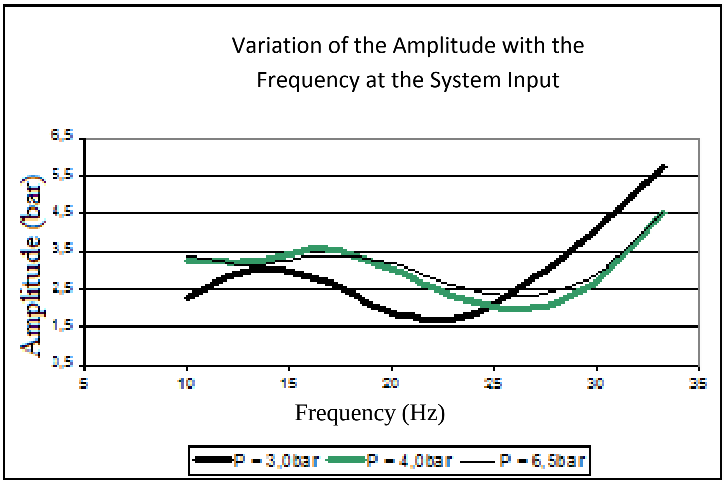

Figure 6. Variation of the wave amplitude in the system input without resonator (SR-TES) with the frequency, for different pressure levels in the hydraulic pump.

2.6. Analysis of the Helmholtz resonator influence in the hydraulic system

This analysis is based on experimental data obtained from the pulse generator (TGP) and on system entrance transducer with the resonator (TES-CR). A comparison between these data and the data obtained in this system shows the influence of the resonator in the system.

For the assembly with the Helmholtz resonator installed, the system input transducer is hereinafter referred by TES-CR (system input transducer with resonator, in Portuguese). Figure 7 illustrates the arrangement of the transducers for the workbench with the Helmholtz resonator. It is observed that the resonator was installed in the pipe connecting the lower pipe to the upper pipe, in order to attenuate pressure waves that propagate towards the upper orifice plate.

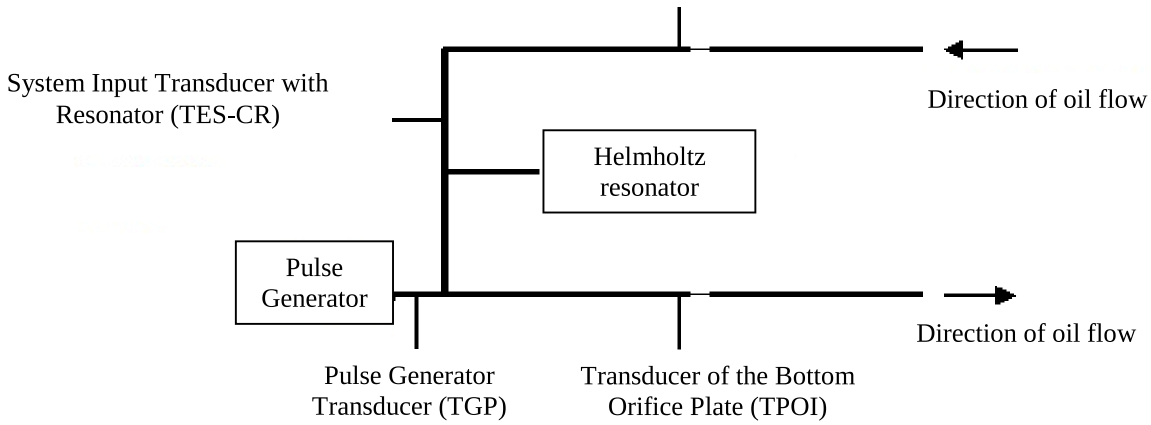

Figure 7. Hydraulic workbench installation diagram with the main pressure reading points. a) assembly without the Resonator; b) assembly with Helmholtz resonators

Based on the measurements performed, the curve of the amplitude variation of pressure waves is elaborated in the system input (TES-CR) in the frequency domain. Figure 8 shows this curve superimposed over the curve of variation of the pressure waves amplitude in the system intake without resonator (TES-SR), for the pressure level of 6.5 bar and a 1.0 meter long neck. As shown in Figure 8, the form of pressure variation amplitude of the curve in the system input without the Helmholtz resonator (TES-SR) has considerably changed in relation to the system input curve with the resonator (TES_CR), mainly on frequencies below 20 Hz. It can be noticed that the Helmholtz resonator changes the system response.

By altering the pressure level in hydraulic bench and the neck length of the Helmholtz resonator, the system behavior is similar to that shown in Figure 7.

The Helmholtz resonator absorption coefficient in the hydraulic system varies with frequency. For this case, the coefficient is obtained from the relation, Eq. (3):

$$\textit{Absorption Coefficient} = \left(1 - \frac{\text{Wave Amplitude in the System Input with Resonator (TES-CR)}}{\text{Wave Amplitude in the System Input without Resonator (TES-SR)}}\right) \times 100 \tag{3}$$

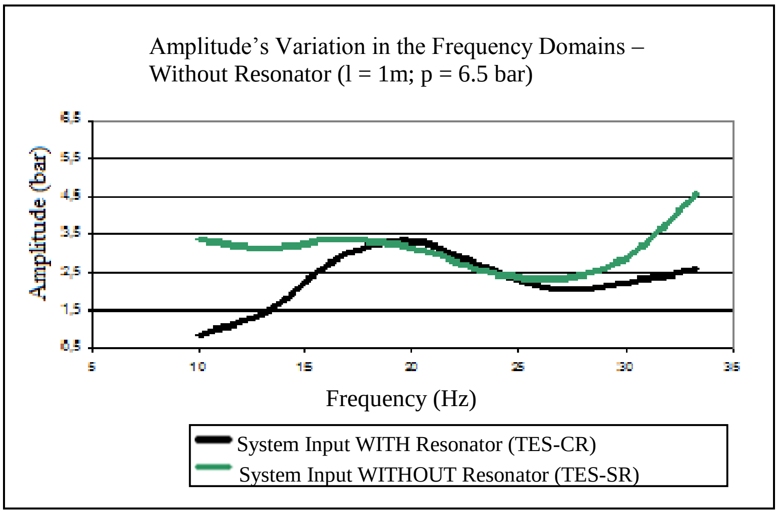

Figure 8. Pressure amplitude variation in the system input with and without the Helmholtz resonator in the frequency domain, with pressure level of 6.5 bar and a neck length of 1.0 m.

Figure 9 shows the curves of the absorption coefficient in the Helmholtz resonator varying with the frequency for different levels of pressure and length of the neck, respectively.

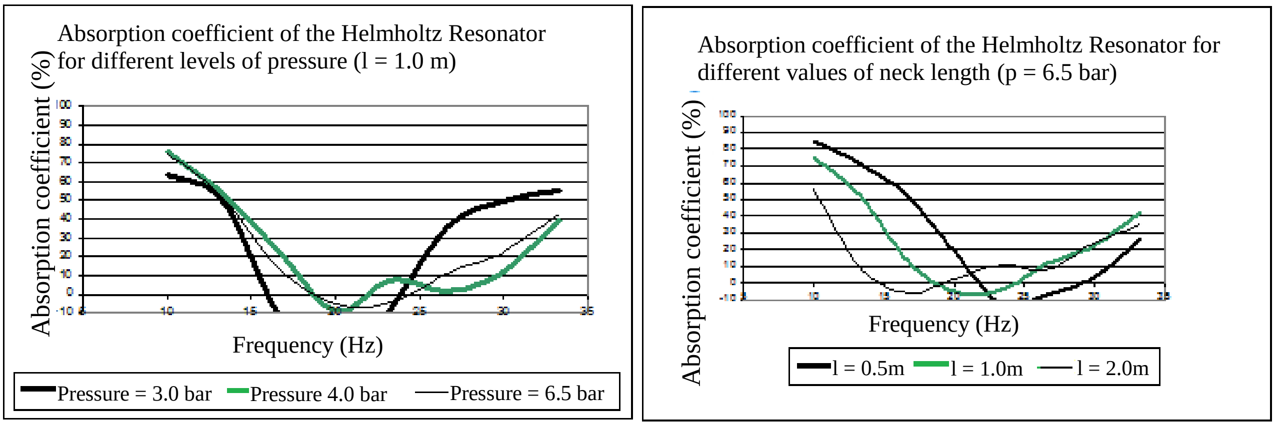

Figure 9. Absorption coefficient of the Helmholtz resonator varying with the frequency for different pressure levels / neck length set at 1.0 m, and for different values of neck length and pressure level set in the system at 6.5 bar.

Analyzing the Figure 9 it can be observed that the installation of the Helmholtz resonator in the hydraulic workbench alters the system response. However, the frequency range that the Helmholtz resonator absorbs pressure waves in the system is small and its installation in the system is unviable.

2.7. Resonator in series, with the neck in the oil flow inlet

For the assembly with the resonator installed in series, a transducer is added on the output of the resonator (TSR). The transducer at the resonator input (TER) should be in the same position of the transducer at the system input without the resonator (TES-SR). Figure 10 illustrates the arrangement of the transducer to the bench with the resonator in series.

For the analysis of the resonator influence with the neck in the oil flow inlet in the hydraulic system, different pressure measurements are made using the pulse generator (TGP), the resonator input (TER) and the lower orifice plate (TPOI), as shown in Fig. 10 and Fig. 11. A comparison is made with the system results without the resonator, to verify the influence of the resonator in series on the installation system in the hydraulic workbench. Based on the measurements performed, the curve is elaborated from the variation of the pressure waves amplitude at the input of the resonator (TER) in the frequency domain.

It is observed that, when installing the resonator in series with the neck in the oil flow inlet, there is a strong absorption of pressure waves prior to the resonator (TER). While the input curve of the system without the resonator (SR-TES) ranges varies from 2.0 bar to 8.5 bar, the entrance curve of the resonator (TER) is ranging from 0.05 bar to 0.30 bar.

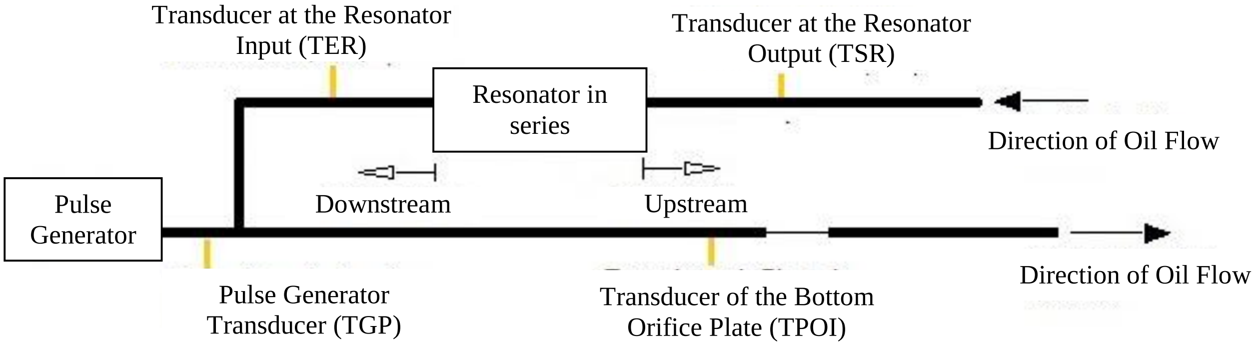

Figure10. Hydraulic workbench installation diagram with the main pressure reading points - assembly with Resonator in Series.

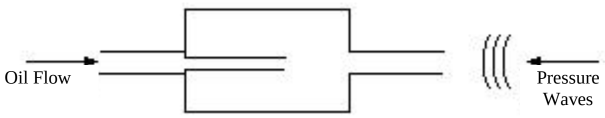

Figure11. Draft of the resonator in series in the system with the neck in the oil flow entry.

The absorption coefficient of the waves at the resonator input is obtained from the following relation, Eq. (4):

$$Absor.coef.attheResonatorInlet = \left(1 - \frac{Waveamplitudeattheresonatorinlet}{Waveamplit.\ atthesysteminletwithouttheresonator}\right) \times 100 \qquad (4)$$

It is found that the simple act of installing the resonator in series in the system with the neck in oil flow input changes the behavior of the hydraulic system upstream of the resonator. In comparison with the system without the resonator, the amplitude of pressure waves in the resonator input has been reduced by more than 90% throughout the frequency range analyzed.

A comparison of pressure waves that enter and leaves the resonator in series is presented. For this, pressure measurements are made in the input transducers (TER) and in the resonator output (TSR), Fig. 10.

Using the data obtained in the measurements, it is calculated for each frequency, the value of the amplitude of the pressure wave in the input (TER) and in the output (TSR) of the resonator.

In conclusion, after installing the resonator in series (neck in the oil flow input), the variation of the hydraulic system pressure levels and the resonator neck length slightly alter the results. For this configuration, in all the tests performed, the cutoff frequency remained at a value close to 43 Hz.

This resonator is more suitable for attenuation of pressure waves in more than 90% over a wide frequency band in hydraulic systems in which the change of the system response upstream the resonator does not cause damage to the operation of the setup.

2.8.Resonator in series, with the neck at the input of pressure waves.

The analysis of the influence of the resonator with the neck at the input of pressure waves in the hydraulic system is made from various pressure measurements in the pulse generator (TGP), at the input of the resonator (TER) and the lower orifice plate (TPOI), Figure 10 and Figure 12. A comparison is done with the results in the system without the resonator to determine the influence of the resonator installation in the hydraulic bench.

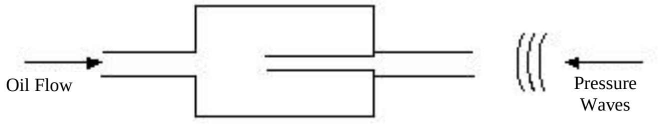

Figure 12. Draft of the resonator in series in the system with the neck in the inlet of the pressure waves.

Based on the measurements performed, the curve is elaborated from the variation of the pressure waves amplitude at the input of the resonator (TER) in the frequency domain. Overlaying this curve to the curve of variation of the wave amplitude in the system input without resonator (TES-SR), it's the Fig. 13.

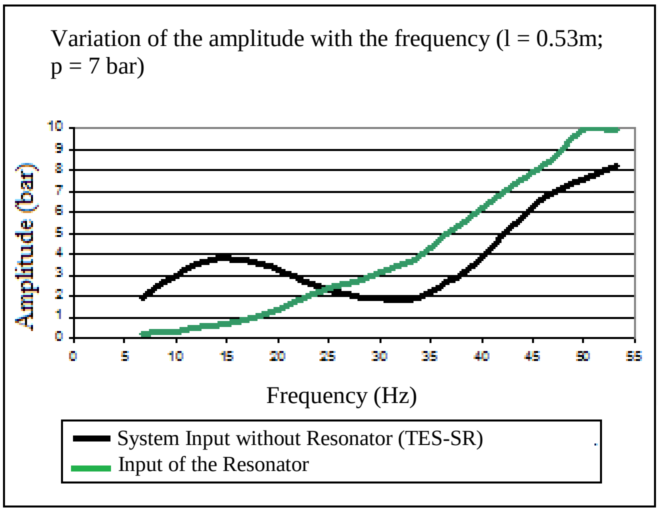

Figure 13. Variation of the pressure wave amplitude with the frequency in the system with and without the series resonator (neck at the input of pressure waves) to 7,0 bar pressure level and neck length 0.53m.

From Figure 13, it is observed that, with the installation of the resonator, there is a reduction in amplitude of the waves before the resonator (TER) in the frequency range from 6 Hz to 25 Hz. Thenceforth, it can be noticed a signal amplification in in relation to the system without resonator. For frequencies from 35 Hz on, the curve of wave amplitude at the resonator input is substantially parallel to the curve of the amplitude at system input without resonator.

The influence of the resonator in the system can be visualized by the curve of the absorption coefficient of input waves in the resonator in series in the hydraulic system (neck at the input of pressure waves) varying with frequency. The absorption coefficient of the wave in the resonator input is obtained by Eq. 4.

Figure 14 shows the curves of the pressure waves absorption coefficients in the resonator for different input levels of system pressure.

When analyzing the Figure 14, it is observed that at low frequencies (below 28 Hz, approximately) there is a strong absorption of pressure waves. This fact may be better understood by analyzing once again Figure 13, which shows the curves of the amplitude of pressure waves in the system input without resonator and at the resonator input (system with resonator).

Several measurements of pressure at the input transducers (TER) and the output resonator (TSR) are performed. From the data obtained is calculated for each frequency the value of the amplitude of the pressure wave.

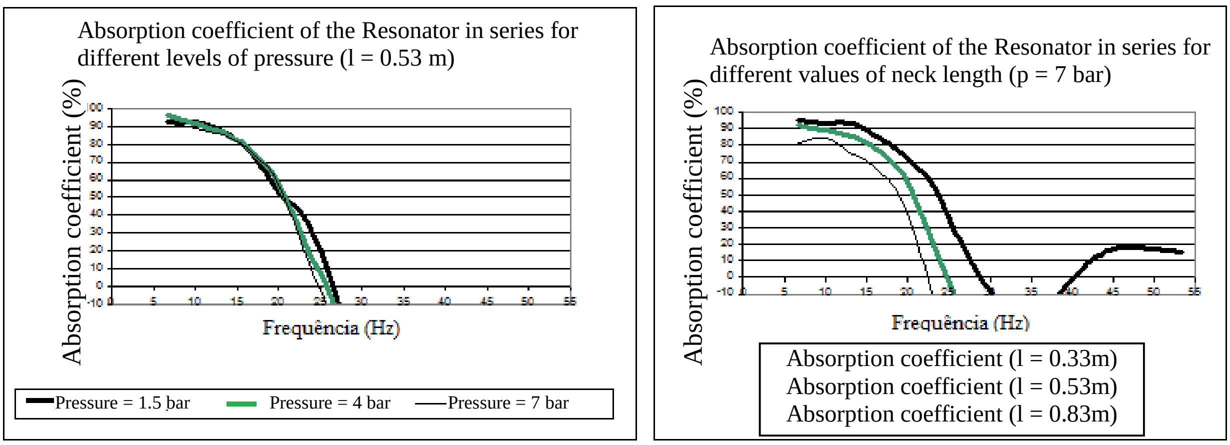

Figure 14. Absportion coefficientn of pressure waves in the resonator in series input with the neck at the entrance of pressure waves, for different levels of pressure and a neck length fixed at 0.53m.

Figure 15 shows the curves, in the frequency domain, of the amplitude variation of pressure waves at the resonator input and output for a neck length of 0.53 m and a pressure set at 7.0 bar in the system.

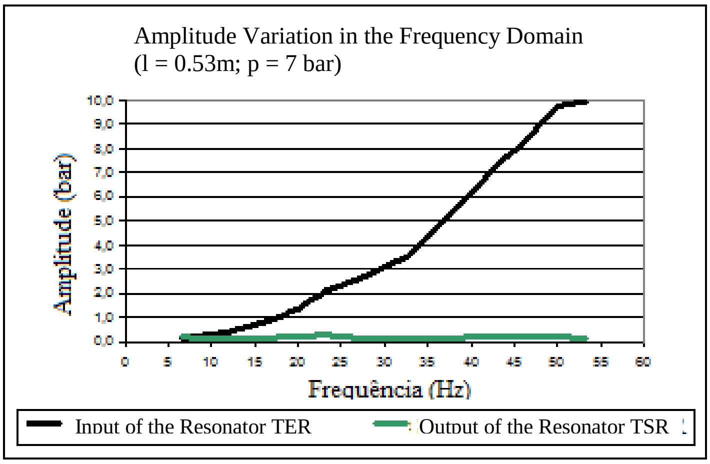

Figure 15. Variation in the frequency domain, of the pressure wave amplitude at the input and output of the resonator in series for a level of pressure set at 7.0 bar and a neck length set at 0.53 m.

In Figure 15, there is a considerable reduction of the amplitudes of pressure waves at the output of the resonator (TSR).

Figure 16 shows the absorption coefficient for the resonator in series on the hydraulic system for different levels of pressure. The absorption coefficient for the resonator in series is obtained by Eq. 4.

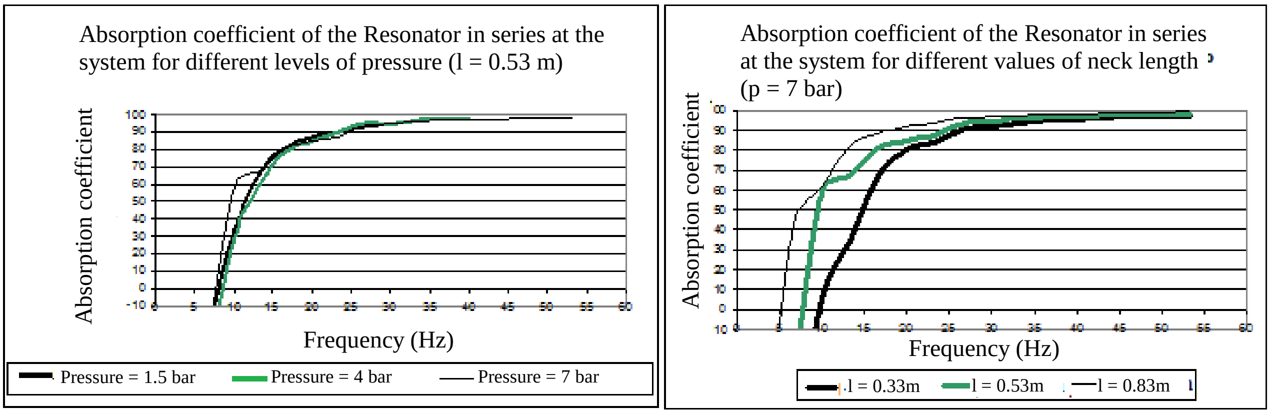

Figure 16. Absorption coefficient of the resonator for different levels of pressure and a neck length set at 0.53m.

By analyzing Figure 16, it is concluded that the pressure waves that pass through the resonator in series (with the neck at the input of pressure waves) are strongly damped after a certain frequency, called the cut-off frequency. For the studied cases, the average value of the obtained cut-off frequency is approximately 8 Hz.

3. RESULTS

After extensive testing and adjustments to the resonators, it was possible to obtain a result that satisfies the operating prerequisites of the flow bench under study: flow in steady state in the upper pipe and pulsating flow in the lower pipe. Thus, upstream the resonator, pressure waves from the pulse generator should not experience alterations or, at most, suffer small changes in order to maintain the characteristics of pulsating flow. Downstream the resonator, the pressure waves must be damped to the maximum in order that the flow in the upper pipe reaches steady state or at least very close to it.

The analysis of the hydraulic system without the resonator was made to, subsequently, take place the comparison of results after the installation of the resonator.

The amplitude of the pressure waves do not increase gradually with the increase in pulsing frequency; in a frequency range (15 Hz to 30 Hz approximately) the curve of the amplitudes of the waves resembles a parabola with the cavity facing down.

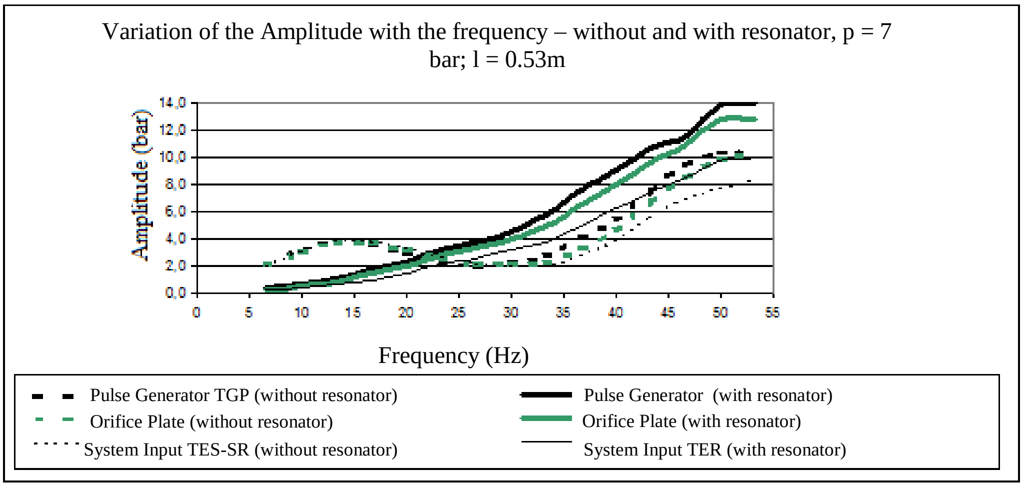

Figure 17. Variation of the pressure amplitude with frequency in the system with and without the resonator for pressure level set at 7.0 bar and neck length set at 0.53 m.

In Figure17, the variation curves, prior to the installation of the resonator in series in the system, of the pressure amplitude can be compared with curves after the installation in the system, with the neck at the pressure waves input. It is observed that, after the installation of the resonator, the response throughout the system altered similarly. For other pressure levels and neck length analyzed, the system's behavior was similar to the one shown in Fig. 17.

Analyzing Fig. 14, it can be observed that, in the system with the resonator in series installed, the variation of the pressure level in the flow bench causes minor changes in the system response, since the curves are practically superimposed. On the other hand, it is observed that, when changing the resonator neck length, the system response is altered significantly.

The absorption of the waves that enters the resonator can be seen in the graphs of the absorption coefficients in the frequency domain for multiple values for the the pressure level, Fig. 16. By analyzing Fig. 16, it is observed that the pressure level variation in the system was not significant, and did not cause changes in the cut-off frequency value, which remained the same. For frequencies above the cut-off frequency, pressure waves are strongly damped. This behavior is characteristic of low pass filter type.

At low frequencies, there is a strong absorption of pressure waves. This fact may be better understood by analyzing again to Fig. 17, which shows the curves of the pressure waves amplitudes in the system input without resonator (TES-SR) and at the input of the resonator (TER).

The best results according to the characteristics described above were obtained by the resonator in series in the hydraulic system, with the neck restriction on the input of pressure waves. The main measures of the analyzed resonator are: Volume = 30 l; Internal neck diameter: 0.015 m; Neck Length: 0.83 m.

The analysis is performed downstream the resonator from the comparisons of results obtained at the input and at the output of the resonator. With such comparisons, it is possible to observe if the resonator was or was not absorbing the pressure waves.

Figure 18 illustrates the behavior of the pressure waves in the time domain at different pulse frequencies. It is observed from Fig. 18 that, with the increase of the pulse frequency, the amplitude of the pressure waves at the input of the resonator (TER) is increased, while the waves at the output of the resonator (TSR) remain practically with the same amplitude.

Since the hydraulic fluid from the pump first passes through the transducer at the resonator output (TSR), entering the resonator and, on the way out, passes through the transducer at the resonator input (TER), the pressure level in TSR is higher than in the level in TER. This difference is due to the pressure loss of the fluid passageway through resonator. Analyzing the graph of Fig. 18, for pulsing frequency of 10.0 Hz, is observed that the pressure loss is small (approximately 0.2 bar).

The amplitude of the pressure waves in the resonator output remained substantially at a value close to 0.3 bar for the whole frequency band analyzed. However, the amplitudes of the waves in the resonator inlet were increasing gradually with increasing frequency. Thus, it can be observed that the pressure waves that are entering the resonator are being absorbed since the waves in the output have practically the same amplitude throughout the frequency range analyzed.

Calculating the cut-off frequency from Eq. 3, there there is a difference from the cut-off frequency obtained experimentally. For the resonator neck with 0.53 m length, volume equal to 30 l and the internal neck diameter equal to

0.015 m, the cutoff frequency calculated from the Eq. 3 is equal to 43.6 Hz; a cut-off frequency of approximately 8 Hz was obtained experimentally.

This difference is probably due to the direction of the flow of the hydraulic fluid being opposite to the direction of propagation of the pressure wave.

For the experimental bench in question, however, the installation of the Helmholtz resonator in a hydraulic system did not achieve its goals because it was expected an attenuation of the pressure waves of at least 85% in the frequency band considered.

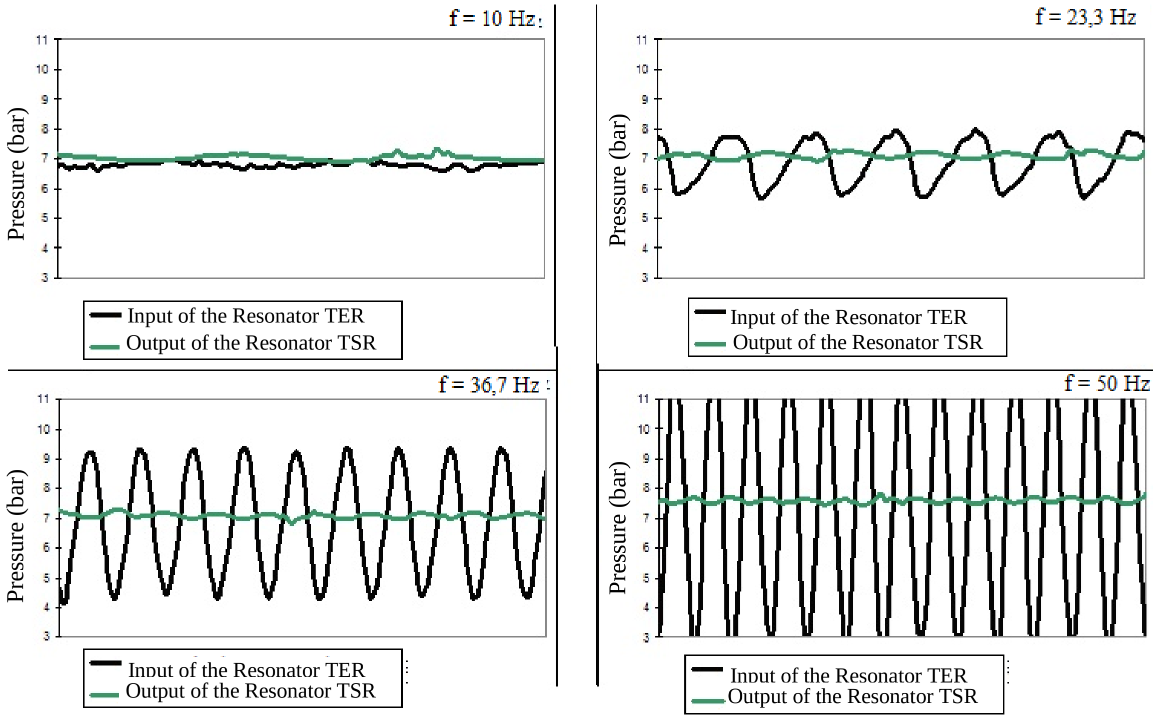

Figure 18. Behavior of the hydraulic system with the resonator in series for a 7.0 bar pressure level, neck length of 0.53 m. Applied frequencies of 10.0 Hz, 23.3 Hz, 36.7 Hz and 50.0 Hz.

4. CONCLUSION

For the operation of the testing bench, it is necessary that the resonator does not have influence on pressure waves upstream and, downstream, are absorbed to the maximum so as to obtain a flow close to the steady flow.

For the resonator in series in the hydraulic system, there were two different configurations that significantly change the results: Installation of the neck on the side of the oil flow input and on the side of the pressure waves input.

The resonator, with the neck in the oil flow input in series with the hydraulic system, has great influence on the system response, but there is absorption on both upstream and downstream pipes throughout the frequency range studied. For the flow bench in question, however, the resonator in series with the neck at the oil flow input should not be used because the flow bench requires that the system response, upstream the resonator, does not change or at most, suffers small changes.

On the other hand, the resonator in series in the installation and with the neck at the input of the pressure waves almost does not change the system response upstream the resonator. For frequencies below approximately 25 Hz, there is an absorption of the pressure waves compared to the system without resonator and, for frequencies above 25 Hz, there is an amplification of the amplitude of the pressure waves. Downstream, there is a great absorption of the pressure waves after a certain frequency, behaving like a low pass filter. For the cases studied, the average value obtained from this cut-off frequency is approximately 8 Hz. Therefore, the installation of the resonator allows the hydraulic bench a pulsating flow upstream thereof and a flow near the steady flow downstream.

For hydraulic bench in question, it is concluded that the resonator in series in the hydraulic system with the neck at the input of the pressure waves was the studied configuration that best fulfilled the objective, since the system response changes downstream the resonator, they were not significant and, at the resonator output, pressure waves were strongly damped. Thus, a pulsating flow through the lower orifice plate flow bench approximately constant through the upper orifice plate is possible.

The Helmholtz resonator influences the hydraulic bench, however, the frequency band of the pressure waves absorbed by it is small. The installation of the Helmholtz resonator in the hydraulic bench changes the system response. Nevertheless, the frequency band that the Helmholtz resonator absorbs the pressure waves in the system is small and its installation in the system is unviable.

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