ASPECTS REGARDING THE FUNCTIONAL DESIGN OF TWO-CHAMBER HYDROACOUSTIC FILTERS

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Abstract: *This paper contains aspects regarding the functional design of a hydro-acoustic filter with two balancing chambers. In this regard, the algorithm for calculating the degree of amortization of frequencies, using the electric-hydraulic analogue, is presented in the case of a low-pass filter.*
Key words: *noise, elastic waves, hydrostatic pump, hydro-acoustic filter.*

1. Considerations regarding the generation of noise in hydraulic systems

The main responsibility for generating noise in hydraulic systems is the functional and constructive principle of the hydrostatic generator (hydrostatic pump) [1].

As long as there is a noise-generating source (hydrostatic pump) in the hydraulic system, this noise will be radiated by all the "coupled" environments. However, deficiencies (constructive, mounting or operating) that exist in any component of the hydraulic system, which can lead to the failure of the whole system, also contribute to degrading effects.

As far as the functional principle of hydrostatic pumps is concerned, they are based on the volume flow of the fluid from the suction zone to the discharge zone through variable volume chambers [2, 3, 11, 12, 13]. Due to the conversion of mechanical energy into energy the hydraulic, predominantly potential hydrostatic pressure, which occurs at the crossing of the pump, the specific energy level of the fluid will increase from aspiration to discharge.

Conversion takes place in the working rooms of the pump and is returned to the pumping bodies which can be: axial or radial pistons, blades, gears, etc. In these cases, the discharge flow is determined by summing the instantaneous flow rates produced by the individual working chambers. Also in the majority of cases, the kinematic chain of the operation of a volumetric pump uses a crank mechanism or equivalent mechanisms. As a result, the kinematic of the liquid determines a pulsating (sinusoidal) flow made in the form of impulses of the volumetric flow [4].

The impulse of the volumetric fuse causes the occurrence of oscillations that propagate in the fluidic environment in the form of elastic waves. The propagation of these is done with a finite-dependent velocity of the nature and properties of the fluidic medium-whose value is different from the oscillation velocity of the different particles [5, 6,2].

In a perfectly rigid and incompressible environment, an impulse is transmitted instantly, unmodified from one element to another. In an elastic or compressible medium the impulse transmission is delayed by the inertia and elasticity of the displaced elements. Hydraulic environments, usually considered incompressible, however, have certain compressibility. It results that, due to the compressibility of the hydraulic environment, there will be unevenness by generating so-called compressive or pressure impulses [2, 4, 9, 10].

The succession of generating the two categories of impulses or associated elastic waves shows the causal links between the Q flow and the *p* pressure. Also, in order to achieve its function, a pump must be a component of a pumping installation made up of structural elements coupled with each other. Under these conditions, they may be at risk of degrading effects due to the non-uniform operation of the volumetric pump, each component of the entire pumping system.

Thus, they appear to be specific to hydraulic pumping installations:

- noise transmitted in the hydraulic environment
- the noise transmitted in the structure, which has as its source both the pump and the structures coupled with it
- the noise transmitted to the air, which is 'heard'.

With regard to methods for noise reduction, different methods can be used in practice: flexible pipes (hoses), interference hydro-active filters or active hydro-acoustic filters (hydro-pneumatic accumulators)[3].

2. Hydro-acoustic filter with two balancing chambers

The hydro-acoustic filter is a passive filter whose functionality is based on the principle of reflecting the sonic wave. It will be analyzed the case of a hydro-acoustic filter in the pumping plant served by a hydrostatic pump, driven by a motor machine with a relatively rigid functional characteristic (with relatively small variations of the angular velocity) [4, 5, 7, 8, 9, 10, 12].

In order to highlight the way in which it performs its functions, the electric-hydraulic

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analogue will be analyzed and the variant of a low-pass electric filter (consisting of shock coils with high inductance L and capacitors of high capacity C. The coils the shock does not allow the alternate current component to pass - a very high reactance - in turn this component is closed by capacitors - which, for the alternating current component, oppose a small reactance. Depending on the acceptable value for the attenuation constant (a), only the quasi-current component is obtained after the passage through the filter band.

Constructively, the hydro-acoustic filter (Fig. 1) represents a balancing chamber system, connected with drosel pipes [5, 7, 8]. The geometric dimensions of the separate elements of the system are small compared to the wavelength that propagates from they also allow the drosel connection tube to play the role of acoustic mass, and the room volume plays the role of acoustic elasticity. These two elements form the cell of the acoustic filter.

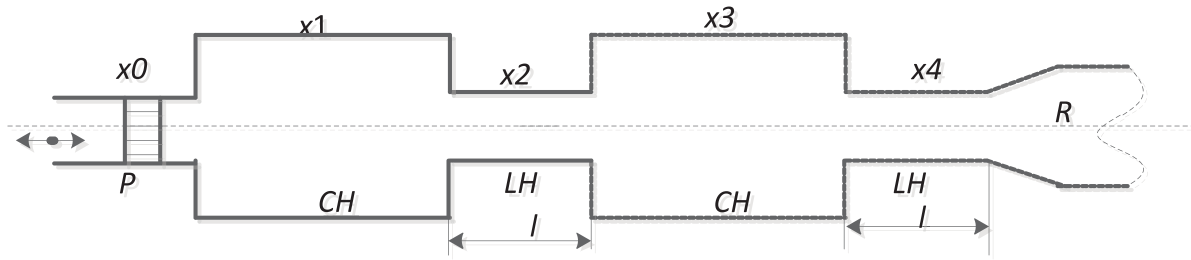

Fig.1 *Hydro-acoustic filter consisting of two balancing chambers and two drosel pipes*

In Figure 1 we have noted with $x_{1,2,3,4}$ - the flow passing through the respective section, L_H the coefficient of inertia (acoustic mass), l the length of the drosel pipe, R acoustic resistance, C_H the hydraulic capacitance coefficient (the elasticity acoustic) and p- pressure.

The phenomenological complexity of wave propagation through this hydraulic system can be studied by using the electrical-hydraulic analogy and by applying the Lagrange equation to the flow that executes the oscillations.

The hydraulic system represented in Figure 1 has three degrees of freedom and its electrical counterpart is represented in Figure 2.

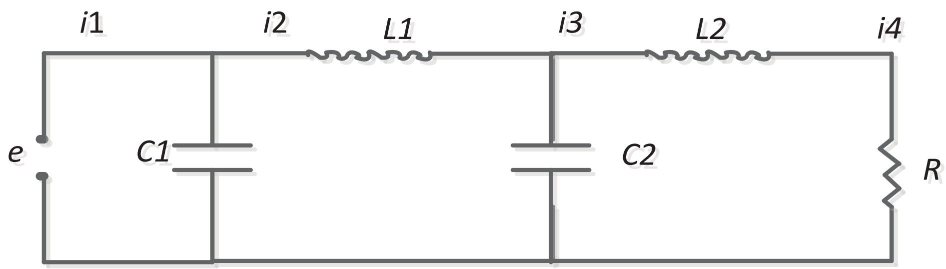

Fig.2 *The electric counterpart of the two-chamber hydro-acoustic filter*

In Figure 2 we used the notations: $i_{1,2,3,4}$- the intensity of the electric current through the respective branch of the circuit, L-inductance of the analog circuit, C-electric capacitance, R-acoustic resistance. Lagrange's equation for flow that performs oscillations can generally be written as:

$$\frac{\partial}{\partial t}\left(\frac{\partial E_c}{\partial x_n}\right) - \frac{\partial\left(E_c - E_p\right)}{\partial x_n} + \frac{1}{2}\frac{\partial D}{\partial x_n} = p \qquad (1)$$

where: E_c is the kinetic energy of the compressed fluid passing through the drosel tube;

$$E_c = \frac{1}{2} L_H\, x^2 \qquad (2)$$

Correspondingly to electro-hydraulic analogy, this kinetic energy is:

$$E_c = \frac{1}{2} L\, i^2 \qquad (3)$$

E_p – potential energy of the balancing chamber;

$$E_p = \frac{1}{2}\frac{E}{C_H} x^2 \qquad (4)$$

E – the modulus of elasticity of the hydraulic-steel medium (determined according to the elastic modulus of the hydraulic environment E_1, the longitudinal elastic modulus of the steel E_o, the diameter of the drosel pipe d and the wall thickness of the pressure pipe h):

$$E = \frac{E_1}{1+\frac{dE_1}{hE_o}} \qquad (5)$$

Corresponding to the electrical-hydraulic analog, the potential energy is:

$$E_p = \frac{1}{2}\frac{q^2}{C} \qquad (6)$$

q - the electrical charge, C - the electrical capacity.
D - sonic energy (because at the exit of the room, the resistance can comprise the active part, then the propagation of the elastic waves results in some absorption of the sonic energy D).

$$D = R\, x^2 \qquad (7)$$

n – the number of independent coordinates.

Considering that the pulsating flow that reaches the balancing chamber is the sum of the flows that reach the hydraulic capacity and inertia of the system, and for stationary sinusoidal oscillations, the symbol of the partial difference in time $\left(\frac{\partial}{\partial t}\right)$ can be replaced by ω ,it is possible to express the volume flow of fluid at the pump on the resistances corresponding to the resistance of the two-chamber balancing filter:

$$X_0 = \frac{p_{2k}[(z_1+z_2)(z_3+z_4)+(z_3 z_4)]}{z_1 z_3 z_4 + z_1 z_2 (z_3+z_4)} \qquad (8)$$

p_{2k} is the maximum value of pump pressure pulses with two balancing chambers.

$$z_1 = \frac{1}{j\,\omega C_{H1}} \qquad (9)$$

$$z_2 = j\,\omega L_{H1} \qquad (10)$$

$$z_3 = \frac{1}{j\,\omega C_{H2}} \qquad (11)$$

$$z_2 = R + j\,\omega L_{H2} \qquad (12)$$

The relations (9-12) are used in relation (8) and we consider the case of the equivalence of the C_H capacitance coefficients and of the inertia coefficients L_H, we determine the maximum value of the pressure pulses at the pump p_{2k}:

$$p_{2k} = \frac{\frac{L_H R}{C_H} - \frac{R}{\omega^2 C_H^2} + j\left(\frac{\omega L_H^2}{C_H} - \frac{2\,L_H}{\omega^2 C_H^2}\right)}{\frac{3L_H}{C_H} - \omega^2 L_H^2 - \frac{1}{\omega^2 C_H^2} + \left(\omega R L_H - \frac{2R}{\omega^2 C_H^2}\right)} X_0 \qquad (13)$$

In the absence of balancing chambers, the pump pressure value is:

$$p_0 = R\ X_0 \qquad (14)$$

The pressure impulse transmission ratio (when the hydro-acoustic filter is connected) is the ratio:

$$\frac{p_{2k}}{p_0} = \frac{(L_H\,\omega^2\,C_H - 1) + j\frac{\omega\,L_H}{R}(L_H\,\omega^2\,C_H - 2)}{(3\,L_H\,\omega^2\,C_H - \omega^4 L_H^2 C_H^2 - 1) + j\,\omega R C_H (L_H\,\omega^2\,C_H - 2)} \qquad (15)$$

The real part of the expression (15) is:

$$\frac{p_{2k}}{p_0} = \sqrt{\frac{(L_H\,\omega^2\,C_H\text{-}1)^2 + \left(\frac{\omega\,L_H}{R}\right)^2 (L_H\,\omega^2\,C_H\text{-}2)^2}{\left(3\,L_H\,\omega^2\,C_H\text{-}\omega^4 L_H^2 C_H^2\text{-}1\right)^2 + (\omega R C_H)^2 (L_H\,\omega^2\,C_H\text{-}2)^2}} \qquad (16)$$

3. Determination of the damping-application rate

We analyze the case of a pumping plant in which a two-chamber hydro-acoustic filter is used, analogous to a low-pass electric filter:

* The hydrostatic generator is a piston type axial piston pump type F 112 with 7 pistons;
* use a hydrostatic oil with density $\rho = 900\ {kg}/{m^3}$ and modulus of elasticity $E_1 = 1500\ MPa$;
* the volume of a balancing chamber, $V = 0{,}005\ m^3$;
* the diameter of the drosel pipe, $d = 0{,}0065\ m$
* the length of the pipe, $l = 0{,}163\ m$;
* the pressure pipe diameter, $D = 0{,}013\ m$;
* wall thickness of the pressure pipe, $h = 0{,}0025\ m$;

The number of impulses of the N pressure corresponding to a complete rotation is determined by the number of pistons z of the pump as follows:

$$N = 2\,z \Rightarrow N = 14$$

The frequency of the pulsation is:

$$f = N\,n_p \Rightarrow f = 14\ \cdot n_p$$

where n_p the pump speed - for this study

$$n_p = 231\frac{rot}{min} = 3{,}85\frac{rot}{s}$$

$$f = 14\ \cdot n_p \Rightarrow f = 53{,}85\ Hz$$

and the pulsation of the oscillations of pressure will be:

$$\Omega = 2\pi\, f \Rightarrow \Omega = 338{,}333\ rad/s$$

The coefficient of hydraulic capacity of a balancing chamber is:

$$C_H = \frac{V}{E} = \frac{V}{\dfrac{E_1}{1 + \dfrac{d}{h}\dfrac{E_1}{E_o}}} \Rightarrow C_H = 3{,}457\cdot 10^{-12}\,\frac{m^5}{N}$$

The coefficient of hydraulic inertia of a drosel pipe is:

$$L_H = \frac{E\ l}{S c_s^2} = \frac{E\ l}{\dfrac{\pi\,d^2}{4}\ \dfrac{E_l}{\rho}} \Rightarrow L_H = 5{,}0206\cdot 10^6\,\frac{N\,s^2}{m^3}$$

where S is the cross sectional area of the drosel pipe, $S = \frac{\pi\,d^2}{4}$;

c_s is the speed of the sound through the working fluid, $c_s = \sqrt{\frac{E_l}{\rho}}$;

The corrugating resistance of the pressure pipe is:

$$R = \frac{E}{F\ c_s} = \frac{E}{\dfrac{\pi\,D^2}{4}\ \sqrt{\dfrac{E_l}{\rho}}} \Rightarrow R = 8{,}439\cdot 10^9\,\frac{N\,s^2}{m^5}$$

The degree of damping is determined by the relationship (16):

$$\frac{p_{2k}}{p_0} = 0{,}4893 = 48{,}93\%$$

This damping value shows that 51,07% of the low frequencies are filtered, the remaining 48,93% are allowed to pass.

4. Conclusions

1. Simplicity, technological accessibility, low cost, total elimination of risk of failure and efficiency (considering the degree of damping) are arguments for the introduction of the hydro-acoustic filter in the hydraulic systems;

2. The hydro-acoustic filter is a solution that can be used to reduce noise in pumping systems for large-scale installations;

3. The insertion of this additional element into a hydraulic system leads to the introduction of additional strength; It is interesting to determine the hydraulic efficiency of this construction.

4. The degree of damping is dictated by the geometry of the filter, the constructive-functional type of the hydrostatic generator, the characteristics of the hydraulic medium used.

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