EXPERIMENTAL INVESTIGATION OF NOISE SOURCES INSIDE AN UNDERWATER ROBOT'S BUOYANCY VARIATION SYSTEM

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Nowadays unmanned underwater gliders have become to play a vital role in ocean exploration and allow to obtain the valuable information about underwater environment. Underwater glider is moved by changing its buoyancy. Buoyancy variation system is the key system that determines the accuracy of robot motion, submersion capability, acoustic properties, reliability and resource. These parameters are determined by working process inside buoyancy variations systems, particularly by occurred pressure pulsations. Pressure pulsations are known to determine vibrations and, as a result, air borne noise. There are five possible types of buoyancy variation systems that can be implemented in gliders. All of them were considered in this paper theoretically. Theoretical analysis showed their advantages and disadvantages and allowed to choose the most effective. Chosen buoyancy variation systems consist of hydraulic pumps, electro motors, valves and accumulators. Buoyancy variation systems were investigated experimentally in several glider operational modes: dive mode, ascent mode, and the mode of emergency ascent. Semi-natural test bench was used for experimental tests. Six vibration acceleration sensors were used for vibration estimation. They were installed on each aggregate of the system. Obtained data was sampled via the LMS hardware and software equipment. Results allowed us to investigate the vibroacoustic efficiency of glider buoyancy variation systems by means of their vibration accelerations and noise that were caused by pressure pulsations on different operating regimes.

Keywords: underwater glider, semi-natural test bench, pressure pulsations, vibrations, ecology, noise impact

1. Introduction

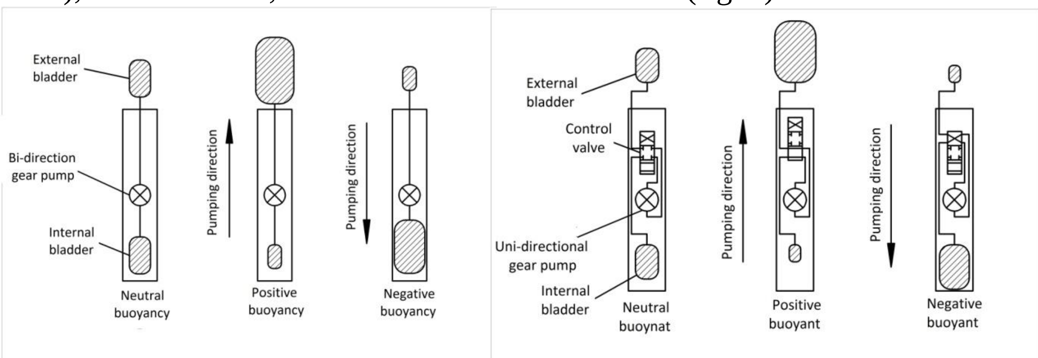
Nowadays underwater gliders have become extremely wide spread. They can be used in military, civil, academic and commercial fields. Having such a big implementation area, underwater gliders have been improving their vibroacoutic characteristics due to decades. Having fixed wings and tail, they glide through the ocean, controlling their buoyancy and attitude using internal actuators [1]. A buoyancy engine controls the magnitude and direction of the buoyant force, acting on a submersed body, by changing the volume or weight of the body [2]. This system can be chemical, electromechanical or hydraulic. Hydraulic systems are the most interested as they are able to work at great depths (more than 1000 meters). However, in spite of high endurance and durability of hydraulic buoyancy variation systems, the noise that they are produce is still have a great impact on the environment. Fluid pulsations and vibrations from the pump transfer to the pipes and robot hull and generate acoustic noise.

Nowadays pump units are being developed in a way to increase their operating pressure and efficiency while reducing pressure pulsations [1], minimizing their dimensions [2, 3], as well as reducing dynamic loads and manufacturing cost [4, 5, 6]. But apart from these requirements there is a requirement on gear pump noise level. Noise generation and transmission inside hydraulic systems has been investigated for the last 50 years [7], [8]. These issues were concerned by W.K. Blake [9], Blokhincev [10], Goldstane [11], Munin [12] as well as by M.J. Lighthill [13], A. Powell [14], M.S. Howe [15] and by many other authours.

The main sources of gear pump noise are believed to have both hydraulic and mechanical nature [16]. Working fluid is known to be unevenly supplied to a pump inlet. This causes pressure pulsation [17]. Compression of the liquid results in significant pressure surges [18]. It stands to reason cavitation follows a working process of a gear pump [19]. Cavitation leads not only to erosion but also to a significant mechanical loading. Additionally, pump operation is accompanied by collision of the gear teeth at meshing [20].

2. Hydraulic buoyancy variation system

Nowadays five hydraulic buoyancy variation systems are known. Over the past 15 years they have been tested on various types of underwater gliders. The most efficient are two integral volume changing systems. They consist of two bladders (external and internal), gear pump (uni-directional or bi-directional), electric motor, control valve and check-valve. (fig. 1)



a b

Fig. 1: Hydraulic buoyancy variation systems

Hydraulic system on fig. 1a is supposed to use bi-directional gear pump for work fluid pumping between external and internal bladders. When working fluid transfers from an internal bladder to an external bladder, underwater glider occupied more integral volume and then it emerges. When working fluid transfers from an external bladder to an internal bladder, underwater glider occupied less integral volume and then it submerges. This is a simplest scheme of the hydraulic buoyancy variation system, which guarantees high durability during all operation cycles. In comparison with second scheme on fig. 1b, basic circuit distinguishes from first one by the uni-directional gear pump and control valve.

Despite the advantages of such a buoyancy variation system at great depths, there are also some disadvantages. The main disadvantage is the noise produced by hydraulic units during the operation of the buoyancy change system. In particular, the vibration from the gear pump is transmitted to the glider hull, which in it turn increases the acoustic impact of the underwater glider on the environment. In such a manner, the main task of our investigation is underwater glider's hydraulic buoyancy variation system modelling. It allows to evaluate the influence of hydraulic system on an underwater robot noise occurring during the transfer of working fluid from the external bladder to the internal bladder and back.

3. Semi-natural experimental test bench

The idea of the semi-natural test bench was based on working principle of hydraulic buoyancy variation system with uni-directional gear pump. Architecture of the bench allows to redesign main scheme to install bi-directional gear pump.

Transducers were placed in the bench to obtain pressure pulsation and vibration acceleration values (fig. 2a). Six sensors of vibration acceleration were placed on the six main units: 1 – Precharge pump (It imitates water pressure on the external bladder); 2 – Hydraulic Accumulator (external bladder); 3 – hydraulic-pneumatic accumulator (internal bladder); 4 – 2/2 control valve D-2; 5 – 4/3 control valve D-1; 6 – Gear Pump. Two pressure pulsation transducers (7 and 8) were placed in the accumulator and pneumatic accumulator (fig. 2b).

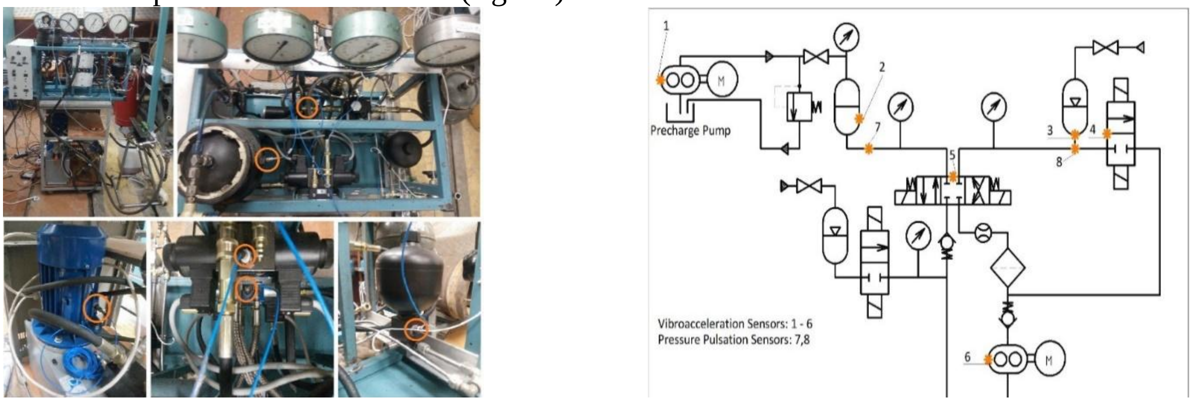


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Fig. 2: a) External view of the semi-natural test bench; b) Arrangement of the sensors on the bench

3.1 Test program

Semi-natural bench testing program is formed by imitating buoyancy variation system principal work. First regime is glider's immersion imitation (work fluid pumping from external bladder to internal bladder). Work fluid is pumping from external bladder (hydraulic accumulator) to internal bladder (pneumatic-hydraulic accumulator). The time duration of the experiment was 51 seconds.

Second regime is glider's emersion imitation (work fluid pumping from internal bladder to external bladder). Work fluid is pumping from internal bladder (pneumatic-hydraulic accumulator) to internal bladder (hydraulic accumulator). The time duration of the experiment was 53 seconds.

4. Experimental results

Six valuable time points have been taken due to the experiment, which can effect on the hydraulic system's operation.

The first regime (fig. 3, a):

— First point at 5 seconds (buoyancy variation system beginning of the work; precharge pump gets started);

— Second point at 10 seconds (first switching of the control valve D-1);

— Third point at 13.88 seconds (first switch on of the gear pump, hydraulic shock effect);

— Fourth point at 19.7 seconds (end of the gear pump work process);

— Fifth point at 25.3 seconds (gear pump is switched off, analyzing system condition before second switch of the control valve D-1);

— Sixth point at 34.5 seconds (second switch on of the gear pump).

The second regime (fig. 3, b):

— First point at 5 seconds (buoyancy variation system beginning of the work; precharge pump gets started);

— Second point at 10 seconds (system before first switching of the control valve D-1);

— Third point at 13.88 seconds (system after first switching of the control valve D-1, pressure equalization);

— Fourth point at 19.7 seconds (system after the first switch on of the gear pump, hydraulic shock effect plus pressure equalization);

— Fifth point at 25.3 seconds (system at the end of the gear pump work process);

— Sixth point at 34.5 seconds (second switch on of the gear pump).

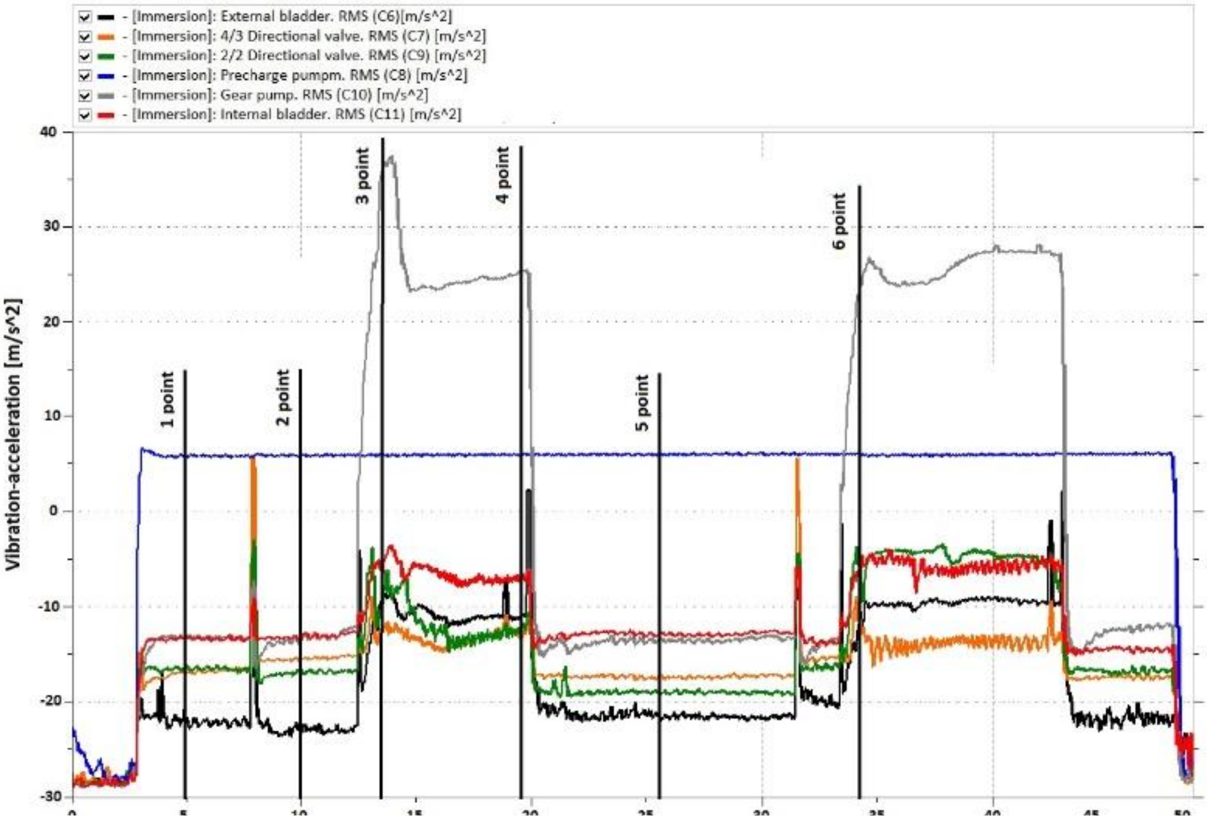


Fig. 3: Immersion simulating (first regime)

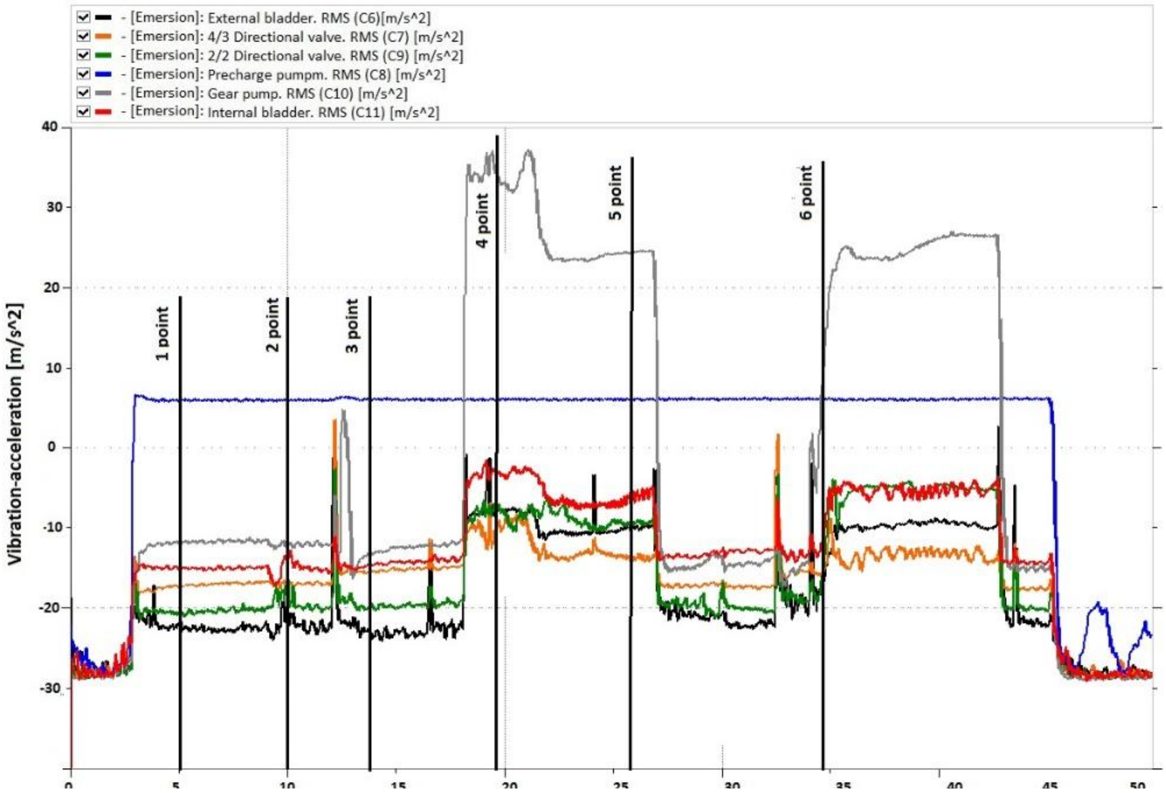


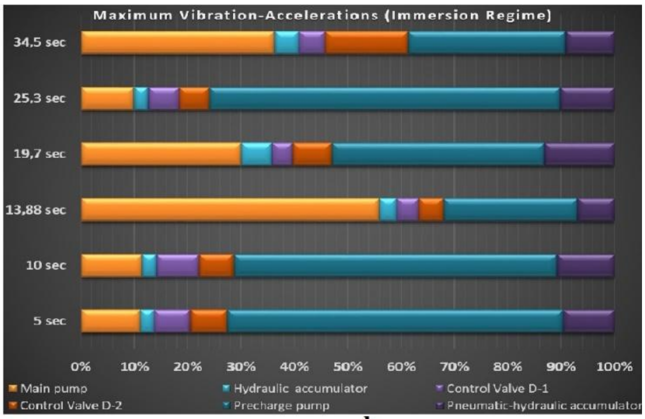
Fig. 4: Emersion simulation (second regime)

For a more thorough analysis, data tables were compiled with maximum, minimum and average values of the vibrations. These data were obtained using LMS from vibration acceleration sensors. The narrowband signal from each sensor was converted to 1/12 octaves.

Data table for first regime is represented in Figure 4a. Figure 4b shows a comparison of the maximum amplitude values of six units at 6 steps of time. At the time when the gear pump does not work, approximately 60% of the total noise is generated by the pre-charge pump. At other times, the maximum vibration amplitudes from the operation of the gear pump are almost equal to the amplitude of the pre-charge pump vibrations. The gear pump generates the highest level of vibrations at 13.88 seconds during the first start, when a hydro-impact effect occurs. Figure 4c shows a comparison of the minimum amplitude values. Also, there are overwhelming percent of the values relates to the pre-charge pump instead of value at 13.88 second (hydro-impact effect). Figure 4d shows a comparison of average amplitude values. When gear pump doesn't work, approximately 78% of vibrations is generated by pre-charge pump. But at the time when gear pump is working, background vibrations were the largest (especially at the end of the first phase of work).

Immersion Regime - Vibration Acceleration [m/s^2]							
		Main pump	Hydraulic accumulator	Control Valve D-1	Control Valve D-2	Precharge pump	Pneumatic-hydraulic accumulator
5 sec	*Max*	0,205	0,049	0,126	0,1277	1,167	0,1777
	Min	1,56E-06	7,50E-05	0,00014	0,000125	0,00092	9,19E-05
	Average	0,0002	0,0017	0,00169	0,00099	0,047	0,00121
10 sec	*Max*	0,208	0,05	0,146	0,117	1,103	0,1966
	Min	9,46E-07	2,29E-05	8,23E-05	7,22E-05	0,00122	6,08E-05
	Average	0,00015	0,0008	0,0017	0,00112	0,0637	0,00125
13.88 sec	*Max*	2,375	0,135	0,175	0,197	1,068	0,292
	Min	0,00102	0,000111	0,00016	7,15E-05	0,000272	4,70E-05
	Average	0,1	0,005	0,0021	0,0014	0,0378	0,00159
19.7 sec	*Max*	0,849	0,164	0,109	0,205	1,128	0,372
	Min	0,00015	6,30E-05	7,85E-05	9,76E-05	0,00146	0,000143
	Average	0,16	0,01	0,00147	0,00156	0,02586	0,00136
25.3 sec	*Max*	0,179	0,0467	0,1044	0,1013	1,1787	0,1825
	Min	7,42E-07	2,95E-05	6,33E-05	9,08E-05	0,0019	0,0002
	Average	0,00018	0,0017	0,00118	0,00147	0,02715	0,001254
34.5 sec	*Max*	1,148	0,146	0,154	0,49	0,936	0,2878
	Min	0,00013	0,00022	8,25E-05	0,00011	0,00142	0,000153
	Average	0,0153	0,0037	0,00085	0,00144	0,03066	0,0017

a



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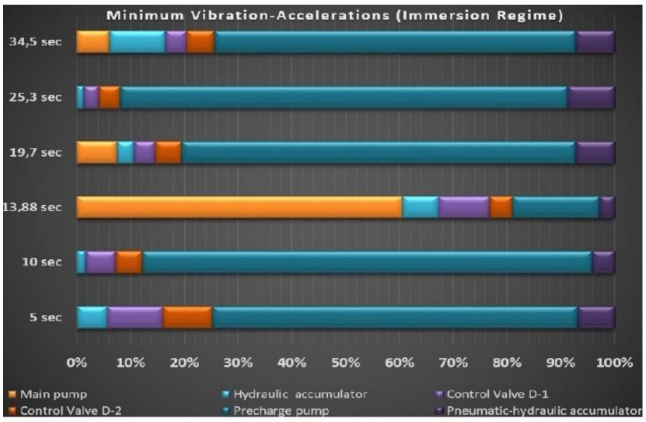

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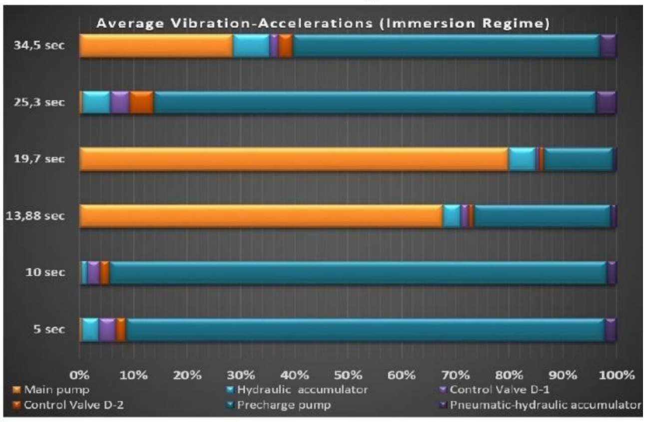

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Fig. 4: a) Vibration acceleration values of the units during the immersion regime; b) Maximum values of vibration acceleration; c) Minimum values of vibration acceleration; d) Average values of vibration acceleration

Data table for second regime is represented in Figure 5a. Figure 5b shows a comparison of the maximum amplitude values. In comparison to an immersion mode, in an emersion mode, the maximum values of the vibration amplitudes from the gear pump are much less. Moreover, because of the much smaller hydraulic shock in the beginning, both modes of gear pump operation do not differ by the percentage of the contribution to the overall vibrations of the system. Figure 5c shows the same vibration distribution between the units at the second regime. However, despite the much smaller vibration amplitudes of the gear pump, the vibrations from the hydraulic accumulator increased by approximately 18%. Figure 5d shows average amplitudes of vibrations. Here, as well as in the case of immersion, the main contribution to total noise is made by the operation of the gear pump and the pump station. However, the percentage of vibrations from the hydraulic accumulator increases significantly.

Emersion Regime - Vibration Acceleration [m/s^2]							
		Main pump	Hydraulic accumulator	Control Valve D-1	Control Valve D-2	Precharge pump	Pneumatic-hydraulic accumulator
5 sec	*Max*	0,0236	0,0474	0,1146	0,06951	1,09698	0,13987
	Min	5,94E-07	0,000111	5,02E-05	2,58E-05	0,00157	5,62E-05
	Average	0,0002	0,00134	0,00115	0,00136	0,04308	0,000864
10 sec	*Max*	0,2332	0,0509	0,126	0,07456	1,19865	0,14865
	Min	1,00E-06	0,000145	3,42E-05	0,000124	0,001345	7,41E-05
	Average	0,00024	0,00131	0,0015	0,00138	0,03217	0,001301
13.88 sec	*Max*	0,1838	0,0318	0,1481	0,07835	1,04801	0,153
	Min	1,29E-06	4,82E-05	2,91E-05	9,02E-05	0,00234	7,69E-05
	Average	0,00024	0,00136	0,0012	0,00181	0,0156	0,00145
19.7 sec	*Max*	1,301	0,125	0,2456	0,42501	1,11398	0,33286
	Min	0,000231	0,000351	0,000105	0,00012	0,00073	0,000119
	Average	0,2405	0,00905	0,00216	0,00257	0,02973	0,00309
25.3 sec	*Max*	1,12315	0,131	0,1231	0,3178	1,0274	0,27941
	Min	8,52E-06	0,00016	5,80E-06	9,86E-05	0,00315	6,33E-05
	Average	0,0746	0,0105	0,0017	0,00149	0,04376	0,001508
34.5 sec	*Max*	0,8597	0,0471	0,1404	0,10018	1,1806	0,21865
	Min	0,000168	0,000103	4,19E-05	6,51E-05	0,001825	2,67E-05
	Average	0,0328	0,00214	0,001106	0,0016	0,04685	0,001735

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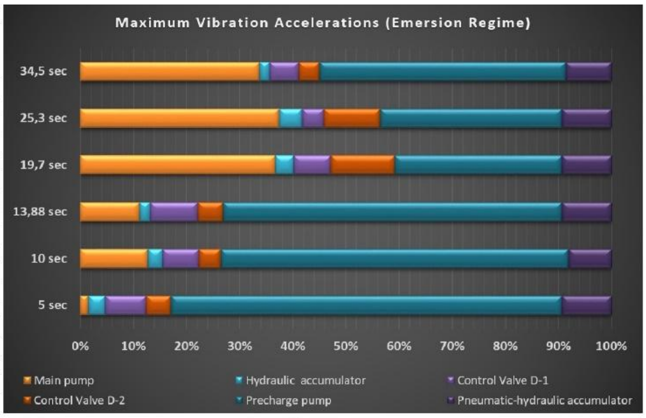

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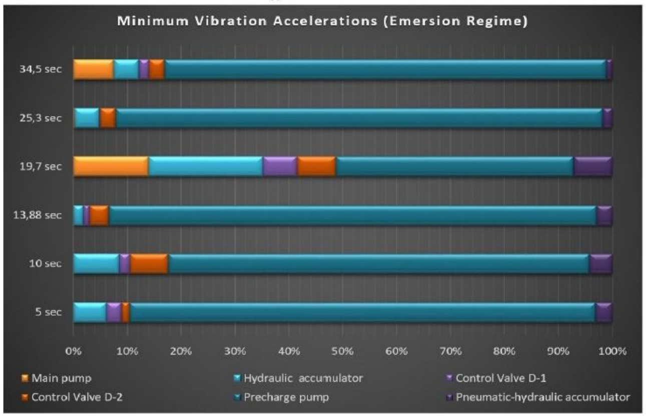

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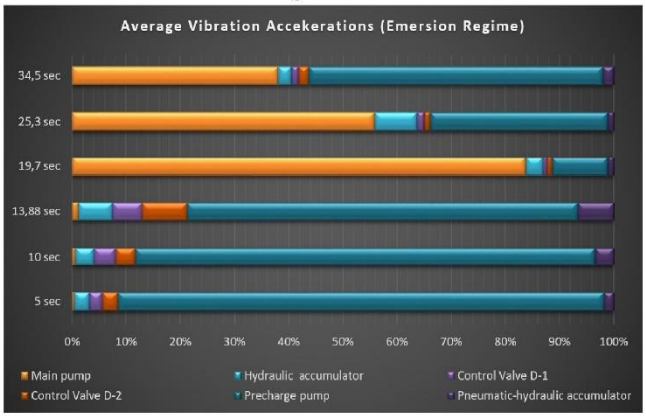

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Fig. 5: a) Vibration acceleration values of the units during the emersion regime; b) Maximum values of vibration acceleration; c) Minimum values of vibration acceleration; d) Average values of vibration acceleration

5. Conclusion

In the work, experimental studies of the hydraulic buoyancy variation system were conducted. The vibration acceleration analysis of the system units made it possible to identify the main sources of noise and determine their maximum vibration amplitudes. According to these data, the contribution of each unit was analyzed to the noise of the whole system. Main background noise in the system was obtained to be defined by pumps. However, despite the short-term operation of the gear pump, it is still the main source of noise (especially during the first start, when the hydrostatic shock is observed). The remaining units practically do not significantly affect the noise of the system. Therefore, we can conclude that first of all, it is necessary to isolate the gear pump (we recall that the prechargeble pump on the glider itself is not installed and is used on the bench only to imitate the depth pressure on the external bladder).

6. Further investigations

Further work will be related to the investigation of the possibilities of reducing the vibrations of the pump, as well as its effect on the operation of other units in the system. It will be necessary to calculate the damper for the gear pump itself, the electric motor and their connection bell, and also to determine which type of support will be preferable: a single common support for the entire drive unit or individual dampers for the units. For the experiments, a damper based on metal-rubber material is proposed to use.

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