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Electro-Hydraulic Vibratory Exciter for Investigating Vehicle Vibration Effects on Humans

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This paper presents a realization of an electronically controlled two-axis hydraulic vibratory exciter used for studying the behavior of the human body under the influence of vibrations. It deals particularly with the influence of vibrations that occur in motor vehicles. Regarding vehicle oscillatory comfort, understanding the transmission mechanism of vibrations through the human body and their influence on psycho-physiological abilities are very important for automotive design. In armored and transport vehicles, military personnel are also exposed to a high level of whole-body vibrations. Since command and control operations are likely to become more mobile in the future, it is of interest to understand the effects of vibrations on the human body and hearing and cognitive performances in particular. The presented vibratory exciter is based on the hydraulic servo drive control and a high-performance reference signal generator. The control system of the vibratory exciter is designed to provide continual amplitude adjustment in a range of 0-50mm and the frequency tuning in a range of 0.1-50Hz. The implemented control system provides the generation of different waveforms (sine, triangle or square waves) at a given frequency as well as the generation of stochastic signals, which is of utmost importance. The experimental results of the displacement of the vibratory exciter (oscilloscopic waveforms and spectra in the frequency domain) are also presented for both perpendicular axes and real mass load.

Key words: **vibrations, vibration excitation, vibration exciter, electro hydraulic platform, influence of vibrations, effects on the human body, vibrations of vehicles, signal generation.**

Introduction

EXPOSURE to vibration is indivertible in many occupational settings (civil or military). Whole body vibration occurs when the body is supported by a vibrating surface. The amount of vibration exposure depends on a number of factors including the type and design of the vehicles, the environmental conditions and the operator's posture. Also, military personnel experience high levels of vibration in armored and transport vehicles [1]. The investigation of the human body behavior under the action of vibrations and their influence on psycho-physiological abilities are of a very great importance for an optimal motor vehicle system design. That influence is nowadays researched in real and laboratory conditions. More attention is given to laboratory research, because stability of micro-environment parameters (noise, thermal load, etc.) and repeatability are assured [2-4].

There are two aspects of research of the vehicle vibration effects on humans [2], [5-7]:

- Health aspect (fatigue, ride comfort, professional diseases, etc.)
- Biodynamic aspect (transmission of vibrations through the human body).

In modern literature influence of vertical vibrations (harmonic at first and after that random) is mostly observed. The frequency range from 1Hz to 31.5Hz is commonly of interest [5]. Also, it is indicated that the man is very sensitive to frequencies lower than 1Hz, such as 0.1Hz, even 0.05Hz, which is represented in detail in [8-10].

Mechanical devices named *vibratory exciters* are utilized in such investigations. Most frequently, exciters are based on the hydraulic principle, due to significant mass load. They are realized like a hydraulic platform with excitation over two independent perpendicular axes [5]. Simultaneous excitation over two axes, i.e. compound movement, is required. In some applications, excitations in one axis are often used.

A specific realization of an electro-hydraulic motion simulator, presented in this paper, was used in experiments. An electro-hydraulic vibratory exciter (EHVE) and its control system were applied in laboratory testing. The main parts of the driving circuit are an analog hydraulic servo controlled amplifier and a digital signal generator. The signal generator output is converted, due to the digital-to-analog converter, into an analog form which is led to a referent input of the analog servo PI controller. The signal generator, with a possibility of choosing different excitation types and frequency and amplitude output signal tuning, is based on the Direct Digital Synthesis Method (DDSM).

Vibratory Exciter Control System

The principal scheme of the EHVE and its control system is shown in Fig.1. It consists of several modules: electrical power supply, hydraulic installation, PI servo

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controllers, digital control module and a measuring system.

The generating of the electrical motors M1 and M2 and the appropriate hydraulic pumps P1 and P2 is often realized from a three-phase AC supply. Feeding of the hydraulic installation and the appropriate hydraulic pumps P1 and P2 is achieved from an oil tank. The hydraulic pumps have constant pressure. In the oil tank, there are temperature and oil level sensors with the function of protecting the hydraulic aggregate. Pressure is measured in the direct pipes as well as in the back pipe and visual monitoring is provided. The *Load platform* (LP) moving is obtained over two perpendicular axes X and Z by the *hydraulic pistons* (HP1, HP2). Either hydraulic piston has a corresponding *valve manifold* (VM1, VM2) and a *servo valve* (SV1, SV2).

Displacement measurement over the X and Z axes is accomplished with the *displacement probes* DP1 and DP2, respectively. The measured signals from the *displacement probes* (DP1, DP2) are led via the *displacement transmitters* (DT1, DT2) on the servo controller's inputs and the *test points* (TP1, TP2). The detection of the end position of the hydraulic pistons is reached by the *limit switches* (LS11and LS12 for the Z axis and LS21 and LS22 for the X axis).

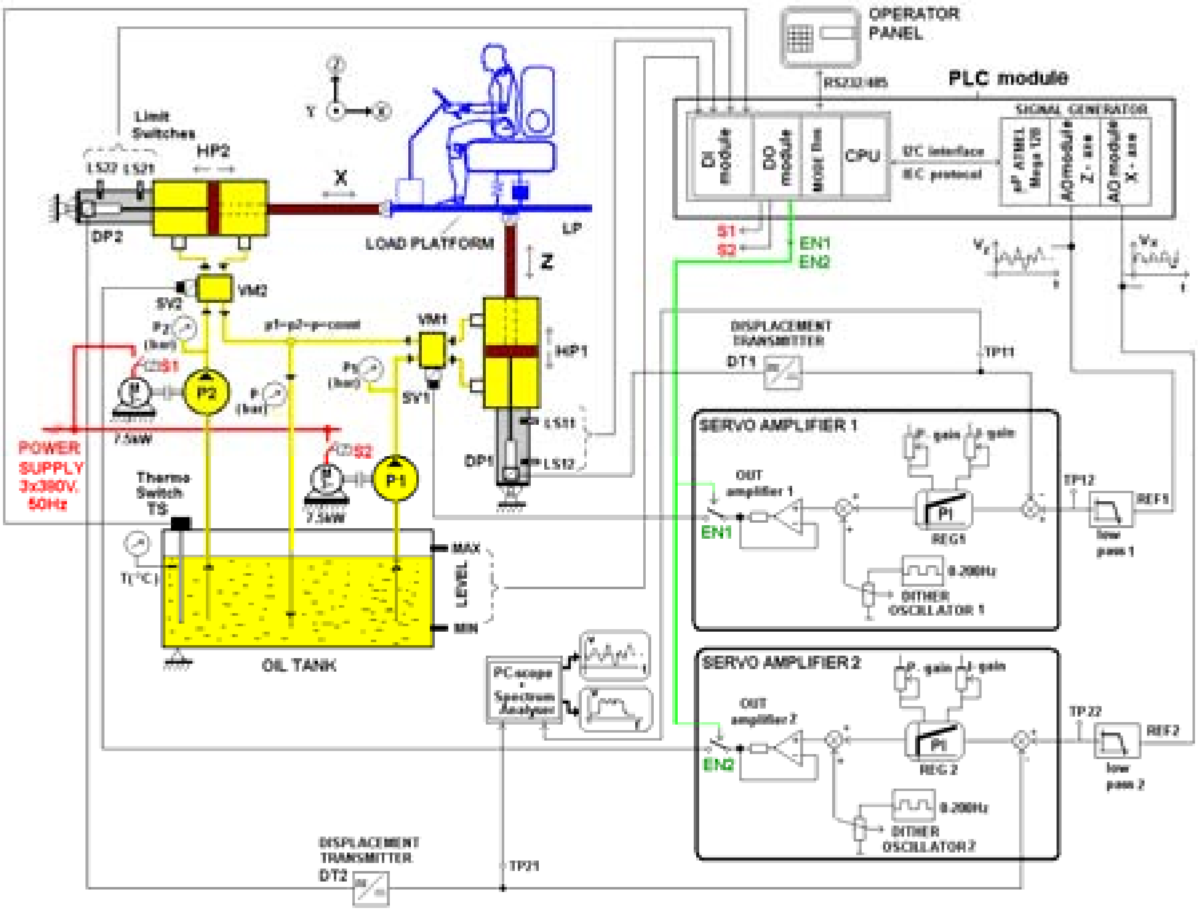

Figure 1. Block scheme of the EHVE control

The main part of the control system consists of the general-purpose, user-configurable PI *servo-amplifiers 1,2*. The selector switches inside each amplifier enable either proportional control or integral control, or both, to be selected. Many aspects of the amplifier characteristics can be adjusted with the front panel pots or selected with the internal switches. The principal scheme of each of servo-amplifiers is shown in Fig.2.

The feedback amplifier has potentiometers for offset and gain adjustment of signal equivalent to displacement. These potentiometers are used for scaling the feedback signal to the full extent of the reference voltage. There is an option of a plug-in resistor, R16, to give a feedback derivative (lead or D) in the output of the feedback amplifier. The reference values REF1 and REF2 are led on the servo controller inputs via the 4^{th} order unity-gain (Butterworth) *low pass filters* 1, 2. The reference signal input is ±10V non-inverting and has two important features. It has a scale pot on its input that enables large inputs to be scaled down to match smaller signals on other inputs. The scale range is 10 to 100%. Being set fully clockwise (FCW), an input of 100V can match a 10V signal on other inputs. It has a switch-selectable lag of 55mS that can be used to remove transients from the input signal that could cause unwanted rapid movement in the output.

The output amplifier configuration is set via selector switches. Select the output to match the input requirements of the valve. When voltage (V) is selected, ±10V is available into a minimum load of 200 Ω. When the current (I) is selected, the current level switches enable ±5 to ±100mA to be selected. The switch selections sum up, so, if for example 45mA is required, 30, 10 and 5 are selected. The output can drive all known valves up to ±100mA.The output amplifier is limited to approximately 105% of the selected full scale output. If both the proportional and integrator stages are saturated, the output will not be twice the selected full scale but only 105% of the full scale. The step push button-STEP P.B injects -50% valve drive into the output. When released, the valve drive reverts to its original level. This feature is useful for closed loop gain optimization.

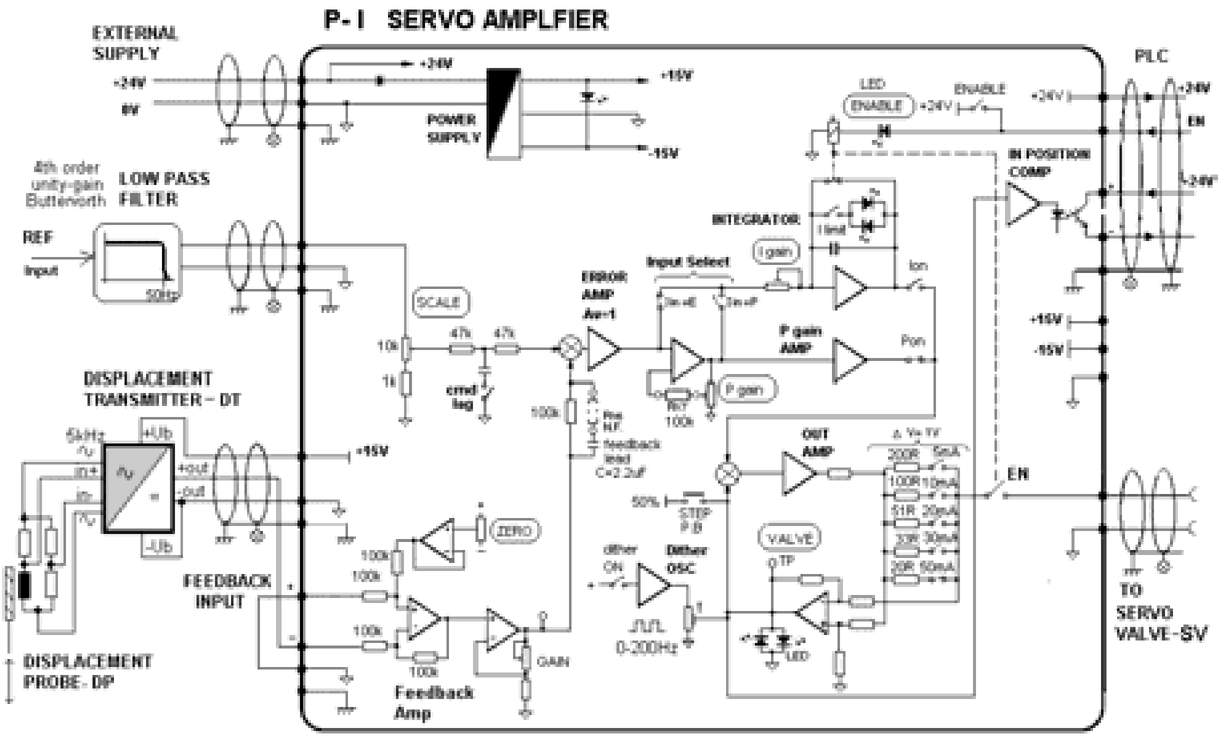

Figure 2. Block scheme of the PI servo-amplifier

The servo-amplifier has a unity gain input error amplifier followed by two parallel stages, one a proportional amplifier and the other an integrator. The outputs of these two stages can be switched to the output power amplifier which then drives the valve. The input to the integrator stage can be switch-selected from either the output of the error amplifier, *Iin* = *E*, or the output of the proportional stage, *Iin* = *P*. The contribution from the integrator to the output amplifier can be reduced by selecting *I - limit* on. When this switch is on, the integrator contribution is reduced to approximately 15% of the level when it is off. This feature is useful in a position loop that may require integral control to achieve the required steady state accuracy. The limited integral control removes valve null error when the final position is reached.

The adjustable *dither oscillators* are here for dynamic system feature improvement. The dither frequency is fixed at 200 Hz and the level is adjustable with the front panel pot to ±10% of the valve drive, regardless of the type and level of the valve drive selected.

A relay on the internal circuit of the servo-amplifier needs to be activated to connect the output stage to the servo valve and to clamp the integrator. The clamp prevents the integrator wind-up when the loop is not operating. Supply +24V to the appropriate terminal to activate the ENABLE relay. The ENABLE switch is set to permanently activate the ENABLE relay, regardless of the external command for the +24V voltage supply (Fig.2). When the valve drive signal falls below ±10% of the selected full scale signal, the *"in position"* signal goes true and provides an optical isolated current path between the + and – terminals. This can be connected to a PLC to initiate the next step in a control sequence.

The PLC module for digital control shown in Fig.1 has the *digital inputs* (DI) for discrete signal acquisition and the *digital outputs* (DO) for the motors M1 and M2 activation and actuating servo amplifiers via the EN1 and EN2 relay switches. The *signal generator* is implemented in the PLC module. The signal generator is based on the micro processor ATMEL Mega 128 and two 12-bits MAX5322 digital to analog converters, for obtaining *analog output* (AO) signals (one for the Z, the other one for the X axis). The micro processor has four timers: two of them are 8-bits (for total working control time), the other two are 16-bits (their interrupts are directly dependent on a desirable resolution frequency value). The ATMEL Mega 128 communicates with the CPU over the I2C interface with the IEC protocol.

The parameters are displayed and can be altered via the *touch panel*. The communication between the CPU unit and the touch panel is through the serial connection RS232/485 with the MODEBUS protocol. The customer can select one out of three operation modes (NO SWEEP, SWEEP, STOCHASTIC), excitation type (sine wave or triangular wave) and axis of working (horizontal or vertical) using the touch panel. Moreover, there are many parameters on the touch panel that could be adjustable (all of them over two channels) – minimum frequency ($f_{\min}$), maximum frequency ($f_{\max}$), total time of working (t_{total}), step of frequency in the case of the SWEEP mode of operation (*step*).

Direct digital synthesis method

The direct digital synthesis (DDS) is a method of producing an analog waveform, usually a sine wave (but triangular and square waves are inherent) at a given frequency value [11]. The frequency depends on two variables: the reference clock frequency and the binary number programmed into the frequency register (tuning word) [12]. The binary number in the frequency register provides the main input to the phase accumulator. If a sine lookup table is used, the phase accumulator computes a phase (angle) address for the lookup table, which outputs the digital value of amplitude – corresponding to the sine of that phase angle – to the DAC. The DAC, in turn, converts that number to a corresponding value of analog voltage or current (voltage in this case), as in Fig.3.

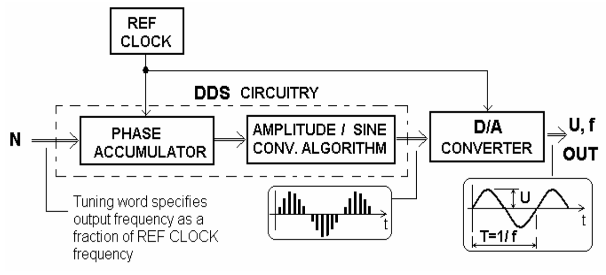

Figure 3. Block diagram of a direct digital synthesizer

To generate a fixed frequency sine wave, a constant value (the phase increment, which is determined by the binary number) is added to the phase accumulator with each clock cycle. If the phase increment is large, the phase accumulator will step quickly through the sine lookup table and thus generate a high frequency sine wave. If the phase increment is small, the phase accumulator will take many more steps, accordingly generating a slower waveform.

EHVE operation modes

There are three modes of the EHVE operation:

NO SWEEP – In this mode of operation, sine or triangle wave will be generated over the whole time range, t_{total}, with the amplitude *A* and with the same operating frequency.

SWEEP – A sweep function is realized over the chosen frequency range from $f_{\min}$ to $f_{\max}$, or vice versa with the same amplitude (*A*), with a selected step (*step*) and during the total time of working (t_{total}). The minimum step of frequency changing is 0.1Hz (that is with the maximal resolution), so after some time which is software-determined, the frequency will be changed from $f_{\min}$ to $f_{\min} + step$, i.e. from $f_{\max}$ to $f_{\max} + step$. The last generated frequency will be $f_{\max}$, i.e. $f_{\min}$, respectively.

STOCHASTIC – The parameters for this working mode are: amplitude, minimum and maximum frequency and the total time of operation. The only excitation type is a sine wave. The stochastic signal is produced from the sum of sine functions at the same time interval, which depends on the frequency range and can vary from 2.5ms to 10ms, as explained later in the next section. All sine functions have the same amplitude, different frequencies (from $f_{\min}$ to $f_{\max}$) and the random initial phases. Therefore, the resulting signal will be random, i.e. stochastic.

Reference signal generation

At the beginning of this section, in Table 1, the required ranges for frequency, amplitude and time of working are presented. With a view to generate different signals for platform driving, there are two lookup tables, one for sine wave and the other one for triangle wave generation.

In the case of the SWEEP or the NO SWEEP operation mode, a desirable resolution value is 0.1Hz, which is contained a whole number of times, like all other frequencies from the range given in Table 1, in 0.01Hz frequency. So, we can proclaim that 0.01Hz frequency is the new smallest frequency, i.e. *resolution frequency*, which determines how finely we decompose the signal. The period of resolution frequency, which is 100s, directly affects the sampling time, i.e. occurring interrupts. In these interrupts, the desirable samples are sent to the digital to analog conversion input which converts that number to a corresponding value of analog voltage.

Table 1. Required ranges for frequency, amplitude and total time of working

Frequency	(0.1 – 31.5) Hz
Amplitude	(0 - 50) mm
Total time of working	(0 – 999) min

One complete sine cycle is stored in the 40000 location sine lookup table (contains amplitude value for each of 40000 samples), which is used for the SWEEP/NO SWEEP sine signal and stochastic signal generation (while the other lookup table is used only for triangle wave generation in the SWEEP/NO SWEEP working mode). If the phase accumulator output increments by one on each clock, then all the stored sine-wave values will be read out consecutively by the time of $100s$. This means that each interrupt will occur after 2.5ms. On each clock, the output phase will advance by $360/40000 = 0.009$ degrees.

In the case of the NO SWEEP/SWEEP working mode with sine excitation, for generating a 0.1Hz sine signal, every tenth point from the sine lookup table will be read.

One complete triangle cycle is stored in the 4000 location lookup table. And if the phase accumulator output increments by one on each clock (that corresponds to 0.1Hz frequency), then all stored triangle-wave values will be read out consecutively. On each clock, the output phase will advance by $360/4000 = 0.09$ degrees. This means that each interrupt will occur after 2.5ms.

It is already mentioned in the previous section that the stochastic signal can be represented by a sum of sinusoid functions with different frequency, different initial phase and the same amplitude. These sinusoid functions are added at the same time intervals, which vary from 2.5ms to 10ms due to a satisfactory number of sinusoid functions per frequency interval ($\Delta f = f_{\max} - f_{\min}$).

It is advisable to have a great number of sine functions per frequency interval. Nevertheless, attainable number of sine functions is restricted by two factors: processor speed (which directly affects the number of sine waves, because it restricts number of arithmetic operations in timers interrupt that can be achieved without signal distortion) and the fact that 10ms is the maximum time for timer interrupt due to motor features (10ms interrupt corresponds to 100Hz frequency, which is the *chattering frequency* for this system). This frequency influenced the servo valves and the hydraulic cylinder, so the flutter of the hydraulic platform occurs and the signal is distorted. Therefore, the maximum 10ms interrupt provides a maximum resolution which is 0.0025Hz). The resolution is better if the interrupt occurs after longer time. With this hardware configuration and the best resolution is 0.0025Hz.

Table 2. EHVE required frequency ranges

Frequency range [Hz]	N
(0.10 – 0.125)	11
(0.125 – 0.16)	10
(0.16 – 0.20)	10
(0.20 – 0.25)	12
(0.25 – 0.315)	14
(0.315 – 0.40)	20
(0.40 – 0.50)	11
(0.50 – 0.63)	14
(0.63 – 0.80)	18
(0.10 – 31.5)	31

Every customer can select any frequency range between boundaries given in Table 1. Some required ranges, important for EHVE working, are in the left column of Table 2, while the obtained sine number N is in the right column (explanation is given later in this section).

The maximum sine number that can be added in a timer interrupt is 50 per channel, but it is decided that a number of 21 sine values is quite enough for all frequency ranges where it is possible, i.e. where $\Delta f > 0.19$ (with a maximum resolution of 0.01Hz). Since there are many ranges with $\Delta f \le 0.19$, the resolution should be better than 0.01Hz. There are several ranges with 0.05Hz resolution, even with 0.0025Hz resolution. These ranges are presented in Table 3.

Table 3. Number of sine functions per frequency range and with determined resolution

Frequency range Δf [Hz]	Precision [Hz]	Number of sine functions
$\Delta f > 0.19$	max 0.01	21
$0.09 < \Delta f < 0.2$	0.01	$\Delta f * 100 + 1$
$0.03 < \Delta f < 0.1$	0.005	$2 * \Delta f * 100 + 2$
$\Delta f < 0.04$	0.0025	$4 * \Delta f * 100 + 3$

Random initial phase generation and amplitude scaling

In respect of random initial phase determination, the algorithm [13] is implemented. Let us assume that a counter, named *COUNT* [0], represents the initial phase for the first sine function, i.e. the sine function with the smaller frequency in the desired range. That initial phase, *INPHASE_0*, is obtained from a micro controller timer, which stopped at the moment of initializing all initial conditions for vibratory exciter operation. The flow chart for the random initial phase generation is given in Fig.4. The digital to analog converter has 12-bits resolution and provides (0-10) V on its output. All values of interest should be mapped on a number range of (0-4094). The amplitude resolution in every mode of operation is 0.1mm and the number of 4.094 corresponds to it. For a stochastic signal, which consists of n sinusoid functions, the amplitude of every sinusoid is decreased by n times.

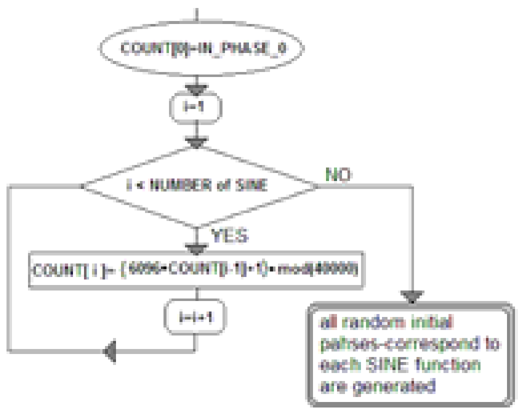

Figure 4. Algorithm for random initial phase generation.

Experimental results

The previously depicted ways of driving signal generation and experimental results are verified on the two-axis EHVE platform. This section presents the measurement values of the vibratory platform movements as well as the frequency features at stationary excitation (sine and triangle wave in the SWEEP/NO SWEEP mode of operation). The generating of electrical motors and appropriate hydraulic pumps is realized from the mains supply 3x380V, 50Hz. The power of each AC motor is 7.5kW.

The time response and the frequency analysis over stationary and stochastic (random) excitation are given here. The experimental results are obtained under certain conditions, presented in Table 4.

Table 4. Conditions for obtaining experimental results

Pressure in hydraulic installation	130bar
Platform mass load	200kg
Displacement probe (vertical axis)	11.7mm/V
Displacement probe (horizontal axis)	11.0mm/V

Figures 5 to 7 represent the oscilloscopic records of both the set and the realized values for sine wave oscillation over two axes, between minimum and maximum frequencies. The CH1 and CH2 are labels for referenced and realized displacement values.

The record for vertical axis excitation is given in Fig.5. The 40mm amplitude is obtained for a frequency of 0.1Hz. It is obvious that the realized signal precisely follows the setting value over the amplitude and frequency.

The waveforms for vertical axis excitation are presented in Fig.6. The 1mm amplitude is obtained for a frequency of 30Hz. It is obvious that the realized signal precisely follows the setting value over the amplitude, but there is some deviation of frequency. The reason for that is that the servo regulator does not have the tuning of adaptive parameters (but compensation of this phase bias was not in the list of requirements, although it could be exceeded by adaptive control).

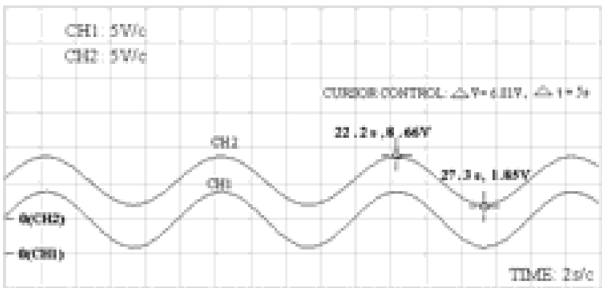

Figure 5. Stationary sine excitation (vertical axis); amplitude-40mm, frequency- 0.1Hz

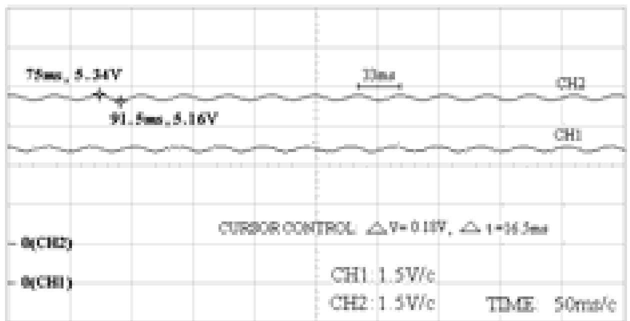

Figure 6. Stationary sine excitation (vertical axis); amplitude-1mm, frequency-30Hz.

Fig.7 shows the waveforms of sine excitation over the horizontal axis. The obtained value is 40mm under 0.1Hz frequency. The realized signal precisely follows the setting values.

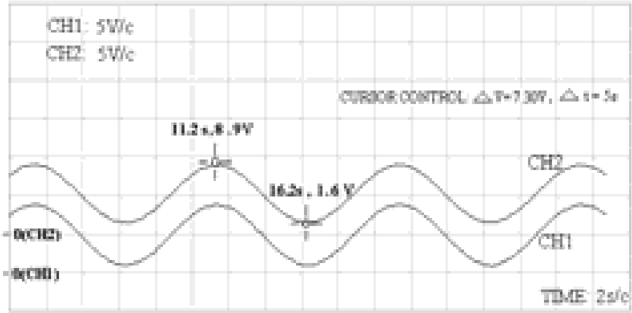

Figure 7. Stationary sine excitation (horizontal axis); amplitude-40mm, frequency -0.1Hz

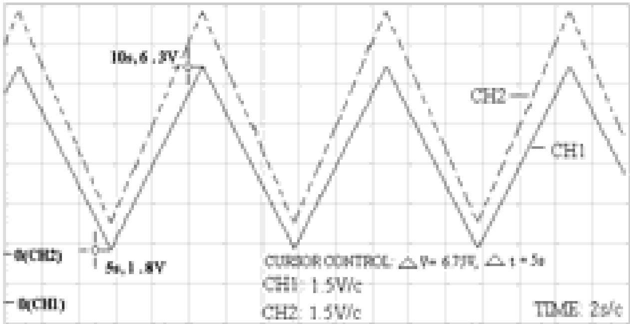

Figure 8. Stationary triangle excitation (vertical axis); amplitude -40mm, frequency- 0.1Hz

Figures 8 and 9 give the records of stationary triangle wave excitation over the vertical axis. The obtained value is 40mm amplitude for 0.1Hz (Fig.8) and 3mm for 10Hz frequency (as in Fig.9). In both cases, the notes very well tracking the reference value.

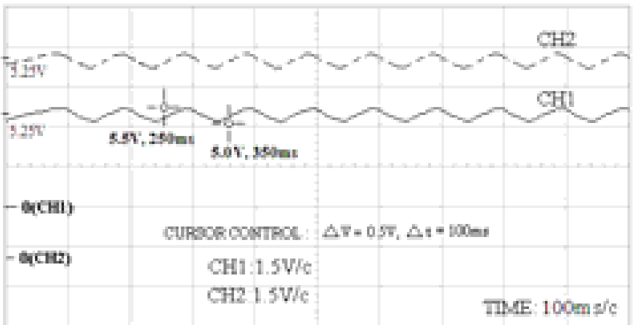

Figure 9. Stationary triangle excitation (vertical axis); amplitude-3mm, frequency- 10Hz.

Fig.10 gives the oscilloscopic record resultant motion of the vibratory platform with simultaneous excitation on the horizontal and vertical axis with the same values of the amplitude (20 mm) and frequency (1Hz), but with a time shift of 160ms. Fig.10 (a) shows the displacement for each axis, while Fig.10 (b) shows the resultant trajectory in the vertical plane which is determined by the directions of excitation, i.e. the X-Z coordinate system.

Fig.11 depicts the system response to stochastic excitation over the horizontal axis with a 40mm amplitude and a frequency range of 0.1-0.125Hz. The sum of N=11 sine waves is obtained. Fig.11 (a) shows the frequency spectrum of displacement while Fig.11 (b) gives the same response in the time domain. The obtained stochastic signal corresponds to the initial excitation in the amplitude, as well as in the frequency range.

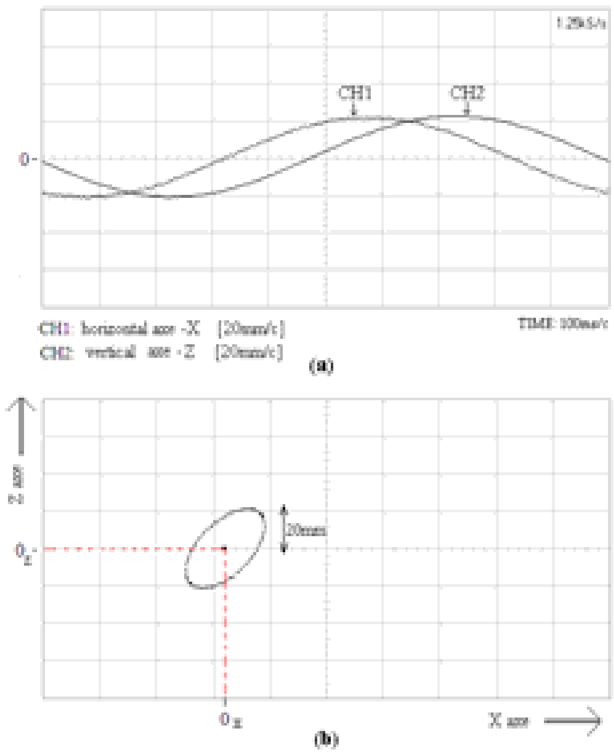

Figure 10. Plane movement of the vibratory platform; (a)-displacement X, Z, (b)-resultant trajectory in the X-Z plane

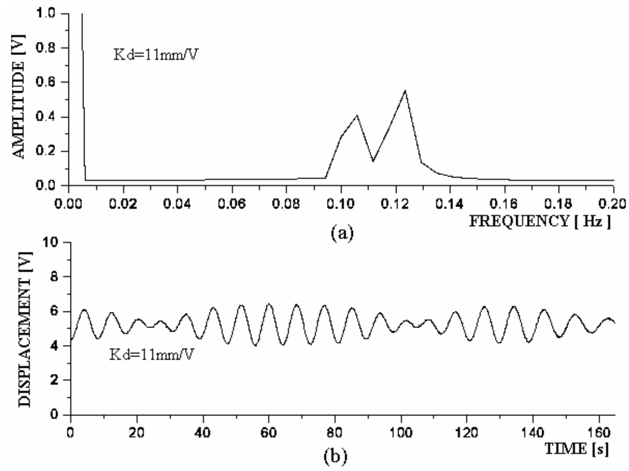

Figure 11. Stochastic excitation (horizontal axis); amplitude- 40mm, frequency range (0.1-0.125) Hz; (a)-frequency spectrum, (b)-time domain

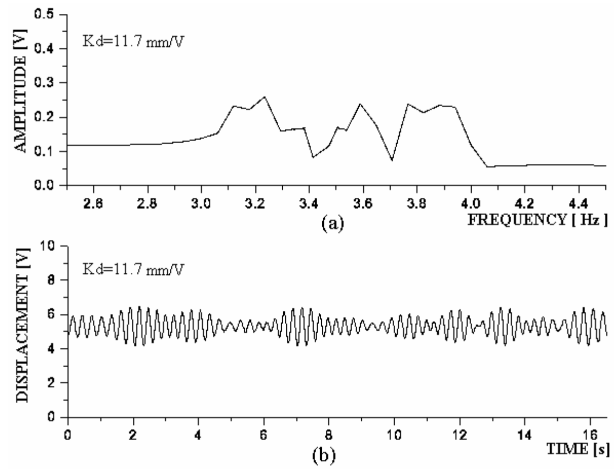

Figure 12. Stochastic excitation (vertical axis); amplitude- 40mm, frequency range (3.15- 4) Hz; (a)-frequency spectrum, (b)-time domain

Similar conclusions can be drawn for some other stochastic excitations over the vertical axis:

Fig.12 shows the system response to stochastic excitation over the vertical with 40mm amplitude and a frequency range of 3.15-4Hz. The sum of N=21 sine waves is obtained. Fig.12(a) shows the frequency spectrum of displacement while Fig.12(b) shows the same response in the time domain.

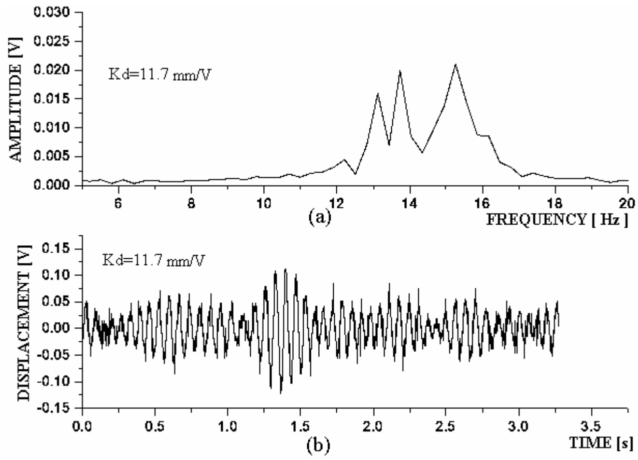

Figure 13. Stochastic excitation (vertical axis); amplitude- 3mm, frequency range (12.5-16) Hz; (a)-frequency spectrum, (b)-time domain

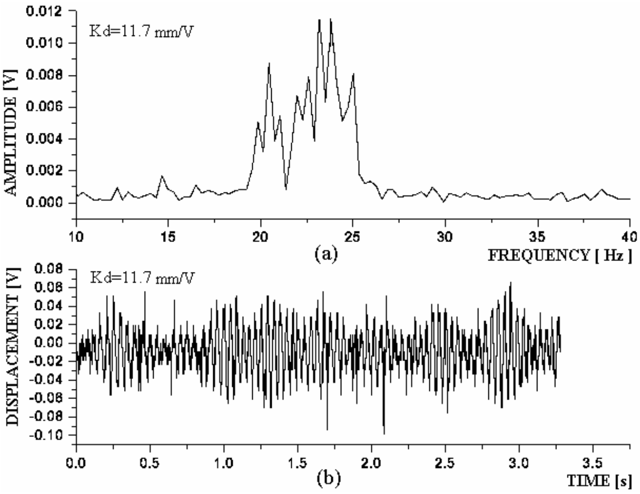

Figure 14. Stochastic excitation (vertical axis); amplitude- 1mm, frequency range (20-25) Hz; (a)-frequency spectrum, (b)-time domain

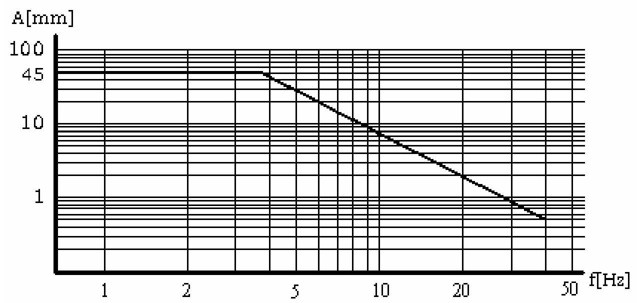

Figure 15. Amplitude-frequency diagram of the hydraulic pulsator in the operating range.

The system response to stochastic excitation over the vertical with the 3mm amplitude and a frequency range of 12.5 - 16Hz is shown in Fig.13. The sum of N = 21 sine waves is obtained. Fig.13 (a) shows the frequency spectrum of displacement while Fig.13 (b) shows the same response in the time domain.

Fig.14 gives the system response to stochastic excitation over the vertical with 1mm amplitude and a frequency range of 20 - 25Hz. The sum of N = 21 sine waves is obtained. In Fig.14(a) the frequency spectrum of displacement is shown while Fig.14(b) shows the same response in the time domain.

Fig.15 presents the amplitude-frequency characteristic of the whole system of the EHVE, for the amplitude operating range of 0 - 50 mm and the frequency operating range of 0.1 - 50Hz.

The amplitude values near 40mm are possible in a frequency range of (0.1 - 4) Hz, while lower amplitude values correspond to greater frequency ranges (0.4mm at a frequency of 50Hz).

The appearance of the mechanical construction of the realized EHVE is shown in Fig.16. The implemented electronic control system is shown in Fig.17.

Conclusions

This paper discusses a specific realization of the EHVE and its driving system for vibration in two perpendicular directions. Desirable signals are generated from the signal generator.

The DDC method, used for generating different waveforms, is software implemented. Some important results are also presented, in relation with stationary and stochastic excitations with different frequency ranges.

The overall presented system is realized and installed in the Department for Motor Vehicles and Motors at the Faculty of Mechanical Engineering, University of Kragujevac.

The realized system of EHVE could be used for military purposes and investigations.

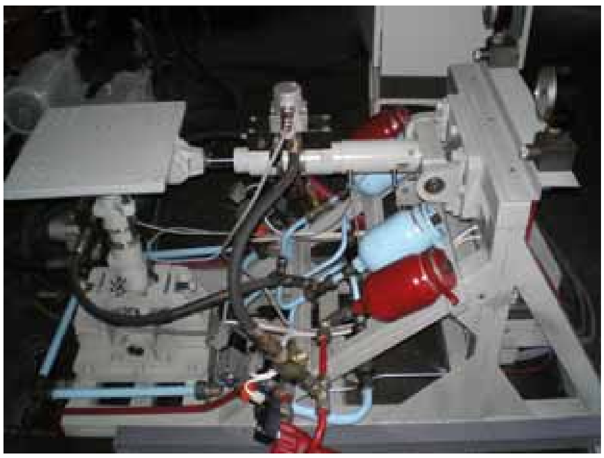

Figure 16. Realized electro-hydraulic vibratory exciter

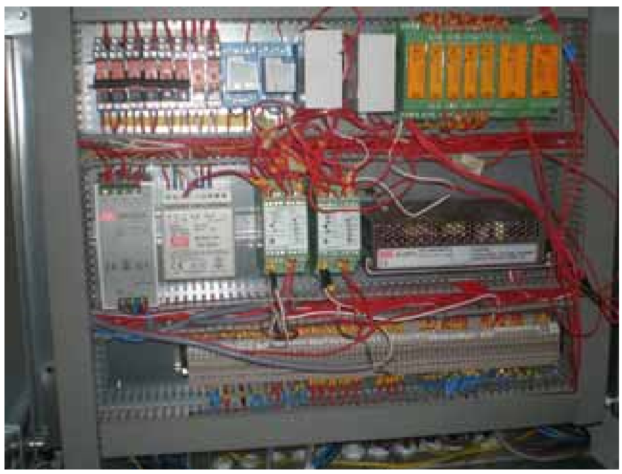

Figure 17. Implemented control system

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Elektro hidraulički pobuđivač za proučavanje uticaja vibracija vozila na čoveka

U radu je predstavljena realizacija elektronski kontrolisanog dvoosnog hidrauličkog vibracionog pobuđivača koji se koristi za proučavanje ponašanja ljudskog tela izloženog dejstvu vibracija. Ovde se prvenstveno misli na uticaj vibracija u motornim vozilima. Sa stanovišta oscilatorne udobnosti vozila, razumevanje prenosa vibracija kroz ljudsko telo i njihov uticaj na psiho-fiziološke sposobnosti su veoma značajne za auto dizajn. Takođe u vojnim oklopnim i transportnim vozilima ljudstvo je izloženo visokom nivou vibracija koje deluju na celokupno telo. Budući da će u budućnosti komandne i kontrolne operacije biti mobilnije, od interesa je razumevanje efekta vibracija na ljudsko telo, slušne i kognitivne performanse. Predstavljeni vibracioni pobuđivač je baziran na hidrauličkoj servo kontroli i referentnom signalnom generatoru visokih performansi. Kontrolni sistem je projektovan da obezbeđuje kontinualno podešavanje amplitude u opsegu 0-50mm i frekventno podešavanje u opsegu učestanosti 0.1-50Hz. Implementirani kontrolni sistem obezbeđuje generisanje različitih talasnih oblika (sinus, trougao ili pravougaoni) pri zadatoj učestanosti i što je veoma značajno generisanje slučajnih (stohastičkih) signala. Takođe su prikazani eksperimentalni rezultati pomeraja vibracione platforme pobuđivača (spektri u frekventnom domenu i osciloskopski talasni oblici) za obe normalno postavljene ose i stvarno maseno opterećenje.

Ključne reči: **vibracije, pobuđivanje vibracija, vibracioni pobuđivač, elektrohidraulični uređaj, uticaj vibracija, uticaj na čoveka, vibracije vozila, generisanje signala.**

Электро-гидравлически вибрационная возбудитель для исследования влияния вибрации автотранспортных средствах на организм человека

Поскольку командование и управление операциями, вероятно, станут более мобильными в будущем, она представляет интерес для понимания влияния человеческой вибрации тела на слух и когнитивные функции. В данной статье представлена реализация электронным управлением двух осей гидравлических вибрационных возбудителя используется для изучения поведения человеческого тела под воздействием вибраций. Конкретно речь идет о влиянии колебаний, которые происходят на автотранспортных средствах. С точки зрения комфорта колебательные транспортного средства, познание передачи вибраций через человеческий организм и их влиянии на психо-физиологических способностей очень важно для автомобильного дизайна. Кроме того, в бронированные транспортные средства и военнослужащих, подвергаются высокому уровню весь организм вибрации. Поскольку командование и управление операциями, вероятно, станут более мобильными в будущем, она представляет интерес для понимания влияния человеческой вибрации тела на слух и когнитивные функции. Предлагаемый вибрационный возбудителя основан на гидравлическое управление диска сервоприводов и высокое ссылкой выступления генератора сигналов. Система управления вибрационные возбуждения предназначен для обеспечения постоянной амплитуде корректировки в диапазоне 0-50мм и перестройкой частоты в диапазоне 0.1-50Hz. Реализована система управления предусматривает различные поколения сигналов (синусоида, треугольник или квадрат волны) при заданной частоте и это очень важно, генерации стохастических сигналов. Экспериментальные результаты вибрационного перемещения возбудителя (oscilloscopic сигналов и спектра в частотной области) для обеих перпендикулярных осей и реальные нагрузки массой представлены тоже.

Ключевые слова: **вибрации, возбудитель вибраций, вибрационная платформа, электро-гидравлически возбудитель, влияние na человеческого тела, сигнал поколения, vibracii автотранспортных средствах.**

Excitateur électrique hydraulique pour l'étude de l'influence des vibrations des véhicules sur l'homme

Ce travail présente la réalisation de l'excitateur vibratoire hydraulique à deux axes contrôlé électriquement et utilisé pour l'étude du comportement du corps humain soumis aux effets des vibrations. Il s'agit ici notamment des vibrations chez les véhicules à moteur. De point de vue du confort oscillatoire du véhicule, la compréhension de la transmission des vibrations à travers le corps humain ainsi que leur influence sur les capacités psychophysiologiques sont très importantes pour la conception d'auto. Dans les véhicules blindés et de transport le personnel est exposé à un haut niveau de vibrations qui agissent sur le corps entier. Vu que les opérations de commande et de contrôle seront plus mobiles dans l'avenir il est d'intérêt de comprendre les effets des vibrations sur le corps humain et aux performances auditives et cognitives. L'excitateur vibratoire présenté ici est basé sur le régulateur de vitesse servo hydraulique et sur le générateur des signaux référentiels de hautes performances. Le système de contrôle est conçu pour assurer l'adaptation continue d'amplitude dans la gamme de 0-50mm ainsi que l'adaptation de fréquence dans la gamme 0.16-50Hz. Le système de contrôle mis en service assure la génération de différentes formes d'ondes (sinus, triangle, rectangle), la fréquence donnée et la génération des signaux stochastiques, ce qui est très important. On a présenté aussi les résultats expérimentaux sur le déplacement de la plate-forme vibratoire de l'excitateur (spectres dans le domaine de la fréquence et les formes oscilloscopes d'ondes) pour les deux axes perpendiculaires et la charge massique réelle

Mots clés: **vibrations, excitation des vibrations, excitateur vibratoire, appareil électrique hydraulique, influence des vibrations, influence sur l'homme, vibrations des véhicules, générations des signaux.**