THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224 – 5615
2004

DYNAMIC ANALYSIS OF ELECTRO-HYDRODYNAMIC VIBRATORY EQUIPMENT USING VIRTUAL PROTOTYPING TECHNIQUE

Prof.univ.dr.ing. Gavril AXINTI
Asist.univ.ing.drd. Silviu NASTAC
Universitatea “Dunarea de Jos” Galati

ABSTRACT

In this paper the authors analyse the functional behaviour of an electro-hydrodynamic vibratory equipment, that could be used to vibro-driving the piles into the powerless soils, to drive a demolition hammer, a.s.o. Virtual prototyping is a relative new technique for modelate and analyse the products or systems, before and without realize and put it them into the practice. This technique suppose the existence both of the physical, mathematical and numerical model, and of the software packages specialised for different analysis, like a stress analysis, dynamic behaviour analysis, kinematic analysis, evaluating the technological performances, a.s.o. In this work, it is presented only the first "tool" from the entire set of virtual prototyping technique, namely mathematical model formulation.

1. Introduction

In construction technologies, the vibratory equipments have a large place of application: in civil engineering – reinforcing operations of building foundation, concrete properties improvement, thin ground reinforcing for direct foundation; in road construction technologies - road basement strengthening, improvement properties of any type of road covering, embankments reinforcing, a.s.o.

A part of this technologies are based on the property that the internal structure of some materials have change their configuration, under vibratory charge. Generally, with this transformation, also appear a strengthening of mechanical properties. This is the surface consolidation category of operations.

Other part, are based on the consolidation element insert, into the ground. This operation suppose that have some elements, like piles, tubes, forepoles, walls, which are fill in into the basement ground and which assure the safe support for construction. Penetration of elements are more quickly and more efficiently by using the vibratory pushing devices (comparatively with the statically pushing). The last operations form the deep consolidation category.

From the briefly upper presentation result that the main equipment of this technologies is the vibratory device. In this work paper the authors present a type of vibratory equipment in which the movement is generated by hydraulic device.

2. The Proposed Physical Model for Hydrodynamic Driving System

The base diagram of operating system is presented in figure no. 1. Symbols used have the next signification: M – heavy mass of ram, P – main piston, EP – equalizer piston, V – main valve, A0 - equalizer system (which contained hydraulic accumulator, safety valve, way valve and pressure connection), A1,A2 – high pressure and, respectively low pressure accumulator, SV – safety valve, BV – bypass valve, HP – hydraulic pump, T – hydraulic tank, F – filter.

Function principle suppose that in starting position the bypass valve is open, hydraulic oil circulating to the tank and the ram is in the low position of lifting drive. By pressing start-button the bypass valve is closed and the main valve is switched to lifting. The high pressure oil is pushing in the below chamber of main piston.

When the pre-selected stroke height (the main piston drive) is reached the main valve reverses to falling position. The ram moves down helped by his mass (free fall) and by supply oil that is switched in the above chamber of main piston.

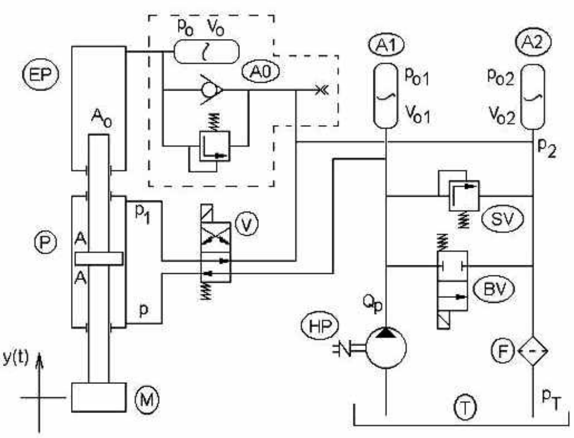

Figure 1. Schematic diagram of hydraulic vibratory device

Therewith the supply oil, that fills the high pressure accumulator of equalizer system in climbing drive, help the falling movement of ram (in the first segment of moving, when the ram is pushing down and the movement is started).

Also, the hydraulic oil energy stored up in the high pressure accumulator help the movement to started (for both drives).

By pressing the stop-button the main valve switched to falling and the bypass valve opens.

A safety valve opens if the pressure exceeds the limit pressure of the system.

3. Formulation of the Mathematical Model for the System

Writing the mathematical equations of model suppose the next few ipothesis:

- Ü on the fall moving the impact between the ram and the pile will be consider plastic type;
- Ü the main valve work very fast, the switched between the two position will be maded safety and instantaneous at the extremity of the main piston drive;
- Ü always the moving started by the low position of ram;
- Ü in this moment interest the hydraulic system modeling;
- Ü hydraulic oil type is H46A and his characteristics are evaluated on 40°C temperature.

The equations of model will be written disjoint for the two strokes of the ram: lifting and falling.

Taking into account the upper ipothesis, the moving equation for the lifting drive, will be:

$$M\frac{d^2y}{dt^2} + k_{fv}\frac{dy}{dt} + F_{ac} = pA - p_1A - Mg \tag{1}$$

where y is the deplacement, k_{fv} - the viscous coefficient of friction, A - the aria of the piston, F_{ac} – resistant force of the hydraulic accumulator of equalizer system and g is the gravity acceleration (9,81 m/s^2).

For all the hydraulic accumulators the process suppose to be isotherm, thereby the F_{ac} have the next expression:

$$F_{ac} = A_o p_o \frac{V_o}{V_o - A_o y} \tag{2}$$

Expression of flow balance give the pressures p and p_1 of the two branches of hydraulic system. It will be taking into account the ipothesis that the loss flow sum on the hydraulic circuit is null. Also, the flow of the accumulators result by isothermal law of process.

Thereby, for high pressure branch, the flow balance equation is:

$$Q_p = A\frac{dy}{dt} + \frac{V_c}{E}\frac{dp}{dt} + V_{o1}\frac{p_{o1}}{p^2}\frac{dp}{dt} \tag{3}$$

where Q_p is the pump flow, first term give the flow into the main piston, second term give the flow in the hydraulic circuit and the third result form the flow into the high pressure accumulator.

In the low pressure branch the flow balance equation can be write:

$$A\frac{dy}{dt} = Q_T + Q_{A2}, \tag{4}$$

where Q_T is flow to tank and Q_{A2} is flow to low pressure accumulator. Suppose that the pressure in the tank is null, (4) equation became:

$$A\frac{dy}{dt} = A_n R_{ret}\sqrt{p_2} + V_{o2}\frac{p_{o2}}{p_2^2}\frac{dp_2}{dt} \tag{5}$$

in which R_{ret} is flow resistance from accumulator A_2 to tank and pressure p_2 is given by loss pressure equation from main piston to accumulator A_2:

$$p_1 - p_2 = \sum \xi_{1-2} \frac{\rho}{2} \frac{A^2}{A_n^2} \left(\frac{dy}{dt} \right)^2 \quad (6)$$

The falling stroke of system can be described in the same mode, writing the movement equation (in the same coordinate system) and the flow balances for both branches of system:

$$M \frac{d^2 y}{dt^2} + k_{fv} \frac{dy}{dt} - F_{ac} = pA - p_1 A + Mg \quad (7)$$

$$Q_p = A \frac{dy}{dt} + \frac{V_c}{E} \frac{dp}{dt} - V_{o1} \frac{p_{o1}}{p^2} \frac{dp}{dt} \quad (8)$$

$$A \frac{dy}{dt} = A_n R_{ret} \sqrt{p_2} + V_{o2} \frac{p_{o2}}{p_2^2} \frac{dp_2}{dt} \quad (9)$$

Equations (1), (3), (5), respectively (7), (8), (9), with equation (6) form the mathematical model of considered hydraulic system. It is a non-linear system of differential equations and it will be solved using numerical methods, like: Runge Kutta 4^{th} order method, finite differences method, a.s.o.
The authors choose the 4^{th} order Runge Kutta method and write a software using Pascal compilator for solve the model equations system and analysis the results.

4. Numerical Analysis

One of the reason for this modeling is estimating the ram velocity in the impact moment with the driven element. In this way it can be able compute the percussion energy, and thus, the energy transferred to the element, and will be able to optimizing the equipment design and technology.

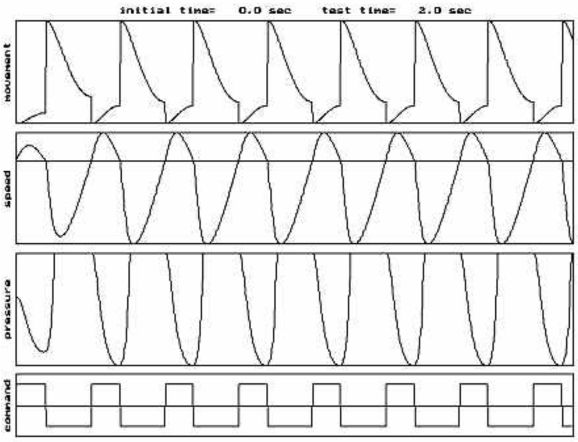

Figure 2. Hydraulic device parameters temporal evolution for 2 sec. beginning at t_o= 0

In the Figure 2 are presented the temporal evolution for the next parametrs of the system: movement and velocity of ram, value in high pressure chamber and command evolution of main valve. These quantities was estimated for the first 2 sec. of movement. The aquired parameters values are: ram movement between 0 and 1.20 m; ram velocity between –9.43 and +3.22 m/sec; pressure between 145.72 and 300 bar. It can be seen a short transient time period, after which, the moving state of system become permanent. This presumption is valid, because for the other simulations (it was proposed a lot of time lengths, less or long) it have been obtained a permanent state for the considered parameters temporal evolutions.

5. The Influences of the Hydraulic Fluid About the System Behaviour

In this tests it was used a H46A hydraulic fluid, with the mainly parameters presented in the Table 1.

Table 1.

t [^{o}C]	ρ [kg/m^3]	E [10^8 N/m^2]	η [kg/msec]
0	908	21.3	0.412
10	900	18.8	0.238
20	893	17.9	0.131
30	886	17.3	0.0618
40	878	16.9	0.039
50	870	16.6	0.024
60	863	16.5	0.0178
70	856	16.4	0.0108
80	848	16.3	0.078

The simulation was maded for 10 sec. from the initial moment. From the analysis of the diagrams it was concluded that the influences of the hydraulic fluid parameters wasn't qualitative, but more quantitative. In the Table 2 was presented the values obtained for a temperature domain between 0 and 80^{o}C.

Table 2.

T	y(t) [m]		v(t) [m/sec]		p(t) [bar]	
	min	max	min	max	min	max
0	0	1.2	-8.69	3.04	152	400
20	0	1.2	-9.24	3.17	147	400
40	0	1.2	-9.43	3.22	146	400
60	0	1.2	-9.48	3.24	145	400
80	0	1.2	-9.50	3.24	145	400

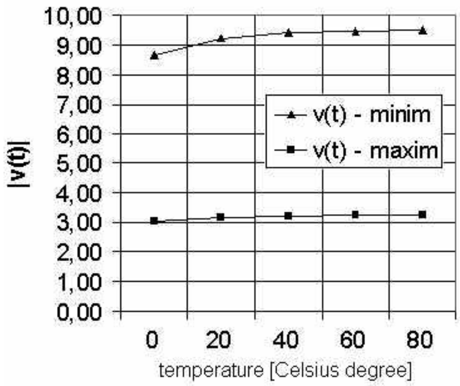

Figure 3. Speed evolution as a function of the fuid temperature

It was observed that the temperature changing suppose only a limit values of the analised parameters. Thus, at one time with growing up the temperature of the hydraulic fluid, grows up the speed too. In this sense, it was obtained o higher value for kinetical energy at the impact moment of the ram with the pilot. But, growing up of the temperature impose the increasing of the variation domain of the pressure. These remarks could be sustained with the diagrams from Figure 3 and Figure 4.

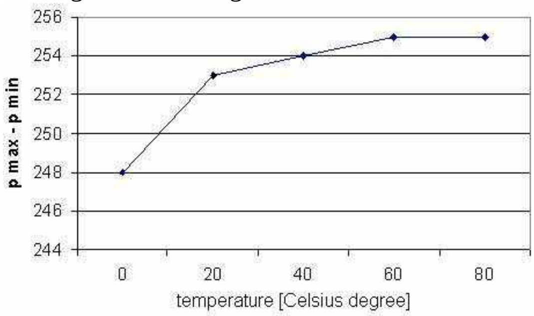

Figure 4. Pressure limits evolution as a function of the fuid temperature

6. The Influences of the Geometrical Parametrs About the System Behaviour

In the case of geometrical parametrs changing, the obtained results from numerical simulation could be observed in the Figure 5, where case (a) represent the diagrams of ram deplacement and speed, pressure and command for plunger diameter of 120 mm, and case (b) represent the same signals diagrams, but for plunger diameter of 90 mm.

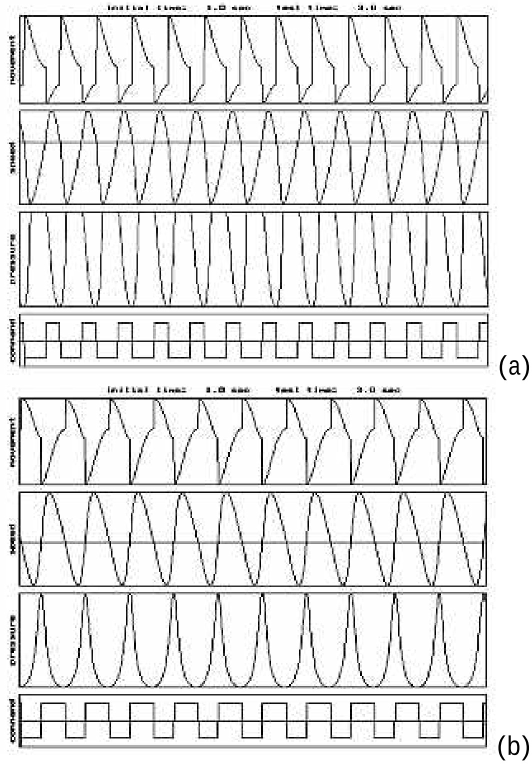

Figure 5. Pressure limits evolution as a function of the fuid temperature

From the previous diagrams results that the system working with shocks (the jumps from the deplacement diagrams shows this fact). Also, results that with increasing the plunger diameter, appear a diminishing of the working frequency values of the ram. In the Figure 6 are presented the speed limits values, respectively the pressures limits, as a functions of the plunger diameter.

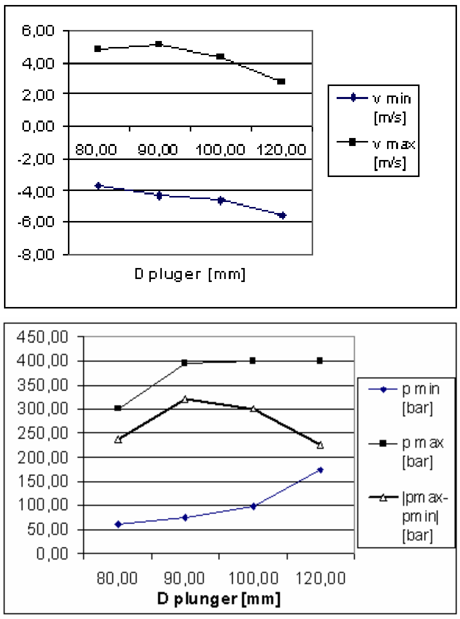

Figure 6. Pressure limits evolution as a function of the fuid temperature

7. Conclusions

Numerical values used to solve mathematical model are low frequency device specifically. For vibratory driving of the piles into the powerless soils, it is necessary to change some characteristics of equipment: mass of the ram must be smaller (decreasing of inertia value), the main piston stroke (amplitude of vibration) must be much smaller and the A and A_o piston surfaces must be bigger (increasing the active force of piston). Thereby it can be obtained high frequencies with small value amplitude vibrations at ram.

For the future, it could be improve the performances of the numerical model, by evaluation of whole process, by taking into account both the driving device, and the driven element.

References

[1] Axinti, G. *Dinamica echipamentelor]i sistemelor de ac\ionare hidraulic`* - Bucure]ti, Editura Impuls, 2000.

[2] Axinti, G. *Dinamica aparatelor hidraulice autoexcitate* - Bucure]ti, Editura Impuls, 1998.

[3] Axinti, G. *Modern Equipment of Shock Crushing used on Construction Machinery and Equipment* – Analele Univ. “Dun`rea de Jos” Gala\i, fasc. XIV, 1995.

[4] Nastac, S., Axinti, G. *Dynamic Behaviour of Electro–Hydraulic Vibrodriving Equipments used for Construction Piles Driving* – Proceedings of 3rd International Conference of PhD Stud., University of Miskolc, 2001.

[5] Oprean, A. *Ac\ion`ri hidraulice. Elemente ]i sisteme.* – Bucure]ti, Editura Tehnic`, 1982.

[6] N`stac S. *Analiza numerica cu aplicatii in ingineria mecanica*, Bucuresti, Editura IMPULS, 2004.

[7] Oproescu Gh., N`stac S. *Elemente de modelare numeric`*, Br`ila, Editura Libertatea, 2000.

[8] Nastac S. *Dinamica vibro[nfigerii elementelor de construc\ii [n sol*, A XXIII-a Conferin\` Na\ional` de Mecanica Solidelor, Ploie]ti, 1999.

[9] Nastac S., Caute] Gh. *Aspecte teoretice privind comportarea solurilor la vibro[nfigere*, A XXIII-a Conferin\` Na\ional` de Mecanica Solidelor, Bra]ov, 1998.