OPTIMISED PROGRESSION RATES BY MEANS OF VIBRO-IMPACT MOTION

Si-Chung Jong*, Vincent Chieng-Chen Lee* & Ko-Choong Woo *
*The University of Nottingham Malaysia Campus, Faculty of Engineering, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia.

Summary An experiment involving two sources of magnetic force interacting with a conductor generates substantial impacts for forward progressive motion into soil, and brick as a typical example of brittle material. A mathematical model is established and solved by means of direct numerical integration. Optimal progression rates are dependent on system parameters such as control frequency, voltage supply and geometrical distances.

INTRODUCTION

In this work. interactions between two sources of electromagnetic flux have been the basis of vibro-impact dynamics for forward progressive motion. Modification has been made to the original mechanism of Nguyen and Woo [1], such that the mechanical spring is replaced by a permanent magnet and direct current solenoid in turn, effectively acting as a nonlinear magnetic spring. Consequently, impact forces have been generated to occur at high frequencies, which have proven to be beneficial to a downward progression rate in soil. These rates are compared for increasing diameters of the penetration head, corresponding to an increasing amount of soil resistance. Consistent progression into soil for comparable parameters of input voltage and control frequency confirms this mechanism as a platform for mechanical impact and penetration. The current setup is capable of high frequency impacts for a minimal amount of energy input, which has been able to achieve steady progression rates in soil.

EXPERIMENTAL RIG

The rig consists of an aluminium frame which houses the permanent magnet and solenoid. A cylindrical piece of mild steel that acts as an oscillating conductor is placed within the solenoid, below the permanent magnet. The permanent magnet provides an upward attractive force, constantly pulling the conductor. Meanwhile, the solenoid, which is connected to an RLC circuit powered by an alternating current power supply pulls the conductor downwards. A solid state relay switches the current signal on and off repeatedly to provide an oscillating signal. This is made possible by connection to a function generator of square waves, the frequency of which can be prescribed. The experimental rig is shown in Figure 1, accompanied by its schematic.

(a)

(b)

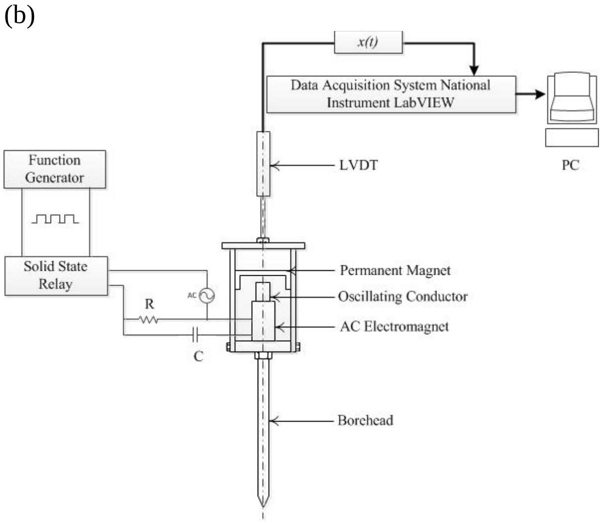

Figure 1: (a) Photograph of experimental rig and (b) its schematic.

A permanent magnet is placed in an optimal position such that large impact forces are generated by the conductor on collision with the stopper. Such dynamics is usually accompanied by high frequency of impacts. The vertical position of the permanent magnet is crucial to maintain the interaction of magnetic force acting on the conductor. If the permanent magnet is too near, it overcomes electromagnetic forces from the solenoid, thus causing the conductor to be attracted to the permanent magnet only. In the converse case, when the permanent magnet is too far from the conductor, its magnetic force is not strong enough to pull the conductor upwards. The range of frequencies corresponding to optimal operating conditions was found to be between 33 to 35 Hz,and the voltage varied from 40 to 60 V. Conductor oscillations were found to be unstable and discontinuous outwith the above mentioned ranges.

MATHEMATICAL MODEL

Establishment of initial mathematical model was based on a physical model shown in Figure 2 for direct numerical integration..

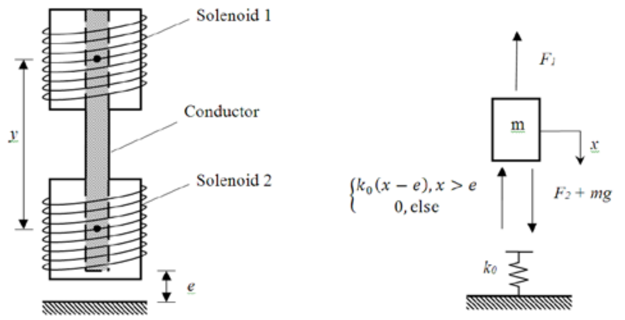

Figure 2: Physical system and free body diagram.

In the figure, the mass of the oscillator is denoted by m, the stiffness of impacting surface by k, the clearance between the oscillator and the base by e, and F_1 and F_2 are the magnetic force of permanent magnet and solenoid respectively. The displacement of the oscillator is described by x. Its equation of motion is written as

$$m\ddot{x} + \begin{cases} k(x-e), & x > e \\ 0, & else \end{cases} + F_1 - (F_2 + mg) = 0 \tag{1}$$

Since the electromagnetic force is dependent on the current flowing in the circuit, another equation for the latter is written as

$$L\frac{d^2 i}{dt^2} + \left(R + 2\frac{\partial L}{\partial x_b}\frac{dx_b}{dt}\right)\frac{di}{dt} + \left(\frac{1}{C} + \frac{\partial^2 L}{\partial x_b{}^2}\left(\frac{dx_b}{dt}\right)^2 + \frac{\partial L}{\partial x_b}\frac{dx_b}{dt}\right)i = \omega P_{ctr} V\cos(\omega t) \tag{2}$$

where x_b denotes displacement relative to solenoid. F_1 is the magnetic force of the permanent magnet, F_2 is the magnetic force from the solenoid, g is the gravitational force, i is the current induced in the solenoid, ω is the frequency of the mains supply which is typically 50 Hz, V_s is the voltage input and R is the resistance. P_{ctr} is the voltage variation due to the solid-state relay frequency, ω_c, represented by a discontinuous function.

EXPERIMENTAL RESULT AND CONCLUSION

Progression in to soil has been observed to be optimal at a control frequency value of 33.3 Hz as shown in Figure 3.

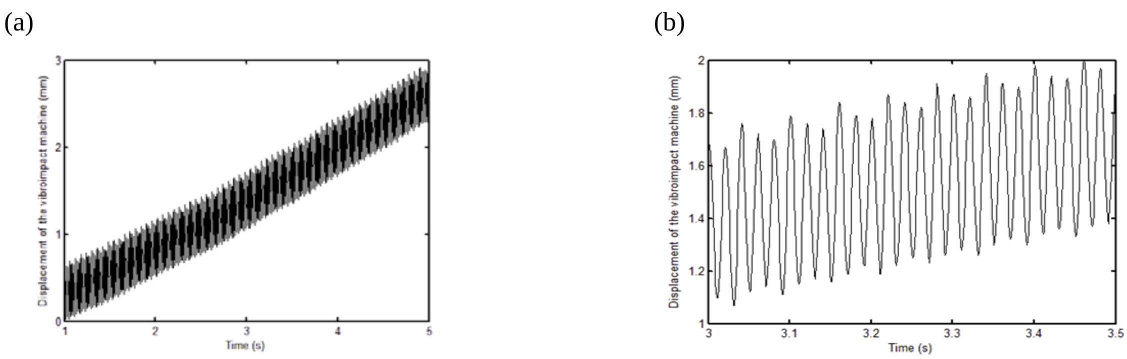

Figure 3: Experimental time histories when the control frequency was set at 33.3 Hz and voltage was supplied at 50 V.

Reference

[1] V.-D. Nguyen and K.-C. Woo, 2008, New electro-vibroimpact system, *Proceedings of the Institution of Mechanical Engineers Part C: Journal of Mechanical Engineering Science*, **222**(C4):629-642.