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Short Communication

The corresponding phenomena of mechanical and electronic impact oscillator

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Abstract

A mechanical impact oscillator and a diode rectifier circuit of an impact oscillator are presented. Time series and phase portrait analysis are performed for both oscillators. The results show that the proposed electronic impact oscillator is in agreement with the mechanical impact oscillator. For varying the driving frequency, a fixed harmonic input force can generate a periodic or non-periodic impact oscillation. The phenomena of bifurcation are also observed in both impact oscillators.

1. Introduction

The motion with amplitude constraint is considered as impact oscillator. Over the past few years, the researchers were interested in the fundamentals of impact dynamics [1–4]. The bifurcation theory was applied to investigate the stability of system behavior as the parameter changed. Rich phenomena have been found and given benefit for understanding impact dynamics. In the practical application of condition monitoring, the experimental impacting signals were examined using blind deconvolution to confirm the bifurcation diagram [5]. Recently, such stable or unstable impact oscillators can be controlled and kept in a desired position [6].

Recent results also show that many rich and complicated phenomena, such as Neimark–Sacker, Hop-flip bifurcation, double Neimark–Sacker bifurcation, etc., are found in a system with two or more degrees of freedom impact oscillators [7,8]. In this paper, a single degree of freedom mechanical impact oscillator and a modified version of the electronic impact oscillator [9–12] are presented. The motion behaviors of both oscillators are investigated using computer simulation.

2. Mechanical impact oscillator

2.1. The model

The model considered here is a mass-spring-damping impact system shown in Fig. 1, where the mass is under a harmonic excitation and the motion is constrained by an endstop. For simplicity, the impact is

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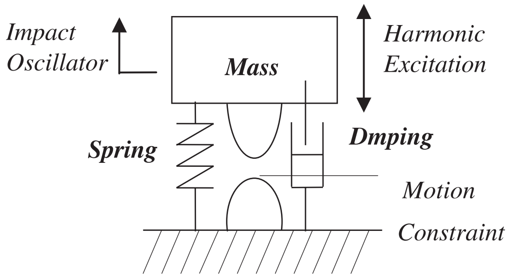

Fig. 1. Mechanical impact oscillator.

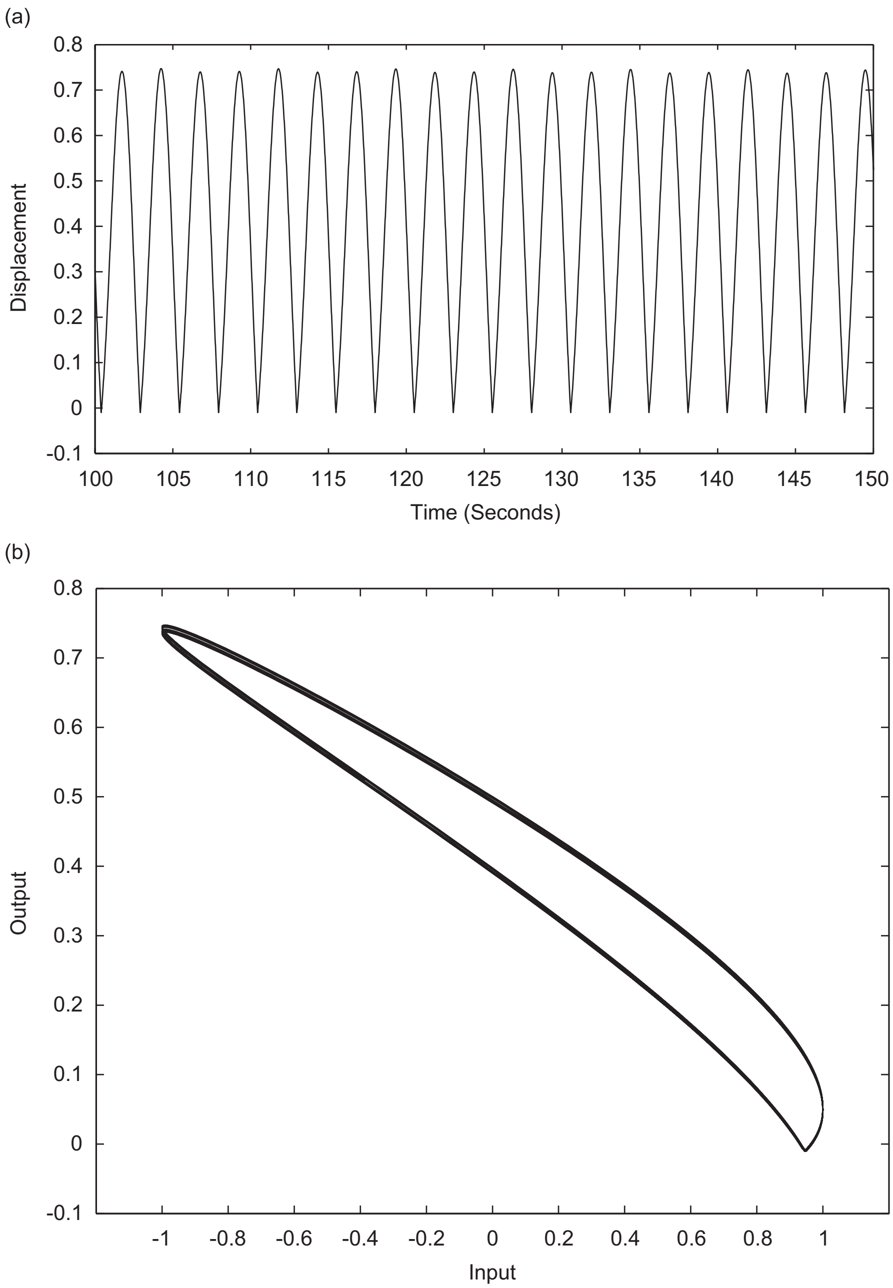

Fig. 2. (a) The mechanical impact oscillator shows period 1 single-impact oscillation at driving frequency $\omega = 2.5$. (b) Phase portrait of input vs. output.

assumed as instantaneous and the impact oscillator is governed by the following equation:

$$m\ddot{x} + 2\zeta\dot{x} + kx = p\cos\omega t \quad \text{for } x > g$$
$$x(t^+) = x(t^-) \text{ and } \dot{x}(t^+) = -r\dot{x}(t^-) \quad \text{for } x \leqslant g, \tag{1}$$

where $\ddot{x}$, $\dot{x}$ and x are the acceleration, the velocity and the displacement and m, ζ, k, p, ω and g are the mass, the damping, the stiffness, the driving amplitude, the driving frequency and the endstop, respectively. (t^+) represents the time after impact, (t^-) represents the time before impact and r is restitution coefficient.

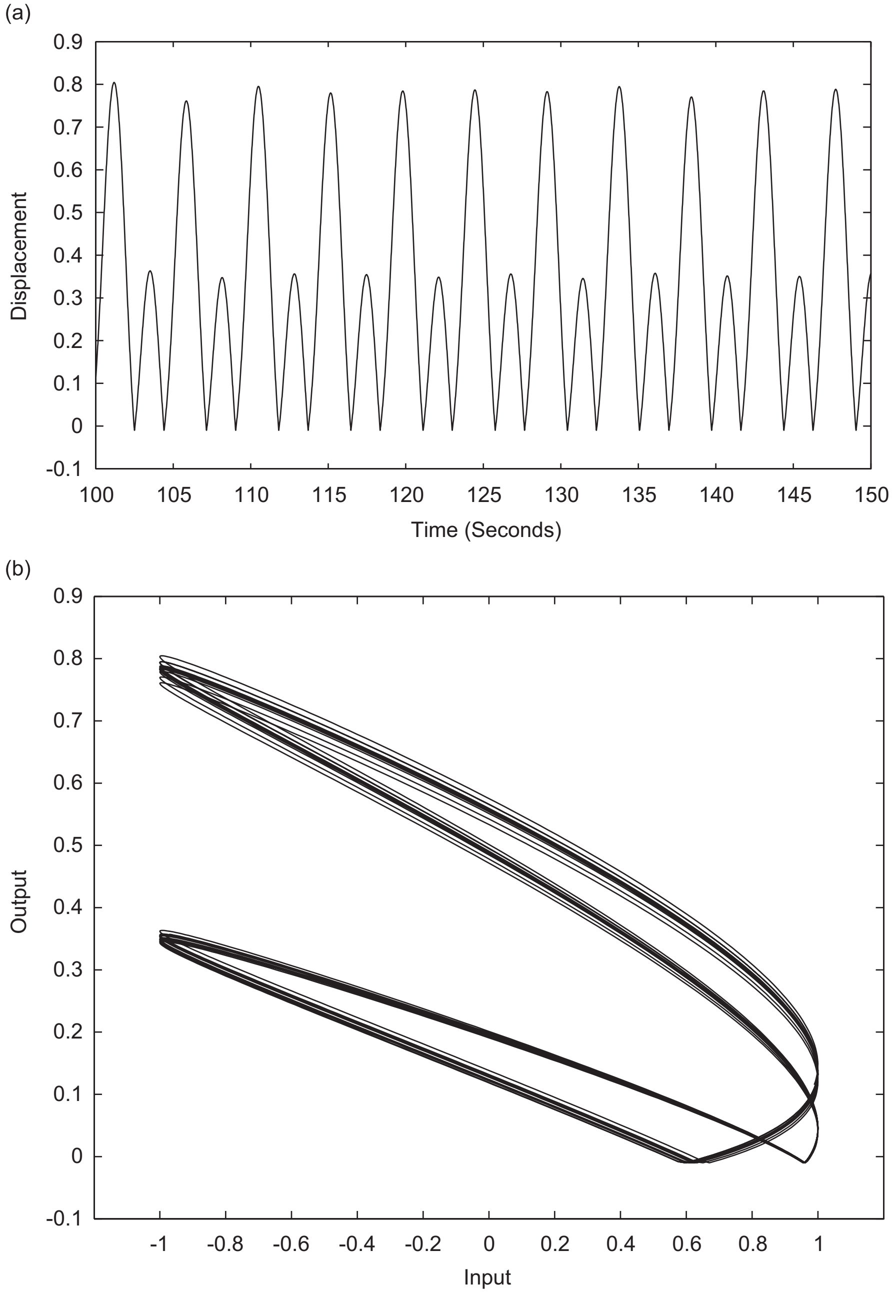

Fig. 3. (a) The mechanical impact oscillator shows period 2 double-impact oscillation at driving frequency $\omega = 2.7$. (b) Phase portrait of input vs. output.

2.2. The results

In this section, the simulation results are integrated by the Runge–Kutta algorithm for Eq. (1). The parameters of Eq. (1) are fixed at $m = 1$, $\zeta = 0.01$, $k = 1$, $p = 1$, $g = 0$ and $r = 0.6$. For different driving frequencies, the simulation results are displayed between 100 and 150 s, ignoring the first 100 s to make sure the system is in the steady state.

The results obtained fixing the harmonic input force but varying the driving frequency from 2.5 to 2.8 are shown in Figs. 2–4. For the input driving frequency $\omega = 2.5$, Fig. 2(a) shows the period 1 single-impact

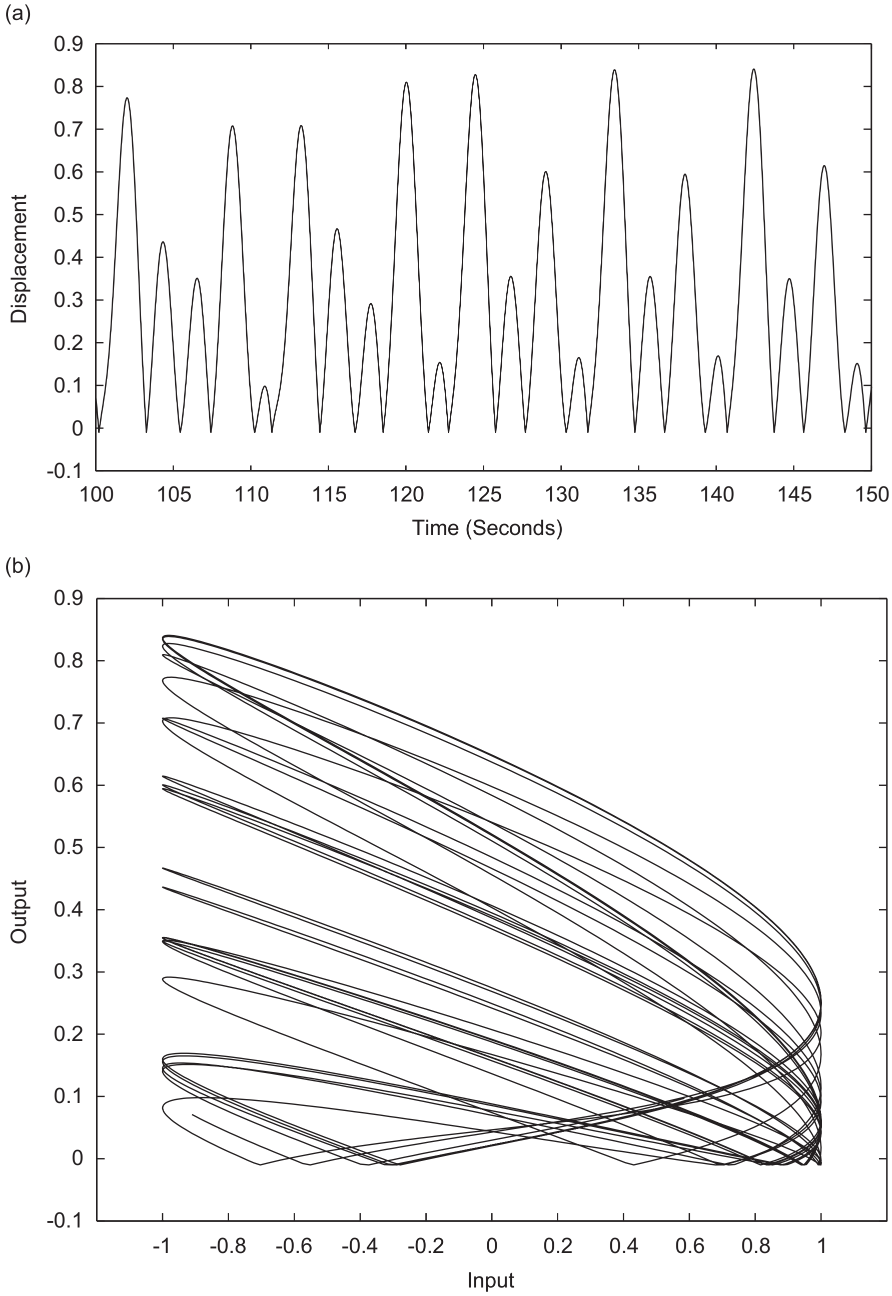

Fig. 4. (a) The mechanical impact oscillator shows non-periodic impact oscillation at driving frequency $\omega = 2.8$. (b) Phase portrait of input vs. output.

oscillation and Fig. 2(b) shows the phase portrait of the input and output oscillations. As the driving frequency increases to $\omega = 2.7$, the impact oscillation transits to period 2 double-impact motion. The bifurcation phenomenon occurs as the results shown in Fig. 3. As the driving frequency ω increases to 2.8, the impact oscillator exhibits non-periodic oscillation. Fig. 4(a) shows a 'random-like' impact motion and Fig. 4(b) shows a complex phase portrait. These results confirm that a periodic input oscillation can generate a periodic or non-periodic impact oscillation in this mechanical impact oscillator.

3. Electronic impact oscillator

3.1. The model

For a motion constraint of impact oscillator in Fig. 1, the impact dynamics show that a harmonic input oscillation can generate a periodic or non-periodic impact motion. This depends on the control parameter of the driving frequency. In this section, the motion constraint of the oscillator is simulated by a feedback diode rectifier circuit as shown in Fig. 5. It consists of a series connection of an ac-voltage source (XFG1), a linear operational amplifier circuit (U3), a nonlinear diode (D1) and two integral circuits (U1 and U2).

In this circuit, the impulse impact force is generated by a short period of the positive voltage in the diode circuit D1. In fact, the impact force is proportional to impact acceleration. Therefore, the velocity and the displacement of impact oscillation can be generated by integral circuits U1 and U2, respectively.

3.2. The results

In the following, commercial electronic circuit simulation software, MultiSim [13], is used. As shown in the schematic circuit in Fig. 5, the electronic impact oscillator circuits are connected by a nonlinear element of

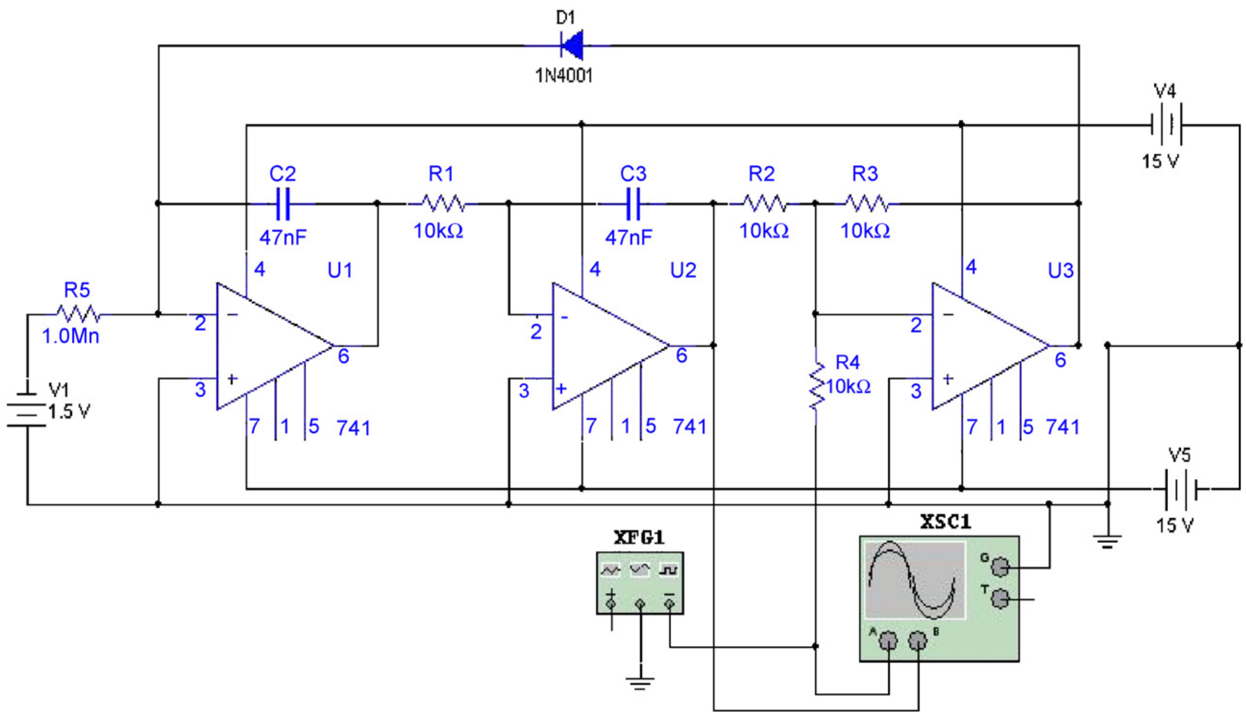

Fig. 5. Electronic impact oscillator.

diode 1N4001 and three linear elements of operational amplifiers $\mu A741$. The input is driven by function generator XFG1 with harmonic sine wave and the output of impact oscillation is illustrated in display XSC1.

The results obtained fixing harmonic input voltage at1.2 V and varying the driving frequency from 50 to 65 Hz are shown in Figs. 6 and 7. For a 50 Hz input driving frequency, Fig. 6(a) shows the period 1 single-impact oscillation and Fig. 6(b) shows the phase portrait of the input and output oscillations. As the driving frequency increases to 60 Hz, the impact oscillation transits to period 2 double-impact motion. The bifurcation phenomenon occurs and the corresponding results are shown in Fig. 7. As the driving frequency increases to

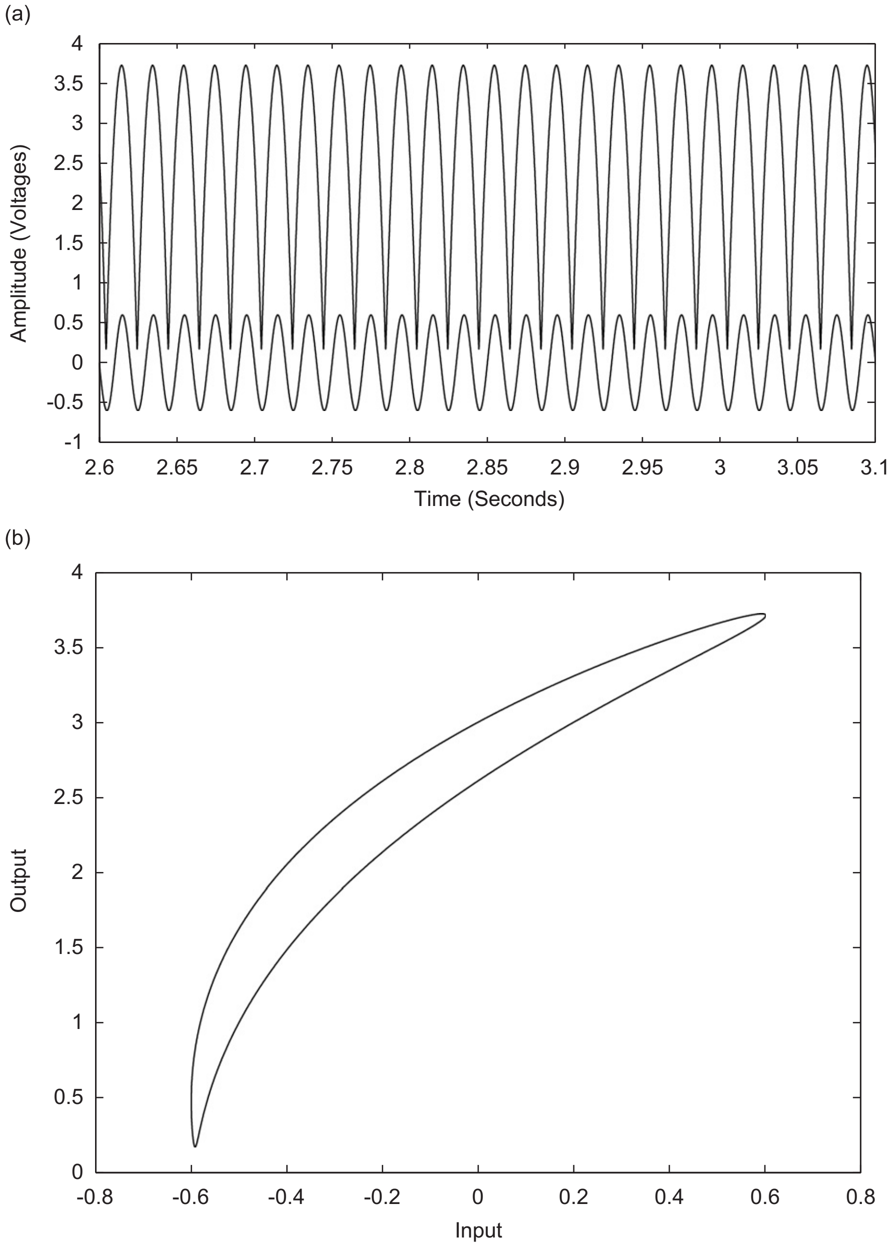

Fig. 6. (a) The electronic impact oscillator shows period 1 single-impact oscillation at driving frequency 50 Hz. (b) Phase portrait of input vs. output.

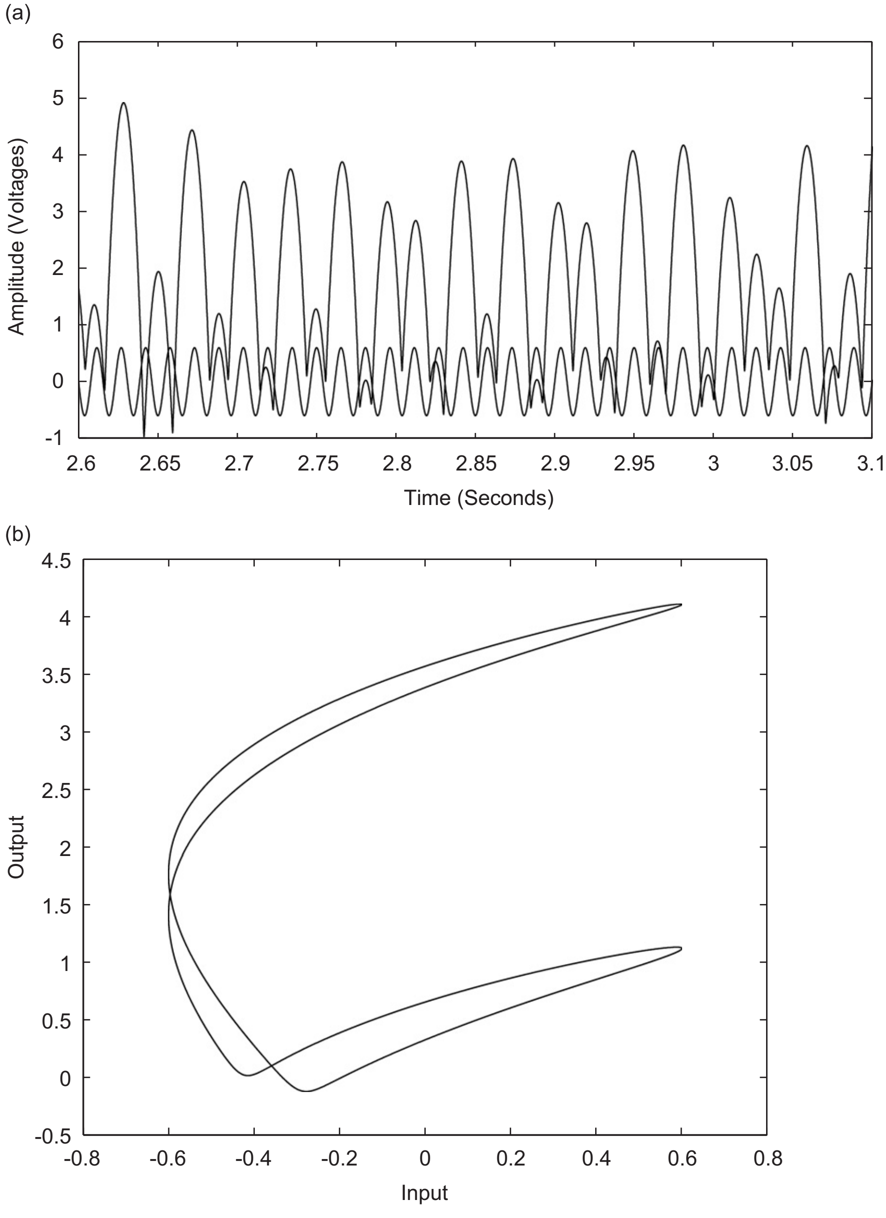

Fig. 7. (a) The electronic impact oscillator shows period 2 double-impact oscillation at driving frequency 60 Hz. (b) Phase portrait of input vs. output.

65 Hz, the impact oscillator exhibits non-periodic impact oscillation. Fig. 8(a) shows a 'random-like' impact motion and Fig. 8(b) shows a complex phase portrait. These results confirm that a periodic input oscillation can generate a periodic or non-periodic impact oscillation in this circuit. These results are also in agreement with the previous investigation of a mechanical impact oscillator.

4. Conclusion

The phenomena of bifurcation are observed both in the mechanical impact oscillator and in the electronic impact oscillator. The impact dynamics showed that a harmonic input oscillation can generate a periodic or

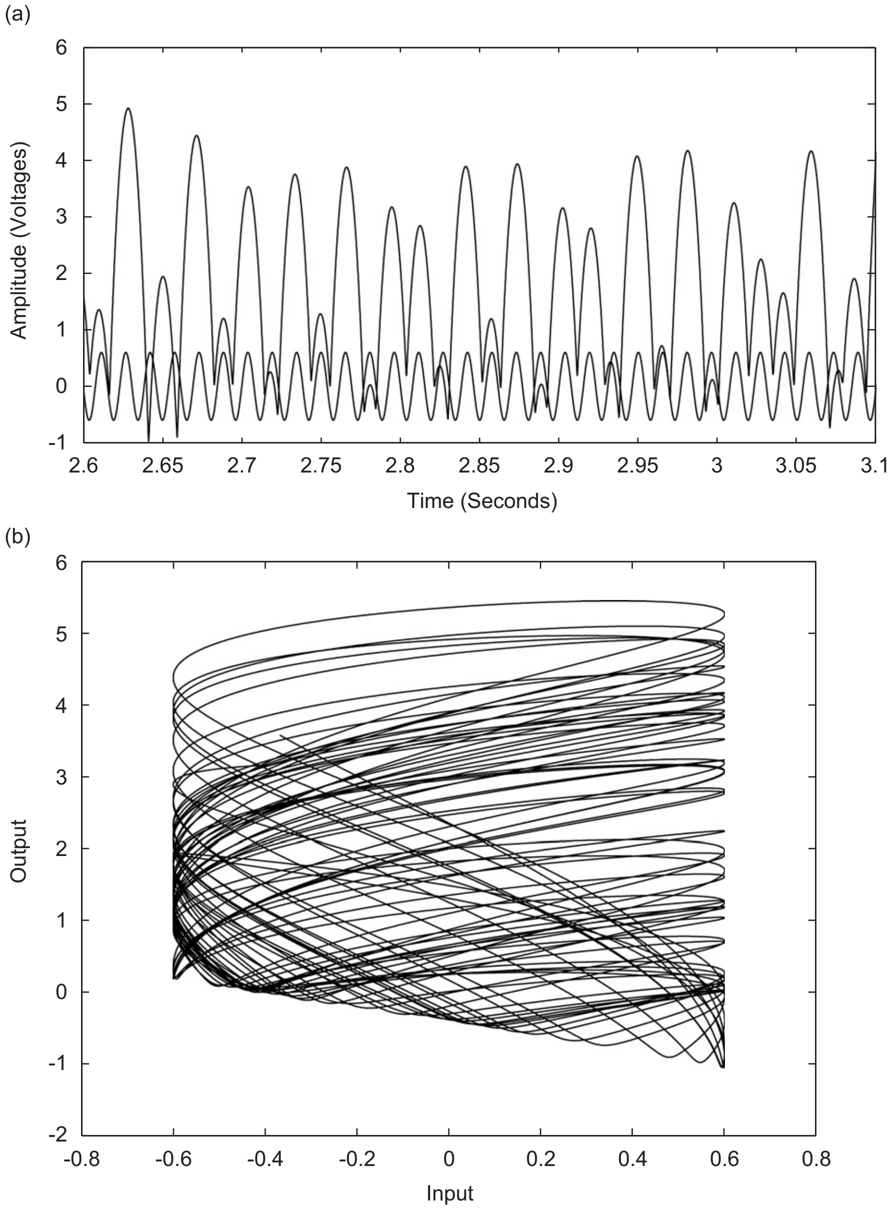

Fig. 8. (a) The mechanical impact oscillator shows non-periodic impact oscillation at driving frequency 65 Hz (b) Phase portrait of input vs. output.

non-periodic impact motion that depends on the control parameter of driving frequency. In terms of implementation, the electronic impact oscillator is much better than the mechanical impact oscillator.

It should be emphasized that the impact oscillator with such good dynamics could benefit the new communication system using chaos. The proposed deterministic impact oscillator can produce periodic and chaotic solutions, which can be used as carriers in analog and digital communication systems.

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References

[1] S.W. Shaw, P.J. Holmes, A periodically forced linear piecewise linear oscillator, *Journal of Sound and Vibration* 90 (1983) 129–155.

[2] C. Budd, F. Dux, A. Cliffe, The effect of frequency and clearance variations on single-degree-of-freedom impact oscillators, *Journal of Sound and Vibration* 184 (1995) 475–502.

[3] F. Peterka, T. Kotera, S. Cipera, Explanation of appearance and characteristics of intermittency chaos of the impact oscillator, *Chaos, Solitons & Fractals* 19 (2004) 1251–1259.

[4] J.Y. Lee, Motion behavior of impact oscillator, *Journal of Marine Science and Technology* 13 (2005) 89–96.

[5] J.Y. Lee, A.K. Nandi, Extraction of impacting signals using blind deconvolution, *Journal of Sound and Vibration* 232 (2000) 945–962.

[6] J.Y. Lee, J.J. Yan, Control of impact oscillator, *Chaos, Solitons & Fractal* 28 (2006) 136–142.

[7] G.W. Luo, Y.L. Zhang, J.N. Yu, Dynamical behavior of vibro-impact machinery near a point of codimension two bifurcation, *Journal of Sound and Vibration* 292 (2006) 242–278.

[8] G.W. Luo, Y.D. Chu, Y.L. Zhang, J.G. Zhang, Double Neimark–Sacker bifurcation and tours bifurcation of a class of vibratory systems with symmetrical rigid stops, *Journal of Sound and Vibration* 298 (2006) 154–179.

[9] A. Azzouz, R. Duhr, M. Hasler, Transition to chaos in a simple nonlinear circuit driven by a sinusoidal voltage source, *IEEE Transactions on Circuits and Systems* 30 (12) (1983) 913–914.

[10] A. Azzouz, R. Duhr, M. Hasler, Bifurcation diagram for a piecewise linear circuit, *IEEE Transactions on Circuits and Systems* 31 (6) (1984) 587–588.

[11] R.L. Zimmerman, S. Celaschi, L.G. Neto, The electronic bouncing ball, *American Journal of Physics* 60 (4) (1992) 370–375.

[12] B.K. Clark, R.F. Martin, R.J. Moore, K.E. Jesse, Fractal dimension of the strange attractor of the bouncing ball circuit, *American Journal of Physics* 63 (2) (1995) 157–163.

[13] Multisim User Guide: Simulation and Capture, Electronic Workbench, 2004.