

An Improving Model on Contact Time of The Inertial Impact Switch

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Abstract. Inertial impact switch is a widely used inertial force recognition element in electromechanical trigger fuze of missiles, rockets and artillery shells. In this paper, the impact responses of inertial switch are investigated with abundant acceleration loads through the dynamics analysis. Based on the Machete hammer experiment, the accuracy of the dynamics model is verified with a very small error. The systematic dynamic analysis shows that the contact time of impact proceeding keeps continuously increasing with greater pulse width and acceleration load. On the other hand, the threshold of switch decreases alone with the pulse time. To improve the performance index of the inertial impact switch, a spherical structure model is proposed. Surprisingly, a significant improvement of the contact time is discovered comparing with the cylindrical structural model. The proposed new structure will provide important technical reference for the practical application of devices in fuze technology field.

Keywords: Inertial switch; Contact time; Fuze.

1. Introduction

The inertial impact switch is widely used as the priming control unit in fuze field. In the electromechanical trigger fuze, the inertia switch is used to control the working state of the first generation explosive element while it is used for the fuse proximity failure and landing backup firing in the shell radio fuze [1-3]. Due to the complex heat treatment process of materials, spring wire diameter, structural design as well as the adverse ballistic environment, most switches failure within the threshold range [4]. It is worth noting that the projectile body will be greatly overloaded in the axial direction during the process of bore out and hitting the target, which will produce a large impact on the inertial switch, resulting in a large displacement of the impact rod to activate pre-trigger or severe damaged of the switch. In order to solve the above problems, researchers have made many attempts on the switch field.

With the development of MEMS, researchers have put forward various MEMS inertial switches with high threshold acceleration in fuze, aerospace and other fields over the last decades [5-7]. On account of the impact acceleration can be up to ten thousand g, Cao et al [8] proposed a single circular mass for universal sensitivity to guarantee the survivability of high-g inertial switch. Yang et al [9] also designed of high-g micro acceleration switch in the form of a cantilever beam with low volume mass and high stiffness springs. In addition to cantilever beams switch, Ma et al [10] investigated the performance index of the mechanical inertial switch with the high loads of axial and radial systematically. In accordance with expectation, the contact issue of the switch including the short contact time and bounce phenomenon is the most vexing problem for researchers.

Short contact time is not conducive to system identification and signal processing, leading to weaken the reliability of the switch [11]. The stable closure time required for normal operation of the single chip microcomputer system is more than 10 μ s. Under the load of pulse acceleration, the phenomenon that switch is closed intermittently several times can lead to electrical wear and collision damage [12]. Therefore, many methods in terms of new structural forms [13-15], flexible materials selection [16,17] and external force control [18,19] have been proposed to enhance the contact time and reduce the contact bounce. Obviously, the abundant papers focus on the performance of MEMS

inertial switch rather than the traditional inertial impact switch. Uniformly, the beneficial attempts in the MEMS field can also be applied equally to the mechanical switch.

Based on dynamics analysis, the inertial impact switch closure responses with a large number of shock acceleration are investigated in this paper. The Machete hammer test is agreeable with the contact time of simulation result. The difference of performance index between the spherical structure and traditional switch is discovered with the same shock acceleration. A surprising result that the contact time has an obvious improvement after the structural change. This result makes the inertial switch has a greater market prospect in the future.

2. Method of Analysis

2.1 Geometric Model

The schematic diagram of inertia switch considered in this work is shown in figure 1a. It is composed of metal shell, impact spring, impact rod, insulating sleeve and conductive sleeve. The shell, the impact spring and the impact rod compose an electrode of the touching switch, and the conductive sleeve forms another pole. Besides, the two poles are separated at ordinary times unless subjected to sufficient inertial forces. There is high-strength fuze shell uniformly distributing outside the inertial switch, so the switch is mainly affected by the inertial force in the exterior trajectory. The axis of the switch installed in fuze is parallel to the axis of bomb. Due to the precompression of impact spring, the impact rod can keep in a balanced position at ordinary times. However, the inertial switch may work in the usual process of handling duties. Once the vibration and impact disappearing, the impact rod will get out of contacting with the conductive sleeve under the preloaded of impact spring. The impact rod can sway forward to overcome the pretightening force of spring as soon as the fuze meets the target in the course of ballistic flight, so as to complete the switch closure. It needs to be emphasized that the short contact time and bounce phenomenon occurred frequently in our previous work. Therefore, a spherical structure between the impact rod and conductive sleeve is examined to improve the switch performance index as shown in figure 1b.

2.2 Dynamics Analysis

The physical model of the inertial switch is a typical mass-spring-damper mechanical system as illustrated in figure 2a. Under the axial acceleration a , the impact rod of mass m is crashed into the conductive substrate as shown in figure 2b. The resulting contact force and displacement are denoted by P and x , respectively. We assume that the impact process follows a rigid body kinematics theory except for the spring. In consequence, the dynamic balance equation of the switch can be expressed as,

$$m\ddot{x} + c\dot{x} + kx = ma \quad (1)$$

where c is the damping coefficient, k is the stiffness coefficient of the suspension spring.

The impact process is simulated using the Automatic Dynamic Analysis of Mechanical Systems on a workstation. It is convenient to understand the dynamic characteristics of designed inertial switch and evaluate the threshold acceleration, contact time, anti-lateral overload ability and other important parameters. The insulating mat is fixedly connected with the insulating sleeve and the conductive sleeve while the metal shell have no displacement to the ground. The material properties of each component are given in terms of the actual situation. In addition, the “Impact” contact force algorithm is adopt between the impact rod and conductive sleeve to improve the accuracy of simulation. And the contact force P is given by a function of these parameters,

$$P = K\delta^e + C\dot{\delta} \quad (2)$$

where K is the contact stiffness coefficient, δ is the contact penetration depth, e is the rigidity index, C is the contact damping coefficient and $\dot{\delta}$ is the relative velocity of the collider. The contact

parameters can be obtained from the empirical data and material testing. Note that the friction of the movement process is ignored compared with the inertia force.

3. Model Verification

In order to make sure the exactitude of dynamics model, a confirmatory experiment is taken, which presents schematic in figure 3. The experimental apparatus mainly includes three parts: the control circuit, a loading system and an oscilloscope. The acceleration sensor and inertial impact switch are bundled together and installed in the hammer machine. The control circuit is applied to signal acquisition and data processing. Besides, the signal of sensor acceleration and contact time can be displayed on the screen of oscilloscope.

At first, it is need to check device and ensure circuit running well. Next, the oscillating arm of Machete hammer is need to be fastened with a high degree. Once the preparatory work has been completed, the impact pendulnm strikes anvil with a high acceleration under the gravity of the balancing weight. The result can be obtained from the oscilloscope as shown in figure 4, which displays that the contact time of the switch is $56\mu\text{s}$ with the blue curve when the maximal acceleration shock is 8160g with the yellow curve. It is need to declare that the voltage value of 1V is equal to 1000g in our experiment.

The dynamics simulation is also carried out to investigate the impact process of the inertial switch on the workstation. In general, the acceleration applied to the switch is a half-sine wave curve in practical situation [20,21]. To contrast the simulation model, the amplitude of the load in the dynamics model is consistent with the maximum value of experiment. The duration of contact force is a measurable criteria to obtain the contact time. As illustrated in figure 5, the contact time is $51\mu\text{s}$ according to the dynamics model with a pulse loading, which approaches to the real scene of the experiment. Therefore, a series of dynamics analysis is researched to explore the switch characteristics in our work.

4. Result and Discussion

The impact responds of inertia switch are investigated under the half-sinusoidal acceleration load with a pulse width of one millisecond firstly. Figure 6 displays the variation of impact rod displacement with respect to the pulse time. On account of the precompression of the impact spring, the impact rod remained stationary in the beginning. With the increase of external load, it is continuously accelerated to strike the conductive sleeve, which will contact to the electrode for dozens of microsecond. Especially to deserve to be mentioned, the contact time is of great importance to the circuit design. It is found that the contact time lagging far behind the time of initial acceleration load point. And the response time is defined as the interval between them, which is also a technical index to evaluate the performance of inertial switch. In the final stage, the impact rod separates from the electrode at a reverse velocity with the disappearing of the shock acceleration.

To assess the mechanical properties of spherical structure switch, the comparison of impact response between the two kinds structure switches is investigated. Figure 7 shows the contact force of the cylindrical and spherical structure switches varies in the impact process with a maximum 500g shock acceleration, and take pulse width 1ms in both cases. It is seen that the key performance index of response time and contact time has obvious difference. Though the response time of the spherical structure switch is slower than the cylindrical one, it possesses a longer pulse closure time. It is a beneficial phenomenon for the inertial impact switch design with longstanding contact time. Notably, the shock response process can be essentially affected by the structure type.

Based on the above analysis, a detailed research scope that we present the numerical results in terms of two variational acceleration parameters applying to the switches. The instability of the contact time is mainly fasten on the magnitude of shock acceleration slightly larger than the closing threshold in the working condition. Therefore, the reasonable shock acceleration amplitude is adopt

in the dynamics analysis. In addition, the value of pulse width varies from 0.6ms to 2ms, which covers most practical engineering. The calculation results of different inertial switch suffered from a variety of acceleration load are shown in figure 8. It is found that the threshold keeps continuously improving with the reducing of the pulse time, while the contact time continues to increase along with the acceleration load. An obvious fact that the closure persistent period of the spherical structure inertial switch has an improvement of 27% by comparison. This will greatly contribute to the performance improvement of the device in future military applications.

5. Conclusion

The impact response of inertial switch with various varying shock acceleration is studied detailedly in this work. The Machete hammer is taken to confirm that the contact time in test is similar to the dynamics model. To improve the performance index of the inertial switch, a spherical structure is proposed, which has a different impact response under the acceleration load. An unexpected discovery that the contact time has an obvious improvement in the same maneuver by plenties of dynamics simulations. Our results provide a potential application value to the fuze field.

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Figureure captions:

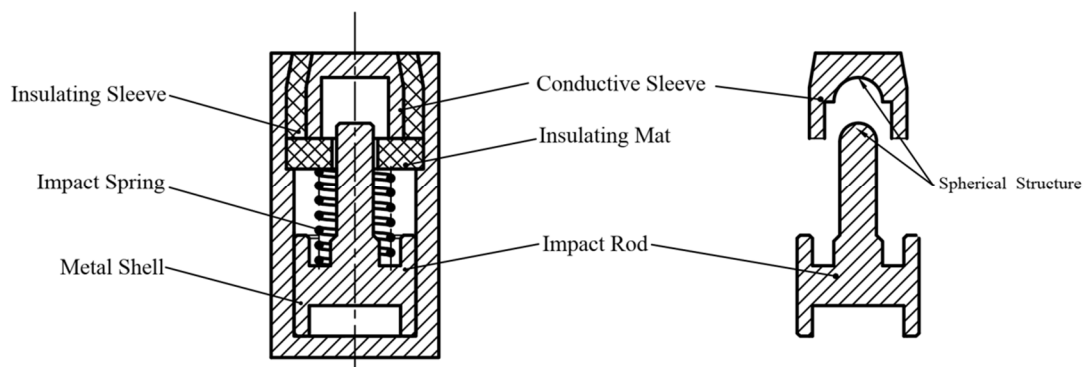


Figure 1. The schematics of (a) inertia impact switch model and (b) spherical structure model.

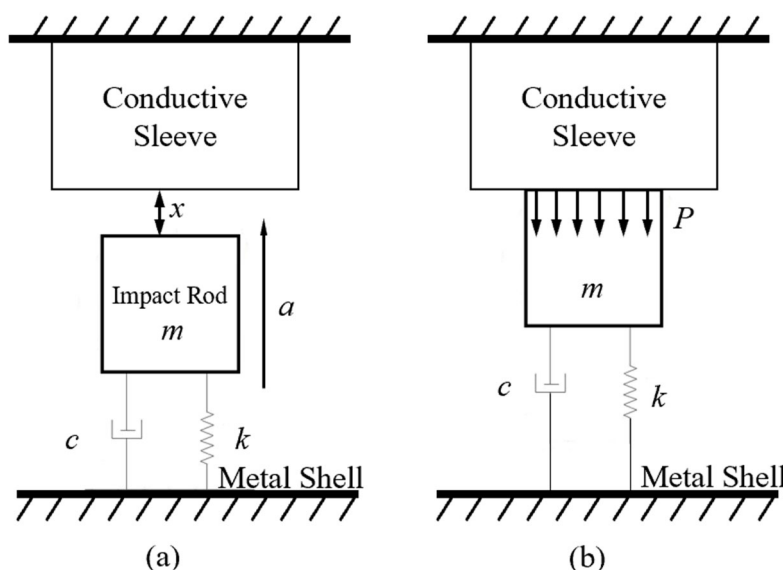


Figure 2. Mass-spring-damper mechanical model of the inertial switch.

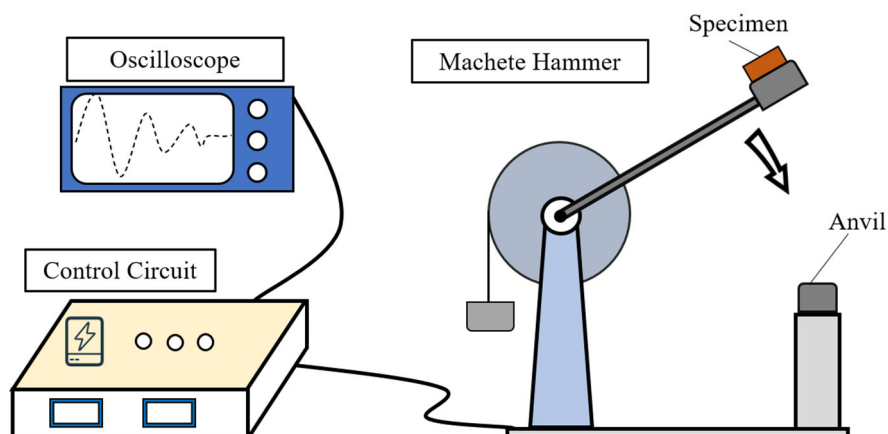


Figure 3. Scheme of the Machete hammer test system to measure load and contact time.

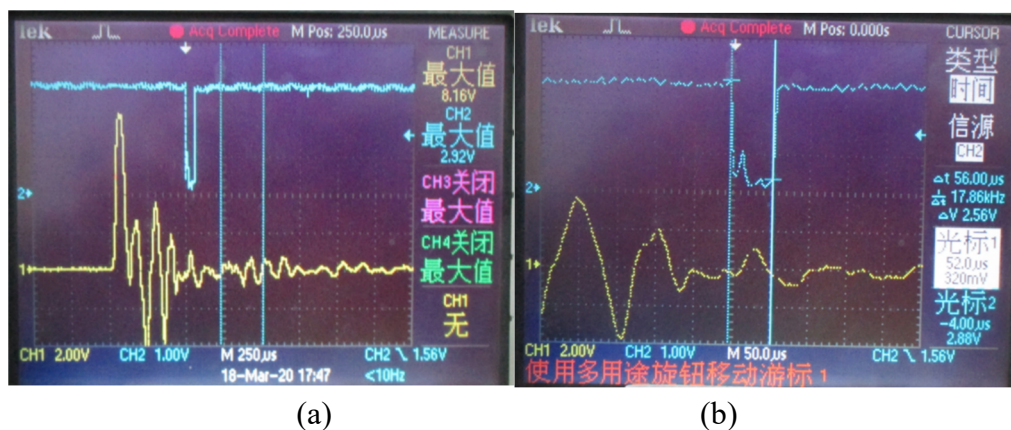


Figure 4. Test results of (a) acceleration curve and (b) contact time.

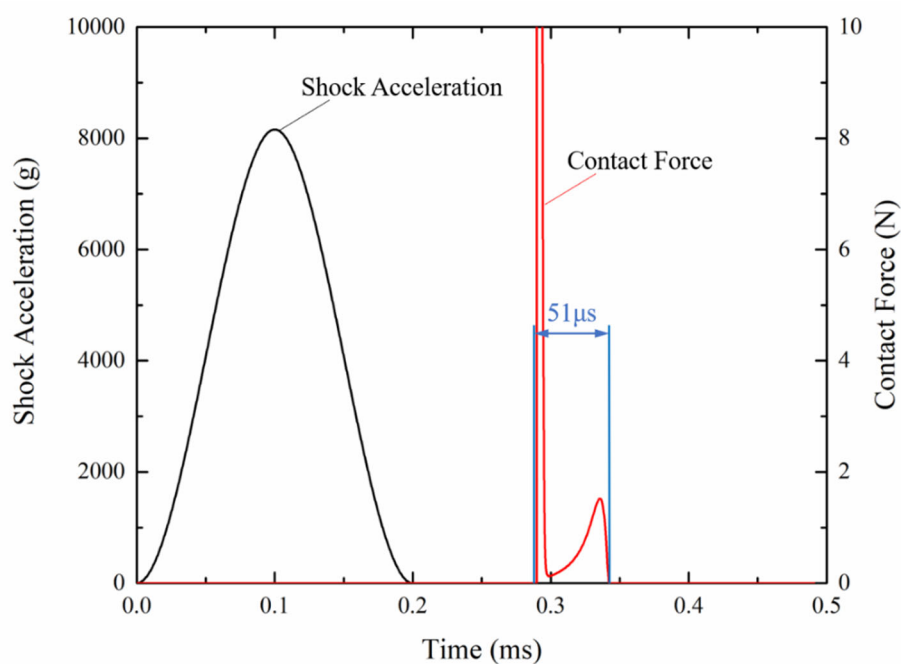


Figure 5. Dynamics result of contact time with shock acceleration of the experiment.

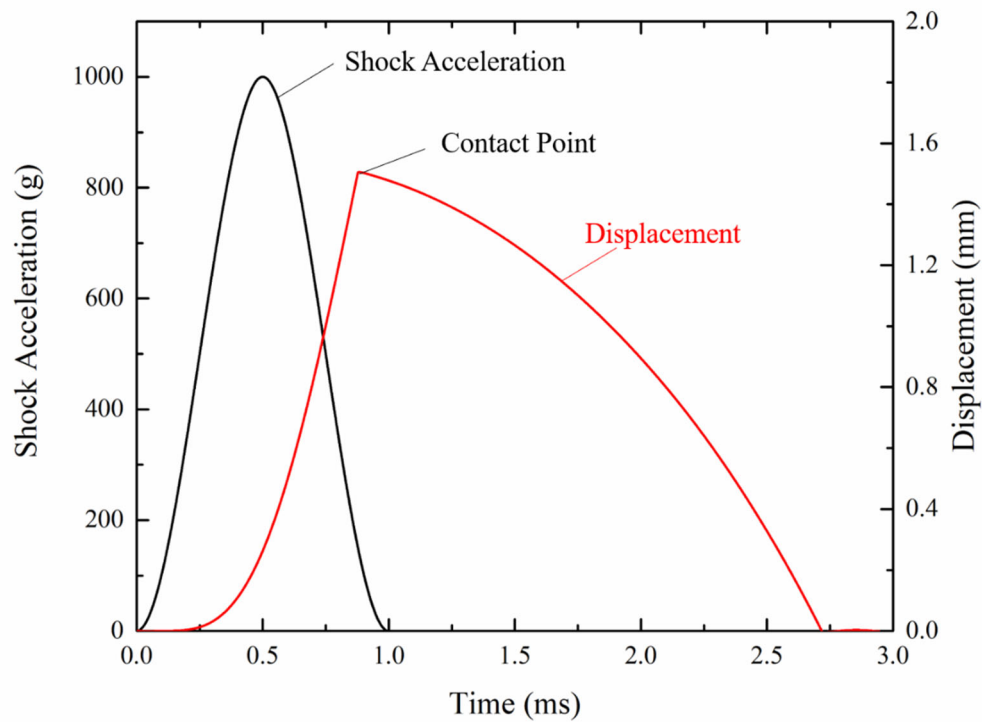


Figure 6. The displacement of impact rod in the switch closing process.

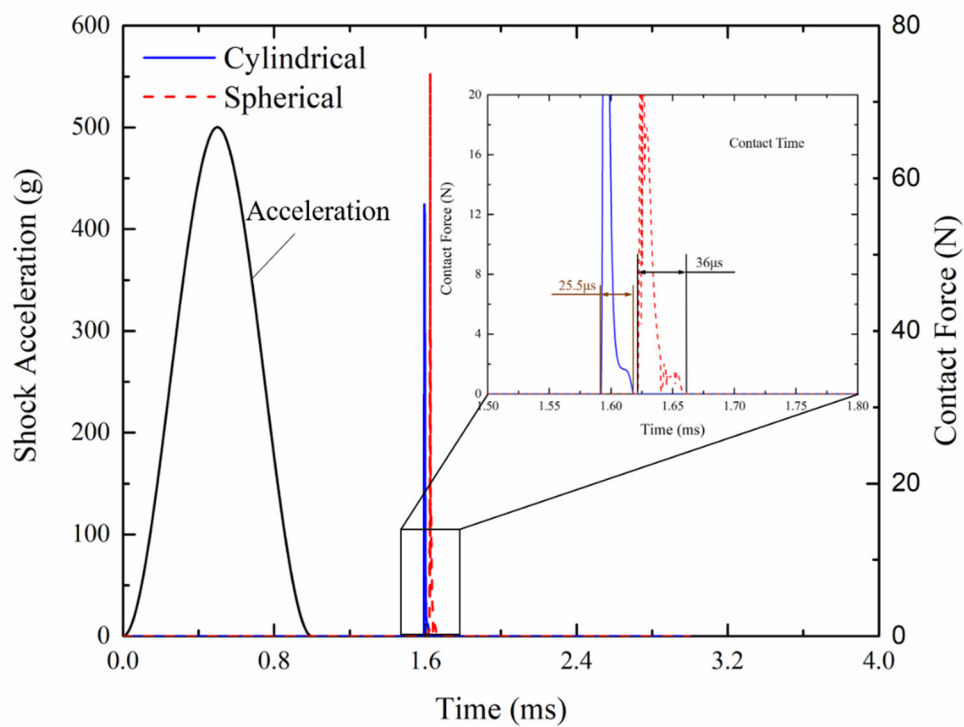


Figure 7. Comparison of the impact response between spherical and cylindrical structure inertial switch.

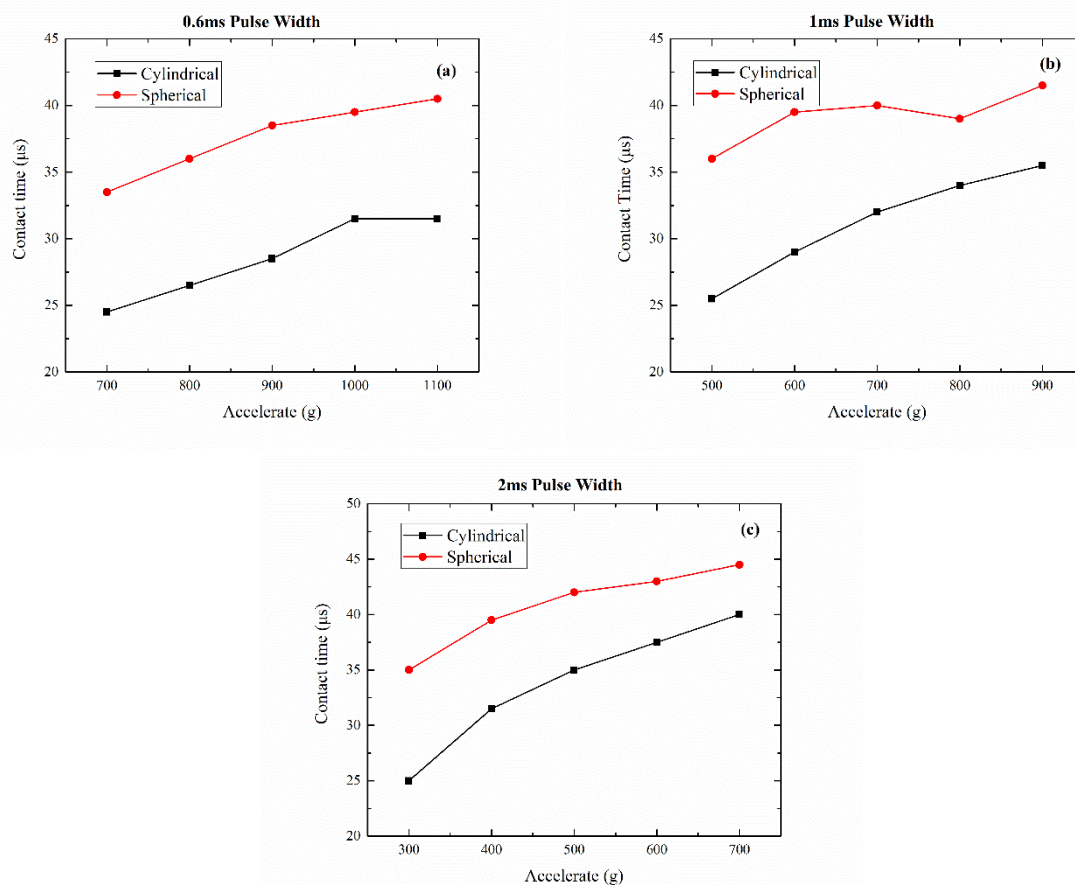


Figure 8. Contact time versus the shock acceleration with (a)0.6ms (b)1ms (c)2ms pulse width

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