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PRESSURE WAVES INFLUENCE ON PERFORMANCE OF A PYROTECHNICALLY DRIVEN DEVICE

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Abstract

This paper contains an experimental investigation of a movable wall with variable shape response to a shock wave. Here, the shock wave was generated by a pyrotechnic gas generator used in the automotive industry. The test station consists on a pyrotechnic actuator in which the movable wall is expressed as a piston. This pyrotechnic actuator was specially design for such type of an investigation. Its design allows withstanding numerous tests without affecting the accuracy. What was under investigation here was the actuators piston stroke velocity and which, as it appeared, changes with respect to the various shape of the actuators interior as well as a corresponding to the barrier velocity total pressure existing within the expansion chamber of the actuator. The results shown here correspond to the flat surface as well as conical and concave cylinder bottom of the actuator. The conical and flat piston surface is considered as a reference for subsequent investigation because such a design is the most similar to the existing pyrotechnically driven designs. The experimental research proves that the performance of pyrotechnically driven devices is dependent upon the shock wave shaping

Keywords: *pyrotechnically driven devices, shock waves, pyrotechnic gas generator*

1. Introduction

A shock wave propagation pattern was investigated by vast number of researchers. This led to in depth understanding of this phenomenon. However, little is known about shock wave influence on movable wall such as for example a piston in pyrotechnic actuators. Shock waves are commonly tested in shock tube. This however, requires implementing simplifications, which affect fully accurate correlation with pyrotechnic actuators.

Literature based knowledge suggests that it is possible to alter the performance of a pyrotechnic actuator by appropriate shaping of its interior [1-8] but such a relationship was not yet fully tested. Latest achievements in numerical computation methods allow performing investigation revealing such a dependences. This work constitutes an approach to identify the dependence of a shock wave propagation pattern on the movable wall (in this case a piston) motion characteristics.

2. The test station

The pyrotechnic actuator (see Fig. 1) used for the tests was design to enable easy interference to the shape of the expansion chamber. This was done by installation of replaceable cylinder bottom and piston insert. The studies presented here assume utilisation of conical and concave cylinder bottom and flat piston surface. In addition, the pyrotechnic actuator was equipped in three seats for pressure sensor; however, this paper considers only one location of the pressure sensor – above the pyrotechnic gas generator. Remaining sittings were plugged and sealed with a screw.

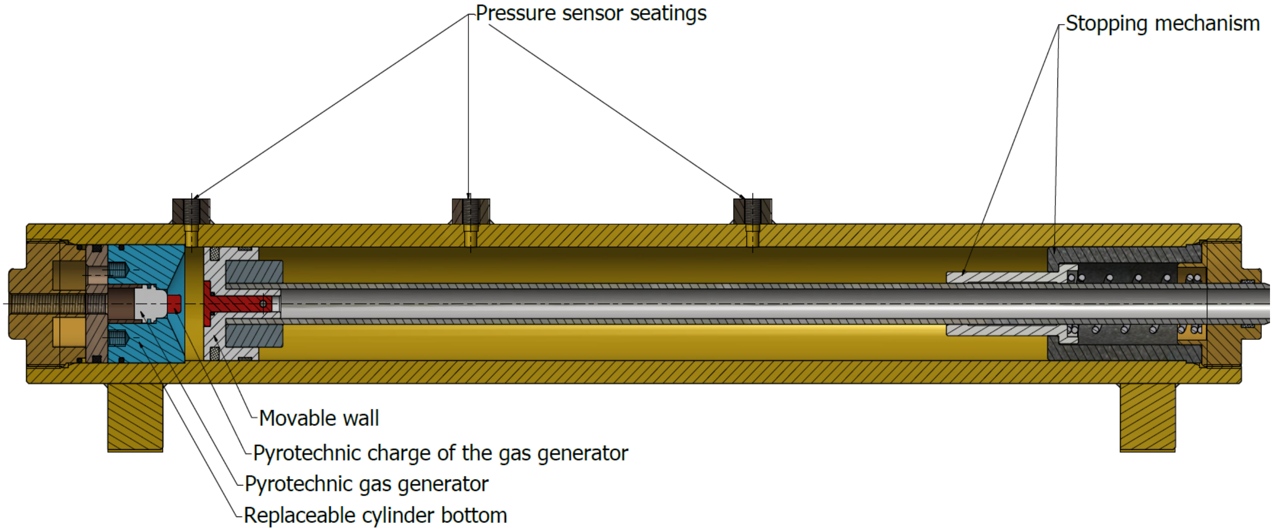

Fig. 1. Schematic representation of the test station

The primary (reference) tests were performed with cylinder bottom of conical faces (shown in Fig. 2a). Than the test was repeated with concave wall of cylinder bottom as depicted in Fig. 2b. The pyrotechnic gas generator was installed inside the cylinder bottom in the way ensuring that the completely pyrotechnic charge (indicated in red colour in Fig. 2) will be fully exposed within the expansion chamber. The construction elements of the pyrotechnic gas generator (i.e. wiring and housing – silver colour in Fig. 2) were fixed within the cylinder bottom to provide uniform location of the charge during numerous repetition of the tests. Furthermore, such installation of the pyrotechnic gas generator seals the holes for wiring the pyrotechnic gas generator. The internally screwed openings inside the cylinder bottoms are design only in order to facilitate installation and uninstallation of the element. It does not affect the investigated process.

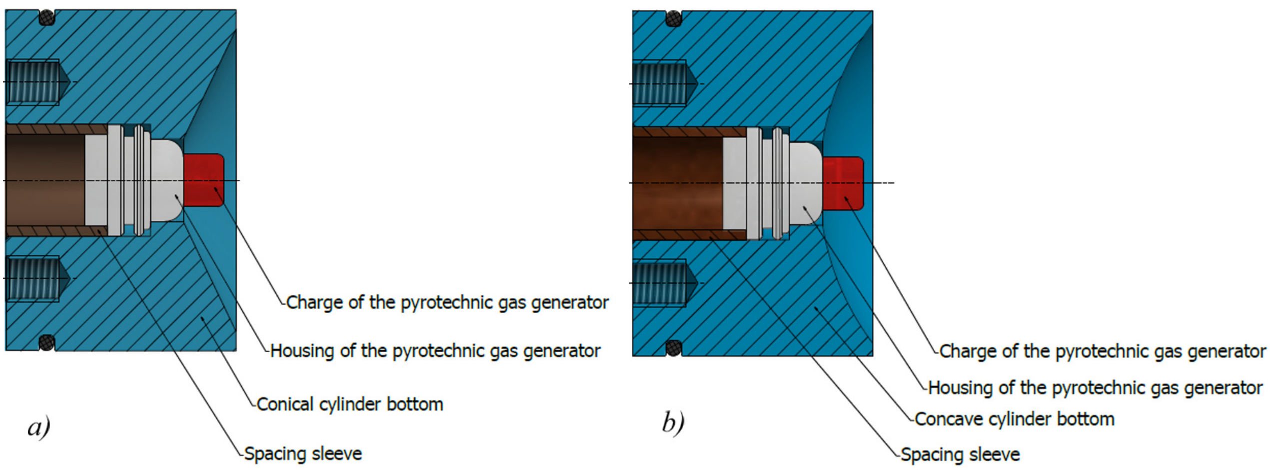

Fig. 2. Replaceable cylinder bottom: a) conical surface, b) concave surface

Movable wall in this paper is understood as a piston equipped with insert piston rod and balancing slug. Such movable wall is depicted in Fig. 3. The insert is installed inside the piston. This piston is in turn connected to the piston rod. All this is fixed together with a pin, which is designated to be a weakest link. In case of forces great, enough to damage the test station the pin is cut off releasing the piston rod from the piston. This significantly reduces the weight, and thus the momentum of moving wall affecting the actuators cap. In order to reduce friction during the stroke the piston is equipped in two Teflon sliding rings. The piston construction remains unchanged throughout these studies. However, for the purpose of subsequent experiments not described here the piston has the ability of introducing inserts with different shapes. The difference of insert shape is related to its different mass. In order to ensure reliable repeatable tests it was crucial to ensure constant mass of the movable wall. For this purpose, the balancing slug was installed on the piston.

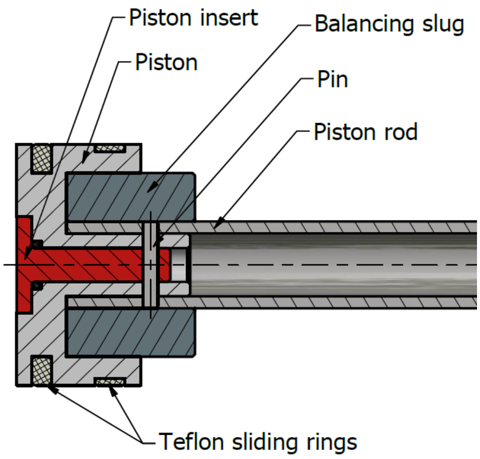

Fig. 3. Movable wall used for the tests

Performance of the pyrotechnic actuator was recorded with Phantom V12 high-speed camera. The records were farther elaborated in TEMA Automotive software, which enables to evaluate piston velocity and acceleration. The screen from the software is shown in Fig. 4. Here the unmovable coordinate system was located on the piston rod at its initial location. Point 1 was set to be movable and the software traced its position within a given period. In consequence, it was possible to evaluate piston velocity and acceleration. Points 2 and 3 were implemented in order to rescale the view from pixel into SI units (in this case – meters)

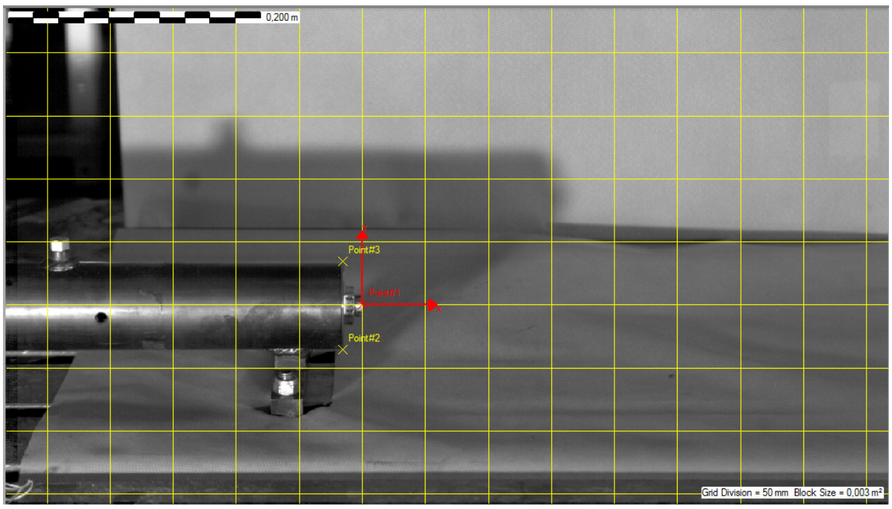

Fig. 4. Experimental data elaboration in TEMA Automotive software

3. Results and discussion

The negative pressure on chards obtained experimentally is a consequence of the actuators design. The first pressure pic was recorded after the ignition of the pyrotechnic gas generator because the sensor was located above it. During the design of actuator, an emphasis was given to the appropriate sealing. Therefore, during piston movement, the volume was increased but the amount of air was kept constant because the actuator could not aspirate the air from surrounding. Upon this sudden volume change, the pressure must have decrease beyond the initial, atmospheric pressure. Noise visible in all figures between 20-25 ms is a consequence of piston passing the ventilation holes. Different velocity of the shock wave caused by various shapes of the piston inserts ware proved by the dynamic pressure readings. The difference in shock waves dynamic pressure, and consequently the wave velocity is the reason of different piston velocity. It should be mentioned here that for all test described in this paper sampling time of the pressure was the same, adjusted in the level preventing aliasing the signal. In consequence, the behaviour of the shock waves responsible for piston motion can be evaluated and compared.

The expedited assumed execution of three-test repetition. The results of maximal pressure and velocity for both piston embodiments considered here is shown in Tab. 1.

Tab. 1. Comparison of the results of maximal velocity and pressure

Test repetition	Cylinder bottom – conical Piston surface – flat		Cylinder bottom – concave Piston surface – flat	
	V [m/s]	P_{max} [bar]	V [m/s]	P_{max} [bar]
1	22.46	103.59	25.28	154.57
2	22.64	108.16	25.78	152.06
3	21.37	110.34	24.95	147.86
Average	22.16	107.36	25.34	151.50

Taking into consideration the pressure measured during the test of the reference embodiment of the actuators chamber (conical cylinder bottom and flat piston surface) it appears that the pressure peak is approximately 107 bars (see Fig. 5), which corresponds to the pistons average velocity of 22.16 m/s. Here, three repetition of the tests are considered. The left column of Fig. 5 shows the total test duration and the right column indicates only the beginning of the process (i.e. 0.45 ms) which corresponds to the initial shock waves formation and reflections. It appeared that at this embodiment of the test station a large number of shock waves reflection could be expected. Furthermore, the amplitude of first and third repetition indicates increasing pressure of subsequent shock waves, while second repetition of the test shows sudden increase of the pressure to its maximal level. It is not clear why such a deviations arose in this test but this wave formation caused the fastest among the other repetition piston velocity. Furthermore, it appears that the shock waves of third repetition were dumped earlier comparing with the other test, which caused the lowest velocity (21.37 m/s). That entire phenomenon clearly indicates the relation between the shock wave formation and the velocity and acceleration of the piston.

Considering replaced cylinder bottom to the concave shape (as indicated in Fig. 2b) it appeared that there was a significant difference in maximal pressure obtained, and in consequence the value of maximal velocity. The pressure diagrams for the concave cylinder bottom and the flat piston surface are shown in Fig. 5. As it can be seen, the average maximal pressure measured here was approximately 150 bar. However, there is a significant difference in a shock wave formation. It appeared that it the case the amplitude and the frequency of the signal is different comparing to the one obtained in a reference actuators embodiment. Repetitions two and three of the test suggests wave interference of the incident and reflected wave with similar frequency. It is because the peak exists only after at least second wave detected by the sensor. Inasmuch the first repetition of the tests suggests greater number of the wave reflection but it was dumped approximately after the same period (i.e. approximately after 5.1 ms). As expected basing on the reference tests the shock wave pattern results in a higher acceleration.

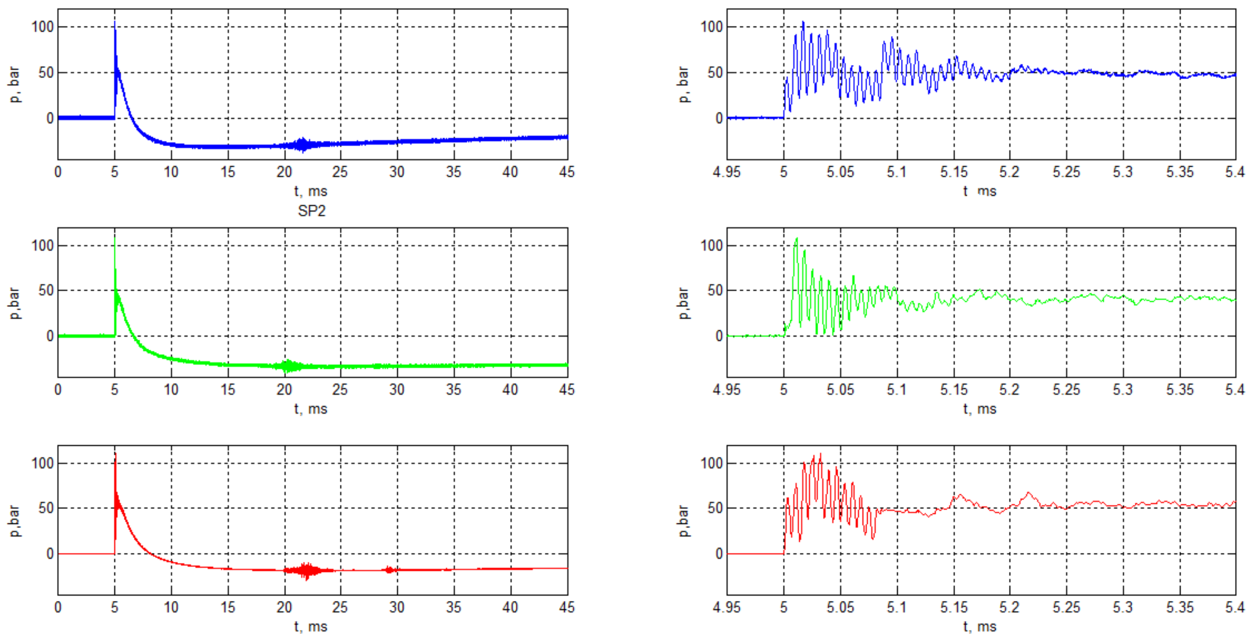

Fig. 5. Dynamic pressure of the experiment with conical cylinder bottom and flat piston surface (reference test)

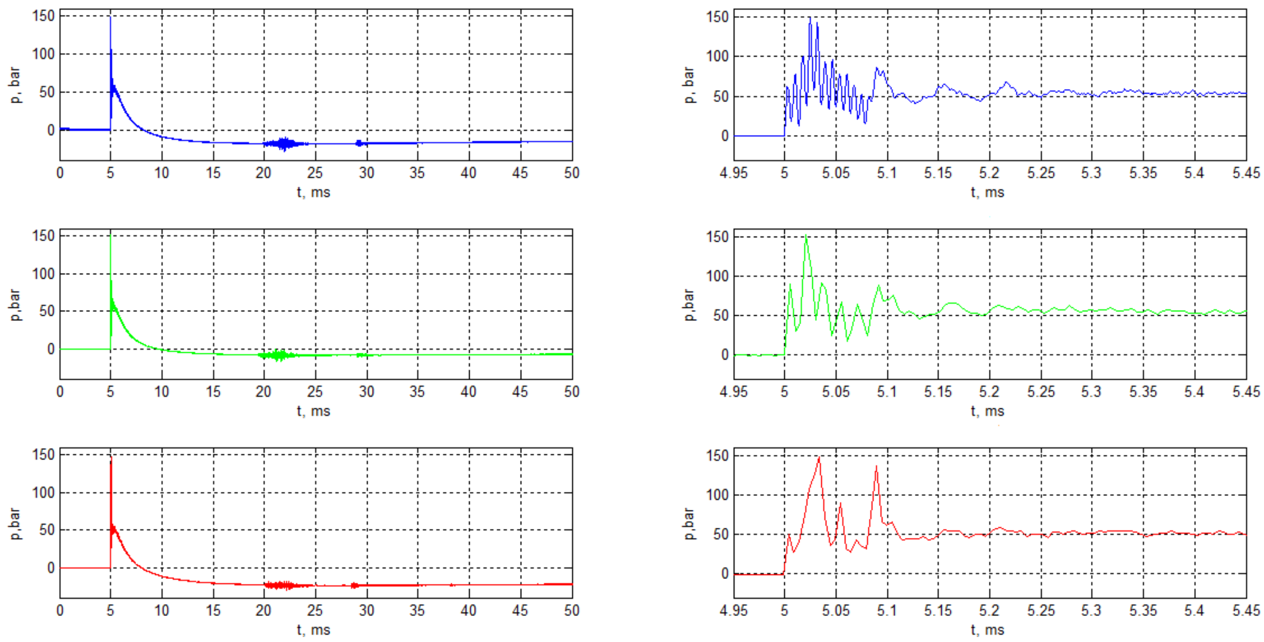

Fig. 6. Dynamic pressure of the experiment with concave cylinder bottom and flat piston surface

It appeared that a large difference of pressures did not result in significant change of piston velocity. The deviation from the reference average velocity of the piston is 3 m/s; however, a large deviation of the piston acceleration occurred. The relation between average velocity and average acceleration is shown in Fig. 7. As it can be seen, the velocity gradient is steeper in the case of a test with concave cylinder bottom, which is further proven by almost twice-greater acceleration of the piston. Taking above into consideration it appears that installation of a concave wall influence mainly acceleration of the piston with relatively little change of piston velocity.

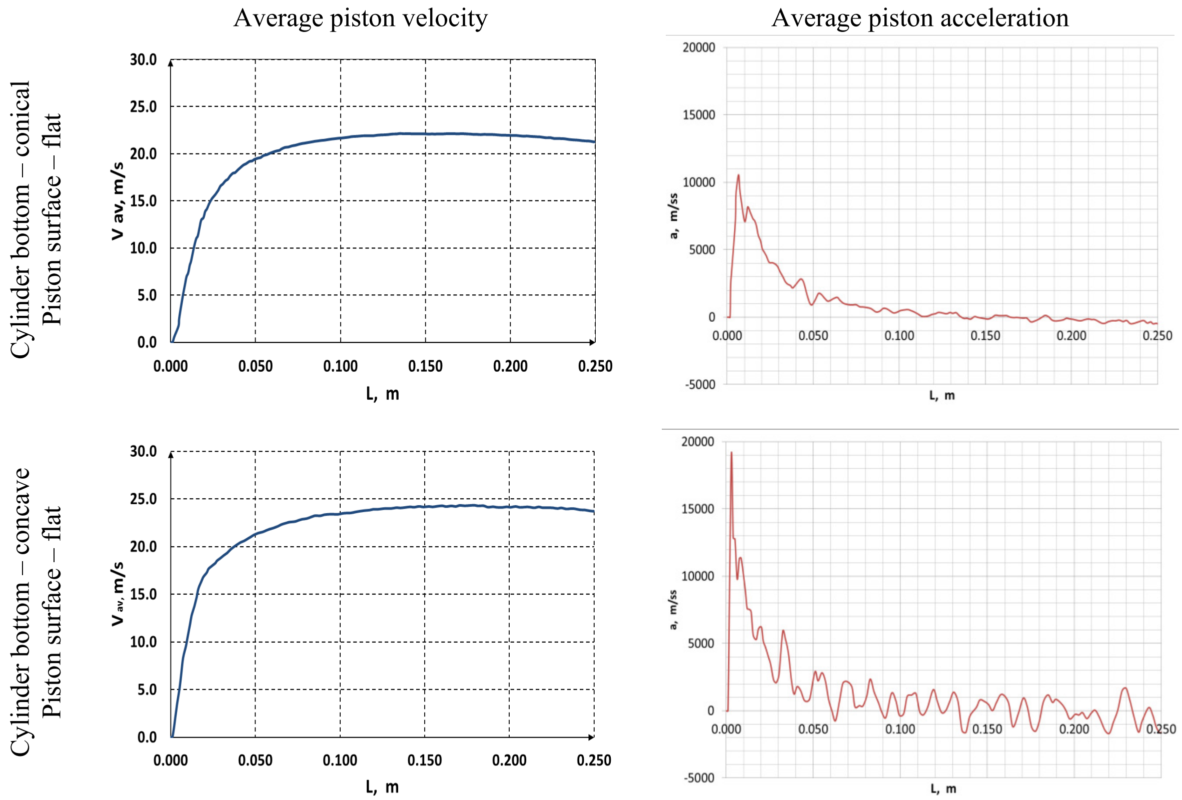

Fig. 7. Comparison of the pistons average velocity and acceleration

4. Conclusion

The goal of the research presented here was verification of the assumption that the performance of a pyrotechnically driven device can be changed by alteration of the expansion chamber, in consequence affecting the shape of the shock waves developed upon explosion of a pyrotechnic charge. Variable pressure waves were detected by the pressure sensor located precisely above the pyrotechnic gas generator. Therefore, it might be concluded that with appropriate shaping of the interior of the pyrotechnically driven devices it is possible to alter the performance of the device.

What was found was that the pressure waves within the device manifests different, corresponding to the shape of the expansion chamber behaviour. Various magnitudes of pressure peaks and amplitude have been detected. This led to alteration of piston velocity. What was even more visible, it almost doubles increase of the piston acceleration. Moreover it appeared that installation of a concave wall influence mainly acceleration of the piston with relatively little change of piston velocity. Therefore, the piston acceleration is dependent mainly on the shock wave propagation pattern.

The results presented here indicate the necessity of the expansion chamber improvement. With aid of an optimisation tool, it is possible to find a shape, which will increase to maximum available velocity of a movable wall using propellant with the same characteristics.

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