# Use of PVDF Pressure Gauges for Blunt Impacts

Laviniu HALLER, Marius CÎRMACI-MATEI, Ioan VEDINAȘ,
Răzvan MIRCIOAGĂ, and Călin CUREA

***Abstract*—The current paper presents a possible method for the use of PVDF gauges in assessing blunt ballistic impacts. The tissue crush mechanism specific to blunt ballistic impacts, together with the overpressure waves induced in the body, raise the awareness regarding the trauma severity that may be induced by this kind of impacts. One of the experimental solutions for measuring the generated pressure may be represented the PVDF gauges, which can be fitted on various surfaces in order to quantify the pressure upon.**

***Index Terms*—PVDF, sensor, pressure, procedure, impacts.**

## I. Introduction

Blunt impacts have been in discussion in many terminal ballistic studies, due to the effects that they may produce towards the human organism. The tissue crush mechanism, together with the overpressure waves induced in the body, raise the awareness regarding the trauma severity that may be induced by this kind of impacts. One of the experimental solutions for measuring the generated pressure may be represented the PVDF gauges, which can be fitted on various surfaces in order to quantify the pressure upon.

The goal of this paper is to identify a way to correlate the response of two PVDF sensors mounted on a human torso surrogate with the data obtained from other sensors mounted on the surrogate, in order to evaluate the behavioural proportionality of them.

## II. PVDF Gauges

Development of PVDF (polyvinylidene fluoride) piezofilms commenced with the need of measuring shock waves and overpressure effects towards the human body. These piezofilms have a relatively small thickness $(10 \div 25\ \mu\text{m})$, they fit in a very thin sensor and they do not require an independent energy source. In order to induce the piezoelectric activity, PVDF films may be uniaxially dilated (Dynasen method) or biaxially dilated (Bauer method) before polarization.

The PVDF piezofilms used in this paper are $25\ \mu\text{m}$ thick films obtained by the Bauer method [1, 2]. For this method, it has been seen that the proportionality of their mechanical response, up to an applied pressure of 200 MPa, is given by the relation:

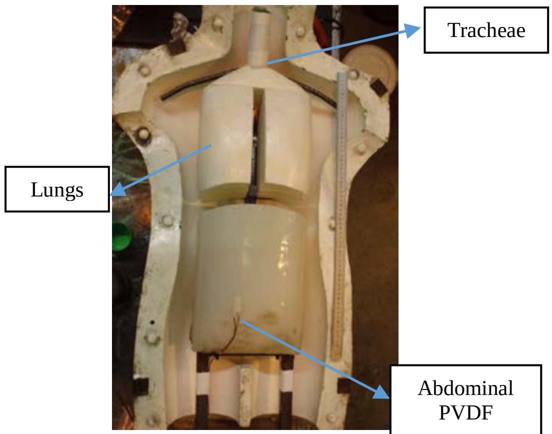
$$Q = a \cdot \sigma^{b}, \tag{1}$$

where $Q$ represents the electric charge density (expressed in $\text{pC}/\text{cm}^2$), $\sigma$ represents the normal stress (expressed in $\text{N}/\text{cm}^2$), while $a$ and $b$ are dimensionless experimental constants.

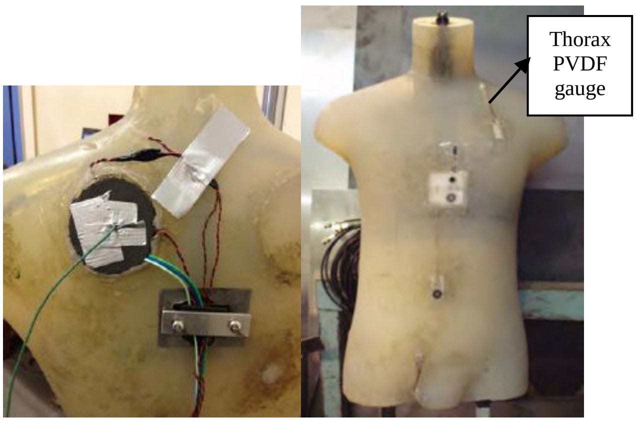
## III. The Test Rig

The test rig, represented by a human torso surrogate weighting 39 kg and fitted with piezoelectric transducers, was developed for the study of the human response when subjected to blast waves. Inside this surrogate there are two silicone hollow lungs, connected by the tracheae, and an abdominal insertion consisting of "Dragon Skin" silicone. The exterior layers of the surrogate are consisted of "Sorta Clear 40" silicone. During the fabrication process, PVDF sensors for measuring the generated overpressure were casted in the abdominal and thorax regions.

The surrogate consistency is presented in Fig. 1.




(a) The inside region




(b) Rear view; (c) Front view

Figure 1. The torso surrogate

L. HALLER is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (e-mail: laviniu.haller@mta.ro).
M. CÎRMACI-MATEI is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (e-mail: marius.cirmaci@mta.ro).
I. VEDINAȘ is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (e-mail: ioan.vedinas@mta.ro).
R. MIRCIOAGĂ is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (e-mail: razvan.mircioaga@mta.ro).
C. CUREA is with the Military Technical Academy "Ferdinand I", Bucharest, Romania.

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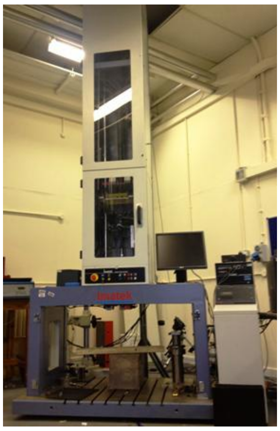
Tests performed involved the response of the thoracic PVDF sensor. The testing procedure, together with the involved instrumentation, is explained in the following section.

## IV. Procedure

The aim of the test was to subject the thorax of the rig to known loads, in order to evaluate the magnitude of response of the thoracic PVDF sensor. The application of a predefined load was done via an Imatek IM10 drop tower, equipped with a Kistler 9331B force transducer. The PVDF transducer was connected to a Kistler Type 5361A 10:1 charge attenuator. Data from both sensors were acquired via an Imatek C3008 controller. Signal response was analyzed with the ImpAcqt Analysis™ software.

(a)





(b) (c)

(a) The baton-like front mass; (b) The drop tower device; (c) The carriage

Figure 2. The test configuration

The drop tower device uses a carriage with a front mass and different mass extensions, which are used to calibrate the desired drop velocity and acceleration. The drop tower trials were performed by using a 26 mm diameter baton-like front mass. Its contact surface was covered with rubber. This front mass weighs 180.6 g. The mass of the carriage was 2070 g. Together with the 400 mm long extension masses, the total falling mass was 3081 g.

During the trials, the thoracic PVDF gauge was protected by covering it with a 5×50 mm cylindrical foam. Its purpose was to protect the sensor from the direct strike of the carriage front mass.

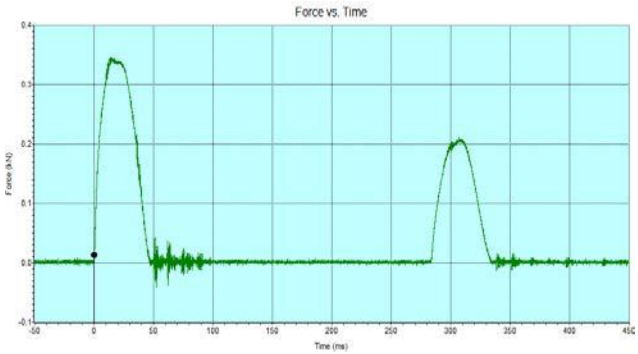
## V. Results

Four trials have been undertaken in order to calibrate the PVDF gauge. Its maximum voltage output and channel amplification, the impact velocities and the impact forces for trials number are summarized in Table I. The pressure upon the PVDF gauge was determined using the relation:

$$p = \frac{F}{S}, \tag{2}$$

where $p$ represents the pressure, $F$ – the force, and $S$ – the impact surface.

For each trial, PVDF gauge mechanical response together with the force that generated it are presented in Fig. 3-6. The black dot on the PVDF gauge graphics represents the trigger.



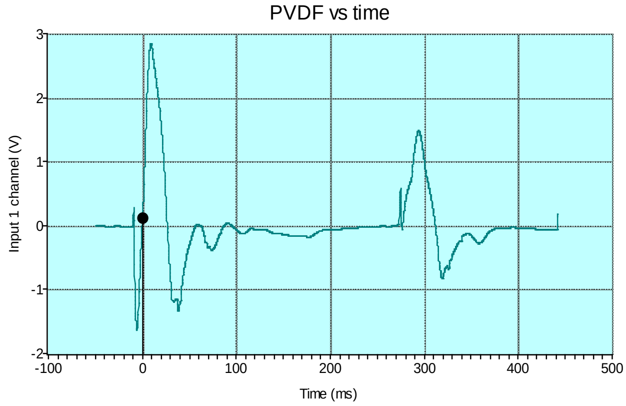




Figure 3. Trial 1. Impact force (up) vs. PVDF response (down)

TABLE I. TRIAL DATA AND RESULTS

| Trial no. | Impact velocity | Max. force | Max. force time | Measured pressure | Max. voltage output, channel amplification | Max. voltage time |
|---|---|---|---|---|---|---|
| 1 | 2 m/s | 345.5 N | 14 ms | 13,288.5 Pa | 2.85 V, $Amp = 100 \times 10^2 \times 10$ | 9 ms |
| 2 | 2 m/s | 349 N | 15 ms | 13,423.1 Pa | 0.753 V, $Amp = 200 \times 10^2 \times 10$ | 9 ms |
| 3 | 2.5 m/s | 346 N | 25 ms | 13,307.7 Pa | 0.521 V, $Amp = 200 \times 10^2 \times 10$ | 9 ms |
| 4 | 2.5 m/s | 400 N | 30 ms | 15,384.6 Pa | 0.37 V, $Amp = 400 \times 10^2 \times 10$ | 10 ms |

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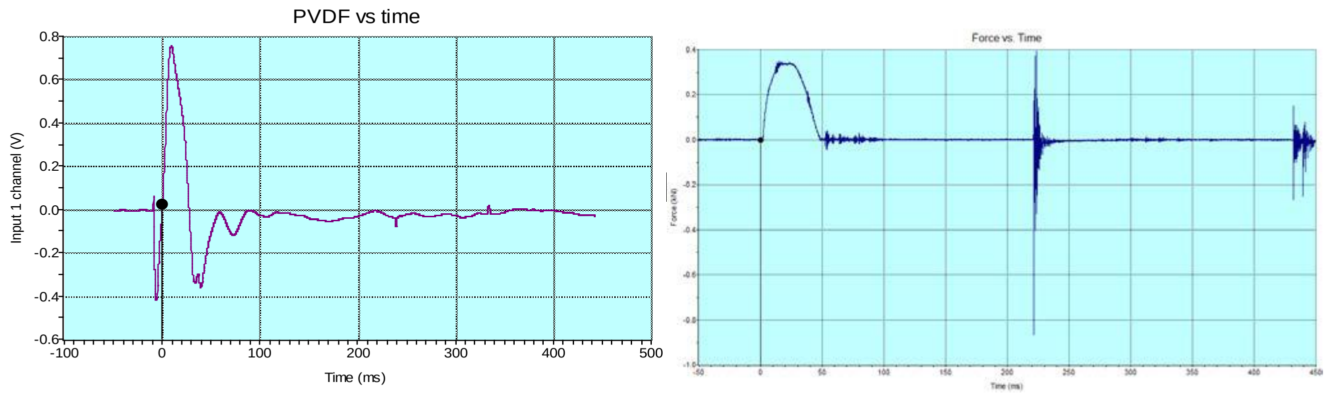


Fig. 4. Trial 2. PVDF response (left) vs. impact force (right)

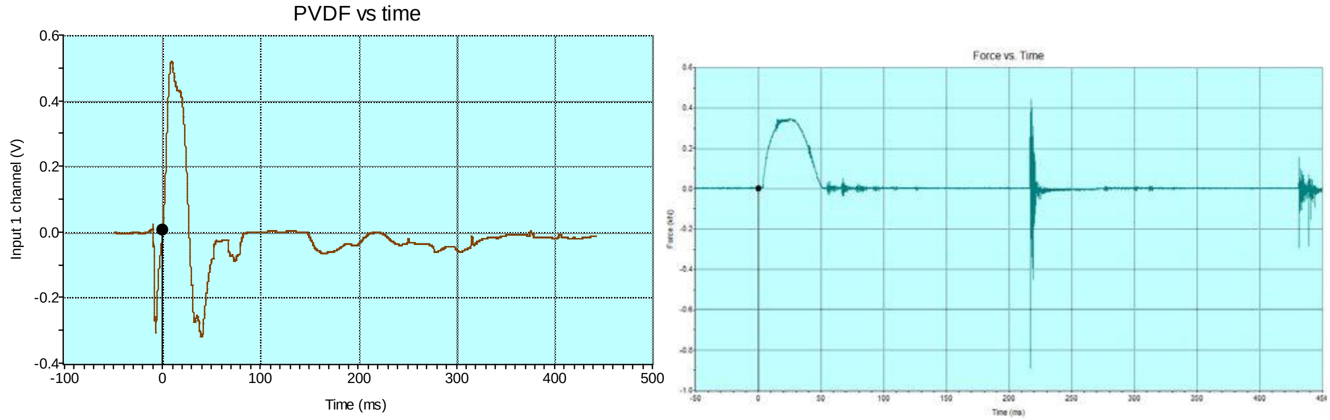


Fig. 5. Trial 3. PVDF response (left) vs. impact force (right)

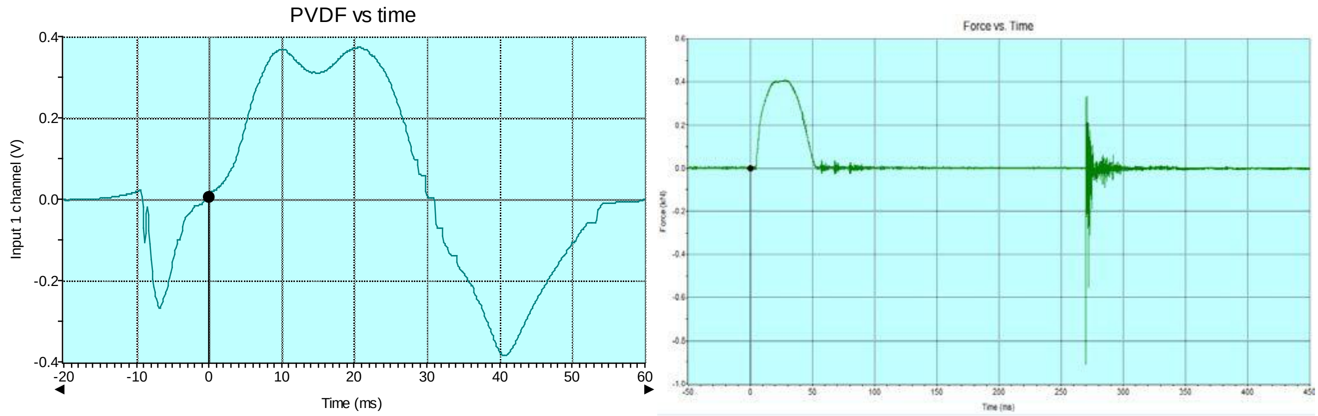


Fig. 6. Trial 4. PVDF response (left) vs. impact force (right)

The force signal recorded on the first trial indicates two loops. These were generated due to the jump of the carriage after the impact with the elastic surrogate. For the following trials, the carriage was blocked after the impact by the catch device from the drop tower.

For trials 2, 3 and 4, at the time $t \approx 220$ ms, a second signal appears on the force graphs. There is, though, no correspondence on the PVDF gauge graph. These times, the second signal, generated by the catch device, is recorded by the force transducer due to the sudden stop of the impacting mass.

## VI. Discussions

With respect to the curve profiles, the PVDF sensor responses, as seen from Fig. 3-6, seem to have the same evolution, which is correlated to the curves plotted from the impact force measurements. On the time scale from 0 to 40 ms, the signal given by the PVDF sensor is due to the compression generated by the front mass of the carriage. The negative response identified before the trigger point is given by the impact of the front mass with the surrogate material, which generates stress waves that axially stretch the PVDF sensor.

TABLE II. Correlation between Measured Pressure and PVDF Sensor Voltage Response

| Trial no. | Measured pressure | Max. voltage output |
|---|---|---|
| 1 | 13,288.5 Pa | 2.85 V |
| 2 | 13,423.1 Pa | 1.506 V |
| 3 | 13,307.7 Pa | 1.042 V |
| 4 | 15,384.6 Pa | 1.48 V |

In order to correlate the measured pressure with the voltage response of the PVDF gauge, data will be manipulated upon identifying the voltage values in accordance to the $100 \times 10^2 \times 10$ charge amplification, as in trial 1. Response magnitude correlation is thus based on the data introduced in Table II.

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Data correlation is made via a polynomial interpolation function. The PVDF gauge response with respect to the measured pressure is shown in Fig. 7.

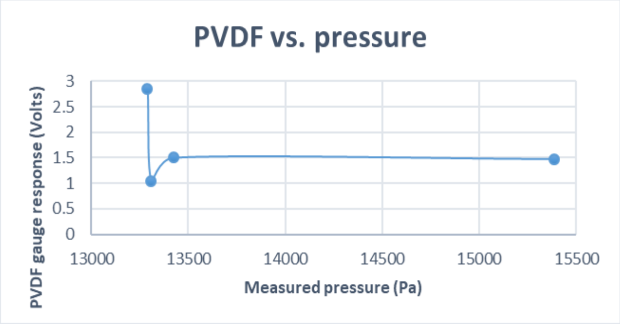


Fig. 7. PVDF gauge response vs. measured pressure

## VII. Conclusions

PVDF sensors give an adequate response regarding the pressure evolution in loading and unloading cycles. Nevertheless, due to their profile and constituency, they

According to the observed results, data response lacks linearity. Linearity is necessary in order to correctly approximate the pressure generated by a given force.

Certain reasons may be identified for the lack of PVDF sensor response lack of linearity. One first reason may be given by the insufficient number of trials. Upon further testing, the PVDF gauge could have been able to reproduce a more linear behaviour. Another reason could consist of sensor damage. PVDF sensor was already mounted on the rig, lacking knowledge of its history and its state.

may be mounted in different regions in order to quantify the magnitude of generated pressure in certain areas of interest. Still, the linearity of the voltage response amplitude is to be strongly considered.

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