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A Prototype Measuring Set for Capturing Dissipated Force on Soft Armor

C. Suppitaksakul[1] N. Chalermklin[1] S. Parsapratet[2] and S. Sungnu[2]

[1] Department of Electrical Engineering, Rajamangala University of Technology Thanyaburi, Thailand
(Tel : +662-549-3425; E-mail: chatchai.s@en.rmutt.ac.th and nara_ch@yahoo.co.th)
[2] Department of Textile Engineering, Rajamangala University of Technology Thanyaburi, Thailand
(Tel : +662-549-3459; E-mail: zoomth99@hotmail.com and somnuk.s@en.rmutt.ac.th)

Abstract: This paper presents a prototype of dissipated force measuring set for testing of soft armor in Thailand. The measuring set consists of (i) The impact absorber (ii) Transducers which were specially designed using two air cylinders, modified air pressure switch and Hall Effect sensor (iii) the Data Acquisition (DAQ) and (iv) the processing part (computer). The impact force is converted into analog voltage by the force transducers using Hall Effect sensors then passed to the Data Acquisition (DAQ). DAQ is controlled and processed by LabView program in order to collect and record the impact force data. The data is plotted in two and three dimension shapes for impact visualization. The obtained results from the measuring set are compared to the traditional testing method according to NIJ standard 0101.04 using Roma Plastilina No.1 clay. The experiments were carried on to capture the impact force from the shooting test. The satisfactory results are given and reported.

Keywords: Soft Armor, Hall Effect sensor, NIJ Standard 0101.04, DAQ

1. INTRODUCTION

Currently, the soft body armor research team at Rajamangala University of Technology Thanyaburi (RMUTT), Thailand has developed the soft amour from textile architectures and fiber material that can produce in the country. The developed armor requires impact testing according to the tradition method using NIJ standard [1]. The impact tests measure two Backface Signatures (BFS) and demonstrate the armor's pass/fail penetration capability. The test series requires the use of a plastically deforming witness media (clay backing material, Roma Plastilina No.1 clay) held in direct contact with the back surface of the armor panel which is used to capture and measure the Backface Signatures (BFS) depression produced in the backing material during nonperforating threat round impacts.

However, the obtained result from the tradition method just provides the armor penetration capacity which is insufficient information for analyzing of the armor structure such as the dissipated force when the bullet impacts on the armor. Besides, there are a few Laboratories in Thailand that support armor testing. Moreover, it is inconvenient for running the test in some particular point. From these reasons, it is inspired in developing an instrument that can capture and visualize the dissipated force of the ammunition impact. So a prototype of the dissipated force measuring set for soft armor testing is proposed and introduced. The measuring set consists of four main parts as the follows: i) the ballistic impact absorber, ii) Transducers, iii) Data Acquisition (DAQ) and iv) the processing part (computer) as the block diagram shown in Figure 1.

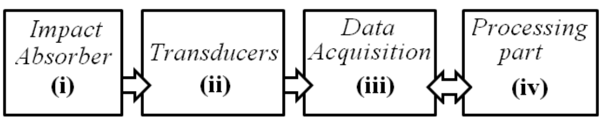

Fig. 1 The measuring set block diagram

The paper is divided into the following sections: Section 2, the physical quantities determination for transducers designing is mentioned and discussed. Sections 3, the designing of transducer is presented and described. The components of measuring set are explained in Section 4. Section 5, the experiments which were carried out on armor testing is demonstrated. Finally in Section 6, the discussion and conclusion regarding the proposed measuring set are reported.

2. PHYSICAL QUANTITIES DETERMINATION FOR TRANSDUCER DESIGNING

Originally, the measuring set is designed to capture the impact force on soft body armor at level II-A [1] which protects against 9 mm full metal jacketed round nose (FMJ RN) bullets, with nominal masses of 8.0g, impacting at a minimum velocity of 341 m/s. The acceptance criterion for BFS compliance that no measured BFS depression depth greater than 44 mm.

There are three physical quantities which are the net impact force, pressure and the return force, need to be calculated for transducer designing.

2.1 The net impact force determination

The net impact force calculates using the equation for motion in a straight line and Newton's second law [2] which express as:

$$v^2 = v_0^2 + 2a\Delta x \qquad (1)$$

$$F = ma \qquad (2)$$

where $\boldsymbol{a}$ is acceleration (m/s^2).
$\boldsymbol{v_0}$ is the initial bullet velocity (m/s).
$\boldsymbol{v}$ is the final bullet velocity (m/s).
$\boldsymbol{m}$ is the bullet mass (kg)
$\boldsymbol{F}$ is the net force (kg-m/s^2 or Newton).
Δx is the displacement (m).

2.2 The pressure calculation

The pressure ***P*** is another quantity requires calculating in order to determine the force exerted perpendicular to a given surface of area ***A*** as (3):

$$P = \frac{F}{A} \quad (3)$$

where ***P*** is the pressure (N/m^2).
F is the net force (kg-m/s^2 or Newton).
A is the surface area (m^2).

Because the pressure is defined as force per unit area, it has units of Pascal (N/m^2) [2]. 1 Megapascal (Mpa) is equal to 1 Newton/mm^2. The pressure is used for pneumatic cylinder selecting that is discussed in the next section.

2.3 The return force determination

Due to the transducer attempt to have the same equivalent property as the backing material therefore the return force value is calculated by compared to the density resistance of the backing material. The NIJ calibration criteria for backing material (the Roma Plastilina #1 clay) [1] which will be accomplished using the drop weight with steel sphere size 63.5 mm ±0.05mm in diameter and mass of 1043 g ±5 g then release at height of 2.0 m. The calibration drop will consist of a free fall of the steel sphere onto the conditioned backing material with the depth of depression is 20 mm ±3 mm. From the information above, the force resistance of the backing material can be calculated using (1) and (2). However, the velocity of the steel sphere ***v*** when reaches the surface of the backing material is required in (1). Therefore the conservation of mechanical energy theorem [2] is applied to fine the velocity of the steel sphere as:

$$KE = PE \text{ or } \frac{1}{2}mv^2 = mgh \quad (4)$$

$$v = \sqrt{2gh} \quad (5)$$

where ***KE*** is kinetic energy (J).
PE is for potential energy (J).
m is the mass (kg).
v is the final velocity (m/s).
g is the acceleration of gravity (9.8 m/s^2).
h is the vertical position of the mass relative to the backing material surface.

3. TRANSDUCER DESIGN

Transducers are employed to convert the impact force into electrical signal. Due to a commercial transducer is costly and unsuitable for the application. Therefore it needs to be designed for this purpose. The designed transducer consists of three components that are: 1. two pneumatic cylinders, 2. the modified air pressure switch and 3. Hall Effect sensing device as illustrated in Fig. 2.

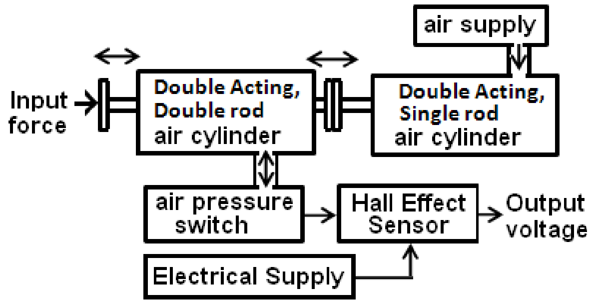

Fig. 2 Block diagram of a transducer

3.1 Pneumatic cylinder

Two types of double acting air cylinders are applied. There are a double acting-double rod (through rod cylinder) [3] that directly contacts to the impact absorber for force receiving and the double acting-single rod (normal double acting cylinder) is employed for generating return force that can be adjusted by air pressure injection.

The net impact force calculates using (1) and (2) is employed to specify the through rod cylinder. The depression depth of 44 mm from the BFS criterion is use as the displacement Δx in (1). The initial bullet velocity is 341 m/s and the final velocity is 0 m/s because the bullet embedded in the armor. So that, he acceleration ***a*** within the distance 44 mm is -1.32×10^6 m/s^2. Therefore, the net force ***F*** is 10,571 N. Then the force per unit area in term of pressure is defined by (3). The diameter of each impact absorber is 23.4 mm and the surface area of an impact absorber is $(\pi\times23.4^2)/4$ or 429.83 mm^2 therefore the approximated pressure that will be applied to each transducer is equal to 10,571/429.83(N/mm^2) or 24.59 (N/mm^2). In our case, the through rod cylinder (SMC model CJ2W16-45) [4] is selected and connected to modified pressure switch. When the input force exerts to the piston rod the air volume in the cylinder is obtained and passed to the modified pressure switch.

The single rod cylinder (SMC model CDJ2B-16B) is directly contact to another end of the through rod cylinder in order to produce return force. Then (5) can be expressed as:

$$v = \sqrt{2gh} = \sqrt{2\times9.8 \text{ m/s}^2\times2\text{m}} = 6.26 \text{ m/s}$$

Hence, the velocity ***v*** = 6.26 m/s is set as v_0 in (1) and Δx is the depression depth of the backing material that is 20 mm therefore, the acceleration ***a*** is -980 m/s^2 and (2) provides the net force ***F*** is 1022.14 N. Then calculate the return force by (3) so that the area of the sphere surface is approximate 2732.58 mm^2. Therefore the density resistance of the backing material in term of pressure is approximate 0.374 Mpa or 0.374 bars. This value is set as the pressure for the single rod cylinder in order to generate return force that equivalent to the density resistance.

3.2 Modified air pressure switch

The function of the air pressure switch is to convert the air volume to electrical voltage. Here, the pressure switch of the washing machine is employed and modified. Two permanent magnetic bars are installed on the little piston inside the housing of the switch. When the air volume is admitted, the diaphragm extends along the inner wall of the housing and moves the piston rod upward. As the result, the magnetic bar is close and far to Hall Effect sensor. The coil spring is used for return the piston to the initial position after the releasing of air volume. The rod moving distance ratio of the trough rod cylinder and the piston rod of the pressure switch is 1.0:0.2 mm. The structure of the modified pressure switch is shown in Fig. 3.

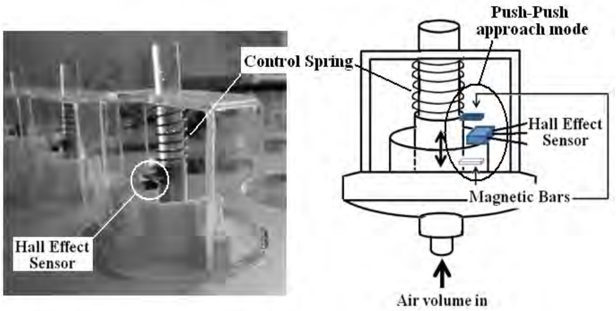

Fig. 3 The modified air pressure switch

3.3 Hall Effect sensing device

The Hall element [5] is constructed from a thin sheet of conductive material with output connections perpendicular to the direction of current flow. When subjected to a magnetic field, it responds with an output voltage proportional to the magnetic field strength. The voltage output is very small (μV) and requires additional electronics to achieve useful voltage levels. The Hall Effect sensor is considered to employ in the force transducer because it provides a linear output voltage, fast respond and cheaply. In the modified pressure switch, the Hall Effect sensor is mounted to the housing between the magnetic bars with Push-push approach mode [6] as shown in Fig. 3.

As the air volume is admitted, the piston is moved upward, it raises a magnetic bar that actuates the sensor and the output voltage is obtained. When the air releases, the coil spring causes the magnetic bar to lower thus reducing the output voltage of the sensor and it is proportional to the magnitude of magnetic field. Since the field magnitude at the particular point is proportional to the moving distance of the piston. The voltage range of the use sensor is 0-5 volts with the cylinder stroke of 0-45 mm. A transducer calibration using the precision pressure indicator calibrator Druck DPI 605 provides graph that the voltage output tend to be linear as illustrated in Fig. 4.

4. THE IMPACT FORCE MEASURING SET

Each part of the dissipated force measuring set is described and explained for more detail.

4.1 The impact absorber

The function of the impact absorber is as same as the clay backing material where the back surface of the armor is directly contacted. The impact is absorbed and passed to the transducer for converting the dissipated force on the armor into electrical potential signal. The designed absorber is made from 25 steel round bars which are arranged 5 in rows and 5 in columns put into housing of the absorber as shown in Fig. 5. Each steel bar can independently move and has diameter of 0.92 inches (23.4 mm) with horizontal moving distance of 50 mm. The absorber surface covers the approximated area of 25 in^2. The size of absorber surface is designed according to the biggest size of the BFS depression produced in the back material by testing with tradition method.

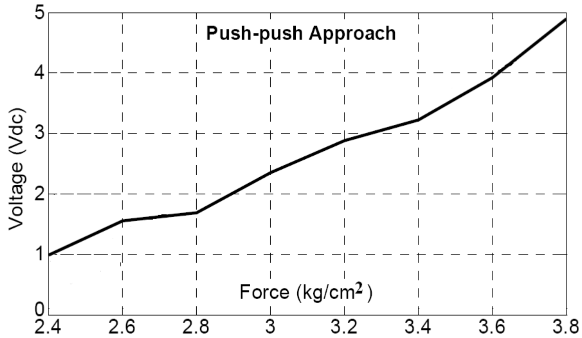

Fig. 4 A transducer calibration graph

Fig. 5 The impact absorber (left) and the set of 25 Transducers (Pneumatic cylinder part)

4.2 Transducers

The principle of the designed transducer is already described in Section 3. The number of transducer is 25 as same as the number of the impact absorber shows in Fig. 5 (right). All of the transducers are calibrated with the precision pressure indicator calibrator Druck DPI 605.

4.3 Data acquisition (DAQ)

The function of DAQ is to receive the obtained analog voltage from the transducers and then converts them into digital signal for recording the data. The Advance Tech Data Acquisition product PCI-Card model C11715U is considered to use in this work. There are 32 channels for analog input with sampling rate of 500 ks/s which should be sufficient for capturing the impact force in the same time.

4.4 The processing part

This part consists of two components that are: Hardware and Software. The hardware is a computer where the DAQ card is installed. The software Labview is used for controlling and processing the DAQ in order to measure and record the impact force data. The recorded data is calculated and improved by the interpolation method in MATLAB for visualizing the graphic of the dissipated force on the testing armor.

5. EXPERIMENTS

The experiments were process follow the step of NIJ Standard-0101.04 for soft armor testing [1].

5.1 Calibration test

To test of measuring set with the drop weight by dropping free fall of the still sphere onto the measuring set detection area as shown in Fig. 6. The result from this test is compared to the tradition method. As the result, the measuring set can capture the impact of the drop weight as illustrated in Fig. 7.

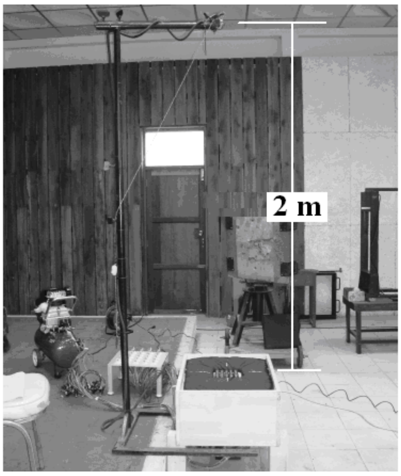

Fig. 6 Measuring set calibration with the drop weight

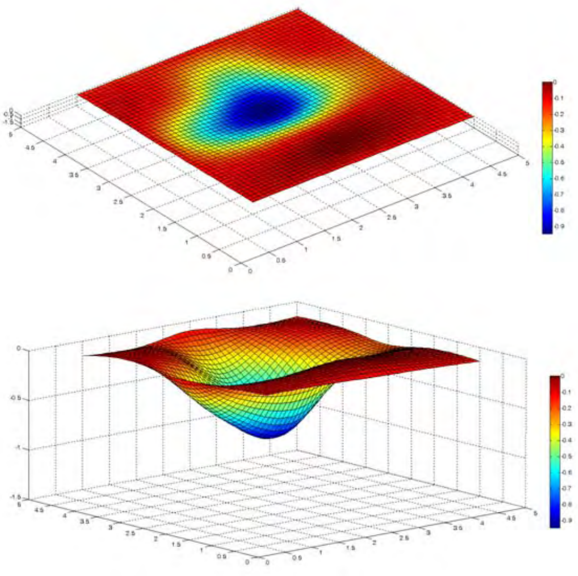

Fig. 7 The 3-D plotting of impact with the drop weight

5.2 The armor perforation test

The armor perforation is tested by firing the armor that place on the backing material (the tradition method) as shown in Fig. 8. If no perforation through the armor panel, then test by using the measuring set. A sample of fabric armor type was tested. It was shot 3 times with the 380 ACP Full Metal Jacketed Round Nose (FMJ RN) bullets by the shooting set (Fig. 9).

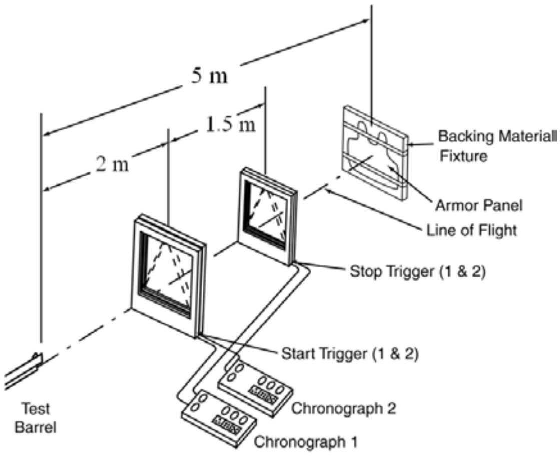

Fig. 8 Test range configuration for armor testing [1]

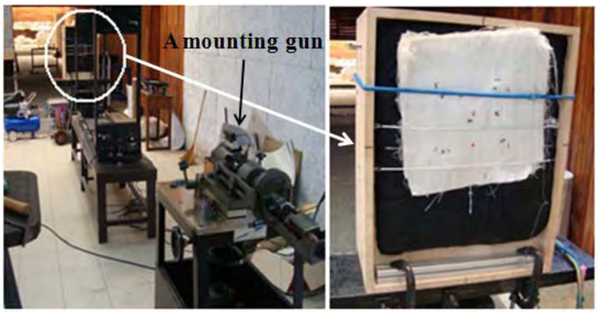

Fig. 9 The shooting set and the proposed measuring set

The first shot of the sample for the perforation test and another two for the impact visualization. The results from the shooting test are plotted as shown in Fig. 10. As the comparing the results of the first shot using the backing material to the measuring set, it is found that the shape of the BFS depression in the backing material almost the same as the graphic result from the measuring set. Due to the uncertain of bullet velocity of each shooting, therefore the depth of the bullet is not equal.

6. DISCUSSION AND CONCLUSION

The prototype of dissipated force measuring set in Thailand and experiments has presented and demonstrated. The main objective to visualize the dissipated force on the armor panel when the bullet hit the armor can be achieved. Also the experiments results tend to the same way with the results of the tradition method using the backing material. The useful information is able to help the researcher in developing of the soft armor.

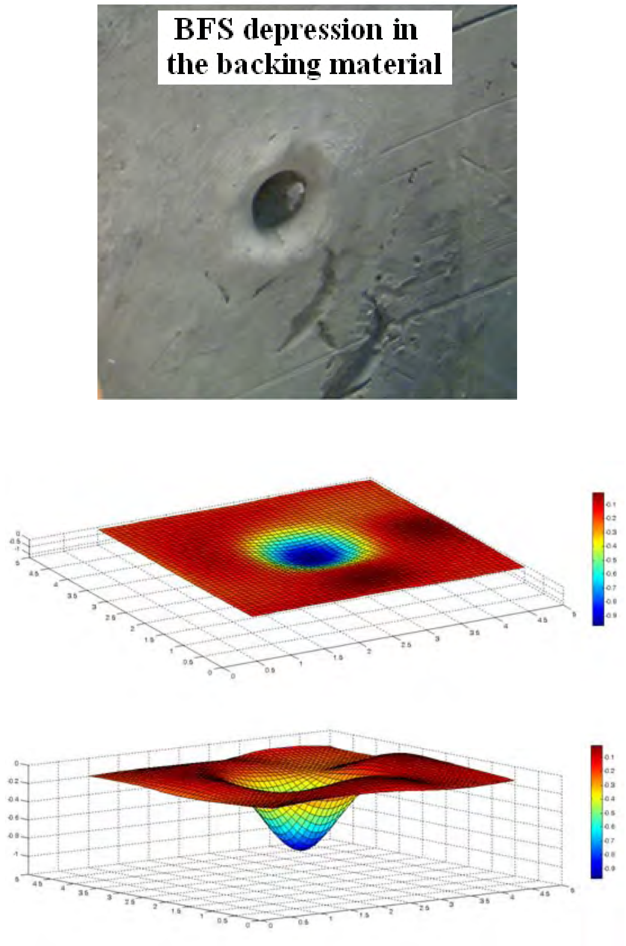

Fig. 10 Comparing results backing material and the measuring set

However, there are still errors and shortcomings need to be improved. For example there are the offset level exist at the transducer output due to each modified pressure switch cannot be calibrated to reach the same level. The accuracy of each the transducers is required to be more accurate. Moreover the programming is also required to improve for more convenient to capture the dissipate force because the program is still running in the manual mode.

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