Projectile Velocity Measurement System Based on PVDF and Data Processing Method

Xiaoxiao Chen¹, Ping Song¹* and Yayu Zhai¹

1Key Laboratory of Biomimetic Robots and Systems (Ministry of Education) Beijing Institute of Technology, Beijing, 100081, China

Email: sping2002@bit.edu.cn

Abstract. Time of flight (TOF) algorithm is mainly used to measure the velocity of a projectile. TOF algorithm measures the time required for the projectile to fly over a fixed distance. We use polyvinylidene fluoride (PVDF) to measure TOF. Based on the analysis of the signal generated by the projectile penetrating PVDF film, a projectile penetrating unit recognition algorithm and a projectile velocity calculation method are presented. In projectile penetrating unit recognition algorithm, we filter all signals generate by PVDF, and identify the projectile penetrating unit. Then, the time when the projectile reaches two PVDF films is determined by the threshold method, and the TOF is obtained, so the flight speed of the projectile is obtained. It is proved that this method can distinguish the penetrating units of the projectile correctly and calculate the velocity of the projectile accurately.

1. Introduction

Research into measuring the velocity of a projectile has been going on for years. One method is to use TOF to measure the velocity of a projectile. TOF has been used in many other scenarios [1,2,3]. In projectile velocity measurement, Y He used the system based on the laser beam interruption to calculate the velocity of the muzzle [4]. The position and time were obtained, the average velocity between the two barriers was determined. M Singh proposed a system to accurately determine the speed of a projectile (bullet) by measuring the time of flight between two parallel laser screens [5]. They used a system with two parallel laser screens to accurately determine the speed of a projectile by measuring the time of flight between laser screens. G Wang proposed a design of an optical fiber-based velocity measurement system [6]. The measurement principle was based on Doppler effect and heterodyne detection technique. They deduced the relationship between the projectile velocity and the instantaneous frequency (IF) of the optical fiber-based system output signal. By using this relationship, they could get the speed of the projectile. G H Yang used magnetoresistive sensor and coil target combination method to real-time measure projectile muzzle velocity [7]. M Courtney put forward a simple method for using a PC soundcard to accurately measure bullet velocity [8]. The result that recorded time between bullet blast and the bullet hitting the target minus the time that sound return from the target to the microphone was the time of flight for the bullet. J Yu used a structure made by two laser light sources, two optical detectors (OD) and two reflectors to measure the velocity of the projectile. J B Jordan developed an equation for the velocity as a function of the FSP mass and the depth of penetration into Celotex recovery media [10]. Using this function, they could compute the velocity of the projectile. However, some of these methods are influenced by the environment and some are expensive. Therefore, this paper proposes a speed measurement system based on PVDF.
2. Method

2.1. Experiment device

The overall diagram of the experiment device is shown in figure 1. The experiment device mainly includes PVDF piezoelectric film, guide rails, support structure, signal conditioning circuit, signal acquisition circuit computer and sky screens. The device consists of two PVDF. Two PVDF are fixed back and forth on the guide rail with the support structure. PVDF piezoelectric film is connected to the signal conditioning circuit, the output of the signal conditioning circuit is connected to the input end of the signal collection circuit, and the output of the signal collection circuit is connected to the computer.

![Overall diagram of the experiment device.](image)

The PVDF films used in this paper have a layered structure as shown in figure 2. At the same time, each PVDF consists of several small PVDF units, as shown in figure 3.

![The layered structure of PVDF.](image)  
![The unit structure of PVDF.](image)

When PVDF is compressed, the electrode (+) and the electrode (GND) will produce equal positive and negative charges. Since the charge signal is not conducive to direct collection, the signal conditioning circuit converts the charge signal into voltage signal, and the core circuit of the signal conditioning circuit is shown in figure 4.

![The core circuit of the signal conditioning circuit.](image)

According to figure 4, we have following equation.
The adjusted signal is connected to the signal acquisition circuit for acquisition and transmission to the computer. The acquisition circuit was mainly constructed by NI pxie-6358, with a sampling rate of 1M and a sampling time of 0.2s. The computer recognizes the penetrating units through the data collected, and processes the data corresponding to the projectile to obtain the time difference between the two PVDF films before and after the projectile arrives, so as to calculate the velocity of the projectile. Then, the time when the projectile reaches two PVDF films is determined by the threshold method, and the TOF is obtained, so the flight speed of the projectile is computed.

2.2. Penetrating unit recognition algorithm
The ideal experiment result is that the signal is generated only on the PVDF units where the projectile hits, and the other PVDF units do not output signals. But the real results are different. On the basis of multiple experiments, the experiment results have the following characteristics: 1. The penetrating units produces pulse signals which are mainly of two types (Figure 5a and Figure 5b), one signal is a simple impulse signal and the other signal has an exponential attenuation signal at the back end of the pulse. 2. Unpenetrated PVDF units sometimes produce interference signals, especially those that have been penetrated by the projectile before. Therefore, a penetrating unit recognition algorithm is proposed. In this algorithm, the signal of each unit is filtered by low pass filtering, then set the threshold to determine the number of pulses, if the number of pulses is one, this unit is penetrating unit.

2.3. Particle velocity calculation method
After the above steps, we get the penetrating unit and extract the corresponding data. The velocity of the projectile is calculated respectively by taking 20% and 80% of the rising edge as the time of arrival.

3. Results

3.1. Results of penetrating unit recognition algorithm
Figure 5 shows the output signal waveform of 4 units in an experiment. Figure 5a and 5b are the output signals of the penetrating units, figure 5c is the output signal of the PVDF unit with interference signal, and figure 5d is the output signal of the PVDF unit without interference signal.
Figure 5. The original signal output by PVDF

Figure 6. The filtered signal
By analysing the spectrum of all signals, we find most of the signals are concentrated at low frequencies with a small amount of high-frequency noise. Filter signals below 250Hz. The signal obtained after low-pass filtering is as follows.

As can be seen from the figure 6, the filtered waveform becomes smooth and white noise is suppressed. Figure 6a is the most obvious. The signal with exponential attenuation at the back end of the pulse is filtered.

The threshold method is adopted for the recognition of the penetrating unit. When the signal crosses the threshold line twice, it is considered that the signal is generated by the penetrating unit. When the signal does not cross the threshold line or cross the threshold line greater than twice, it is considered that the signal is not generated by the penetrating unit. For the experiment in this paper, the threshold line \( U=1V \) is adopted, so it can be seen that PVDF units corresponding to figure 6a and 6b are penetrating units.

3.2. Results of projectile velocity

The velocity of the projectile can be calculated after determining the penetrating units. In this paper, two threshold selection methods are used to estimate the velocity of the projectile. The threshold is 20\% of the maximum and 80\% of the maximum. The velocity of the projectile was estimated in 10 experiments, and the estimated value and true value of the projectile velocity were shown in the table 1. It can be seen from the table 1 that both threshold methods can calculate the velocity. The error between the velocity calculated with the threshold value of 20\% of the maximum value and the real value is small, which is more suitable for the calculation method of velocity.

| Number of experiments | 20\% of the maximum (m/s) | 80\% of the maximum (m/s) | Real value (m/s) |
|-----------------------|---------------------------|---------------------------|-----------------|
| 1                     | 722.0333                  | 710.8140                  | 737.3           |
| 2                     | 724.1904                  | 729.0638                  | 734.4           |
| 3                     | 720.5491                  | 719.9771                  | 731.9           |
| 4                     | 729.1315                  | 721.3024                  | 734.4           |
| 5                     | 733.7466                  | 705.2806                  | 735.5           |
| 6                     | 732.7274                  | 713.3891                  | 734.6           |
| 7                     | 726.7425                  | 712.0294                  | 734.2           |
| 8                     | 723.7014                  | 726.3892                  | 737.3           |
| 9                     | 725.1310                  | 721.3111                  | 735.1           |
| 10                    | 715.5321                  | 701.4436                  | 732.0           |
| Average               | 725.34853                 | 716.10003                 | 734.67          |

4. Discussion

The penetrating unit recognition algorithm can extract penetrating units effectively. In the case of determining the penetrating units, the velocity can be calculated by threshold method. It can be seen from the results that the accuracy of the speed calculated with the maximum value of 20\% as the threshold is higher than the speed calculated with the maximum value of 80\% as the threshold.
5. Conclusions
In this paper, a velocity measurement system based on PVDF is presented. At the same time, a data processing method is proposed. The system and method can calculate the velocity of the projectile. Taking 20% of the maximum value as the threshold value, the error is -1.2688%.

Acknowledgement
This work was partially supported by the National Defense Basic Scientific Program of China (JCKY2016208B008). We are also very grateful to the reviewers for their useful opinions and suggestions, which have improved representativeness.

References
[1] T K Ghosh, S Pal, T Sinha, S Chattopadhyay, K S Golda and P Bhattacharya 2005 *Nucl. Instrum. Methods A* 540 285.
[2] E M Kozulin, A A Bogachev, M G Itkis, I M Itkis, G N Knyazheva, N A Kondratiev, L Krupa, I V Pokrovsky and E V Prokhorov 2008 *Instrum. Exp. Tech.* 51 (1) 44.
[3] V Priola and M J Brannan 2003 *Meas. Sci. Technol.* 14(1), 1.
[4] Y He, S Song, Y Guan, C Cheng, W Dai, X Qiu and Y Li 2015 *IEEE Trans. Plasma Sci.* 43(5) 1647-1651
[5] M Singh 2007 *Optical Engineering* 46(4) 4303
[6] G Wang, J Sun and Q Li 2014 *Rev. Sci. Instrum.* 85(8) 351-356.
[7] G H Yang and X M Zhang 2015 *Transducer and Microsystem Technology* 34(2) 76-78.
[8] M Courtney and B Edwards 2006 arXiv preprint physics/0601102.
[9] J Yu, X Wang and Y Li 2009 *Symposium on Photonics and Optoelectronics* 1-4.
[10] J B Jordan and C J Naito 2010 *Int. J. Impact Eng.* 37(5) 530-536.