ELECTRONIC SYSTEM FOR EXPERIMENTAL EVALUATION OF PROJECTILE'S VELOCITY FOR NAVAL ORDNANCE AMMUNITIONS

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REZUMAT. Lucrarea cuprinde descrierea unui sistem de tip cronograf pentru determinarea vitezei proiectilului, în special viteză proiectile specifice muniţiilor calibru mic din domeniul naval. Sistemul prezentat este proiectat şi realizat de către specialiştii CCSFN şi are ca obiectiv final interconectarea acestui sistem la o aplicaţie software „in-house" care are capabilităţi de: integrare a liniei balistice, modelare simulare numerică balistică exterioară şi interioară, evaluare date experimentale şi numerice, determinarea experimentală a parametrilor balistici viteză proiectil, presiune ţeava balistică şi indice de formă proiectil pentru o muniţie utilizând senzori de diferite tipuri. În lucrare sunt prezentate: schema generală ce conţine elementele componente principale ale sistemului de determinare a vitezei proiectilului cât şi modul de funcţionare al acestuia în raport cu elementele sale. Realizarea unui astfel de sistem „in-house" permite utilizatorului un acces total la posibilităţile reconfigurare al acestuia funcţie de nevoile de testare evaluare identificate.

Cuvinte cheie: fotodiodă, diodă IR, viteză iniţială, IC 555 timer, proiectil, cronograf, microcontroller, software „in-house".

ABSTRACT. The paper includes the description of a chronograph system used for velocity determination, specially the velocity of small caliber projectiles used by naval ordnance. The presented system is designed and realized by the CCSFN's specialists and has the final goal the interconnection of this system with a software „in-house" application which has capabilities for: ballistic line integration, numerical simulation for exterior and interior ballistics, experimental determination for projectile's velocity, pressure in ballistic barrel and projectile's shape index for an ammunition using different types of sensors. In paper are presented: system's general scheme with its main components and his functionality taking into account his main components. In the end, the construction of such an „in-house" system permits to the user a full access to its possibilities of reconfiguration due to identified needs in testing and evaluation process.

Keywords: photodiode, IR diode, initial velocity, IC 555 timer, projectile, ballistic chronograph, microcontroller, „in-house" software.

1. INTRODUCTION

The projectile's velocity is an important ballistic parameter needed to solve exterior ballistics and terminal ballistics problems. As a main important problem is the evaluation of projectile's effect on the target. This problem can be solved by doing the following experimental measurements: projectile's initial velocity measurement, projectile's velocity on the trajectory measurement, projectile's drag coefficient measurement.

The projectile's velocity can be measured using a simple system called ballistic chronograph, which in general is composed of: sensors for projectile's presence detection, a time evaluation system, a display and editing data system and a system for monitoring forecast. Taking into account the type of projectile's presence sensing sensor used the ballistic chronographs are: chronographs with coils, chronographs with optical gates, chronographs of Doppler radar type and chronographs with contact gates.

The projectile's velocity can be easily measured, with a very good precision, near the barrel muzzle. To do this, in Fig. 1.1 is presented schematic, how this can be done.

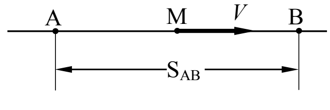

Fig. 1.1. Velocity measurement schematic.

The main idea of this principle is simple; we measure the time duration in which the projectile is passing by the gates. Usually for velocity measurements are used two gates, one in point A and the second in point B, see Fig. 1.1. Let's say that the projectile's time passing throw the two gates is t_{AB} and the distance between gates A and B is s_{AB} the velocity can be obtain using the known relation, (1.1):

$$V = \frac{s_{AB}}{t_{AB}} \text{ [m/s]} \quad (1.1)$$

Usually the distance s_{AB} between the gates can be different because of the sensors used. Relation (1.1) permits the evaluation of velocity in a point which is at the middle of the distance between the gates A and B, in Fig. 1.1 is the represented as the point M.

The most frequently used ballistic chronographs are: chronographs with solenoids sensors, chronographs with optical sensors and chronographs with contact sensors.

The chronograph with electromagnetic sensors has the gates as coils which sense the projectile when it is passing by. When the projectile, with magnetic properties, is passing by the gate it generates a current which starts or stops the chronometer. This type of chronograph can be used for velocity determination for projectiles made from ferromagnetic materials but cannot measure the velocity for projectiles with detachable elements.

The chronograph with optical sensor mounted on the gates measure the projectile velocity using the light in the visible or IR domain using as sensors photodiodes or phototransistors. When the projectile intersects the gate the illumination of the sensor drops. The signal obtained from the optical sensor starts and stops the timer. This makes possible the evaluation of the time when the projectile is travelling between the gates and to calculate the velocity. These types of chronographs are used to measure the projectile velocity to different angles also are using the visible light and focalization lenses or IR light and IR sensors without focalization lenses. The IR sensors can eliminate the problems which appear when measuring the projectile velocity for projectiles with tracers.

The chronograph with Doppler radar sensors has an antenna which emits a signal on a known frequency. After is reflected by the projectile this signal is coming back to the antenna with a different frequency. The difference between the emission frequency and receiving frequency is proportional with the projectile's radial velocity. This system can measure directly the projectiles velocity and not indirect using the time. This type of chronograph can give the velocity of the projectile on the first part of his trajectory. In some cases this chronograph can give error in measurements caused by moving objects on the main lob of the antenna (for example projectiles with detachable elements) or high ionized projectiles (projectiles with tracers).

The chronograph with contact gates permits the projectile's velocity measurements using a grid made from wires. These wires are broken when the projectile is passing by the gate and starts or stops the chronometer. This type of system is used yet today too and permits to measure the projectile's velocity on different shooting angles.

The needed chronograph has as main requirements: to measure projectile's velocities higher then 1000 m/s, the length of the measured projectile is minim 100 mm and the projectile's diameter 30 mm. The system must measure the velocity for projectiles with tracers too.

To accomplish the requirements in the following chapter are presented the objectives for the ballistic chronograph design.

2. STUDY'S MAIN OBJECTIVES

Taking into account the types of ballistic chronographs presented before and the needs of such a system for military use we defined the objectives for the system's design and capabilities. These objectives are:

− design of a ballistic chronograph which can measure the projectile's velocities higher than 1000 m/s and for projectile's calibers higher than 30 mm;

− design of a system which can measure the projectile's velocity according to standards presented in [1, 2, 3];

− design of a portable and independent functioning ballistic chronograph;

− design of a chronograph which can permits to make the measured data corrections taking into account the forecast as is presented in [2];

− design of a ballistic chronograph which can be software updated using a computer link too.

In this case we define a few capabilities for the ballistic chronograph presented in Table 1.

Table 1. **Ballistic chronograph defined capabilities**

Parameter/ Capability	Value
Projectile's velocity	>1000 m/s
Projectile's caliber	> 30 mm
Projectile's minim length	100 mm
PC Connection	USB
Velocity correction	Yes
Velocity display	LCD 16x2 or in a PC software
Projectile's types	With or without tracers

Using the data presented in Table 1, were estimated the specifications for the designed ballistic chronograph sensors, gate's signal emitters and receivers.

For signal and receivers we estimate the needed frequency using the time in which the projectile travels throw the gate. For this we use the relation, (2.1):

$$T = \frac{L_{projectile}}{V_{projectile}} \text{ [s]} \quad (2.1)$$

in which: $L_{projectile}$ – projectile's length; $V_{projectile}$ – projectile's velocity; T - projectile's time travel throw gate.

In our case the travel time is:

$$T = \frac{100 \cdot 10^{-3}\,\mathrm{m}}{1000\,\frac{\mathrm{m}}{\mathrm{s}}} = 10^{-4}\ [\mathrm{s}] \qquad (2.2)$$

The time T permits to calculate the working frequency for sensors, signal generators and chronometer. The working frequency considered is between 90 kHz and 200 kHz.

In the next chapter is presented the solution proposed for this ballistic chronograph and a short description of its main parts and its functioning.

3. BALLISTIC CHRONOGRAF DESIGNED SOLUTION AND RESULTS

Taking into account the requirements for the ballistic chronograph we used as solution an IR option for projectile's presence detection sensors.

In this case the system has as main components:

− tripods to sustain and maintain fixed the gates with the sensors;

− two gates which contain matrices with sensors for transceiver – receiver to identify the projectile's presences;

− IR diodes matrix for emission, which contain diodes of 5 mm diameter and emits in IR. The IR diodes wavelength is 875 nm, the maximum emission power of 210 W also the degree of emission is 12°;

− IR photodiodes matrix for receiver, which contain photodiodes of 5 mm diameter and has a maximal sensibility on the 940 nm wavelength, and a reception angle of 20°;

− system for data acquisition from the gates and 16x2 LCD display for velocity measurements display. The acquisition system has as main component the Atmel ATMega 328P-PU microcontroller which permits PC connection and real time data manipulation;

− system for monitoring the forecast which contain pressure sensors, humidity sensors and temperature sensors. Also data from these sensors are integrated by a microcontroller Atmel ATMega 328P-PU. This system can be connected to a PC using the USB port or it can display data on a 16x2 LCD display;

− elements for interconnection;

− PC for data monitoring or for microcontrollers software upgrades;

− Vcc source.

The configuration of ballistic chronograph presented before allows measuring the projectile's velocity and forecast data monitoring for velocity measurements data correction. The presented configuration can be completely independent by using a thermal printer for data reports printing.

The schematic of the designed ballistic chronograph is presented in Fig. 3.3.

Fig. 3.1. Half of the IR diodes matrix PCB without IR diodes.

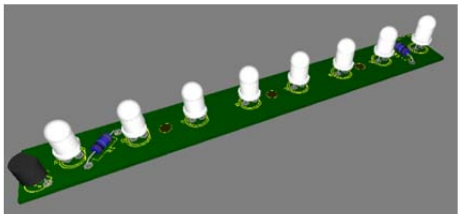

Fig. 3.2. Half of the IR diodes matrix PCB with components 3D virtual model.

The components from the designed ballistic chronograph, presented in Fig. 3.3, can be identified as follows:

− **A.** Tripods to sustain and maintain fixed the gates with the sensors is a mechanical system for sensors positioning;

− **B.** Gates with matrices of sensors with transceiver-receiver. Permits to put fixed the sensors matrices in position.

− **C.** IR matriceal sources for emission see Fig. 3.1 and Fig. 3.2. These sources contain 16 IR diodes which emits on 875 nm wavelength. Also these matriceal sources contain an electronic circuit which transmits a PWM signal between 90 kHz and 200 kHz and a duty cycle of 10 %.

− **D.** Receiver IR matrix contain 16 photodiodes with a sensibility peak at wavelength of 940 nm. Also this matrix has an electronic circuit which receives and transmits the data from the receiving matrix to the data acquisition system.

− **E.** The system for data acquisition from the gates has the purpose to receive and calculate the projectile's velocity. This system contain a microcontroller, Atmel ATMega328P-PU which calculates the velocity and display it on the LCD display and send using the PC's USB port the data to the acquisition software. The microcontroller is presented in Fig. 3.4.

− **F.** System for monitoring the forecast has in his structure an Atmel ATMega328P-PU microcontroller, the pressure/ altitude sensor MPL311A2 and SHT 11 sensor for humidity and temperature monitoring. These sensors get the environment data and transmit the data to the microcontroller which displays this data on a 16x2 LCD.

− **G.** The PC is optional taking into account that the ballistic chronograph is designed to function as a standalone system. The use of the PC connection is important to get data from sensor but also to upgrade the microcontroller's software.

− **H.** Vcc source is PS-3010D model, 30 V and 10 A, and is used for firing the ammunition with electric initiation systems.

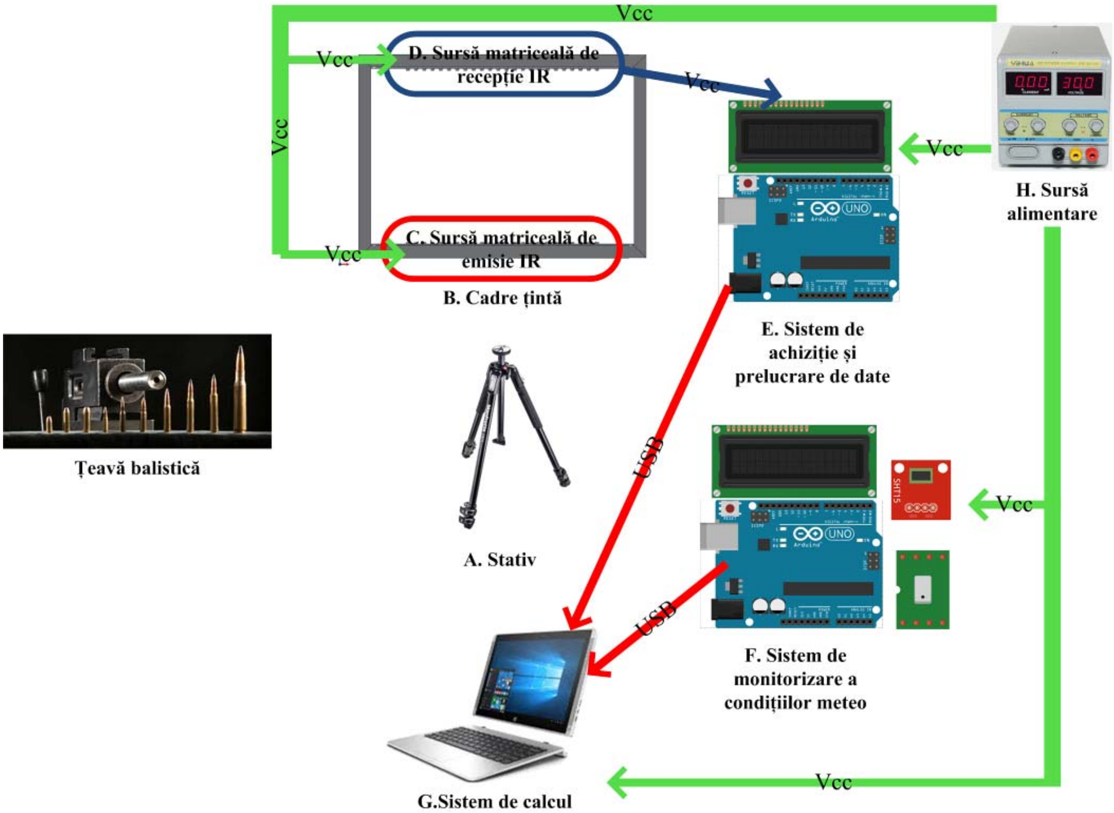

Fig. 3.3. Schematic of the designed ballistic chronograph.

The emission and reception between the emission IR matrix C and the receiver matrix D is improved using a pulses generator which is built using a 555 timer circuit. This circuit can generate a signal between 90 kHz and 200 kHz, and duty cycles from 10% to 90 %. The schematic of this circuit is presented in Fig. 3.5.

This pulse generator is designed to generate pulses from 90 kHz to 200 KHz.

The signal measured on oscilloscope for this generator is presented in Fig. 3.6.

The receiving circuit is build using a 555 timer too and his schematic is presented in Fig. 3.8.

The pulse generator circuit is presented in Fig. 3.7. This pulse receiver is based on 555 timers and can receive and amplify the signal received from the source. This circuit was design to give a pulse when the projectile is passing throw the gate. The signal measurement is presented in Fig. 3.9.

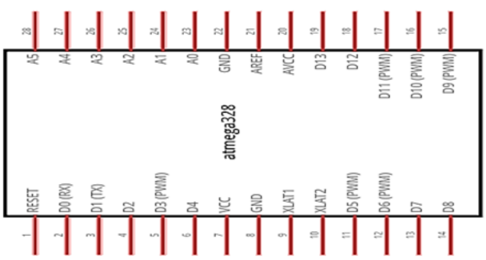

Fig. 3.4. Atmel Atmega 328P-PU pins scheme.

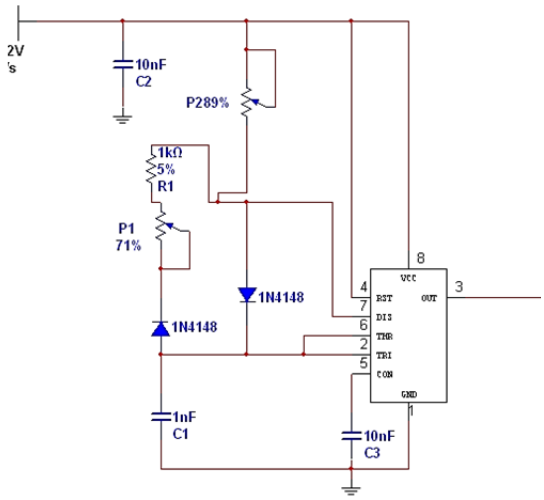

Fig. 3.5. Pulse generator schematic.

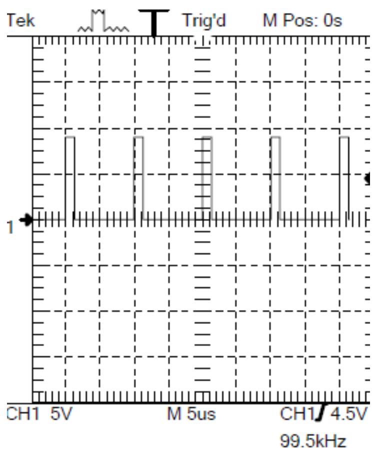

Fig. 3.6. Signal given by the pulse generator to the IR matrix generator.

The electronics of the ballistic chronograph is special designed to permit to the Atmel ATMega328P-PU microcontroller to detect the pulse of time-start and pulse of time-stop these two values of time help us to determine the value of velocity for a known distance between the two gates.

In final as we can observe the system designed can offer the capabilities and fulfill the objectives proposed in chapter 2.

Fig. 3.7. Signal pulse generator using the schematic presented.

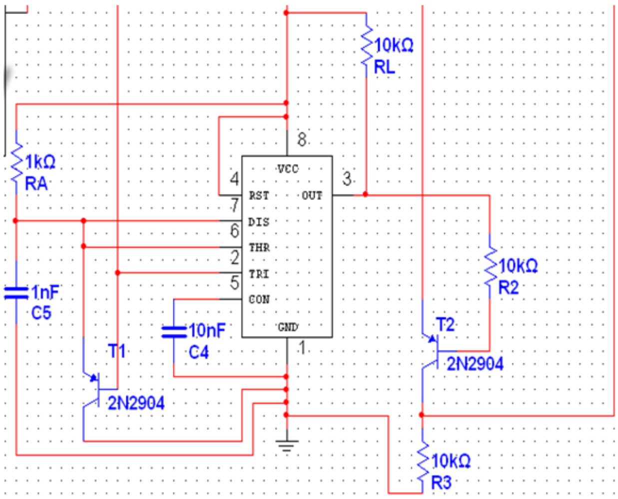

Fig. 3.8. Pulses receiver schematic.

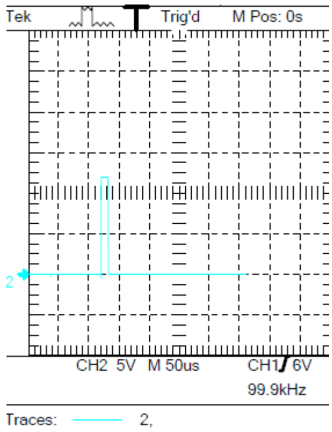

Fig. 3.9. Signal when the projectile passes throw the gate.

3. CONCLUSIONS

In this study was presented a solution for an „in-house" ballistic chronograph used to measure projectile's velocities near the muzzle. This solution offers to CCSFN's specialist an instrument for ballistic evaluations for projectiles of 30 mm caliber and velocities greater that 890 m/s. Also were fulfill the objectives proposed in chapter 2 to solve this problem. As a perspective for this problem we want to go further more and connect this instrument to complex software which makes ballistic calculus such as projectile's velocity experimental data statistical estimations, drag coefficient evaluation or even trajectory evaluation. In this was developed a software interface as can be seen in Fig. 4.1. This software is named StatTech and is an „in-house" application too. The software and the ballistic chronograph were used together as an experimental model and it works fine. In future the software and the ballistic chronograph will be used for further tests to ensure their proper functionality.

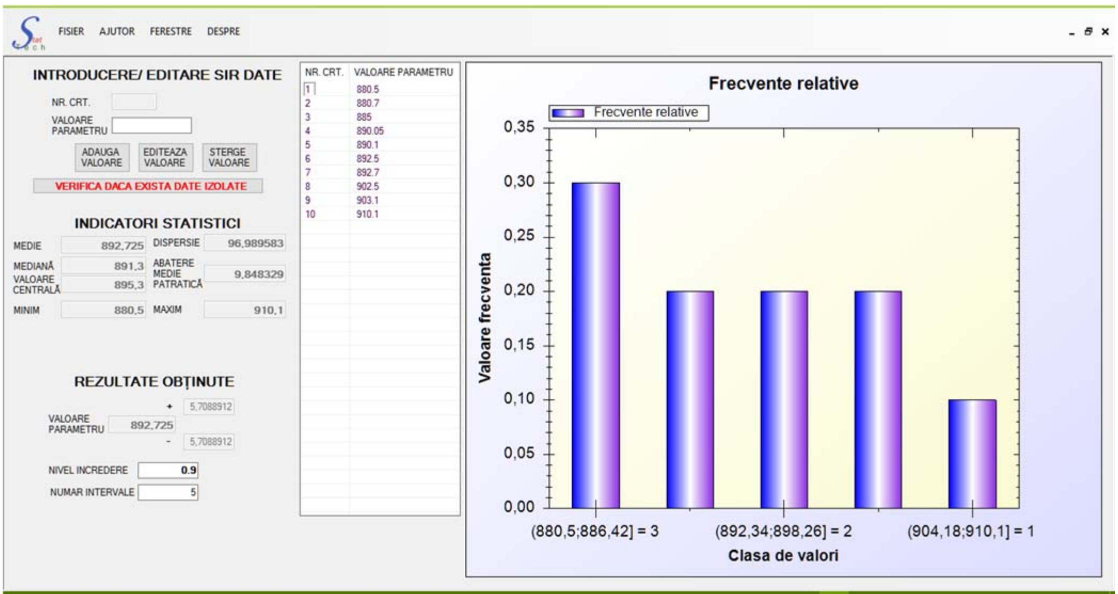

Fig. 4.1. StatTech application used with the ballistic chronograph real time data statistics evaluation [4].

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