

Researching the explosive train detonation time of the electronic time fuze for the underwater pressure device

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ABSTRACT

In this paper, using numerical simulation combined with experiment, the detonation time of the explosive train of the electronic time fuze from the signal source to the fuze booster has been determined. The results show that the influence of the transmission line and the connector on the detonation train time is very small, this influence in the design can be ignored. The results after the study are proven experimentally and the experimental results show that the simulation results are reliable and highly applicable. The results of the article are applied to manufacturing and testing electronic time fuze use for the underwater pressure device.

Keywords: Electronic time fuze; Underwater pressure device; Explosive train; Detonation time.

1. INTRODUCTION

Currently, Vietnam uses underwater pressure device fuzes that use a watch mechanism or lead pin as a safe and arm system. These types of fuzes have the advantage of being more technologically accessible than the modern fuzes that are being used around the world. But these types of fuzes partly do not meet the requirements of modern warfare, such as large timing errors and the dangers of use and combat. The watertight depth is small as well as the accuracy of the system is highly dependent on the temperature of the environment. In particular, in the combat capability of detonating a group of devices at the same time, there is no fuze in use in Vietnam that can meet this feature.

In the world, many countries have researched, produced and equipped the military with various types of devices for underwater special forces, using electronic time fuze. For example MILA 6C, PDM 120, PPZ-2B, PDM-1C [1]. The fuze system is operated with safety and arm mechanisms including mechanical and electronic. The fuze is activated remotely by microprocessors with less dependence on ambient temperature, timer errors controlled using electronics, ability to use devices at higher depths, possibly greater than 50 m. In particular, the fuze can be used to activate a group of devices at the same time, capable of hitting multiple targets at the same time with high accuracy. This feature will make the combat force much more convenient in hitting targets such as oil platforms and modern ship systems.

During the detonation of the fuze explosive train, it will take some time between the source of the signal and the full detonation of the fuze booster. With respect to the requirement to detonate multiple different fuzes at the same time, the detonation time is one of the factors that cause the detonation time error between the fuzes. Requirements in actual combat, the detonation time from the signal source to the detonation of the booster must be less than 1 ms. Solving the problem of detonating the explosive train completely since the activation signal source is given as a basis for designing, researching and perfecting the explosive train so that the system of many fuzes can be activated to ensure the error within the allowable error.

2. FUZE EXPLOSIVE TRAIN TIME DETERMINATION

After the fuze is fully armed, at the appropriate time when receiving the detonation signal source, the signal will pass through the transmission line to activate the electrical primer. The electrical primer will detonate the booster of the fuze. At this time, the total time of the explosive train is calculated as follows: total time is equal to the time signal of the transmission line and connector plus the time of the primer-booster explosive train. The research model is shown in figure 1.

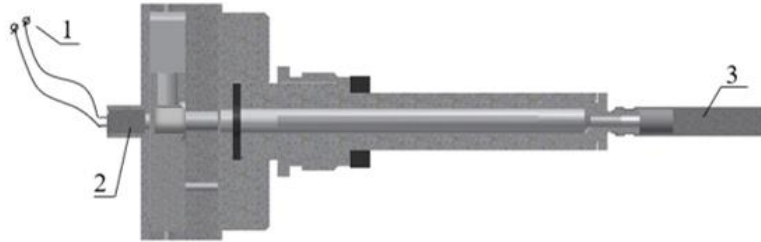


Figure 1. Explosive train of the electronic time fuze
1. Signal source; 2. Electrical Primer; 3. Booster.

2.1. Signal propagation time in transmission line and connectors

The propagating signal time and length of the transmission line [2] are related by:

$$TD = \frac{Len}{v} \quad (1)$$

where: TD: Propagating signal time, in nsec; Len: Transmission line length, in inches; v: Speed of the signal, in inches/nsec;

The speed of the change, or the kink, v, is given by:

$$v = \frac{1}{\sqrt{\epsilon_0 \epsilon_r \mu_0 \mu_r}} \quad (2)$$

where: ϵ_0 : permittivity of free space = 8.89×10^{-12} F/m; ϵ_r = relative dielectric constant of the material; μ_0 = permeability of free space = $4\pi \times 10^{-7}$ H/m; μ_r = relative permeability of the material.

Putting in the number, v is:

$$v = \frac{11.8}{\sqrt{\epsilon_r \mu_r}} \left(\frac{\text{inches}}{\text{nsecs}} \right) \quad (3)$$

For virtually all interconnect materials, the magnetic permeability of the dielectrics, μ_r , is 1.

With $\epsilon_r = 7$ (for rubber), the velocity is calculated as follows:

$$v = \frac{11.8}{\sqrt{7}} = 4.45 \left(\frac{\text{inches}}{\text{nsecs}} \right) \quad (4)$$

For the transmission line length of the electrical time fuze, the total transmission line through the 1000 inch:

$$TD = \frac{1000}{4.45} = 224.7 \text{ (nsec)} = 0.225 \text{ (}\mu\text{s)}$$

2.2. Time of primer – booster explosive train

- Simulation model using Ansys software [3-7]

Shock equation of state

$$p = p_H + \Gamma p(E - E_H) \quad (5)$$

$$p_H = \frac{p_o c_o^2 \mu (1 + \mu)}{[1 - (s - 1)\mu]^2} \quad (6)$$

$$E_H = \frac{1}{2} \frac{p_H}{p_o} \left(\frac{\mu}{1 + \mu} \right) \quad (7)$$

Shock velocity is calculated as follows:

$$U = C_1 + S_1 u_p + S_2 u_p^2 \quad (8)$$

where C_1 , S_1 and S_2 are constants, u_p is particle velocity and Γ is Gruneisen coefficient.

Johnson–Cook constitutive equation

This model is used to express the strength behaviour of materials, typically metals, exposed to high stress and high temperatures. Such behaviour could arise in problems of intense impulse loading due to high-velocity impact. In this model, the yield strength varies with stress, strain rate, and temperature. The model defines the strength Y [5]:

$$Y = [A + B \varepsilon_p^n][1 + C \ln \varepsilon_p^*][1 - T_H^m] \quad (9)$$

where ε_p is the effective plastic strain, ε_p^* is the normalized effective plastic strain rate, T_H^m is the homologous temperature and A , B , C , n and m are material constants. The expression in the first square bracket gives the stress as a function of strain, when $\varepsilon_p^* = 1,0 \text{ s}^{-1}$ and $T_H^m = 0$ (for laboratory experiments at room temperature).

Equation of state JWL for explosive materials [6]

The JWL EOS is widely used in different forms (two, or three terms) according to the level of accuracy in the pressure-volume domain that applications need. The foundations of the relationship chosen to represent the reference curve, Chapman-Jouguet (CJ) isentrope, can be found assuming that the DP expansion isentrope issued from the CJ point is very nearly coincident with the Crussard curve in the pressure-material velocity plane. Its mathematical expression, using an appropriate relationship between shock velocity and material velocity leads to the exponential terms of the JWL EOS.

$$p = A \left(1 - \frac{w\eta}{R_1} \right) e^{-\frac{R_1}{\eta}} + B \left(1 - \frac{w\eta}{R_2} \right) e^{-\frac{R_2}{\eta}} + wpe \quad (10)$$

where $\eta = \rho / \rho_0$, ρ_0 is the reference density ρ the density. The values of the constants A , B , R_1 , R_2 and w for many common explosives have been determined from dynamic experiments.

In this paper, Johnson and Cook constitutive equation, Equation of state JWL and Shock equation of state are used to describe the properties of materials. The explosive material properties for electrical primer and booster are built as follows in table 1. The explosive used is TEN, this is a widely used explosive and has a studied material parameter and is in the library of Ansys software.

Table 1. Material properties of explosive.

N ^o	Name	Value	Unit
1	Density	1770	kg/m ³
2	Equation of state	JWL	-
3	Parameter A	6.17e8	kPa
4	Parameter B	1.69e7	kPa
5	Parameter R ₁	4.4	-

Research

N ^o	Name	Value	Unit
6	Parameter R_2	1.2	-
7	Parameter W	0.25	-
8	C-J detonation velocity	8300	m/s
9	C-J energy	1e7	kJ/m ³
10	C-J pressure	3.35e7	kPa

D16T aluminium material is used to research, design and manufacture fuze body. This is the widely used material in current research and design, the material properties of the piston are presented in table 2.

Table 2. Material properties of fuze body.

N ^o	Name	Value	Unit
1	Density	2770	Kg/cm ³
2	Shear Modulus	2.86e10	Pa
3	Specific Heat	875	J/(kgK)
4	Equation of state	shock	-
5	Gruneisen coefficient	2	-
6	Parameter C_1	5.3e3	m/s
7	Parameter S_1	1.33	-
8	Constitutive equation	Johnson Cook	
9	Yield strength	395	MPa
10	Hardening constant	343	MPa
11	Hardening exponent	0.18	-
12	Melting temperature	946	°C

Figure 2 shows the boundary conditions of the simulation problem. The boundary conditions are developed based on the basic tactical specifications of the primer-booster explosive train operating condition. To measure the detonation time of the explosive train, gauge points are attached to the primer and booster locations when the simulation is set up. At the location of the primer, a detonation point is constructed.

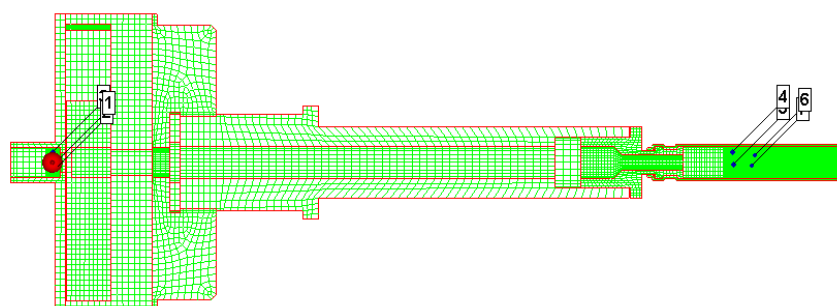


Figure 2. The boundary conditions of the simulation problem.
1,2,3. Detonation point gauges; 4,5,6,7. Booster gauges.

- Simulation results

Ansys Explicit dynamic module [7] is used to solve the primer-booster explosive train time problem with the assumptions presented above. The time of the primer-booster explosive train is determined.

Figure 3 shows the result of the process of propagating explosive waves from the electrical primer to the booster.

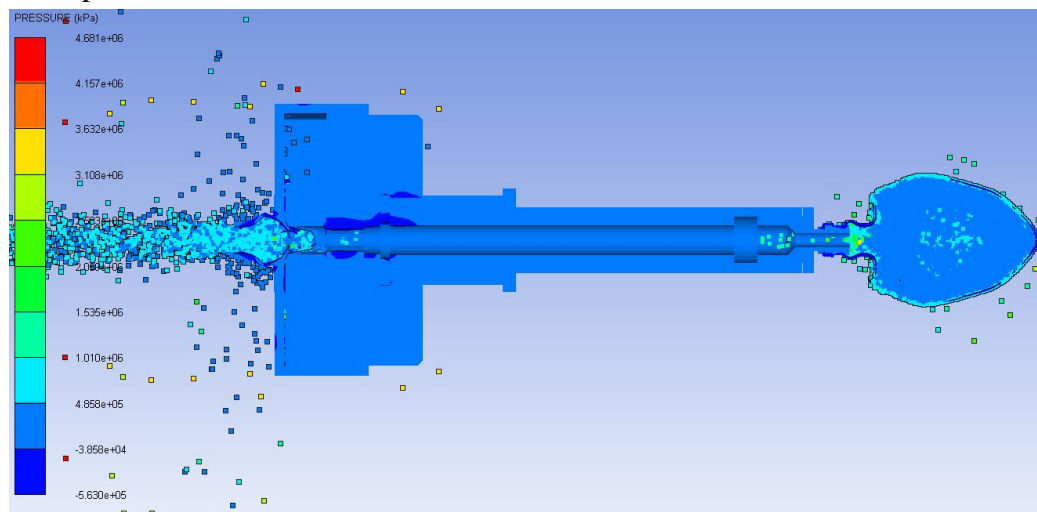


Figure 3. The moment during the explosion of the booster.

Figure 4 shows the result of the primer–booster explosive train time. At time $t=0$, which is primer detonation time, after 0.35 ms the booster is detonated. Gause points from 1 to 3 represent primer pressure and gause points from 4 to 7 represent booster pressure.

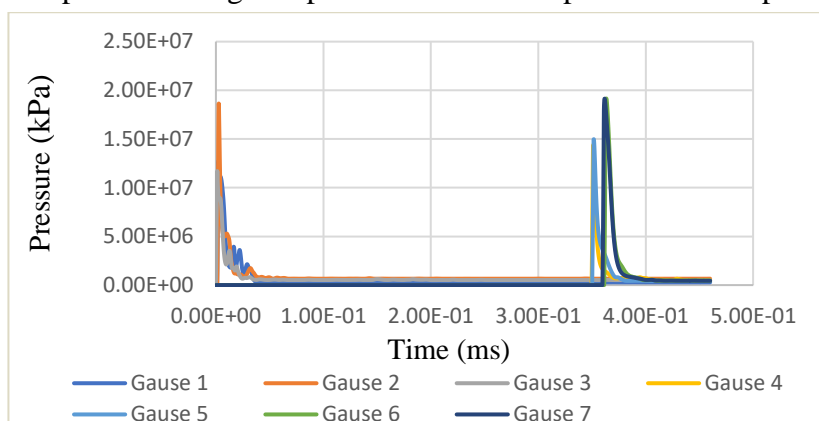


Figure 4. The primer–booster explosive train time.

From simulation and calculation results of signal transmission time from the signal source to the connector and detonation time of primer – booster explosive train, it can be seen that the detonation time of primer – booster explosive train accounts for a large proportion, while signal transmission time from the signal source to the connector can be ignored.

3. EXPERIMENT AND DISCUSSION

3.1. Signal transmission time experiment

The influence of connectors has not been studied theoretically in this paper. The signal transmission time from the signal source through the line to the connector is determined experimentally, the experimental results are shown in figure 5 and table 3.

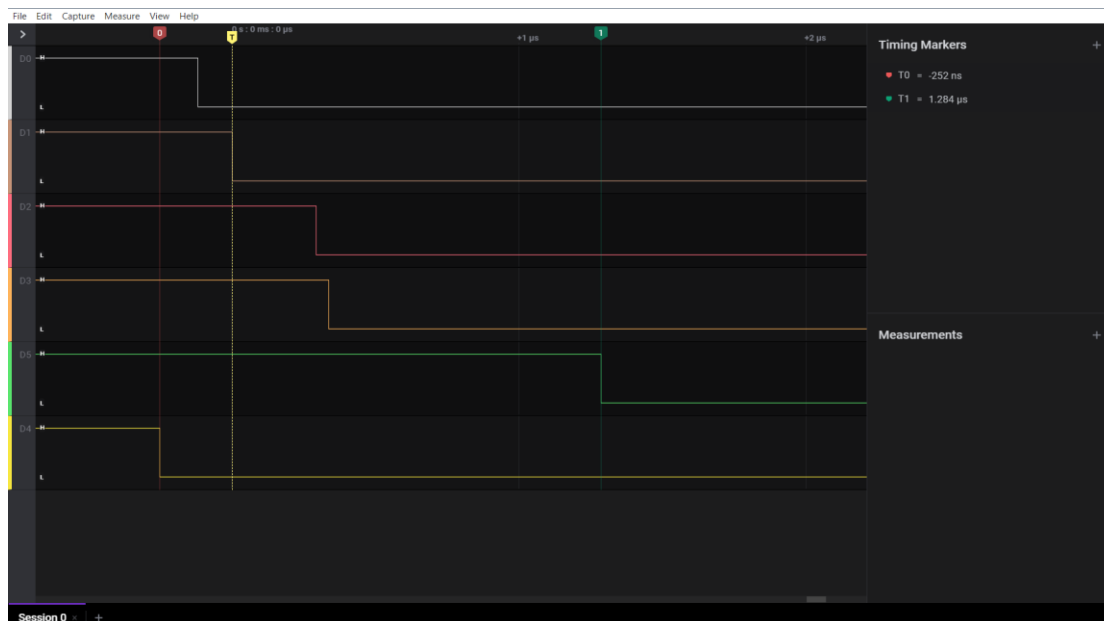


Figure 5. Experimental results of signal transmission time from source to the connector.

Figure 5 shows the experimental results of the measurement of the time taken to transmit the signal from the signal source to the connector. During the experiment, a signal source will transmit the signal simultaneously to 6 connectors.

Table 3. Result of signal transmission time from the signal source to the connector.

N ⁰	The first signal T0 (10 ⁻³ ms)	The last signal T1 (10 ⁻³ ms)
1	0.252	1.284
2	0.388	1.748
3	0.420	2.536
4	0.432	2.548
5	0.158	1.928
6	0.236	2.232
7	0.180	1.228
8	0.244	1.780
9	0.400	2.592
10	0.380	2.944
11	0.340	2.492
12	0.324	2.316
13	0.416	2.480
14	0.352	2.420
15	0.464	2.652
16	0.444	2.308
17	0.332	2.776
18	0.396	2.164
19	0.468	2.288
20	0.364	2.796

Thus, signal transmission times from the signal source to the connectors are very small, falling in the range of microseconds. In design calculations, these values can be ignored.

3.2. Explosive train detonation time experiment

The experiment was conducted at the firing range of the Weapons Institute - General Department of Defense Industry. The experiment is arranged as shown in figure 6. The electrical primer is ignited with a current of 0.15 A, the booster is arranged in a bunker to ensure safety during the test. Before conducting the test, the resistance values of the primer-booster train were measured.

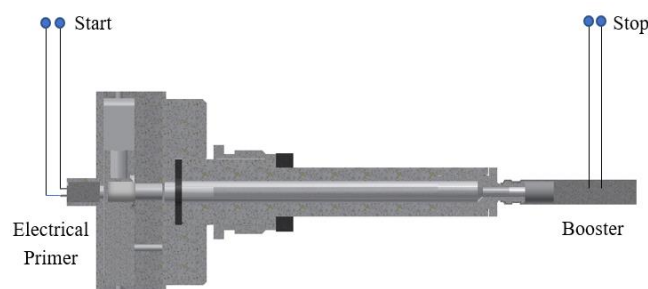


Figure 6. The experiment diagram.

Experiments using 10 samples have been carried out for the simulation results confirmation. The results of the primer-booster explosive train time are shown in table 4 and figure 7.

Table 4. The primer-booster explosive train times of experiments

N ^o	Name	R, Ω	t, ms
1	Primer-booster explosive train time	10	0.34
2		9.3	0.41
3	Primer-booster explosive train time	9.2	0.33
4		9.7	0.38
5		9.7	0.37
6		9.3	0.42
7		9.5	0.35
8		9.6	0.39
9		9.8	0.43
10		9.7	0.33
The average value		9.58	0.375

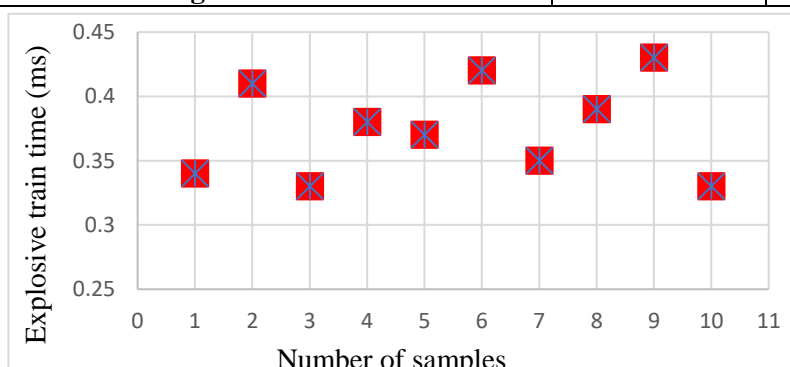


Figure 7. Experimental results.

3.3. Comparison of simulation and experimental results

Figure 8 presents the comparison of the simulation and experimental results of the

primer–booster explosive train times. The results of the simulation agree very well with the experimental results. The difference between an experimental and theoretical value can be explained by the following reasons:

The manufacturing dimensions of the fuze body and the explosive mass of primer and booster have tolerances, while the dimensions and explosive mass of the simulation model are the nominal values;

Material properties of the model have errors compared with the material manufactured of the TEN explosive and fuze body (Aluminum);

Measurement error during measurement of experimental results.

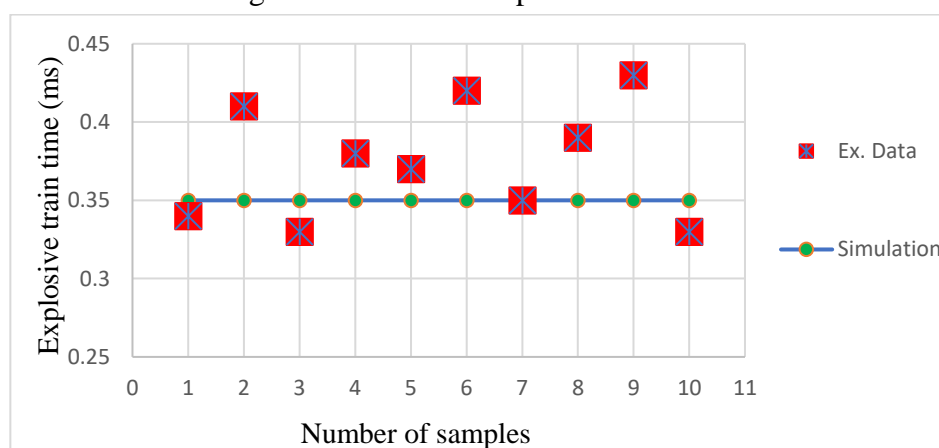


Figure 8. Comparison of simulation and experimental results.

The average primer-booster explosive train time of experiments is 0.375 ms and the error between the explosive train time of the simulation and the average of experiments is about 6.7%. The error between the simulated value and the minimum experimental value is about 6%, and the error between the simulated value and the maximum experimental value is about 18%.

4. CONCLUSIONS

The simulation model using Ansys explicit dynamic is built for solving the explosive train time between the signal source and the fuze booster. In this article, the influence of the connector has not been fully theoretically studied. However, signal transmission times from the signal source to the connectors are very small, falling in the range of nanoseconds and microseconds. In design calculations, these values can be ignored. All dimensions of the fuze body, explosive mass and the length of the transmission line are according to basic tactical specifications and sketches.

The model uses uniform three-dimensional solid elements and the Johnson and Cook constitutive equation, Equation of state JWL and Shock equation of state for material properties. Analysis of the explosive train time is presented in this paper to determine the value of the detonation time from signal source to fuze booster, as a basis for designing the maximum number of fuzes that can be detonated from a single signal source with an error within the permission request.

Comparison of simulation results using ansys explicit dynamic and experimental

results confirm that all results of simulation agree with the results of experimental very well. The error between the explosive train time of the simulation and the average of experiments is about 6.7%.

The results of the article are applied to manufacturing and testing the electronic time fuze.

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TÓM TẮT

Nghiên cứu thời gian kích nổ chuỗi nổ của ngòi hẹn giờ điện tử sử dụng cho thiết bị áp suất dưới nước

Trong bài báo này, sử dụng phương pháp mô phỏng số kết hợp với thực nghiệm, thời gian của mạch nổ của ngòi hẹn giờ điện tử từ nguồn tín hiệu đến trạm nổ của ngòi được xác định. Kết quả chỉ ra rằng, sự ảnh hưởng của dây dẫn và giắc kết nối đến thời gian chuỗi nổ là rất nhỏ, rơi vào micro giây, trong quá trình thiết kế có thể bỏ qua. Kết quả sau nghiên cứu được chứng minh bằng thực nghiệm, kết quả thực nghiệm cho thấy kết quả mô phỏng là tin cậy và có tính ứng dụng cao. Kết quả của bài báo được áp dụng vào chế tạo và thử nghiệm ngòi hẹn giờ điện tử sử dụng cho thiết bị áp suất dưới nước.

Từ khóa: Ngòi hẹn giờ điện tử; Thiết bị áp suất dưới nước; Mạch nổ; Thời gian kích nổ.