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MEASUREMENTS OF SHOCK WAVE FORCE IN SHOCK TUBE WITH INDIRECT METHODS

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Key words: civil explosive, initiation, time delay, shock tube, impact energy, shock wave force, blasting

Abstract

Tests have been conducted at the "Laboratory for testing of civil explosives, detonators, electrical detonators and pyrotechnical materials", Department for mining and geotechnics of the Faculty of mining, geology and petroleum engineering, University of Zagreb with the purpose of designing a detonator that would unite advantages of a non-electric system and the precision in regulation of time delay in electronic initiation system. Sum of energy released by the wave force in shock tube is a pre-condition for operation of the new detonator, and measurement of wave force is the first step in determining the sum of energy. The sum of energy is measured indirectly, based on two principles: movement sensors and strain

Ključne riječi: Gospodarski eksploziv, iniciranje, usporenje, udarna cjevčica, energija udara, sila udarnog vala

Sažetak

U Laboratoriju za eksplozive, Rudarsko geološko naftnog fakulteta, Sveučilišta u Zagrebu, obavljaju se ispitivanja s ciljem pronalaženja izvedbe detonatora koja ujedinjuje prednosti neelektričnog sustava iniciranja i preciznost regulacije intervala usporenja elektroničkog detonatora. Količina energije koju oslobađa udarni val cjevčice preduvjet je za djelovanje novog detonatora, a prvi korak za njeno određivanje je mjerenje sile udarnog vala. Sila udarnog vala mjerena je posredno, na dva načina; senzorima pomaka i otpornim mjernim trakama.

Introduction

A non-electric system of firing in civil blasting has a number of advantages in comparison with other initiation methods. Those advantages are: resistance to static electricity and currents, simple connecting to blast field, resistance to humidity, greater mechanical durability and volume of the tube, no limitation of the number of blast holes (degrees of firing) in blast field, no destruction of blast hole stem, no air shock wave production, multiple time-differentiated detonations, preserved structure of emulsion and ANFO explosives. One of the disadvantages is a significant difference in time delay for greater degrees of firing (5000 – 6000 m/s) used more frequently in construction of tunnels, underground objects and ravines. For contour blasting, time synchronization is a paramount factor for shape of contour blast. Time is determined by delay-element of the detonator, pyrotechnic mix with precise time consumption, which is undeterminable for the total time greater than 5000 m/s. This element requires a new delay element that can solve this problem, and was found in the new system (detonator) that combines advantages of non-electric (simplicity, speed, and cost) and electronic regulation of time delay. Determination of shock wave force in shock tube is a basis for selection of an optimal time delay transducer for the new type of detonator.

Measurement of shock wave force in shock tube

Shock wave velocity measurement

Characteristics of shock tube used for testing were the following: inner diameter 1.2 mm ± 5(%), and outer diameter 3 mm ± 5(%), octogen-HMX filling 15-17 (mg/m). Shock tube was initiated using «Spark blasting machine jr-1» in all tests.

Shock wave measurement in shock-tube was conducted in order to determine the in uence of velocity on the force of the shock wave. Electro-optical method was used for measurements. Velocity of shock wave is measured with electronic stop-timer and direct measurement of shock wave travel time in shock-tube. The device is receiving impulses through optical fiber cables. In measurements, device calculates the velocity on basis of time and distance between probes. Measuring device is electronic stop-timer «Explomet-FO-2000» of the following characteristics: max. measurable velocity 10,000 m/s, time interval from 0.1 do 10 s, with the accuracy of +/- 0.1 s. Velocity was measured on meter-segments on 1 to 4 meters of the tube to determine velocity per length, and its in uence on shock wave force. Measured velocities were in range from 1642 to 1754 m/s. Table 1 presents measurements results. Measurement equipment is shown in Fig. 1.

Table 1 Velocity of shock wave measurements results

Tablica 1. Rezultati mjerenja brzine udarnog vala

Measurement No.	Type of explosive	Initiating System	Probe distance (m)	Time t(μs)	Velocity (m/s)
			L =1	577,1	1732
1	Shock	SPARK	L_2 =1	570,1	1754
	tube	BLASTING	L_3 =1	575,5	1737
		MACHINE	L_4 =1	581,3	1720
			L =1	608,8	1642
2	Shock	SPARK	L_2 =1	583	1715
	tube	BLASTING	L_3 =1	595	1680
		MACHINE	L_4 =1	595,5	1679
			L =1	571,8	1748
3	Shock	SPARK	L_2 =1	575,7	1737
	tube	BLASTING	L_3 =1	582	1718
		MACHINE	L_4 =1	579,8	1724

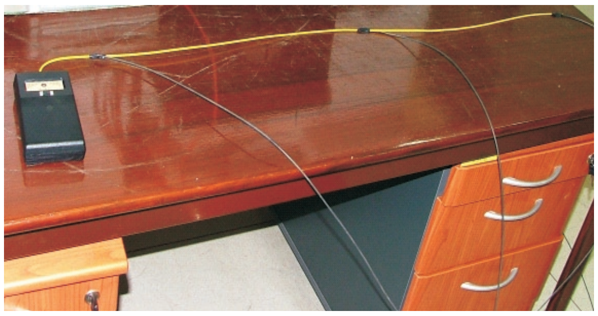

Figure 1 Velocity of shock wave, measurement equipment

Slika 1. Mjerna oprema , mjerenje brzine detonacije

Shock-wave force measurement with LVDT sensors

LVDT sensors work on shift principles. Shift in tin-plate membrane during firing of shock tube is measured. Prior to measurement, measuring apparatus was calibrated with static load on hydraulic press with dynamometer. Used equipment is as follows: hydraulic press, dynamometer, LVDT sensor, measuring frame, computer registrator (Spider 8). The measuring frame consists of: body, tin-plate membrane, transition piston, basis for tube. The tube is fixed to the basis, sitting tightly on transition piston attached to tin-plate membrane. During the calibration, determined force is applied through additional piston to transition piston that elastically deforms tin-plate membrane up to values expected during measurement of shock wave force. Membrane shifts are measured on LVDT probes, transferred to calibration curve. Measuring frame is displayed in Fig. 2 and measuring apparatus in Fig. 3.

Measurement Description. Measuring is indirect, by measuring of deformation of circular tin-plate membrane using LVDT probe, size of deformation is proportional to the deforming force.

Measuring Phases are:

a) Calibration of LVDT probes
b) Measurement of shock-wave in shock tube

LVDT probe measures shifts with the electro induction method. Calibration of probes with static force creates correlation of shift (elastic deformation of tin-plate membrane) and force used. A curve with the highest correlation factor R was extracted from specific Calibration series and was used in further results handling. Calibration was performed till shifts, after the applied force, were repeated, or till Calibration and permanent plastic deformation of tin-plate membrane was achieved. Measuring apparatus is schematically given in Fig. 3. Calibration curve and LVDT diagram are presented in Fig. 4. Maximum force used for calibration was 50(N). This value was maximum force against the strength of tin plate membrane. Load force above this value caused larger plastic deformations of the membrane and maximum shift of LVDT probes. Force value is determined through LVDT measured values (mV/V), which are transformed according to calibration. (Fig. 4).

The same equipment that was used for calibration of LVDT probes is used for shock wave force measurements, under the same conditions as for the calibration. This ensures accuracy of measurement.

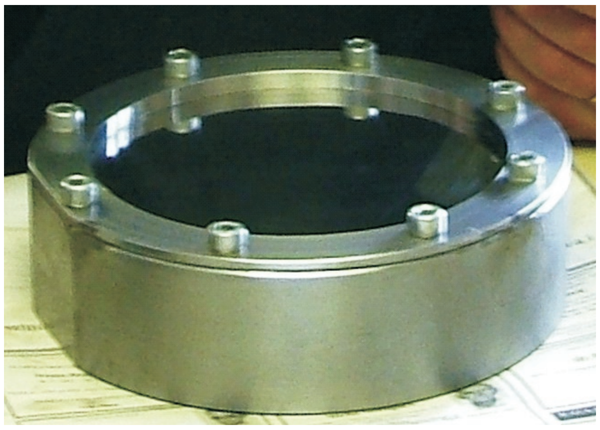

Figure 2 Measuring frame

Slika 2. Mjerno kućište

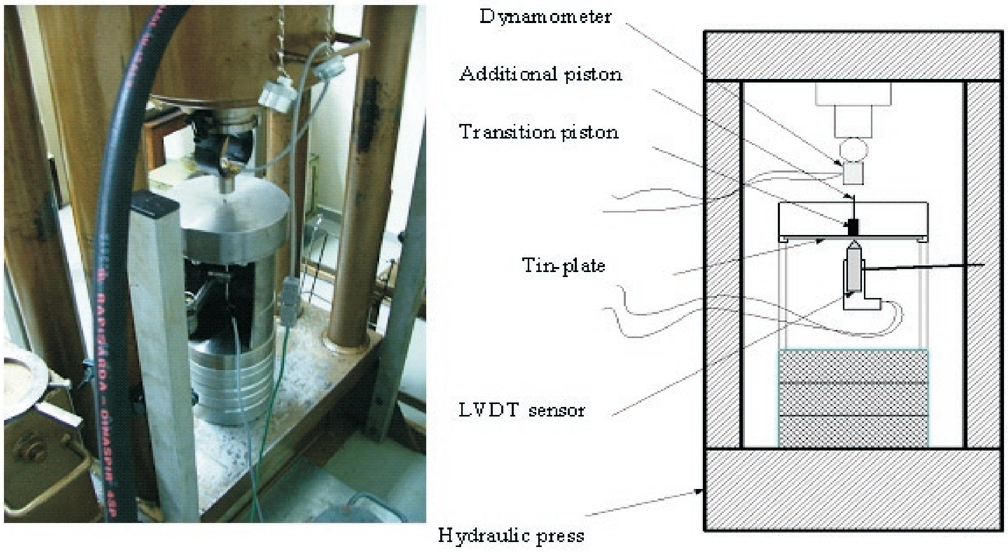

Figure 3 Measuring apparatus

Slika 3. Mjerna oprema

Table 1 Measured shock-wave force values

Tablica 2. Mjerene sile udarnog vala

Measure no.	LVDT [mV/V]	Force [N]
1	9,96048	190,685
2	8,80944	156,790
3	10,26144	216,0931
4	12,24432	308,5739
5	10,47216	225,291

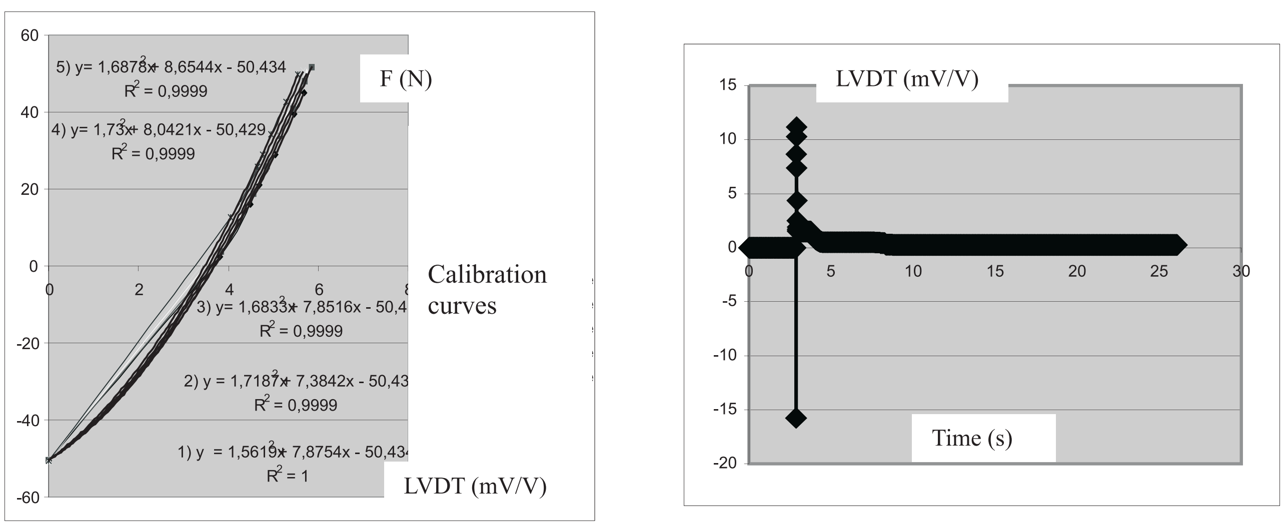

Figure 4 Calibration curve and LVDT diagram

Slika 4. Umjerna krivulja i dijagram LVDT-a

Shock tube is fired at the segment, where additional piston was placed for calibration. An additional piston was attached to transition piston of 4.1 mm diameter applied to tin-plate-membrane. Measurement was performed with tubes of a different length, to correlate the amount of charge to shock wave force. Shock wave reaches the piston, transferring the impulse to membrane and shifting a probe. LVDT sensor data are calculated and in correlation to calibration curve, values of shock wave force are determined.

Measured shock wave force values are given in Table 2.

Negative values on LVDT diagram are caused with inertness of probes. Transition shock impulse travels with the speed of shock wave (~1700 m/s), and probes are designed for static loading. Because of such measuring system inertness, probe is "confused" and the value is negative. The negative value has no practical meaning.

Shock-wave force measurement with strain gauges

Equipment and apparatus used in this measurement are the same as used in LVDT measurements. While LVDT measurement observed shift in membrane, strain gauge sensors change is in electric resistance with different load. Measurement is indirect, from the deformation of circular tin-plate membrane using strain gauge, where the size of deformation is proportional to the force that has caused it.

Measurement phases with strain gauges are; calibration of strain gauge and measurement of shock wave force in shock-tube. Measurement frame with sensor is given in Fig. 5.

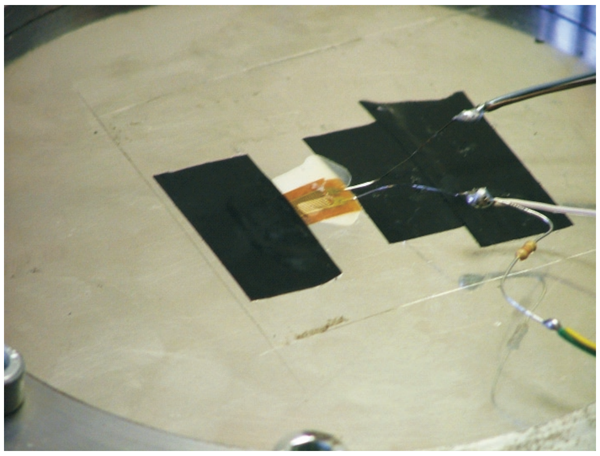

Figure 5 Measurement frame with sensor

Slika 5. Mjerno kučište sa senzorom

Measurement equipment is the same as in LVDT process. Tin plate membrane is 1 mm thick, with sensor applied to it 24 h prior to the test.

Calibration of strain gauge is performed in the same way as the calibration of LVDT probes. Calibration curve and strain gauge diagrams are given in Fig. 6. Mean values of the measured force for different lengths of shock tube are given in Table 3.

Table 3 Mean values of measured force Strain gage

Tablica 3. Srednje vrijednosti mjerene sile sa mjernim otpornim trakama

Tube length (m)	Force [N]
0,5 m	71,32
1.0 m	53,63
2.0 m	64,43
4.0 m	208.87
1.0 m, fixed	208,29

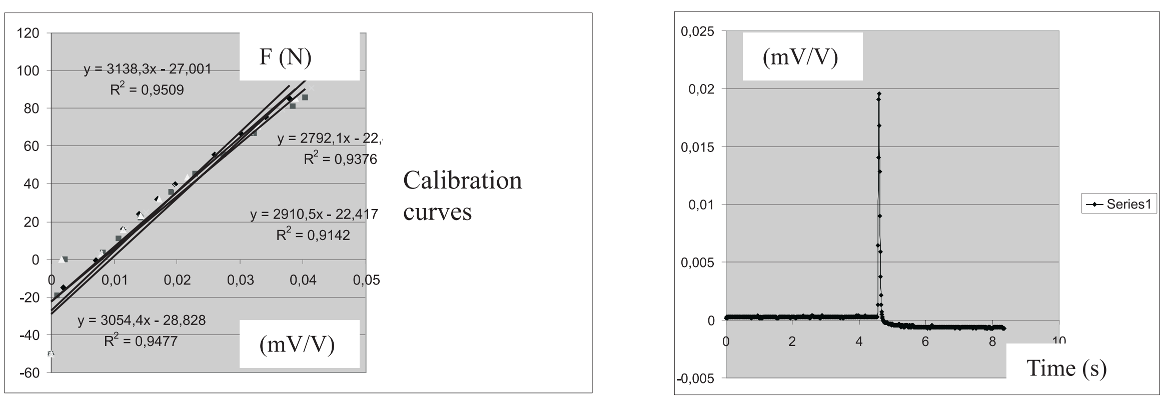

Figure 6 Calibration curve and strain gage diagram

Slika 6. Umjerna krivulja i dijagram otporne mjerne trake

Conclusion

Shock-wave force in non-electric shock-tube in this test is determined by tube length, velocity, outer diameter of the tube and tube fixation.

Increasing of velocity of shock wave is proportional to tube length; the greater is the length, the greater the velocity, and proportionally – the greater the force. After stabilization, velocity depends on the amount of explosive charge used in different segments of the tube. Increase in velocity during the first meter of length is 5% that results in force increase of 20% according to maximum of mean force and velocity values for groups of different tube length.

Correlation diagram of shock wave velocity and force is constructed depending upon maximum mean values. The maximum value on the diagram (100%) is represented by the maximum mean force value and maximum mean velocity, and all the other values are shown in percentage to maximum values. X-axis is series of measurement. Diagram is given in Fig 7. The in uence of velocity to force is evident. Changes in speed are relatively small and range between 96 and 100%, while changes in force vary from 73 to 100%. Incremental changes in speed result in significant change in force inside the tube.

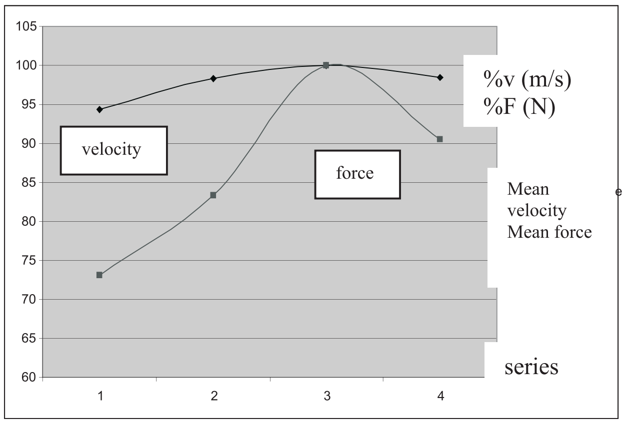

Figure 7 Velocity-force diagram

Slika 7. Dijagram zavisnosti sile o brzini

Tube fixation. Tubes of different lengths and various diameter and thickness were used in this test. Rated diameter of the tube is 3 mm +/- 5%, resulting in

outer diameter range of 2.85 to 3.15mm. A tube is fixed into 3 mm diameter frame. Depending on the tube diameter, the tube is fixed with bigger or smaller friction, which is relevant to energy loss during firing through space between tube and frame.

Fixing and tight sealing of the tube in frame increase shock wave force. The results of compared measurements are given in Table 4 and the diagram is presented in Fig. 8.

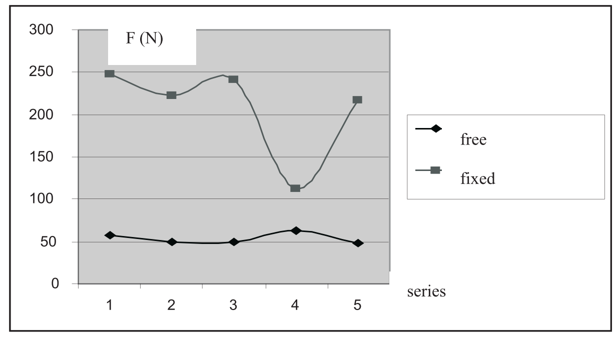

Figure 8 Shock wave force, free and fixed shock tube

Slika 8. Dijagram sile udarnog vala, učvršćena i slobodna udarna cjevčica

Table 4 Compared measurements force results

Tablica 4. Usporedni rezultati mjerenja sile

Series no.	Force (free) [N]	Force (fixed) [N]
1	57,75	248,15
2	49,76	221,74
3	50,06	241,39
4	62,66	113,028
5	47,92	217,132

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