ISSN 2229-5518

Design and Implementation of Electronic Measurement System for Velocity of Detonation of Explosive

Aruna D.Tete, Dr.Amol Deshmukh, Dr.Rajendra Yerpude

Abstract— The rate at which the detonation wave travels through an explosive column is the Velocity of Detonation (VOD). It is one of the most important property of explosive on which its performance is dependent. In this paper design and implementation of VOD measurement unit is discussed. This unit has to be compatible with sensor designed earlier and has to work in synchronism with the detonation wave as sensed by the sensor in real time. A high speed event capturing unit based on high frequency stable clock, signal acquisition hardware to capture fast rising/falling edges of the event and long line driving capability are some of the basic requirements of the unit. This paper offers a design of an unit which has a low cost sensor, is easy to install/ setup, has reduced susceptibility to electrical noise, design and algorithm sufficient enough to be able to calculate and display VOD directly without compromising accuracy. To aid the discussion some commercially available VOD meter comparison is also presented. After review of the existing units available commercially and study of their respective merits and demerits, feature of an ideal system for the given requirement is proposed and implemented.

Index Terms— Velocity of Detonation, Sensor, Explosive, VOD meter, Electrical noise, high speed stable clock.

——————————   ◆   ——————————

1 INTRODUCTION

THE detonation velocity is a measure, in meters per second or feet per second, of the speed at which the detonation wave travels through a column of explosives. Usually these VOD values are based on laboratory measurements and empirical calculations and hence theoretical values. Evaluation of the blast design is carried out with the assumption that the explosives have performed as per the specification, which may not be true in all cases. A reduction in the VOD will cause a reduction in the detonation pressure as well as in the availability of the shock energy of the explosive. Beside all these degree of fragmentation, ground vibration produced and safety in charging and handling of explosives are equally important parameters. It is important to establish the relationship between the product's VOD characteristics to the rock environment, blast design and other parameters. The selection and evaluation of the explosive performance depends on the properties of explosive used which directly affect the blast performance. Many factors affect the detonation velocity such as explosive type, diameter, confinement, temperature and priming. Velocity of detonation (VOD) for common explosives fall within the range of 2000m/s to 6000m/s.

In order to measure the VOD electronically a transducer is required which would convert the detonation into electrical form. Such a transducer described as sensor is the basic element which has to give output in form of electrical signal in tandem with the detonation wave.

- *Author is currently pursuing Ph.D in Electronics Engineerg from Nagpur University, India.*
  aruna.tete@raisoni.net (corresponding author)
- *Second co-author is Professor of electronics engineering in G.H.Raisoni College of Engineering, Nagpur amol.deshmukh@raisoni.net*
- *Third co-author is professor of Mining engineering in V.N.I.T, Nagpur drrry61@gmail.com*

In this paper main VOD measurement unit in conjunction with the sensor design as proposed in earlier paper[1] is discussed. The sensor design[1] is continuous wire but discrete resistance type which is shown in fig.1. In this technique step change in resistance is proposed to serve as start and stop points with intermediate small step changes. This helps to increase the system reliability. This sensor is a low cost sensor, is easy to install/ setup and has reduced susceptibility to electrical noise.

Measurement of Velocity of Detonation (VOD) of an explosive in confined or unconfined space involves design and use of a sensor which faithfully follows and produces electrical signal in synchronism with the detonation wave. The electronic unit has to be compatible with the sensor. The strength of explosive and hence the dynamics of explosion may vary from explosive to explosive and may be influenced by external conditions like moisture, temperature etc. The combination of sensor and the electronic unit has to be truly faithful in these conditions and should sense detonation of varying strength/amplitude. It may be noted that the strength of explosive and it's detonation velocity are two distinct parameters and may not always be proportional or related. For eg. VOD of emulsion explosive in 25mm cartridge cost may be up to 1.5 times more than slurry (free flowing) explosive in 83mm cartridge. Strength of 25mm cartridge is much less than that of 83mm. Thus the sensor and electronics associated with it should be able to sense detonation correctly for varied type of explosives under varied conditions.

Further, in view of the destructive nature of event and to minimize cost of consumable the sensor designed uses a single pair of interconnecting wires. This helps in ease of set-up. Since long length electrical wires are involved a current source design is used to minimize noise. However since the event is very fast lasting typically a few tens of microseconds (or few

IJSER

hundreds of microseconds per meter) the electronics including the current source needs to be fast enough to report the changes correctly and accurately in real time.

In practice it is not always possible to measure VOD of explosive in hole (bulk explosives) hence usual practice is to pack the bulk explosive in cartridge form and perform VOD measurement on it. Cartridge is a single closed bag or tube of circular cross-section containing explosive material. It is punctured from one side to insert and place electric detonator for initiating it. This paper is based on experiments on such cartridged explosive.

2 Proposed Design of VOD Measurement Unit

Worldwide some VOD meters are available to measure velocity of detonation.

- VODMate from Instantel and Minitrap and Handitrap from MREL are based on resistance wire continuous VOD system, some of them can also use probe rod. In this method constant current is passed through a resistive wire pair which gets shortened continuously due to detonation. The rate of voltage drop gives VOD.
- SpeedVOD, ShotTrack are system which are based on Time Domain Reflectometer (TDR).The unit sends an electrical pulse down a coaxial cable and measures the time for the pulse to be reflected from the end of the cable.
- VODEX-100A uses point to point technique. It relies on the highly charged plasma generated within the explosion detonation front to sequentially increase the electrical conductivity at the end of series of wire pairs located at desired positions in the charge. Timers associated with these points directly gives VOD.
- FO-2000P uses point to point fiber optic system for VOD measurement. Cost of consumable for such system is very high. The resistive technique's resolution advantage was compromised by noise.
- ShotTrack has a limitation of incorrect readings when joiner is used.

Following are the field observations based on the various studies

- In most cases measurement of in-hole VOD does not even form part of any regular or periodic testing procedure. This is because no reliable and practical instrument is available to do the measurement quickly.
- Some of the constraints observed in use of present day equipment available for VOD measurement are non pickup of proper start signal, cutoff of connecting cable by fly-rock, electrical noise generated during explosion.
- Non uniformity in interconnecting cable (in case instrument is based on Corrtex method).
- Requirement of expensive and complex software to derive VOD value. Result are still dependent on user interpretation of record data.
- It is also observed that most of the units are sophisticated and costly. They require skilled man power to operate it.
- Cost of consumables varies from moderate to very high.
- It may be observed that continuous resistive wire is the least cumbersome method and easy for setup with low cost of consumable. However due to continuous monitoring huge amount of data is gathered which can be handled only by means of software and hence requires skilled manpower. Also considerable time and skill is required to select appropriate data thus making it a rather time consuming and tedious process.
- A unit like VODEX-100A which gives direct display of VOD requires careful handling during setup and is not user friendly. Also accuracy level is not as good as continuous wire method. A supervising microprocessor circuit controls the counting operation and calculates VODs, stores recorded data and provides the means to communicate with DOS or Windows compatible computers. Optional PC compatible software allows data from the VODEX-100A to be transferred to a PC for analysis, graphical presentation and permanent storage.
- Fiberoptic method which is not susceptible to noise is a good method but requires costly consumables.

3 Proposed Design of VOD Measurement Unit

Following are the different issues considered for the effective design and implementation of a measuring unit.

Type and nature of sensor/transducer- This element is the most critical part of the system and has to faithfully sense and track the detonation wave. The VOD unit has to effectively and truly match this sensor.

Safety- One of the foremost requirement out of any device associated with explosive is safety. Under no circumstances should it cause initiation of explosive used. Typically in India with all the production work pressure, technical awareness not being up-to-date and hesitancy to adapt to new ideas, safety aspect has to be clearly defined in a way that totally satisfies the utility/end users.

Ease of set-up- The time window available for blasting and hence testing is short. Setting up of the unit including laying of interconnecting cables, power on the unit, setting parameters if any should be within shortest possible time. Moreover

IJSER

this work has to be done in synchronism with other activities like charging up the hole, vehicular movement within the area. The design of VOD unit should facilitate its set-up by unskilled worker within short time.

Distance between sensor and VOD unit- The destructive nature of event means VOD unit cannot be kept nearby. Minimum distance of 50-60 meters has to kept. A microsecond level event, low voltage and current operation (due to safety concerns) and transmission of this signal more than 100 meters poses a real challenge for electronics.

Harsh environment- Temperature reaching 50^{0}C, very dusty environment, wet slushy ground, occasional rains, possibility of fly rocks are some of the conditions under which this unit has to operate successfully and correctly.

Low cost of consumables- Event being of destructive in nature the sensor and some length of interconnecting cable is consumed. As such the type of interlinking cable used should be low cost type. The design of VOD unit should accommodate this.

One shot nature of event – The units needs to be setup and kept ready prior to test. Thus it may have to wait for 10-20 minutes and still able to capture this microsecond level event. Also it is single occurrence event or one shot event which should not be missed. This means electronics of VOD unit should be ready for the event when set-up. More importantly the trigger has to be defined very carefully taking all possible conditions into consideration.

Portability - The VOD unit should be portable and handy. It has to operate on battery with battery condition indicator.

Direct display of VOD value on screen- Direct display of VOD value on the screen of the unit as soon as the event is completed. It should not require choosing points on recorded data to get the VOD value. This means the start trigger point and stop trigger point for sensor type used should be very clearly defined and prefixed in the VOD unit either permanently or during the set-up.

Use of prefab connectors- To facilitate easy, quick and secure interconnections prefab connectors are to be used. Cost of connector used near sensor needs to be low as it gets destructed.

Non volatile memory, real time clock to time stamp the record, visual display in the form of LCD/LED, high speed and very stable clock source, electronics for sensor interface are some of the other requirement out of the VOD unit.

Figure1 continuous wire discrete value resistor PCB based sensor

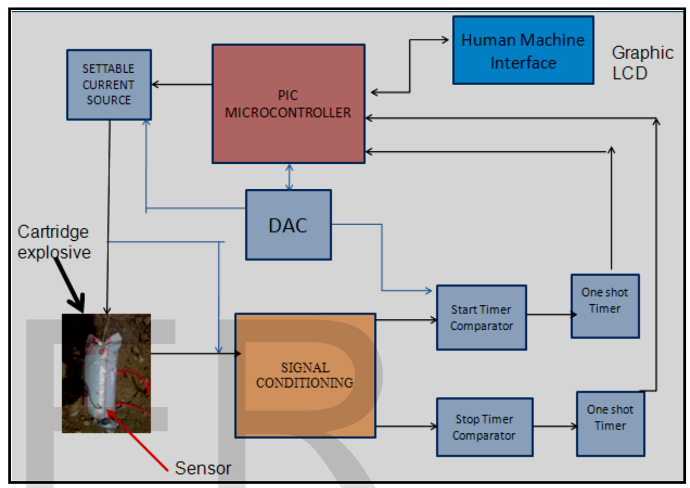


Figure 2 Proposed design of VOD measurement unit

4 EXPERIMENTATION

Case Study:

1. *Set-up required on site*

Set-up required for the experimentation on the field are VOD meter, 100 mtrs twisted pair cable. The picoscope with laptop computer(which monitor the event) is optional to compare the VOD value actually measured on site by VOD meter by capturing the event and calculated value of VOD after the event. Twisted pair wires were used to connect the sensor and the VOD meter. VOD meter has got a output port for connecting picoscope. Required set up is shown in fig.3 Initial settings of the VOD meter includes the following parameter which are highlighted in fig.4

Battery Voltage – 22V
Set Voltage SV – 17V
Set Current SI – 19.6 m amp (set automatically by instrument)
Start Event Voltage SV1 (start trigger) – 15.5V
End Event Voltage SV2 (end trigger) – 2.5V

ISSN 2229-5518

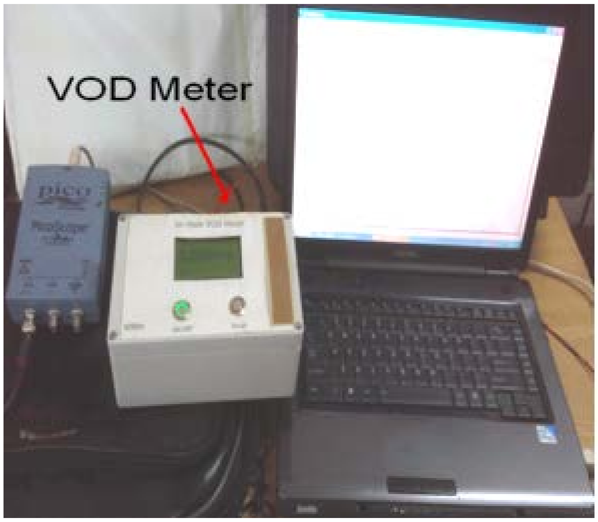


Figure 3 Typical set-up at site

Figure 4 Initial parameters setting for VOD measurement

The voltage across the sensor is also monitored by the picoscope. Velocity of Detonation (VOD) is calculated by distance to time calculation where distance is nothing but the length of the sensor and time is the difference between duration of starting and ending point of the sensor and the VOD calculated is expressed in m/s.

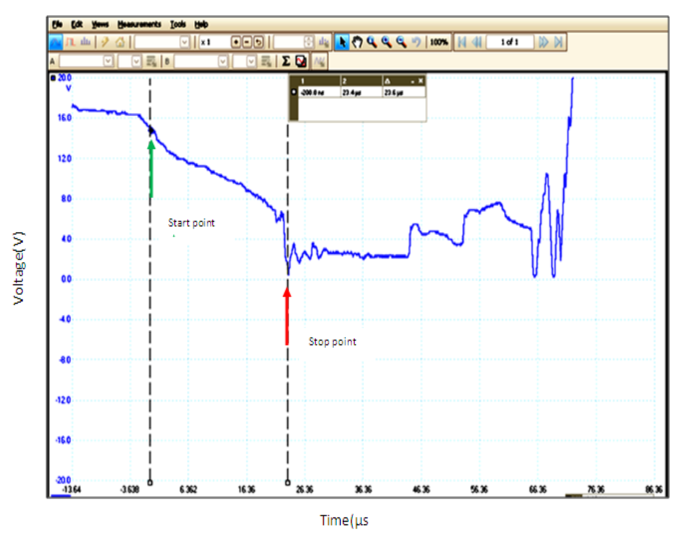
5 Design Aspects

Microcontroller based unit has following feature built in-

- High speed 20MHz clock with 0.05µs resolution, accuracy 0.01%.
- This system has operational amplifier based current source with 10MHz bandwidth, operating voltage for current source is 20~24V and settable current range is 1mA to 50mA.
- Current source value is auto set so as to give about 17V across the sensor. This type of design is opted to take care of varied type (resistance variation) of sensor.
  e.g. if sensor resistance is 1000Ω and lead wire (from sensor to VOD meter) is 100Ω then current source set will be-
  I=V/R
  = 17V/1100Ω = 15.45mA
  This value will maintained constant throughout the test/ experiment.
- Self diagnostic indication for low battery and open sensor connection or beyond range.
- The start trigger voltage is present at 15.5V.
- The stop trigger voltage is set at 1.5V to 2.7V (setting manually).
- Both start and stop trigger have monoshot filter to achieve clean and stable clock cycles feed to the timer with micro-controller unit.

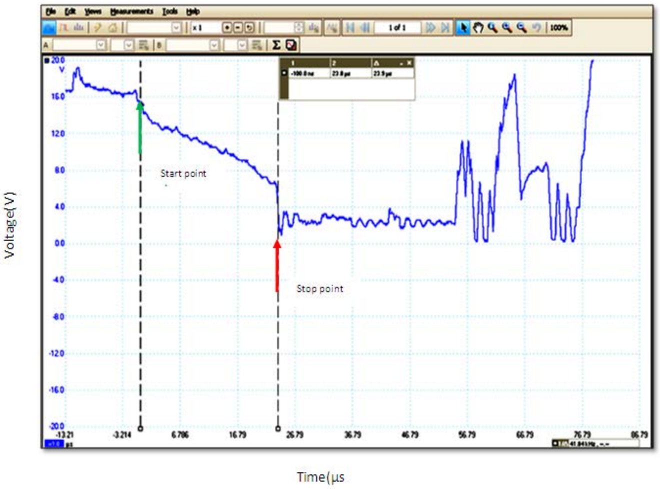
Velocity of detonation which is calculated by VOD meter with the length of the sensor (d) inserted in explosive column in meters and time required between starting and ending of the event. It is measured in m/s. The start point and stop point have significant change in resistances as compared to the rest of the sensor. This reflects in a significant step voltage change (reduction) in the voltage as read in the unit. Thus start reference point and stop reference point is defined and generated within the unit. The length of the sensor is fed to the unit beforehand. Thus "d" is known. Two high speed comparators are used to generate raw start and stop signals. The start signal is true when sensor voltage falls below the start reference voltage (set a predefined step below the normal sensor voltage before detonation). The sensor voltage keep on dropping as the sensor gets consumed by the detonation wave till it falls below the stop reference signal. The raw stop signal is fed to monoshot which in turn is connected to stop the timer. Since "d" is known before hand and "t" time is measured by the timer, computation "d/t" gives the detonation velocity directly on screen in meter/second.

6 Test Results



(a)

IJSER



(b)

Figure 5 a,b -Test results captured on picoscope to calculate VOD value

With the above value of sensor which is designed for this VOD meter and the set-up used in field, the tests are conducted out of which the waveforms captured by picoscope are shown in Fig.5a,b. The reading of VOD are display on screen of VOD meter. The table1 shows the details of the tests.

IJSER

Fig.No.	*Type of explosive*	*Length of sensor*	*Time between start & stop point*	*VOD on picoscope*	*VOD meter*
5a	Cartridge of 83mm diameter	80mm	23.6µs	3389.8305	3317
5b		80mm	23.9µs	3347.2803	3453

7 CONCLUSION

This paper offers a view towards design of an unit which has a low cost sensor, is easy to install/ setup, reduced susceptibility to electrical noise, design sufficient enough to be able to calculate and display VOD directly without compromising accuracy. The sensor has large change in resistance for the given blast length. Sensor is based on change in resistance either continuous or in steps. Step change in resistance is preferred as it reduces the system complexity as well as increases reliability. Use of only a particular grade of cable is not a prerequisite i.e. system is able to accommodate at least a certain range of cable/wire types. Sensor system is flexible enough to be suitable for explosive length from 10cm to 10mtrs. Moreover it is easy to setup and connect. The acquisition unit designed is matched to the sensor for accurate tracking of detonation wave under most of the conditions. Sensor and it's acquisition unit has self diagnostic feature to detect sensor fault. The sensor and acquisition unit design helps minimize any noise generated during explosion. Efforts are made so that sensor is not be affected by presence of moisture or other conducting media. Design allows sufficient interconnecting cable length so that unit can be kept at a safe distance from explosion. Efforts are made to keep the cost of cable low since some portion of cable gets destroyed in explosion. System does not require elaborate manual interpretation of data acquired to calculate VOD. Design is optimized in a way that it is able to give only VOD output for given requirement of in hole VOD. Nothing more nothing less. Instruments which can give continuous VOD record may help in deeper study of explosive but for most practical purposes is not desirable as it causes much complexity and is difficult to interpret. By contrast direct reading unit such as this one is less complex, easy to setup and handle and leaves no ambiguity in arriving at the VOD value.

REFERENCES

[1] Aruna D. Tete, Amol Deshmukh, R.R.Yerpude "Design and Implementation of Sensor for Velocity of Detonation Measurement "*(IOSR-JEEE) 2320-3331, Volume 9, Issue 3 Ver. I (May – Jun. 2014), PP 77-83*
[2] Edwin M.Chan, Vivian Lee, Samuel P. Mickan, Phil J. Davies "Low cost optoelectronics devices to measure velocity of detonation", Proceedings of SPIE Vol. 5649(SPIE, Bellingham, WA,2005)
[3]. M. Pradhan, "Effect of Charge Temperature on the detonation Velocity of Bulk Emulsion Explosives" IE(I) Journal-MN vol.90, August 2009.
[4]. "Evaluation of explosive performance through in-the-hole detonation velocity measurement" by National Institute of Rock Mechanics August 2001.
[5]. J.Benterou, E. udd, P.Wilkins, F.Roeske, E.Roos, D.Jackson"In-Situ Continuous Detonation Velocity Measurements using Fiberoptic Bragg Grating Sensors"
[6]. Lun K. Cheng and Jan van Bree "Fibre-optic sensors in explosion and detonation experiments" SPIE 10.1117/2.1200705.0729
[7]. Jerry.Benterou, Corey V. Bennett, Garrett Cole, D.E. Hare, Chadd May, Eric Udd "Internal Detonation Velocity Measurement Inside High explosives", SPIE Defence Security and Sensing Orlando, FL, United States April 13, 2009
[8]. M.J.Louw, R.S.Sarracino and S.M.Vather, "Comparison of the theoretical and measured velocities of detonation for selected eexplosives" Journal of The South African Institute of mining and Metallurgy.vol.93, no.6.June 1993 00 147-153.
[9]. Smart structure devices and system II, proceeding of SPIE vol.5649 (SPIE, Belingham, WA2005)
[10]. Gil Smith "ShotTrack VoD system evaluation", MATRIX Consultants Australia Pty Ltd June 2000.