Measurement of Impact Sensitivity of Liquid Explosives and Monopropellants

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INTRODUCTION

Because of the importance of knowing what mechanical shocks a liquid explosive will withstand, what the relative order of sensitivity is for different liquid explosives and monopropellants, and how effective are those additives considered desensitizers, much work has gone into the development of standard methods for determination of impact sensitivity. Starting with Bowden and Yoffe's adiabatic compression hypothesis (1), a method and apparatus, the Olin-Mathieson (O-M) Drop Weight Tester, were developed by a committee (2). In the course of investigating the effect of desensitizers on nitroglycerin (3), the authors introduced certain significant modifications in the O-M Tester. The published results of that investigation describe the instrumented drop weight apparatus in possibly insufficient detail. The modification does not affect the measured values of impact sensitivity of nitroglycerin solutions (comparing data obtained on the same apparatus prior to incorporation of instrumentation), and a fuller description of the apparatus may be useful to other workers. In addition, further work has revealed certain interesting phenomena relative to the measurement of impact sensitivity, which will be discussed here.

APPARATUS

The original O-M apparatus has been adequately described (2). The modifications which permit determination of pressurization rate, maximum pressure, and impulse due to impact have been briefly described (3). The piston type pressure gauge has now been calibrated over the range of 1 to 6800 atm. A photograph of the gauge is shown in Fig. 1. It is machined from a single piece of metal and consists of a piston, column, and a threaded base which serves to anchor the gauge firmly to the sample cup assembly. The sensing elements are Baldwin strain gages (BLH FAB 12-12) which are bonded to the surface of the column with an adhesive; they are protected with a cloth covering. The strain of the column is directly proportional to the applied pressure. Calibration with a Tinius Olsen dead weight tester showed the response of the pressure gauge to be linear over the entire range. Placing the two strain gauges on opposite faces of the pressure gauge compensates for any bending of the column.

A line filter removes any extraneous signals generated from other electrical equipment in the area. The 3-conductor, shielded cable from the gauge to the Wheatstone bridge (Fig. 2) is about 6 feet long. Type D Tektronix plug-ins are used in their differential mode with the oscilloscopes. The bridge is balanced by means of variable resistance R_2. This is done very accurately by means of a Leeds and Northrup potentiometer or a calibrated galvanometer. Alternatively, it can be done (less accurately) by changing the input setting from AC to DC at the oscilloscope until there is no deflection of the beam when switching from AC to DC.

The sample cup is then precompressed by means of a spanner wrench. The resistance change of the strain elements unbalances the bridge current, providing a deflection of the potentiometer, galvanometer, or oscilloscope beam. The same electrical equipment was used in calibrating the gauge. In this manner, an accurate measure of initial precompression and pressure versus time during impact and explosion is obtained. Temperature compensation is not a prime consideration in these tests. Heat conduction during the test cannot affect the gauge elements because of the short duration of the test.

The pressure developed in the initial pre-compression is measured with the more sensitive galvanometer or potentiometer; the higher pressures due to impact and explosion are read as a function of time on the oscillograph. The falling weight triggers the oscilloscope sweep when it contacts the ball and piston of the sample cup assembly. Fig. 4 is a block diagram of the apparatus.

An instrumented drop weight apparatus has also been described by Griffin (4). It contains the standard sample holder components. Pressure from the impacted sample cup is transmitted through a system of pistons with O-rings and hydraulic fluid to a transducer. Considerable frictional losses and binding occur in this system. Substantial energy losses were noted by Griffin, who found that much greater impact energies were required for initiation of explosives in his instrumented apparatus as compared to the uninstrumented apparatus. Such deficiencies do not exist in the apparatus described in this paper*.

RESULTS AND DISCUSSION

The earlier paper (3) reported results obtained by use of the instrumented drop weight apparatus. Impact pressure, rate of pressurization, ignition delay time, and pressure-time relationships during explosion were determined as a function of concentration of desensitizers in nitroglycerin. The data helped to explain the difficulty in getting reproducible test results on liquid explosives when the impacting weight is small; it was found that excessive pressure oscillation occurred during impact when a 1 kg weight was used. The oscillographic data also threw light on a number of phenomena associated with impact testing, e.g., the effect of impacting weight and of drop height on the efficiency of conversion of momentum to impulse delivered to the sample and also on the pressurization rate of the sample. It was concluded that, in order to eliminate differences in rate of impact pressurization, weights should be dropped from a constant height, as far as practicable, so that variation in the energy delivered is obtained by varying the weight only. The paper reported the increases in initiation delay time, in deflagration rate, in impulse delivered to the sample, and in impact weight required for 50% probability of initiation as a function of increasing desensitizer concentration. No difference was detected in effectiveness of the common desensitizers, triacetin, dibutylphthalate, and dimethylphthalate. A plot of impact weight at the 50% point versus desensitizer concentration showed a much lower slope for the region 0-16% desensitizer (by weight) than for 16-30%. A "memory effect" was found, i.e., repeating the drop test with the same weight and height on a sample which had previously failed to ignite at or near the 50% point resulted in a positive test every time.

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* Credit is due Mr. H. Cleaver of this Laboratory for development of the instrumentation.

We have now found that a plot of peak impact pressure (rather than impacting weight) versus desensitizer concentration gives a continuous, nearly linear relationship. Fig. 4 is a plot of peak impact pressure versus impacting weight from a height of 1 cm. Fig. 5 is the plot of peak impact pressure versus desensitizer concentration. These data were obtained, using samples pre-compressed by the technique specified in the standard procedure (2), i.e., by tightening the sample assembly cap with a torque wrench to a reading of 7 inch-pounds. This procedure we have found to give an initial pressure (before impact) of 18.5 ± 2 atm.

In order to get better reproducibility of initial pressure, we have changed the pre-compression technique, using a spanner wrench and controlling pressurization by reading the galvanometer or potentiometer. This is of some importance in obtaining reproducible data, for it has been shown (5) that the percent of impacts which result in explosion is decreased when initial pressure is increased. We have also found that the ratio of peak impact pressure to initial (pre-compressed) pressure is a most significant factor in determining probability of explosion of nitroglycerin. This is consistent with quasi-adiabatic compression as a mechanism of initiation. Fig. 6 shows probability of explosion as a function of compression ratio for nitroglycerin impacted from a height of 1 cm with varying weights, using pre-compression to various initial pressures. The measurements of probability of explosion in Fig. 6 are rather crudely performed (from a statistician's viewpoint); for each point, ten nitroglycerin samples were prepared, the sample cups pre-compressed to identical initial pressures, the same weight dropped on each sample, and the number of positive tests recorded. Although the limit of precision of each impact pressure reading is estimated at ± 3 to ± 5%, a correlation between compression ratio and probability of explosion is apparent.

The "memory effect" we had noted in the earlier paper has been found to be due to the fact that pressurization within the sample cup is decreased following an impact which does not produce explosion. Twenty samples initially pressurized to 18.5 atm were found to average 12.0 atm after impact without explosion; the loss is presumably leakage from the sample cup. On subsequent impact of the same sample cup with the same weight, the pressure ratio is substantially higher and explosion results.

A significant conclusion from the data on the importance of compression ratio in initiating explosion of nitroglycerin is that the processing or handling of liquid explosives and monopropellants under reduced pressure introduces a hazard by sensitizing the liquid to weak impacts.

REFERENCES

(1) Bowden, F. P., and Yoffe, A. D., Initiation and Growth of Explosion in Liquids and Solids, Cambridge University Press, 1952.

(2) Liquid Propellant Test Methods, Test Number 4, Drop-Weight Test, Chemical Propulsion Information Agency, Johns Hopkins University Applied Physics Lab., Silver Spring, Md., 1964.

(3) Levine, D., and Boyars, C., The Sensitivity of Nitroglycerin to Impact, Combustion and Flame, in press.

(4) Griffin, D. N., The Initiation of Liquid Propellants and Explosives by Impact, Propellants, Combustion, and Liquid Rockets Conference, American Rocket Soc., Apr 26-28, 1961, Palm Beach, Fla., Paper No. 1706-61.

(5) Bowden, F. P., and Yoffe, A. D., op.cit., p. 34-35.

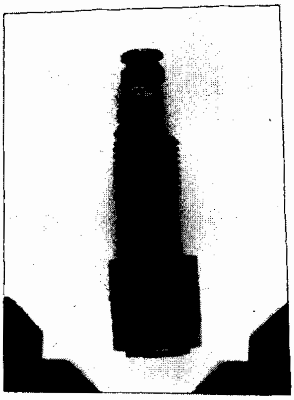

Fig. 1 - Pressure Gauge

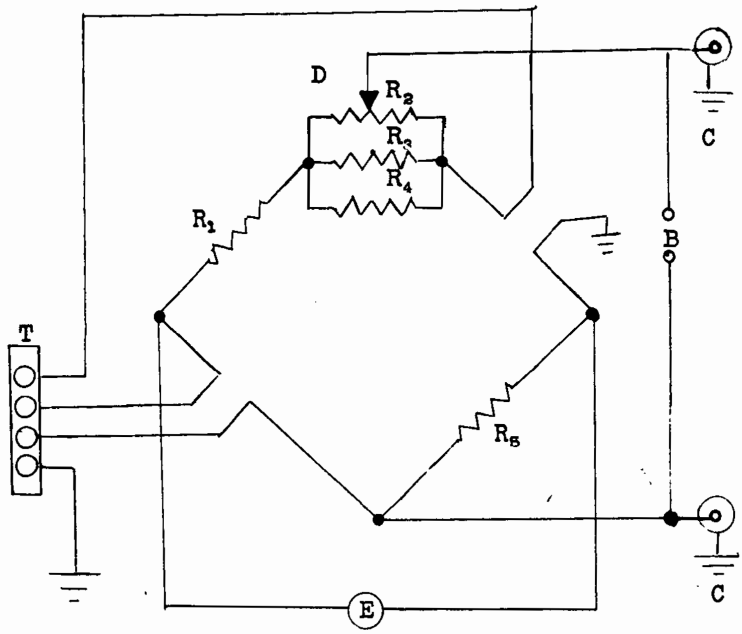

Fig. 2 - Bridge Circuit
R_1 = R_5 =120 Ohm Resistor; R_2=100 Ohm 10 Turn Resistor;
R_3 = R_4 =10 Ohm Resistor; C=Signal Output to Oscilloscope
E= 6 Volt Power Supply; D=Balance Control; T=To NOL Gauge;
B= Zero Balance Checkpoint To Galvanometer/Potentiometer

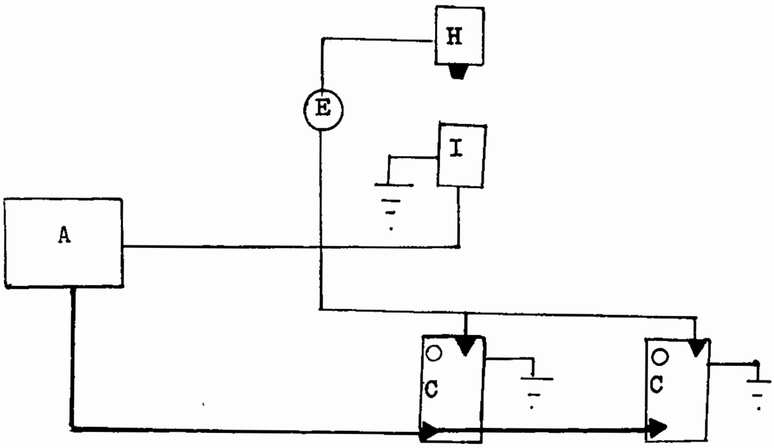

Fig. 3 - Instrumentation on Drop Weight Apparatus
A=Bridge; E=22 Volt Battery; H=Drop Weight Hammer;
I=Assembly Containing Sample Cup and NOL Gauge;
C=Oscilloscopes

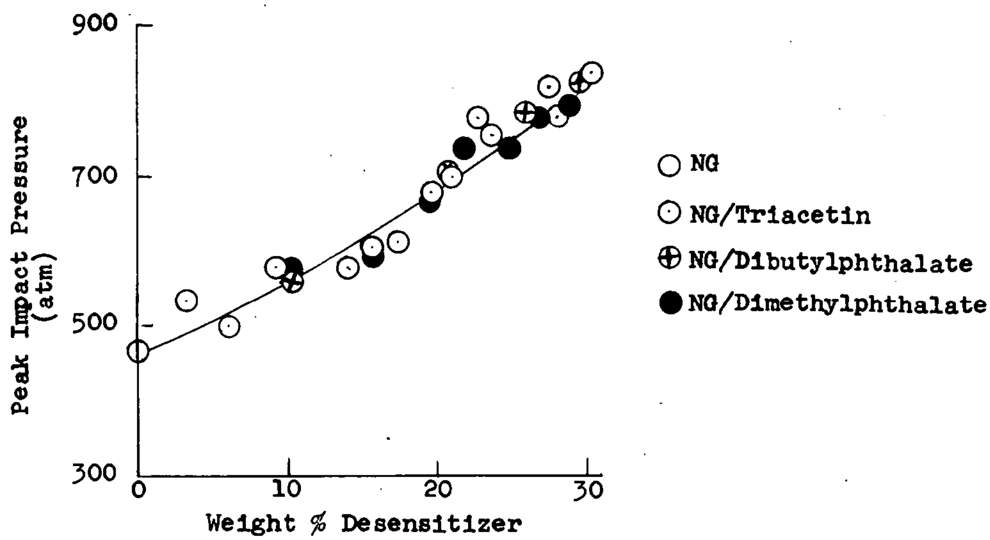

Fig. 5 - Impact pressure necessary to cause explosion (50% point) of NG solutions when impacted from a height of 1 cm with varying weights

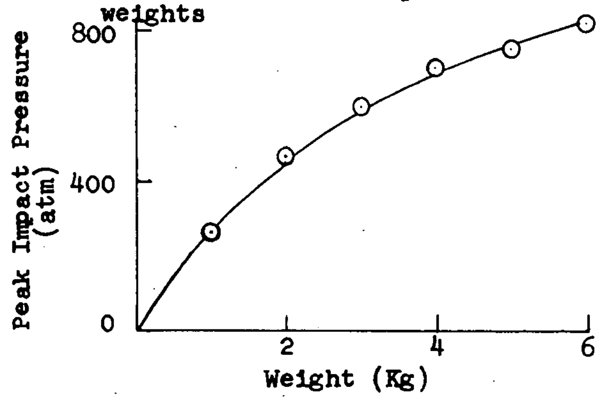

Fig. 4 - Peak pressure due to impacting weight from a height of 1 cm

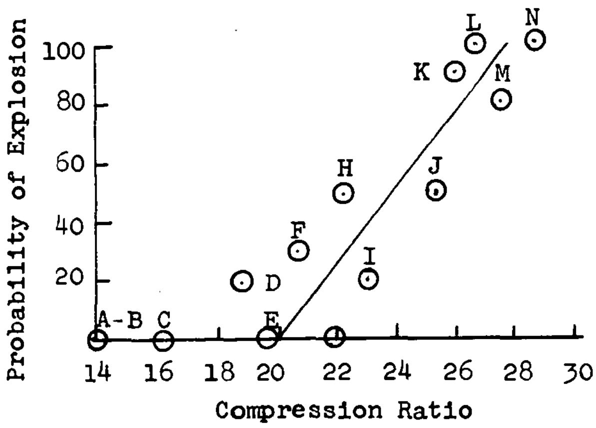

Fig. 6 - Probability of ignition vs. compression ratio for NG impacted from a height of 1 cm. with varying weights, using pre-compression to various initial pressures

	Weight (Kg)	Initial Pressure (atm)
A	4.8	51.2
B	2.3	37.6
C	2.8	36.9
D	4.8	38.4
E	1.5	18.5
F	2.3	25.6
G	1.7	18.5
H	6.0	38.4
I	1.8	18.5
J	2.0	18.5
K	4.8	27.8
L	6.0	32.0
M	2.2	18.5
N	2.3	18.5