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INSTRUMENTED DROP BALL TESTER FOR PERCUSSION PRIMERS

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The drop ball tester has historically been used for determining the threshold characteristics of percussion primers. Typically, the data obtained from such a tester show a wide variation with significantly large standard deviations. This requires that the acceptance specifications for primers be fairly lax. To determine how much of the data scatter was due to the tester alone, a drop ball tester was instrumented with a force monitoring gage, velocity capabilities, deflection gages, and a pressure time output measuring system. This paper deals with the basic fundamental physics involved with the tester and presents results of improvements to the tester geometry. Threshold test results are presented, correlating all of the variables measured.

INTRODUCTION

The drop ball tester has been used for years to determine the initiation characteristics of percussion primers [1]. The test consists of dropping a ball of known mass, from a known height, to impact a punch assembly that deforms and initiates an explosive primer. A schematic representation of the test is shown in Figure 1. The general intent of this type of test is to determine the all-fire and no-fire behavior of a primer.

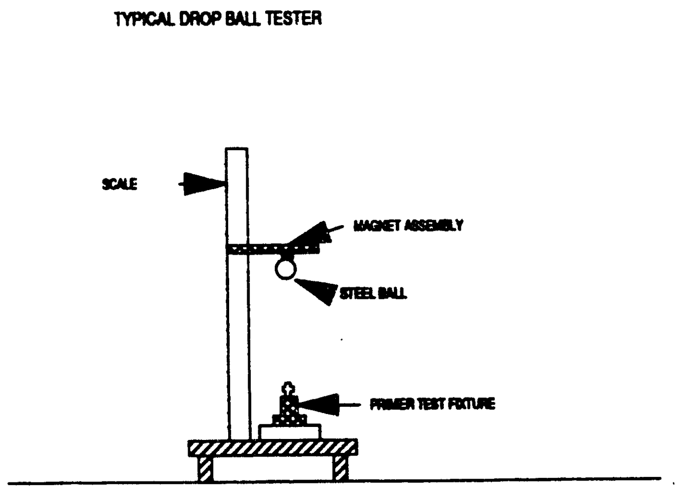

FIGURE 1: Schematic representation of a typical drop ball tester used for assessing primer ignition sensitivity.

Historically, a steel ball having a mass of 55 g was dropped from a known height to impact a firing pin and drive it into the contact cup of a primer. Whether or not the primer fired was recorded, and the next primer was tested at another drop height. The test sequence and drop heights were statistically determined by one or more methods [2 - 6]. The resulting data were then analyzed using a suitable technique [7, 8] to determine the 50% all-fire threshold. This threshold value was then used as an indication of the primer sensitivity. Threshold values have routinely demonstrated reasonable reproducibility for a particular primer design but have exhibited significantly large standard deviations.

The intent of this study was to examine the drop ball technique and to determine if the large standard deviations that have been observed were due to the test, the primers themselves, or some combination. Ultimately, the goal was to develop an improved technique that would yield more usable data than just the height at which a ball had been dropped. The other parameters of interest chosen to be measured were load, loading rate, deflection, deflection rate, function time, and output pressure.

DISCUSSION

A drop ball tester similar to that shown in Figure 1 was constructed. The tester consisted of a variable height platform containing an electromagnetic release mechanism that would drop a steel ball upon activation of an electric relay. The ball dropped and impacted a firing pin that was forced downward into the top of the primer causing deformation to the primer cup. Early experiments with this device on Olin WW42C1 primer assemblies gave threshold values that were reasonably reproducible but exhibited fairly large standard deviations. The release mechanism was examined to determine if the ball was striking the firing pin in a reproducible fashion. Blue dye was painted on the top surface of the firing pin, and the ball was dropped numerous times to impact this surface. Observations of marks in the dye showed that the point of impact of the ball with the firing pin varied significantly from the center to the outside edge and was quite random, as illustrated in Figure 2.

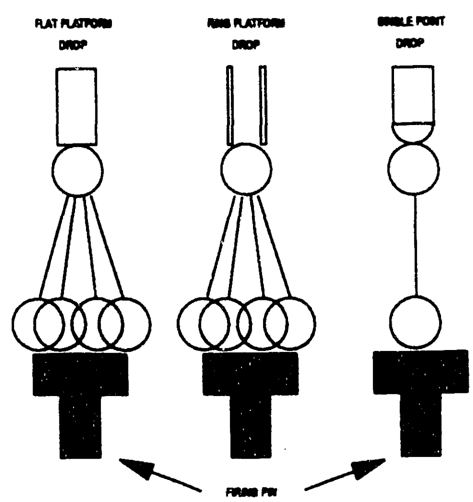

FIGURE 2: Illustration showing random strike patterns for flat, ring, and spherical drop platforms.

Closer examination of the release mechanism showed that the collapse of the magnetic field in the electromagnet was not always exactly the same and that, because of slight irregularities in the surface of the ball and release platform, the ball would not always drop from the same point. The ball was observed during several drops to roll slightly before release, resulting in a small amount of horizontal momentum. This slight variation in the release caused a large scatter at the point of impact with the punch. To verify the idea that the magnetic field might be the source of the problem, a golf-tee-like drop platform was constructed. The ball was held in place by contact with a ring of lesser diameter. The ball was dropped several times and was observed to roll and release from the ring contact quite randomly (Figure 2). This strongly indicated that the magnetic field collapse in the ball and magnet system was not very reproducible. Because of the difficulty encountered with achieving a reproducible drop from the classical flat platform mechanism, it was decided to develop a point contact drop mechanism. This is shown in the third illustration of Figure 2. A steel ball of smaller diameter than the drop ball was attached to the end of the flat platform release mechanism. Contact between the attached ball and drop ball occurred at a single point at the lowest extremity of the platform. This produced extremely reproducible drops as illustrated in Figure 2.

Improvement in the drop pattern resulted in a significant improvement in the standard deviation of primer test lots. Eight lots of twenty primers each were tested using the ring drop mechanism and a 55 g ball. The ball was found to have impacted the firing pin within a circular zone as large as 0.6 cm in diameter. The average threshold for these eight test lots was found to be 12.2 cm (0.066 N-m) with a standard deviation, expressed as a percentage of the mean, of 24.5 %. Six lots of twenty primers each were tested using the single point drop mechanism and a 55 g ball. The ball repeatedly struck the firing pin in the center. The average threshold for these six lots was determined to be 10.8 cm (0.058 N-m) with a standard deviation of 16.4 % of the mean. In addition, five lots of twenty primers each were tested using the single point drop mechanism and a 21.8 g ball. This test was a little more severe because, with the flat and ring platforms, the added drop height usually resulted in a greater spread in the impact zone on the firing pin. The ball repeatedly struck the firing pin in the center. The average threshold for these five lots was found to be 24.2 cm (0.52 N-m) with a standard deviation of 17.4 % of the mean. The single point drop mechanism allowed for perfect alignment on every shot, which resulted in reducing the standard deviation by over 30 %. The results of these tests are summarized in Table 1.

TABLE 1

DROP BALL TESTER MECHANISM RESULTS

BALL MASS (g)	PLATFORM TYPE	THRESHOLD (cm)	THRESHOLD (N-m)	SIGMA % OF MEAN
55	RING	12.2	0.066	24.5
55	SPHERE	10.8	0.058	16.4
21.8	SPHERE	24.2	0.052	17.4

Since the only data acquired from a drop ball tester of the sort described above are the heights at which the ball was dropped or the equivalent striking energies, it was decided to build an instrumented version capable of generating data pertinent to the primers. An instrumented drop ball tester (IDBT) was designed and fabricated. The IDBT is capable of measuring the ball velocity, a time resolved force imparted to the primer, the time resolved deflection behavior, primer function time, and time resolved pressure output. An illustration of the tester is shown in Figure 3. A more detailed view of the same

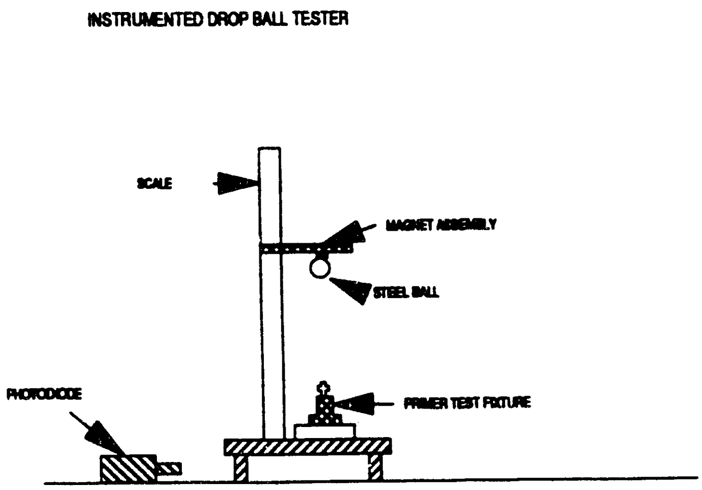

FIGURE 3: Schematic illustration of the instrumented drop ball tester (IDBT).

primer test fixture can be seen in Figure 4. The test fixture consists of a firing pin, Kaman eddy current displacement gage, Kistler load cell, Hewlett Packard photodiode, Kistler pressure transducer, and associated mounting hardware.

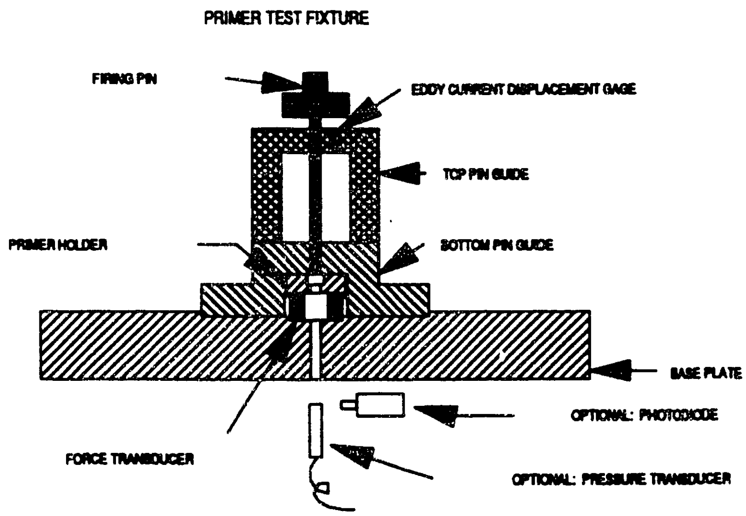

FIGURE 4: Schematic representation of the primer test fixture showing the positions of the displacement gage, load cell, photodiode, and pressure transducer.

The primer test fixture is capable of directly measuring the input stimulus to the primer. The eddy current displacement gage measures the penetration of the firing pin into the primer cup as a function of time. The load cell measures the actual load imparted to the primer as a function of time. The integral of these two quantities gives the actual work done on the primer by the drop ball, and the energy application rate can be obtained by differentiating this work integral as a function of time. These quantities can be expressed as:

$$W(t) = \int F(t) dl(t)$$

and

$$\omega = \delta W(t)/\delta t$$

where W(t) is the work integral, F(t) is the time resolved force, l(t) is the time dependent deflection, and ω is the energy application rate.

In order to obtain the force-time profile, it was necessary to understand how the measured force related to the actual applied force. Figure 4 shows that the load cell is anchored in the fixture by a combination of the primer holder, which floats on the load cell, and the bottom pin guide, which, when torqued into place, applies a small preload to the load cell. This preload is important because it is necessary to be able to measure resonance in the structure without the load cell becoming loose during tensile wave cycles. This configuration, however, creates a parallel loading situation that must be characterized in great detail or significant error in measurement can result. Figure 5 illustrates a simple spring model that accurately depicts the fixture loading configuration. P1 and P2 are equilibrium forces present before the application of P, the force applied by the ball.

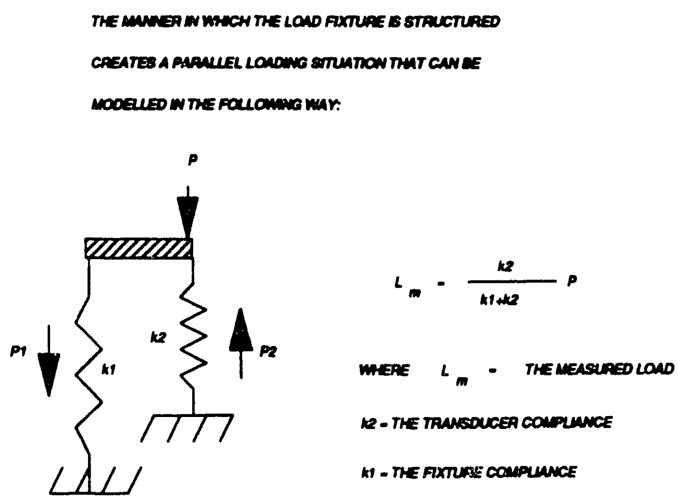

FIGURE 5: Spring model depicting loading situation in fixture.

Using the principle of force equilibrium together with an appropriate deflection diagram allows the derivation of the measured load as a function of the system compliances and the applied load as shown in Figure 5. In reality, all mechanical assemblies have tolerance stackups that affect the system compliance. When an actual test is run, the fixture is disassembled and reassembled in order to insert a new primer in the primer holder. The extent to which the fixture is torqued together has a significant effect on the system compliance and therefore the measured load. This marked effect is shown in Figures 6 and 7. Figure 6 shows the results of calibration tests run on the primer fixture at various levels of assembly torque. The fixture was assembled at several torque levels ranging from 3.4 - 7.9 N-m. The assembly was placed in an MTS servo-hydraulic test system where known loads were applied to a mock firing pin in contact with a solid primer holder insert. For each applied load, the corresponding measured load was recorded from the fixture load cell. The data illustrate two important features of the test fixture. The measured load tracks linearly with the applied load, which verifies the equation derived from theory. The convergence of the slope at higher levels of

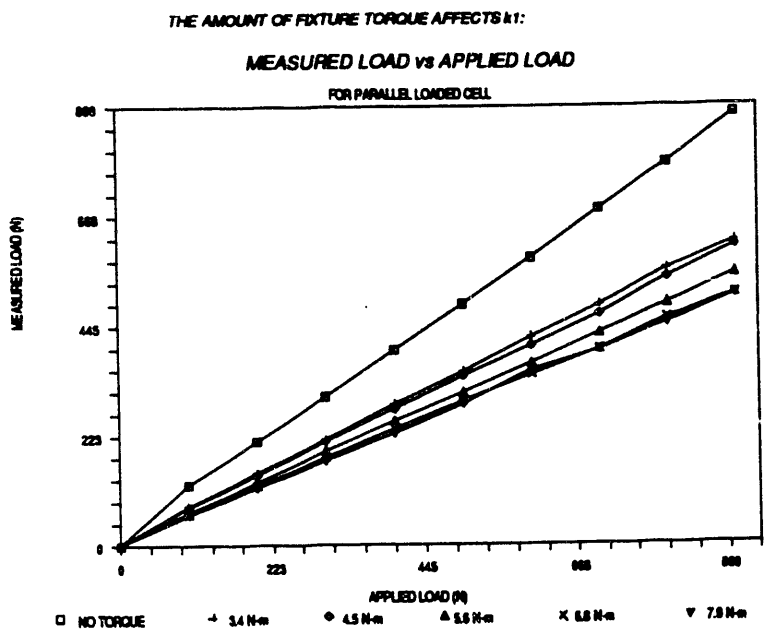

FIGURE 6: Effects of fixture torque on fixture compliance.

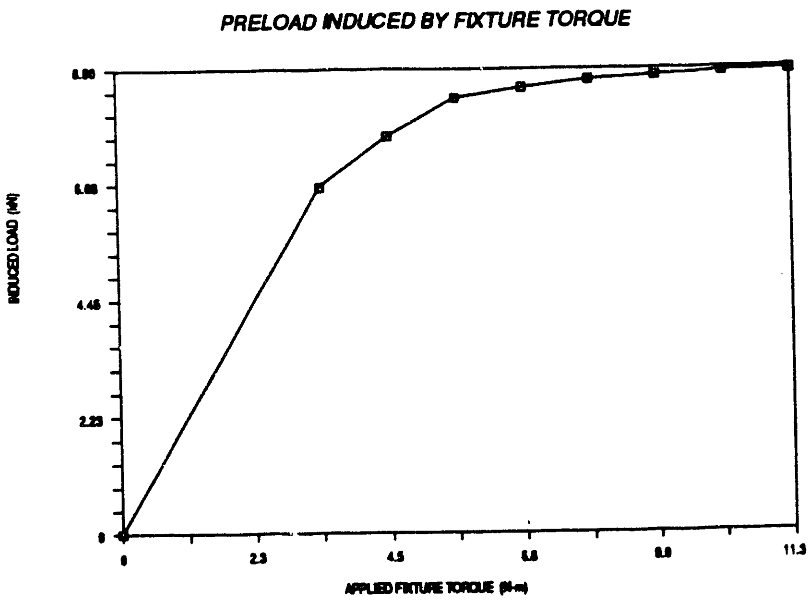

FIGURE 7: Load cell preload induced by fixture torque.

torque indicates a bottoming out of the fixture tolerances. This is further confirmed by the data in Figure 7 that show convergence of load cell preload at torque values above 7 N-m.

Static calibration of the primer fixture load cell was quite successful and shown to correlate well with theory. In the actual test, however, the load cell had to be able to make measurements of rapidly changing loads. The dynamic calibration was carried out in the following manner. The force created by one object on another during an elastic collision can be expressed as the change in momentum with time and given as

$$F = \delta\rho/\delta t$$

where F is the force and ρ is the momentum. For the case of a free-falling mass dropped from a known height onto a rigid elastic body, the force can be shown to be

$$F = [2m(2gh)^{1/2}] / \Delta t$$

where m is the mass, h is the height from which it is dropped, and g is the gravitational constant. The force that a ball can exert on the load cell should vary as the square root of the drop height. The test fixture was configured as in the static tests with a rigid primer holder insert and a flat-ended firing pin. A 55 g ball was dropped three times each at several different heights spaced 0.6 cm apart. A time resolved force waveform was recorded for each impact. Δt was determined from the width of the force peak at half maximum and used in the calculation of force as described above. A plot of measured force maxima and calculated force maxima as a function of drop height is shown in Figure 8. The agreement between the measured and calculated values was excellent.

A simple test was run to determine if the instrumented tester could detect any differences in the applied force because of the way the ball was dropped. The drop platform was set up in the ring drop mode and a 55 g ball was dropped 20 times each at several different heights. The measured load was found to be reproducible to within +/- 54 N. The same test was run using the single point drop platform. The measured load was found to be repeatable to within +/- 31 N. This represents a significant improvement in the standard deviation just because of the alignment afforded by the improved drop mechanism. Drop mechanisms that allow too much variability in the position where the ball impacts the

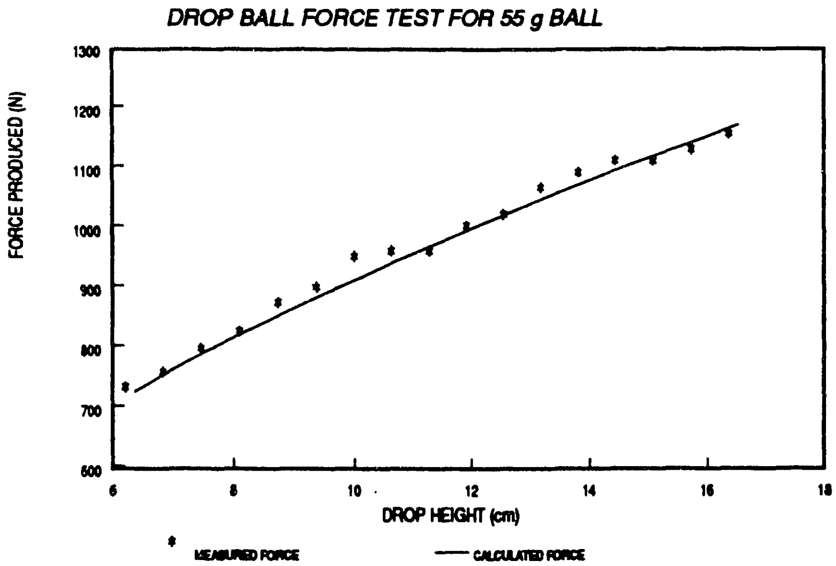

FIGURE 8: Measured and calculated force imparted to the fixture load cell by the dropped ball.

firing pin cause side loading of the pin, which results in variations in the load imparted to the primer and most likely the loading rate.

RESULTS

Since the instrumented drop ball tester was built and proven to give valid data, it has been used to test thousands of primers in all different types of test configurations. Some of the conditions of interest involved the weight and end configuration of the firing pin. Studies of primer cup height and seat position have been done. The effect of ball mass and rate of energy deposition have been studied. These subjects and many more will be covered in a sequel to this paper. It has been demonstrated that both static and dynamic loads can be accurately measured by the IDBT. Figure 9 shows the result of a 55 g ball dropped from a height of 13.5 cm onto a WW42C1 primer. The waveforms are plotted to an arbitrary scale. The solid line curve is the load measurement. The hatched line is the displacement measured by the eddy current gage. The small dotted line represents the output of the photodiode. All three curves are synchronized in time. Each division along the x-axis represents 200 μsec. It is obvious from the fact that there was no light output detected by the photodiode that this test was a no-fire. Figure 10 shows the results of an exact duplicate test on a different WW42C1 primer. It is apparent from the output of the photodiode that this test was a fire. Notice the difference in the

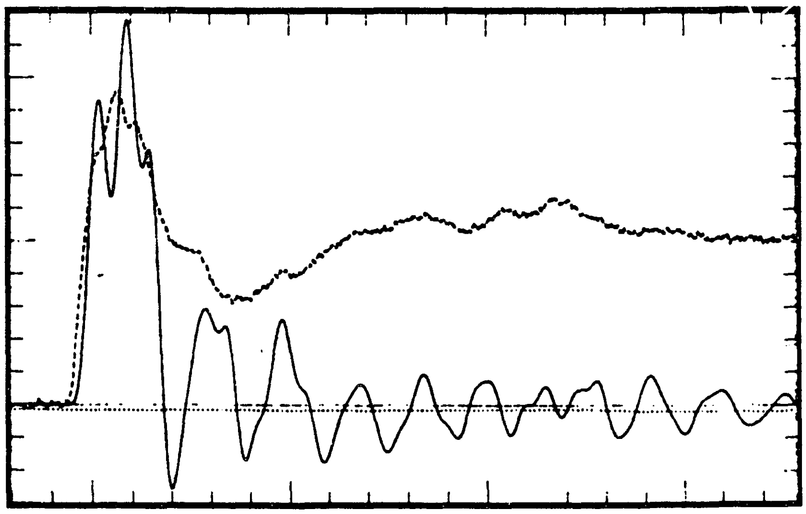

FIGURE 9: Load (solid line), displacement (hatched line), and photodiode output (small dotted line) for a 55 g ball dropped from 13.5cm onto a WW42C1 primer. This test was a no-fire. Time base (x-axis) is 200 μsec per small division.

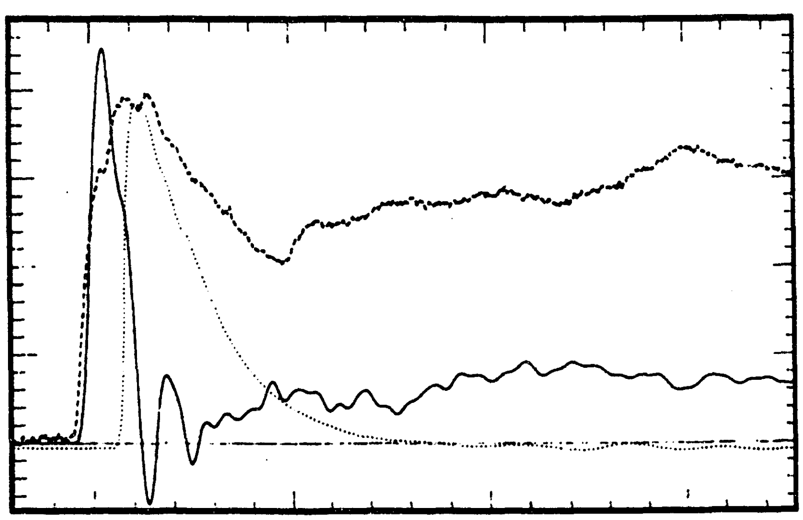

FIGURE 10: Load (solid line), displacement (hatched line), and photodiode output (small dotted line) for a 55 g ball dropped from 13.5cm onto a WW42C1 primer. This test was a fire. Time base (x-axis) is 200 μsec per small division.

load waveforms. The no-fire shows several peaks where the fire shows only one. This is due to the primer going off rapidly during application of load for the successful fire shot. The no-fire shows evidence of multiple strikes with accompanying system resonance.

CONCLUSIONS

It has been demonstrated that attributes of the primer initiation mechanism can be measured with great accuracy. It has been shown that the force applied to the primer during functioning can be modelled and subsequently measured with a high degree of precision and repeatability. An improved drop ball platform mechanism was built and verified. Side loading of the firing pin due to off-center drops was shown to be the reason for a good portion of the standard deviation observed in drop ball tests. A system now exists that will be useful in determining the important characteristics and mechanisms involved in the primer initiation process.

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