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MEMORANDUM REPORT ARBRL-MR-03331

MEASURING DISPLACEMENTS OF GUN SYSTEM COMPONENTS BY THE USE OF OPTRON OPTICAL TRACKERS

Bailey T. Haug

January 1984

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-03331	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MEASURING DISPLACEMENTS OF GUN SYSTEM COMPONENTS BY THE USE OF OPTRON OPTICAL TRACKERS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) BAILEY T. HAUG		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory, ARDC ATTN: DRSMC-BLI(A) Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162618AH80
11. CONTROLLING OFFICE NAME AND ADDRESS US Army AMCCOM, ARDC Ballistic Research Laboratory, ATTN: DRSMC-BLA-S(A) Aberdeen Proving Ground, MD 21005		12. REPORT DATE January 1984 13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Projectile-Gun Dynamics
Instrumentation and Measurement Techniques
Optical Tracker
Optron
Angular Displacement
Linear Displacement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) jmk

Optical trackers are often the instrument of choice for measuring displacement in a gun system during firing. This report deals with the setup and operation of optical trackers, in particular the Optron, and the use of this tracker is demonstrated by several examples. The accuracy of the Optron and the ease with which it can be set up and the data can be analyzed make it a valuable tool in the analysis of gun systems.

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I. INTRODUCTION

In the performance evaluation of the kinematics of a weapon system or in the analysis of the projectile/gun tube interface it is often necessary to measure linear and angular displacements without altering the system response. A simple noncontacting method of measuring displacement is the use of an optical tracker such as the Optron Model 501. The use of such a device allows the data to be recorded directly on an analog or digital data acquisition system; thus, the reduction of the data is no more complex than that required for any other transducer or sensor.

Alternatives to the optical tracker include the high-speed movie camera or the displacement time camera, but both of these require more involved data reduction procedures. For some measurement problems the solution might be a system of proximity gages, which sense displacement with an inductive probe. From our experience the setup and calibration of the proximity gages or either of the camera techniques are more involved than those required for the optical tracker. It is understood that the instrumentation to solve a particular problem is selected based on that problem's requirements; however, because of its ease of installation and data reduction and analysis, the optical tracker is often our first choice.

The first Optron purchased by the Mechanics and Structures Branch, Interior Ballistics Division (IBD), Ballistic Research Laboratory (BRL), was acquired in 1971, and Optrons have been used successfully on many projects. The objective of this report is to document the use of the optical tracker as an instrumentation tool for the analysis of gun system dynamics. A description of the setup and operation of the Optron is followed by several examples of how it has been applied here at IBD, a summary of the difficulties encountered in the operation of this instrument, and the benefits derived from its use.

II. DESCRIPTION OF THE OPERATION OF THE OPTRON

The Optron consists of the head unit, which is the camera, and the control box that contains the power supply as well as the input, output, and control electronics. Figure 1 is a photograph of an Optron unit, showing the head and the control box as well as a typical light source. The head has a lens that allows it to be focused on a target and a viewfinder that permits the operator to look at the target. The lens mounts by means of an adaptor to the standard Leica threads on the head unit. The viewer on these units must be lowered to allow the operator to see through the lens; however, the newer units have a fixed viewer which eliminates the problem of forgetting to raise the viewfinder before attempting to make a measurement.

The control box has an analog meter on which the operator can read the d.c. output, the light intensity at the target, or the peak amplitude of the output. The meter is also used to aid in locking the Optron on the target once the lighting and target orientation have been chosen. The input to the meter is controlled by the switches and potentiometers located on the front panel. The output of the Optron taken from the control box may be recorded on analog tape or acquired digitally with a dynamic range of ± 5V. The frequency response is 25 to 50K hertz, but the signal may be low pass filtered by

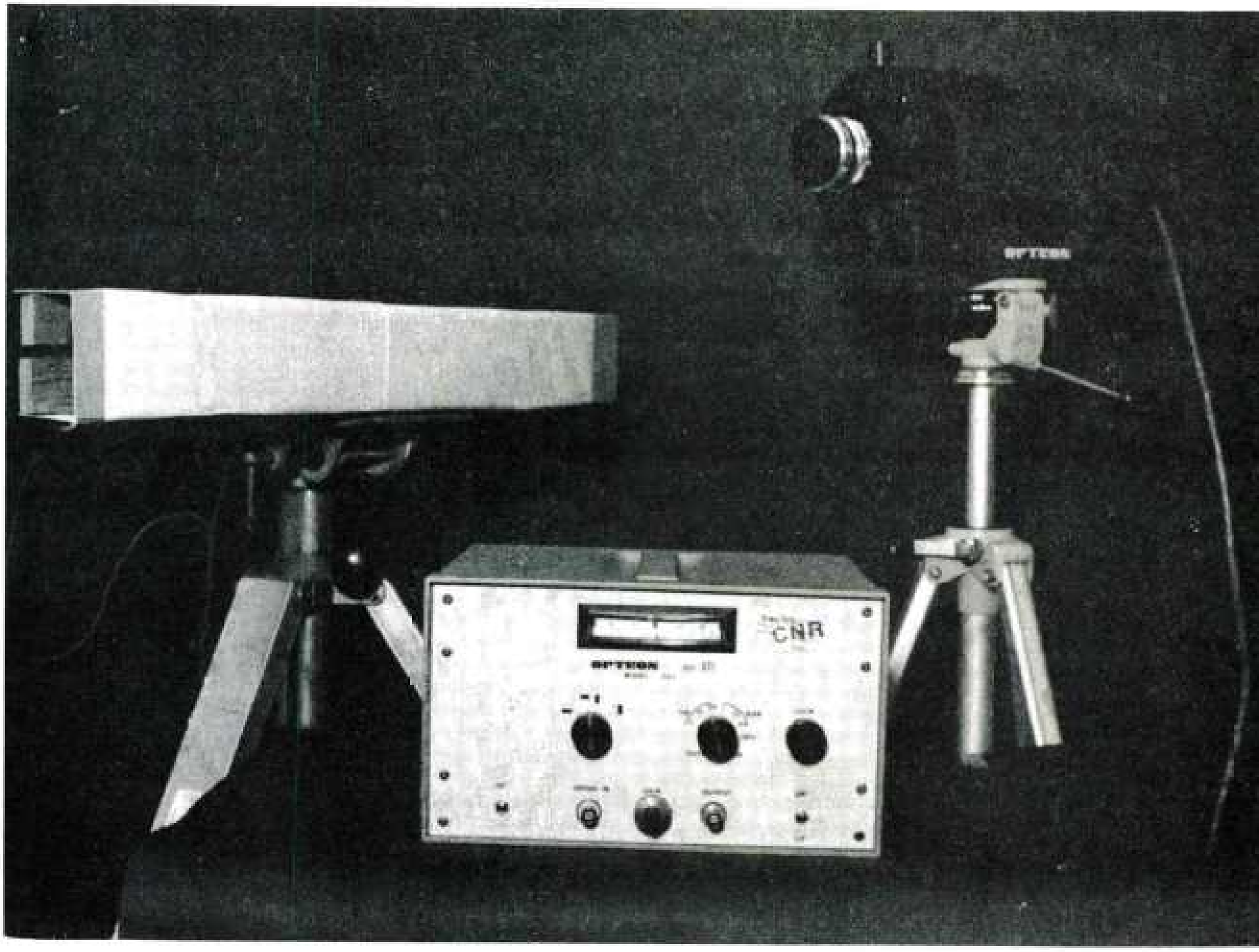

Figure 1. Components of the Optron Optical Tracker

internal filters at 1, 10, 100, 1K, 10K hertz selected from the front panel.[1]

As with other electrooptical trackers, the Optron is designed to track a discontinuity within its field of view. This discontinuity is a distinct interface between a dark and light area which may be created by at least two methods. Using white tape or paint to create a target on an inherently dark subject and lighting this target from the same side where the Optron is positioned creates a frontlighted target. A backlighted target is created by positioning a diffuse light source behind a dark target and aiming the light directly at the Optron lens. The Optron is then focused on the edge of the target, giving a very sharp edge for the tracker to follow. Wherever possible the backlighted target technique is used because one can obtain a cleaner signal due to the well defined edge that is created. In both cases the light source must be a d.c. light, as the tracker will pick up and amplify any a.c.

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1 *Optron Div. of Universal Technology, Inc., "Model 501 Electro-Optical Displacement Follower," Instruction Manual.*

component in the light source. Problems encountered in lighting targets, especially outside, will be discussed later in this report.

Figure 2 shows what the operator sees through the viewfinder as well as the tracking axes which are not visible to the operator. The width of the target must be at least 10% of the lens displacement. The smaller square visible through the viewer represents 100% of the lens displacement. The electronics allows for 100% over range in the displacement as represented by the larger square, but the linearity is not guaranteed in this section of the viewer. It is recommended that the Optron be set up so that the maximum displacement anticipated falls within the 100% range. Figure 3 shows the viewfinder with the target visible through the sight. The Optron has two

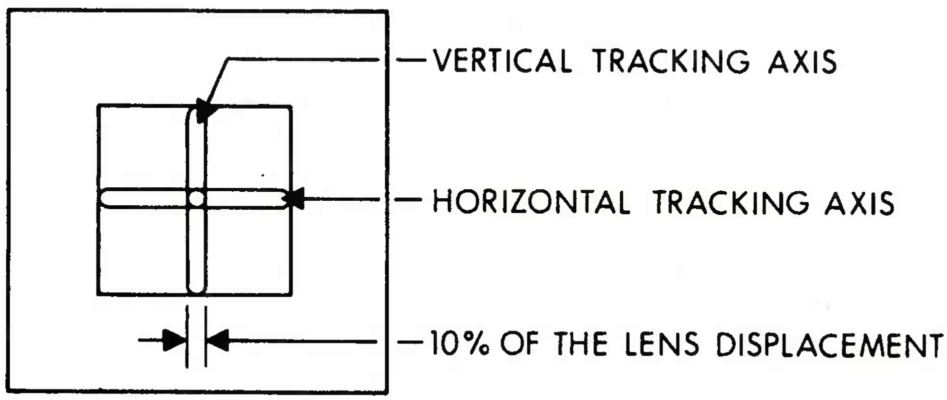

Figure 2. Optron Viewfinder

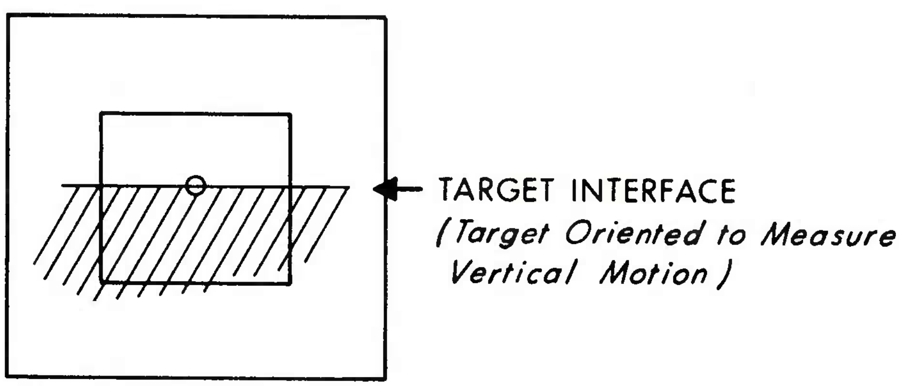

Figure 3. Optron Viewfinder with Target

tracking axes and the target may be oriented orthogonal to either axis depending on the direction of the displacement which must be measured. The head may be rotated within the holder which allows for measuring displacements other than horizontal and vertical. The black and white interface may be oriented either white over black or black over white for the vertical axis, and white left of black or white right of black for the horizontal axis. On the front panel of the control box is a switch with which the operator selects the target orientation.

On setting up the optical tracker, several items must be considered, such as the resolution desired, any restrictions on how far away from the target the Optron must be placed, and the anticipated displacement of the target. Most of the work done at IBD has been with a 50-mm focal length lens and a set of extension tubes to allow the Optron to be placed closer, thus obtaining more resolution. To get more resolution while maintaining a safer distance from the gun tube, a longer focal length lens could be used. The resolution is 0.1% to 0.02% of the lens displacement. It is possible to obtain resolution in excess of $2x10^{-7}$m; however, remember that the dynamic range is reduced with increasing resolution. Ultimately, either the resolution is limited by the displacement which is to be measured, or the displacement is limited by the required resolution. If the anticipated displacement is oscillatory about the rest position, then the target may be aligned in the center of the viewfinder, and if the displacement is expected to be mostly or totally to one side of the rest position, then the target should be offset to one side to allow the Optron to follow the displacement through the tracker's full dynamic range. While aligning the head, consideration should be given to the stability of the stand to which the head is attached. Head motion caused by blast will affect the measurement and should be avoided by the use of heavy camera stands and sandbags if necessary. The Optron manual gives no indication of the limits of overpressure or vibration to which the head may be subjected, but, if the expected overpressure is sufficient to cause concern, then the head should be shielded from the environmental factors.

Once the target has been established and the location of the head has been determined, then it is necessary to light the target. As mentioned earlier, a d.c. light source is used. It is important to evenly illuminate the target area as variations in light intensity may be interpreted as motion of the target. To determine the light intensity required for the Optron, place the meter switch on the control box in the light position and place the lens cap on the lens. Now adjust the lock-on control so that the meter reads -20%. Open the lens cap and look through the sight. To measure the light intensity on the target, the center circle in the viewer must be entirely in the white area of the target. Now raise the viewer and adjust the aperture ring of the lens to cause the meter to read somewhere between +18 and +40%. The manual suggests +20%, but experience has taught us to try to get the light up to 30%. If a backlighted target is to be used, then the light source should usually be covered with a diffusive material to spread the light out more evenly. Variations in the intensity of the light source as the target moves across the source will affect the accuracy of the output.

Once the lighting is set up, the next step is locking on the target. This is accomplished by first placing the meter switch on "OP." Turning the lock-on control counterclockwise will eventually result in the meter jumping off scale to the right. Turning the lock-on back in a clockwise direction will lead to a meter reading somewhere on the scale. Continuing to rotate the control clockwise will cause the meter to jump off scale on the left side. The best lock-on position lies somewhere between the point where the meter falls off scale on the left and the point where it falls off the scale on the right. The manual suggests locating the lock-on control halfway between these two points; however, a better method is to look at the output on an oscilloscope and place the lock-on control where the noise in the output is minimized within this range. Manually moving the target, if possible, through the full scale of the anticipated motion and observing the tracker output on the oscilloscope will reveal if the lock-on is satisfactory and if the position of the Optron will allow the tracker to follow the motion which is to be measured.

Knowing the range of the displacement and the focal length of the lens, it is possible to use the factory calibration to determine the scale factors of the output. But this has not been the practice at IBD for several reasons: first of all, the gain on the control box may be readily changed which makes the factory calibration somewhat questionable; and second, the resolution of the Optron is so good that errors in determining the lens displacement make using the factory calibration less than adequate. Our standard procedure is to move the target through some portion of the anticipated displacement by a variety of methods depending on the application. The output of the Optron is recorded while the displacement is measured by some alternate method such as a dial indicator. This not only provides a calibration factor but also a check on the linearity of the system. Sometimes it is impossible to move the device under test in a controlled manner that lends itself to a quasi-static calibration. If this occurs then it is usually possible to simulate the motion by sliding a surrogate target along the test item at the same distance from the head and measure the displacement of this target.

The Optron instruction manual (Reference 1) contains a detailed description of the theory of operation of the tracker and the associated electronics. A summary of the operation should be sufficient to gain an understanding of how the Optron works. The head contains an image dissector tube, and the lens focuses the target discontinuity onto the photocathode of the tube. The photocathode then emits a beam of electrons proportional to the intensity of the light reflected or emitted from the target. The beam is focused on the aperture of the tube. As the target moves, a control loop drives the electron beam in such a way as to maintain the same beam intensity through the aperture. The current required by the control loop to drive the electron beam is proportional to the target displacement. The lock-on procedure discussed earlier allows the image dissector to see the target and optimizes the control loop.

III. MEASUREMENT OF LINEAR GUN TUBE MOTION

The most common application of the optical tracker at IBD is probably the measurement of linear barrel motion, both recoil and transverse displacement, the latter being the motion normal to the recoil direction. Figure 4 is a representative drawing of the type of setup used to measure transverse barrel

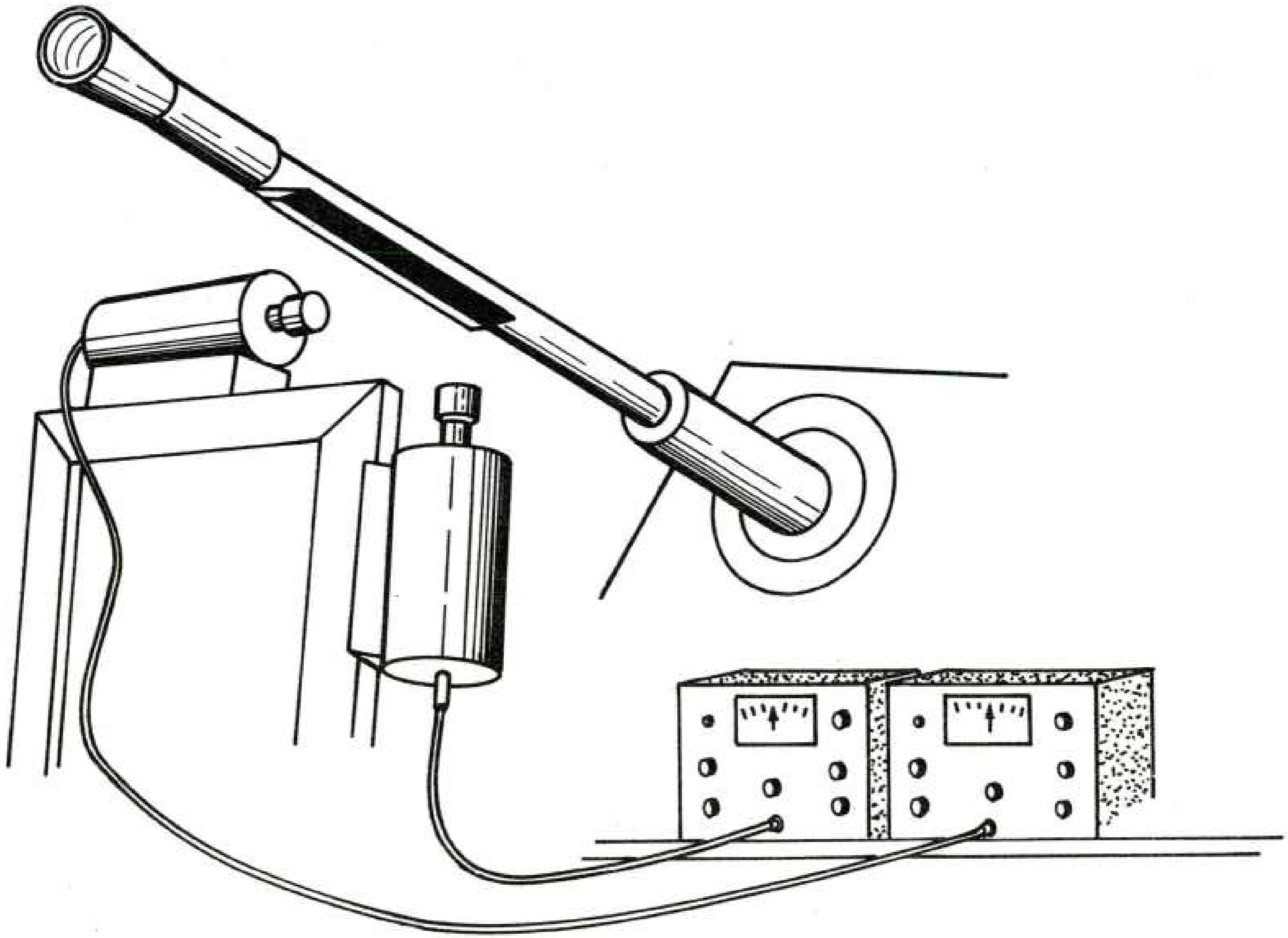

Figure 4. Orthogonal Implementation of the Optrons

motion of a 30-mm, L21E1 RARDEN gun mounted on a Sheridan vehicle.[2] Two trackers were installed in the same plane to measure vertical and horizontal tube motion near the muzzle. Since this test was conducted outdoors, the lighting was provided by the sun, and frontlighted targets were used. When measuring motion normal to the direction of recoil, if the gun tube is tapered, the trackers will pick up the taper as well as the lateral motion as the tube recoils. It is possible to remove the taper component of the measurement later if the taper and the recoil are well-known. A more direct method to solve this problem would be to either paint a target with white paint on the tube or attach a target as shown in Figure 4. The purpose of this test was to determine the effect that adjusting the barrel support mechanism had on muzzle motion, particularly the damping times of the muzzle vibration for various settings of the damping pads.

The outputs of the Optrons were fed directly to an analog tape recorder. A voltage substitution calibration was recorded just prior to firing the gun by using an event timer. The calibration of the vertical tracker was performed by hanging weights on the gun tube and measuring the displacement of the tube with both a dial indicator and the Optron. The horizontal Optron was calibrated simply by deflecting the tube manually and using the dial indicator to arrive at a calibration coefficient in mm/volt. In an attempt to control the lighting, a tarpaulin was suspended above the gun tube. This was mostly successful but, since light variations due to passing clouds affected the measurements, we attempted to shoot only when it appeared the light would be constant during the firing sequence. The blast from the gun lifted the tarpaulin and allowed additional light to strike the targets. By the time this occurred, the time frame of interest had passed, except in the case of burst firing, where a baseline shift was apparent. The imaging tube in the head is very sensitive to light, so caution must be exercised to keep the lens stopped down or keep the lens cap on when using the Optron outside. Direct sunlight on the lens could permanently damage the tube. Figures 5 and 6 show sample data taken with the trackers on this project. The plot of the vertical motion contains both the motion of the gun tube and the rocking motion of the Sheridan vehicle during the recoil cycle. A separate tracker was later used to measure the vehicle motion which was then subtracted from the displacement seen at the muzzle. The Optrons were successfully used to determine the proper settings for the damping pads in the barrel support mechanism of this gun system mounted on this vehicle.

Another example of using the optical tracker to measure linear gun tube displacement is a test performed on the M139 gun to measure tube bending. The gun was mounted on a pivot and was rocked about this pivot in the vertical plane by an electric motor and an eccentric mass. The objective of the test was to determine tube bending by measuring relative displacement. The first method used was to place a tracker near the muzzle and another near the breech end of the tube and set the gains of these two trackers to yield the same output for the same static tube position. The outputs of the two Optrons were fed through a differential amplifier, resulting in zero output as long as the

2 *A.F. Baran, B.T. Haug, "Muzzle Motion Measurements of the 30-mm, L21E1 RARDEN Gun Mounted in a Sheridan Vehicle as Compared with Rigid Mount Tests," BRL Memorandum Report ARBRL-MR-03182, June 1982 (AD B065739).*

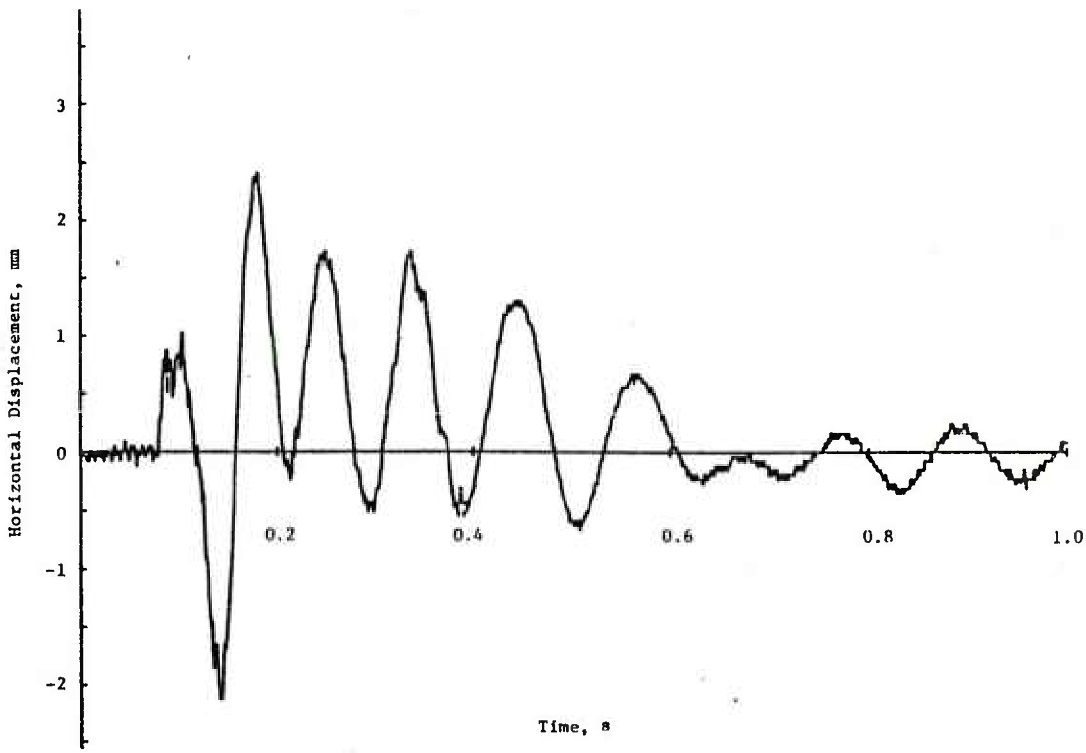

Figure 5. Horizontal Displacement of Gun Tube

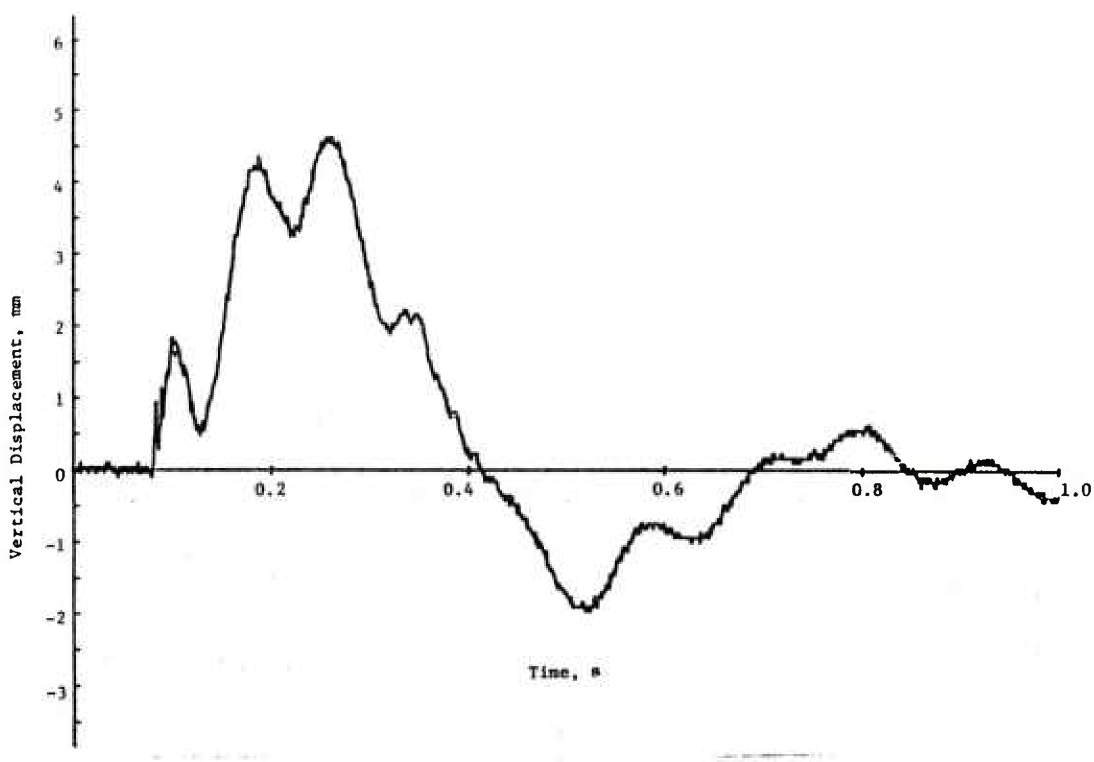

Figure 6. Vertical Displacement of Gun Tube

tube did not bend. Tube bending could therefore be determined by the difference output. To obtain a more detailed picture of the tube, three Optrons were set up to measure motion along the tube. For tube motion of this type the best lighting technique proved to be by backlighting the target.

Often it is required to measure the recoil of a gun system in order to analyze the entire recoil cycle, not just to determine the maximum displacement. The optical tracker is well suited to make this type of measurement. In a kinematic evaluation of the Bushmaster 25-mm, PFB-25 automatic cannon, it was desired to measure the recoil cycle to evaluate the gun functioning.[3] The recoil was measured on the gun tube by wrapping white tape on the tube for a target and using front lighting with a d.c. light source. Figure 7 shows a typical plot of the recoil motion.

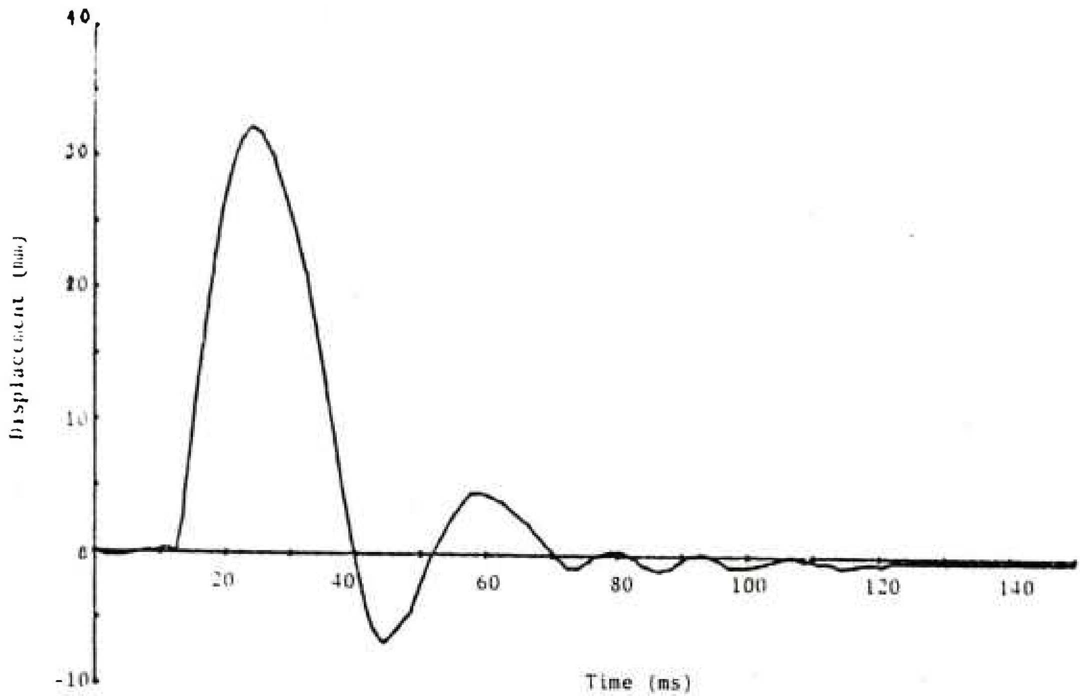

Figure 7. Recoil Motion of the Bushmaster 25-mm

IV. APPLICATION TO MEASUREMENT OF LINEAR DISPLACEMENT OF GUN PARTS

The Optron may also be used to measure the displacement of components of a gun system during the firing cycle. For some applications the optical tracker can replace the displacement-time camera which has been used by the BRL for displacement measurements for many years. One such example is the work recently completed by R.P. Kaste on the Hughes Helicopter 7.62-mm chain gun.[4] A kinematic evaluation of this gun was performed to determine the

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[3] *A.F. Baran, B.T. Haug, R.B. Murray, "Evaluation of the Dynamics of the Bushmaster 25-mm, PFB-25 Automatic Cannon," BRL Memorandum Report 2605, March 1976 (AD B010565L).*

[4] *R.P. Kaste, "Kinematic Investigation Hughes Helicopter 7.62-mm Chain Gun," Memorandum Report 3157, February 1982 (AD A113114).*

energy distribution during firing under various conditions. As a part of this test, an Optron was used to track the motion of the bolt carrier. The carrier was painted black and a white target placed on it. The cover had to be removed to expose the bolt carrier, preventing the firing of the gun, but, since the gun is chain driven, most of the components could be actuated without firing. The target was frontlighted and the Optron tracked a total displacement of around 100mm. Figure 8 shows a sample of the data taken with the Optron, and Figure 9 is an internal view of the components of the gun system.

The Optron has successfully been used to measure the motion of the bolt carrier and the striker on the M231 Firing Port Weapon during actual firing tests. The test was designed to determine the maximum velocity of the bolt carrier during the recoil cycle, to find out if the striker bounced during the firing and, if so, to measure this bounce quantitatively. Targets were placed both on the bolt carrier and the striker, illuminated from the front, and tracked by two separate trackers. A representative plot of the acquired data is shown in Figure 10. With two Optrons using 50-mm lenses and tracking targets so close together, space was a problem. The Optrons had to be positioned carefully to see the targets and to avoid the ejecting cases as much as possible. This is one test where longer focal length lenses would have made the measurement easier to carry out.

V. ADDITIONAL APPLICATIONS

The Optron is not restricted to making gun system measurements at IBD. The tracker is also being used to measure displacement of propellant samples in a drop weight mechanical properties tester initially designed by R. Wires and improved upon by R.J. Lieb.[5] The purpose of this apparatus is to subject propellant samples to high strain rates, approximating those found in the ballistic cycle. The requirement is to make dynamic measurements of displacement and force. A PCB force gage is used as the anvil in the drop tester, and the Optron tracks the displacement during the event. The ram transmits the force to the sample being tested. A knife edge is built into the ram, and it is backlighted to provide a target for the Optron. The ram rests on the propellant sample, and when the weight strikes the ram, the propellant is deformed and the Optron measures the vertical displacement of this deformation. Because of the high frequency response of the Optron and its high resolution, it is possible to determine the rate at which the propellant is deformed as well as the total deformation. This, in combination with force gage measurements, yields data for interior ballistic codes so that the grains will no longer need to be treated as incompressible and nondeformable.

Another interesting application of the Optron was performed by B.K. Stearns at General Electric in Burlington, VT.[6] Figures 11 and 12 detail the

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[5] *R.J. Lieb, J.J. Rocchio, "Standardization of a Drop Weight Mechanical Properties Tester for Gun Propellants," BRL Technical Report ARBRL-TR-02516, July 1983 (AD A132966).*

[6] *B.K. Stearns, R.C. Walker, "Measurement of Gun Barrel Motion with Optical Trackers," Proceedings of the Second US Army Symposium on Gun Dynamics, September 1978.*

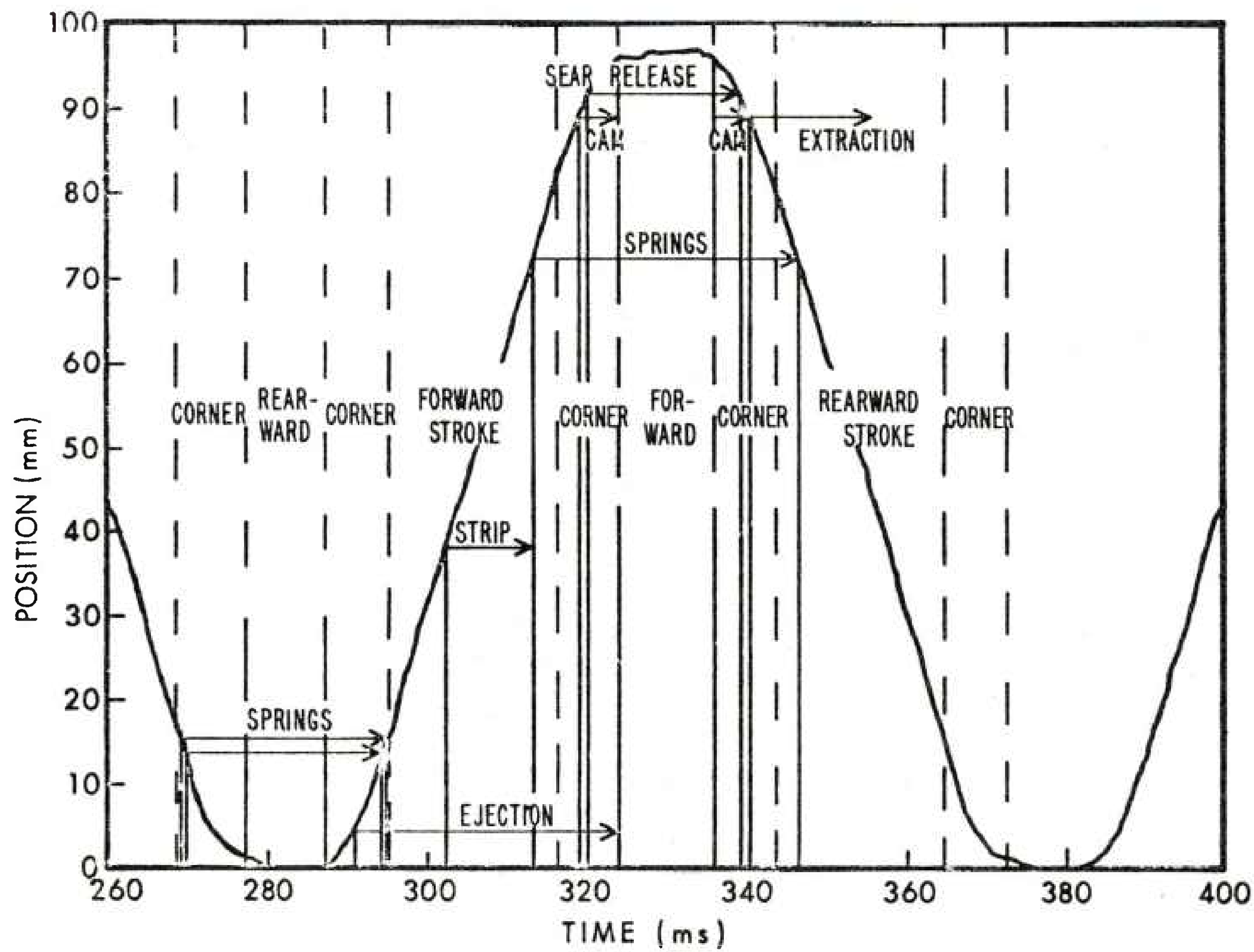

Figure 8. Bolt Carrier Motion of the 7.62-mm Chain Gun

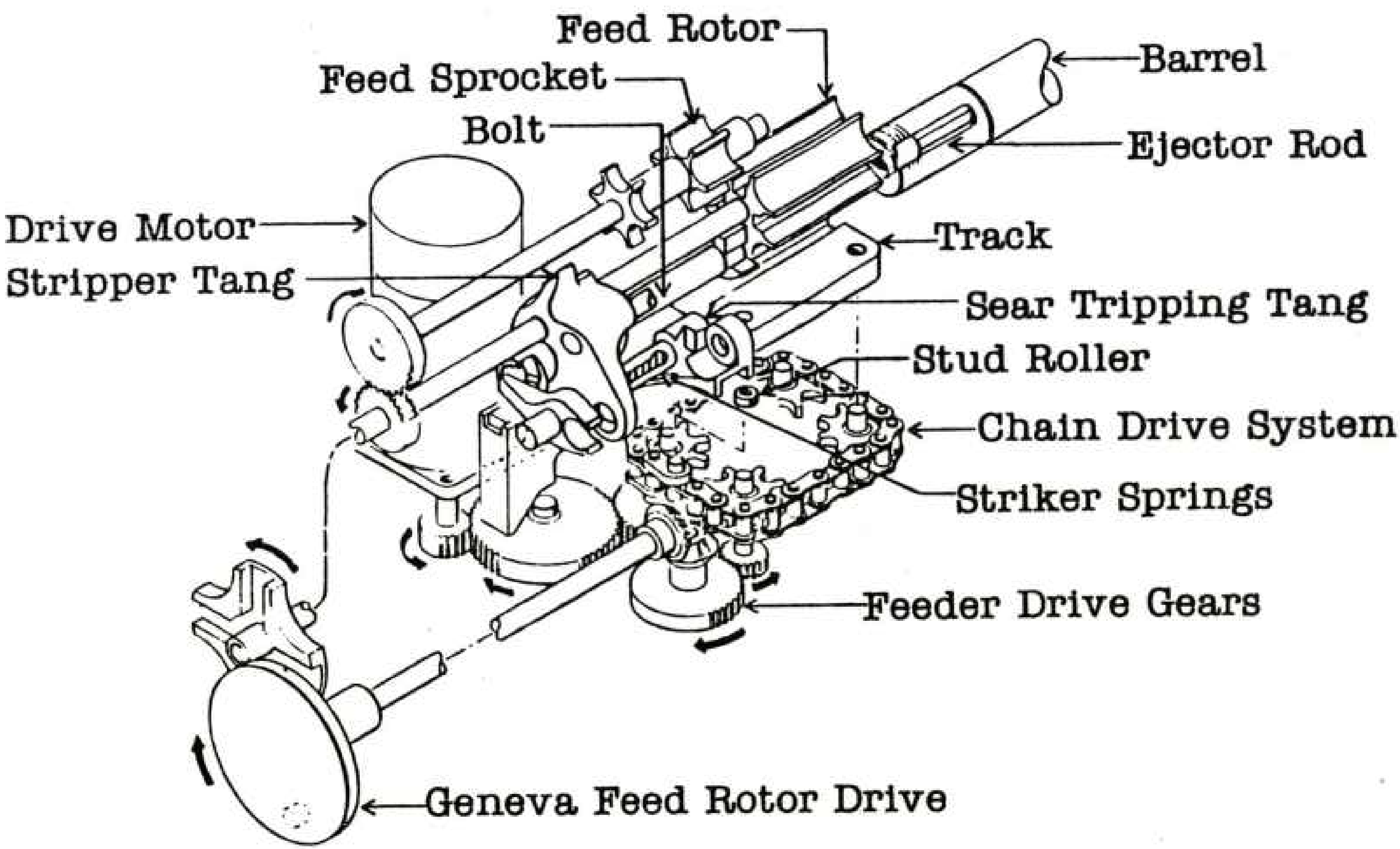

Figure 9. View of the Internal Components of the 7.62-mm Chain Gun

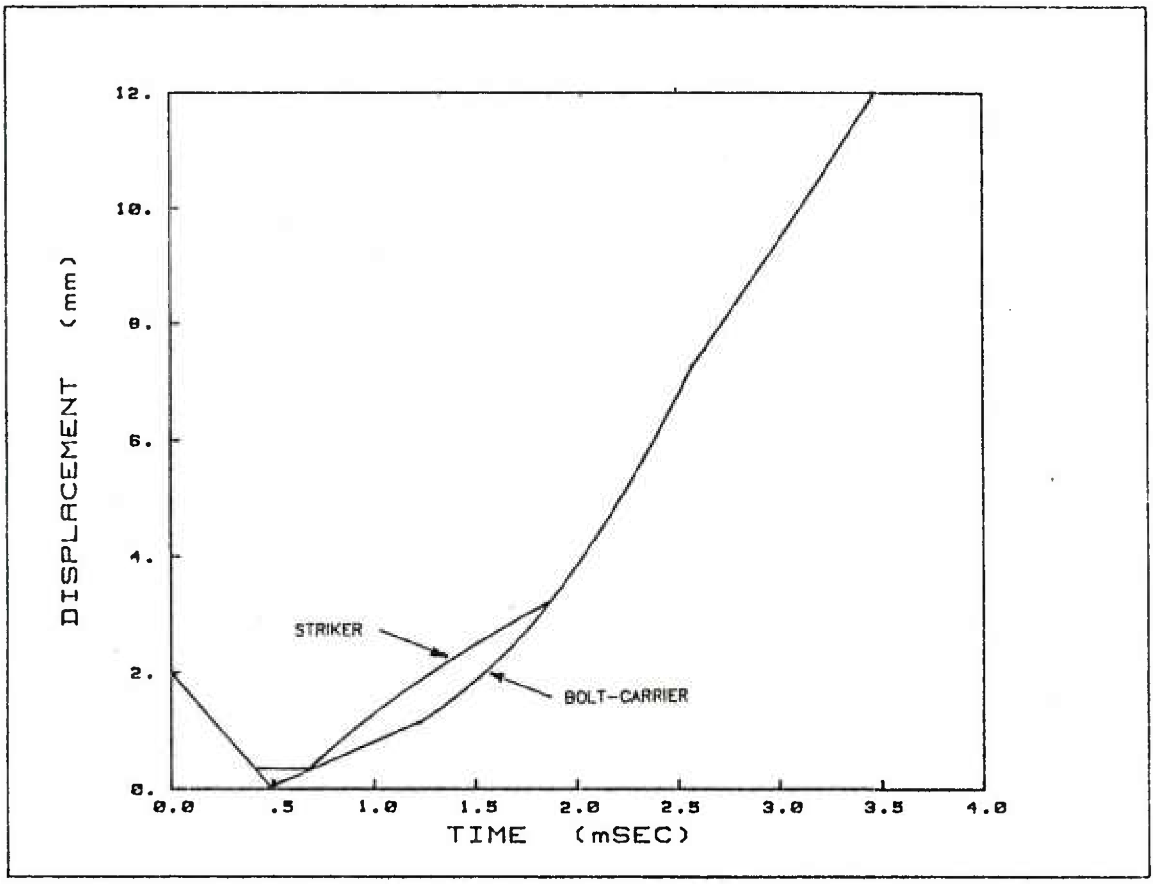

Figure 10. Bolt Carrier and Striker Motion Overlay

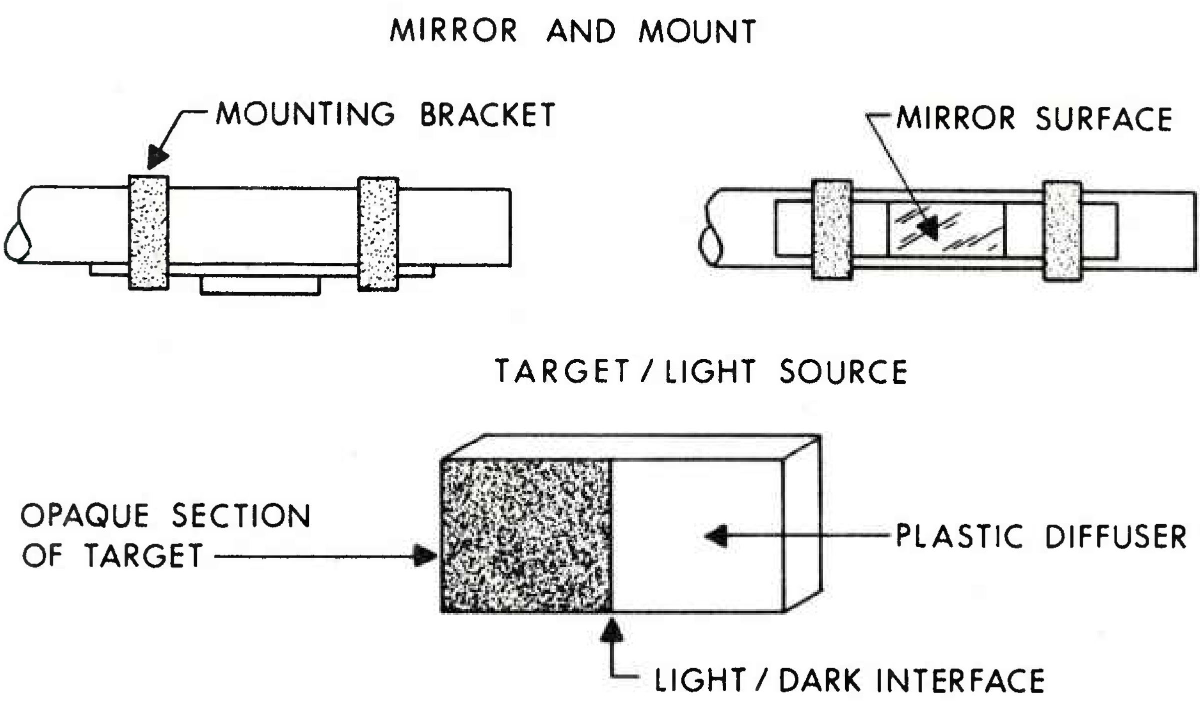

Figure 11. Reflector and Light Source for Angular Measurements

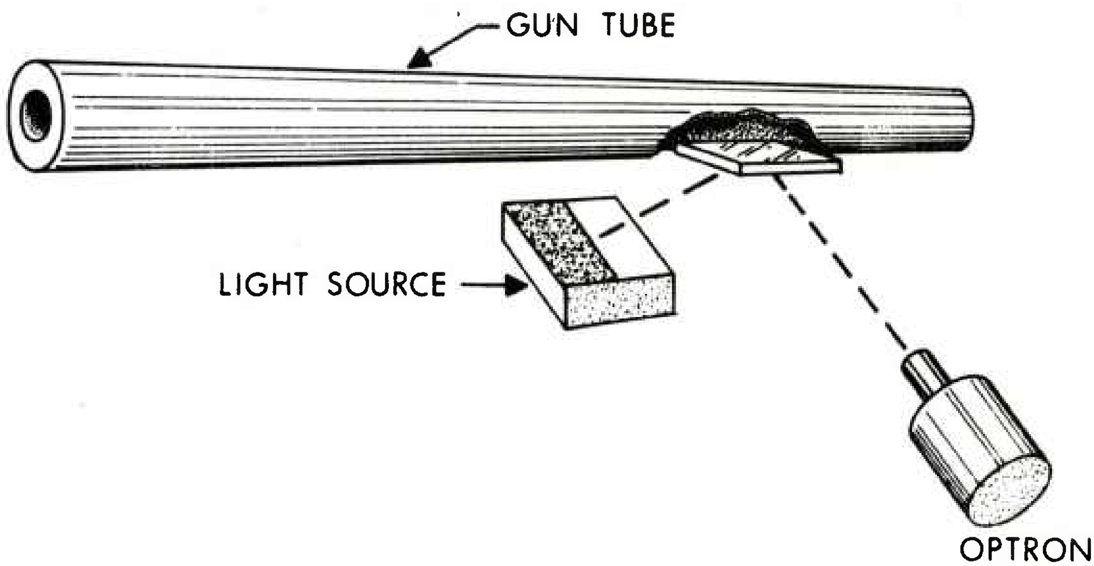

Figure 12. Test Setup for the GE Technique for Measuring Angular Tube Motion

test setup and show how the optical tracker may be used to measure angular tube motion directly. The light source doubles as the target with a section of the light blacked out, as shown in Figure 11. The front of the light source is a diffusive material, such as translucent plastic. If it is possible to deflect the tube at a known angle or if a second mirror can be placed over the first at a known angle, the Optron may be calibrated rather simply. Notice how the Optron will not see longitudinal or lateral displacements but only angular motion in the vertical plane. A complete measurement system would include a second Optron to measure the angular motion in the horizontal plane. This type of measurement is valuable in determining the muzzle pointing direction during in-bore travel and possibly at muzzle exit. The disadvantage of this technique is that the required mirror could be very long if the gun is allowed to recoil and the tracker is supposed to measure the angular motion during the total recoil. This would not only add weight to the gun barrel, but also might adversely affect the dynamics of the gun system. Since the tracker would no longer be measuring the angular displacement at just one point on the gun, the analysis becomes more complex.

VI. AVOIDING DIFFICULTIES IN THE APPLICATION OF OPTICAL TRACKERS

As has been discussed earlier in the report, the lighting of the target plays a critical role in the operation of the optical tracker. In a frontlighted application it is important that the light source cover the entire area of anticipated motion with even illumination and that the light source be powered by a d.c. supply. In a backlighted situation the light source should present an evenly illuminated target area to the tracker. This is readily obtained by placing a lamp or lamps behind a diffuser such as a translucent piece of plastic or paper. Fluctuations in light intensity as a result of either uneven illumination or an a.c. light source will cause an error in the signal. The Optron may be used outdoors, but, since the lighting is no longer under strict control, extra care must be taken to assure valid results. Lighting the target with open shade rather than with direct sunlight will help for two reasons. The open shade will be a more even light source and will fluctuate less with time, and, since the tube in the camera is very sensitive to light, using the device in shade reduces the chance of exposing the tube to excessive light. When in direct sunlight, keeping the lens stopped down and the lens cap in place when not in use is recommended. If the tracker is used outdoors with a backlighted target, the background should be carefully considered to insure an evenly lighted target area. Minor variations in the light intensity between events being measured will not affect the output if the Optron is locked on the target prior to data acquisition for each event. Variations in light intensity during the event will alter the results.

Once the optical tracker is in place and the lighting is established, the Optron may be calibrated according to the procedure discussed in Section II. With the calibration completed, the tracker and stand should be held firmly in place by whatever means necessary. Avoid bumping the stand or in any way altering the distance between the camera and the target. The calibration factor is completely dependent on the focal length of the lens, any extension tubes used, and the distance to the target. The quality of the data will be affected by the lighting and the focus of the lens on the target as well as the calibration.

If the signal-to-noise ratio (SNR) of the output is not satisfactory, the first item to check is the target displacement versus the total lens displacement. Using more of the dynamic range of the tracker improves the SNR. Poor target lighting and ambient light will adversely affect the SNR. If the optics are not properly focused or if the lock-on is not set correctly, the SNR will be bad. If these possible sources of trouble have been checked carefully and the output is still noisy, then it may be necessary to check the power supply in the control box. If the high voltage supply is not set properly, the output will suffer. Extreme caution should be exercised when working inside the control box as the voltage levels are hazardous. Optron recommends only "qualified" personnel work around the high voltage.

VII. BENEFITS DERIVED FROM THE USE OF OPTICAL TRACKERS

The ease of setting up an experiment and the relatively short time involved in reducing the data make the optical tracker, in our case the Optron, a valuable tool. Because the tracker does not generally require any mechanical modification to the equipment under test and does not affect the motion being measured, the Optron has been used extensively to make dynamic measurements of weapon systems. Because of the dynamic range the tracker can cover, it can be used to measure small motions of a gun tube prior to muzzle exit as well as the total recoil of gun systems. The flexibility of the optical tracker makes it an extremely valuable instrumentation tool.

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1. Optron Div. of Universal Technology, Inc., "Model 501 Electro-Optical Displacement Follower," Instruction Manual.

2. A.F. Baran, B.T. Haug, "Muzzle Motion Measurements of the 30-mm, L21E1 RARDEN Gun Mounted in a Sheridan Vehicle as Compared with Rigid Mount Tests," BRL Memorandum Report ARBRL-MR-03182, June 1982 (AD B065739).

3. A.F. Baran, B.T. Haug, R.B. Murray, "Evaluation of the Dynamics of the Bushmaster 25-mm,PFB-25 Automatic Cannon," BRL Memorandum Report 2605, March 1976 (AD B010565L).

4. R.P. Kaste, "Kinematic Investigation Hughes Helicopter 7.62-mm Chain Gun," BRL Memorandum Report 3157, February 1982 (AD A113114).

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6. B.K. Stearns, R.C. Walker, "Measurement of Gun Barrel Motion with Optical Trackers," Proceedings of the Second US Army Symposium on Gun Dynamics, September 1978.

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