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VISUAL CHARACTERIZATION OF WEAR IN LARGE CALIBER WEAPONS

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Abstract: As part of the Army Test and Evaluation Command (ATEC) the Metrology and Simulation Division at the U.S. Army Yuma Proving Ground (USAYPG) has the mission to measure and record the detrimental effects of firing conventional and experimental munitions on large caliber cannon tubes. The primary objective is to ensure that the weapon to be fired will safely meet mission requirements for the quantity and energy of the munitions under live fire testing. One aspect of this mission is to conduct physical measurements on rifled and smooth bore cannon tubes. The measured value is compared to the acceptable tolerance; from this the disposition of the weapon is then determined.

In the past physical measurements were taken with a "star gage". The star gage is used to measure wear on rifled cannon tubes. This device measures the wear of the reference "land and groove" at the zero and 90-degree positions respectively. Although this method offers a high degree of precision, faults that exist at other positions are not recorded. As a result of this limitation, wear phenomena such as erosion or build up could not be quantified. Recent developments in barrel measurement instrumentation have expanded the analytical capabilities of the status quo. Instead of two data points, 2000 data points may be measured from 0 to 360 degrees. From this data, tooth profiles for rifled barrels and wear in smooth bore cannon tubes may be displayed and three-dimensional models may be developed. Different algorithms have been developed to display collected data from a variety of perspectives. The resulting types of perspectives and the visual characterization of different types of wear will be examined in the body of this paper.

INTRODUCTION

In order to maximize safety, and to accurately assess the performance of conventional and experimental munitions, regulation dictates that physical measurements be performed to gage the wear induced from firing. Figure 1 defines the terminology and conventions subsequently used in the body of this paper. Inspections normally occur at specific distances with respect to the "origin of rifling" for the weapon being tested. The origin of rifling (OR) is usually indicated as $d=0$ and zero degrees corresponds to top dead center or 12 o'clock. Subsequent measurements down the bore are positive. Figure 2 shows the tooth profile at the OR for a 155mm cannon tube measured radially from the centerline of the bore. The displacement between 120 degrees and 330 degrees indicates wear on the lands. A three-dimensional model may be constructed by adjusting for the twist of the rifling and piecing the data together linearly using a Delaunay triangulation method [1,2]. Figure 2 illustrates this methodology. Although the raw data is useful for generation of computer models, the amount of data is cumbersome to process and not easily interpreted by the untrained eye. By reducing the data to 48 land and groove radii, the data processing is faster and produces clearer results. Averaging the radial values with respect to lands and grooves reduces the data. Using this method, the wear effects between firing missions

may be quantifiably visualized. Groove radial analysis, land radial analysis, land/groove height radial analysis, percent wear analysis and a comparative analysis showing the cumulative effect of firing an additional 496 rounds through a 155mm cannon tube will be illustrated and discussed. The standard statistical analysis may be applied to the data from each measurement position. This discussion will focus on three dimensional analysis techniques and how this method may be used to gage the increase in wear from mission to mission.

DEFINITION OF TERMS AND CONVENTIONS

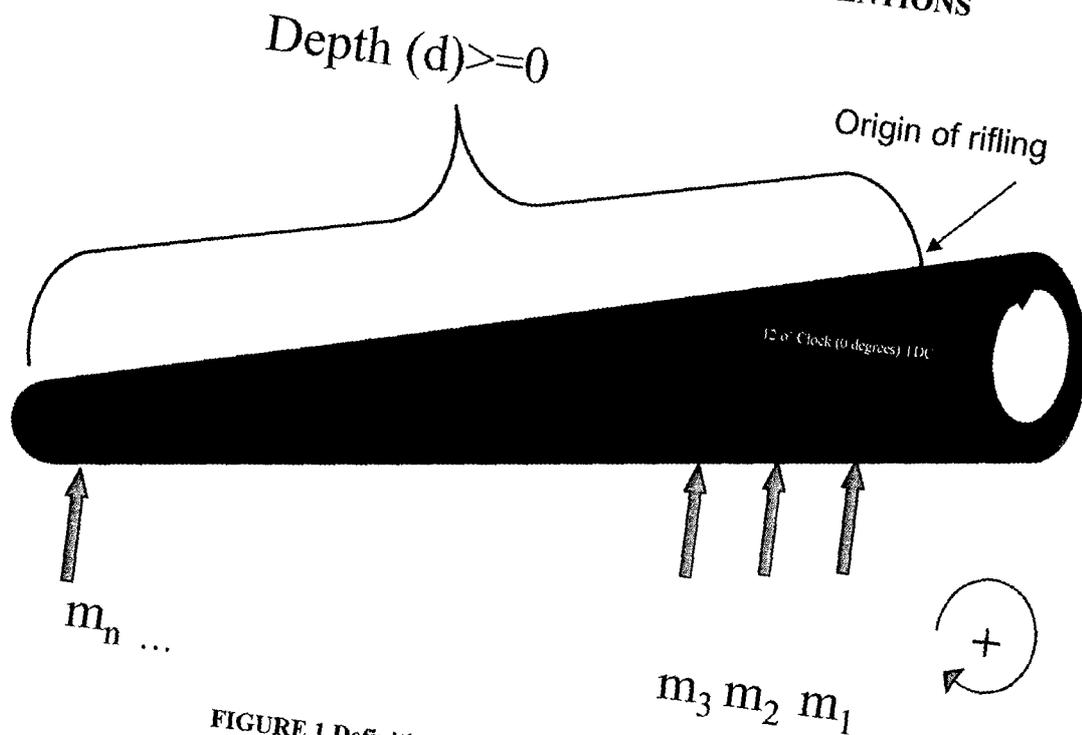


FIGURE 1 Definition of Terminology and Sign Conventions.

The parameters shown in Figure 1 are defined as follows:

Origin of Rifling (OR): The point at which the commencement of full rifling begins.

Depth (d): The length down the bore at which the measurement is taken in millimeters. The origin of rifling is designated as $d=0$.

$m_1 \dots m_n$: An index of measurements at a specific depth.

12 o' Clock: Zero degrees top dead center (TDC) of the cannon tube with positive rotation clockwise.

MODELING

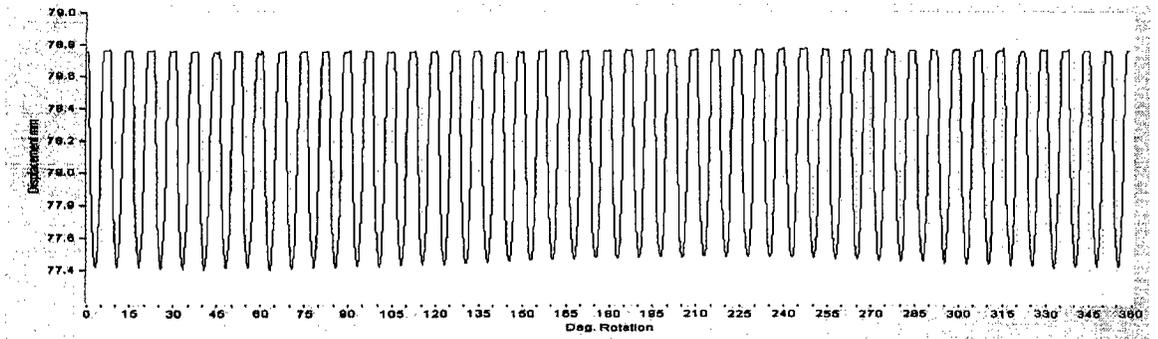


FIGURE 2 Tooth Profile at Origin of Rifling (OR), Depth=0

As indicated in Figure 3., the protuberance on the first groove represents a loss of material. In the corresponding density (top view) plot the chrome loss shows as a darker line at approximately 7 degrees rotation. Loss of land material (tooth wear) is indicated by the different intensities at approximately 3 degrees and 11 degrees rotation respectively

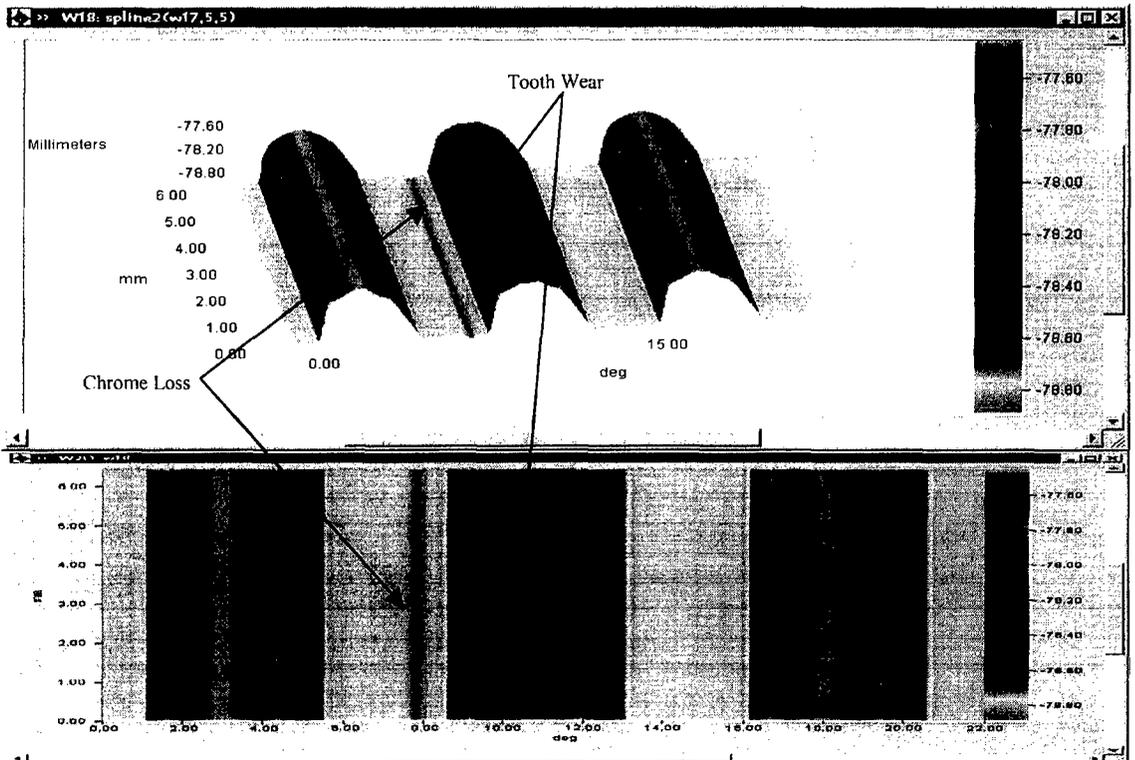


FIGURE 3 Three Dimensional Tooth Profile and corresponding Density plot.

RADIAL ANALYSIS

Let us now examine the effect of firing 496 rounds through a tube. The data at 2060 rounds will serve as a baseline measurement. The advantages and disadvantages for each type of analysis will be discussed.

Three Dimensional Groove Radial Analysis

The reduced data may be represented as a surface plot with corresponding top view (contour plot). Since most of the wear is on the rifling (lands), the groove radius is consistent with the manufacturing tolerance of the weapon. This is a useful technique for acceptance of new cannon tubes. Since the grooves see a minimal amount of wear throughout the lifetime of the weapon, this radius is expected to remain consistent. An example of summary statistical calculations is shown in Figure 4. Subsequent measurements can then be compared to the baseline data (ideally a new gun tube). Although this is a poor indicator of wear, this is a useful method to visualize and quantify any buildup of material in the grooves.

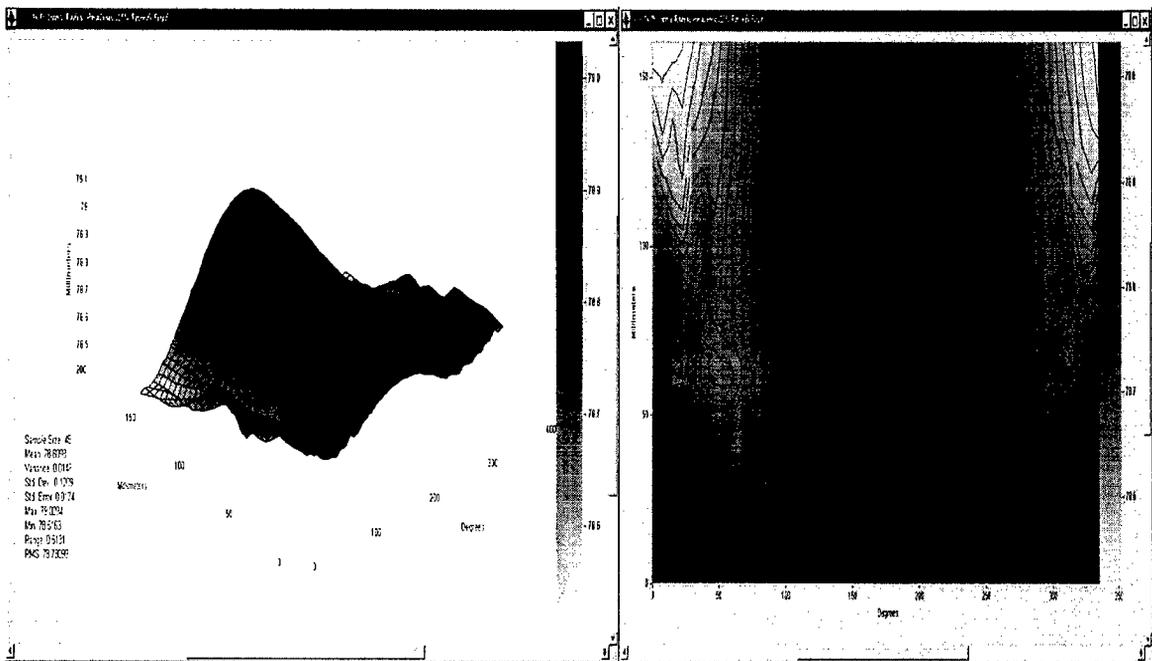


FIGURE 4. Land Radial Analysis 3 Dimensional Surface plot and corresponding top view

Three Dimensional Land Radial Analysis

Figures 5 and 6 illustrate wear on the lands. Unless the person viewing the data is familiar with measurement tolerances, the degree of wear measured is not clearly evident. However people such as inspectors and test engineers would notice significant wear about the zero degree position.

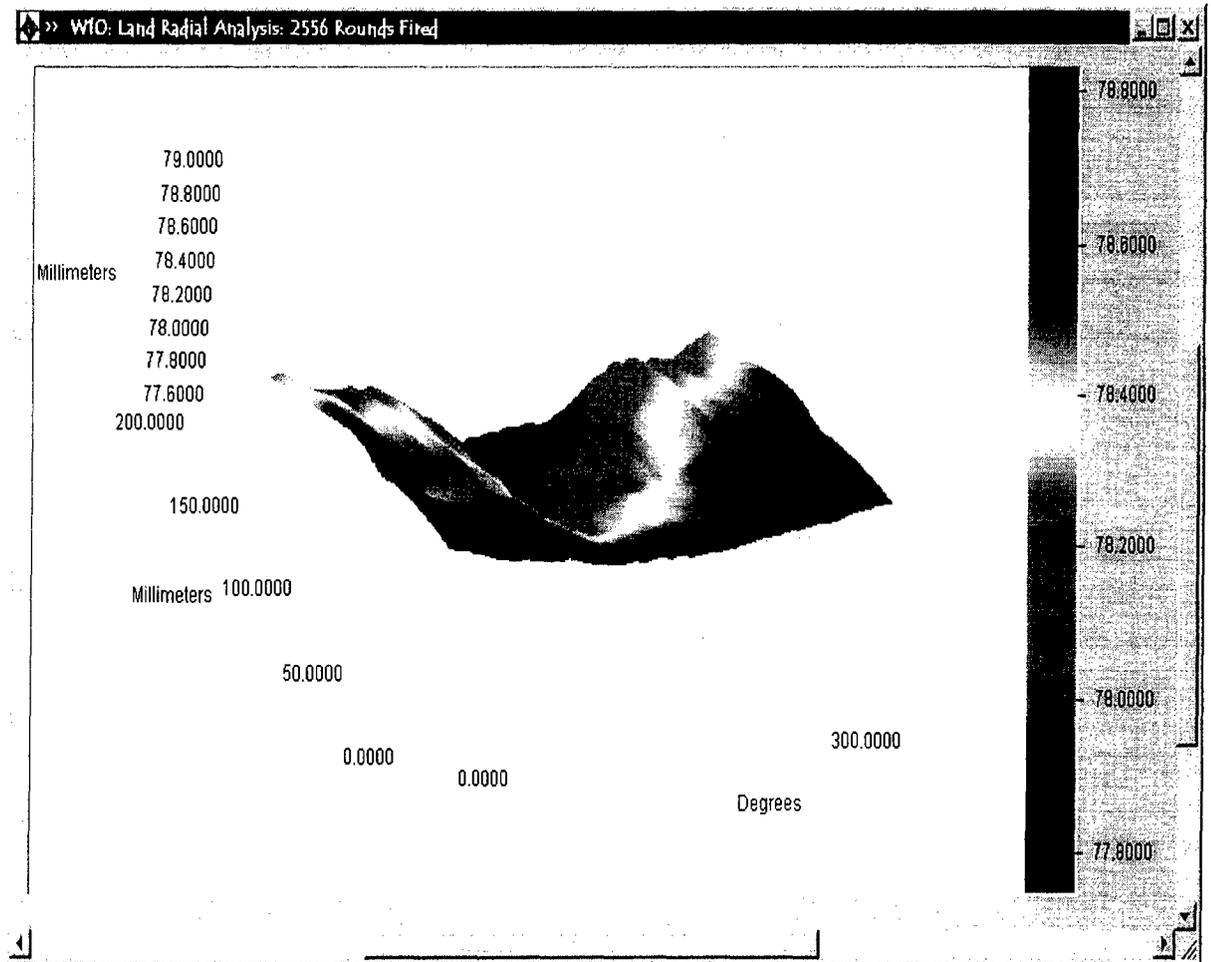


FIGURE 5 Land Radial Analysis 3 Dimensional Surface Plot

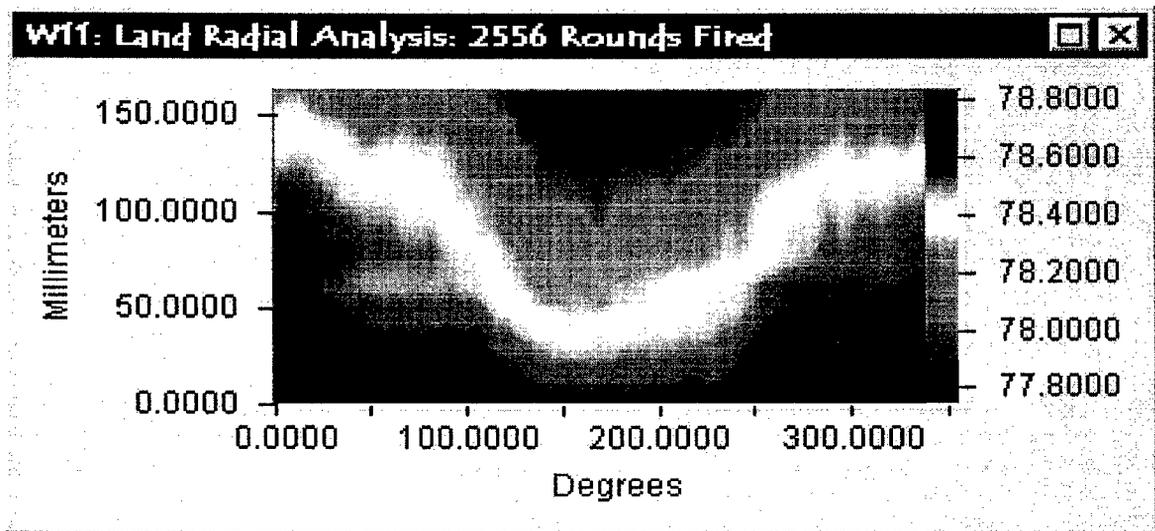


FIGURE 6 Land Radial Analysis corresponding top view

Three Dimensional Land/Groove Height Analysis

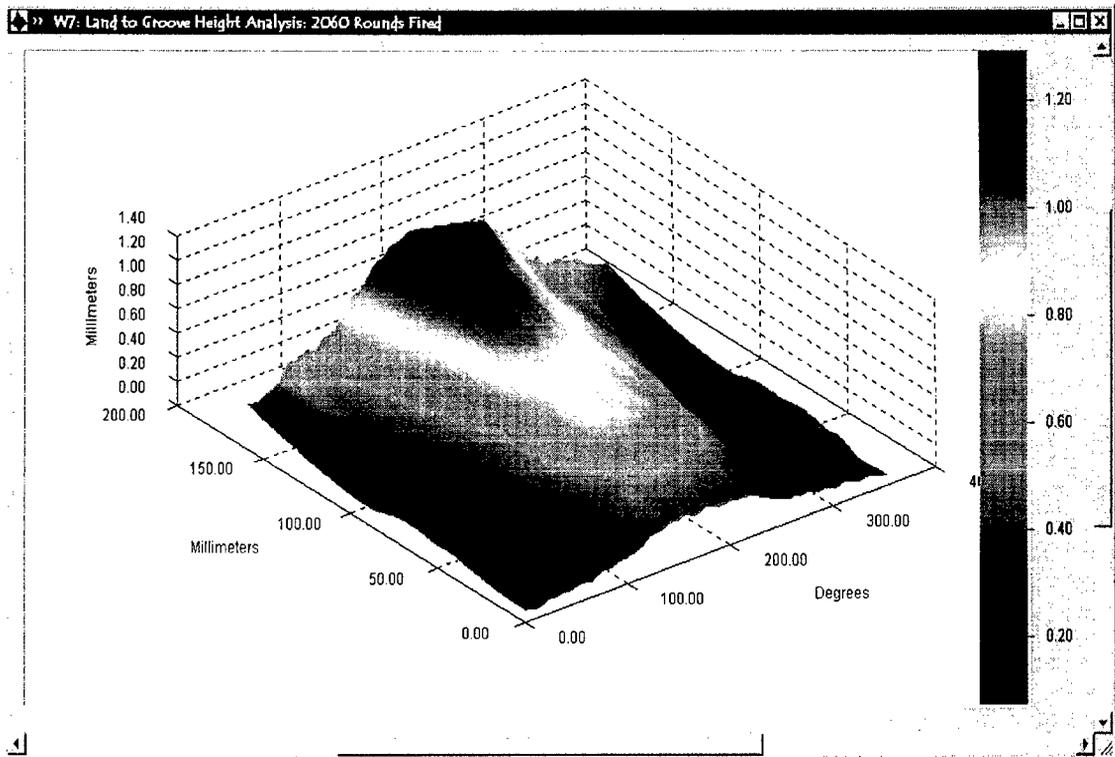


FIGURE 7 Land/Groove Height Analysis 3 Dimensional Surface Plot

This analysis is the most indicative of wear with respect to the weapon under test [3]. The relation of land to groove heights is plotted as a three-dimensional surface with the corresponding top view Figures 7 and 8. Note that the height is approximately zero at the zero degree (12 o'clock) position indicating a significant tooth loss and that this weapon is nearly at the deadline criteria [4]. This method still requires that the analyst is familiar with the tolerances and deadline criteria for this particular weapon.

PERCENT WEAR ANALYSIS

In order to compare and to quantify the degree of wear induced from mission to mission on a particular cannon tube, the land to groove height is normalized with respect to the nominal land to groove height. The model, caliber and manufacturing process determines this value. The value used in this discussion was obtained from the inspection history of the cannon tube. Normalization maps the data into a 0 to 100 percent scale by calculating the percent difference from the measured value versus the nominal land to groove height Figure 9 shows the wear pattern at 2556 rounds and 2060 rounds respectively.

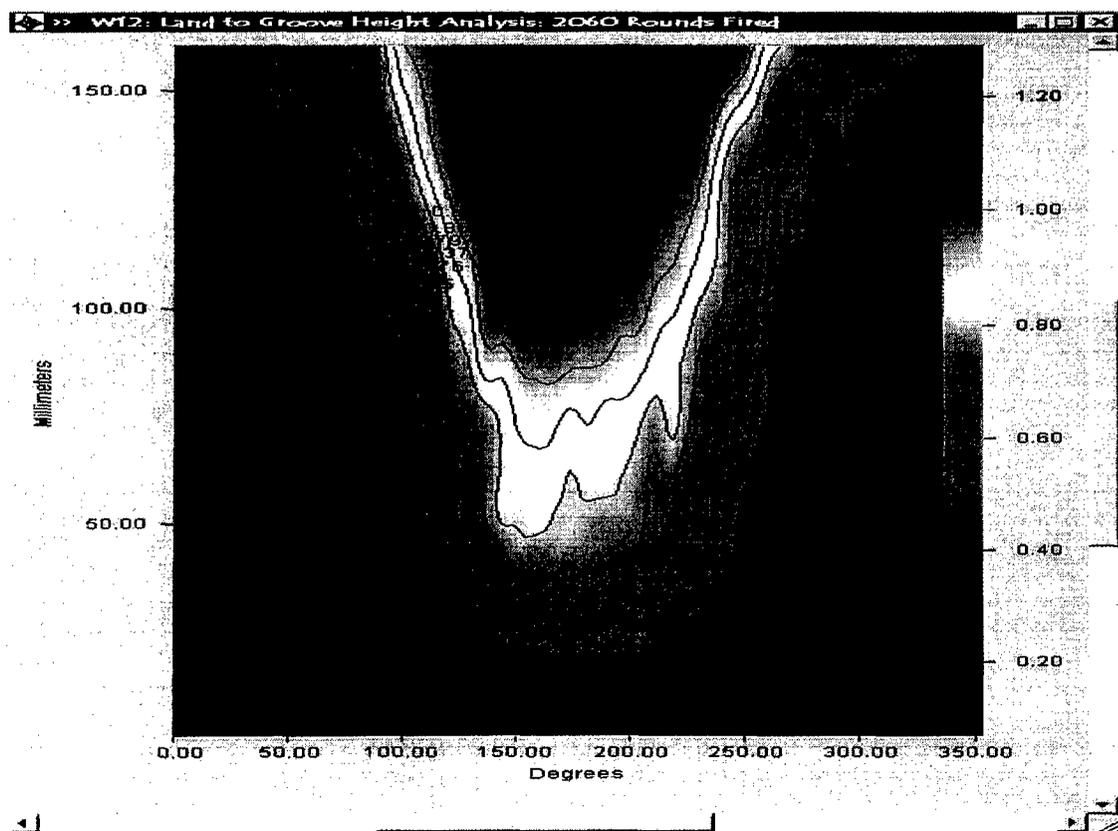


FIGURE 8 Land/Groove Height Analysis Top View with labeled contour lines

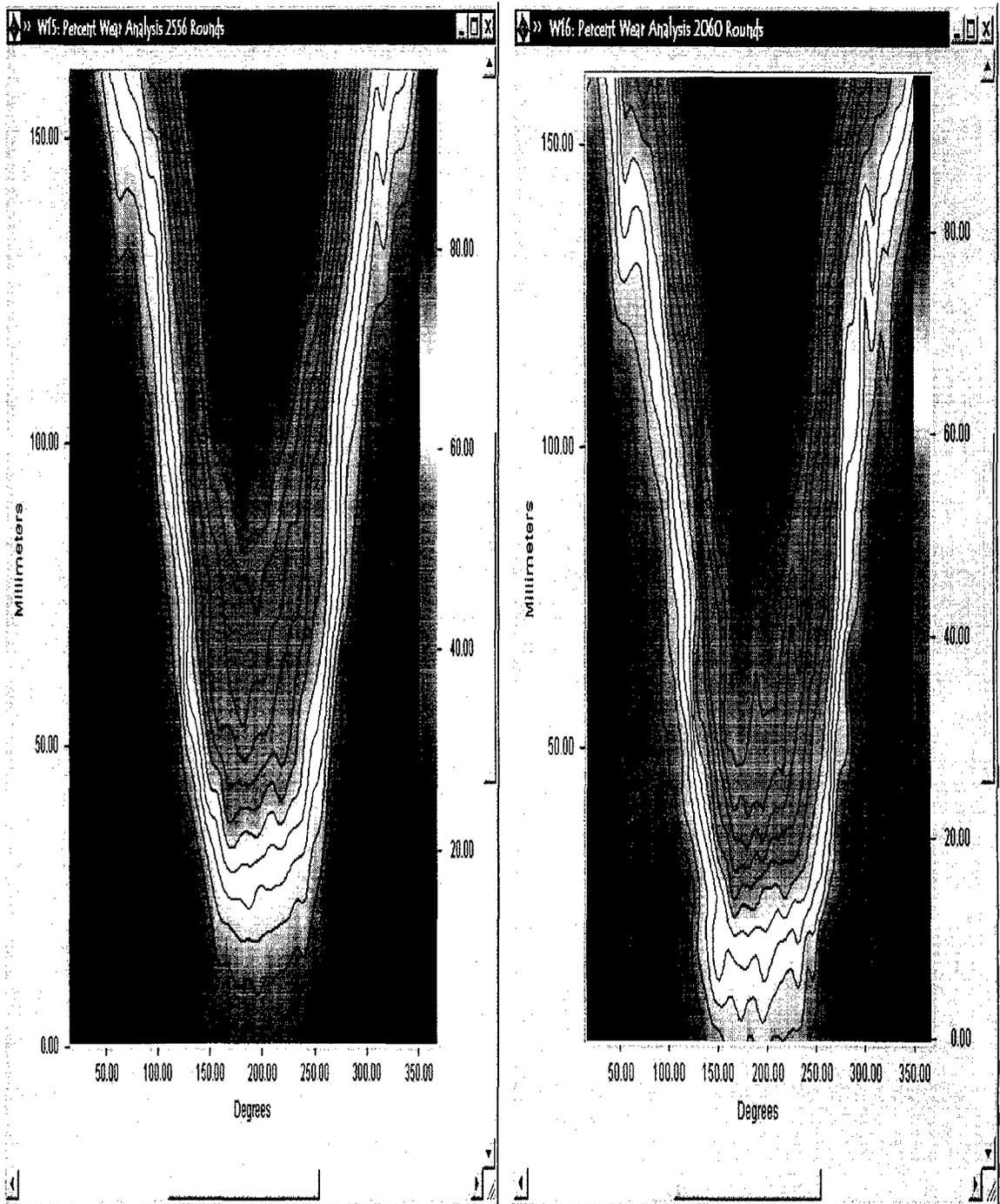


FIGURE 9 Comparison of Normalized Wear Maps at 2556 and 2060 Rounds Fired

The above illustrations show the effect of firing 496 rounds. Notice that the wear is progressing up the cannon tube. Since most of the wear occurs at 0 degrees (12' o' clock) the wear pattern may be rotated 180 degrees and plotted with respect to o'clock position (Figure10).

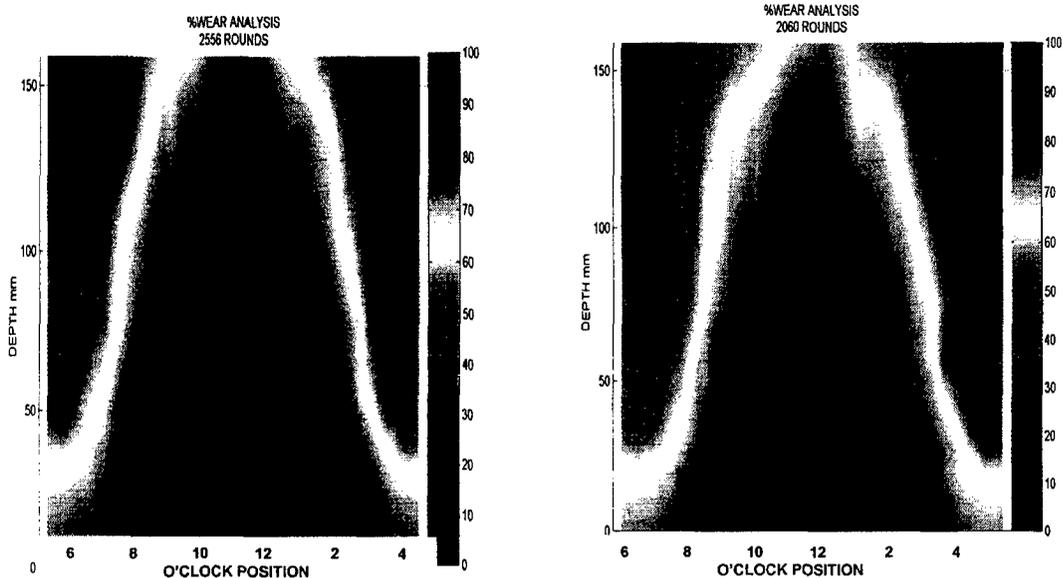


FIGURE 10 Normalized Wear Pattern rotated 180 Degrees

The wear incurred by firing 496 rounds is the difference of the maps in Figure 10 and is portrayed in Figure 11 with respect to o'clock position.

% Increased Wear Analysis from 2060 to 2556 Rounds

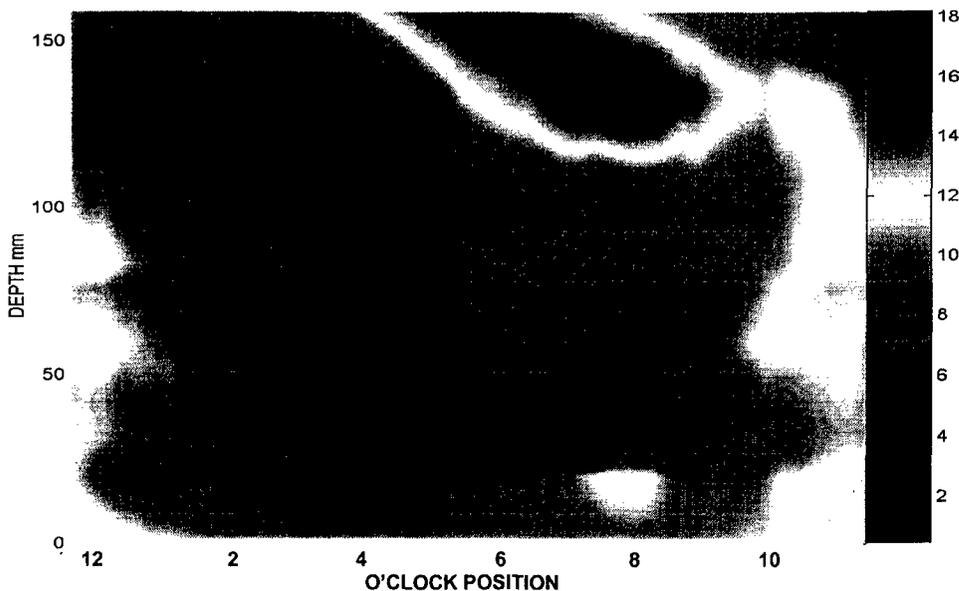


FIGURE 11 Map of Percent Increased Wear illustrating the effect of firing 496 Rounds

DISCUSSION

As illustrated above the analyst may now easily quantify wear patterns as a function of the number and/or type of munitions fired. Although the entire gun tube may be mapped by the same methodology, the author feels that the methodology is best exemplified by concentrating in the area where most of the wear will occur. The above analysis was performed with a commercially available software package. The analyst may use all of the potential of the software package to expand the scope of the analysis or to easily automate the analysis and explore new methodologies. If the illustrations are confined to grayscale, some of the impact that color has to offer is somewhat diminished. Albeit, even with this limitation, the reader may notice distinct wear patterns. The comparative analysis in Figure 11 readily illustrates and quantifies the location and severities of wear incurred by the additional firing of 496 rounds. By starting with new cannon tubes as a baseline, cross-referencing the type and quantity of munitions tested, and incorporating visual inspection (borescope) one can conduct a long-term controlled experiment to generate a computer wear model.

CONCLUSION

The advent of measurement technology in the arena of munitions testing has provided a means to visually characterize and gage the effect of testing on the weapon. A historical database is planned such that a computer model may one day simulate the effect of virtual firing missions. The above methodology, as well as the standard two-dimensional analyses may be tied into the Wear Analysis Database [5] currently in use at the U.S. Army Yuma Proving Ground. In closing, it is the opinion of the author that this technology has the potential to serve as a valuable tool in the U.S. Army's initiative to enhance overall operations, minimize developmental costs, and ensure safer operations by the use of computer generated models.

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