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INDEX TO BENET LABORATORIES TECHNICAL REPORTS - 2002

R. D. SHUMAN

APRIL 2003

TACOM-ARDEC

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
Close Combat Armaments Center
Benét Laboratories
Watervliet, NY 12189-4000

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SONIC RAREFACTION WAVE LOW RECOIL GUN

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6. AUTHOR(S)

E. Kathe and R. Dillon

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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This report was originally drafted for presentation at the 36th AIAA Joint Propulsion Conference to be held in Huntsville, AL, July 2000. However, all gun related papers were removed from this conference. It was later presented at the 39th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, January 2001, as paper AIAA-01-0743. Therefore, the contents of this paper predate those of ARCCB-TR-01008, despite the latter's earlier publication date.

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13. ABSTRACT *(Maximum 200 words)*

A principal challenge faced by the U.S. Army TACOM-ARDEC Benét Laboratories in the design of armaments for lightweight future fighting vehicles with lethality overmatch is mitigating the deleterious effects of large caliber cannon recoil. The sonic RArefaction waVE low recoil guN (RAVEN) is a novel invention to dramatically reduce the gas momentum contribution to recoil with absolutely no reduction in the ballistic efficiency of launch. This technology is being investigated as part of the future combat vehicle armaments program conducted at Picatinny Arsenal, NJ, and Watervliet Arsenal, NY.

14. SUBJECT TERMS

FCS, MRAAS, Recoilless Rifle, Interior Ballistics, Propulsion, Cannon, Gun, Novel, Recoil, de Laval Nozzle, Vent

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GUN BARREL VIBRATION ABSORBER
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Andrew Littlefield, Eric Kathe, Robert Messier, and Kenneth Olsen

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13. ABSTRACT *(Maximum 200 words)*

Gun barrel vibrations lead to dispersion in the shot patterns. Thus, reducing these vibrations should lead to increased accuracy. Since the muzzle is the anti-node for all vibration modes and its vibrations have the greatest effect on shot dispersion, it is the obvious location to attempt to dampen the vibrations. A model of the gun barrel was created in MATLAB® and verified by modal impact testing. Modal impact testing was done for the barrel alone and for three different muzzle brake vibration absorber configurations. Additionally, the gun was fired with and without the absorber to determine its performance. Significant reduction in shot dispersion was observed.

14. SUBJECT TERMS

Gun Barrel, Vibrations, Accuracy,
Vibration Absorber, Firing Test, Dynamics

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13. ABSTRACT *(Maximum 200 words)*

Gun barrel vibrations lead to dispersion in the shot patterns. Thus, reducing these vibrations should lead to increased accuracy. Since the muzzle is the anti-node for all vibration modes and its vibrations have the greatest effect on shot dispersion, it is the obvious location to attempt to dampen the vibrations. A model of the gun barrel was created in MATLAB® and verified by modal impact testing. Modal impact testing was done for the barrel alone and for three different muzzle brake vibration absorber configurations. Significant reductions in muzzle vibrations were achieved using the vibration absorber. Methods of making the vibration absorber adaptive and models of such a system are presented.

14. SUBJECT TERMS

Vibration Absorber, Passive, Smart Structures,
Gun Barrels, Accuracy, Vibration, Dynamics

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

This report presents results from Benet Laboratories' evaluation of 120-mm diameter smoothbore AISI 4347 steel cylinder specimens treated by the University of Tennessee Space Institute with their Laser-Induced Surface Improvement (LISI) process. The specimens were designated "100% Cr," "90% Cr/10% CrB_2," and "100% CrB_2." These designations refer merely to the compositions of the precursor coatings, and not to the compositions of the final materials, even near their surfaces. This Phase I evaluation was performed to investigate the suitability of LISI coatings for wear and erosion protection of cannon bore and/or other critical cannon surfaces. The Office of the Project Manager, Crusader (OPM-Crusader) sponsored the current study.

14. SUBJECT TERMS
Gun Bore, Gun Tube, Coatings, Laser Surface Treatment,
Cannon Bore, Crusader, Chromium Coatings, Erosion

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YIELD PRESSURE MEASUREMENTS AND
ANALYSIS FOR AUTOFRETTAGED CANNONS

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6. AUTHORS
John H. Underwood, David B. Moak, Michael A. Audino, and
Anthony P. Parker (Royal Military College of Science, Cranfield University, Swindon, UK)

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13. ABSTRACT *(Maximum 200 words)*

Yield pressure for a small permanent strain was measured in quasi-static laboratory tests of autofrettaged ASTM A723 steel cannon pressure vessels. Yield pressure was found to be a consistent ratio of the yield strength measured in close proximity to the area of observed yielding. Comparable yield pressure measurements for cannons firing with typical 5-ms pressure pulse duration gave 14% higher yield pressures, attributed to strain-rate effects on plastic deformation.

Calculated von Mises' yield pressure for the laboratory test conditions, including the Bauschinger-modified inner diameter residual stress and open-end vessel conditions, agreed with measured yield pressure within 3 to 5 %. Calculated yield pressure was found to be insensitive to the value of axial residual stress, since it is typically the intermediate value in the von Mises' yield criterion.

A description of yield pressure normalized by yield strength was given for autofrettaged A723 open-end pressure vessels over a range of wall ratio and degree of autofrettage, including effects of Bauschinger-modified residual stress. This method for calculating yield pressure is proposed as a design procedure for cannons and other pressure vessels.

14. SUBJECT TERMS
Yield Pressure, Cannons, Yield Strength,
High-Strength Steels, Autofrettage, Bauschinger Effect

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13. ABSTRACT *(Maximum 200 words)*
As part of the *Army After Next* effort, TACOM-ARDEC's Benet Laboratories undertook a radical departure from current tank gun recoil to engineer a soft recoil tank gun. Such a leap in technology may be required to enable a lightweight future combat system to withstand the recoil imparted by a large caliber gun, especially during fire on the move. Although soft recoil is not new to smaller caliber guns and howitzers, implementation for a large caliber tank gun is unprecedented. The theoretical foundations of this recoil management technology will be presented here. Experimental test results from a 105-mm fire out-of-battery tank gun demonstrator will be presented in a separate report.

14. SUBJECT TERMS
Gun Mount, Soft Recoil, Fire Out-of-Battery, Future Combat System

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6. AUTHORS
M.A. Doxbeck, M.A. Hussain, J. Rama,
A. Abbate (Panametrics, Inc., Waltham, MA),
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13. ABSTRACT *(Maximum 200 words)*
We used single-source and single-detector laser-ultrasonic measurements to generate and detect Rayleigh waves on tantalum sputtered steel substrates. Group velocity dispersion curves were calculated from the single-detected signals using wavelet techniques. Theoretical dispersion curves were calculated via the Achenbach and Keshava analysis. A simplex minimization technique between theory and experiment, using known values for the substrate, allowed us to evaluate the coating parameters. The coating thickness was measured accurately with micrometers, and gives the most easily available comparisons with the output of the simplex method. The results using the straightforward wavelet method were compared with an adaptation thereof.

14. SUBJECT TERMS
Algorithm, Coatings, Lasers, Ultrasonics, Rayleigh Waves, Wavelet Analysis, Sputtered Tantalum

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13. ABSTRACT *(Maximum 200 words)*

A new variant of the nonlinear kinematic hardening model is proposed that accommodates both nonlinear and linear strain hardening during initial tensile loading and reduced elastic modulus during initial load reversal. It also incorporates the Bauschinger effect, as a function of prior tensile plastic strain, during the nonlinear compressive loading phase. The model is shown to fit experimental data from a total of five candidate gun steels. The numerical fits will be employed in subsequent work to predict residual stresses and fatigue lifetimes for autofrettaged tubes manufactured from the candidate steels.

14. SUBJECT TERMS Kinetic Hardening Model, Elastic Modulus, Bauschinger Effect, Autofrettage, Steels, A723 Steel, HY180 Steel, PH 13-8 Mo Steels, Residual Stress, Pressure Vessels, Gun Tubes			15. NUMBER OF PAGES 16 16. PRICE CODE
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6. AUTHORS
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13. ABSTRACT *(Maximum 200 words)*

Modern tank guns, such as the one on the Abrams, are stabilized to allow fire on the move while traversing uneven terrain. The current barrel is short enough that treating it as a rigid beam allows engagement of another tank at ranges of over a kilometer. However, as the length of the tube is extended, to meet required muzzle exit velocities, the terrain-induced vibrations lead to increased muzzle pointing errors. A method to reduce these vibrations is to use the forward thermal shroud as part of a mass tuned damper. In this case the system under study is an extended length version of the gun currently fielded. This extended length increases its susceptibility to terrain-induced vibrations. The forward thermal shroud has been shortened and additional mass has been added onto its forward collar. This collar is then supported by springs, which are preloaded so that they stay in contact through the full range of the shroud's movement. Varying the stiffness of these springs allows for tuning of the absorber. Different types of springs and attachments have been tried. The current version uses leaf springs and a wedge collar. This system has been modeled, and experiments have been conducted to validate the model.

14. SUBJECT TERMS
Vibrations, Vibration Absorber, Cannons,
Gun Barrel, Passive, Accuracy, Dynamics

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4. TITLE AND SUBTITLE
EVOLUTION OF SURFACE STRUCTURES IN SPUTTERED COATINGS

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6. AUTHORS
Mark A. Johnson and Paul J. Cote

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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13. ABSTRACT *(Maximum 200 words)*
The evolving surface structure of sputtered tantalum and niobium coatings was characterized in terms of dynamic scaling exponents using atomic force microscopy (AFM) to map surface structures over a range of scales from 10-nm to 5-□m. New numerical techniques are introduced to systematically determine the time evolution of the spatial scaling parameters associated with the coating surface morphology. These dynamic scaling parameters define a unique *universality class* that is associated with the deposition process, and provides insight into the dynamics of the growth processes of thick metal films.

14. SUBJECT TERMS
Image Processing, Universality Class, Dynamic Scaling Exponents, Fractals

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13. ABSTRACT *(Maximum 200 words)* Changes in the intrinsic structure of paint surfaces resulting from extended UV exposure can significantly alter the appearance of the paint due to a breakdown in the resin that binds the fine paint particulates. In this study, the coating structure of a solvent-based polyurethane was analyzed to establish correlations between the intrinsic spatial scaling properties of the coating and UV exposure time. Atomic force microscopy (AFM) and laser scanning confocal microscopy (LSCM) were employed to map surface structures over a range of scales from 100-nm to 100-□m. The roughness of the polyurethane surface was characterized in terms of scaling exponents by quantifying the local roughness using detrended fluctuation analysis (DFA) to identify long-range power-law correlations and correct for inhomogeneities in the surface structure. This approach provides a means to directly compare AFM and LSCM results over a range of scales consistent with those of a self-affine fractal. The time-dependent dynamics of the roughening process was also determined in order to provide a metric for characterizing the evolving surface morphology. The results provide fresh insight into the mechanisms of polyurethane coating degradation under UV exposure.			
14. SUBJECT TERMS Detrended Fluctuation Analysis, UV Degradation, Image Analysis, Fractals			15. NUMBER OF PAGES 15
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SAFE MAXIMUM PRESSURE DETERMINATION FOR THE M829E3/M256 CANNON QUALIFICATION PROGRAM

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6. AUTHORS
David C. Smith and Eugene E. Coppola

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13. ABSTRACT *(Maximum 200 words)*

The M256 120-mm cannon is the main armament of the M1A1 and M1A2 tanks. With the increased pressure generated by the latest version of the M829 APFSDS-T cartridge (A3), the yield strength of the cannon would have been insufficient to prevent elastic deformation of the tube. Classical theory indicated that this pressure could not have been contained, but it was known that the theory is somewhat conservative. By testing to elastic deformation and using statistical analysis, a new Safe Maximum Pressure (SMP) as defined by NATO Standardization Agreement (STANAG) 4110, was determined. This resulted in the M256 tube yield strength being redefined and capable of firing the M829A3.

14. SUBJECT TERMS
M256, Cannon, Test, Yield, Yield Strength,
Safe Maximum Pressure, Hydraulic, Strain Rate

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6. AUTHORS
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13. ABSTRACT *(Maximum 200 words)*

The design and construction of a planar magnetron-sputter deposition system with a beryllium chamber was accomplished to perform *in-situ* x-ray diffraction growth study of refractory coatings. The deposition system was set on top of a laboratory θ-2θ x-ray diffractometer. A two-dimensional array detector was interfaced for observation of the Debye rings during growth. Integration along the 2θ and χ directions allows fast phase and texture determination. The system was built to study effects of sputter deposition parameters on the structural properties of tantalum on steel, silicon, and glass substrates without exposing the system to atmosphere pressure.

Two sputter depositions of tantalum films onto glass substrate in argon gas are reported here, one was deposited at 25-mm target-detector distance, 3.9 Pascal argon gas, and the other at 108-mm target-detector distance and 1.3 Pascal argon gas. The first film grew to 250-nm in 39 minutes at an average growth rate of 6.4-nm/minute. It consisted of 45-nm of interface layer, which showed no crystalline structure, and was most likely amorphous film. It was followed by 15-nm growth of β-tantalum, and then followed by 190-nm growth of α-tantalum. From the full-width half maximum of the χ-plot, it was determined that the β-tantalum region was <002> textured, and the α-tantalum region was <110> textured, and grew more textured with deposition time. The second film grew to 36-nm in 22 minutes at an average growth rate of 1.6-nm/minute. It consisted of 31-nm of layer, which showed no crystalline structure, and was most likely amorphous film. It was followed by 5-nm of surface layer of β- and α-tantalum. *Ex-situ* grazing incidence x-ray diffraction performed on the film surface confirmed the *in-situ* results. *Ex-situ* pole figure analysis showed <110> fiber texture in α-tantalum, and highly <002> texture in β-tantalum.

14. SUBJECT TERMS
In-Situ Characterization, Magnetron Sputtering, Real-Time X-Ray Diffraction, Tantalum, Two-Dimensional Detector

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6. AUTHORS
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13. ABSTRACT *(Maximum 200 words)*
A rational approach to disturbance rejection is proposed and applied to a simple three degree-of-freedom flexible gun tube model using feedforward and feedback compensation. The first two natural frequencies of the pin-free and cantilever tube are matched by adjusting the dimensions of the rigid segments and the stiffness of the torsional springs that join them. It was found that, contrary to the previously analyzed two degree-of-freedom segment model, the muzzle-end segment could be stabilized by the proper choice of transfer functions and elevation driveline response. The analysis serves to establish the requirements for the transfer functions and stabilizing actuator systems.

14. SUBJECT TERMS
Gun Tube, Flexible, Stabilization

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CHARACTERIZATION OF EXPLOSIVELY BONDED AND FIRED TANTALUM LINERS APPLIED TO 25-MM GUN TUBES

5. FUNDING NUMBERS
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6. AUTHORS
C. Mulligan, M. Audino, P. Cote, G. Kendall, C. Rickard, S. Smith, and M. Todaro

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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13. ABSTRACT *(Maximum 200 words)*
Characterization analyses were conducted on sections taken from three truncated 25-mm gun tubes that were explosively bonded with pure tantalum. Two of the barrels had been test fired and one was received in the pre-fired condition. The two test-fired tubes consist of one smoothbore design and one no-twist rifled bore design. The specimen received in the pre-fired condition was the smoothbore design. Characterization work included macroscopic examination, liner thickness measurements, microstructural analysis, microhardness testing, adhesion testing, scanning electron microscopy, energy dispersive spectroscopy, wavelength dispersive spectroscopy, hydrogen analysis, and pulsed laser heating. Characterization results indicate vast improvement over the erosion characteristics of standard nitrided 25-mm Bushmaster gun tubes when firing the unfielded, original M919 propellant (100% HE 9053). Some areas of concern in the performance of the liner include heavy heat-check cracking, severe gas erosion, high concentration levels of hydrogen, and surface oxidation of the tantalum liners.

14. SUBJECT TERMS
Explosive Bonding, Tantalum. 25-mm Gun Tubes, Wear, Erosion, Refractory Coatings

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6. AUTHORS
S. Sopok, G. Pflegl, and C. Rickard

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13. ABSTRACT *(Maximum 200 words)*

Erosion modeling predictions are given for the current M829E3 round configuration and weighted averages per temperature for the computer correction factor (CCF). Our gun erosion model was developed through a ten-year joint partnership with Software and Engineering Associates, Inc., Carson City, NV. These predictions are based on recent cannon characterization data. These latest predictions include significant changes in propellant configuration and projectile weight that were made to the current M829E3 configuration compared to our initially presented M829E3 modeling predictions two years ago. For the last two years, additional nonablative M829E3 erosion modeling predictions have not been conducted or presented. This was due to a diversion of erosion modeling resources toward ablative M829E3 erosion predictions and erosion predictions related to the selection of six M256 cannons for M829E3-related fatigue testing. For the current M829E3 configuration, these changes in gas pressure, gas temperature, gas velocity, and increased projectile weight collectively contributed to a predicted increase in M256 cannon erosion life compared to our initially presented M829E3 modeling effort. In addition, the current set of M829E3 weighted averages per temperature for CCF from Fort Knox (19% hot 49°C/120°F, 64% basic 21°C/70°F, 16% cold -7°C/20°F, and 1% severe -32°C/-25°F) collectively contributed to a further predicted increase in M256 cannon erosion life compared to the two-year-old set of weighted averages per temperature (33% hot, 33% basic, 0% cold, and 33% severe). For the current predictions, the peak eroded cannon axial position remains at approximately 60 inches from the rear face of the tube ±6 inches; and this position dictates the erosion life of the cannon. Erosion life predictions at this position are given for each of the round-conditioning temperatures and the Fort Knox mixture of round-conditioning temperatures. At this peak eroded position, the respective 49°C/120°F, 21°C/70°F, -7°C/20°F, -32°C/-25°F, and Fort Knox mixture round-conditioning temperature cases have predicted erosion lives of approximately 183, 287, 388, 302, and 269 rounds. The mixture of M829E3 rounds with some types of HEAT and slug rounds significantly moves the peak eroded axial position up-bore to the bore onset region.

14. SUBJECT TERMS
Erosion Modeling, M256 Cannon, M829E3 Round, Erosion Predictions

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