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Law Enforcement and Corrections Standards and Testing Program

NIST Random Profile Roughness Specimens and Standard Bullets

NIJ Report 601–00

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This report was prepared by the Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) under the direction of Alim A. Fatah, Program Manager for Chemical Systems and Materials, and Kathleen M. Higgins, Director of OLES. The work resulting from this report was sponsored by the National Institute of Justice (NIJ), David G. Boyd, Director, Office of Science and Technology.

FOREWORD

The Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. OLES's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

OLES is: (1) Subjecting existing equipment to laboratory testing and evaluation, and (2) conducting research leading to the development of several series of documents, including national standards, user guides, and technical reports.

This document covers research conducted by OLES under the sponsorship of the National Institute of Justice. Additional reports as well as other documents are being issued under the OLES program in the areas of protective clothing and equipment, communications systems, emergency equipment, investigative aids, security systems, vehicles, weapons, and analytical techniques and standard reference materials used by the forensic community.

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Office of Law Enforcement Standards, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8102, Gaithersburg, MD 20899–8102.

David G. Boyd, Director
Office of Science and Technology
National Institute of Justice

CONTENTS

FIGURES

COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	henry	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz	Ω	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	IR	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	parts per million
dc	direct current	L	liter	qt	quart
°C	degree Celsius	lb	pound	rad	radian
°F	degree Fahrenheit	lbf	pound-force	rf	radio frequency
dia	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (base e)	SD	standard deviation
F	farad	log	logarithm (base 10)	sec.	section
fc	footcandle	M	molar	SWR	standing wave ratio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	UV	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	miles per hour	vhf	very high frequency
g	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	λ	wavelength
gr	grain	N·m	newton meter	wt	weight

area=unit^2 (e.g., ft^2, in^2, etc.); volume=unit^3 (e.g., ft^3, m^3, etc.)

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^{2})
m	milli (10^{-3})	k	kilo (10^{3})
µ	micro (10^{-6})	M	mega (10^{6})
n	nano (10^{-9})	G	giga (10^{9})
p	pico (10^{-12})	T	tera (^{1012})

COMMON CONVERSIONS
(See ASTM E380)

0.30480 m =1ft	4.448222 N = lbf
2.54 cm = 1 in	1.355818 J =1 ft_lbf
0.4535924 kg = 1 lb	0.1129848 N m = lbf_in
0.06479891g = 1gr	14.59390 N/m =1 lbf/ft
0.9463529 L = 1 qt	6894.757 Pa = 1 lbf/in^2
3600000 J = 1 kW·hr	1.609344 km/h = mph

Temperature: T_$_C$ = (T_$_F$ -32)_5/9
Temperature: T_$_F$ = (T_$_C$ _9/5)+32

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NIST Random Profile Roughness Specimens and Standard Bullets

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Based on the numerical controlled (NC) diamond turning process used previously for manufacturing random profile roughness specimens, two prototype standard bullets were developed at the National Institute of Standards and Technology (NIST). These standard bullets are intended for use in crime laboratories as check standards to help verify that the computerized optical-imaging equipment in those laboratories is operating properly. There is also a potential use of these standard bullets for enabling nationwide and worldwide ballistics measurement traceability and unification. Testing results showed that these standard bullets have identical signature marks and minimal geometrical nonuniformities such as pits, damage, etc. The digitized bullet signature is stored in a computer and can be used for reproducing the same bullet signature anytime. In this paper, the design, manufacturing technique, testing results, and potential use are discussed.

The Authors gratefully acknowledge the advice and support of Martin Ols, Ben Wilson, and Robert Thompson of the Bureau of Alcohol, Tobacco and Firearms, and Alim Fatah of the NIST Office of Law Enforcement Standards.

*NIST, Precision Engineering Division, Manufacturing Engineering Laboratory (MEL).
** NIST, Automated Production Technology Division, MEL.

1. INTRODUCTION

As with fingerprints, every firearm has unique characteristics and, when fired, imprints unique signatures on the bullets and casings. By analyzing these ballistics signatures, examiners are able to connect a particular firearm to one or more criminal acts. In the early 1990s, the DRUGFIRE system and the system known as Integrated Ballistics Identification System (IBIS)[1] were established in laboratories of the Federal Bureau of Investigation (FBI) and the Bureau of Alcohol, Tobacco and Firearms (ATF), respectively, as components of efforts to develop a nationwide ballistics identification network [1–2][2]. Both systems are based on image capture, image analyses, and database techniques. However, these systems are not yet compatible because the measurements are made under different instrumentation and testing conditions, and the data files have different formats. In 1997, the ATF and FBI signed a concept paper to establish the National Integrated Ballistics Information Network (NIBIN) [1–2]. One of the key steps was to establish measurement traceability and unification in ballistics measurements, and to realize nationwide ballistics information sharing between these two systems.

The National Institute of Standards and Technology (NIST) standard bullets and casings are being developed as check standards for crime laboratories to help verify that the computerized optical-imaging equipment in those laboratories is operating properly. The equipment will be used for instrument calibrations and measurement quality control, and have a potential use for enabling nationwide and worldwide ballistics measurement traceability and unification.

In December 1995, the ATF Firearms Examiner wrote to the Director of the Office of Law Enforcement Standards (OLES) at NIST. In the letter, the firearms examiner outlined the concept of mass-producing Quality Assurance Standards for bullets and casings. These bullets and casings would bear such a high degree of reproducible and recognized patterns of striae, that they could be entered at several different IBIS locations, which would then maintain scores within a relative consistency and rank.

As a result of this letter, in 1997, the Precision Engineering Division (PED) at NIST started a new project: NIST standard bullets and casings. After consulting with bullet examiners and instrument manufacturers, PED personnel found that the surface texture of the proposed standard bullets have some similarity with the random profile roughness specimens developed at PED in 1997. PED has a long history of developing different roughness specimens, including both periodic profile and random profile roughness specimens manufactured by different techniques [3–7]. Based on these techniques, four designs and manufacturing techniques, including cold drawing, electro-formation, grinding, and lapping, were considered for producing the standard bullet prototypes. Finally, the NC diamond turning process was used for manufacturing the prototype NIST standard bullets.

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[1]Certain commercial equipment, instruments, or materials are identified in this paper to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology (NIST), nor does it imply that the equipment, instruments, or materials are necessarily the best available for the purpose.

[2]Numbers in brackets refer to references in section 8.

In April 1998, five master bullets and casings were fired using a 9 mm Luger caliber pistol and recovered at the ATF National Laboratory Center at Rockville, MD. One of the digitized bullet signatures was used for producing two bullet prototypes, by means of the NC diamond turning process, at the Precision Manufacturing and Research Facility (PMRF) at NIST. Testing results at NIST, ATF, and FTI (Forensic Technology Inc., Canada) have shown that these standard bullets have identical and reproducible signature marks. Furthermore, the digitized bullet signature is stored in a computer and can be used for reproducing standard bullets with the same bullet signature anytime. Bullet examiners at ATF, and engineers and managers at FTI believe that the unique properties of the NIST standard bullet make it a powerful tool for quality control and nationwide unification in ballistics measurements [8].

In this paper, we discuss technical requirements and design for the prototype NIST standard bullets in section 2. We describe the development history of periodic and random profile roughness specimens at NIST in section 3, and how to use the same technique for manufacturing the prototype NIST standard bullets in section 4. We describe some testing results in section 5, and discuss our future work and potential use of the standard bullets in section 6.

2. TECHNICAL REQUIREMENTS AND DESIGN FOR THE PROTOTYPE NIST STANDARD BULLETS

2.1 Technical Requirements

After consulting with bullet examiners at ATF and FBI, and instrument manufacturers for both IBIS and DRUGFIRE systems, we defined some basic requirements for the NIST standard bullets:

- **Size, shape, color, and material.** The size, shape, color and material of the NIST standard bullets should be as close as possible to the real bullets. A hard coating may be used on the bullet surface for protection of rust and long life. However, this coating should not change the geometry of the bullet signatures.
- **Bullet signature.** Bullet signature patterns on the standard bullets must come from real bullets. Bullet signatures on the standard bullet must be identical in different axial sections on the same standard bullet. Furthermore, identical bullet signatures must also be found in a group of standard bullets. Geometric nonuniformity, including pits and damage on the surface of the standard bullets, should be minimized.
- **Repeatability and reproducibility.** Bullet signatures on the standard bullets should show high repeatability and reproducibility. Repeatability here means that the bullet signatures are highly repeatable in different axial sections on the same standard bullets. Reproducibility means that the bullet signatures on different standard bullets are highly uniform. It is desirable to use information technology for the production of the NIST standard bullets. By storing the standardized bullet signatures in a computer, they can be produced and reproduced anytime on NC turning machines.

2.2 Technical Design

The prototype NIST standard bullet was designed as shown in figure 1. The bullet signature AB was measured from a master bullet shot at the ATF National Laboratory Center in Rockville, MD. The digitized bullet signature was stored in a computer and reproduced by a NC diamond turning machine on six lands of the standard bullet, numbered from 1 to 6, as shown in figure 1. The purpose of making six lands having the same bullet signature is to test the repeatability and reproducibility of the manufacturing technique. In the future production of the NIST standard bullets, six different bullet signatures will be made.

For the design of the prototype NIST standard bullets, four bullet signatures, numbered 1, 2, 5, and 6, were designed on a curved surface, while signatures 3 and 4 were designed on a flat surface (fig. 1). Furthermore, bullet signatures on lands 3, 4, 5, and 6 were designed in a clockwise direction, while bullet signatures on lands 1 and 2 were designed in a counter-clockwise direction. The purpose of designing bullet signatures in such a way is to test the NC manufacturing process, including repeatability and reproducibility, and to test the optical property of different bullet-measuring instruments. Future NIST standard bullets will be produced with all six-bullet signatures manufactured on a curved surface.

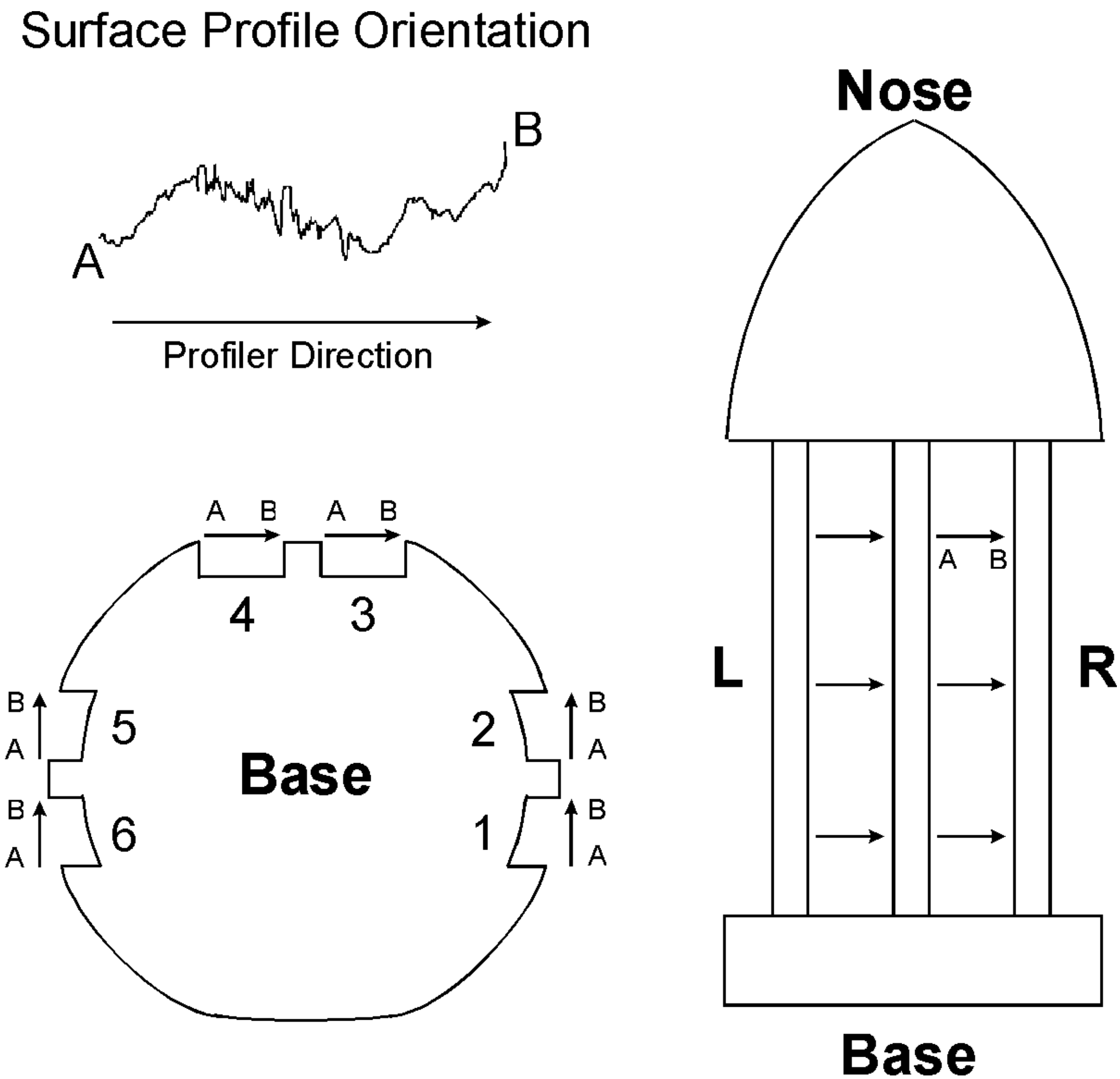

Figure 1. Design of the NIST prototype standard bullet

3. MANUFACTURING TECHNIQUES FOR NIST PERIODIC AND RANDOM PROFILE ROUGHNESS STANDARDS

Different surface roughness specimens are defined in both the International Standards Organization (ISO), and the American Society of Mechanical Engineers (ASME) standards [9–10], including periodic and random profile roughness specimens. These roughness specimens are used as calibration and check standards for different surface measurement instruments for measurement quality control, and surface measurement unification.

NIST has a long history of developing different roughness specimens, including both periodic and random profile roughness specimens [3–7]. In 1982, Teague, Scire, and Vorburger developed prototype NIST sinusoidal profile roughness specimens using the NC diamond turning process [4]. Based on this work, the NIST Standard Reference Material (SRM) series of 2071 – 2075 sinusoidal profile roughness specimens were developed. These NIST SRM standards cover an amplitude range of 1 µm to 10 µm (Ra = 0.3 µm to 3 µm), and a wavelength range of 40 µm to 800 µm. In 1985, Song developed random profile roughness specimens using a lapping process [5]. In 1991, Song, Vorburger, and Rubert also used an electro-formation process for manufacturing replicas of these specimens [6]. In 1997, Song et al. used the NC diamond turning process for manufacturing a NIST random profile roughness specimen [7].

4. MANUFACTURING THE NIST STANDARD BULLETS USING THE NC DIAMOND TURNING PROCESS

There is some similarity between the surface textures of the NIST random profile roughness specimen [7] and the proposed NIST standard bullets. First, both of their surface textures are composed of unidirectional random surfaces with high geometrical uniformity and reproducibility. Second, both unidirectional random surfaces have about the same amplitude and wavelength range. That makes it possible to use the same NC diamond turning process for manufacturing random profile roughness specimens [7] to produce the proposed standard bullets.

Figure 2 shows the proposed design for the manufacturing setup for the future production of the standard bullets on the NC diamond turning machine. A big ring is manufactured first and set on the diamond turning machine. On the right side of the ring, six bullet signatures are manufactured by inside turning, outside turning, and face turning using the NC diamond turning process (fig. 2, view A). The measured bullet signature (see fig. 1, AB) from the real bullet is digitized and stored in a computer of the NC diamond turning machine. The machine then produces the same bullet signatures on the standard bullets. A diamond tool with a 2 μm tip radius is used for the cutting process. After manufacturing the bullet signatures, the big ring is cut into small pieces, where each piece is used as a standard bullet.

In the future, the design shown in figure 2 will be used for batch production of standard bullets; for example, more than 100 standard bullets can be produced in the same batch. For the current production of two prototypes of the NIST standard bullets discussed in this paper, a small holder secured the bullet on the diamond turning machine for manufacturing bullet signatures.

One of the five master bullets and casings from the ATF National Laboratory Center, Rockville, MD, specifically, the No. 1 master bullet, is shown in figure 3, left. Its bullet signature at the No. 1 land was traced using a stylus instrument at NIST. On April 23, 1998, two prototype NIST standard bullets were made at the PMRF at NIST using an NC diamond turning machine, also shown in figure 3. The nose and base on the standard bullet, which are designed for protection of the inside bullet signatures, are separately manufactured.

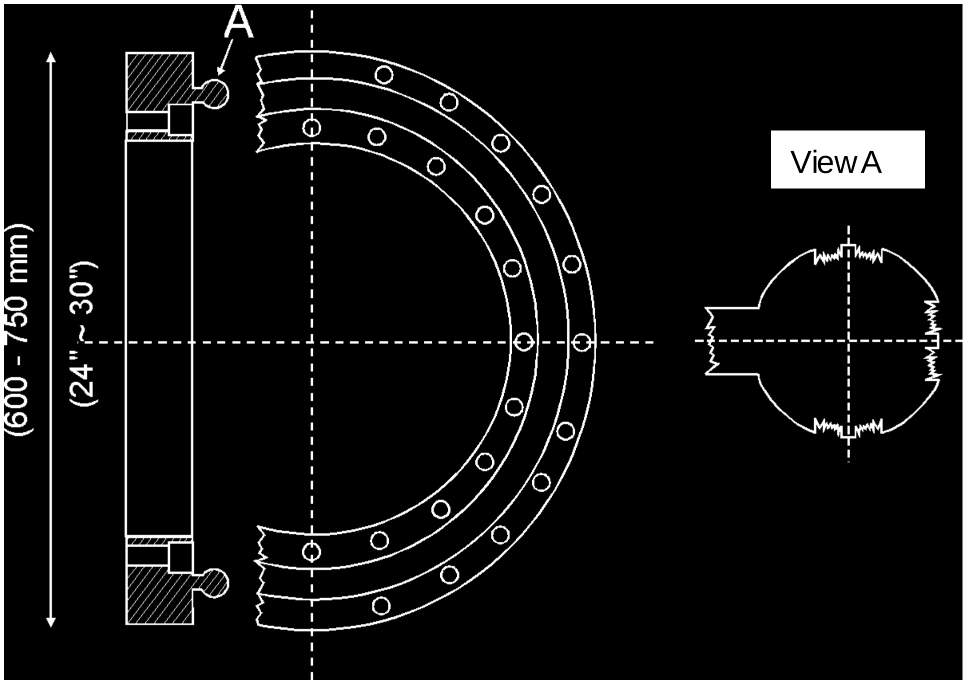

Figure 2. Manufacturing setup of the NIST standard bullets on the NC diamond turning machine

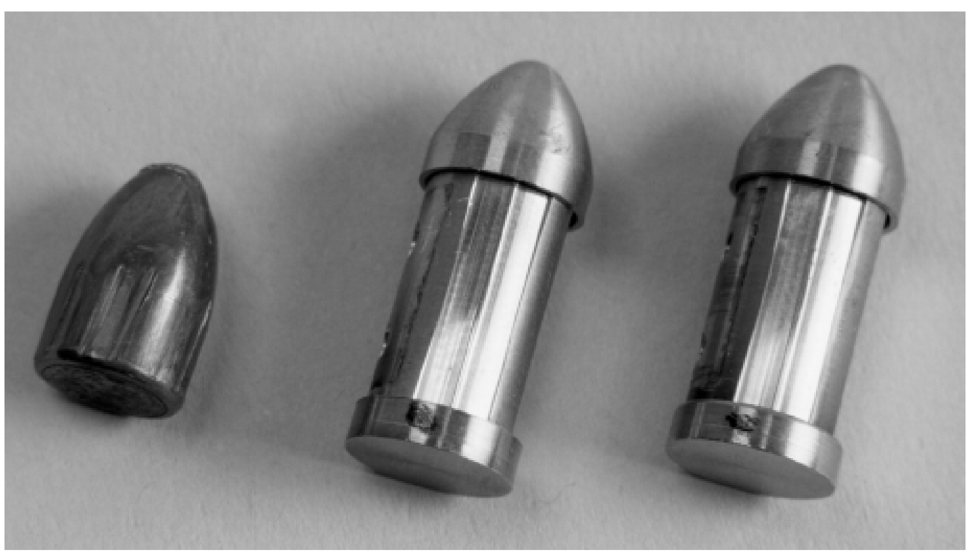

Figure 3. Master bullet by standardized shooting at ATF (left) and two NIST standard bullets made by NC diamond turning process

5. TESTING RESULTS

Figure 4 shows bullet signature comparison between the master bullet and the standard bullet. These bullet signatures were measured at NIST using a commercial stylus instrument. The stylus radius is 2 µm. Figure 4a shows the bullet signature from land 1 of the master bullet. Based on this signature, the prototypes of the standard bullet were manufactured. Figure 4b shows the bullet signature from land 3 of the No. 2 standard bullet. The bullet signature on the standard bullet shows high fidelity with respect to the master bullet.

The bullet signatures of the No. 2 standard bullet were also tested in different lands and different axial sections. For example, figures 5a and 5b show bullet signatures from land 4 and 3, both measured at the top section. Figure 5c shows a bullet signature from the bottom section of land 3. As shown, the bullet signature can be made highly repeatable from land to land and from section to section on the same bullet.

Figure 6 shows the bullet signature comparison between the No. 1 and No. 2 standard bullets, both measured at the No. 4 land's central section. This comparison shows that the standard bullets can be manufactured with high reproducibility.

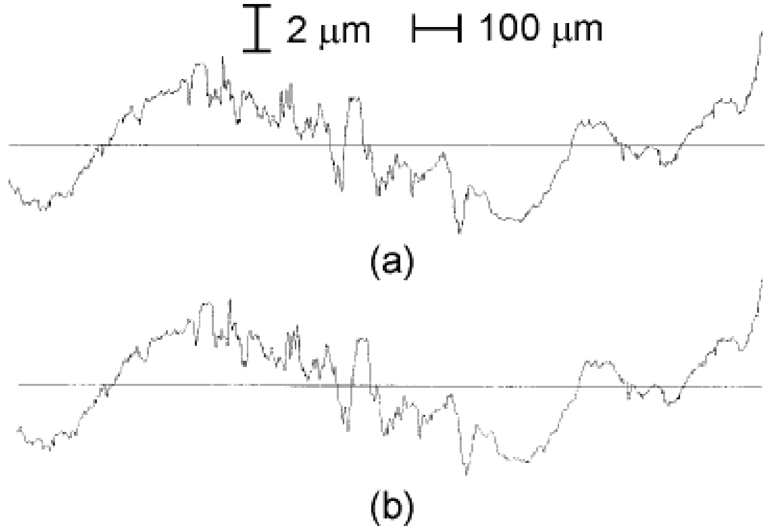

Figure 4. Bullet signature comparison between the No. 1 master bullet, land 1 (fig. 4a), and the No. 2 standard bullet, land 3 (fig. 4b)

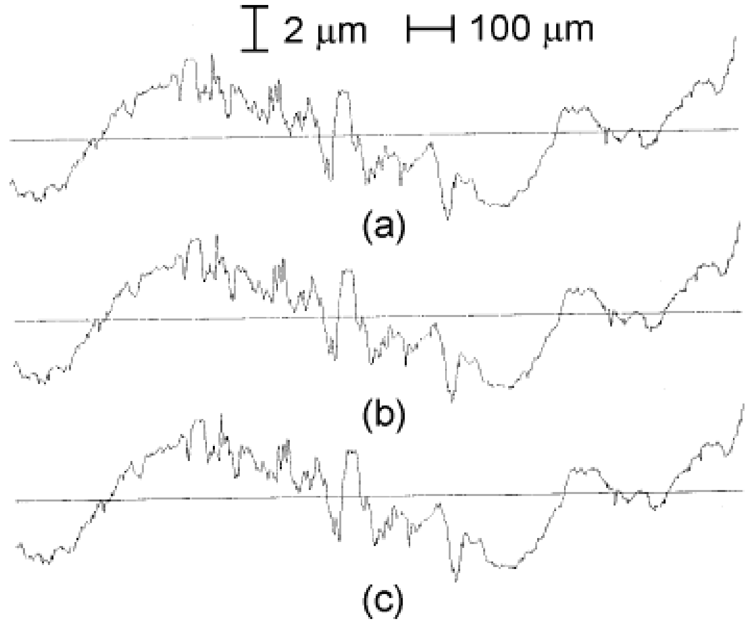

Figure 5. Bullet signature comparison on the same standard bullet No. 2, between land No. 4 and No. 3, both in the top section (fig. 5a and 5b), and land No. 3, bottom section (fig. 5c)

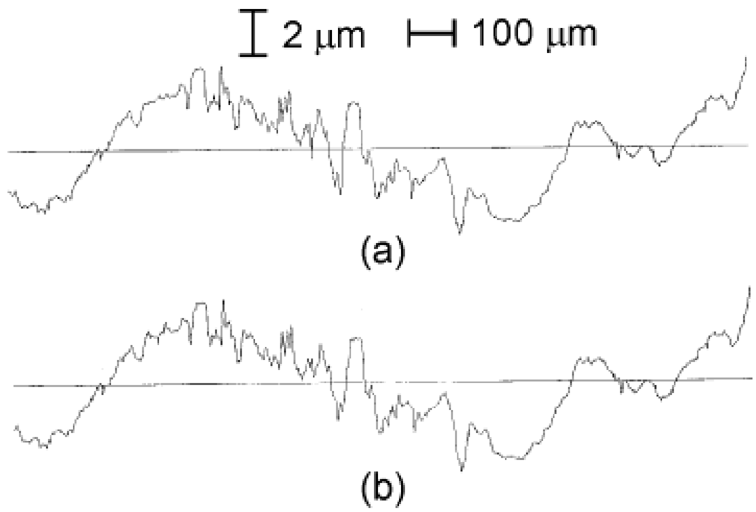

Figure 6. Bullet signature comparison between standard bullet No. 1 and No. 2, both on land No. 4, central section

6. FUTURE WORK AND POTENTIAL USE OF NIST STANDARD BULLETS

Based on the testing results and feedback information, we have finished the design of the second version of NIST standard bullets. The prototype standard casings are currently under development. Our plan for future work is as follows:

- Develop 6–8 second versions of NIST standard bullets in the year 2000, distribute them nationwide for testing using both IBIS and DRUGFIRE systems, and collect comments for the batch production of NIST SRM standard bullets.
- Develop 10 prototype NIST standard casings in 2000, distribute them nationwide for testing using both IBIS and DRUGFIRE systems in 2000, and collect comments for the batch production of NIST SRM standard casings.
- Produce NIST SRM standard bullets and casings for nationwide ballistics measurement quality control and unification.
- Develop parameters, algorithms and programs for 2D and 3D bullet signature comparisons for the quality control of NIST standard bullets and casings.

The NIST standard bullets will be used as check standards for crime laboratories to help verify that the computerized optical-imaging equipment in those laboratories is operating properly. They also have the potential use of enabling nationwide and worldwide ballistics measurement traceability and unification. The NIST standard casings project is currently in progress. The first prototypes of the NIST standard casings were delivered in October 1999.

7. SUMMARY

The following important findings are discussed in the report:

- The NC diamond turning process used for manufacturing NIST random profile roughness specimens has been successful in producing prototype NIST standard bullets, and meets essentially all technical requirements of standard bullets.
- Testing results of two prototype standard bullets showed highly uniform and reproducible bullet signatures; i.e., the bullet signatures are highly repeatable from land to land and from section to section on the same prototype bullet, and highly reproducible from one bullet to the other.
- NIST standard bullets can be used as a powerful tool for the quality control and unification of ballistics measurements.

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