Establishment of Ballistics Measurement Traceability Using NIST RM 8240 Standard Bullets

Speaker: J. F. Song
National Institute of Standards and Technology
100 Bureau Drive, Mail Stop 8212
Gaithersburg, MD 20899 USA
Phone: 301-975 3799, Fax: 301-869 0822,
Email: song@nist.gov

Authors: J. F. Song, T. V. Vorburger, R. Clary and E. Whitenton
National Institute of Standards and Technology, Gaithersburg , MD 20899

M. Ols
Bureau of Alcohol, Tobacco and Firearms, Rockville, MD 20850

Abstract: The NIST RM (Reference Material) 8240 standard bullets are being developed to support the traceability of ballistics measurements nationwide. Six master bullets from ATF and FBI are measured at NIST using a stylus measurement system. The resulting set of six digitized 2D profile signatures is used as a 2D virtual bullet signature standard for the production of RM bullets using a numerically controlled diamond turning machine at NIST. These RM bullets are designed to have nearly identical 2D signatures, and will be measured by IBIS (Integrated Ballistics Identification System) at ATF under standardized measurement conditions. A set of 3D digitized images from these measurements can be used as 3D virtual bullet signature standards, and transferred to local IBIS sites. Meanwhile, the NIST RM bullets can be distributed to local IBIS sites. By measuring the RM bullets at the local IBIS sites, and comparing the images with those of 3D virtual bullet signature standards measured at ATF under the standardized IBIS measurement conditions, ballistics measurements at local IBIS sites can be quality controlled, and traceable to the ATF's National Laboratory Center.

Keywords: reference material, RM, standard bullet, bullet signature, ballistics measurement, traceability.

1. Introduction

As with fingerprints, bullets and casings when fired or ejected from guns pick up characteristic signatures, which are unique to the weapon. Striations on the bullet are caused by its passage through the gun barrel. Marks on the casing are caused by impact with the firing pin, breech face and ejector. By analyzing these signatures, firearm examiners can connect a particular firearm to

criminal acts. In the early 1990's, the IBIS* (Integrated Ballistics Identification System) and the DRUGFIRE system were established for this purpose in laboratories of the Bureau of Alcohol, Tobacco and Firearms (ATF) and the Federal Bureau of Investigation (FBI), respectively. Both systems are based on image capture, image analysis and database techniques. In 1998, ATF and FBI initiated a joint project to establish the National Integrated Ballistics Information Network (NIBIN) [1,2]. One of the key steps in this project is to establish measurement traceability and unification in ballistics measurements and to implement a nationwide ballistics information network by sharing data between ballistics laboratories at ATF and FBI.

The National Institute of Standards and Technology (NIST) RM (Reference material) 8240/8250 standard bullets and casings are being developed as reference standards for crime laboratories to help verify that the computerized optical-imaging equipment in those laboratories is operating properly. They 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.

Based on a numerically controlled (NC) diamond turning technique, NIST developed two prototype standard bullets in 1998. Test results showed that their bullet signatures are highly repeatable and reproducible [3-6]. The bullet signatures are stored in a computer, and can be reproduced. Based on the prototypes, 20 NIST RM 8240 standard bullets were delivered in January 2002. Meanwhile, some prototype standard casings were developed in 1999 and 2000 [7], and are currently under test. Based on these prototypes, NIST RM 8250 standard casings are planned for delivery in 2002.

In order to compare bullet signatures and to quantify bullet signature differences, a new parameter and algorithm based on autocorrelation functions was developed at NIST [8]. The issue of establishing measurement traceability for 2D bullet signature measurements to NIST dimensional standards has also been discussed [9]. NIST, ATF and FTI (Forensic Technology Inc., IBIS manufacturer in Montreal, Canada) have been considering plans to establish measurement traceability using NIST standard bullets for measurement quality control of local IBIS sites.

According to the VIM [10], traceability is defined as:

> *Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.*

There are three general considerations for the establishment of measurement traceability, these are national or international standards; unbroken comparison chain and stated uncertainties. In this paper, we discuss how to use NIST RM 8240 standard bullets to establish bullet signature measurement traceability to NIST and the National Laboratory Center at ATF. In Section 2, we

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

discuss how to establish 2D and 3D virtual/physical bullet signature standards. We discuss the establishment a comparison parameter and an unbroken chain of comparisons in Section 3. Some uncertainty issues are discussed in Section 4.

2. Establishment of 2D and 3D Virtual/Physical Bullet Signature Standard

2.1 Establishment of a set of 2D virtual bullet signature standards

Using the numerically controlled (NC) diamond turning technique previously used at NIST for developing surface roughness specimens, two prototype standard bullets were manufactured in 1998 [3,4]. Testing results shown high repeatability and reproducibility of bullet signatures on these prototype standard bullets [3-6]. In 2000, ATF National Laboratory Center and FBI Central Laboratory provided NIST with six master bullets, three from ATF and three from FBI. All were fired under standardized conditions. These master bullets underwent profile measurements at the NIST surface calibration laboratory using a commercial stylus instrument. The tip radius of the stylus instrument was about 2 μm, the contact force was very small, about 0.001 N, to ensure no significant contact deformation could happen. Each bullet was traced on one land. A set of six digitized 2D bullet signatures was stored in a NIST computer as the 2D virtual bullet signature standard [6].

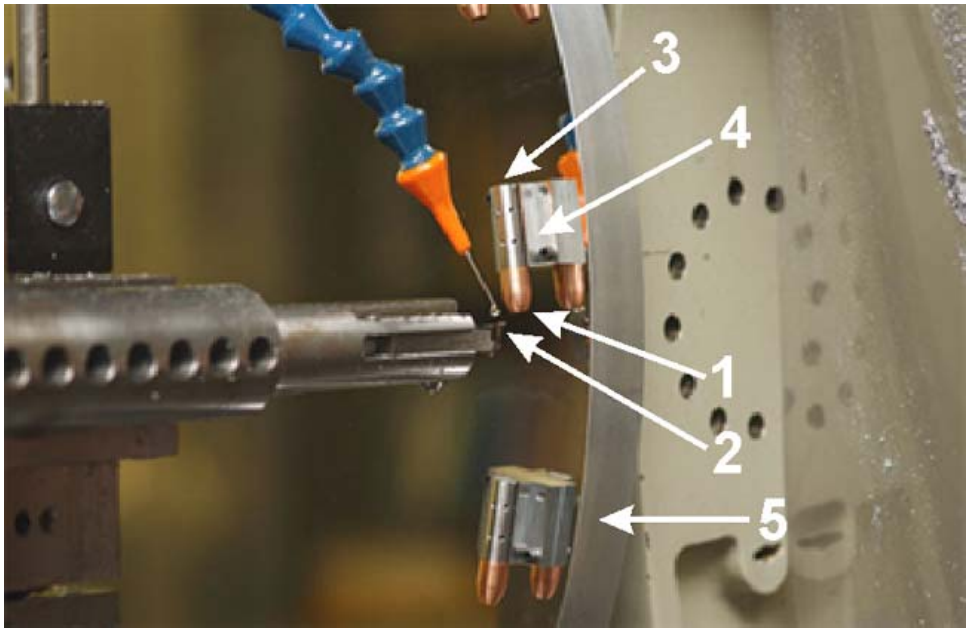

Fig. 1. Manufacturing setup for NIST RM 8240 standard bullets: One (1) of 20 standard bullets cut by a diamond tool (2). Each bullet was fastened to a cylinder (3), which was mounted on a "V" block (4) set on an aluminum wheel (5). 20 bullets were manufactured at the same time.

2.2 Establishment of physical standards – NIST RM 8240 standard bullets

A numerically controlled diamond turning machine at the NIST instrument shop was used to produce the physical standards – NIST RM 8240 standard bullets. As shown in Fig. 1, the set of standard bullets (1) were cut by a diamond tool (2). The bullets were fastened to cylinders (3), which were mounted on "V" blocks (4) set on an aluminum wheel (5). 20 bullets were manufactured at the same time. After cutting one signature, the cylinder (3) was rotated for 60° to cut the next signature until all six signatures were finished. These was a 5° tilt for the "V" block (4) alignment on the aluminum wheel (5), so that a 5° twist of bullet signature land could be made on the RM standard bullets. That gave the RM bullet a shape closer to real ones.

2.3 Establishment of a 3D virtual standard for bullet signature comparisons

The 3D virtual bullet signature standard will be a set of digitized 3D optical intensity images. It can be generated by two methods: (1) By testing a RM standard bullet using a IBIS under some pre-determined standardized testing conditions. The set of digitized 3D optical intensity images can be used as 3D virtual bullet signature standard. (2) By using the 2D bullet signature standard obtained from surface profiling and a computer image generation and simulation software, a set of digitized 3D bullet signature topographies could be generated. The computer generated virtual signature standard would be verified by comparing it with the digitized 3D intensity images from the IBIS measurements.

3. Establishment of an Unbroken Chain of Comparisons for Bullet Signatures

3.1 Establishment of a comparison parameter

In 2000, NIST proposed a comparison parameter to quantify bullet signature differences. This parameter was based on autocorrelation functions. Detailed definitions and algorithms can be found in Ref. [8]. There are some advantages of using the NIST algorithm:

- The signature information of all 2D or 3D data points is used for comparison. That suggests this parameter could have high sensitivity, and could ensure high repeatability and reproducibility;
- It can be used for quantifying signature differences for both 2D and 3D bullet signatures;
- When the same 2D or 3D signatures are compared with each other, their signature difference, calculated by the NIST algorithm, is zero. When any 2D or 3D signature difference is calculated as zero, these two compared signatures must be exactly the same.

3.2 Establishment of a national ballistics measurement traceability and standardization system

In order to establish measurement traceability for ballistics measurements to NIST, ATF and FBI laboratory centers using the standard bullets, a proposed national bullet signature measurement traceability and standardization system is shown in Fig. 2. In the very beginning, ATF and FBI provided NIST with six master bullets. These bullets were traced at the NIST surface calibration laboratory using a stylus instrument, as shown in Fig. 2, channel 1. A set of six digitized 2D bullet signatures was used as a 2D virtual bullet signature standard to control a numerically controlled diamond turning machine at NIST to produce the NIST RM 8240 standard bullets as physical standards. One of them, numbered RM 8240-001, would be kept at NIST as a check standard. This check standard would be routinely measured at the NIST surface calibration laboratory, and compared with the established 2D virtual signature standard for measurement

quality control, as shown in Fig. 2, channel 2. The other RM bullets would be distributed to ATF and FBI national laboratories, to FTI and local IBIS sites. At the national laboratories of ATF and FBI, and the FTI measurement laboratory, these RM bullets, numbered RM 8240-002, 003 and 004, respectively, would be measured under pre-determined standardized IBIS testing conditions. The resulting digitized 3D optical intensity images would be used as the 3D virtual bullet signature standard and be transferred to local IBIS sites. As mentioned before, the 3D virtual standard could also be generated by computer-imaging techniques. Meanwhile, the RM bullets would also be distributed to local IBIS sites. By measuring these RM bullets at local IBIS sites, and comparing the measured images with those of 3D virtual standard measured at ATF, FBI or FTI under standardized IBIS testing conditions, differences of IBIS testing conditions between the local IBIS sites and ATF, FBI and FTI can be perceived. That can enable traceability for ballistics measurements nationwide to NIST, ATF and FBI, and ensure the measurement quality control of local IBIS sites.

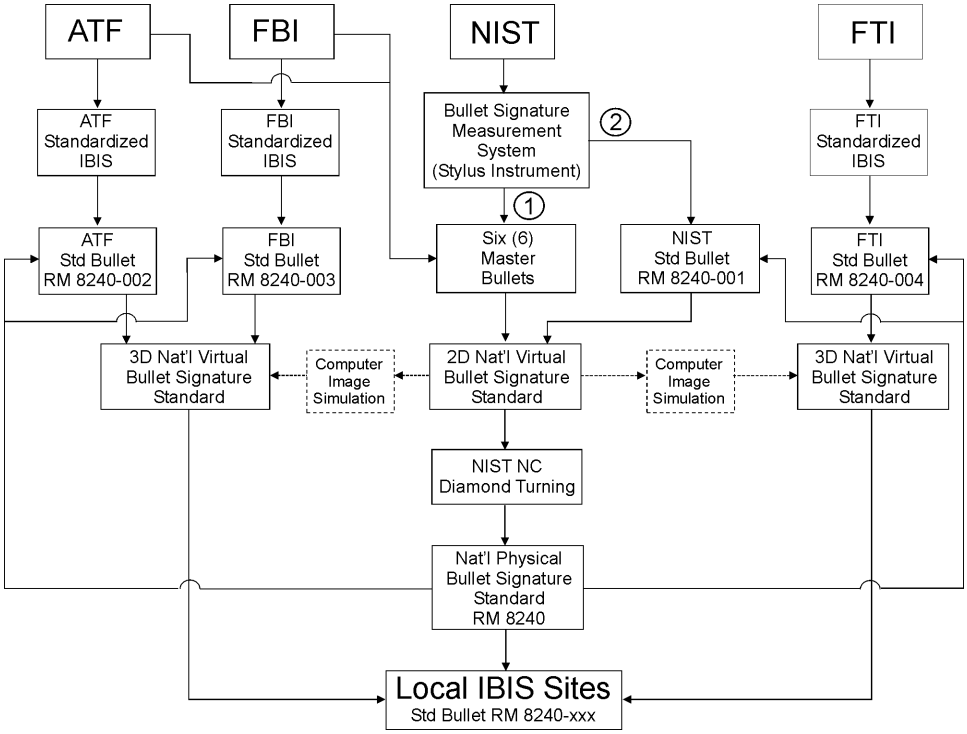

Fig. 2. A proposed national bullet signature measurement traceability and standardization system.

4. Establishment of Uncertainty Procedures for 2D and 3D Bullet Signature Measurements

4.1 For 2D bullet signature measurements using a stylus instrument

For the 2D signature measurements using a stylus instrument at NIST, a parameter and a related algorithm based on autocorrelation functions were proposed for comparison of 2D bullet signature differences between the RM bullets and the 2D virtual standards [8]. Analytical and

experimental work based on GUM [11] and NIST TN 1297 [12] are planned for the development of an uncertainty procedure to report measurement uncertainties. Experimental methods based on statistical analysis of the historical control charts of measuring the same RM bullet as check standard could be used for verifying the uncertainty procedure.

4.2 For 3D bullet signature measurements using IBIS

For the 3D signature measurements using IBIS, an uncertainty procedure could be established by the following steps:

- Assessing influence quantities. It may include:
  - IBIS calibration;
  - IBIS repeatability and reproducibility;
  - Reproducibility of NIST RM standard bullets;
  - Change of RM standard bullets due to the wear of use or the stress relieve over time;
  - Change of measurement setup;
  - Change of lighting;
  - Computer software and digitization;
  - Optical system's non-linearity;
  - Non-linearity of linear and rotational motion;
  - Filter,…
- Establishing a set of standardized IBIS measurement conditions at ATF and FTI by standardizing the influence quantities;
- Determining the possible variation range of each influence quantity at the local IBIS sites relative to the standardized measurement conditions at ATF and FTI;
- Determining the sensitivity coefficients between each of the influence quantities and the resulting IBIS scores either by a theoretical or an experimental approach;
- Calculating uncertainty based on GUM [11] and NIST TN 1297 [12].

5. Summary

Traceability issues are discussed for the establishment of a national ballistics measurement traceability system to NIST, ATF and FBI national laboratories. These include the establishment of 2D and 3D virtual/physical bullet signature standards and comparison parameters, an unbroken comparison chain for bullet signature measurements, and an uncertainty procedure. A set of 2D virtual bullet signature standards was established at NIST. Based on this virtual standard, some physical standards, NIST RM 8240 standard bullets, have been developed. A comparison parameter was proposed by NIST using autocorrelation functions for bullet signature comparisons. It is necessary to define a set of standardized IBIS testing conditions, under which the 3D virtual bullet signature standard could be established by measuring the RM bullets at ATF, FBI or FTI. It is also necessary to develop an uncertainty procedure for bullet signature measurements. By measuring the RM bullets at the local IBIS sites, and comparing the images with those of 3D virtual bullet signature standards measured at ATF, FBI or FTI under the standardized IBIS measurement conditions, ballistics measurements at local IBIS sites can be quality controlled and traceable to the ATF and FBI Laboratory Centers.

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