Manufacturing and Quality Control of the NIST Reference Material 8240 Standard Bullet

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EXTENDED ABSTRACT:

The National Integrated Ballistics Information Network (NIBIN) is currently under development by the Bureau of Alcohol, Tobacco and Firearms (ATF) and the Federal Bureau of Investigation (FBI). In support of this effort, the National Institute of Standards and Technology (NIST) is developing both physical and virtual reference standards. These are designed to be used by crime laboratories to verify that results obtained when using the NIBIN meet legal requirements and that the NIBIN equipment is operating properly. It is also intended to use these standards for the establishment of ballistics measurement traceability to NIST, ATF and FBI [1].

One of these reference standards is the NIST RM (Reference Material) 8240 standard bullet shown in Fig 1. The surface profile of six master bullets from ATF and FBI were measured at NIST using a stylus measurement system. The profiles have a 0.25 μm point spacing. The resulting set of six digitized 2D profile signatures are used as a 2D virtual bullet signature standard for the production of standard bullets using a numerically controlled diamond turning machine at NIST. These standard bullets are designed to have nearly identical 2D signatures, and will be used for instrument calibration and measurement quality control for the NIBIN. This document focuses on the manufacturing and quality control of these standard bullets.

Figure 1: A master bullet from ATF National Laboratory Center (left), a NIST prototype standard bullet (center), and a NIST RM 8240 standard bullet (right).

Commercial equipment and materials are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Because the bullets are manufactured by diamond turning the profile signatures onto the bullet lands, bright acid copper is the preferred material for electroforming the substrate. The deposit is electroplated onto copper cylinders as shown in Fig 2. The electrolyte is a basic copper sulfate electrolyte, to which proprietary agents have been added. These agents serve not only as grain refiners, but also level the deposit on a microscopic scale. The deposit, shown in Fig 3, is specular and ductile as plated, with a sub-micron, equiaxed, crystalline grain structure. The bright acid copper electrolyte has a high deposition rate of 1.25 μm/minute.

Figure 2: OFHC copper blanks, separated by spacers, destined to be electroplated and then machined into reference bullets.

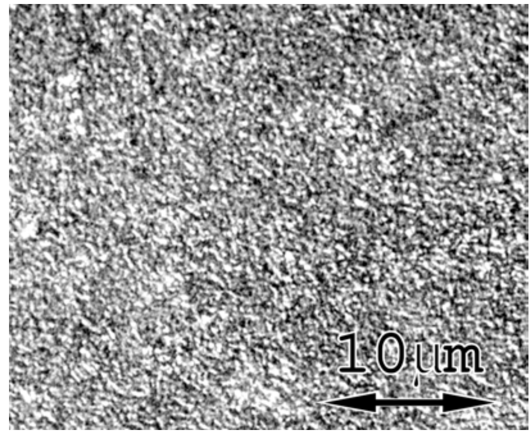

Figure 3: Photomicrograph of electroplated surface showing sub-micron grain structure.

Once electroplated, each bullet is mounted on a small cylindrical arbor and turned on a conventional lathe to near net shape. Next, up to 20 bullets are mounted to the face plate of the diamond turning machine spindle as shown in Fig 4. One of the profile signatures is machined on to the bullets. They are then rotated and remounted, and the next profile is machined. This process is repeated for all six profiles. The photomicrograph in Fig 5 compares a portion of a land from 2 different bullets. It shows that, qualitatively at least, there is a very good match in the land patterns.

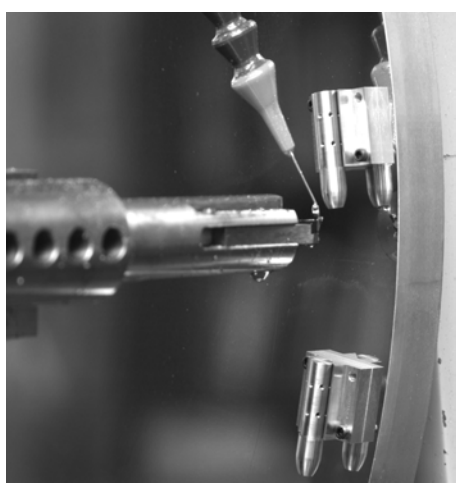

Figure 4: Machining lands using diamond turning machine.

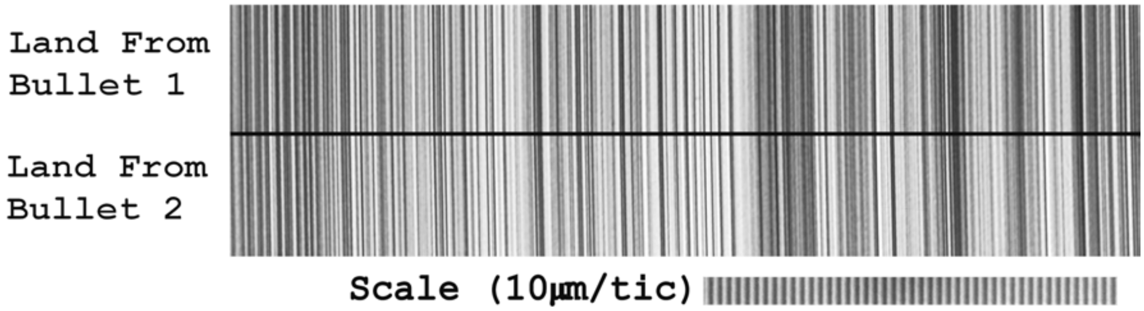

Figure 5: Photomicrograph of a portion of the land area from two different reference bullets shows excelent reproducability.

Next is the measurement and quality control phase of the production process. In order to verify the quality of the bullets, each is measured using a stylus measurement system. The desired profiles (the 2D virtual bullet signature standards noted above) and the measured profiles are compared using a NIST developed parameter based on auto- and cross-correlation functions [2]. A minimum of 95% correlation is required, but often the correlation is better than 99%. There are two paths of data flow through the quality control process as shown in Figure 6 below. The left-most path shows the data flow of the virtual signature standard, while the right path shows the data flow of the signature of the manufactured bullet being checked.

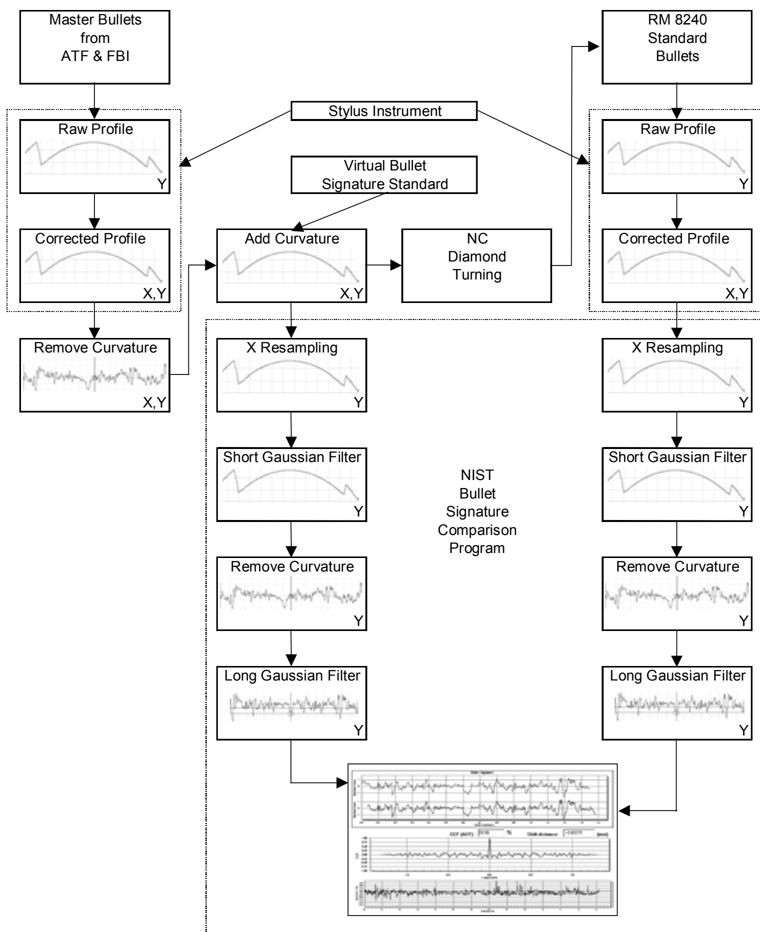

Figure 6: Flow of data in the quality control process.

Both paths emanate from the six different master bullets from the ATF and the FBI. As a result, the radius of curvature for each of the lands is initially different. The time required to machine the lands using the diamond turning machine is minimized when the radius of those lands are the same as the radius of the standard bullet itself. In order to minimize the machining time, the radius was removed from each of the six lands and the radius of the standard bullet added back to each land. By doing this, the virtual bullet signature standard is generated.

As the bullet signatures were measured on a highly curved bullet surface, the total range of Z heights in the profiles is significant. The stylus instrument initially acquires the profiles as points equally spaced in the X direction. However, as with most stylus instruments, the stylus actually measures the angle of the stylus tip as it rotates about a pivot point and not the Z height. When the stylus instrument converts these angles into true Z heights, the once equally spaced points become unequally spaced. Unequally spaced points are not a problem when manufacturing the bullets, but most profile analysis techniques are significantly easier to implement with equally spaced points. Fortunately, cubic spline functions may be used to resample the profile data to make the profiles equally spaced again. Cubic splines were chosen over linear interpolation because linear interpolation yields results with a systematic bias towards being too small.

Before computing the correlation between the signatures, the virtual bullet signature and the signature of the bullet being tested are both filtered so that the features with wavelengths either too small or too large to be important are removed. To accomplish this, first a low-pass Gaussian filter with a 0.0025 mm cutoff length is used to remove high frequency noise. The large scale curvature is removed by fitting and then subtracting a circle. Finally, a 0.25 mm long cutoff low-pass Gaussian filter is used.

In conclusion, both the visible comparison and the correlation measurements show that the profiles diamond turned on to the standard bullets reproduce well and can be produced in relatively large quantities. This allows different forensic laboratories to use a common physical artifact. It should be noted that this research involved samples a few months old. Future research will involve checking the long term stability of the profiles.

This work was supported in part by the National Institute of Justice through the NIST Office of Law Enforcement Standards.

References:

[1] J. Song, L. Ma, E. Whitenton and T. Vorburger, "Bullet Signature Measurements at NIST," *Proceedings of 2003 Measurement Science Conference (MSC),* January 2003, CA.

[2] J. Song, T. Vorburger, "Proposed Bullet Signature Comparisons Using Autocorrelation Functions," *Proceedings of 2000 NCSL*, July 2000, Toronto.

Key words: reference material, ballistics, diamond turning, electroplated, correlation function, reference bullets