

Firearms Examinations By Scanning Electron Microscopy: Observations And An Update On Current And Future Approaches

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Abstract

The use of scanning electron microscopy (SEM) in the examination of firearms evidence was introduced in the literature over twenty years ago. Due to cost and convenience factors, however, scanning electron microscopy has remained largely inaccessible and therefore under-exploited in the firearms community. We will review the significant advantages of SEM in the examination of firearms evidence and present information on recent and future improvements in methodology which make this approach more attractive and available to forensic laboratories.

The use of a scanning electron microscope in the performance of firearms comparisons is not new. Three of the earliest forensic scanning electron microscopy papers published in the Journal of Forensic Sciences were entitled "Examination of Firing Pin Impressions by Scanning Electron Microscopy" [1], "Evaluation of SEM Potential in the Examination of Shotgun and Rifle Firing Pin Impressions" [2], and "SEM Microstriation Characterization of Bullets and Contaminant Particle Identification" [3]. These papers appeared in 1972 and 1974. Two earlier papers published in other journals in 1970 [4] and 1971 [5] showcased scanning electron micrograph comparisons of bullet and extractor striae and firing pin impressions as excellent examples of forensic SEM applications. The dates of these publications are all the more remarkable because scanning electron microscopes weren't commercially available until the mid-sixties. Clearly the advantages of scanning electron microscopy in the examination of firearms evidence were recognized early and announced quickly.

The advantages of using a scanning electron microscope in the examination of firearms evidence include:

1. **Depth of Field:** The large depth of field available through the use of a scanning electron microscope permits imaging, comparison and micrography of deep depressions such as firing pin impressions in their entirety, or of large sections of a rounded surface such as a whole bullet land or groove.
2. **Magnification:** The broad range of magnification offered by an SEM, approximately 15X to several thousand times, permits continuous monitoring of the sample surface without changing objectives and presents significant and comparable surface details which are well out of range of conventional optical microscopy.
3. **Imaging:** The scanning electron microscope is designed to produce high quality, high resolution images in a number of formats. The NFWFL instrument can produce digital micrographs on thermal paper, archival quality micrographs on 4" X 5" Polaroid and Kodak sheet films and live time images on VCR tape. The advantage of the ability to clearly micrograph match results, particularly at higher magnifications, is that the examiner will have hard copy proof of lab observations and the court can have a quality visual display to associate with the firearms examiner's verbal testimony.

The National Fish & Wildlife Forensics Laboratory routinely uses optical and scanning electron comparison microscopy in the examination of firearms evidence. Based on these examinations, we have observed that scanning electron microscopy has significant advantages over conventional optical comparison microscopy in cases where bullets, jackets or cartridge cases are seriously damaged, the available comparable surface area is reduced, or the striae detail is too shallow for optical examinations. Photographs 1 and 2 illustrate the utility of the SEM in the examination of damaged evidence.

Photograph 1 (X17) shows the base of a 7 mm copper jacket which was removed from the skeletonized remains of a bear. The jacket was flattened, petaled and with the exception of an approximately 1.5 mm of area adjacent to the base terminus, it was of minimal value for comparison purposes. The 1.5 mm strip displayed only half of the barrel's six land/groove sets. Although optical microscopy was able to pinpoint an area of possible value on this jacket, the topography of the surviving striae in this region was significantly reduced and conventional optical microscopic techniques were unable to resolve a conclusive match. High magnification examination and comparison against a known source bullet by scanning electron microscopy resulted in the isolation and documentation of two consecutive match areas, one of which is presented in Photograph 2 (X500).

Further, even in cases where the samples are in relatively good condition, SEM expands the magnification range of conventional optical examinations, provides greater detail through substantially improved resolution, magnification and depth of field, and produces vivid and incontrovertible match documentation. Photographs 3 and 4 illustrate the examination by optical (3) and scanning electron (4) comparison microscopy of firing pin impressions from a .348 Winchester Model 71 rifle. The optical micrograph was taken at the maximum available magnification (X40) of our firearms comparison microscope, a Reichert Universal Forensic Microscope IV. The scanning micrograph (X36), which shows significantly improved detail and depth of

field, represents the low end of the SEM's magnification range. Photographs 5 and 6 are successive comparison overlay micrographs at 250X and 2000X of the scratch defect observed in Photograph 4. These micrographs dramatically illustrate the capabilities of scanning electron microscopy and the highly complex nature of seemingly ordinary tool marks. At two orders of magnitude greater than conventional optical comparison microscopy, Photograph 6 shows reproducible striae spacings of less than one micron. Detail at this level is not an unusual finding in the materials we have examined. A future paper will explore the physical geometry of striae formation relative to firearms examinations.

The major disadvantage of using a scanning electron microscope in the comparative examination of firearms evidence is cost. For laboratories without an SEM the purchase price of a good instrument is equivalent to the annual salary of two to three examiners. Laboratories already in possession of a scanning electron microscope which is compatible with the introduction of a firearms comparison stage will find that the current price for such a stage is approximately \$25,000 to \$30,000 [6]. It is possible, however, to successfully perform scanning electron microscopy comparisons of firearms evidence without the use of special additional equipment.

Three basic approaches exist for the scanning electron microscopy comparison of firearm evidence. Versions of two of these approaches were presented at the 1972 [1] and 1981 [7] Association of Firearm and Tool Mark Examiners meetings. We will be presenting information on a third method. The first approach to the SEM examination of firearms evidence requires no additional equipment, is the least technically sophisticated and the most time consuming of the three methods.

In its simplest form this first method requires the placement of one sample within the chamber of an SEM, locating and micrographing significant comparable details, removal of that sample from the chamber and repeating the whole operation with second, third, etc. samples. The resulting micrographs are compared to each other for the purpose of obtaining a match.

With the exception of firing pin impressions and breech face markings on cartridge cases which can be mounted and examined without pre-alignment, this early approach to SEM firearms comparisons generally requires a great deal of patience and time. The process can be accelerated by placing two or more items on a single specimen stub or mount in the chamber but since none of these items are independently tilt or rotatable relative to each other, pre-insertion alignment of the items relative to the primary electron beam and electron detector can be critical and exacting. The ability to digitize, temporarily store and overlap images greatly facilitates this approach but may not obviate the need for precise orientation of the samples prior to examination. Frequent removal and re-adjustment of samples from the instrument's chamber, especially in the case of striation comparisons at higher magnifications, can take a great deal of time. The reward is often worth the effort, however, as excellent comparison matches have been produced in this manner.

The second approach to firearms comparisons by scanning electron microscopy is the most expensive and the most technically sophisticated. The Compare Scan system was introduced by Katterwe, Goebel and Grooss [7,8] of Wiesbaden Germany in the early 1980's. The Compare Scan system was the scanning electron microscopy version of a conventional firearms comparison microscope. Two SEMs were set up in tandem, electronically synchronized, and "bridged" by a single viewing screen. One SEM controlled most of the electronic operations of both instruments.

Samples mounted in each of the two SEM chambers were viewed simultaneously as live images on one video screen. Each specimen could be independently manipulated relative to the other without being removed from their respective instruments. This method was elegant, technically advanced and, obviously, very expensive. Few forensic laboratories can afford to purchase two scanning electron microscopes.

The third approach to the SEM comparison of firearms evidence is arguably the most cost effective/time efficient to date. It involves the use of a dedicated firearms comparison stage. This stage holds two specimens. X and Y traverse and specimen tilt are performed in unison with rotation and relative Z positions independently adjustable. There are two versions of this stage, both of which were designed and developed for use in CamScan scanning electron microscopes.

The first version required the installation of an auxiliary off axis beam deflection coil, associated cable, and a replacement secondary electron detector prior to stage insertion. The beam deflection coil alternately scanned each sample, resulting in effectively live time simultaneous viewing of both samples on a single viewing screen. The replacement of the standard secondary electron detector was mandated by the configurational geometry of the stage/specimen-deflection coil combination [6].

The limitations of this first version were both mechanical and electronic. Mechanically, the installation of the coil, cable, and detector was time consuming and technically demanding. Because the samples were viewed as a result of beam deflection/off axis scanning, they had to be relatively small and close together in order to stay within the range of the scan. The presence of the auxiliary coil, which rested between the final lens and the specimens, necessitated a very long working distance. Long working distances adversely affect the potential resolving power of the instrument. Due to the limitations imposed by the range of deflection (the exaggerated deflection angle) of the primary beam, the use of the upper level accelerating voltages was compromised, and spherical aberrations and astigmatism problems could become profound at higher magnifications.

The second version of the CamScan firearms comparison stage [see Photographs 7, 8 and 9] is much simpler to install and has few of the operational limitations of the first version. Because the stage system relies on digital frame store hardware for sample imaging and comparison, the installation of an off-axis beam deflection coil is not required. The absence of this deflection coil in the system removes the accelerating voltage and subsequent magnification limitations which marked the use of the first stage, and spherical aberration and astigmatism are reduced to levels associated with normal on-axis scanning instrument operation. The stage was also redesigned to accommodate larger samples and a shorter working distance, although the working distance is still significantly large, and the replacement of the standard secondary electron detector is no longer required. The removal of the standard SEM stage and its replacement with the updated firearms stage takes approximately five to seven minutes. The installation of the first version of the stage, particularly when the stage was infrequently used, could take well in excess of an hour.

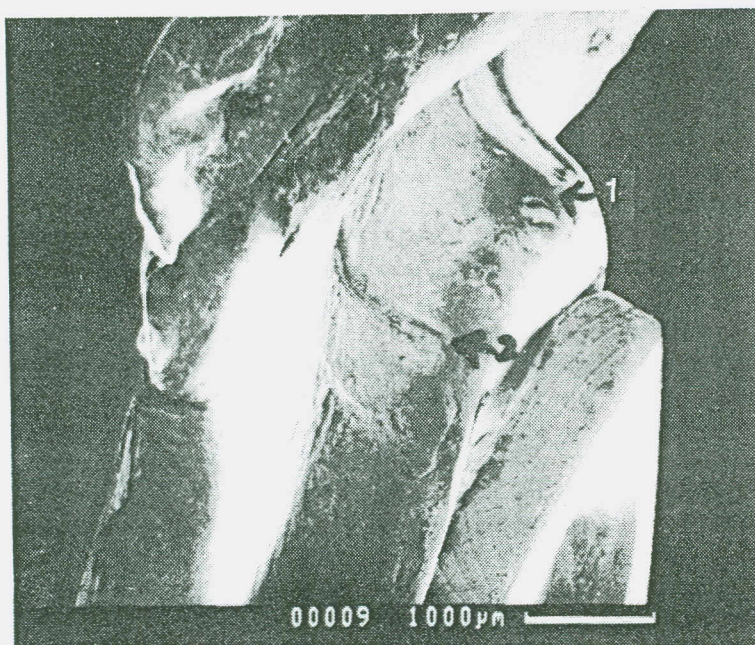
The frame store imaging system associated with version two of the stage utilizes one effectively live and one digital image. The digital image of an area of interest on one sample is acquired and temporarily stored. The second sample is then placed under the primary electron beam and scanned as a live image. A slider control on the instrument's console allows the operator to cursor the digital image across the surface of the live image. When a satisfactory match is observed, the overlapping

images may be micrographed.

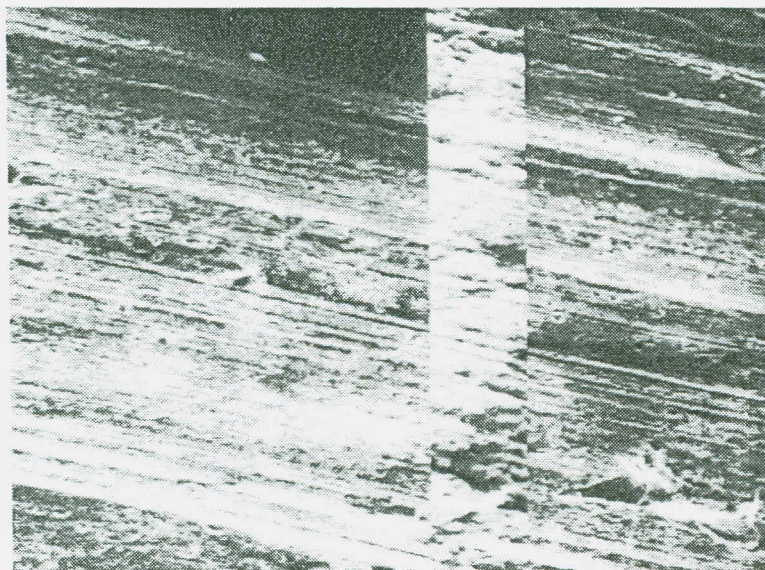
We believe that the analytical advantages of scanning electron microscopy justify more frequent utilization of this instrument in the examination of firearms evidence. A dedicated firearms stage and frame store system greatly facilitate these examinations. However, since most of the newer instruments have frame store capabilities many forensic laboratories are currently capable of performing comparative scanning electron microscopy of firearms evidence with existing equipment. Future developments may make this type of examination even more accessible. A relatively inexpensive comparison module which will attach to the regular SEM stage is currently under consideration by CamScan. Competition among vendors may also advantage end users. One other SEM manufacturer has recently expressed an interest in the development of a firearms stage.

REFERENCES

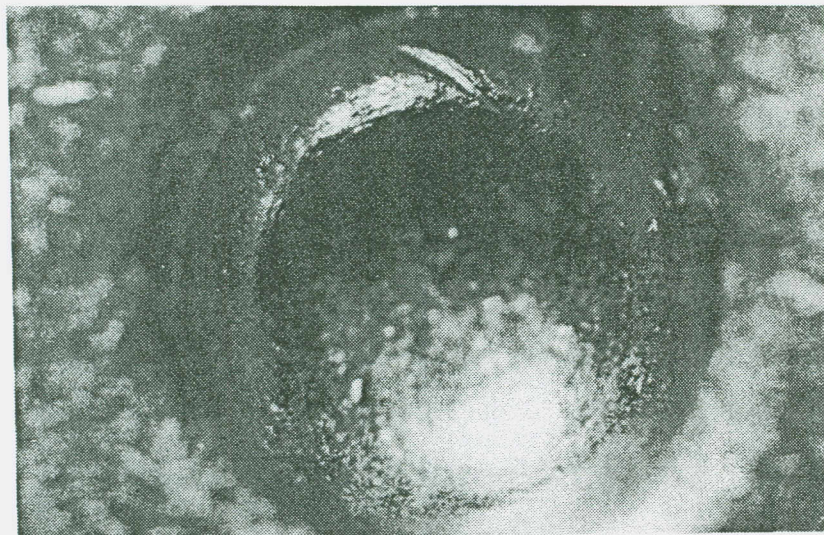
- 1 Grove, C.A., G. Judd, and R. Horn, "Examination of Firing Pin Impressions by Scanning Electron Microscopy", Journal of Forensic Sciences, Vol. 17, No. 4, 1972, pp.645-658.
- 2 Grove, C.A., G. Judd, and R. Horn, "Evaluation of SEM Potential in the Examination of Shotgun and rifle Firing Pin Impressions", Journal of Forensic Sciences, Vol. 19, No. 3, 1974, pp.441-447.
- 3 Judd, G., J. Sabo, W. Hamilton, S. Ferriss, and R. Horn, "SEM Microstriation Characterization of Bullets and Contaminant Particle Identification", Journal of Forensic Sciences, Vol. 19, No. 4, 1974, pp. 798-811.
- 4 Korda, E.J., H.L. Macdonell, and J.P. Williams, "Forensic Applications of the Scanning Electron Microscope" Journal of Criminal Law, Criminology and Police Science, Vol. 61, No. 3, 1970, pp. 453-458.
- 5 Devaney, J.R. and L.W. Bradford, "Applications of Scanning Electron Microcopy to Forensic Science at Jet Propulsion Laboratory, 1969-1970", Scanning Electron Microscopy/1971 (Part II), Proceedings of the Workshop on Forensic Applications of the Scanning Electron Microscope, IIT Research Institute, Chicago, IL, pp. 561-568.
- 6 Owen, T., and W. Key, CamScan, Personal Communications, 30 and 31 March 1992.
- 7 Goebel, R., K.D. Gross, H. Katterwe, and W. Kamrath, "The Comparison Scanning Electron Microscope First Experiments in Forensic Application", AFTE Journal, Vol. 15, No. 2, 1983, pp.47-55.
- 8 Katterwe, H. R. Goebel, and K.D. Grooss, "The Comparison Scanning Electron Microscope within the Field of Forensic Science", Scanning Electron Microscopy/1982, SEM Inc., pp. 499-504.



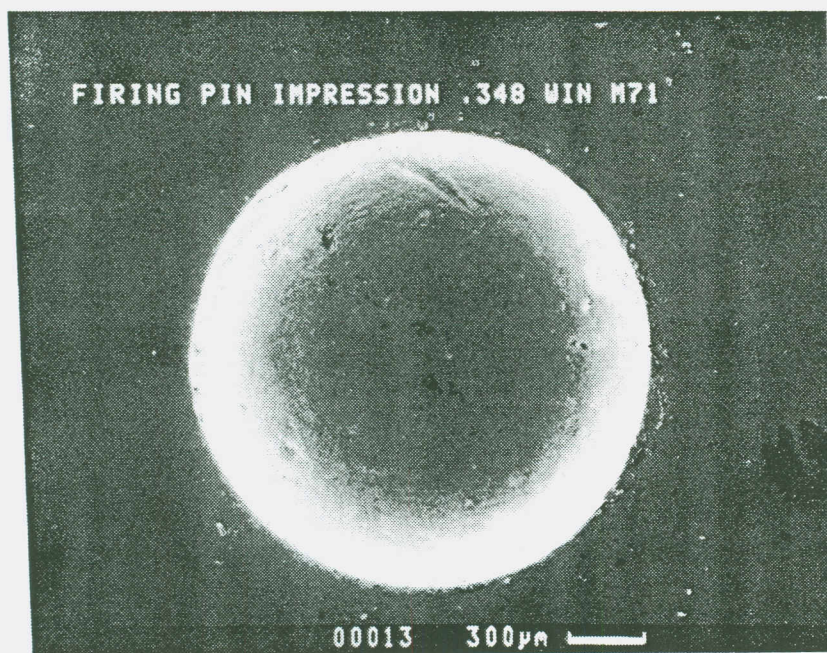
Photograph 1: Scanning electron micrograph of a damaged bullet jacket which was removed from the skeletonized carcass of a bear. Numbered areas mark the locations of striae matched to a known source bullet jacket. Original magnification X17.



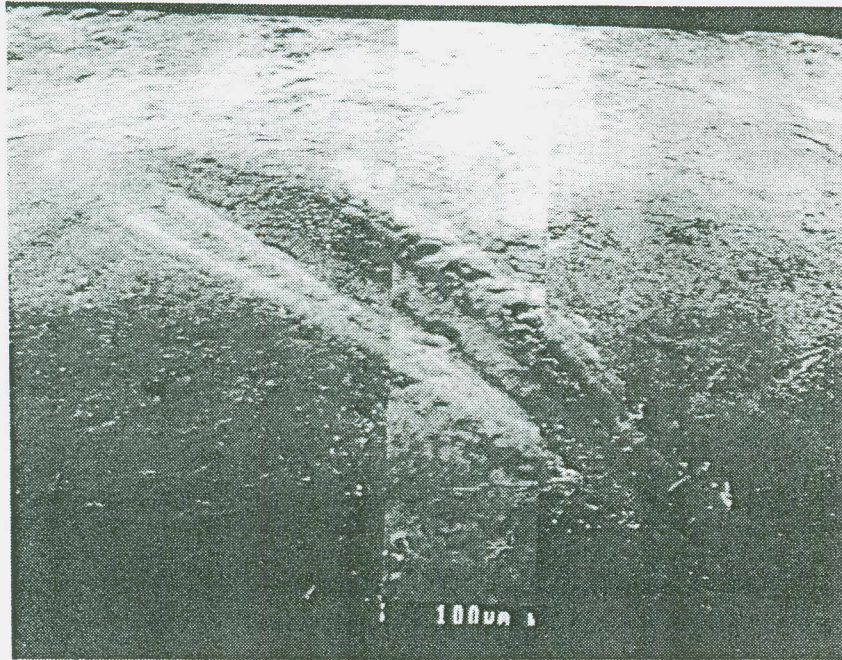
Photograph 2: Scanning electron comparison overlay micrograph of one of two match areas from photograph 1. The cursor strip is a digital image of the questioned jacket electronically overlapped on a "live" image of the known bullet jacket. Original magnification X500.



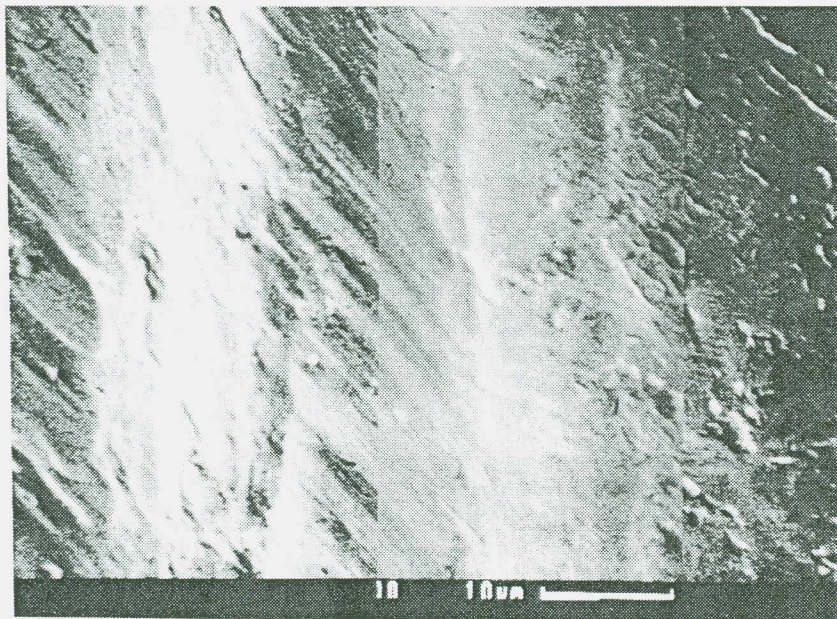
Photograph 3: Optical micrograph of a firing pin impression made by a .348 Winchester Model 71 rifle. Note the scratch type defect in the upper portion of the impression. Original magnification X40.



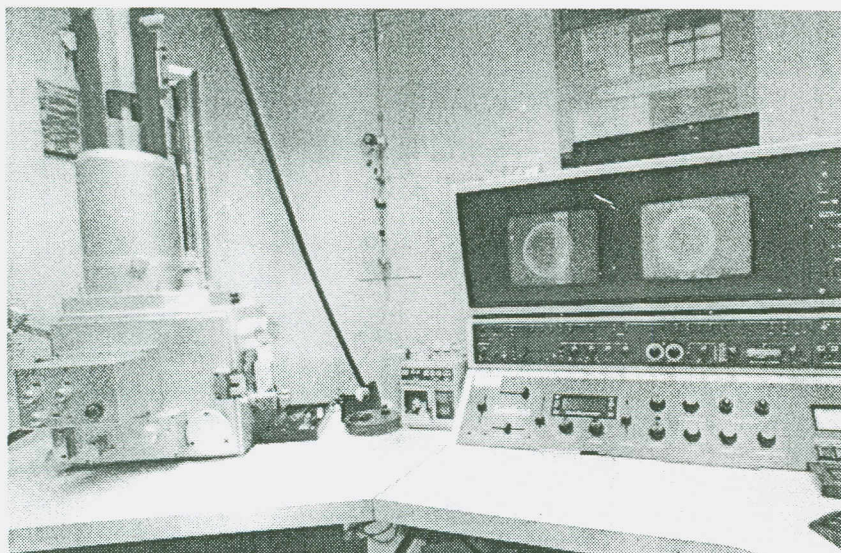
Photograph 4: Scanning electron micrograph of a firing pin impression made by the same rifle listed in photograph 3. The scratch type defect is apparent. The three dimple like defects at the 2, 8 and 10 o'clock positions in the impression were reproducible in all five of the test fires from this rifle yet they are virtually unnoticeable in photograph 3. Original magnification X36.



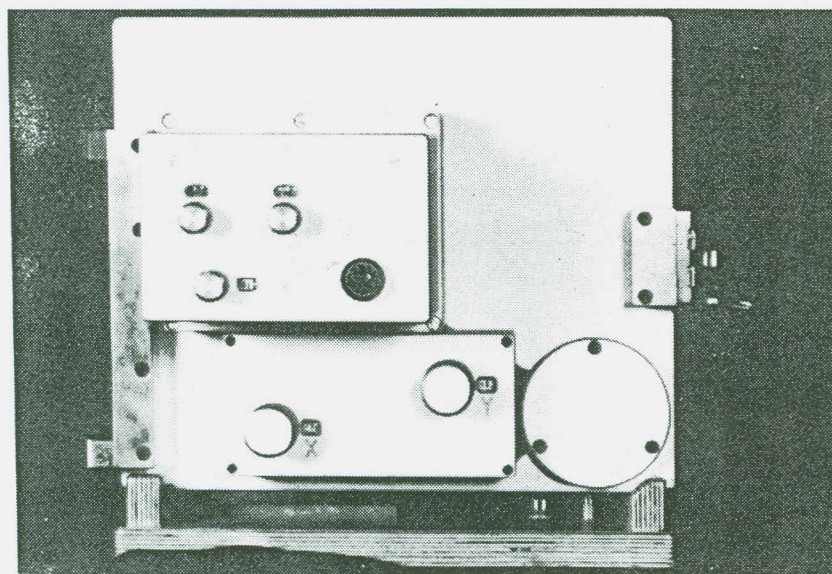
Photograph 5: Scanning electron comparison overlay micrograph of the scratch type defect in photograph 4. Note the striated area on the left side of the defect. Original magnification X250.



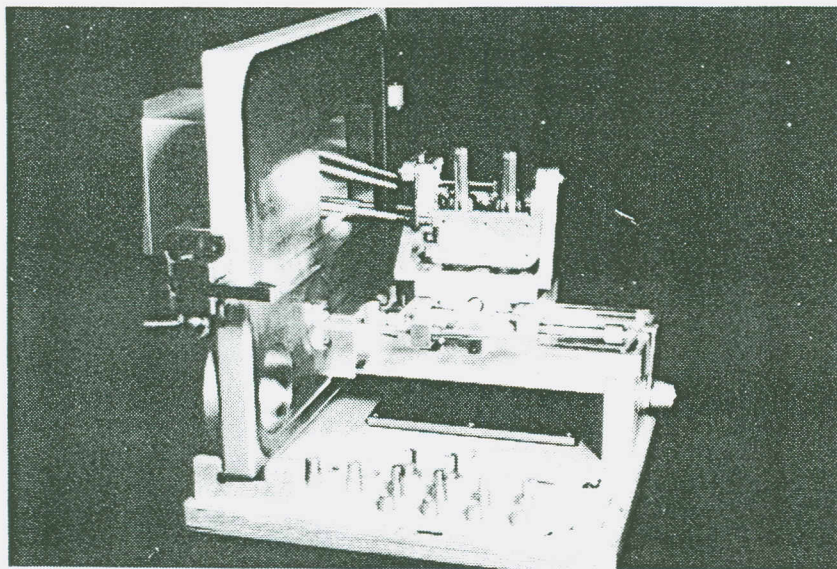
Photograph 6: Scanning electron comparison overlay micrograph of the striated area visible in photograph 5. Original magnification X2-000.



Photograph 7: Photograph of the National Fish & Wildlife Forensic Laboratory's scanning electron microscope with firearms comparison stage in place. The cathode ray tube on the left shows an overlay of a digital image on a live image. The CRT on the right maintains the digital image.



Photograph 8: Photograph of the front panel of the firearms comparison stage.



Photograph 9: Photograph of the chamber portion of the firearms comparison stage. Two cartridge cases are mounted in the dual specimen bucket. The objects in the lower foreground are various sized accessories for mounting bullets and cartridge cases.