MAGNETIC PARTICLE RECOVERY OF SERIAL NUMBERS

Dave Utrata & Marcus J. Johnson

Midwest Forensics Resource Center

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EXECUTIVE SUMMARY

Magnetic particle testing is used by crime laboratories for the recovery of obliterated serial numbers, but with limited success. The purpose of this project was to define conditions that would increase the likelihood that the technique could be successfully applied in forensic work. The success of this technique depends on a number of variables. Use of a magnetic field of appropriate magnitude and orientation, the correct nature of the magnetizing current and a suitable choice of magnetic particle suspension are all important considerations for this subtle, often challenging work. The material properties (mechanical and magnetic) of the firearm in question also play a vital role in serial number recovery. Also, the degree of challenge in the obliteration itself, or how, and how aggressively, the numbers were removed, influences the outcome of the recovery process.

These concerns notwithstanding, it is suggested that many (but perhaps not all) carbon/alloy steel and magnetic stainless steel firearms are viable candidates for magnetic particle serial number recovery based on their material properties. The use of fluorescent particles is seen as an aid in the recovery process. These particles seem sensitive enough to distinctly create the visual indications (due to deformation from under the stamped serial numbers) fundamental in this work. Also, the inherent contrast of fluorescent particles viewed under ultraviolet (UV, or black) light against a dark background creates dramatic visual images which are easy to interpret. As the degree of obliteration is lowered, so the likelihood of a successful magnetic particle recovery of serial numbers seems to understandably increase. However, it was also noted that additional polishing of the damaged area (to approximately 600 grit or so) over coarse grinding seems to increase the signal to noise ratio of the recovery process, making the indications a bit clearer for the inspector.

Certain steel firearms will respond better in magnetic particle serial number recovery than others. Based on a very limited sample, most of the firearms appear to fall into the range of "highly likely" for a successful recovery action, although a method of pre-screening a firearm to predict its suitability for the test is not currently possible. However, it seems most firearms have the right kind of material properties required for a successful test. The recovery of serial numbers will be dependent on other factors also, but it would thus seem quite reasonable to submit steel firearms to this test, making sure one uses proper technique as described in this paper. By doing so, one could expect very good results for the recovery of obliterated serial numbers.

Recommendations

- Fluorescent magnetic particles require the use of an ultraviolet light to reveal serial number indications. But they present images with higher contrast and greater legibility than using visible particles and should be used in serial number recovery.
- Portable yokes used to magnetize firearms have some drawbacks in properly fitting the array of sample configurations for which they will be used. A more flexible design that provides optimum magnetic transfer in the area of the serial number would conceivably improve effective magnetization, and such developments should be followed.
- DC electrical power should be supplied to magnetic inspection yokes. It is not clear as to whether this magnetization should be a rectified current, or a "true" DC electrical input to the yoke provided by an electric power converter. Nonetheless, better serial number recovery seems clearly possible using DC instead of the conventional AC electric power.
- The inspection surfaces of several steel firearms seem to provide better results when the serial number surface is finely ground, perhaps even polished, than by testing on rough ground surfaces. Although the results have not been quantified as to grit level and such, this means fine grit polishing equipment will likely provide a better sample condition than using a coarse grinding hand tool.
- The manifestation of the recovered serial number is a visual indication. As such, the use of digital photography clearly presents advantages over interpretation simply by using the investigator's vision. Additionally, very simple contrast and brightness enhancements, along with the high resolution imaging possible with new digital cameras, make for very legible documentation of the recovered serial number.

Items of Concerns

- Magnetization of a firearm, specifically focusing on the serial number area, may not be an easy task in many firearms. This will be particularly true if the component bearing the serial number is part of a complex assembly of varying pieces, some perhaps not magnetic.
- Magnetization of the desired area may vary greatly between firearms. Changes in the volume of one firearm over another, such that the same desired level of magnetization is reached, needs to be accounted for in a manner which is not yet clear.
- The design of an optimal magnet/electromagnet for use in magnetic particle inspection is not obvious. An inherent adaptability to different firearm configurations will likely be necessary in such a design.

Remaining Questions

- The orientation of the magnetizing field in magnetic particle inspection does not seem to be an important consideration, having little apparent effect on the visual indications created in serial number reconstruction. This is surprising, based on the knowledge of general NDT principles, and the reason for this behavior in firearm serial number recovery is not clear.
- The various steel and magnetic stainless steel firearms show a range of response in their applicability to serial number reconstruction. Although a good to very good response has been detected in most of the firearms studied in this work, it is not clear how completely such a response can be predicted.
- Based on this work, it is somewhat surprising that crime labs do, in fact, sometimes get very good results using methods with identified limitations. It is not clear is successful inspections are the results of optimized material response, whether obliteration attempts are not of a significant challenge, or a combination of several factors.

MAGNETIC PARTICLE RECOVERY OF SERIAL NUMBERS

INTRODUCTION

One method used by crime labs to recover obliterated serial numbers in steel firearms (ferrous samples) is the magnetic particle technique. The use of this method is predicated on the detection of metal deformation present under stamped serial numbers after the visible stamp has been removed. Equipment specialized for this detection is not used in these attempts; a portable magnetic yoke used typically for flaw detection on large weldments or structures, along with dry visible magnetic powders, have been the tools of criminologists working in this area. Crime labs have reported low success rates using these tools [1, 2]. This is not surprising when one considers that little formal development has apparently evolved for use in such investigations since the publication of seminal work in this area some time ago [3].

The aim of this project is to investigate specific aspects of magnetic particle inspection for serial number recovery. This includes attempts to understand the magnetic characteristics of different steels that affect their performance in the test, such as varying results for carbon steels and alloy steels after different thermal and forming treatments. Also investigated are the effects of the nature of the sample magnetization (AC, rectified DC, and true DC) and the use of various detection media, such as visible powders and fluorescent sprays, on test outcome. Additionally, some aspects of surface preparation of firearm samples prior to number recovery were included in this work.

The scope of this report includes a brief overview of the magnetic particle inspection method in general and its applications to forensic serial number recovery. This is followed by a description of how such investigations were simulated on lab samples, including a look at how the microstructure of a given steel will affect its performance in the test. Investigations into the serial number recovery in a series of ferromagnetic firearms (both steel and certain stainless steels) will then be presented. Recommendations for modifications to current approaches used in crime labs for serial number recovery, as well as suggestions for future work, conclude this document.

OVERVIEW OF MAGNETIC PARTICLE INSPECTION & FORENSIC APPLICATIONS

Magnetic particle testing has been practiced in various industries that use steel components, such as shipbuilding, pipeline work, steel mills and many welding arenas. The test method has been used extensively for a number of years, and much has been written about the test principles and application in literature in the nondestructive testing field. This section is intended as only a brief overview of the concept and principles behind this testing.

Figure 1 shows an illustration of the process of magnetic particle inspection. A ferromagnetic part (such as iron, steel, or a magnetic type of stainless steel) is flooded with a bath of magnetic “fines” in suspension. The part is then magnetized, which causes lines of magnetic flux to form in the part. Such lines are schematically shown as “flowing” from a north to a south pole, although the flow is really more of a magnetic direction indicator. These flux lines will generally stay contained within the part, although certain features of the part may cause them to leak out into the surrounding air. Geometric features such as tight fillets can cause this, as well as cracks.

The magnetic flux leakage creates a magnetic field gradient in the vicinity of the feature, which in turn locally attracts a cluster of the magnetic particles. The nature of the magnetic fines is such that they are intended to visually contrast with the background color of the sample. This is done by either inherent coloration of the particle or through the use of a coating of some sort on them. Therefore, the inspector does not see a crack *per se* but rather a somewhat larger area of visually contrasting material.

The principle of applying this technique to obliterated serial number recovery is shown in Figure 2. In this instance, the initial state of the sample includes an indentation of a serial number with the resultant sub-surface material deformation. The visible indentation is removed during the obliteration, but the deformed material remains. The part is then flooded with magnetic fines and magnetized, as in the previous example. Assuming that the deformation causes enough of a localized change in the magnetic properties of the material, the site of the deformation can cause magnetic flux to leak out and attract particles. Because the nature of this discontinuity is more subtle than, say, a crack, the implementation of this approach for forensic work is less forgiving than its usage for simple flaw detection.

The photomicrographs in Figure 3 show evidence of the deformation associated with serial numbers. The extent of this deformation is likely to be dependent on the severity of the stamping process, and will likely vary between different materials. At this time it is not clearly evident to what degree such deformation must be present in firearms in order to adequately create magnetic particle indications for recovery purposes.

TEST PROCEDURE ON STEEL SAMPLES

A series of step-wedge samples were produced for this work from a bar of 4340 alloy steel. The sample design is shown schematically in Figure 4, along with photos of one sample. Each block was made by stamping numbers on the steps under uniform pressure (in this case, 3000 pounds) on steel type stamps. The steps, each machined in an increment of 0.005”, were then milled away until the second row of numbers was just barely visible. The samples were then ground and polished using conventional metallographic preparation techniques. This created samples that had visible serial numbers on one row, and deformation under stamped numbers progressively further-removed from such stamps in the rows above it.

The various samples were heat treated by taking 5 pieces of the as received (hot rolled) material, normalizing them all for 1 hour at 1600^{o}F, then furnace cooling one piece, air cooling another piece, quenching two pieces in oil (one of which was later tempered at 900^{o}F) and quenching one piece in water followed by tempering. This provided a total of six samples of identical composition but varying microstructures, including the as received hot rolled sample.

The test method was straightforward: observe the visual indications provided by the magnetization of the samples after application of the magnetic suspension. At this stage of the work, two problems were evident. The interpretation of the samples’ appearances could be somewhat subjective, and the capture and presentation of data relied on the inspector’s photographic skills. While these were not deemed to be highly detrimental constraints on the current work, ideally they will be more fully resolved in future efforts.

The steel blocks were tested in a horizontal wet magnetic stand using a coil shot to induce magnetization in the steel. A photo of such a device is shown in Figure 5. Use of this equipment is not intended to be representative of recovery efforts performed in crime labs. Rather, the use of larger, laboratory or factory grade equipment such as this was intended to provide enough inspection "power" to distinguish between the expected ranges of response of various samples in a semi-quantitative manner. Both AC and rectified DC excitation to the coil were used initially. Early results indicated that the use of AC current for the induced magnetization provided significantly inferior results yielding essentially no indications of recovered serial numbers. This caused the bulk of the wet stand testing to be focused on using rectified DC current in the test coil.

The sample that provided the most vivid indications of serial number recovery was further tested by using various different magnetic particle media, and by using a portable yoke for magnetization, similar to those in use at crime labs, to observe if/how serial number recovery degraded with alternative inspection devices. Such a device, along with a power supply to control the excitation to it, is shown in Figure 5 also.

There were several variations of magnetic particles themselves investigated: fluorescent particles in the horizontal wet bath were used, as were visible (using white light for inspection) and fluorescent particles in aerosol suspension. Also, a variety of dry powders of various colors were available, all viewed under white light. Use of the aerosol sprays evolved over the course of the study, based on modifications suggested through use by the Division of Criminal Investigation (DCI) in Des Moines.

TEST PROCEDURE ON SAMPLE FIREARMS

Additional tests were also made on actual firearm components, provided through the assistance of the DCI in Des Moines, Iowa. The firearms included a Ruger speed-six .357 magnum, a Ruger .22 single-six, a Ruger .22 Mark II target, a Remington 12 gauge shotgun, a Ruger .38 special, and a Taurus .357 magnum The first four samples were carbon and/or alloy steels (which will be referred to as simply "steel" in this document) while the last two firearms were of the magnetic type of stainless steel, likely in the 410 series of stainless (and will henceforth be referred to as "stainless"). Figure 6 shows the sample firearms used in this study.

The steel firearms were disassembled, with the component having the serial number isolated. The numbers, and in some cases, wording, stamped on the pieces were ground away using a Dremel® tool. These samples were tested in the coil of the magnetic test stand using a rectified DC current to induce magnetization, and they were also tested using a portable yoke attached to a power source that produced a true DC magnetization. The serial recovery attempts were made after the information on these samples was ground using the Dremel® tool, and such attempts were repeated after further polishing the surfaces using 400 and 600 grit sandpaper on a flat grinding disc.

The two stainless firearms were received from DCI with their serial numbers already obliterated. They were tested using a portable yoke operating with true DC magnetization. Both visible (observed using white light) and fluorescent (observed under UV light) magnetic particles were used. At this stage in testing, the aerosol sprays were used in a "condensed" form, pouring solutions onto the test pieces after they had been sprayed into small plastic bottles. This clever modification in the procedure made the application of the magnetic particles much cleaner and more controlled.

Because of the visual nature of serial number recovery attempts on firearms, the experiences gained, and results from the samples in this study are presented individually as a series of attachments at the end of this report.

RESULTS

As mentioned above, the assessment of how well or how poorly a sample performed in this test was a somewhat subjective call. A sample's performance was based on determining how many rows of "hidden" serial numbers were revealed using magnetic particle inspection. In this manner, steels with magnetic/microstructural conditions that produced the visualization of a greater amount of numbers were ranked as doing better in the test. The best results were obtained on these samples by placing a piece in the test coil, bathing it with the fluorescent magnetic particle bath, magnetizing for 0.75 seconds, and then gently permitting runoff of excess particles from the surface of the sample. Magnetic particles were retained at the locations of magnetic flux leakage, caused by differential magnetic properties in the deformed metal under the stamped regions versus the undeformed base metal. In this manner, the samples were magnetized, indications of the recovered numbers made, and then moved to a convenient spot for photographs.

Figure 7 contrasts the appearance of the various 4340 steel blocks after testing. The samples that provided the best imaging of hidden stamping deformation were the quenched and tempered steels. For this photo, the water quenched and tempered sample had been loaned out; its performance was essentially similar to that of the oil quenched and tempered sample, shown in the figure. The ranking of the other samples was found to be reproducible when the test procedure was repeated on different days. Also, different individuals from the lab indicated a consistent ranking in the relative legibility of the serial number recovery in each sample. This suggests that concerns about the subjective nature of interpreting the recovered serial number indications were not too important; the results appeared quite similar to various individuals, who ranked them all in the same order. Obtaining photographic evidence of the various samples was the least consistent variable in this procedure.

Figure 8 shows the results of further testing of the oil quenched and tempered sample. It was of interest to see how the examination of this sample would change when examined using different magnetization methods. This figure shows that optimum results were obtained when using DC excitation of the magnetizing coil, very poor results when using AC excitation in both fixed and portable coils, and low to moderate results when using a handheld yoke for magnetization. In addition, this sample was examined using both fluorescent and visible aerosol magnetic particle suspensions, as well as dry magnetic powder. Photographs of the quenched and tempered sample tested with these media are shown in Figure 9.

The use of an aerosol magnetic particle spray, either fluorescent or visible, did not provide quite the dramatic results obtained when using the bath of fluorescent particles in the horizontal wet stand. Hidden serial numbers were revealed to a degree using these particle suspensions, but the indications did not appear as robust as when using the bath. However, the indications provided by using the aerosol sprays required using a full 5-second spray application of the material. This would suggest that getting enough of the magnetic particles themselves onto to the sample to provide a vivid indication using these sprays was problematic.

As mentioned above, an interesting modification of using aerosol sprays was developed by investigators at DCI. Staff there simply sprayed the visible magnetic particle aerosol into plastic bottles that had small application spouts. This seemed to provide excellent results. The process was repeated for this study, using both visible and fluorescent magnetic particle aerosol sprays. Although some settling of the magnetic particles appears to occur when the solutions are left to rest, simple agitation seems to return the liquid back into a useful suspension of magnetic fines in a carrier base.

An assessment of the use of dry powder to recover serial numbers did not suffer from subjective interpretation: using dry powder gave very poor results. Even when using the quenched and tempered steel sample and DC coil excitation, the use of dry powder did not reveal any hidden serial numbers. The dry powder collected on the surface of the sample in a clumped appearance, using either a wet-stand coil (with the bath protected from powder contamination) or a portable yoke. These results suggest that it would be surprising that crime labs, using dry powder as the media for illumination of obliterated serial numbers, would ever achieve successful results. However, this does not explain why a number (albeit low; 10% or so) of number recovery attempts do, in fact, succeed.

The serial number (and name) recovery attempts on actual firearms, as mentioned, are shown in attachments to this document. Due to the intense visual aspect of results in these investigations as visual images, numerous photographs have been assembled into a series of PowerPoint presentations. The images in these collections are reasonable attempts to document the steps of serial number removal and recovery at various stages. As noted previously, the documentation of results in this study is limited by the photographic skills and visual acuity of the investigator. A Minolta DiMAGE 7 digital camera and tripod (as necessary) were used to record the images in this work.

DISCUSSION

Based on the relative merits of different heat treated samples in this study for revealing hidden serial numbers using magnetic particle examination, it would seem that quenched and tempered steels would be the best candidates for forensic serial number recovery. The explanation for this apparently lies in a combination of effects. First, for a sample to give good results, it should exhibit a significant magnetic response so as to create a suitable signal level in the magnetic particle test. In addition, the deformed material under stamped serial numbers on such a sample needs to create enough of a local discontinuity in the magnetic properties to cause adequate flux leakage during testing to generate a viable indication.

In an effort to identify a sample that would be a likely candidate for the successful magnetic particle recovery of serial numbers, magnetic properties of the samples used in this study were obtained. This was done by using the Magnescan, a device that permits observation of magnetic properties by performing hysteresis tests on samples. Using this device, the relative permeabilities and coercivities of the steel samples could be assessed in a scatter plot. This analysis is shown in Figure 10. This plot suggests that there is perhaps a favored combination of magnetic properties for serial number recovery. The as-received steel sample and the oil quenched sample would lie outside this region; this was evidenced by their relatively poor performance in the samples studied. The air cooled sample presumably represents material with more borderline magnetic properties, based on its intermediate performance in the magnetic particle number recovery tests. The quenched and tempered sample and the furnace cooled sample, having performed significantly better in the recovery test using magnetic particles, would represent steels with an optimum combination of magnetic properties.

The plausibility of this measurement of magnetic properties relating to forensic magnetic particle recovery, of course, requires validation and comparison on real firearms that undergo such tests. The various steel firearms did have magnetic property tests performed on them. However, metallographic samples were taken from three of the steel firearms. Based on this limited information, two firearms could be seen as being predictably "OK" material for inspection, while a third presented a structure quite different from any of the steel samples. The actual number recovery attempts on these samples were only mildly supportive of these interpretations. Although interesting as a brief study, it does not seem very worthwhile to dwell extensively on such microstructural comparisons. Future work should focus on relating those more directly important sample properties, such as magnetic permeability and coercivity.

The overall improved benefit of using DC magnetization for forensic recovery of serial numbers is not fully explained at this time. One could argue that the regions of deformation that give rise to the magnetic particle indications are largely subsurface discontinuities, and therefore, DC current in magnetization should be employed to give better results over AC. True AC excitation is often used to demagnetize specimens and as such cannot be expected to yield good inspection results. It is suspected that the term AC excitation is often used erroneously in place of rectified AC. Rectified AC has a resultant bias that could lead to magnetization and hence the possibility of good inspection results. A permanent magnet is sometimes used for firearm magnetization in this test. However, no suitable results were obtained on lab samples using some truly strong such magnets available for demonstration purposes. Anecdotal evidence of using simple horseshoe magnets to do this forensic work seem to counter all of this; it is unclear if the obliteration levels in such cases were really quite trivial, if the material was of a optimum composition and magnetic state, or some combination of the above.

In any case, it certainly seems that using DC magnetization, whether as a rectified or a truly direct current is a vast improvement over using AC magnetization. Some evidence exists to suggest that different types of rectification (single- versus three-phase rectification) can result in subtle differences in subsurface discontinuity detection [4]. No direct evidence of detection sensitivity toward a particular mode of rectification was found in the small number of samples examined in this study. Whether or not a particular "type of" DC magnetization would cause a firearm that yielded borderline serial number recovery results to behave much better than other types of DC is not clear. But the evidence clearly suggests highly improved results, or at least potential for better results in more challenging obliterations, using DC over AC.

Improved inspection results using the coil in the large horizontal stand instead of a portable yoke were not surprising. It was anticipated that the test samples could be magnetized to an adequate level using this device, avoiding possible magnetic field strength considerations that might arise using a portable yoke. This cause for concern was seen in the comparison of really good recovery for the quenched and tempered steel in the large coil, but only meager performance in the portable yoke, even using DC magnetization.

However, this makes it hard to reconcile any success reports on forensic work coming from labs that have only the small yokes. One suggestion might be is that if the obliterated serial numbers on a steel firearm are recovered in current forensic work, the firearm steel presumably was the "right" material with respect to magnetic properties, and the level of obliteration was not very significant to begin with. Therefore, the relatively lower magnetizing power of a handheld yoke could conceivably be adequate.

The apparent necessary duration of using the aerosol sprays was counterintuitive, but it may simply be based on a limitation of the volume of useful magnetic media applied by this technique. In any case, if magnetic particle aerosol sprays are to become typical in such work, their successful use would require strict instructions to overcome the tendency to spray lesser material. Alternately, uniform and consistent distillation of the aerosol sprays into drip-bottles seems to be a useful modification to the procedure. It should be insured that a suitable mixture of magnetic particles and their suspension remain after being sprayed into a small bottle and allowed to settle. Evaporation of the carrier for the particles could conceivably result in an overly viscous slurry, but keeping the sprayed material in a small closed container seems to be quite practical in the short term.

RECOMMENDATIONS

It appears that certain aspects of magnetic particle inspection have been highlighted. Their implementation or further study suggest that serial number recovery would be improved by:

- using fluorescent magnetic particles in the recovery attempt,
- using a DC power supply for control of the magnetic yokes used,
- modifying the design of such yokes to permit better contact with firearms,
- performing some surface preparation prior to magnetic particle recovery attempts,
- attempting magnetic particle recovery first, avoiding damage to the surface through the use of chemical etchants later, and
- using digital photography to capture images.

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