small arms survey

Issue Brief

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The Method behind the Mark

A Review of Firearm Marking Technologies

Introduction

Record-keeping is an essential prerequisite for limiting the illicit proliferation of small arms and light weapons. A robust record-keeping system provides the necessary means to trace small arms[1] and investigate the illicit trade. The marking of small arms is a necessary component of the record-keeping; it links a specific small arm to a unique record for that item.

Proper marking can be applied through a variety of marking technologies, each carrying its own strengths, limitations, and costs. In order to support states in choosing the most effective solution for their specific marking needs, this *Issue Brief* provides an in-depth analysis of different marking technologies and methods, comparing their main characteristics.

Marking is included in all of the main international and regional instruments that are designed to curb the illicit trade in small arms. Each instrument has its own set of marking requirements, yet these provisions are not always compatible, harmonized, or implemented at the same pace. These discrepancies result in ambiguity and allow room for interpretation, especially for states that are party to one or more instrument.[2] As a result, current marking practices, including marking methods, vary widely from state to state, even within the same region (Persi Paoli, 2009).

Despite the differences in marking practices, the application of adequate marking on small arms is among states' obligations as part of overall international efforts to facilitate firearm traceability. Proper marking and efficient record-keeping are two interdependent and mutually reinforcing factors of any effective plan to investigate and interdict illicit small arms trafficking and, as such, they are key features of solid and effective arms control.

This *Issue Brief* refers to the marking provisions included in two international instruments. The first is the United Nations Protocol against the Illicit Manufacturing of and Trafficking in Firearms, Their Parts and Components and Ammunition, known as the Firearms Protocol and adopted by the UN General Assembly in 2001 (UNGA, 2001);[3] the second is the International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons, known as the International Tracing Instrument (ITI) and adopted by the UN General Assembly in 2005 (UNGA, 2005).

These two documents represent the only two international instruments that concern the issue of small arms in general, and of marking in particular, at the global level. Specifically, the UN Firearms Protocol constitutes the only global, legally binding instrument addressing the illicit trafficking of firearms. The International Tracing Instrument is a politically binding instrument that was developed within the framework provided by the 2001 UN Programme of Action to Prevent, Combat and Eradicate the Illicit Trade in Small Arms and Light Weapons in All Its Aspects.

The marking process involves two different phases, though in some cases all marks are applied at the same time. Ideally, the first marking phase occurs at the time of manufacture and includes, according to the instruments considered, information on the country and year of production, manufacturer, serial number, firearm type or model, and calibre. The second phase involves the marks applied after the manufacturing process is over. These post-manufacture marks include, but are not limited to, the importing country and year of import, marking of firearms permanently transferred from government stockpiles to civilian use, marking of state-owned firearms, and proof marks.

The ITI stipulates that the choice of the marking method is a national prerogative as long as all marks required under the instrument are on an exposed surface, conspicuous without technical aids or tools, easily recognizable, readable, durable, and, as far as technically possible, recoverable. Box 1 highlights the marking provisions of both the Firearms Protocol and the ITI, revealing that the ITI provides more guidance as to what good practice should be on marking. While the Firearms Protocol makes no mention of where or how required marks should be applied, it does encourage states to develop measures against the removal or alteration of markings (art. 8.2), as does the ITI. The ITI provision for frame/receiver marking (art. 10) is especially important as that component is the building block of a firearm and usually functions as the element of control for record-keeping and tracing purposes.

Background information relevant for this *Issue Brief* was obtained through the analysis of existing literature.

Box 1 Marking provisions in the Firearms Protocol and the ITI

The issue of marking small arms is extensively addressed in both the Firearms Protocol and the ITI. In the Firearms Protocol, provisions on the 'marking of firearms' are found in Article 8:

1. For the purpose of identifying and tracing each firearm, States Parties shall:

(a) At the time of manufacture of each firearm, either require unique marking providing the name of the manufacturer, the country or place of manufacture and the serial number, or maintain any alternative unique user-friendly marking with simple geometric symbols in combination with a numeric and/or alphanumeric code, permitting ready identification by all States of the country of manufacture;

(b) Require appropriate simple marking on each imported firearm, permitting identification of the country of import and, where possible, the year of import and enabling the competent authorities of that country to trace the firearm, and a unique marking, if the firearm does not bear such a marking. The requirements of this subparagraph need not be applied to temporary imports of firearms for verifiable lawful purposes;

(c) Ensure, at the time of transfer of a firearm from government stocks to permanent civilian use, the appropriate unique marking permitting identification by all States Parties of the transferring country.

2. States Parties shall encourage the firearms manufacturing industry to develop measures against the removal or alteration of markings.

In the ITI, Section III on 'marking' comprises marking provisions in Articles 7–10:

7. The choice of methods for marking small arms and light weapons is a national prerogative. States will ensure that, whatever method is used, all marks required under this instrument are on an exposed surface, conspicuous without technical aids or tools, easily recognizable, readable, durable and, as far as technically possible, recoverable.

8. For the purpose of identifying and tracing illicit small arms and light weapons, States will:

(a) At the time of manufacture of each small arm or light weapon under their jurisdiction or control, either require unique marking providing the name of the manufacturer, the country of manufacture and the serial number, or maintain any alternative unique user-friendly marking with simple geometric symbols in combination with a numeric and/or alphanumeric code, permitting ready identification by all States of the country of manufacture; and encourage the marking of such additional information as the year of manufacture, weapon type/model and calibre;

(b) Taking into account that import marking is a requirement for the States parties to the Protocol against the Illicit Manufacturing of and Trafficking in Firearms, Their Parts and Components and Ammunition, supplementing the United Nations Convention against Transnational Organized Crime, require to the extent possible appropriate simple marking on each imported small arm or light weapon, permitting identification of the country of import and, where possible, the year of import and enabling the competent authorities of that country to trace the small arm or light weapon; and require a unique marking, if the small arm or light weapon does not already bear such a marking. The requirements of this subparagraph need not be applied to temporary imports of small arms and light weapons for verifiable, lawful purposes, nor for the permanent import of museum artefacts;

(c) Ensure, at the time of transfer from government stocks to permanent civilian use of a small arm or light weapon that is not marked in a manner that allows tracing, the appropriate marking permitting identification of the country from whose stocks the transfer of the small arm or light weapon is made;

(d) Take all necessary measures to ensure that all small arms and light weapons in the possession of government armed and security forces for their own use at the time of adoption of this instrument are duly marked. Markings on these small arms and light weapons do not necessarily have to meet the requirements of subparagraph 8 (a) above;

(e) Encourage manufacturers of small arms and light weapons to develop measures against the removal or alteration of markings.

9. States will ensure that all illicit small arms and light weapons that are found on their territory are uniquely marked and recorded, or destroyed, as soon as possible. Pending such marking, and recording in accordance with section IV of this instrument, or destruction, these small arms and light weapons will be securely stored.

10. States will ensure that every small arm or light weapon always receives the unique markings prescribed in subparagraph 8 (a) above. A unique marking should be applied to an essential or structural component of the weapon where the component's destruction would render the weapon permanently inoperable and incapable of reactivation, such as the frame and/or receiver, in compliance with paragraph 7 above. States are encouraged, where appropriate to the type of weapon, also to apply the marking prescribed in subparagraph 8 (a) above or other markings to other parts of the weapon such as the barrel and/or slide or cylinder of the weapon, in order to aid in the accurate identification of these parts or of a given weapon.

Particularly relevant is the work conducted in the field of marking by the Groupe de recherche et d'information sur la paix et la sécurité (the Group for Research and Information on Peace and Security, GRIP), the Small Arms Survey, and the United Nations Institute for Disarmament Research (UNIDIR).

Data on different marking technologies and methods has been collected through different channels: desk-based research, consultation with experts, a questionnaire sent to different companies[4] supplying one or more marking technologies, and on-site visits.

Overview of selected marking methods

The spectrum of marking methods is very wide, with several approaches applicable to firearms. For a marking method to be efficient, it should:

- avoid damaging the performance and technical quality of the firearm;
- be practical to use;
- preferably be able to apply marks to several components;
- result in a readable, durable, and possibly recoverable mark; and
- have an acceptable cost per unit produced or marked.[5]

All the major marking methods currently used for firearms marking fall into two main categories on the basis of the physical principle they use: (1) deformation or (2) removal of material. Both categories have distinctive strengths and limitations.

'Deforming' marking methods, such as stamping and dot peen, apply the mark by deforming the surface either through impact or by compression. The act permanently alters the physical properties of the material in the marked area. The depth achieved varies according to several factors, including the characteristics of the machine, the hardness of the material, and the nature, size, and length of the string to mark.

'Material removal' methods are usually referred to as 'engraving methods'. Material can either be carved mechanically, such as in the case of scribing marking, with the use of cutters or pins, or it can be superficially ablated, melted, or burned (the physical process of marking depends on the material) with the use of a laser beam or head (laser engraving).

Following are brief descriptions of the most common marking methods: stamping; dot peen or micro-percussion; mechanical engraving through scribing; laser engraving; and other methods.

Stamping[6]

While new technologies such as lasers have entered the market in recent years, stamping remains the most common marking method (see Figure 1). The two main types of stamping are press marking and roll marking; both leave a permanent plastic deformation of the crystalline structure of the material.[7]

Press marking is generally more economical and faster than roll marking. It can be divided in two kinds: impact press and squeeze (compression) action press.

Impact presses mark numbers and letters into the surface of parts with a single stroke. These presses are typically used for stamping plates or solid parts. The impact pressure required for a metal marking application depends on three main factors: character size, the material being marked, and the number of characters to be marked with a single stroke.

Compression action presses offer enhanced control of stamping pressure, which may be desired if the impact could damage the components to be marked. There is no impact or bounce as the marking pressure is delivered in a straight, smooth compression. Compared to impact presses, these units offer reduced stress for the parts being marked and less wear on the tooling in the machine. There are no limitations on the shape of the area to mark; flat, cylindrical, or contoured parts can be marked with the use of flat, convex, or concave dies.

As stated above, stamping is a method that marks the surface by deforming the material. A stamping machine thus needs to exert a certain pressure (tonnage requirements) determined by both the type of material and the length and size of the string to mark. The longer and the bigger the string to be marked, the higher the required pressure and the more expensive the machine.

Roll marking is a recommended solution if tonnage requirements make a press too costly and fragile parts risk being damaged by heavy stamping pressure. Data is literally 'rolled' into a part instead of stamped in with a press. The rolling process involves a single contact point between the die and the part being marked. Each character in a string is individually marked as the die rolls over the part. As a result, roll marking machines need just enough tonnage to indent one character per line of marking while, by comparison, a stamping machine requires enough pressure to indent the entire string at one time.

Figure 1 **Stamped marks**

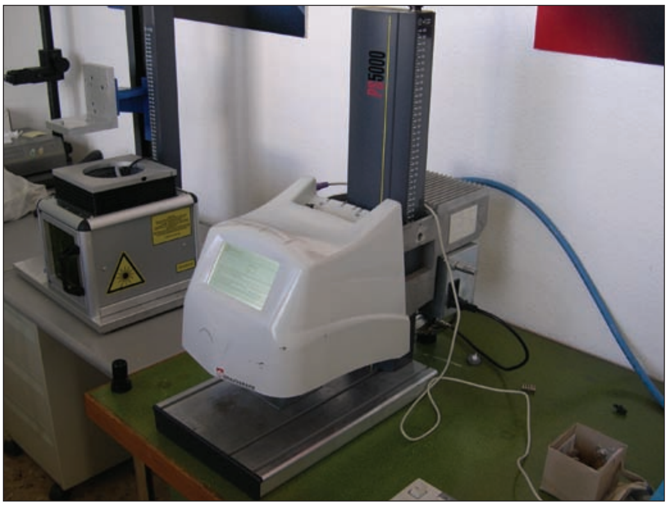
Photos courtesy of Royal Canadian Mounted Police, Canada

Dot peen or micro-percussion[8]

Dot peen (or micro-percussion) is a second possible method of marking through deformation of the material (see Figure 2). The principle of micro-percussion is that it marks material with the use of a hardened stylus, which imprints a series of individual dots to reproduce alphanumeric characters. The oscillating, or vibrating, carbide stylus can mark up to five characters per second on flat, concave, or convex surfaces (see Figure 3). This technology can mark all materials provided they are not harder than 62 HRC[9] and would not weaken the material regardless of its thickness.[10]

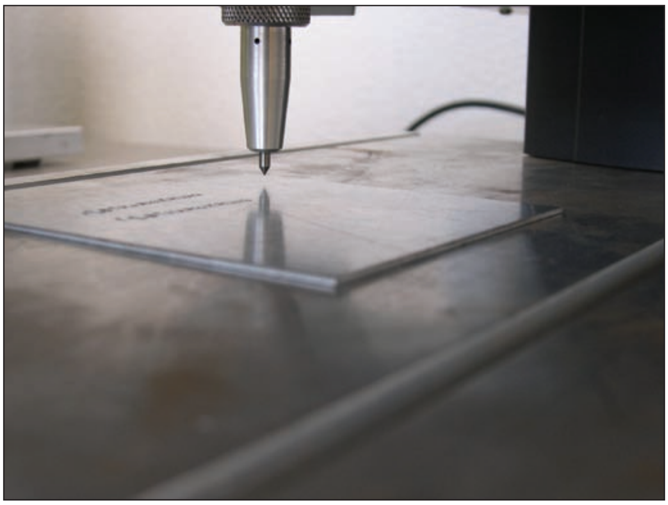
Dot peen or micro-percussion machines are usually available in two versions: pneumatic and electromag-

Figure 2 **Dot peen marking machine**



In this pneumatic dot peen marking machine, the air is supplied through the blue pipe. The user interface includes a built-in liquid crystal display (LCD) and an external keyboard (standard computer keyboard). Photo courtesy of GravoTech GmbH, Switzerland

Figure 3 **Dot peen marking**



The carbide stylus oscillates, or vibrates, up to 300 times per second, resulting in up to five characters per second on flat, concave, or convex surfaces. Photo courtesy of GravoTech GmbH, Switzerland

netic. The pneumatic version (see Figure 2) is less costly, but it is very loud and requires, in addition to electrical supply, an air supply with a pressure of 87 PSI (6 bar).[11] The electromagnetic version, while being more expensive, has the advantage of requiring only electrical supply, which allows for easy relocation, and it is significantly quieter than the pneumatic version.

Dot peen or micro-percussion machines are also available as hand-held units (see Figure 4) with built-in liquid crystal display (LCD) screens and the possibility of operating with a battery pack for complete mobility.

Mechanical engraving: scribing[12]

An alternative solution to deforming the material is to remove it. Mechanical engraving, for example with a scribing machine, is a fairly widespread practice that involves less aggressive action than stamping. Material is removed with the use of rotation carbide cutters, diamond cutters, or hardened pins (see Figure 5).

The final result depends on the material, but it is usually a high-quality, deep, smooth, and continuous mark. Thanks to the 'drop and drag' action, the whole marking process is very quiet; once the pin or cutting tool penetrates into the material at the desired depth, it is dragged to form the desired character.

Laser engraving[13]

Light amplification by stimulated emission of radiation—or laser—engraving is based on a focused laser beam that removes material (by burning it out) from the component without requiring physical contact (see Figure 6). Laser machines generate lasers within a specific range of wavelengths, which vary depending on the type of system (such as YAG, fibre, or CO_2).

Each material absorbs the laser at specific wavelength levels; based on its material, each component to be marked thus requires the use of laser beams with an appropriate wavelength. Not every laser machine is efficient on all materials with the same laser beam or head. While plastic materials, wood, cardboard, paper, leather, and acrylic are often marked with relatively low-power CO_2 lasers, these lasers are less suitable for metallic surfaces, which are characterized by a low absorption

Figure 4 **Hand-held dot peen marking unit**

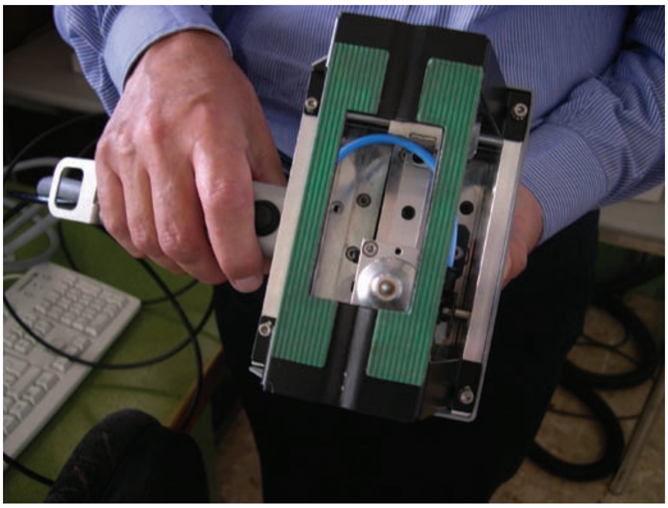


Photo courtesy of GravoTech GmbH, Switzerland

Figure 5 **Mechanical engraving**

This scribing machine applies marks by mechanically engraving the surface. The quality of the mark is high, though the process is slower than other marking methods. Photo courtesy of GravoTech GmbH, Switzerland

Figure 6 **Laser engraving**

Since laser marking machines such as this one apply marks without any physical contact, the firearm does not need to be locked to avoid movement during the marking process. Once the object to be marked is positioned, the safety cabinet needs to be closed before the marking begins. Photo courtesy of GravoTech GmbH, Switzerland

rate at the wavelength at which CO_2 lasers operate.

Two options are suitable for the marking of small arms and light weapons: lamp- or diode-pumped lasers or fibre lasers. Research and consultations with the supplying company should inform any purchase of a laser machine.

A **diode-pumped laser** ($Nd:YVO_4$ or Nd:YAG) offers outstanding marking quality thanks to its small spot size and is thus optimal for marking accuracy on metal and plastic parts. A laser diode source is used to excite the crystal, producing a high-quality laser beam suitable for marking text, logos, and designs on metals, plastics, and a variety of other surfaces. The laser diode source is air-cooled and does not require an external chiller or flash-lamp replacement, resulting in low maintenance operation for 15,000 hours or more.

Fibre laser machines require a higher initial investment compared to the diode-pumped YAG lasers, but they have several advantages that make them more convenient in the long run. The structural and operating benefits are smaller dimensions, less need for periodic maintenance, a lower likelihood of internal damage, a longer lifespan (100,000 hours), lower utility costs, greater power, and a higher reliability of the laser source.

Laser engraving allows for marking with extreme precision, even on very small areas that would be inaccessible to other marking instruments. While this marking solution requires the highest initial investment, it is certainly the most efficient and effective in terms of quality and speed of marking.

Other methods

Two other methods should be noted, although they are not considered in depth in this *Issue Brief*. With plastic replacing metal more and more frequently in firearm grips, **casting** is commonly used to mark information that is uniform for every firearm, such as the manufacturer's logo and name. This type of information is added to the original mould that is to be used to cast copies of the same component (such as plastic grips).

Permanent superficial marking on metals can also be obtained through **electro-chemical marking**. This process involves the use of a stencil that transfers, through the electrolyte fluid, the mark from the applicator or die to the part to be marked. This process works only with electrically conductive metal surfaces; it would not work on metals that have already been treated (with paint or other coating).

Comparative analysis

Overview

Modern marking machines are generally very efficient, capable of imprinting a code in a matter of seconds. Nevertheless, some may be more effective than others in meeting a state's specific needs. In fact, as modern firearms are built using different materials (plastics and metals), it is possible for a single firearm to require a number of different methods (see Figure 7).

Some solutions might therefore require a combination of different marking machines, each used on the component whose material is most responsive to the specific method. Arms producers often employ such combined applications at the time of manufacture, whereas states generally add their marks using a single approach. As it is not possible to identify a 'one-method-fits-all' solution for fulfilling all national requirements, it is important to highlight the parameters that should be taken into consideration during the evaluation process. These parameters can be divided into technical and costs factors.

Primary technical factors

The machine's ability to mark different materials. This factor is critical since modern firearms are composed of a combination of polymers, metals, and, in some cases, wood. The choice of machine should thus be informed by the types of firearms in stock and the types of firearms that a state plans to acquire in the short to medium term. Yet anticipated markings may not be limited to state-held or -acquired firearms; private firearms may be subject to marking at permanent import or for record-keeping purposes under national law. In this case, a more comprehensive analysis of the type of firearms manufactured or imported in a country is advisable. In addition, states acquiring new firearms may be able to arrange for their appropriate marking at the time of manufacture.

Recoverability of the mark. Given that all marks applied with the presented methods are deemed 'permanent' (assuming regular usage and proper storage), a second factor to consider is the recoverability of the mark in the

Figure 7 **Firearms carrying a combination of marks**

Modern firearms are increasingly built using a combination of materials such as plastic and metal. A single firearm can thus be marked with different methods, depending on the specific material of the component that is marked. These handguns carry a combination of stamped, laser-engraved, and cast marks.
Photos courtesy of Royal Canadian Mounted Police, Canada

Figure 8 **Use of metal tags for weapons with plastic receivers**

This handgun's receiver (or frame) has a metal tag bearing a stamped serial number.
Photo courtesy of Royal Canadian Mounted Police, Canada

event of intentional alteration or defacing. This is a crucial element for successful tracing. Yet only marks applied to metal have a chance (about 50 per cent)[14] of being recovered through analysis of the altered physical structure; such recovery is not possible with plastic and other composite materials. These materials are increasingly used to produce firearm frames (or receivers), which are usually referred to as the main components for identification purposes. Thus, firearms with plastic frames frequently feature an integrated metal tag with the serial number stamped on it (see Figure 8). The use of metal tags is far from a fail-safe solution to the problem of recovering marks on firearms with plastic frames, however; indeed, the metal tag could be removed without causing critical damage to the firearm.

Suitability of marking an assembled firearm and **damage risk assessment.** Some methods run the risk of creating functional problems on a finished firearm, for example by altering its performance or structural integrity and, consequently, its durability and reliability. Certain marking methods require greater physical contact and may thus not be suitable for use on fragile parts. Others have limitations on the ability to mark specific components due, for example, to their size or limited accessibility. States whose holdings are mainly based on imported firearms and that do not have any or have only limited domestic small arms production should be particularly conscious of this factor; having to disassemble firearms at the time of import in order to mark them would cause long delays in the delivery.

Marking speed and the **marking rate.** These two parameters have very different meanings. The speed factor reflects the rate at which a machine can imprint a code; given a material and a code to mark, it depends exclusively on the marking technology. In contrast, the marking rate—the number of firearms marked per hour, day, or year—is a product of various factors, such as the marking technology in use and the efficiency of the production line. The marking rate reveals how quickly a firearm can be prepared for marking, the rate of creating a unique marking code, as well as the registration of that code into a database. This *Issue Brief* regards the marking speed as the only objective parameter; individual states should estimate the marking rate on a case-by-case basis.

Secondary technical factors

Those concerned with the aesthetics of the mark may wish to consider secondary factors such as the **quality of the mark** and the **capacity to mark logos and symbols** in addition to strings of alphanumeric characters. These factors may be particularly important with respect to firearms produced, or imported, for commercial distribution, such as sport and hunting rifles or collectors' firearms.

An additional secondary factor is the **estimated lifespan** not only of the whole machine, but also of its critical components. Modern machines are expected to have a long lifespan (measured in hundreds of thousands—or even millions—of firearms). Nevertheless, some technologies may require either periodic maintenance or replacement of certain components (such as the cutters, pins, or lamps), which has an impact on medium-term operating costs.

Finally, in certain cases the **energy requirements** for a technology might be important. All methods under review operate with a standard 100–220-volt electrical supply and have a maximum energy consumption of less than 1 kW. The most energy-demanding is the fibre laser, which has a maximum power consumption of 800 watts and an average usage of less than 500 watts. Mechanical methods consume less energy; an electromagnetic dot peen machine, for example, has a maximum power consumption of 575 watts and average usage of less than 200 watts. Some mechanical machines, such as the standard dot peen, may require a supply of compressed air in addition to an electrical supply.

Cost factors

From a cost perspective, the first and most obvious factor is the **cost of the machine**. Mechanical marking machines have comparable prices; the choice should thus be made on the basis of technical considerations. Laser marking machine costs vary but are significantly more expensive than other technologies, even among entry-level models. The cost of the machine will also vary according to the number and type of optional features. Consequently, a cost comparison should be made on a case-by-case basis, in view of a state's desired technical specifications and features. This *Issue Brief* focuses on the average costs of entry-level models, which provide a useful scale of the price of each technology. In this context, the volume of firearms that a state intends to mark in the medium to long term plays a decisive role. If several thousand firearms are to be marked, for instance, the purchase of relatively high-cost laser machines would be easily justified.

Further factors concern **maintenance costs**, which vary widely with the technology in use, and **operating costs**. The latter include both energy and labour costs, which vary from state to state and from manufacturer to manufacturer; they depend on both the technology in use and the level of automation of the marking process. A more automated marking process implies higher energy consumption but lower human labour requirements, and vice versa.

The final cost factor to consider is the **training cost** (see below). The training usually takes no longer than one day for laser machines and one half-day for other machines. Companies usually provide basic training packages when the machine is delivered and installed. In this case, 'training' includes only the time and costs necessary to illustrate how the machine works. More in-depth training could be elaborated to include the time and costs necessary to become proficient in the use of the machine, given the intended usage, and to train future personnel; since these factors vary depending on needs, the costs of more advanced training should be evaluated on a case-by-case basis.

The following analysis compares different marking methods on the basis of the technical and cost factors outlined above. With the exception of speed, which is discussed separately, technical factors are grouped according to strengths and limitations (see Table 1).

Comparative analysis: technical factors

The main advantage of **stamping** consists of the recoverability of marks. The impact required to leave a clear and deep mark permanently alters the physical structure of the metal, thus allowing for future recoverability even in the case of external defacing.

To reach the depth required to ensure recoverability, however, the marked component is subject to very high pressure. To avoid causing structural damage, components are usually stamped separately during the manufacturing process, before the firearm is assembled and finished. While some forms of stamping are less aggressive, such as roll marking, they prove limited in their ability to reach some areas of an assembled weapon. For this reason, stamping is not the best solution for post-manufacture marking. To limit the potential damage to components other than the one being marked, highly specialized manual stamping may be applied; this practice has the advantage of being affordable and effective, but it has the critical limitation of being very slow and, consequently, efficient only with very limited volumes of firearms.

The main strengths of **dot peen or micro-percussion** include the low cost, the speed, the efficiency when installed in a production line, the flexibility afforded by the hand-held, battery-powered units, and the low stress on components. In fact, the dot peen process minimizes stress on the material because each dot is marked individually to create the alphanumeric characters. The technology was specifically developed to identify highly stressed aerospace engine components, such as turbine and fan blades, and the dot-by-dot, low-stress approach is widely used as the only acceptable permanent marking method for critical aerospace engine components.

As the mark is generated by an impact pin without material removal, it may be possible to recover a mark by analysing the material's structure. The same marking technology is used to mark vehicle identification numbers on vehicle frames and engines. These marks are known to be recoverable even following an abrasion process. Nevertheless, as the application of dot peen technology to firearms marking is a relatively recent development, the extent to which this method would allow recoverability of a defaced or altered mark on a small arm remains to be determined.

Figure 9 **Dot peen marking**

The typical features of dot peen marking are visible on this revolver. The numbers '2027' are created with a sequence of microdots, which yields a less defined and more discontinuous edge compared to the name 'TAURUS' on the barrel or the stamped '85' on the frame.
Photo courtesy of Royal Canadian Mounted Police, Canada

The relatively low quality of mark compared to other methods can certainly be considered among the main weaknesses of dot peen (see Figure 9). In addition, the marking process is very loud, especially when using the pneumatic version, and needs a dedicated room (and specific safety equipment for the worker). As in the case of mechanical engraving, the necessity to lock the component to be marked in the optimal position could cause issues during the marking of firearms that have already been assembled, or it could affect the costs by calling for specifically shaped locking systems.

An important asset of the **mechanical engraving or scribing** method consists of the quality of the mark, as compared to dot peen results, for example. Scribing produces well-defined, smooth engravings; in addition, the marking process is a quiet one. With the use of special locks, including rotational locking components, mechanical engraving could theoretically be used to apply marks on an assembled firearm. In addition, engraving is particularly precise and thus also often used for ornamental or aesthetic marks, though laser engraving would be more efficient for this purpose (see Figure 10).

The fact that the mark is not recoverable in case of alteration or defacing represents a major drawback of this technology. Moreover, when marking hard metals, the cutter, or the peen, needs to be checked often to maintain the quality of the mark; indeed, the blade of the cutter should be whetted after every 50 marks or so. For this reason, mechanical engraving is not recommended for installation in an automatic production line. In addition, as mentioned above, the component to be marked must be locked in the optimal position with the use of special locking devices. While not excluding the possibility of marking assembled firearms, this locking need is a limitation of mechanical engraving techniques.

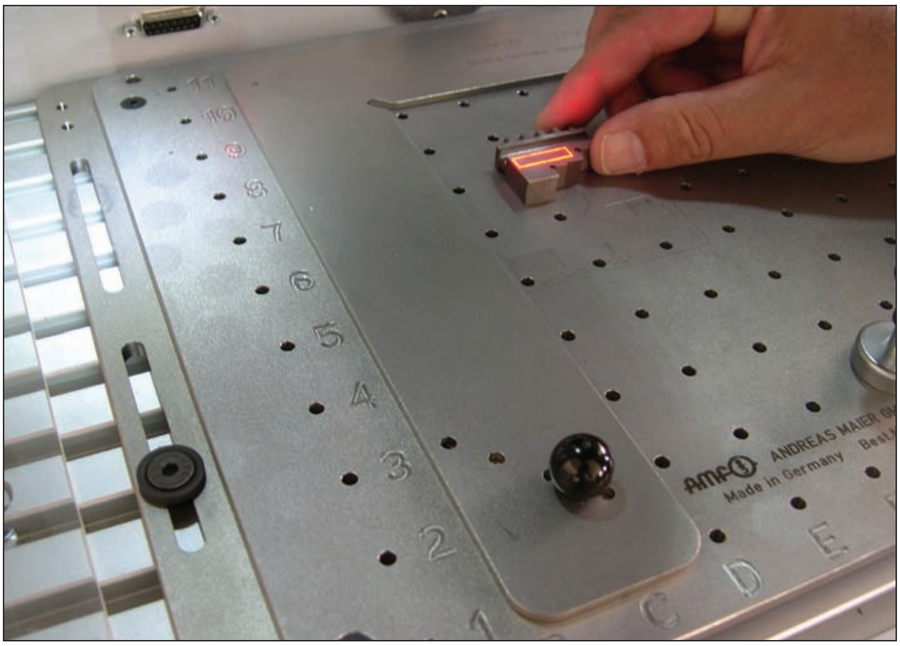
Laser engraving is increasingly the marking method of choice among arms producers. Among its numerous advantages, laser technology counts the possibility of marking efficiently on any metal or plastic without any sort of physical contact with the part to be marked, thereby minimizing the risk of damaging the firearm. Nevertheless, certain laser settings have been known to create 'micro-cracks' in the metallic structure. As a result, laser marking is not used for identification of critical aerospace engine components. While it is possible to overcome this problem with the use of special techniques, cross-section tests for micro-cracks should be carried out on sample materials when evaluating which laser settings to use in critical applications such as firearms marking.

Thanks to their extremely high precision and capacity to mark on small surfaces, lasers may be used to mark assembled firearms. Their application

Figure 10 **High-quality marks through mechanical engraving**

Mechanical engraving produces high-quality marks, the best achievable with mechanical methods. For this reason, it is usually used to create sophisticated logos or decorations, such as those on this special-edition Smith&Wesson revolver. Photos courtesy of Royal Canadian Mounted Police, Canada

Figure 11 **Preview of the marking area**



Laser machines allow for a preview of what the marking area will look like once selected engravings have been applied. This feature facilitates positioning and minimizes the risk of errors. Photo courtesy of GravoTech GmbH, Switzerland

is thus particularly recommended for post-manufacture marking, as they do not require the firearm to be disassembled to be marked efficiently. Laser machines can easily be integrated in production lines and offer a set of useful features that minimize the risk of error. For example, they usually allow for a preview of engravings on the marking area (see Figure 11); they also permit test runs without leaving any mark, which allows operators to visualize the 'engraving path' that the laser will follow on the marking area. Lasers are usually very durable: a YAG laser can operate for 15,000–20,000 hours, while a fibre laser can reach 100,000 hours of operation. The durability of a laser machine depends on usage, but considering that it takes less than five seconds to mark a serial number of 16–18 digits, it is possible to mark several thousand firearms within the laser's lifespan. Ultimately, the quality of the marking is the best available on the market.

As mentioned above, not all lasers are able to mark on all materials. The ability to mark depends on the wavelength that each material can absorb, and different lasers work with different wavelengths. Given that metals and plastics are most commonly used in modern arms production, diode-pumped YAG lasers should be considered the optimal choice.

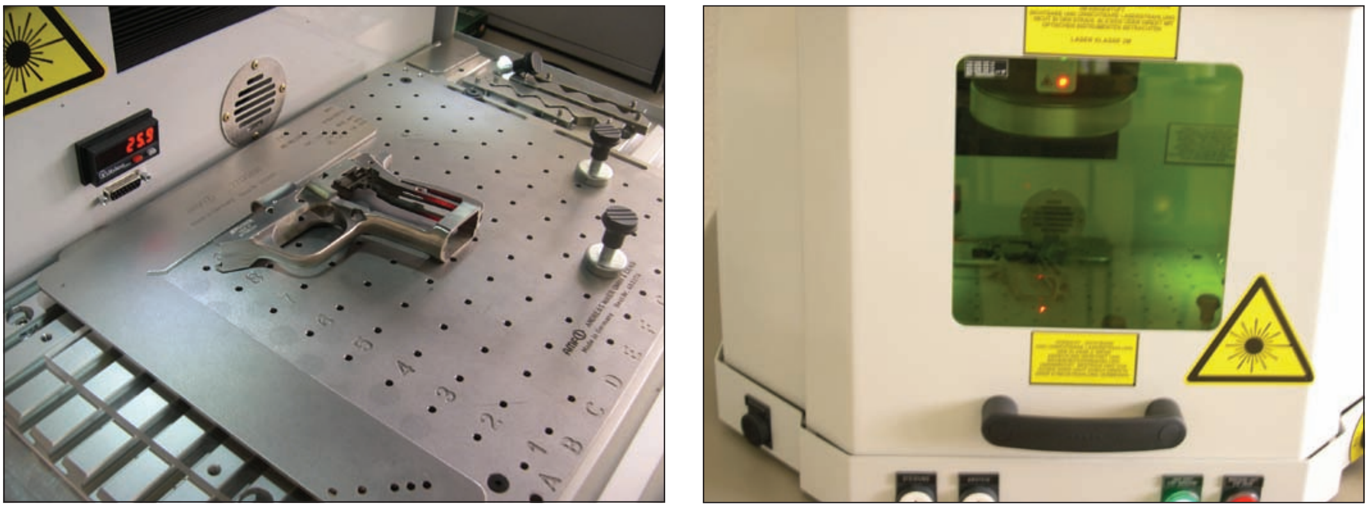
Another limitation is that laser machines need to operate either with the provided safety cabinet or, if the safety cabinet is not in use, in a dedicated room that is completely isolated from the outside and with the use of special protections for the operator. The presence of the safety cabinet determines the maximum dimensions of the object to mark. Consequently, marking assembled firearms is possible as long as they fit within the safety cabinet (see Figure 12).[15]

Comparative analysis: speed

As mentioned above, the marking speed is distinct from the marking rate. The marking speed of modern technologies is very fast; while some methods are faster than others, even the slower speeds can be measured in seconds (see Table 2). It is thus important to recall that the number of firearms that can be marked daily and annually depends essentially on factors such as the number of marks that each firearm receives, the efficiency of the production line (in case of marking machines installed in an automated system), and the quality and quantity of the labour force (in case marking is conducted outside a production line).

The fastest method is the laser, closely followed by dot peen. The slowest appears to be mechanical engraving or scribing. A YAG laser machine, for example, can mark a 20-character-long string[16] in fewer than five seconds; a

Figure 12 **Laser machine safety cabinet**



A standard laser machine can easily accommodate handguns and machine guns inside the safety cabinet. For larger arms, the laser machine may have to operate without the safety cabinet, requiring additional safety measures. Photos courtesy of GravoTech GmbH, Switzerland

Table 1 **Strengths and limitations of marking methods**

	Strengths	Limitations
Stamping	■ Recoverability of the mark (highest probability among marking methods). ■ Low price.	■ Possible issues in marking completely assembled firearms; not recommended for post-manufacture marking. ■ Does not work on plastics.
Dot peen or micro-percussion	■ High speed. ■ Low price. ■ Low stress on components.	■ Low definition of the mark. ■ Very noisy process. ■ Not optimal on plastics. ■ Need to lock the object to mark.
Mechanical engraving: scribing	■ High quality of the mark. ■ Quiet process.	■ Relatively low speed. ■ Need to lock the object to mark. ■ Frequent maintenance of the cutter to ensure the quality of the mark. ■ Not optimal on plastics. ■ Marks are not recoverable if altered.
Laser engraving	■ High speed. ■ High quality of the mark. ■ Marks both metals and plastics. ■ Does not require locking systems. ■ High automation capacities. ■ No physical contact with the object during the marking process and resulting possibility of marking assembled firearms. ■ High precision even on extremely small surfaces.	■ High price. ■ Marks are not recoverable if altered. ■ Special safety requirements: if using the safety cabinet, its dimensions limit the size of the object that can be marked; if not using the cabinet, additional safety measures should be taken to protect the operator and isolate the room.

Table 2 **Speed comparison using a 20-digit alphanumeric code marked on a metal plate**

	Speed
Dot peen or micro-percussion	7-8 seconds
Mechanical engraving: scribing	16 seconds
Laser engraving	4 seconds

Table 3 **Price comparison of entry-level models**

	Price range (USD)
Stamping	5,500-6,800
Dot peen or micro-percussion	6,800-9,000
Mechanical engraving: scribing	16,000-19,000
Laser engraving	41,000-48,000

dot peen machine can mark the same string in seven to eight seconds; and a scribing machine takes about 16 seconds. These values refer to a test conducted on a stainless steel plate.

The generation of serial numbers and the data registration and record-keeping are two factors that may influence both the speed and the cost of marking systems. In fact, these steps can be easily undertaken by the same computer that controls the marking machine, as long as the correct software is purchased and installed. Given that the same software is usually compatible with different marking machines, serial number generation and data registration would not add any delay to the marking process and could basically be considered a constant, equal feature among the machines. This applies to micro-percussion, mechanical, and laser engraving. In the case of stamping, if the generation of a consecutive code cannot be controlled through a computer, then the serial number increases automatically through a mechanical action similar to an automobile's mechanical odometer.

Comparative analysis: costs factors[17]

Independently from the marking technology considered, costs can vary widely depending on the models, accessories, and software that are purchased. The majority of companies offer upgrade packages that increase both hardware and software performances to meet all needs. While it is possible to compare price ranges for entry-level models (see Table 3), it is important to note that an entry-level laser machine already comes with many features and capacities that other technologies do not offer (or offer as upgrades).

Laser marking machines are by far the most expensive, but the cost is offset by the advantages that this technology offers as compared to other mechanical systems. The price range of an entry-level laser machine is EUR 30,000–35,000 (USD 41,000–48,000), with advanced models selling for up to EUR 50,000 (USD 68,000). Nevertheless, studies show that in case of mass production of several tens of thousands of firearms per year, manufacturers can reduce marking costs to USD 1 and less per unit within short periods of time (Berkol, 2004a). Thus, depending on the circumstances, the cost per unit marked would be relatively small even with the use of laser technology. The mechanical engraving or scribing machines start at about EUR 12,000–14,000 (USD 16,000–19,000). This solution works well when the quality of the mark is a priority while speed is not an asset. Dot peen or micro-percussion machines have a price range of EUR 5,000–6,500 (USD 6,800–9,000) for an entry-level model and can reach EUR 12,000 (USD 16,000) for more advanced models with, for example, special locking systems and software personalization for specific data entry needs. If the look of the mark is not a priority, but recoverability is required, the solution is the most cost-effective, user-friendly, and rapid machine (in terms of marking speed). Approximately the same price range applies to stamping machines that would be recommended for marking metal components during the manufacturing process, as they guarantee the highest probability of recoverability (about 50 per cent) of the mark.

On-site basic training packages that teach operators how to use the machines are available once the machines have been delivered and installed. The average cost of training packages is EUR 400 (USD 550) for mechanical marking systems and EUR 700 (USD 950) for laser machines.

Based on responses to the questionnaire, maintenance-related costs can vary widely and are related to the type and quantity of marks applied to each firearm. On average, maintenance costs within the first five years can be estimated at around EUR 1,000 (USD 1,400) for both mechanical and laser systems, while within ten years costs would increase to EUR 3,500 (USD 4,800) for mechanical marking systems and EUR 5,000–8,000 (USD 6,800–11,000) for laser marking systems.

Conclusion

Marking of small arms and light weapons is a fundamental element of any efficient and effective record-keeping and tracing mechanism. It is regulated by several instruments at the international, regional, and sub-regional levels, as well as by national legislation. Focusing on the UN Firearms Protocol and the International Tracing Instrument, this *Issue Brief* has noted that the choice of the marking method is a national prerogative. To assist states in making the right choice to meet their specific marking needs, this study offers an overview of the most common marking methods, describing their approaches and comparing their strengths and limitations on the basis of both technical and cost factors.

This analysis reveals that it is not possible to find a one-method-fits-all solution to satisfy all marking needs and meet all marking requirements as expressed in the Firearms Protocol and the ITI. The optimal solution involves a combination of different methods. If this approach is not possible, a state should consider the following factors before selecting a marking method:

- the available budget;
- the ratio between imported and domestically produced firearms (to determine the relevance of the ability to mark assembled firearms);
- the quantities of firearms to be marked and the time available to mark them (to determine whether a highly automated line is required);
- the type of firearms and their material (to determine the most effective method);
- the reliability of the energy supply and the need to use the same machines in different locations (to consider the importance of machines that can operate using battery packs or that can be easily relocated); and
- the relevance of recoverability of altered marks.

The choice of the marking method remains a national prerogative and all methods reviewed can fulfil national needs to a certain extent. Nevertheless, some methods and techniques are better suited than others for certain contexts. Given that each small arm should bear at least one recoverable mark to allow for tracing in case of defacement, it should ideally feature at least one stamped or 'dot-peened' mark. In the absence of initial budget constraints, the acquisition of laser machines is generally recommended since lasers offer reliability, speed, and useful capacities, not only for states with extensive national production, but also for those that import significant quantities (thousands) of firearms per year for state or private use.

If budget constraints do not allow for the acquisition of laser machines, or if a state imports or produces only limited quantities of firearms per year, dot peen marking is recommended. This technology is fast and simple, requiring a low initial investment and, not unlike stamping methods, allowing for a certain probability of recovering altered or obliterated marks. Dot peen would also be recommended for regional or sub-regional usage if states have access to the machines on a rotational basis, requiring the machines to be frequently relocated.

Finally, states whose production or import is mainly oriented towards the commercial sector and private ownership might wish to consider the use of mechanical engraving techniques as a low-budget alternative to laser machines. The quality of mechanically engraved marks is certainly higher than what can be obtained with dot peen machines.

Before any purchase, states are encouraged to ask marking machine suppliers if they offer tests runs and to consult technology suppliers to identify the best solution for the required needs and the available budget. ■

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Endnotes

1 This *Issue Brief* uses the term 'small arms' to refer to 'small arms and light weapons'.

2 For more information, see Persi Paoli (2009).

3 The Firearms Protocol entered into force on 3 June 2005.

4 The companies that returned the questionnaire were Gravograph, Pryor, and Simet. The information collected from the questionnaires was complemented through analysis of brochures and catalogues of the following companies: Marking Methods, Inc. (n.d.), Numberall (n.d.), and Schmidt Marking Systems (n.d.).

5 These criteria are drawn from the forthcoming Firearms Protocol Guidelines; author correspondence with Ilhan Berkol, November 2010.
6 This section draws on information provided in Numberall (n.d.) as well as brochures and a catalogue of Schmidt Marking Systems (n.d.).
7 Author correspondence with Ilhan Berkol, 1 November 2010.
8 This section draws on information in Gravograph's questionnaire, Marking Methods, Inc. (n.d.), Pryor's questionnaire, Simet's questionnaire, and on Schmidt Marking Systems' website.
9 In the Rockwell scale, which is used to characterize a material's indentation hardness, 62 HRC (hot rolled coil) corresponds to 'very hard steel'.
10 This information was obtained from questionnaires sent to and filled out by different suppliers of dot peen technology. The value of 62 HRC appears to be the standard for this kind of technology as all respondents reported the same information.
11 PSI (pound per square inch) and bar are measures of pressure.
12 Author interview with Gravograph business manager and on-site visit, Murten, Switzerland, 3 August 2010; Schmidt Marking Systems (n.d.).
13 Author interview with Gravograph business manager and on-site visit, Murten, Switzerland, 3 August 2010; Gravograph questionnaire; Pryor questionnaire; Simet questionnaire; Schmidt Marking Systems (n.d.).
14 Author correspondence with Ilhan Berkol, 1 November 2010.
15 Generally, pistols and machine guns may be marked in standard safety cabinets; customized cabinets may be designed to accommodate most common small arms and light weapons.
16 The 20 alphanumeric characters were used to simulate a code containing the information requested (and part of the information suggested) by the International Tracing Instrument and the UN Firearms Protocol: country and year of manufacture, unique serial number, weapon type, country and year of import, and calibre.
17 The estimated costs in this section represent an average of those provided by different suppliers in their questionnaires.

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