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Information technology – Automatic identification and data capture techniques – Guidelines for Direct Part Marking (DPM)

Technologie de l'information - techniques automatiques de saisie d'identification et de données - directives pour l'inscription directe de partie (DPM)

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Contents

Foreword

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The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

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ISO/IEC Technical Report 24720, Information Technology, Automatic identification and data capture techniques – Guidelines for direct part marking (DPM), was prepared by ISO/IEC JTC 1/SC 31/WG 3 Automatic Identification and Data Capture Techniques, Working Group on Conformance

Introduction

Identification technologies have become an essential part of managing the life cycle of manufactured goods, from their "birth" to the scrap recovery process. The need to identify parts easily and correctly is critical for controlling and error proofing the assembly process, tracking work in process and building traceability. Fast and accurate identification methods are also important after the product leaves the plant.

Industries worldwide rely heavily on the use of various marking methods. Because many of these methods were originally designed to apply human-readable marks, they frequently are not appropriate for applying high-density machine-readable symbols.

With the widespread implementation of machine-readable marking, the parts identification industry began to refine existing marking methods. Dot peen machines replaced manual metal stamping and embossing techniques. Desktop publishing systems were developed for the production of stencils. Ink jet machines were built to replace rubber stamps. Laser marking systems were designed to replace electric-arc etching and hot stamping processes.

One of the most popular methods of identifying a part is with a two-dimensional (2D) symbol applied directly onto the surface of parts. Compared with printing and applying labels, marking directly on parts is more secure, more cost-effective and easier to automate. When direct marked, two-dimensional symbols are able to withstand harsh manufacturing processes and abuse in the field.

Several direct part marking (DPM) technologies are addressed in this report, such as ink jet printing, laser etch, chemical etch and dot peen marking. Ink jet printing is one of the least expensive of the marking methods. Laser etch is popular because of its ability to produce small, precise marks, and the ability of lasers to mark symbols on many materials, from hardened steel to soft plastic. Lasers can also access small, tight locations. Dot peen marking is usually reserved for marking metal. This marking method uses a stylus to indent the surface of the part to create the desired mark. Chemical etch marking is often used to mark printed circuit boards (PCBs), since it is already part of the normal manufacturing process.

For the purposes of this Technical Report, direct part marking (DPM) is considered a generic term referring to methods of applying a permanent mark directly onto a surface of an item. There are two generic direct marking techniques described in this report, intrusive and non-intrusive.

Intrusive (or subtractive) marking methods alter the surface of a part and are considered controlled defects. Of the intrusive marking methods, this Technical Report addresses dot peen and direct laser marking, and briefly describes other technologies.

Non-intrusive marking methods, also known as additive markings, are produced as part of the manufacturing process or by adding a layer of media to the surface of a part. Of the non-intrusive methods, this report addresses ink jet marking and other technologies.

Information Technology – Automatic identification and data capture techniques – Guidelines for Direct Part Marking (DPM)

1 Scope

This Technical Report describes several methods for applying permanent machine-readable symbols to items – including components, parts and products – using the Direct Part Marking (DPM) methods outlined in the report. This document describes marking methods, marking surface preparation, marking location, protective coatings and other parameters that contribute to the production of quality symbols, but does not specify the information to be encoded.

2 Terms and definitions

For the purposes of this document, the terms and definitions contained in ISO/IEC 19762, Parts 1 and 2, and the following shall apply.

2.1
intrusive marking
marking method designed to alter a surface to form a human or machine-readable symbol

NOTE: This marking category includes, but is not limited to, methods that abrade, burn, corrode, cut, deform, dissolve, etch, melt, oxidize or vaporize a surface. Intrusive marking methods include stamping, laser etching, chemical etching, dot peen and micro-sandblast.

2.2
non-intrusive marking
marking method designed to add material to a surface to form a human or machine-readable symbol

NOTE: Non-intrusive marking methods include ink jet, some forms of laser bonding, liquid metal jet, screen process, stencil and thin film deposition

2.3
permanent marking
intrusive or non-intrusive markings designed to remain legible for at least the normal service life of an item, subject to operating or usage conditions

3 Symbols (and abbreviated terms)

EDM Electrical Discharge Machine or Machining

LISI Laser Induced Surface Improvement

4 Overview of DPM

4.1 DPM methods

For the purposes of this Guideline, Direct Part Marking (DPM) is considered a generic term referring to methods of applying a mark directly onto the surface of an item. There are two techniques for applying a mark, intrusive and non-intrusive.

4.1.1 Intrusive

Intrusive (also known as "subtractive") marking methods physically alter the surface or structure of a part (abrade, cut, burn, vaporize, bond etc.) and the marks are considered controlled defects. It is highly recommended that all item identification manufacturing methods should be controlled by appropriate manufacturing instructions, approved by Engineering Design and that testing of materials should be conducted before an intrusive mark is applied to an item. Typical intrusive marking methods include:

- Abrasive blast
- Direct laser marking
- Dot peen
- Electro-chemical marking
- Engraving/milling
- Fabric embroidery/weaving
- Stamping

Of these intrusive methods, this report addresses some forms of direct laser and dot peen marking, and briefly refers to other marking technologies.

4.1.2 Non-intrusive

Non-intrusive (also known as "additive") markings are produced as part of the manufacturing process or by adding a layer of marking media to the surface using methods that have no adverse effect on material properties. These methods include:

- Automated adhesive dispensing
- Cast, forge, and mold
- Ink jet
- Laser bonding (limited forms)
- Laser engineered net shaping (LENS)
- Liquid metal jet
- Screen printing
- Stencil (not when used by Electro Chemical Etch marking methods)

Of the non-intrusive marking methods, this report addresses ink jet marking in depth and other technologies only briefly.

4.2 Reasons for utilizing DPM

- If traceability is required after the product is separated from its temporary identification.
- When the part cannot be marked with labels or tags.
- If the part will be subjected to environmental conditions that preclude the use of add-on identification methods.
- When the use of DPM methods is more cost efficient than applying individual item labels.
- When identification is required for the anticipated life cycle of the part, as defined by the manufacturer.

5 Marking method selection

The overall quality of any form of part identification depends on several characteristics. These characteristics can include the material being marked, the shape or geometry of the marking surface and any surface coatings or discoloration that affects decode or readability of the mark.

It is, therefore, important to review all of these factors before selecting a marking method. If a component definition instructs a specific marking method for that component, that method should always be selected.

Table 1 below provides a cross-reference of marking methods and commonly marked materials and provides guidance for selecting marking methods appropriate for the listed materials.

Table 1 — Marking Method Selection

MATERIAL TO BE MARKED / MARKING PROCESS	METALLICS								NON-METALLICS								
	Aluminum	Anodized	Beryllium	Carbon Steel	Copper	Brass	Magnesium	Titanium	Ceramics	Glass	Cloth	Painted	Plastics	Rubber	Teflon	Wood	Epoxy-glass
Abrasive Blast	•	•		•	•	•	•	•	•			•	•		•		
Adhesive Dispensing	•	•	•	•	•	•	•	•	•	•	1	•	•	•		•	
Cast, Forge Or Mold	•	•	•	•	•	•	•	•	•				•	•			
Dot Peen	•			1	•	•		•				1	1				
Electro-Chemical Coloring	•	•	•	•	•	•	•	•									
Electro-Chemical Etching	•	•	•	•	•	•	•	•									
Embroidery											•						
Engraving/Milling	•	•		•	•	•						1	•			•	
Ink Jet	•	•	•	•	•	•	•	•	•	•	1	•	•	•			•
Laser Bonding	•		•	•		•	•	•	•	•			•				
Laser - Short Wave Lengths	•	1	•	•	•		•	•	•	•		1	•	•	•	•	•
Laser Visible Wave Lengths	1	1		•	1	•						1	•				•
Laser – Long Wave Lengths		1							•	•		1				•	•
LENS	•	1	•	•	•	•	•	•									
LISI	•	2		•	•		2	2									
Silk Screen	•	•	•	•	•	•	•	•	•	•		•	•	•		•	•
Stencil	•	•	•	•	•	•	•	•	•	•		•	•	•		•	
Thin Film Deposition	•	•	•	•	•	•	•	•	•	•			•	•			

•. = Acceptable marking process for this material if marking location and marking parameters are agreed
1 = Additional technical input required from design authority and equipment / material suppliers
2 = Marking method under development for this material
Blank space = Marking method not recommended for this material0

The physical size of the item to be marked is also a factor in DPM. When available marking space falls below an accepted size, it may be necessary to review the data string and/or select a different marking method that is acceptable to the component definition and/or operating condition. Table 2 below provides additional guidance in the selection of an appropriate marking process.

Table 2: Symbol sizes by marking process

Symbol Size Categories	Marking Process	Typical Data Cell Size (Assenting Order)	Data Format		
			P/N, EI and S/N - Typically 29 Characters (24x24 matrix)	EI and S/N - Typically 13 Characters (18x18 Matrix)	S/N Only - Typically 7 Characters (12x12 Matrix)
Micro - <0.008-inch (0,203 mm) data cells	Laser Marking – Short Wave Length (Excimer)	0.0002 inch (0,005 mm)	0.004 inch (0,102 mm)	0.003 inch (0,076 mm)	0.002 inch (0,051 mm)
Typical - 0.08 inch *(2,032 mm) to 0.034* (0,864 mm) data cells	LaserShot Peening	0.009 inch (0,238 mm)	0.216 inch (5,486 mm)	0.162 inch (4,115 mm)	0.108 inch (2,743 mm)
	Stencil(Photo-Process)	*0.010 inch (0,254 mm)*	*0.240 inch (6,096 mm)*	*0.180 inch (4,572 mm)*	*0.120 inch (3,048 mm)*
	Laser Bonding	0.010 inch (0,254 mm)	0.240 inch (6,096 mm)	0.180 inch (4,572 mm)	0.120 inch (3,048 mm)
	Laser Marking	0.010 inch (0,254 mm)	0.240 inch (6,096 mm)	0.180 inch (4,572 mm)	0.120 inch (3,048 mm)
	Stencil(Mechanical Cut)	*0.020 inch (0,508 mm)	0.480 inch (12,192 mm)	0.360 inch (9,144 mm)	0.240 inch (6,096 mm)
	Adhesive Dispensing	0.020 inch (0,508 mm)	0.480 inch (12,192 mm)	0.360 inch (9,144 mm)	0.240 inch (6,096 mm)
	Dot Peen*	*0.022 inch (0,558 mm)	0.528 Inch (13,411 mm)	0.396 inch (10,058 mm)	0.264 inch (6,706 mm)
	LISI	0.024 inch (0,610 mm)	0.576 inch (14,630 mm)	0.432 inch (10,973 mm)	0.288 inch (7,315 mm)
	Stencil (Laser Cut)	*0.024 inch (0,610 mm)	0.580 inch (14,732 mm)	0.440 inch (11,176 mm)	0.288 inch (7,315 mm)
	Abrasive Blast	0.025 inch (0,635 mm)	0.600 inch (15,240 mm)	0.450 inch (11,430 mm)	0.300 inch (7,620 mm)
	Ink Jet	0.030 inch (0,762 mm)	0.720 inch (18,288 mm)	0.540 inch (13,716 mm)	0.360 inch (9,144 mm)
Macro – ≥0.035 inch (0,889 mm)	Engraving/Milling	*0.040 inch (1,016 mm)	0.960 inch (24,384 mm)	0.720 inch (18,288 mm)	0.480 inch (12,192 mm)
	Fabric Weaving	0.040 inch (1,016 mm)	0.960 inch (24,384 mm)	0.720 inch (18,288 mm)	0.480 inch (12,192 mm)
	LENS	0.040 inch (1,016 mm)	0.960 inch (24,384 mm)	0.720 inch (18,288 mm)	0.480 inch (12,192 mm)
	Fabric Embroidery	0.045 inch (1,143 mm)	1.080 inch (27,432 mm)	0.810 inch (20,574 mm)	0.540 inch (13,716 mm)
	Cast, Mold & Forge	0.060 inch (1,524 mm)	1.440 inch (36,576 mm)	1.080 inch (27,432 mm)	0.720 inch (18,288 mm)

Note: Table courtesy NASA-STD-6002B and is reproduced here verbatim.

* Includes spacing between data cells

Note: See Annex A and Annex B for descriptions of marking methods.

Note: Technology developments in the marking processes are continuously improving the resolution that is achievable using that process. It should be noted, however, that some equipment might achieve better or worse results than those indicated in Table 2.

6 Marking methods

For most two-dimensional symbols to be read successfully, the decoding software requires a quiet zone (a clear space of a specified minimum width) around the entire periphery of the symbol. In addition to this requirement, manufacturers often impose additional marking location restrictions within their drawings and/or specifications. This report recommends that care be exercised when marking in the following locations:

- Highly polished curved surfaces
- In direct air streams (e.g., leading edge of wings, helicopter rotors, exposed portions of turbine blades, etc.)
- Near high heat sources
- Sealing surfaces
- Wearing surfaces

In addition, the effects of adjacent structures on the imager's illumination source must be considered. Fixed station imagers with movable light sources can usually be configured to illuminate symbols placed in recesses or adjacent to protruding structures. These structures, however, can pose a challenge for hand-held imagers with fixed positioned light sources. It is therefore advisable to read marked parts in places that provide maximum access to lighting. (See Grading considerations in section 12.2)

7 Cleaning

Cleaning processes used for removing soil and contamination from parts to be marked are varied, and their effectiveness depends on the requirements of the specific application. The appropriate cleaning method should be selected according to the needs of the specific application. In selecting a cleaning process, many factors must be considered, including:

- The nature of the soil to be removed
- Substrate to be cleaned (e.g. ferrous, non-ferrous, etc.)
- Importance of the condition of the surface to the end use of the part
- Degree of cleanliness required
- Capabilities of the available facilities
- *Environmental impact of the cleaning process*
- Cost
- Total surface area to be cleaned
- Effects of previous processes
- Rust inhibition requirements
- Material handling factors
- Surface requirements of subsequent operations, such as phosphate conversion coating, painting, or plating

8 Marking surface preparation

8.1 Assessment

Prior to marking, operators are required to determine if additional surface preparation is required. This assessment should address:

- *Surface finishes that cause excessive amounts of shadow and/or specular reflection*
- Surfaces that do not provide the necessary contrast for decoding
- Safety critical parts that cannot be marked using intrusive marking methods
- Materials that are not suitable for marking with the user's preferred marking method

The most common methods utilized to prepare surfaces for marking are additives and coatings.

8.1.1 Additives

To assist readability of the mark, specialized additives can be mixed with metal alloys and thermoplastic formulations to enhance and optimize marking contrast. These additives increase the ability of the material to absorb or reflect specific wavelengths of light, but do not generally affect overall material performance.

8.1.2 Coatings

In a limited number of applications, it is possible for coatings to be used to modify the surface of a part to improve readability and/or to provide corrosion protection. Coatings can be utilized to aid part marking by:

- Smoothing rough surfaces to reduce the effects of shadowing
- Providing increased contrast for surfaces of parts that inherently provide insufficient contrast
- Dulling highly polished surfaces to reduce specular reflection
- Providing a surface that can be removed with intrusive markings to expose a substrate of contrasting color
- Serving as a medium for marking using a stencil as a mask

Following are the processes most commonly used to coat surfaces prior to marking:

8.1.3 Dip, Barrier and Conversion Coating.

"Dip, barrier, and chemical conversion coating" is a term that encompasses an entire family of processes used to prevent corrosion. The appropriate method should be selected according to the needs of the application.

8.1.4 Laser induced surface improvement (LISI)

LISI is a laser process utilized to impart stainless properties to carbon steel. The process can also be used to improve the wear characteristics of aluminum surfaces. LISI treated surfaces can be discolored or removed to create a symbol.

8.1.5 Plating and electroplating

Plating and electroplating processes are divided into two categories: Electro-deposition and Non-electrolytic deposition processes. These techniques should be selected according to the needs of the application.

8.1.6 Vacuum controlled-atmosphere coating and surface modification processes

"Vacuum and controlled-atmosphere coatings" is a general term that encompasses thermal spray, chemical vapor deposition, physical deposition, diffusion, and pulsed-laser deposition processes. This family of processes is used to modify surfaces by depositing material onto a surface that is subsequently marked. Vacuum controlled-atmosphere coatings and surface modification processes are frequently used in conjunction with stencil marking.

8.1.7 Machining

Because extremely rough surfaces can produce shadows that adversely affect reader performance, machining is often performed to smooth the surface roughness of parts to be marked. A number of machining methods are commonly used for surface smoothing, and the appropriate method should be selected according to the needs of the application.

8.2 Protective coatings

Metals are often unstable and susceptible to degradation by corrosion from hostile environments. Protective coatings are often applied to marked surfaces to protect the marking and prevent corrosion. It should be noted, however, that surface coatings might adversely affect the performance of some types of mark.

Intrusive markings applied to a surface that has been previously coated should be re-coated to prevent corrosion in or around the area of the marking.

Note that a protective coating may alter the specular characteristics of the part and the optical quality should be measured in its final configuration. Typical coatings include, but are not limited to, the following:

8.2.1 Clear anodize

Anodizing is an electrolytic oxidation process in which the surface of the metal is converted to a coating having desirable protective, decorative, or functional properties.

8.2.2 Lacquer

Lacquer is a coating formulation based on thermoplastic film-forming material dissolved in an organic solvent. The coating dries primarily by evaporation of the solvent.

8.2.3 Thin film deposition

Thin film deposition is a technique for depositing a thin film of material onto a substrate or onto previously deposited layers of material. This process may be used to aid in adhesion or substrate cleaning or to smooth surface roughness prior to marking.

9 Human readable marking

Whenever possible, the data encoded in the symbol should be marked in human readable form for use when code-reading devices are not available or when a symbol is unreadable. Human readable characters can be applied using the marking methods defined in this Technical Report, so whenever practical, the human readable and symbol marking should be applied simultaneously and by the same method. Human readable markings, when used, should be applied in close proximity to the two-dimensional symbols, as demonstrated in Figure 1 below.

Figure 1: Human readable marking in close proximity to two-dimensional symbol

10 Symbol quality

The quality of direct marking is affected several factors, including the material to be marked, the selected marking method and component operating conditions.

See Table 1 of this report for guidance in matching the marking method and selected materials appropriately.

Methodologies for measuring the print quality of machine-readable marks using DPM procedures are not available.

11 Reading and grading DPM symbols

The ultimate purpose of DPM that produces a machine-readable symbol is for a scanner to be able to read the symbol. Historically, marks were either scanned in a fixtured environment custom-tailored for each mark or *not scanned at all. Application standards generally specified marks in terms of mechanical and dimensional* properties. "Marks," meaning dimensionally accurate patterns which change a substrate using methods described in this document, become "symbols", meaning the light reflecting from the combination of the mark and the substrate, intended to be read by a scanner in an application. Depending on many factors, sometimes a great "mark" is not a good "symbol".

As more actual scanning became the norm, many marks that were mechanically correct failed to scan in application environments. Good marks may not scan if the background has either too much texture or not enough, if inks are the wrong color or any number of other marking combinations occurs such that the lighting and scanning configuration of the application do not match the optical properties of the symbol. On the other hand, in some cases, marks that scanned easily were not deemed acceptable from a dimensional standpoint. This lack of scanning predictability lead to considerable technological development in the area of camera based symbol quality evaluation, sometimes called "verification" (see Verification Section 13).

As of the writing of this document, there is a mix of mechanical and optical-based quality measurement methods that are specified by various industries. It is important for the engineer who specifies the symbol and for the manufacturer who creates the symbol to make sure that they are designing and marking to the latest version of the industry application specification that covers the eventual scanning environment of the symbol. For this reason it is only possible to produce a machine-readable symbol to meet physical geometry definitions and not to the requirements of any particular imaging device. It is important to stress, given the correct imaging device, that mark *quality* is the consideration and *readability* is the output.

Reading considerations for the marking methods included in this report are outlined in the guidelines provided in Annex A and Annex B.

12 Verification

12.1 General

In order to assure that the marking equipment applies a machine-readable symbol that will meet the requirements for achieving the highest read rates, it is highly recommended that a form of acceptance be carried out for mark quality acceptance. Not only is this an important factor for downstream reading performance, but it reduces costs associated with rejected parts due to unreadable codes. If a part loses its identity due to the poor quality of the mark, it cannot be used. A verification system will immediately detect a problem, which could be due to poor fixing of the part, damage to the machine such as a broken stylus tip on a dot peen machine or incorrect settings during part changeover.

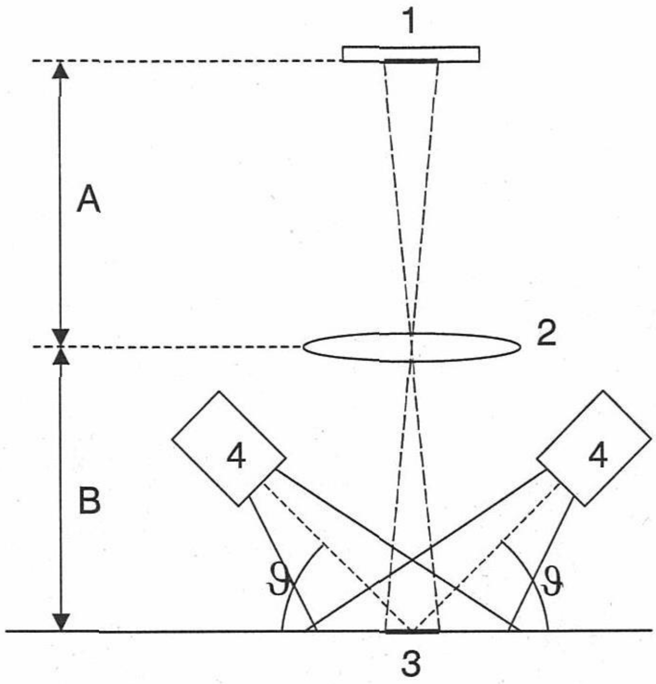
12.2 Configuration

A symbol verifier is a system that includes lighting, optics, camera, symbol verification software, and calibration. Due to the various types of materials, surface conditions and marks a verification system for DPM symbols, based on the scanning requirements, needs to be defined for each application.

Lighting and optics should be configured to ensure an optimal image formation that delivers good contrast with adequate resolution. In order to have meaningful verification results, it is recommended that the resolution at the verification station be at least twice that of the reading station resolution. This can be accomplished with either higher magnification optics or an imaging device in which the resolution is twice that of the reading devices to be used. Another important step in generating consistent and meaningful results is consistent part presentation.

12.3 Possible equipment setup

As an example, the arrangement described here and illustrated in Figure 2 and Figure 3 below may be found suitable for many open applications. A standard monochrome video camera images the test symbol directly on axis with its centre and normal to its plane. The lens used is appropriate to frame the entire symbol (including any required quiet zones) in good focus, and with a sufficiently small field of view to minimize optical distortions whilst also ensuring that the effective resolution obtained is appropriate to the *X* dimension of the symbol. Light illumination uniformly floods the symbol area with a 45° angle of incidence. Test images are captured with 8-bit grey-scale digitization using standard frame capture equipment, and the grey-scale is calibrated using targets of known diffuse reflectance.



1 – Light sensing element
2 – Lens providing 1:1 magnification (measurement A = measurement B)
3 – Inspection area
4 – Light sources
ϑ - Angle of incidence of light relative to plane of symbol (default = 45°, optionally 30° or 90° diffuse)

Figure 2: Reference optical arrangement, side view

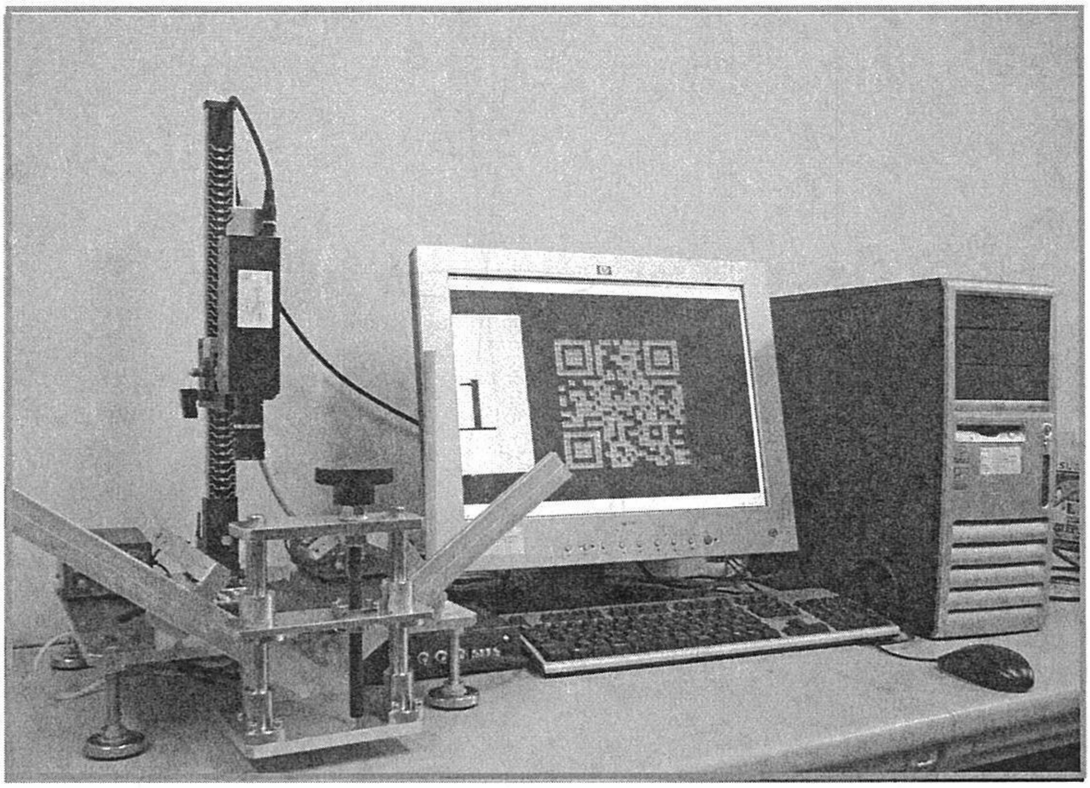


Figure 3: Example of a quality testing setup. Marking quality verifiers are available from multiple sources.

13 Imagers for direct part marking applications

13.1 General description

There are three types of imager (decoder) products for DPM in general use today: fixed-mount imagers, presentation imagers, and hand-held imagers. Imaging systems include:

- a means of illuminating the symbol
- optics for focusing an image of the symbol on a detector
- software for processing the image and decoding the symbol
- an output device, either a display or interface to a data processing system

13.2 Fixed-mount imagers

Fixed-mount imagers are used in reading symbols on parts that are handled and moved automatically by conveyor, indexer, or robot. Typically, fully automated manufacturing lines such as those found in electronics and automotive manufacturing use fixed-mount imagers.

In operation, this type of imager (Figure 4) is mounted in a fixed position where the symbol can be repeatedly placed in front of the imager in either continuous or indexed motion. The imager is signaled that the part is ready for reading by a "trigger". This trigger event is performed by an external sensor that detects the presence of the part or by an encoder that knows the position of the part at all times and can signal the imager to decode.

Fixed-mount imagers are configured with either an integrated light source or with an external light source as required by the application. Advantages of a fixed-mount imager without an integrated light source are that it can be mounted at varied distances from the part and supplemental lighting can be selected to meet the application needs.

Figure 4: Example of a fixed-mount imager

13.3 Presentation imager

Similar to a fixed-mount imager, a presentation imager (Figure 5) is mounted in a fixed position; however, it operates in a continuous reading cycle, automatically performing the decoding task once the operator places the part bearing the symbol in front of the imager. Presentation imager can provide a very fast way of reading *symbols in areas where parts are handled manually. A presentation imager can be implemented with either a* fixed-mount or a hand-held imager. Using a hand-held imager in presentation mode provides the opportunity for multi-use, as one can also remove the imager from its stand and bring it to the part.

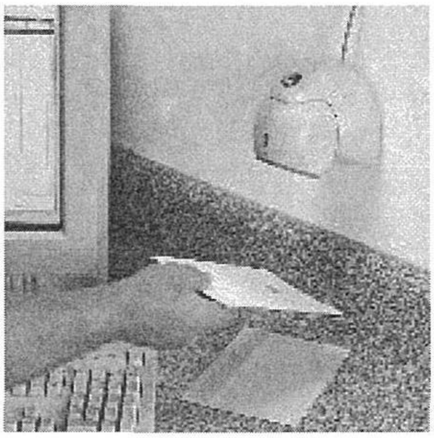


Figure 5: Example of a presentation imager

13.4 Hand-held imager

Hand-held imagers (Figure 6 below) are typically used in applications where the symbol size is fixed and the part is too large or it is difficult to bring the part to the imagers. Variable or multiple lens imagers are used in applications in which two-dimensional symbols of more than one size are to be read.

Hand-held imagers are preferred in those environments where part handling is not automated or parts vary greatly in size. Handhelds are used in job shop manufacturing operations, QC test stations, and in logistics areas. Hand-held imagers come in either tethered (with a cord), or cordless configurations. Tethered hand-held imagers have the advantage of not being displaced from the application location. Cordless operation is required in cases where part size or position is a practical limitation to cord length.

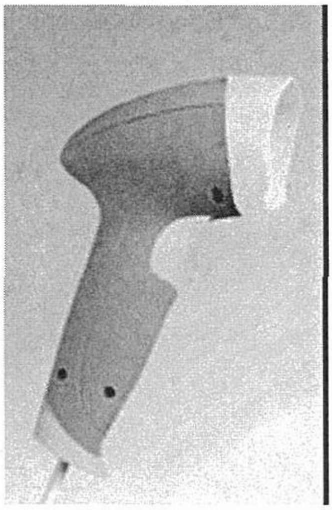


Figure 6: Example of handheld imager

Annex A
(informative)

Intrusive marking methods

A.1 Intrusive marking

Intrusive Marking is designed to alter the surface of a material to form a human readable mark or a machine-readable symbol. This marking category includes, but is not limited to, devices that abrade, burn, corrode, cut, *deform, dissolve, etch, melt, oxidize or vaporize the surface of a material.*

Because intrusive markings alter the surface of a part (abrade, cut, burn, vaporize, etc.) they are considered to be controlled defects. If not done properly, they can degrade material properties beyond a point of acceptability. Consequently, some intrusive markings, especially direct laser, are generally not used in safety critical applications without appropriate metallurgical testing. Typical intrusive marking methods include:

- Abrasive blast
- Dot peen
- *Electro-chemical marking*
- Engraving/milling
- Fabric embroidery/weaving
- Direct laser marking

Figure A.1 below provides cross section views of intrusive markings described in this section.

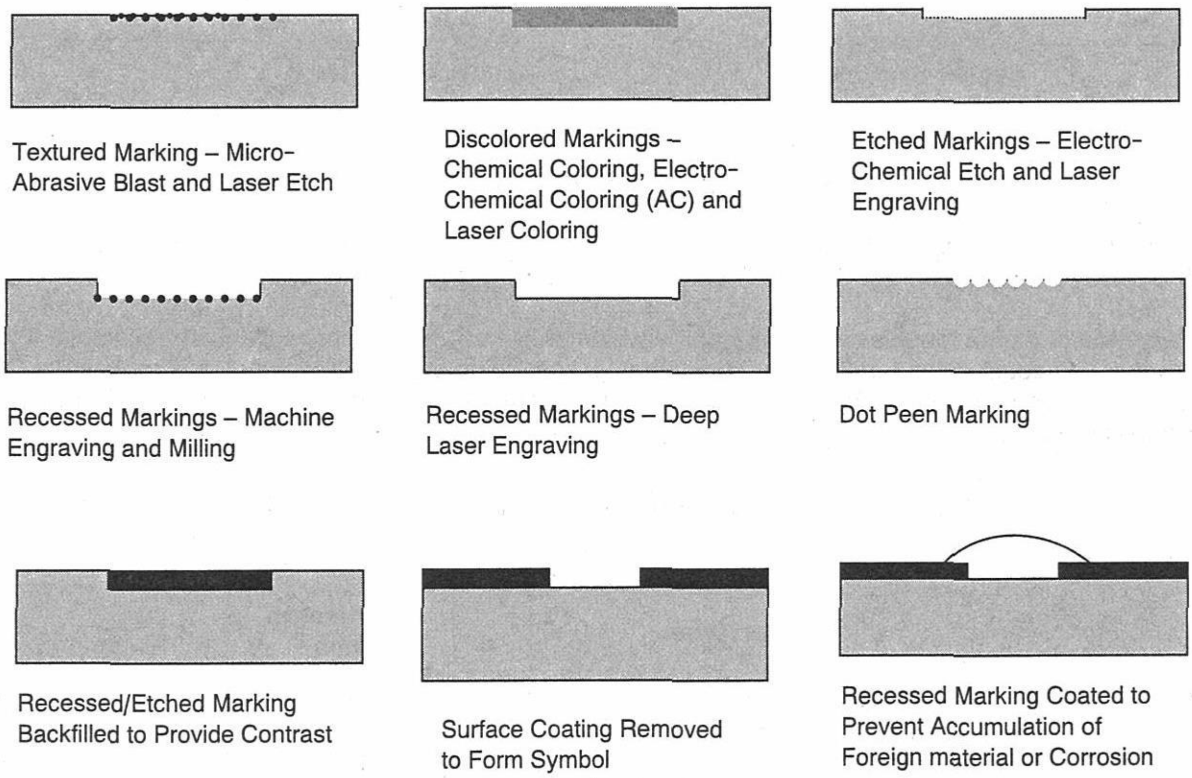


Figure A.1 — Intrusive marking cross-sections

A.2 Re-marking requirements using intrusive marking methods

Because the application of a single mark using an intrusive marking method causes material degradation, additional intrusive markings made to obliterate or change those original markings could reduce material properties beyond a point of acceptability. Therefore, approval should be secured from the responsible quality assurance or engineering organizations before additional markings are permitted.

A.3 Laser marking

A.3.1 General

Selecting a system for laser marking involves choosing the proper wavelength for the material to be marked. Marking applications can cover a wide range of laser wavelengths: Nd:YAG (1064 nm), CO_2 (10,6 μm) and other infrared wavelengths as well as light in the visible spectrum.

For purposes of marking, laser wavelengths can be broken into three major categories: short wavelengths, visible wavelengths and long wavelengths (i.e. in the Infrared region of the spectrum) as illustrated in Figure A.2 below.

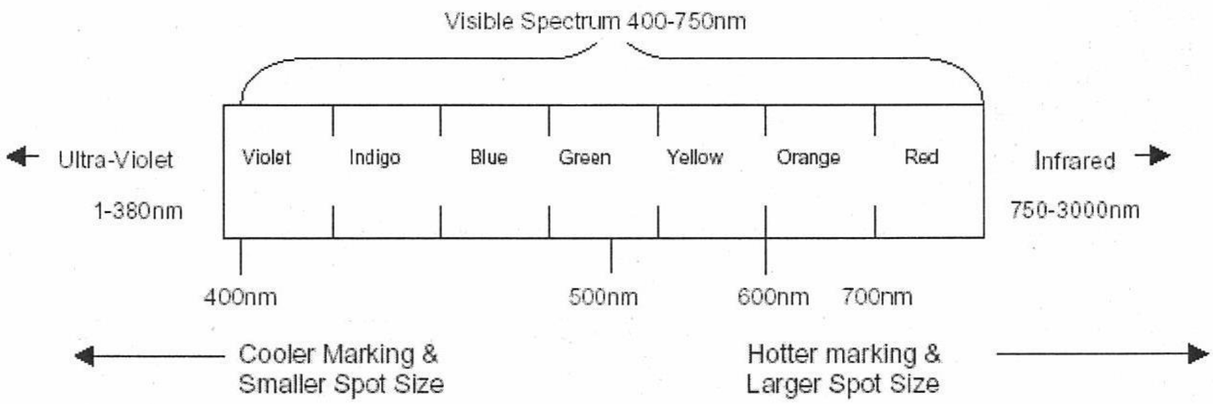


Figure A.2 — Light wavelengths

The two major choices for industrial applications are Nd:YAG (1064 nm) and CO_2 (10,6 μm), each working best with an array of materials. See Table A.1 below for wavelengths for common types of lasers.

A suggested rule of thumb for selecting the proper wavelength is to use the "microwave oven" example: If it is something that you could put in a microwave oven (that is, something organic, not metal), it is probably a CO_2 application. If it is something you would not put into a microwave oven (something metal) it is probably an Nd:YAG application.

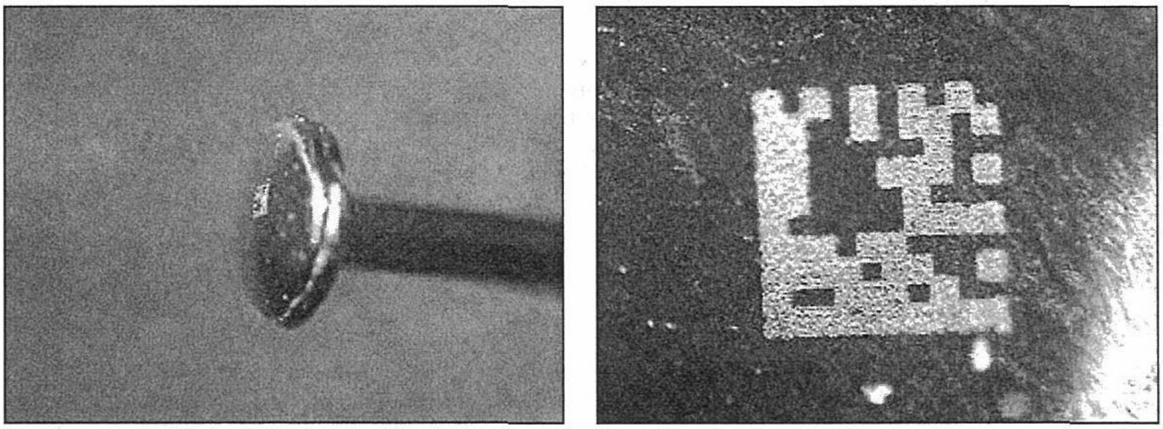
Table A.1 — Wavelengths for common types of lasers

Laser Type	Wavelength (nm)
Nd:YAG (neodymium: yttrium-aluminum garnet)	1064
Yb Fiber Laser (ytterbium fiber laser)	1060
CO_2 gas (carbon dioxide)	10,600
Nd:YVO_4 (neodymium: yttrium-vanadate)	1060

At room temperature, all materials will absorb, transmit, refract and/or reflect light energy at a particular wavelength or range of wavelengths. The ability of a material to absorb light and thus react in some manner to that energy is the desired property. For example, CO_2 lasers excel at marking anodized aluminum, plastics, wood, glass and ceramics. Ferrous metals can also be marked. A CO_2 laser is a good choice when an engraved mark in plastic (without a color contrast) is desired. Glass can also be marked using CO_2 lasers with a process known as controlled fracturing.

A.3.2 Short wavelength lasers

Short wavelength ultra-violet lasers utilize light in the lower end of the light spectrum and mark using a cold marking process. Lasers included within this category include excited dimer (excimer) lasers. Short wavelength lasers mark by ablation, the removal of a pre-applied coating on the surface of the part to be marked, and are preferred for use in safety critical applications. Excimer lasers are used to mark extremely thin materials, wire insulation and very small parts, as demonstrated in Figure A.3 below.



Photograph Magnified 25 Times

Photograph Magnified 200 Times

Figure A.3 — Two-dimensional symbol applied to the head of a straight pin using an excimer laser

A.3.3 Visible wavelength lasers

Visible wavelength lasers utilize light in the visible light spectrum and produce marks using heat action or pressure. Lasers included in this category include, Ruby - Neodymium doped: Yttrium Lithium Fluoride (Nd:YLF), Neodymium doped: Yttrium Aluminum Garnet (Nd:YAG), Neodymium doped: Yttrium Aluminum Perovskite (Nd:YAP), Neodymium doped: Yttrium Vanadate Orthovanadate (Nd:YVO_4), and Ytterbium doped Fiber (Yb:Fiber). Visible wavelength lasers are generally used to mark metal substrates.

A.3.4 Long wavelength lasers

Long wavelength infrared lasers utilize light in the infrared spectrum. Carbon Dioxide (CO_2) lasers are included in this category. CO_2 lasers are effective for marking organic materials such as wood, leather and some plastics.

A.3.5 Laser marking processes

A laser creates a mark by directing a concentrated beam of coherent light onto the surface of a part. The marking beam is controlled via a high-speed computer that deflects the laser beam utilizing galvanometer-controlled mirrors. The movement of the laser spot can reach speeds of 2 000 mm/sec with a positioning accuracy of +/- 0,010mm.

Six different types of markings can be made:

- Changing metal color by tempering (annealing)
- Changing plastic color through heat action on pigments embedded in the material

- Changing metal color by surface melting (laser etching)
- Changing surface texture by material vaporizing (laser engraving)
- Removing coatings to expose an underlying substrate of contrasting color (coat & remove)
- Generating a shockwave that indents a pattern (peening)

Marking quality is controlled by adjusting the machine settings: lamp current (power in amps), pulse rate (frequency in kHz), beam velocity (mm per second) and line/dot spacing.

A.3.6 Marking considerations

A.3.6.1 Marking Speed

Marking speed is determined by the desired process cycle time. Most systems mark by steering the beam with X and Y galvanometers, with attached mirrors. Marking speeds are difficult to quantify. It can be difficult to translate 'marking speed' directly into characters per second for all cases because a wide range of factors must be considered. For example, a single-stroke takes less time to mark than one more elaborate. The size of the character—its height, width and pitch (spacing between the respective characters)—will also be a factor.

Another factor that will have an impact on the achievable speed is the amount of power that needs to be applied, the amount of time that energy needs to be delivered and the frequency at which the laser system needs to be pulsed (if the energy requirement dictates the need for pulsing).

A.3.6.2 Power

Getting the right amount of power delivered to the part for the right amount of time is the essence of laser marking. For a given material, there will be a change in the material as a result of its interaction with laser power converted to energy.

For most CO_2 marking lasers, power is delivered in the form of a continuous wave beam. A constant average level of laser power is delivered and is switched on and off as required. Q-switched Nd:YAG lasers achieve high peak powers, allowing a greater amount of laser energy to be delivered in a unit amount of time. By controlling the rate at which the laser is pulsed, different peak values of laser energy can be developed.

A.3.6.3 Mark quality

Laser marking quality is affected by and dependent on the item being marked and the selected laser marking method. For example, laser etch on metal, commonly used in the electronics, automotive and aerospace industries, will produce a low contrast symbol. The same symbol etched on rubber (automotive industry) is *very* low contrast, but on glass epoxy (electronics industry) the method will produce a better contrast resulting in a much more readable symbol.

The resolution achieved by laser marking is based on the focus of the laser beam on the marking area and the diameter or spot size of the beam. Resolution can be far more precise than with inkjet or dot peen. However, the manufacturing process, as well as variations in the material being marked, can affect mark consistency and quality. Matching the marking method to the material being marked is critical, and guidance is provided for a number of materials and marking methods in Table 1 of this report. Table A.2 provides attributes for the various types of laser marking methods.

A.3.7 Laser safety standards

Internationally, laser safety is regulated by the standard ISO 11553:2005. In some countries national regulations may apply to the use of laser marking equipment.

A.4 Dot peen marking

A.4.1 General

Dot peen marking technology typically produces round indentations on a part's surface with a pneumatically or electromechanically driven pin, also known as a stylus. Critical to the readability of dot-peen marked symbols are the shape, size, and spacing of the indented dot. The dot size and appearance are determined mostly by the cone angle of the stylus, the marking force and the hardness of the material being marked. The indented dot created should be suitable to trap or reflect light and large enough to be distinguishable from the surface roughness of the part. It should also have spacing wide enough to accommodate varying module sizes, placement and illumination.

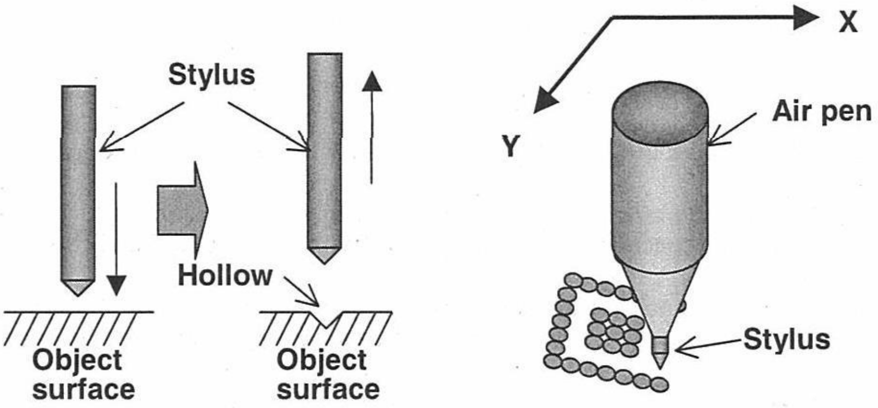


Figure A.4 — Dot peen marking

The concerns associated with marking and reading dot peen marked symbols on metals are different from those of symbols printed on paper. The fundamental difference is that the contrast between dark and light fields is created by artificial illumination of the symbol. Therefore, the shape, size and spacing of the module, as well as the surface finish of the part, can all affect readability of the symbol.

The key to a successful dot-peen marking project is to control the variables affecting the consistency of the process. Symbol verification systems can also provide feedback of the process parameters to some extent.

A.4.2 Dot Peen Marking Variables

A.4.2.1 Stylus to Target Surface - Height Control

Dot size is controlled primarily by the amount of force delivered to the stylus and the distance the stylus needs to travel before impact. It is therefore important to consider how to control this distance to maintain an acceptable process capability. The actual distance of the stylus to surface height is achieved during the set up procedure or postproduction trials. This height can be judged manually by the use of calibrated gauges such as slip gauges or by the employment of a device such as an automatic sensing control – auto sense. This auto sense searches out the surface and immediately after contact the stylus retracts to a set distance before commencing with the marking process.

A.4.2.2 Axis Movement - Accuracy

The build quality and overall accuracy of movement for any dot peen solution is vital for acceptable machine-readable symbol quality, repeatability and life of operation. Many traditional low-end specification dot peen machines producing human readable identification only may not be suitable for applications that require the marking of machine-readable two-dimensional symbols.

A.4.2.3 Power System

Consistent force delivered at the point of contact between stylus and component is important to maintain acceptable dot size and code quality. Electromechanically driven pin movement is recommended for overall consistency.

A.4.3 Limitations of dot peen marking

- Some materials are so thin that marking would compromise their structural integrity. Dot peen marking should not be used on these components.
- Parts must be held firmly in place during the marking process. Parts that cannot be held firmly should not be dot peen marked.
- Nonmetallic materials that chip, shatter, or regain shape after impact should not use this marking method.
- Metals hardened above 54 on the Hardness C Scale prevent the use of dot peen marking. (See Annex C.)
- Consideration must be given to requirements for finish machining after marking to smooth metal displaced during the marking process. Shadows caused by the displaced metal could affect readability of the mark.
- After marking, consideration should be given to surface treatments such as shot peen, painting, anodizing, etc. These surface treatments will affect the readability/performance of the mark.

A.4.4 Marking considerations

When marking with dot peen, the hardness of the stylus should be properly matched to the hardness of the part. In addition, the shape of the stylus should be matched to the application. Dot peen marking uses changes in depth to create the contrast between the light and dark elements of the symbol. In addition, the *shape* of the mark directly affects how light is reflected and affects the readability of the symbol. If the marked elements in the symbol are crowded to the point that they overlap, the marking is too hard and too deep. If the elements are too spread out, the marking wasn't hard enough.

A.4.5 *Reading considerations*

Because dot peen marking typically results in a non-illuminated, low contrast mark, successful reading could depend on the application of colored backfill media or by utilizing a lighting solution that produces artificial contrast.

When selecting the location for a symbol, illumination of the mark must be taken into consideration. If the symbol is recessed or adjacent to a protruding surface, lighting becomes more difficult.

Figure A.5 illustrates the effect of illumination on dot peen markings. The lighting setup used with a fixed station imager must be adjusted to compensate for differences in surface roughness and stylus wear.

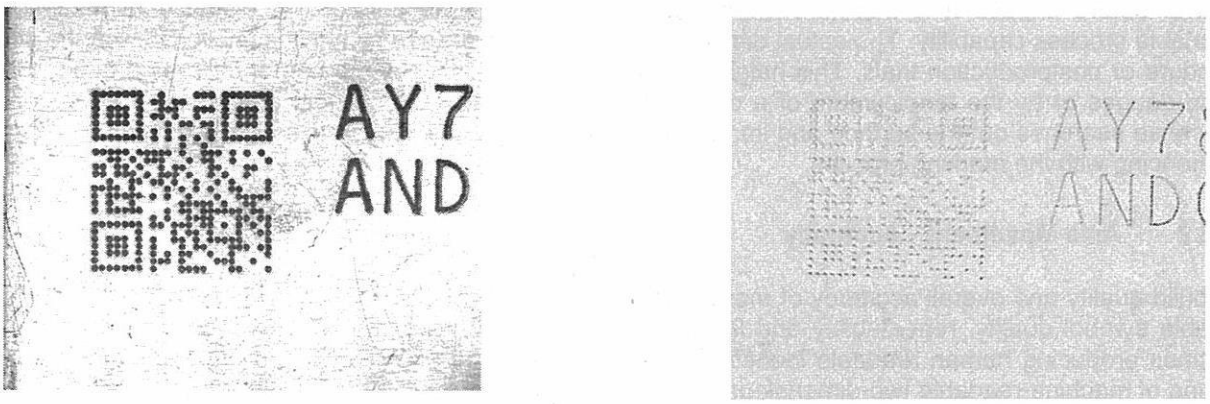


Figure A.5 — Image of dot peen marking with and without proper illumination.

A.5 Other Intrusive marking methods

A.5.1 Abrasive blast

The micro-abrasive blast marking system operates by directing a mixture of dry air and abrasive (silica, baking soda, etc.) through a small tungsten carbide nozzle at high velocity. Software automatically controls the direction and speed of the nozzle, the length of the stop-and-go pulses and the flow pressure to create the mark.

Marking quality is controlled by the type of abrasive used, the amount of air pressure, nozzle speed, and gap (nozzle to target distance). Abrasive blast marking is commonly utilized to texture surfaces prior to marking to reduce glare.

Figure A.1 illustrates the textures finish that is created by the abrasive blast marking method. Table 2 of this report provides guidance regarding the symbol size that can be achieved using this marking process.

Following are limitations of the abrasive blast marking method:

- The method cannot be used in humid conditions
- It cannot be used to mark irregular shaped surfaces
- It should not be used where particle contamination is an issue
- Care must be taken to ensure that there are no corrosion or compatibility issues between the grit and the marking surface

A.5.2 Electro-chemical marking (ECM)

Electro-chemical marking (ECM) can be used on all conductive metallic parts. It is one of the processes of choice for critical parts because it does not weaken, deform or fracture the substrate beyond the marking depth, *and the process is repeatable.*

The shape/pattern of the ECM mark is determined by a stencil generated by a desktop, computer-controlled, thermal transfer printer. This process can mark all conductive metal parts. (Anodized parts, normally considered insulated by the anodized coating, can also be marked.) Etching depths can be precisely controlled and range from 0,002 to 0,254 mm. Materials as thin as 0,254 mm can be etched. Following etching, the part may be anodized and/or protected with clear coatings.

Though not lengthy, this is a very manual process and is best suited for individual piece parts, since a new stencil should be created for each new serialized part being marked. It is inexpensive, with the equipment cost at approximately $5,000 - $12,000 for the ECM equipment, a thermal transfer printer, and a computer and stencil material.

The ECM marking method uses electrolytes that are safe to handle and corrosion free and marked objects do not require neutralization following the marking process. With some metal/electrolyte combinations, colored marks (black, white, blue, etc.) can be obtained.

An ECM marking system features:

- Low acquisition cost.
- Ease of operation with minimal operator training.
- Outside vendors are not required to make marking stencils.
- Flat surfaces as well as simple curved surfaces can be marked.
- Markings are of high quality.

ECM may be accomplished by either of two processes:

- Electro-chemical etching uses electrolysis to remove metal from the surface of the object being marked. This process can mark all conductive metal parts. (Anodized parts, normally considered insulated by the anodized coating, can also be marked.) Etching depths can be precisely controlled and range from 0,003 mm to 0,250 mm. Materials as thin as 0,025 mm can be etched.

- Electro-chemical coloring marks by discoloring the surface of the object without removing, melting, or vaporizing the material and is frequently used to enhance the contrast of the etched mark.

Electro-chemical etching, as shown below, uses a DC power source while electro-chemical coloring uses AC. In both methods, the voltages are low to ensure operator safety.

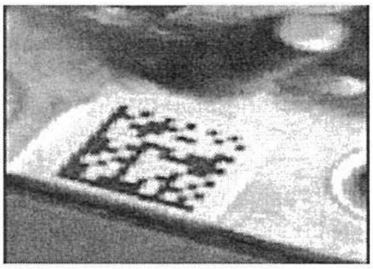


Figure A.6 — Electro-chemical etch marking on metal.

ECM is not an appropriate marking method for:

- Non-metallic objects. (See Table 1 of this report.)

- Objects characterized by compound curves of small radius. However, simple curves and cylinders are easily marked by this DPM method.

Since ECM is a more involved process than other methods, it is not suited for highly automated applications and is commonly used for small product runs.

A.5.3 Engraving/milling

Engraved and milled markings are applied by removing material from the surface of the part using a computer-guided, carbide-tipped cutter or diamond drag. Adjusting cutter depth, air pressure, rotation and dwell time controls the quality of the mark.

Marking readability can be improved by backfilling the recessed marks with a material of contrasting color. Engraved markings can be applied to glass, plastic, phenolic, ferrous and non-ferrous metals. Symbols created by this method must be located a minimum distance of twice the base material thickness from any edge, including holes. Milling and engraving is not recommended in areas smaller than 5,126 mm.

This process should not be applied to:

- Materials less than 1,500 mm thick
- High pressure system components
- Components subjected to severe loads
- Multi-layer or fabric reinforced laminates
- Alloys or other metals hardened above 32 Rockwell C (See Annex C.)

Figure A.1 provides a cross-section view of the recessed marking achieved by the engraving and milling marking method. Table 2 of this report provides guidance regarding the symbol size that can be achieved using this marking process.

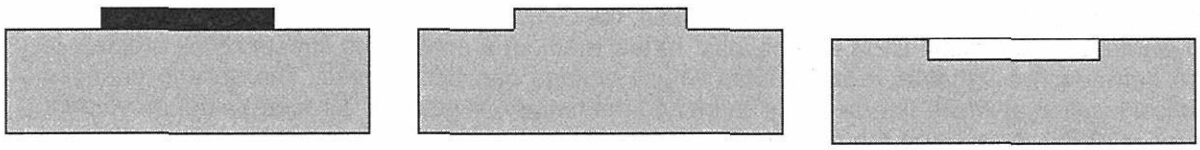
Annex B
(informative)

Non-intrusive marking methods

B.1 Non-intrusive marking methods

Non-intrusive markings, also known as additive markings, are produced as part of the manufacturing process or by adding a layer of media to the surface using methods that have no adverse effect on material properties. Figure B.1 below illustrates these methods that include:

- Automated adhesive dispensing
- Cast, forge, and mold
- Ink jet
- Laser bonding
- Laser engineered net shaping (LENS)
- Liquid metal jet
- Screen Printing
- Stencil



Additive Markings – Adhesive dispensing, Ink Jet, Laser Bonding, LENS, Screen printing, Stencil, and Thin Film Deposition

Raised Markings – Cast, Forge, or Mold

Recessed Markings – Cast, Forge, or Mold

Figure B.1 — Non-intrusive marking cross sections

Of the non-intrusive marking methods, this report addresses the ink jet marking method in depth and will briefly address some other additive technologies.

B.2 Ink jet marking

Ink jet technology is a non-intrusive marking method that sprays precisely controlled drops of ink through the air in a pattern capable of creating a symbol. These drops are made of a fluid that evaporates, leaving a colored dye on the surface of the item.

The permanence of an ink jet mark is dependent on several factors: composition of the ink used, curing requirements of the ink, chemical interaction between the ink and surface resistivity of the part and other materials to which the part may be exposed e.g., cleaning solvents. Care must be taken to ensure that the chemical properties of the ink being used are compatible with the material being marked, and with the processes to which the part will be exposed.

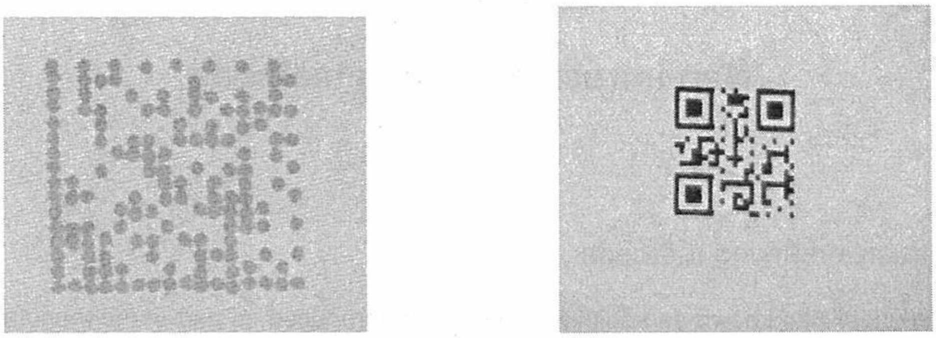


Figure B.2 — Ink jet marks

There are two primary methods for generating ink jet drops, drop-on-demand and continuous ink jet. See Figure B.2 above. Drop-on-demand uses valves or piezo-electric technology to force the ink through an orifice(s). This method has significant printing resolution advantages over the continuous ink jet method. The distance the ink is projected affects print quality and should be adjusted to ensure adequate print quality. This restricts the use of drop-on-demand in most industrial DPM applications, and the technology is not further addressed in this report.

Depending on the size and shape of the item to be marked, the Continuous Ink Jet method may be preferred over Drop-on-Demand for industrial DPM applications. In this method, a continuous stream of ink droplets is made to pass between two variable voltage plates whose voltage can be adjusted. The voltage changes adjust the vertical location at which the drops will land, and the horizontal position is varied by the movement of the target (or part) in reference to the print head. When no marks are being formed, the drops circulate from the nozzle to the ink reservoir.

When printing on non-absorbent surfaces using the continuous ink jet system in DPM, the ink is required to include an evaporation fluid, normally referred to as the "make-up" or "system" fluid. Industrial ink jet printers have automatic viscosity management algorithms to control the correct mixture of ink and evaporation fluid. Evaporation of the fluid allows for the deposition of the ink dye on the surface, generating the contrast of the mark to the target surface.

Solvent-based fluids are available for a wide range of applications. They can be selected for very fast drying, pigmented, colored, UV curable, Mil-Spec marking permanent, alcohol based, water based, non-flammable, high gloss, thermo-chromic, boil resistant and many other applications. Most solvent-based inks are touch-dry immediately after printing.

The concerns associated with marking and reading ink jet symbols placed directly on parts are different from those of symbols printed on paper. The condition of the substrate on which the ink is to be deposited is a particular concern. Cleaning the surface to remove coatings, rust and discoloration with an abrasive pad, or using an air knife to blow away excess machining fluids, debris or oil can greatly improve the readability of the mark. Contrast is another concern. In some cases a white or light pigmented ink patch may be required, followed by a black or dark symbol in order to achieve an acceptable print contrast.

B.2.1 Ink jet modules (dots)

It is preferable to use a single ink drop or spot to represent each module of a machine-readable symbol, although multiple dots per cell can be used to create a square cell. The decision of whether to use a single or multiple dots is dependent on the following factors: the maximum number of vertical dots available with the selected ink jet printer, the amount of data to be encoded within the machine readable code and the physical space provided for the code.

B.2.2 Limitations of ink jet

In some applications ink jet marking cannot be considered a permanent marking method. For applications where the ink jet marking will be subjected to secondary operations involving abrasion, sand or grit blasting and/or remanufacturing conditions ink jet marking is not recommended for permanent marking. When evaluating industrial ink jet marking for permanent marking applications it is critical to identify the correct ink and curing method. Military marking permanent inks are available for some applications. After a permanent ink is selected, care must be exercised to ensure the selected ink withstands all operational processes showing no evidence of degradation of machine-readable symbols. Another limitation to ink jet marking is that either the part or ink jet head must move at a constant or known speed during printing. Most ink jet suppliers can offer a satisfactory solution for specific applications.

To achieve consistent marks with an ink jet system, the cleanliness of the environment must be evaluated. If the surface of the part has debris such as dirt or oil, the ink will adhere to the debris instead of the part, resulting in an inconsistent and poor quality mark.

B.2.3 Ink jet nozzle selection

Depending on the desired ink jet module or cell size, various ink jet nozzle orifices are available, as outlined in Table B.1 below. Continuous ink jet printers are available with "normal," "medium" or "high" resolution nozzle orifices. The table below illustrates the relative shortest and tallest character height, dependent on the nozzle orifice selected. The table comparisons are based on printers with a maximum 24-dot tall capability and the assumption is made that dots are touching to minimize the risk of variation in the spacing of the dots. (Ink jet printing is a dot matrix process. It is important to avoid separation of the dots.)

Table B.1 – Ink jet nozzle orifice size comparisons

Resolution	Nozzle Orifice Size	Smallest Character Height	Tallest Character Height
Normal	60–70 microns	1,270 mm	8,380 mm
Medium	50–55 microns	1,070 mm	6,350 mm
High	36–42 microns	0,760 mm	4,570 mm

If proper ink jet print-head periodic cleaning and maintenance procedures are not followed, the ink jet print head can clog, preventing the symbol marking process from producing good quality machine-readable symbols.

B.2.4 Ink and background color

Ink marking color should be selected to maximize symbol contrast. Contrast will be dependent on the interaction of the ink color and the natural background color of the part, as well as the color of light used by the reading device. Colors may appear different under various light sources and lighting conditions. For example, Figure B.4 illustrates the effect of white ink under red light. In this particular case, black ink would offer no contrast.

Another option for improving symbol contrast is the use of inks that fluoresce at a specific light wavelength such as near Infrared (IR) or Ultraviolet (UV), as illustrated in Figure B.3 below. If the symbol reading device uses IR light sources, a part could be marked with a symbol not visible to the naked eye, but it could still be read without special equipment. Even if a symbol appears to have very low contrast, an imager might see it as near white on black or black on white.

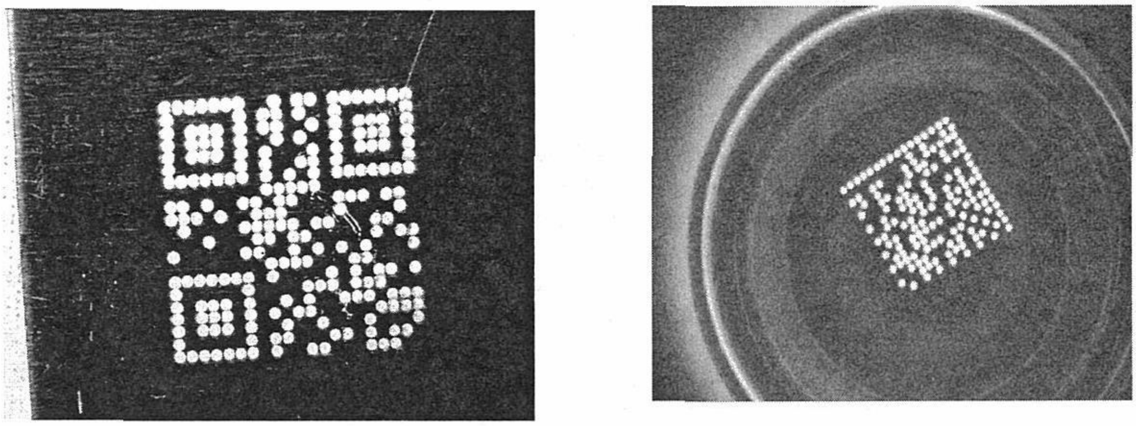


Figure B.3 — Ultraviolet ink jet marks

In some cases, symbol reading can be improved by the application of a colored media as a backdrop to the area where the symbol will be applied as illustrated in Figure B.4.

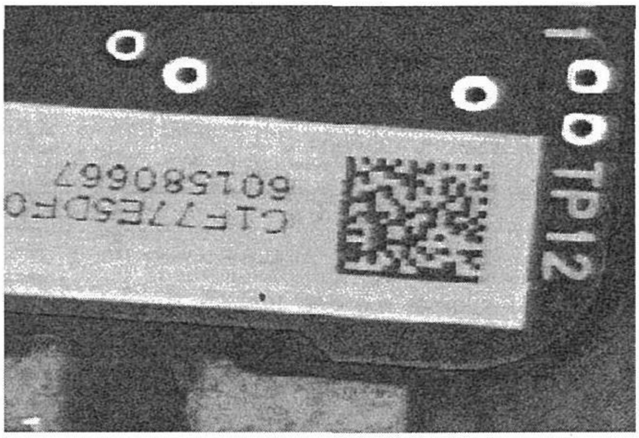


Figure B.4 — Ink jet marking with white background added

B.3 Fabric embroidery/ weaving

Fabric marking can be incorporated into the cloth during manufacture (fabric weaving) or after manufacture using embroidery methods. Both processes are computer controlled. The fabric weaving process is generally utilized to create identification labels that are sewn onto clothing or similar articles. Fabric embroidery involves the stitching representations of part identification markings onto knits, cotton, canvas, leather and many other materials after their manufacturer using a wide range of different thread sizes and materials. Figure B.5 illustrates a machine-readable symbol created using fabric weaving.

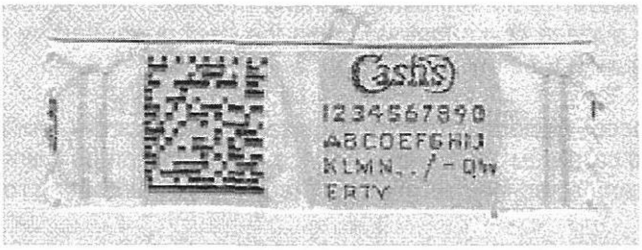


Figure B.5 — Cloth label produced using fabric weaving technique

This marking technique cannot be used on fabrics impregnated with additives to support use in high temperature applications and is otherwise limited to tight weave fabrics.

Table 2 of this report provides guidance regarding the symbol size that can be achieved using fabric embroidery and fabric weaving.

NOTE: The base material weave may generate a degree of noise which may be reduced by careful illumination, or compensated for to some extent by the use of a larger than normal reading aperture.

B.4 Forge, cast

Figure A.1 provides a cross-section view of the raised or recessed markings that can be achieved by the forge and marking methods described below. Table 2 of this report provides guidance regarding the symbol size that can be achieved using these processes.

B.4.1 Forge

Forging involves placing a metal blank between two halves of a mold (the moveable half of the mold is called a "tool"; the stationary half is called a "die."), and then applying pressure, causing the metal to form into the shape desired. Forging develops a grain structure in the metal, which makes it stronger in the direction that it has been stretched. Because the tools and dies can be expensive to create and the press is large and costly, the process is expensive to set up, but can be cost effective when producing large quantities of parts.

B.4.2 Cast

Casting, the process of forming metal parts by pouring molten metal or other material into a mold, is the least expensive method of making large quantities of parts that are of shapes that cannot be produced by stamping. The parts are not generally as strong as those made by the forging process, and the shape of parts made in a re-usable mold cannot be as complicated as is possible with CNC machining, because some shapes cannot be removed from a mold without breaking.

An expensive process called investment casting or "lost wax" casting permits casting of complicated shapes by using single-use plaster molds that can be broken apart to free the cast part from the mold.

Investment casting can be used for the marking of two-dimensional symbols by printing a pattern of the symbol in physical or 3-dimensional form using a 3-dimensional printer. Three-dimensional printers produce physical objects by using an ink jet print head that uses a wax-based thermoplastic instead of ink, and prints layer upon layer to build up the “ink” thickness into a 3-dimensional object. For the cast metal marking application, the 3-dimensional printed pattern of the symbol is incorporated into a coupon made from a wax-based material. Once printed, this coupon can be turned into a cast metal equivalent by putting the wax coupon pattern through the investment casting process.

There are various methods to improve performance or readability of the symbols. Some of these include heat-treating which colorizes the individual mark, causing it to stand out from the rest of the material. The use of paint can be used to enhance the final result of the symbol. On certain rough finishes, sand blasting can be used to take away the rough edges of the individual cells can improve readability.

B.5 Laser bonding

Laser bonding is usually considered a non-intrusive marking process. This process involves the bonding of laser marking materials to the surface of a substrate using the heat generated by an Nd:YAG, YVO_4, CO_2 or fiber lases, as illustrated in Figure B.6 below.

The materials used in this process generally consist of glass frit powders or ground metal, oxides mixed with inorganic pigment, and a liquid carrier (usually water). These materials can be painted or sprayed directly onto the surface to be marked, or transferred via pad printer, screen printer, or coating roller.

Laser bonding is accomplished using low laser power levels that have no measurable detrimental effect on metal or glass substrates and are safe for use in material critical applications. The process also can also be performed using a CO_2 laser and ink foils for use in less harsh environments. The marks produced using this technique (dependant upon the material used), are resistant to high heat, are unaffected by salt fog/spray and *are extremely durable.*

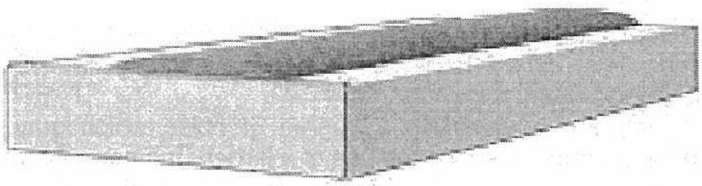


Figure B.6 — Material fused to a surface using the laser bonding process

Figure B.1 provides a cross-section view of the markings that can be achieved by the laser bonding process. Table 2 of this report provides guidance regarding the symbol size that can be achieved using this DPM method.

Some limitations associated with the laser bonding marking method are as follows:

- Coatings are application specific
- Generally limited to flat or slightly curved surfaces
- Restricted to materials thicker than 0,025 mm.
- May affect material resistance to stress/fatique.

B.6 Laser engineered net shaping (LENS)

Laser Engineered Net Shaping (LENS) utilizes the heat from an Nd-YAG laser to form a small weld-pool on the surface of the part to be marked. Simultaneously, metallic powder is injected into the molten pool, building up a feature. 3-D CAD software is used to manipulate the head or the part to deposit the symbol. The injected metallic material does not have to be of the same material as the part, and can be chosen to be corrosion resistant, wear-resistant, or with any other desirable characteristic. LENS-deposited materials offer a rough surface finish, providing good diffuse reflection of light. LENS is compatible with all common steels, titanium, aluminum, nickel, and copper alloys. LENS markings can be resistant to abrasion and chemical reactions. *Since this is a non-intrusive (additive) marking process, LENS marking will protrude above the surface of the* part, as shown in Figure B.7.

Figure B.1 provides a cross-section view of the raised markings achieved using LENS. Table 2 of this report provides guidance regarding the symbol size that can be achieved using this process.

Note: Although generally considered a non-intrusive process, LENS marking may affect the surface characteristics of the part being marked and its use should therefore be considered carefully when these characteristics are important to the part's expected use.

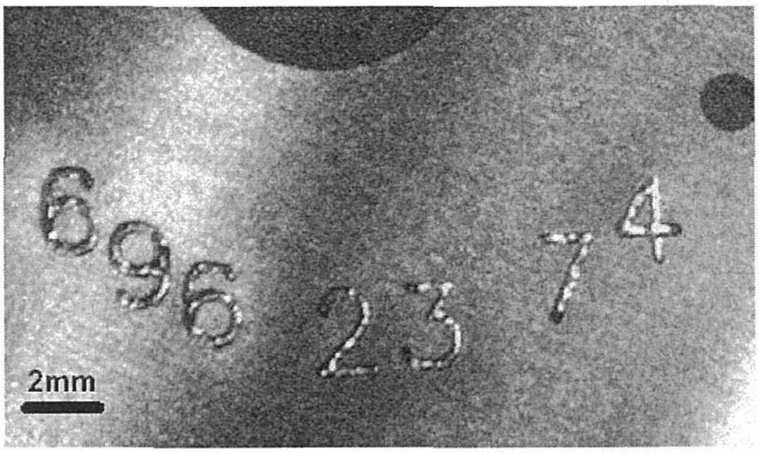


Figure B.7 — Raised lettering using LENS marking

B.7 Screen printing

Screen printing is the most versatile of the marking processes. It can be used to mark a wide variety of substrates, including paper, paperboard, plastics, glass, metals, fabrics, paper, plastics, glass, metals, nylon and cotton.

Screen printing consists of three elements: the screen which is the image carrier; the squeegee; and ink. The screen printing process uses a porous mesh stretched tightly over a frame made of wood or metal. Proper tension is essential to accurate color registration. The mesh is made of porous fabric or stainless steel mesh. A stencil is produced on the screen either manually or photo-chemically. The stencil defines the image to be printed. In other printing technologies this would be referred to as the image plate.

Screen printing ink is applied to the substrate by placing the screen over the material. Ink with a paint-like consistency is placed onto the top of the screen. Ink is then forced through the fine mesh openings by drawing squeegee across the screen, applying pressure and forcing the ink through the open areas of the screen. Ink will pass through only in areas where no stencil is applied, thereby forming the image on the substrate. The diameter of the threads and the thread count of the mesh determine how much ink is deposited onto the substrate.

Using the screen printing process, two-dimensional symbols can be printed in a manner very similar to that used to produce printed labels.

This marking method should not be used on:

- Items exposed to liquid spray or splash
- Items exposed to high temperatures (over 149° C)
- Items exposed to rubbing wear or abrasion

B.7.1 The affect of tension on registration

With under-tensioned mesh, the squeegee actually drags the material with it during the print stroke and stretches the mesh slightly, because the mesh simply doesn't have the tension to resist the pull. This not only increases the likelihood of a blurred print, but the stencil also gets pulled right along with the mesh. The result is that the imprint moves a bit further down the substrate.

Furthermore, there will be inconsistencies from print to print depending on how much squeegee pressure is applied. The squeegee will actually pull the mesh down with it, so variations in squeegee pressure will show up in imprints that have shifted to varying degrees. Another registration problem results from the exaggerated off-contact distances required by under-tensioned mesh. When mesh has to travel a greater distance to reach the surface of the substrate, it becomes harder to control the position of the imprint.

B.7.2 Improved print quality

Proper mesh tension creates noticeable improvements in print quality, notably images with sharp, well-defined edges and smooth uniform color. This is how it works: As the squeegee passes over the mesh, tension quickly lifts it up off the substrate, getting it out of the way of the ink. This also allows the ink to flow very slightly, eliminating mesh marks and leaving a smoother ink surface. In addition, less ink is required with the correct tension during a print job.

B.8 Stencil

Stencil markings are applied by depositing a marking agent onto a surface using a mask that has openings that correspond to the shape of the desired marking. Figure A.1 provides a cross-section view of the raised or recessed markings that can be achieved by the forge and marking methods described below. Table 2 of this report provides guidance regarding the symbol size that can be achieved by various methods of stencil marking.

There are four common types of stencil material:

B.8.1 Photographically etched stencils

These stencils are manufactured in pre-cut sizes containing impressions of the required image. The image is then generated onto a plate that is used to form the image onto the stencil material, a high precision polyester mesh material. Once the image is photographically etched into the stencil material, the stencil will withstand the marking of a large volume of parts. This method should be used for applications where the marking data does not change between markings, making the method unsuitable for serialized part marking. Although a good quality image is produced with this method, the stencils may be relatively expensive.

B.8.2 Thermal wax stencil

This method uses a colored permeable paper with a wax surface. The image to be marked is printed onto the thin wax surface by means of a thermal process, which removes the wax to leave an image. The method tends to be fragile because the wax degrades easily and tends to produce a mark of poor quality.

B.8.3 Die impression

Die-impression stencil paper is widely used for producing electro-chemical etch marks. The stencil is made from a colored permeable fabric with a thin non-permeable laminate surface on one side of the stencil. A dot matrix printer is used to punch holes through the laminate coating in the shape of the image to be marked. Die-impression stencils are durable and can produce marks of a good quality.

B.8.4 Thermal transfer printed stencil – disposable

This type of stencil material is similar to the die-impression paper, with a permeable fabric and a non-permeable laminate, the main difference being that the laminate is only microns thick. The laminate is thermally removed from the stencil using a thermal printer leaving the image on the permeable fabric. The process is generally reliable and produces a good quality mark. The stencils are normally used once and then disposed of. Slight variations in print quality are mainly due to the weave of the permeable fabric structure.

Annex C
(informative)

Rockwell Hardness

Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. Although hardness testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties. Hardness testing is widely used for material evaluation due to its simplicity and low cost relative to direct measurement of many properties.

Rockwell hardness testing is an indentation testing method. An indenter is impressed into the test sample at a prescribed load to measure the material's resistance to deformation. A Rockwell hardness number is calculated from the depth of permanent deformation of the sample after application and removal of the test load. Various indenter shapes and sizes combined with a range of test loads form a matrix of Rockwell hardness scales that are applicable to a wide variety of materials.

Table C.1 is a conversion chart from Rockwell to other methods of measuring metal hardness.

Table C.1 — Metal hardness conversion chart

Brinell Hardness	Rockwell Hardness			Tensile Strength	Brinell Hardness	Rockwell Hardness			Tensile Strength
Tungsten CarbideBall 3000 KG	A Scale 60KG	B Scale 100KG	C Scale 150KG	(Approx.)	Tungsten Carbide Ball 3000 KG	A Scale 60KG	B Scale 100KG	C Scale 150KG	(Approx.)
-	85.6	-	68.0	-	331	68.1	-	35.5	166,000
-	85.3	-	67.5	-	321	67.5	-	34.3	160,000
-	85.0	-	67.0	-	311	66.9	-	33.1	155,000
767	84.7	-	66.4	-	302	66.3	-	32.1	150,000
757	84.4	-	65.9	-	293	65.7	-	30.9	145,000
745	84.1	-	65.3	-	285	65.3	-	29.9	141,000
733	83.8	-	64.7	-	277	64.6	-	28.8	137,000
722	83.4	-	64.0	-	269	64.1	-	27.6	133,000
712	-	-	-	-	262	63.6	-	26.6	129,000
710	83.0	-	63.3	-	255	63.0	-	25.4	126,000
698	82.6	-	62.5	-	248	62.5	-	24.2	122,000
684	82.2	-	61.8	-	241	61.8	100.0	22.8	118,000
682	82.2	-	61.7	-	235	61.4	99.0	21.7	115,000
670	81.8	-	61.0	-	229	60.8	98.2	20.5	111,000
656	81.3	-	60.1	-	223	-	97.3	20.0	-
653	81.2	-	60.0	-	217	-	96.4	18.0	105,000
647	81.1	-	59.7	-	212	-	95.5	17.0	102,000
638	80.8	-	59.2	329,000	207	-	94.6	16.0	100,000
630	80.6	-	58.8	324,000	201	-	93.8	15.0	98,000
627	80.5	-	58.7	323,000	197	-	92.8	-	95,000
601	79.8	-	57.3	309,000	192	-	91.9	-	93,000
578	79.1	-	56.0	297,000	187	-	90.7	-	90,000
555	78.4	-	54.7	285,000	183	-	90.0	-	89,000
534	77.8	-	53.5	274,000	179	-	89.0	-	87,000
514	76.9	-	52.1	263,000	174	-	87.8	-	85,000
495	76.3	-	51.0	253,000	170	-	86.8	-	83,000
477	75.6	-	49.6	243,000	167	-	86.0	-	81,000
461	74.9	-	48.5	235,000	163	-	85.0	-	79,000
444	74.2	-	47.1	225,000	156	-	82.9	-	76,000
429	73.4	-	45.7	217,000	149	-	80.8	-	73,000
415	72.8	-	44.5	210,000	143	-	78.7	-	71,000
401	72.0	-	43.1	202,000	137	-	76.4	-	67,000
388	71.4	-	41.8	195,000	131	-	74.0	-	65,000
375	70.6	-	40.4	188,000	126	-	72.0	-	63,000
363	70.0	-	39.1	182,000	121	-	69.8	-	60,000
352	69.3	-	37.9	176,000	116	-	67.6	-	58,000
341	68.7	-	36.6	170,000	111	-	65.7	-	56,000

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