CERP

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Machine Vision Inspection System Development Cost Study

Technikon # 1410-610

May 2005
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EPA United States Environmental Protection Agency

CISA

AFS

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

USCAR

DAIMLERCHRYSLER Ford Motor Company General Motors

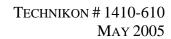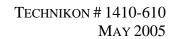*this page intentionally left blank*

Machine Vision Inspection System Development Cost Study

Technikon # 1410-610

This report has been reviewed for completeness and accuracy and approved for release by the following:

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Abstract

Machine vision inspection systems and associated costs are evaluated based upon inspection of a standard test casting. Recommendations for setting budget requirements, specification development and procurement procedures are delineated for future acquisition of a stand alone machine vision inspection system. The application of automated surface inspection will result in reduced labor costs and the elimination of subjective judgment in casting quality control.
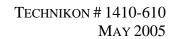
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1. Introduction:

1.1. OVERVIEW

Surface inspection is still undertaken manually by skilled staff involved in costly, time-consuming manual operations. The absence of machine vision surface inspection may be due to existing technologies which are unable to cope with a wide range product configurations and defects. However, the reduction of processor and memory costs would suggest that machine vision applied to casting surface inspection has potential as a low cost alternative to manual inspection by trained technicians. The application of machine vision surface inspection would result in reduced costs, elimination of subjective judgment and availability of statistical product data.

1.2. ADVANTAGES OF MACHINE VISION

Machine vision systems offer many advantages over visual inspections performed by humans. Machine vision systems operate objectively and free from fatigue and can quantify variables such as dimensions, angles, surface flaws, texture and topography. Additionally, inspection findings can be documented and statistically evaluated. The application of machine vision technology is ideally suited to both foundry production and foundry research applications.

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2. Scope and Purpose

This study focuses on the application of machine vision technology to the surface inspection of test castings used in a foundry emission research facility. The purpose of this effort is to:

- Augment the subjective manual surface inspection of a metal casting with a repeatable quantitative machine vision process.

- Review machine vision technology through vendor contacts and literature search.

- Determine the availability and cost of a machine vision system as applied to an existing, well-documented casting inspection process.

- Request bids from vendors to determine available technology and implementation costs for a stand alone machine vision system suitable for a foundry research environment.

- Document development and implementation costs.

- Identify optimal procurement procedures.

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3. Machine Vision Surface Inspection

3.1. MACHINE VISION BASICS

Machine vision surface inspection involves the use of optical non-contact sensing to acquire and interpret images in order to obtain information. A typical machine vision system consists of one or more monochrome or color video cameras, lighting, vision hardware (frame grabber and/or processor board), vision software (image processing/analysis), and a computer system. Inspection systems can process both two-dimensional and three-dimensional images using grayscale or color image analysis. The current state of the art has advanced to include 3D holographic imaging.

3.1.1. The Stages of Machine Vision

Typically, machine vision involves four stages:

- **Image Acquisition:** An optical system gathers an image, which is converted to a digital format and placed into computer memory. Image acquisition is achieved through careful structuring of the lighting arrangement and camera position to enhance features of interest such as pin holes or surface texture.

- **Image Processing and/or Segmentation:** The processor uses various algorithms to enhance elements of the image that are important to the inspection process. This consists of segregating the desired features from all other parts of the image.

- **Feature Extraction:** The processor then identifies and quantifies critical features in the image, such as surface finish or the positions of defects on a casting. Feature extraction is concerned with the quantification of the segmented image feature, typically in terms of a collection of descriptors or quantitative feature measurements.

- **Feature Classification:** Classification, or feature recognition, is the process of assigning features that share a common property to a predetermined set of flaws such as sand inclusions or pin holes in a casting.

3.1.2.   Vision System Elements

- **Front-end optics for Image Acquisition:** The front end includes the lighting, the lens, and the camera. The lighting highlights those features important to the measurement, while minimizing distracting artifacts. The lens must be capable of faithfully imaging the critical features of the object. Equipment configurations based on analog, digital and smart cameras are shown in Figure 1.

- **Frame grabber for Image Conversion:** A frame grabber is a processor board that accepts the video input from the camera, digitizes it, and stores it for analysis. Some frame grabbers include special processing electronics that speed the image processing and feature extraction tasks.

- **Processor:** A processor such as a personal computer (PC) is required to control the vision application.

- **Software:** Software that makes decisions on image data received and controls the vision tasks and overall system operation. Machine vision software packages typically include a number of different image processing and feature detection techniques such as the following:

  - **Pixel Counting**: counts the number of light or dark pixels.

  - **Thresholding:** converts an image with gray tones to simply black and white.

  - **Connectivity & Segmentation:** used to locate and/or count parts by differentiating between light and dark connected regions of pixels.

  - **Gauging:** measurement of object dimensions in inches or millimeters.

  - **Edge Detection:** finding object edges.

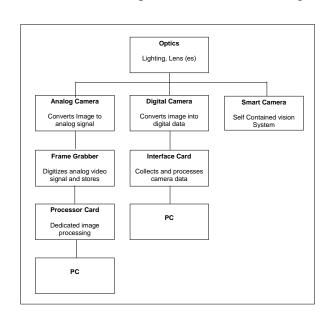 - **Template Matching:** finding, match-

Figure 1   Vision System Equipment Configurations Based on Analog, Digital and Smart Cameras

ing, and/or counting specific patterns.

○ **Pattern Recognition:** location of an object that may be rotated, partially hidden by another object, or varying in size.

3.2. CASTING SURFACE ATTRIBUTES AND MACHINE VISION SYSTEMS

3.2.1. Casting Surface Definition

Casting surface defects may take the form of an irregularity in the reflectance and/or variation in three-dimensional surface shape. Surface topographic inspection can be divided into two categories. The first relates to the detection of isolated defects, where the task is to ignore normal shapes, but detect undesirable shapes such as holes or protrusions. The second category is concerned with pattern inspection where the whole surface is considered subject to a pattern and an effort is made to categorize various undesired variations in the pattern. That is, separating pattern features from the background clutter. An example of separating topographic features from background reflectance is shown in the processed image of a ceramic tile (Figures 2 and 3).
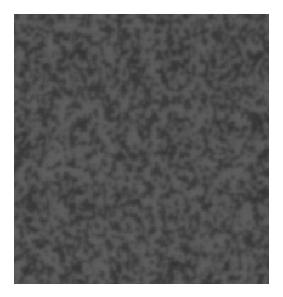

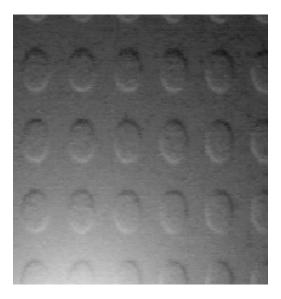**Figure 2   Camera Image of Ceramic Tile**

Figure 3   Separated Surface Topology of Ceramic Tile after Processing Image

3.2.2. Key Surface Attributes and Assumptions

By using an explicit casting defect representation scheme, it becomes feasible to describe a characteristic casting flaw in terms of its shape and/or reflectance signature. The key is the ability to determine a deviation in the surface map of a metal casting with consideration of the following assumptions:

- Castings display unique surface flaws such as burnt-on sand, pinholes, slag inclusions, smoothness, porosity, cracks, holes and dimples (Figures 4 – 7)

- The type of defect is predictable based on type of casting process.

- If the causal mechanism is known, then a quantitative analysis of those defects can be used for process control.

- A casting surface may be defined in terms of shape, surface topology and reflectance. A flaw may be described as an aberration in those features.

- Acceptable deviations in casting surface topology may be quantified and programmed into the machine vision system and used for ranges of part acceptance or rejection.

- Comparisons can be drawn from an idealized "good" casting or from CAD drawings.

- Traditional methods of surface texture measurement, such as the use of a microfinish comparator (Figure 8) can be achieved using machine vision technology.

Figure 4   Burnt-0n Sand

Figure 5   Pinholes

Figure 6   Pitting

Figure 7   Edge Deformation Caused by Gas Bubbles
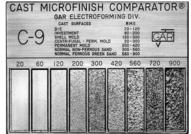

Figure 8   Traditional Cast Surface Measurement Using a Microfinish Comparator.
Machine Vision Systems Can Perform This Task.
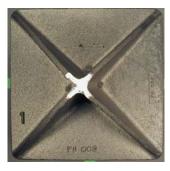
4. Vendor Contacts

4.1. APPROACH

Machine vision vendors were identified from an internet search and contacted using an informal request for proposal (RFP) letter requesting their interest in developing a prototype system. The RFP included photographs of the part to be inspected and a Power Point presentation showing how the part is manually sorted and graded. Following initial contact, requirements were further clarified and examples of the star pattern casting to be inspected were sent to the vendors for their evaluation and system design.

4.2. FUNCTIONAL REQUIREMENTS

Vendors were asked to meet the following general performance requirements.

- Example Test Part: Perform surface inspection of a standard test casting used for foundry emissions testing (Figure 9).
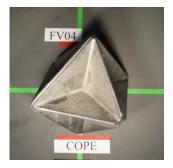
Figure 9   Standard Star Pattern Casting Used for Foundry Emissions Testing.
The casting is 8" x 8" x 10" and weighs 17.5 lbs

- Operator Defined Parameters: The acceptance/rejection parameters for the part will be determined by the inspection staff and programmed into the system. The acceptance parameters shall include detectable surface texture and topographical features as listed in section 4.3.

- Operator Input: Surface threshold values or parameters for acceptance or rejection shall be dialed-in by an operator for a given part.

- Display of Inspection Data: The inspection system shall provide graphical and numerical data displays with indicators of acceptance or rejection clearly identified.

- System Configuration: The machine vision system shall be configured as a stand alone unit intended to operate in a research foundry environment.

4.3. SURFACE FLAWS TO BE DETECTED

Vendors were provided with general inspection criteria and sample star pattern castings to assist with system design and performance. Criteria for surface inspection included:

- 100 % of the casting surface.
- Surface Finish < 420 micro inches.
- Porosity
- Pitting
- Holes
- Cracks
- Protrusions
- Dimples
- Burnt-on sand

5. Vendor Responses

5.1. DISCUSSION

Vendor responses and projected development costs are summarized in Table 1. All of the vendors recommended a feasibility or design study to determine hardware and software requirements prior to building a surface inspection system. The major emphasis of the design study would be on developing algorithms and software for image processing and surface feature extraction. Hardware considerations were similar for each vendor and typically configured around a camera, frame grabber, lighting frame, x-y table, computer, part holding fixture and support table. Vendor contact information is listed in Appendix A.

5.2. PROPOSAL EVALUATION

Coherix, Inc.: Coherix, Inc. was not able to respond with a cost proposal in time for inclusion in this report. They are working on a 3DX multiple camera system that may have application potential for casting surface inspection. This company has a measurement product called ShaPix that is in use by several automotive manufacturers for inspecting machined surfaces. Some of these users have multiple installations of ShaPix and include:

- GM Proving Grounds, Milford, MI for brakes, rotors and hub measurements.
- Delphi, Sandusky, Ohio for hubs, rotors and wheels.
- TRW, Livonia, MI for product development.
- Bosch, Clarksville, TN for process control for brake rotors and pads.
- Daimler-Chrysler, Kokomo, IN for measurement of transmission valve bodies.
- Pontiac Coil, Clarkston, MI for measurement of solenoid flatness.

Lightway systems Corp.: The Lightway Systems Corp. submitted a detailed proposal configured around a stand alone optical based inspection system to detect and quantify a variety of surface defects. The system will have a feature resolution of 1mm (0.04"). Images would be captured under several lighting conditions, switched and controlled by computer. The resulting image will be the composite results of these multiple images. The resulting display will graphically and numerically identify the various defects in location and size. Display data can be logged with operator entered data such as date, mold number, batch number, comments, etc. Inspection data

results can be exported with operator entered data for spreadsheet type analysis. The system will detect porosity (holes in the casting surface), protuberances (defects coming out of the surface) and anomalies (dimples, cracks and inclusions). The location of the feature will be identified by color coded contouring based on size. An operator acceptance threshold will identify the features determined to be unacceptable by a red "X" within the contour. A numerical value will be displayed at each feature to quantify the surface area of the respective feature. This parameter will be the threshold mentioned above. A matrix of size (user adjustable) and quantity (number of occurrences) will be provided.

Dr Melvyn Smith, University of the West of England: Dr. Smith recommended an evaluation of what machine vision techniques (including both hardware and software) are best suited to analysis of the defects. This will be determined through tests that will be conducted in the dark room. In each trial a selected defect will be imaged using a range of light sources/cameras/lenses, in order to determine a specification for suitable lighting configurations and camera parameters. Techniques such as diffuse/directional illumination, as well as structured light (examples include laser triangulation and photometric stereo) will be employed. Images of defects will be employed in investigations of suitable image processing algorithms. This could, for example, involve the processing of photometric stereo images to determine bump (gradient) maps for the parts, which would then be used in virtual renderings of the surface of the parts to enhance the visibility of the defects. Such techniques would be employed in conjunction with conventional image processing techniques (e.g. thresholding and segmentation).

Novacam technologies Inc.: The Novacam Technologies Inc. proposal included a design specifically planned for a stand alone manual casting surface inspection system. The Novacam basic display and inspection software calculates the percentage of the surface with defects. Classification of the defect and calculation of casting surface finish would have to be developed as part of the design phase of the project. Scan times took up to 25 minutes which would have to be reduced to five minutes or less for use in a foundry test lab environment.

Saber Engineering: Saber Engineering would require a feasibility study to develop the hardware, basic algorithms and software for casting surface inspection followed by a system integration effort. No technical details were given in the proposal.

Vulcan Engineering Co.: The Vulcan Engineering Co. proposed a feasibility study to determine if surface finish and specific surface defects can be detected with the same equipment. Vulcan

Engineering has experience with casting quality inspection systems and has a line of machine vision systems built for specifically for casting inspection. These applications include:

- Identification and orientation of castings.
- Dimensional gauging and measurement
- Surface Inspection to check for pores, stickers and other surface defects.
- Ultrasonic testing
- Fixed automated casting inspection systems. The inspection system can be designed to meet specific needs.

Webview, Inc.: Webview Inc. experimented with several configurations of their Spectrum Vision System. Based on preliminary data, they can provide a system that will define surface characteristics of a casting and detect and locate defects that are defined by user input. Webview Inc. conducted extensive testing using a sample star casting and provided confidential pictures of scanning results.

Wintriss Engineering Corp.: The Wintriss Engineering Corp. proposed a design study to prototype a method to inspect the star casting. They would scan the part using their proprietary lighting technique and perform surface finish measurements to develop a detection algorithm.

Table 1 Summary of Vendor Responses

VENDOR	FEATURES DETECTED	TECHNICAL APPROACH	EQUIPMENT	SYSTEM DEVELOPMENT COST ESTIMATE
Coherix	Proposal not complete at time of publication of this report	TBD	TBD	TBD
Lightway Systems	- Porosity – holes in the casting surface - Protuberant – defects coming out of the surface - Anomalies – other surface discontinuities such as; dimples, cracks and inclusions	Optical based area scan camera graphically and numerically identifies defects compared to user acceptance threshold. Software for categorizing defects would have to be developed.	Camera with PCI frame grabber, lighting modules , computer and LCD monitor, application software, support fixture	Basic equipment cost not including software $14,450.00
Dr Melvyn Smith	Vendor requires feasibility study. Some preliminary imaging has been completed. See figures 10 and 11.	Vendor requires feasibility study.	TBD	Feasibility study only £5,000.00 ($9,480.21)
Novacam	3D surface map of porosity, cracks, holes, dimples and burnt-on sand. Classification of defect not available without further testing. See Figure 12.	Fiber based profilometer and x-y table. Output of profilometer provides 3D image of defects classified by an application program which would have to be written.	Fiber based profilometer with depth scanning range of 8mm, 150mm probe, acquisition 1000 points/sec, 10" x 10" x-y table with motion control and display station. See Figure 13.	$84,500
Saber (COGNEX)	Vendor requires feasibility study	Vendor requires feasibility study	CCD camera(s),Frame grabber, lighting, software	Feasibility study and system cost $50,000 .00
Vulcan Engineering	Vendor requires feasibility study	Vendor requires feasibility study	TBD	Feasibility study only $25,000.00

Table 1   Summary of Vendor Responses

VENDOR	FEATURES DETECTED	TECHNICAL APPROACH	EQUIPMENT	SYSTEM DEVELOPMENT COST ESTIMATE
Webview	Cracks, pits, protrusions, burnt-in sand, dimensions and surface texture. See figure 14.	Optical based scan camera and software for detecting and classifying surface flaws.	Three camera system, light frame, PC and fixture table for mounting part to be inspected.	Complete system $75,000
Wintriss Engineering Corporation **(Surface Inspection Co.)**	Vendor requires feasibility study	Optical based scan camera. Would have to develop algorithms and software for detecting surface flaws.	Linescan camera, part manipulator arm, fixture table and software	Feasibility study and system cost $75,000.00

(a) **(b)**
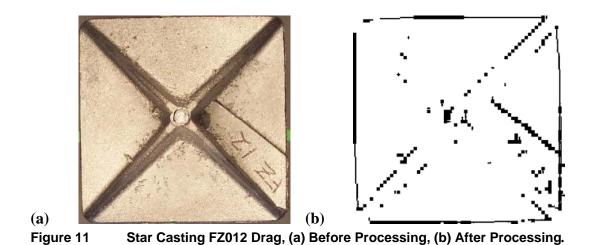
Figure 10   Star Casting FZ001 Cope, (a) Before Processing, (b) After Processing

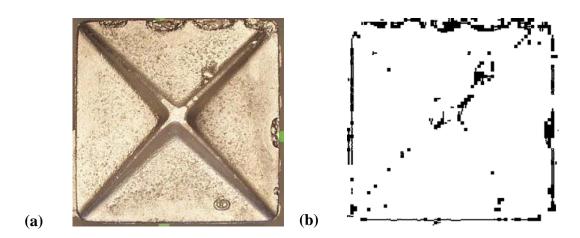

(a) **(b)**

Figure 11   Star Casting FZ012 Drag, (a) Before Processing, (b) After Processing.

These results have been achieved through basic image processing routines using the images sent to Dr Melvyn Smith. The black regions in Figures 10(b) and 11(b) indicate possible defective regions and their weighting provides some indication of severity.

COPE | DRAG

o | o
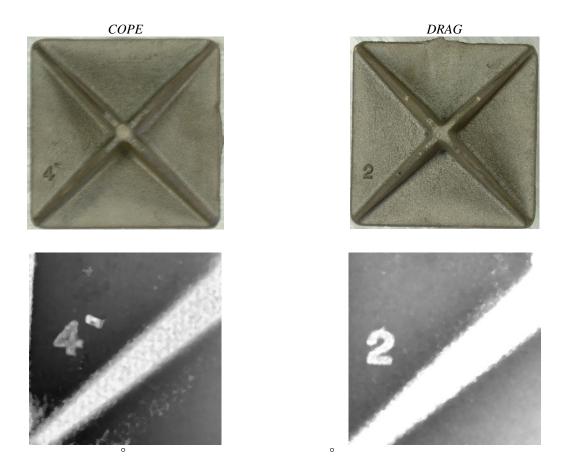
Figure 12   Portion of Cope and Drag Surfaces Mapped by Novacam

- *9x9cm surface mapped*
- *Acquisition time: 25min*
- *Acquisition matrix 40µm x 80 µm*
- *Brightness represents height*
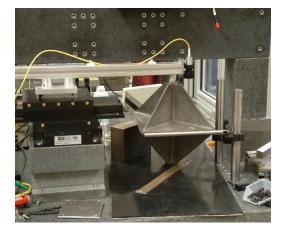
Figure 13   Novacam Profilometer

Figure 14   Display Reveals Pinholes Detected in a Casting by SPECTRUM Vision System Built by Webview

The system is programmed to detect and highlight (rectangles) surface flaws. Although this part was evaluated statically, SPECTRUM has the ability to evaluate moving parts.

6. Procurement Procedures

6.1. TWO-STEP DESIGN-BUILD CONTRACT

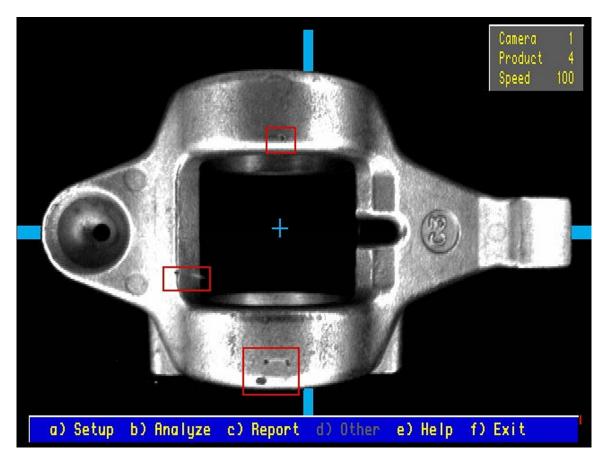Virtually all of the vendors contacted   would require feasibility or design study to build an inspection system that could detect and classify casting surface defects. Consequently, the recommended approach for developing a surface inspection system would be to use a two-step design-build procurement specification where the hardware, software and defect grading definitions would be worked out in step one resulting in a system design specification which would include a set of performance and acceptance test plans. In step two, the inspection system would be built and subjected to the performance/acceptance tests developed in step one. The procurement specification for the design-build contract will need to include star casting process standards as described in section 6.2.

6.2. STAR CASTING PROCESS STANDARDS

Star casting process standards are the core of the system design specification. The performance standards are particularly important for the development of algorithms and software that will detect, analyze and classify surface features such as texture, porosity, protrusions, dimples, cracks, burnt-on sand and inclusions. All tasks to be performed by the system must be defined. An effort must be made to translate human and qualitative parameters such as good, bad, big, little, bright, dark, and color into rules and measures. For example, a statement such as "pin holes can't be too big" must be quantified. A more precise definition for pinholes would be: "pin holes can't be bigger than 0.5 mm in diameter and 0.5 mm deep and cover more than 5% of the total surface area." Detecting surface defects is the first step followed by comparing the defects to a set of process standards and then grading the outcome of that comparison. Using the pinhole example from above, a rejection algorithm could be written into software for pin holes greater than 0.5 mm wide by 0.5 mm deep that exceed an area greater than 5% of the total surface area. Likewise, all other defects would be detected, classified and compared to the process standards resulting in a composite score useful for grading the finished casting. It is recommended that a process standard for the star pattern casting be written that defines and quantifies defects as well as defining the grading and ranking process for star pattern castings. This process standard will form the basis for vendor hardware and software design and follow-on acceptance testing of the system. See Appendix B for an example of a metal casting standard and Appendix C for the ASTM Standard A 802/A 802M-95.

6.3 **BUDGET REQUIREMENTS**

Preliminary system development costs ranged from $14,450.00 for basic equipment without software to $84,500.00 for the most complete budget proposal. Four vendors shown in Table 1 submitted cost estimates for a complete design-build project that ranged from $50,000.00 to $84,500.00. There are many unknown design features that would surface during a properly funded design-build contract making it difficult to forecast an exact purchase price. Consequently, allowing for variation in the final system specifications, it would be reasonable to anticipate that the preliminary cost estimates could increase by as much as 20% for an installed system (Table 2).

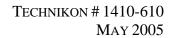**Table 2   Estimated Design-Build Project Cost**

VENDOR	ESTIMATE	20% INCREASE
Novacam	$84,500.00	$101,400.00
Saber	$50,000.00	$60,000.00
Webview	$75,000.00	$90,000.00
Wintriss Engineering	$75,000.00	$90,000.00

7. Conclusion

A diverse range of machine vision inspection vendors were contacted for this cost study. From the vendor responses several points became clear:

- The technology exists to duplicate the human inspection and analysis process for evaluating the surface quality of the star mold castings.

- There are enough qualified vendors within the United States and world-wide with the experience and the technology to allow for competitive and creative response to a request for proposal (RFP).

- Careful preparation of the statement of work (SOW) is critical to achieving the desired level of inspection accuracy, precision and functionality. It can not be stressed enough that the human inspection process be documented and quantified in process standards for the part to be inspected. Acceptance and rejection criteria must be spelled out in the process standards to allow ready development of algorithms and software. Finally, the SOW must clearly communicate exactly how the acquired data are to be used and how those data are to be reduced down to meaningful displays and reports.

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APPENDIX A   VENDOR CONTACT INFORMATION

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Web: http://www.vulcangroup.com/index_castfin.htm

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Ph: (707) 588-7982

FAX: (707) 588-7987

Attn: Philip Russo

Email: prusso@webspec.com

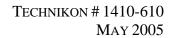Web: www.webinspection.com

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APPENDIX B   EXAMPLE PROCESS STANDARDS

DUCTILE (NODULAR) IRON LOWER CONTROL ARM - VISUAL INSPECTION STANDARD

1.0 GENERAL

1.1 Purpose of the Standard

The purpose of this standard is to assure that ductile iron lower control arm castings consistently meet engineering and manufacturing requirements.

1.2 Coverage of this standard

This standard describes the visual standards used to accept or reject front suspension lower control arm ductile iron castings.

2.0 REQUIREMENTS

2.1 Part Characteristics

Castings shall be produced in accordance with all the requirements of the specified material standard.

2.2 Visual Inspection

All castings, after cleaning and prior to shipment to the machining source, shall be visually inspected 100% for imperfections according to the following procedures:

2.2.1 Surface defects or pits resulting from sand or slag inclusions on all control arm edges/corners including the front or leading arm when viewed in car position will be limited in size to a maximum of 1.5 mm (0.059 in.) diameter x 1.5 mm (0.059 in.) depth.

Repair procedures to reduce the size of as-cast edge/corner surface defects to comply with the above requirements are not permitted.

2.2.2 Surface defects or pits resulting from sand or slag inclusions on all remaining as-cast surface areas of a machined lower control arm, excluding areas described in 2.2A will be limited in size to a maximum of 3.0 mm (0.118 in.) diameter x 1.5 mm (0.059 in.) depth.

2.2.3 Sharp bottomed nicks of any size resulting from handling defects or snag grinding are cause for rejection, without reworking.

2.2.4 Casting defects revealed on a subsequently machined surface will not be tolerated and cause for rejection, without reworking.

APPENDIX C   ASTM STANDARD A 802/A 802M-95

Designation: A 802/A 802M – 95 (Reapproved 2001)

Standard Practice for
Steel Castings, Surface Acceptance Standards, Visual Examination[1]

This standard is issued under the fixed designation A 802/A 802M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers the acceptance criteria for the surface inspection of steel castings by visual examination. Four levels of acceptance standards are provided.

1.2 Acceptance levels utilize Steel Castings Research and Trade Association (SCRATA)[2] graded reference comparators for the visual determination of surface texture, surface roughness, and surface discontinuities described as follows:

Acceptance levels

A—Surface Texture
B—Nonmetallic Inclusions
C—Gas Porosity
D—Solidification Discontinuities
E—Sand Expansion Discontinuities
F—Metal Inserts
G—Thermally Cut Surfaces
H—Mechanically Prepared Surfaces
J—Welded Surfaces

1.3 Descriptions of terms related to casting discontinuities are in Section 2.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *expansion discontinuities:*

2.1.1.1 *veins, n*—raised, narrow, linear ridges that form upon cracking of the sand mold or core due to expansion of sand and the resulting mold or core stresses during filling of the mold with liquid steel.

2.1.1.2 *rat tails, n*—long, narrow, linear depressions or small steps occurring on a casting surface. Rat tails form as a result of sand expansion and minor buckling of the mold surface during filling of the mold with liquid metal.

2.1.1.3 *scab, n*—a raised, rough area on a casting that usually consists of a crust of metal covering a layer of sand. Sometimes, a scab consists of a raised, rough area of essentially solid metal on the surface of a casting.

2.1.2 *external chills:*

2.1.2.1 *external chills, n*—usually metal blocks, or graphite and carbon blocks, that are incorporated into the mold to locally increase the rate of heat removal during solidification. Brackets have the same purpose but represent an integral part of the casting. Brackets are produced by providing suitable cavities in the mold or core. External chills may produce flat spots and edges (raised areas or depressions) on the casting surface. Brackets merely change the casting appearance due to their presence. Brackets may be removed or allowed to remain on the casting.

2.1.2.2 *parting line and core print fins, n*—thin projections of excess metal at the parting plane between mold halves or core and mold. Causes are improper closing of the mold, insufficient weighting or clamping of the mold for pouring, or uneven pattern surfaces at the matching locations. Core print fins are usually caused by improper dimensions of core prints of the pattern or core box, by rough placement of cores in a soft mold, or by inadequately secured cores.

2.1.3 *fusion discontinuities:*

2.1.3.1 *wrinkles, n*—elongated, smooth depressions of the casting surface, frequently appearing in closely spaced groups. Wrinkles result from irregularities of the liquid metal flow in the mold cavity, frequently associated with low temperature, and are distinguished from the more severe phenomenon of laps, folds, or cold shuts where the casting surface is actually folded over.

2.1.3.2 *laps, folds, and cold shuts, n*—interchangeable terms to describe the appearance of the casting surface that is actually folded over. They develop due to low temperature, unfavorable flow conditions caused by oxide films, or combinations thereof.

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.18 on Castings.

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[2] Available from The Castings Development Centre, 7 East Bank Road, Sheffield, UK S2 3PT.

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2.1.3.3 *misrun, n*—an incompletely formed casting, due to only partial filling of the mold cavity when the liquid metal solidifies prematurely. The resulting casting appearance is characterized by rounded edges, for a mild degree of misrun. Irregular, malformed edges of more severe misruns, and not fully formed castings, are characteristic. Frequently, misruns are associated with such discontinuities as wrinkles or laps and folds, or both.

2.1.4 *gas porosity, n*—a concave discontinuity in castings due to the evolution of gas, either from the solidifying metal or the surrounding mold.

2.1.5 *inserts:*

2.1.5.1 *chaplets, n*—metallic (steel) devices used to maintain the spacing between the core and the mold. Low liquid metal temperature and unfavorable flow conditions in the mold may produce insufficient fusion and cause irregular contact areas on the casting surface.

2.1.5.2 *internal chills, n*—metallic (steel) devices used to locally increase the rate of heat removal during solidification. Incomplete fusion due to low liquid steel temperatures and prevailing flow conditions may produce irregularities of the surface similar to those that may be associated with chaplets.

2.1.6 *linear discontinuities, n*—elongated discontinuities are considered linear if their length equals or exceeds three times the width.

2.1.6.1 *cracks, n—cold and hot*, less jagged, sometimes straight ruptures that occur after solidification of the casting, due to excessive strain. Sometimes cracks are referred to as cold, hot, or heat treat-cracks to indicate the condition of the castings, or the operation during which the cracks occur.

2.1.6.2 *hot tears, n*—jagged ruptures in castings that occur during the final stages of solidification, while there is still some liquid in the interdendritic spaces, or shortly after solidification is complete.

2.1.7 *metal removal marks, n*—flame cutting and air carbon-arc cutting produce parallel grooves in the cut-off area. Finer marks are produced with the abrasive cut-off wheel and grinding.

2.1.8 *nonmetallic inclusions, n*—casting surface inclusions such as ceroxides, slag, and sand are partially or completely removed during the cleaning process of pressure blasting. Surface discontinuities left by these inclusions are referred to by the inclusion type that caused their formation:

2.1.8.1 Ceroxides cause depressions on the surface of the casting by displacement of molten metal. Ceroxides consist of a mixture of low-melting oxides and partially fused sand. The crater-like appearance of the casting surface depression is typical.

2.1.8.2 Depressions on the casting surface caused by slag are similar to those caused by ceroxides. They differ by a more rounded appearance of the depression and do not exhibit the crater-like appearance of ceroxides.

2.1.8.3 Depressions caused by sand are similar to those of ceroxides and slag. Their appearance may, at times, more closely reflect the granular nature of the sand.

2.1.9 *shrinkage under risers and gates, and revealed by machining, n*—a shrinkage void is a discontinuity in castings due to the lack of available liquid feed metal during solidification contraction. Riser removal and machining may reveal shrinkage that extends from the interior of the casting to the near surface area.

2.1.10 *surface texture, n*—cast surfaces have a multi-directional lay, without the uniform sequence of ridges and valleys of machined surfaces.

2.1.11 *welding:*

2.1.11.1 *weld undercuts, n*—narrow elongated depressions that border the weld contour and result from improper welding conditions or inadequate control of welding operations.

2.1.11.2 *weld spatter, n*—weld metal droplets that solidified against and adhere to the component being welded.

3. Ordering Information

3.1 The inquiry and order should specify the following information:

3.1.1 *Acceptance Level*—More than one acceptance level may be specified for different surfaces of the same casting (see Section 4),

3.1.2 If any types of discontinuities are unacceptable,

3.1.3 Extent of casting surfaces to be examined, and

3.1.4 Number of castings to be examined.

4. Acceptance Standards

4.1 Levels of acceptance for visual inspection are listed in Table 1.

4.2 Surface discontinuities not covered in Practice A 802/A 802M shall be a matter of agreement between the purchaser and the manufacturer.

5. Keywords

5.1 steel castings; surface acceptance standards; visual

TABLE 1 Visual Inspection Acceptance Criteria

Surface Feature	Level I	Level II	Level III	Level IV
Surface texture	A1	A2	A3	A4
Nonmetallic inclusions	B1	B2	B4	B5
Gas porosity	C2	C1	C3	C4
Fusion discontinuities	. . .[A]	D1	D2	D5
Expansion discontinuities	. . .[A]	. . .[A]	E3	E5
Inserts	. . .[A]	. . .[A]	F1	F3
Metal removal marks:				
Thermal	G1	G2	G3	G5
Mechanical	H1	H3	H4	H5
Welds	J1	J2	J3	J5

[A] No reference comparator plate is available for this surface feature and level.

2
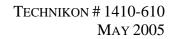
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