

**ENHANCING ENGINE BLOCK QUALITY BY REDUCING METAL CHIPS IN
POROSITIES – A CASE STUDY**

A Thesis

Presented to

**the Faculty of the College of Science and Technology
Morehead State University**

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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March 25, 2009

Accepted by the faculty of the College of Science and Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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Quality assurance plays an important role in ensuring that products are of good quality because any defects in the products cause poor performance or product failure. The presence of porosities and inclusions (chips) in composite materials or aluminum alloys is one of the most serious problems encountered in the production of aluminum castings. Inclusions that affect the mechanical properties are detrimental to surface finish, increase porosity and are linked to increased corrosion.

Non-destructive methods such as Ultrasonic inspection, X-Ray diffraction, and Borescope inspection are the most common methods used to detect internal defects in castings. Previous methods, results, and statistics are taken from Toyota Motor Manufacturing Kentucky. Five different methods, 1) Notched Drill, 2) 2-Sec dwell, 3) Increase Drill Point Angle, 4) Increased Feed Rate and 5) Slow Retraction are used to drill the journal holes of an AR block. A total of 123 AR blocks were used to test the drilling of the journal holes and the research team found that the Slow Retraction method was the most effective. Using this method, the research team found only 13% of the

AR blocks had left over chips inside the porosities, which could subsequently be removed by using air pressure and by manual brushing.

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ACKNOWLEDGMENTS

I would like to say thanks to everyone who supported and encouraged me in finishing my thesis. Especially Toyota, for their invitation to come and learn about their projects and the opportunities provided for my thesis.

Thanks to my advisor, Dr. Ahmad Zargari, Department Chair of Industrial and Engineering Technology and thesis committee member, for his consistent motivation and encouragement. He is a person who has helped me during my stay at Morehead State University in getting an assistantship and is the person who aided me in finding a thesis project at Toyota Motor Manufacturing Kentucky, Inc.

I would also like to thank Dr. William Grise, my thesis director, for his continuous guidance and feedback. He was so patient and always encouraged me to continue my research throughout the process.

I admire Dr. Steven Hunt, my external committee member, because of his willingness to help me in writing my thesis. His encouragement and motivation has guided me throughout this process, in particular his suggestions and directions have been invaluable in finishing my thesis.

Special thanks to Mr. David A Cox, General Manager, Toyota Motor Manufacturing Kentucky, Power train, for giving me the opportunity to work with Toyota and giving me the necessary access to the company to finish my thesis.

I would like to express my gratitude towards Mr. Scott Watkins, Power Train Production Engineering, who made all his resources available to me and guided me through the proper techniques to find a solution to the problem of my thesis despite

his busy schedule. He was so patient in answering all my questions and helping me with my doubts about the research methods used.

I owe a great deal to my parents, Mr. Mohan Rao Kurella & Mrs Lalitha Kurella, for without their love and support I wouldn't have been able to finish this process. Finally I would like to say thanks to my friends Brittany Lunsford and Robin Watson for their support and their consideration in helping me proof read my thesis.

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CHAPTER 1

Introduction

According to D'Orazio, T. L. M. (2008), in manufacturing, quality assurance plays an important role in ensuring that products are of good quality because any defects in the products cause poor performance or product failure. The presence of porosities and inclusions (chips) in composite materials or aluminum alloys is one of the most serious problems encountered in the production of aluminum castings. Inclusions that affect the mechanical properties are detrimental to surface finish, increase porosity and are linked to increased corrosion.

Therefore, detection of porosities and foreign inclusions has received great attention in recent years in order to enhance quality during production phases and for in-service inspection during maintenance operation. Results from several non-destructive techniques are integrated to analyze the internal properties of structures without causing damage to the materials. Some of the non-destructive techniques are ultrasonic inspection, X-ray diffraction, eddy current detection, thermography imaging, shearography analysis, magnetic particle attraction, penetrant detection, etc. For example, the visual inspection of an engine cylinder is time consuming one and cannot detect small and internal defects. Therefore, a computerized inspection and data collection equipment is required to detect internal porosities and inclusions.

Significance of the Study:

Toyota is one of the leading producers of automobiles in the present world. It manufactures cars, SUV's, trucks and other automobiles that make life easier for human beings. According to customer surveys, the word quality is the synonymous to Toyota as they have never disappointed their customers with their product. Just as all other automobiles have problems in leakage of engine oil and failure of engine after certain thousands of miles, so Toyota had similar problems as well. The primary causes of engine oil leakage and engine failure are due to excess porosities and foreign inclusion (chips) inside the (porosities) journal holes and oil gal hole of an engine cylinder. Forty-five percent of the AR blocks were found to have chips inside the porosities of journal holes which causing increase in production cost as well as decreasing the performance of an engine.

Problem Statement:

The primary causes of engine oil leakage and engine failure are due to excess porosities and foreign inclusion (chips) inside the (porosities) journal holes and oil gal hole of an engine cylinder (Toyota Motor Manufacturing Kentucky Inc, Georgetown). In an AR block, the journal hole #1.1 is provided to bring oil to the crank case, while the other journal holes #1 through #5 are to bring oil to the engine cylinders. Most of the porosities are formed from air bubbles while casting, and are impossible to eliminate. These porosities provide traps for the chips which can block the oil holes and even settle into the bearings while the engine is running. This can cause oil leaks and even engine failure after some thousands of miles.

Research Objectives:

- To improve the performance of an engine block.
- To increase the rate of production.
- To suggest the best possible method to drill journal holes of an AR block.

CHAPTER II

Review of Literature:

Ultrasonic Inspection:

According to D'Orazio, T. L. M. (2008), over the last several years, ultrasonic inspection techniques have been shown to be very promising for non-destructive inspection and interestingly, they have been more effective than the traditional approaches such as thermography, eddy current inspection, or shearography.

Ultrasonic inspection is used to locate defects in castings. Let us consider a sound wave passing through a steel object, with a wavelength in the ultrasonic range. When the energy is passed, the sound waves are induced to travel in straight lines rather than diffusing in all directions. If there are any porosities and inclusions, the path of the ultrasonic beam will be deflected. The deflection of the beam then is monitored by a detector placed opposite to the transducer. The size and depth of the defect can also be determined when short bursts of sound energy are introduced and subsequently picked off of a detector. In ultrasonic testing, sometimes a frequency of 50MHz will be introduced to detect internal flaws and properties of the material. The average frequency of an acoustic wave will be in the range of 0.1 to 15 MHz

Ultrasonic testing is mostly performed on aluminum castings, steel and other metals and alloys. This test can also be conducted on concrete, wood and composites, albeit with less resolution. Ultrasonic testing is one of the most useful forms of non-

destructive testing, and has been deployed in many industries such as the automotive, aerospace and transportation areas.

The two important steps that need to be considered while interpreting ultrasonic data are the pre-processing technique and the multi-level neural approach. The pre-processing technique is used to normalize the signals from composite structures with different thicknesses. In this step, to detect classes of similar point and for ultrasonic signal comparisons, different classification techniques are used. In the second step, the defective areas are separated from the sound ones and divided according to their defect type and depth of the defect. Typically, an ultrasonic inspection system consists of the following components: pulsar, receiver, transducer, and display devices. The function of the pulser is to produce a high voltage electrical pulse; the transducer converts the voltage into a high frequency ultrasonic wave which then transports sound energy into the material in the form of waves driven by the pulser. Ultrasonic inspection devices may or may not be in contact with the testing material. The main difference between the transmission mode and reflection mode is the position of the receiver. In transmission mode, it is placed on the opposite side of the material from the pulser whereas in reflection mode, it is placed on same side of the material. In non-contact ultrasonic inspection, a liquid couplant is used to transmit ultrasonic vibrations from the transducer to the testing surface. The three most common formats for displaying ultrasonic data are A-scan, B-scan and C-scan presentations. The analysis of ultrasonic data is different in all three formats. The

ultrasonic signal's strength depend on the thickness of the inspected materials, in order to minimize the signal variations, a proper normalization technique must be introduced. Normalization is required to analyze the signal variations. This technique helps to suppress non significant samples from deeper material until the path of the ultrasonic signal becomes equal to the signals emitted from thinner samples. To process normalized data, a two level set of neural classifiers is used. The first level set of the neural network helps to produce a binary image that shows defect areas on which successive processing can be carried out. The second level consists of three neural networks which helps to detect the positions of defects in a material and both the displacement and the type of defect in a single step.

Data pre-processing:

According to D'Orazio, T. L. M. (2008), for the analysis of ultrasonic data by an automated system, the researcher need to consider the materials that have the same thickness so that the signals are normalized and can compare the path length of the signals. Therefore, thicknesses of the material can be observed from the normalized ultrasonic data. As different thicknesses of material have different delays between frontal echo and back echo, researcher needs to align signals that relate to materials of different thicknesses. If the thickness of the material, distance of the probe from the standard, frequency and compliant type are known, the distance between the Back echo and Frontal echo can be computed mathematically.

Experimental set up for an Ultrasonic Testing:

According to Suresh Palanisamy (2009), the most common automated ultrasonic inspection equipment has an immersion tank where the part is placed under water and the transducer is placed just above the inspection area of the part. The testing equipment also consists of an ultrasonic flaw detector (EPOCH1III), immersion probes capable of detecting frequency of 10MHz and 20 MHz, a water tank, probe holding and handling devices, and calibration blocks. The probe holding device should be designed using Pro/Engineer and CAD software so that the total payload that the PUMA robot (probe handling device) will handle is 4.0 kg under static conditions and 2.5kg under dynamic conditions so that the probe is easily recovered. Two laser pointers are attached to the probe holding device to focus on the immersed part. When the sample part is immersed in the inspecting tank, the PUMA robot will move to the top of the casting where the ultrasonic inspection will take place. The readings will be stored in the flaw detector.



FIG. 1

An example of Ultrasonic Testing on blade roots of a V2500 IAE aircraft engine.

Step 1: The UT probe is placed on the root of the blades to be inspected with the help of a special bore scope tool (video probe).

Step 2: Instrument settings are input

Step 3: The probe is scanned over the blade root. In this case, an indication (peak in the data) through the redline (or gate) indicates a good blade; an indication to the left of that range indicates a crack. (Ultrasonic testing, 2008)

Sample Parts for an Ultrasonic inspection:

A good example that can serve as a benchmark for ultrasonic testing will be found in the manual transmission case (MTC) where in most of the subsurface discontinuities are found around the bearing and seal bosses (where extensive porosity is found which cause leaks in parts containing fluids as well as tool breakage which results in product failure and incur significant cost penalties). This complex casting requires extensive machining which adds further cost. Another sample casting where one can use ultrasonic testing is the structural oil sump pan (SOSP), which suffers from leaks caused by porosity in the gate region. As the gate area is the last area to solidify, shrinkage in this zone causes porosity with openings of up to 2 to 3 mm in depth. Other important locations where chips settle inside the porosities are oil gal hole and journal holes in an AR block of a 4-cylinder engine. After running the engine for a long time, these chips from the porosities (journal holes) block the oil holes and enter into the bearings, which can cause engine failure.

Advantages of Ultrasonic Testing:

Ultrasonic inspection is a useful and versatile non-destructive testing method.

Some of its important advantages are

- a. It is sensitive to both surface and subsurface discontinuities.
- b. The depth of penetration for flaw detection or measurement is superior to other NDT methods.
- c. Only single-sided access is needed when the pulse-echo technique is used.
- d. It is highly accurate in determining reflector position and estimating size and shape.
- e. Minimal part preparation is required.
- f. Electronic equipment provides instantaneous results.
- g. Detailed images can be produced with automated systems.
- h. It has other uses, such as thickness measurement, in addition to flaw detection.

(Basic Principles of Ultrasonic Testing, December 15, 2008)

Limitations of an Ultrasonic Testing:

As with all NDT methods, ultrasonic inspection also has its limitations which include:

- a. Surface must be accessible to transmit ultrasound.
- b. Skill and training is more extensive than with some other methods.
- c. It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.

- d. Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- e. Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- f. Linear defects oriented parallel to the sound beam may go undetected.
- g. Reference standards are required for both equipment calibration and the characterization of flaws. (Basic Principles of Ultrasonic Testing, December 15, 2008)

X-Ray Inspection:

X-ray Inspection is another type of nondestructive testing method used to detect and evaluate internal defects in castings such as porosities, cracks, and foreign inclusions. According to Yinggan Tang, X. Z. (2008) for continuous inspection of castings, X-ray inspection technique is integrated with digital image processing and automatic image assessment. But in practical applications, the quality of X-ray images are poor and highly skilled labor is needed to implement this technique which adds further cost. To get more effective detection of internal defects in castings from an X-ray inspection, the integration of fuzzy set theory and the bound histogram technique is required. The X-ray inspection technique is widely used to detect and evaluate internal defects in castings and also in industry products encountered in micro miniature electronic circuits. In the X-ray inspection method, when a collimated beam of ionizing radiation emitted from the setup X-ray tube is passed through the

inspecting material, the X-ray energy level is attenuated in proportion to the material thickness. As the beam passes through the casting, any porosities or foreign inclusions will come a shadow to form on the imaging device, which may be either image-intensifier coupled to a charge-coupled device camera or to a digital imaging system.

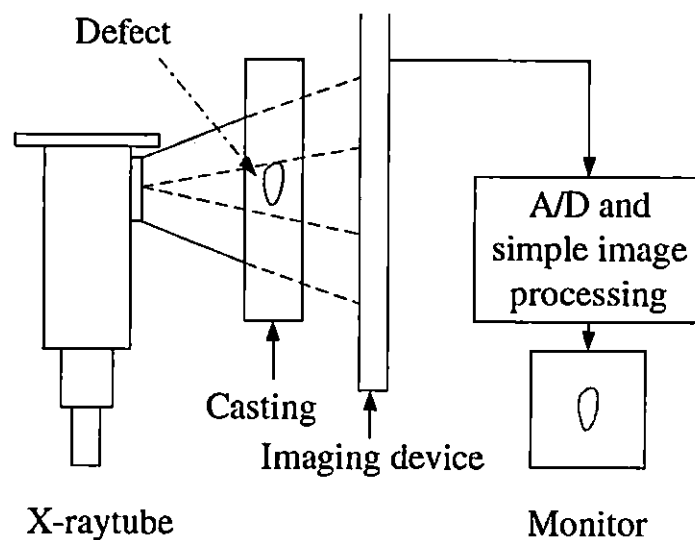


FIG. 2

Experimental set up for an X-ray inspection (Yinggan Tang, 2008)

The digital image shows the defects in castings such as porosities, cracks or any foreign inclusions. By analyzing the image, it will be easy to classify whether the casting is normal or abnormal. There are two steps to classify it. The first step is to determine what is and what is not a defect and the second step is to classify the type of defect that appears in the X-ray image. Traditionally, the X-ray images of an

inspected material are analyzed by a human inspector. As there are more chances of making an error, and because the inspection quality depends on the quality of images, an automatic inspection system which is equipped with modern computer and its associated software will improve the detection objectivity and reduce manpower cost. As X-ray images usually contain noise, and are corrupted by nonuniform illumination and low contrast, it is always difficult to detect defects in X-ray images in an automated inspection system. Background subtraction is a common approach to determine defects in X-ray images. In the background subtraction method, a reference image without defect is obtained initially and subtracted from the original image. Finally, the residual image contains only defects. But the filtering of an original image to eliminate the defects while preserving the normal grey level variation of images is very difficult to derive a reference image.

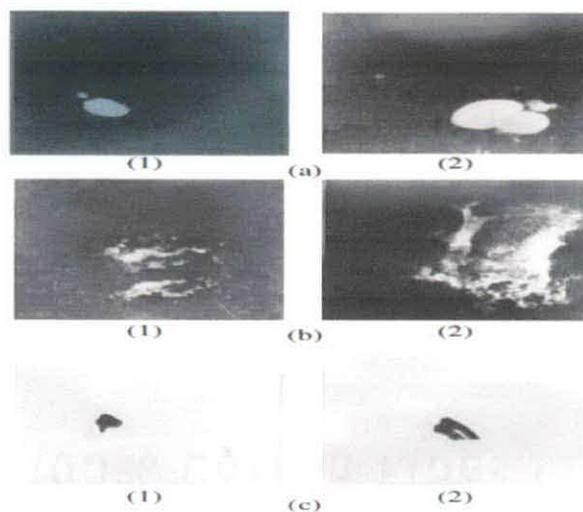


FIG. 3

(Yinggan Tang, 2008) Internal defects in castings: a) Air hole defects, b) Foreign object defects, c) Shrinkage cavity defects

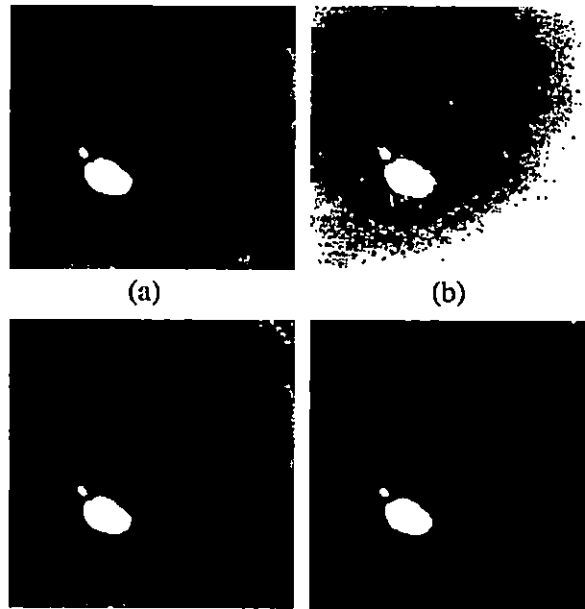


FIG. 4

Segmentation results of air-hole defect (Yinggan Tang, 2008)

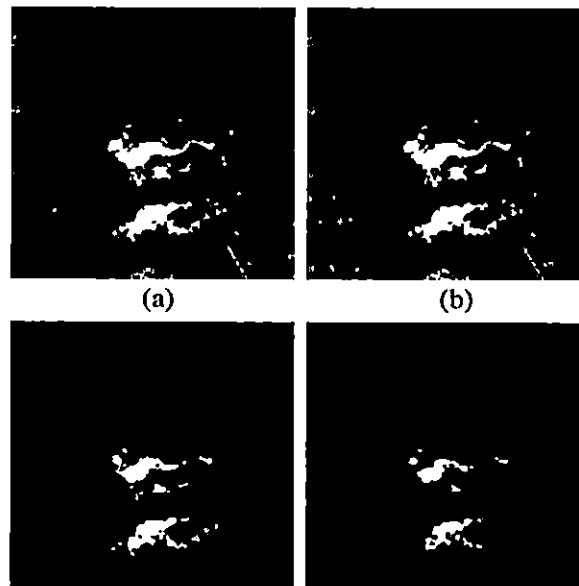


FIG. 5

Segmentation results of shrinkage-cavity defect (Yinggan Tang, 2008)

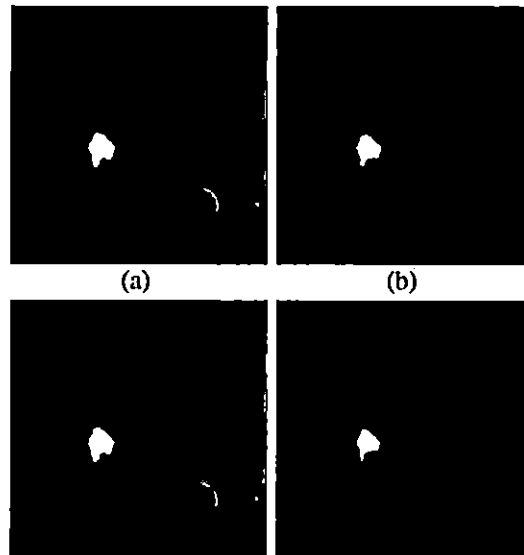


FIG. 6

Segmentation results of foreign-object defect (Yinggan Tang, 2008)

Confocal Method:

According to *Confocal Chromatic Sensors for Displacement and Position* (2008), confocal technology is another non-contact displacement and thickness measuring method used to detect internal defects of a casting such as cracks, porosities and foreign inclusions. This system consists of a sensor and a controller which are connected by fibre-optic sensor cable. An example of this system is represented by optoNCTD2401/2402. Since the sensor is reflective, does not have any moving parts, and loses no heat, the accuracy of the sensor and the equipment used to determine defects is maximized. Care is to be taken while handling the fibre-optic sensor cable which connects the sensor to the controller to avoid bending the fibre to a radius of curvature of less than 20 mm. In order to avoid contaminating the

tips of the fibre, the ends of the fibre should be connected to the sensor and controller at all times or it should be fitted with their protective caps.

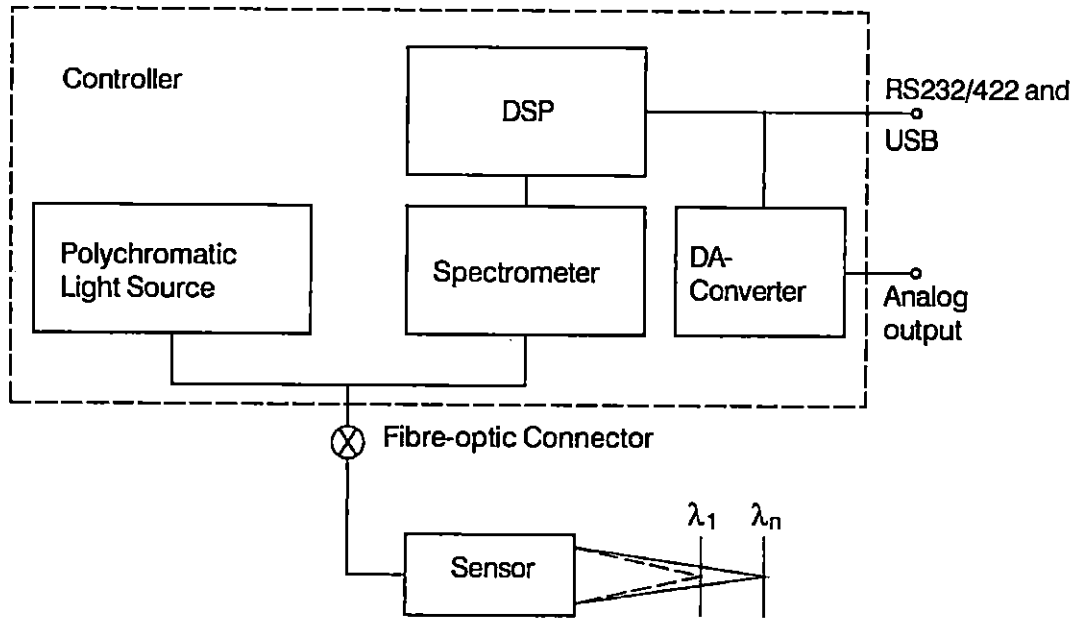


FIG. 7

Block diagram of optoNCDT2401/2402 (Confocal chromatic sensors for displacement and position, 2008)

The controller incorporates a LED light source and converts the light signals received from the sensor. Other important functions that it performs are calculating the distances via the on-board DSP processor and also providing display and data transmission functions via the RS232 or USB link or via the 0-10 volt analog output.

Measurement Principle:

According to Confocal Chromatic Sensors for Displacement and Position, In optoNCDT, lens are arranged in such a way that when a polychromatic white light is

focused on a target by a multi lens optical system, the white light is dispersed into a monochromatic light by controlled chromatic deviation. The wavelength or focal point is focused on the target that is used for measurement. When the light is focused on the target, the reflected light from the surface of the target is passed to a receiver which detects and processes the spectral changes via confocal aperture. Since optoNCDT is a unique measuring principle, it enables displacements and distances are measured with high precision. Also shadowing is easily avoided as both emitter and receiver are arranged in one axis. (Confocal chromatic sensors for displacement and position)

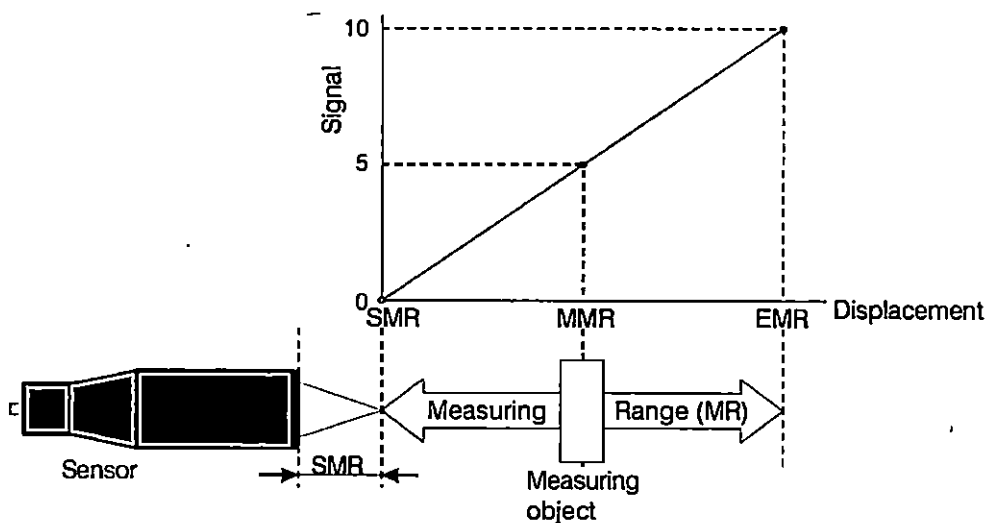


FIG. 8

Measuring range and controller output signal (Confocal chromatic sensors for displacement and position, 2008)

SMR: Start of measuring range. Minimum distance between sensor front and measuring object

MMR: Midrange

EMR: End of measuring range (start of measuring range+ measuring range).Maximum distance between sensor front and measuring object.

MR: Measuring range.

Typical applications:

- a. This system is capable of measuring thickness from few tens of microns to several millimeters.
- b. Measures profiles and surface topographies when the sensor is combined with a 3D measurement station.
- c. Measures surface reflections.
- d. Readings are calibrated automatically and no skilled labor is required.

Model (standard)	IFS 2401-0.12	IFS 2401-0.4	IFS 2401-1	IFS 2401-3	IFS 2401-10	IFS 2400-10	IFS 2400-24	IFS 2401-25	
Measuring range	120 μm	300 μm	1 mm	3 mm	10 mm	10 mm	24 mm	22 mm	
Start of measuring range approx	3.4 mm	9.9 mm	10.0 mm	16.3 mm	27.0 mm	67.0 mm	213.0 mm	20.2 mm	
Spot diameter	7 μm	10 μm	10 μm	25 μm	50 μm	50 μm	100 μm	100 μm	
Linearity	diffuse reflective target ¹⁾	0.24 μm	0.6 μm	2 μm	6 μm	20 μm	20 μm	-50 μm	-50 μm
	specular target ²⁾	$\leq \pm 0.1\% \text{ FSO}$			$\leq \pm 0.05\% \text{ FSO}$				
Resolution		-0.005 μm	0.012 μm	0.04 μm	0.12 μm	0.4 μm	0.4 μm	-1 μm	-0.9 μm
		0.004 % FSO							
Weight	sensor	0,20 kg	0,22 kg	0,22 kg	0,16 kg	0,19 kg	0,68 kg	0,52 kg	0,19 kg
	sensor+MA 2400	0,38 kg	0,40 kg	0,40 kg	0,34 kg	0,37 kg	0,90 kg	0,76 kg	0,37 kg
Max. tilt	direct reflection	$\pm 43^\circ$	$\pm 28^\circ$	$\pm 27^\circ$	$\pm 22^\circ$	$\pm 14^\circ$	$\pm 14^\circ$	$\pm 5^\circ$	$\pm 8,5^\circ$
	diffuse reflection	$\pm 80^\circ$							
Repeatability	0.01 % FSO								
Measuring rate	selectable from 100 Hz up to 2000 Hz, optional 30 kHz								
Ambient light	30.000 lx								
Light source	LED								
Protection class (sensor/controller)	IP 40								
Stability (sensor)	$\pm 0.02\% \text{ FSO/month}$								
Temperature stability (sensor)	0.01 % FSO / °C								
Operation temperature	+10 up to +50 °C								
Storage temperature	-30 °C up to 70 °C								
Output	0 - 10 V / RS 232 / RS 422 / USB								
Supply	24 VDC								
Sensor cable (fiber optic cable)	standard 3 m option up to 50 m								
Controller	dimensions (W x H x D): 168 x 138 x 111.5 mm (6.61 x 5.43 x 4.39 inches)								
	functions: touch keys, trigger, synchronization, storage of up to 20 configurations (for sensors with different ranges)								
Electromagnetic compatibility (EMC)	EN 50081-1 and EN 61000-6-2								

FIG. 9

(Confocal chromatic sensors for displacement and position, 2008)

Technical data IFS2401

FSO=Full scale output

- 1) Applying to perpendicular and diffuse surfaces with reflection (intensity) >5%
- 2) Applying to perpendicular and specular surfaces (polished glass)

All data based on constant ambient temperature.

Model (standard)	IFS 2402-0.4	IFS 2402-1.5	IFS 2402/90-1.5	IFS 2402-4	IFS 2402/90-4	IFS 2402-10	IFS 2402/90-10
Measuring range	400 μm	1.5 mm	1.5 mm	3.5 mm	2.5 mm	6.5 mm	6.5 mm
Start of measuring range approx.	1.5 mm	0.9 mm	2.5 mm ¹⁾	1.9 mm	2.5 mm ¹⁾	2.5 mm	1.5 mm ¹⁾
Spot diameter	10 μm	20 μm	20 μm	20 μm	20 μm	100 μm	100 μm
Linearity	diffuse reflective target ²⁾	0.8 μm	3 μm	3 μm	7 μm	5 μm	-30 μm
		$\leq \pm 0.2\%$ FSO					$\leq \pm 0.5\%$ FSO
Linearity	specular target ³⁾	-0.3 μm	1.2 μm	1.2 μm	2.8 μm	2.0 μm	13 μm
		$\leq \pm 0.08\%$ FSO					$\leq \pm 0.2\%$ FSO
Resolution		0.016 μm	0.06 μm	0.06 μm	0.14 μm	0.10 μm	≤ 0.7 μm
		0.004 % FSO					0.01 % FSO
Weight	50 g						
Max. tilt	direct reflection	$\pm 8^\circ$	$\pm 5^\circ$	$\pm 5^\circ$	$\pm 3^\circ$	$\pm 3^\circ$	$\pm 1.5^\circ$
	diffuse reflection	$\pm 50^\circ$					
Repeatability	0.01 % FSO						
Measuring rate	selectable from 100 Hz up to 2000 Hz, optional 30 kHz						
Ambient light	30.000 lx						
Light source	LED						
Protection class (sensor/controller)	IP 40						
Stability (sensor)	$\pm 0.02\%$ FSO/ month						
Operation temperature	+10 up to +50 °C						
Storage temperature	-30 °C up to 70 °C						
Output	0 - 10 V / RS 232 / RS 422 / USB						
Supply	24 VDC						
Sensor cable (fiber optic cable)	integral cable: standard 2 m option up to 50 m						
Controller	dimensions (W x H x D): 258 x 316 x 116 mm						
	functions: touch keys, trigger, synchronization, storage of up to 20 configurations (for sensors with different ranges)						
Electromagnetic compatibility (EMC)	EN 50081-1 and EN 61000-6-2						

FIG. 10

(Confocal chromatic sensors for displacement and position, 2008)

Technical data IFS2402

FSO=Full scale output

- 1) Start of measuring range (SMR) measured from sensor axis
- 2) Applying to perpendicular and diffuse surfaces with reflection (intensity) >5%
- 3) Applying to perpendicular and specular surfaces (polished glass)

All data based on constant ambient temperature.

Borescope:

According to Atkinson, a Borescope is an optical device consisting of a flexible tube with an eyepiece and an objective lens opposite to each other. The Borescope is mainly used to detect the internal defects in castings such as porosities, cracks and foreign inclusions. Flexible borescopes are mostly used in automotive and in aircraft engines to detect porosities visually. The optical system is surrounded by the optical fibres used for illumination of remote objects. When the flexible Borescope is inserted into any hole that is to be detected, the inside images of the hole can be viewed on the computer screen from where we can judge if there were any cracks, foreign inclusion or any porosities.

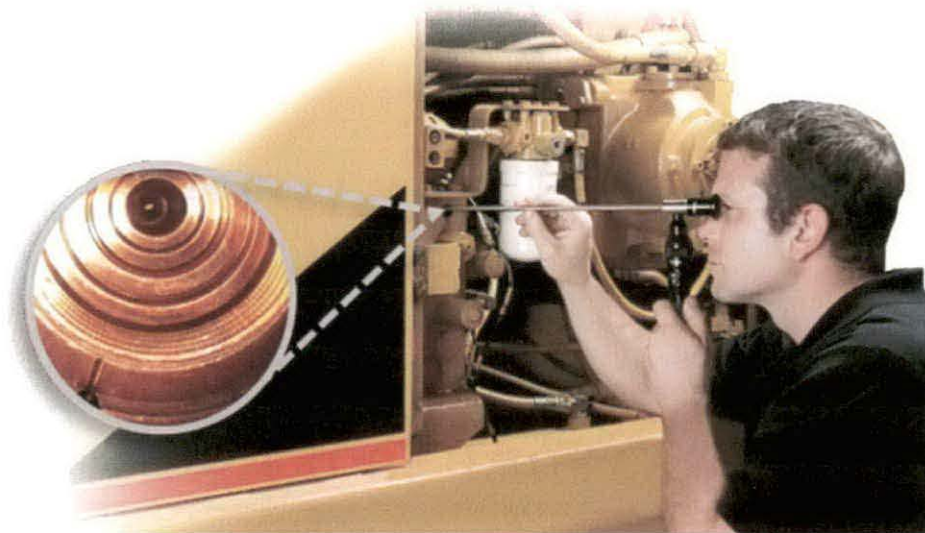


FIG. 11

Typical Borescope application with sample of image seen through Borescope

(Atkinson, 2008)

The most common area that the Borescope will be used in automotive industry is in engine cylinder block to detect the porosities, cracks and foreign inclusions. This method is very easy and highly effective and no skilled labor is required.



FIG. 12

Journal hole of an engine cylinder has porosity



FIG. 13

A small chip in the journal hole of a 4-cylinder engine

Chapter III

Methodology

Restatement of the Problem:

The primary causes of engine oil leakage and engine failure are due to excess porosities and foreign inclusion (chips) inside the (porosities) journal holes and oil gal hole of an engine cylinder (Toyota Motor Manufacturing Kentucky Inc, Georgetown). Most of the porosities are formed from air bubbles while casting, and are impossible to eliminate. These porosities provide traps which can block the oil holes and even settle into the bearings while the engine is running. This can cause oil leaks and even engine failure after some thousands of miles.



FIG. 14

A small chip in the journal hole of a 4-cylinder Camry engine

Dimensions of the chip:

1-1: 746.46 μm (the longest side) and 490.76 μm (the shortest side)

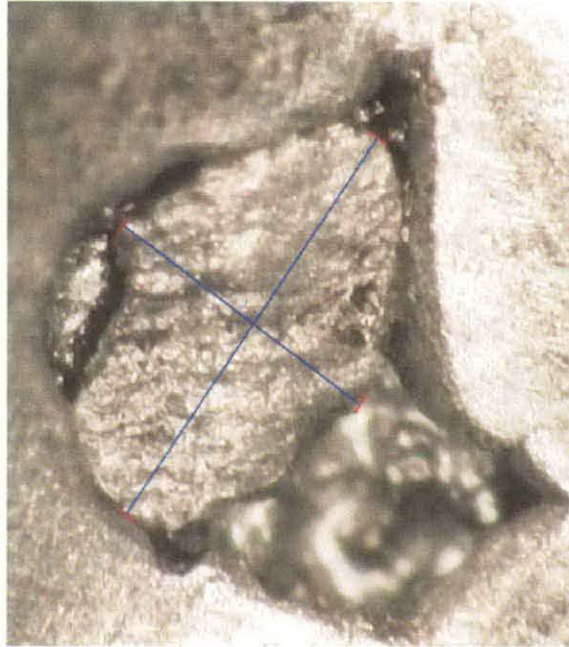


FIG. 15

The chips can settle inside the porosities either when one drills the journal holes or while machining the cylinder block. Thus the problem for Toyota and other automobile companies is to eliminate the chips while drilling the journal holes so that they do not fit into the porosities. There are several methods to drill journal holes that are effective and prevent migration of the chips to the porosities. Those methods are explained in the next chapter, on Methodology.

Methodology:

Several methods are used to drill the journal holes of a 4-cylinder engine so that the chips do not fit or settle into the porosities of the journal and oil gal holes. In each method, the research team trialed 25 AR-cylinder blocks and the results are tabulated.

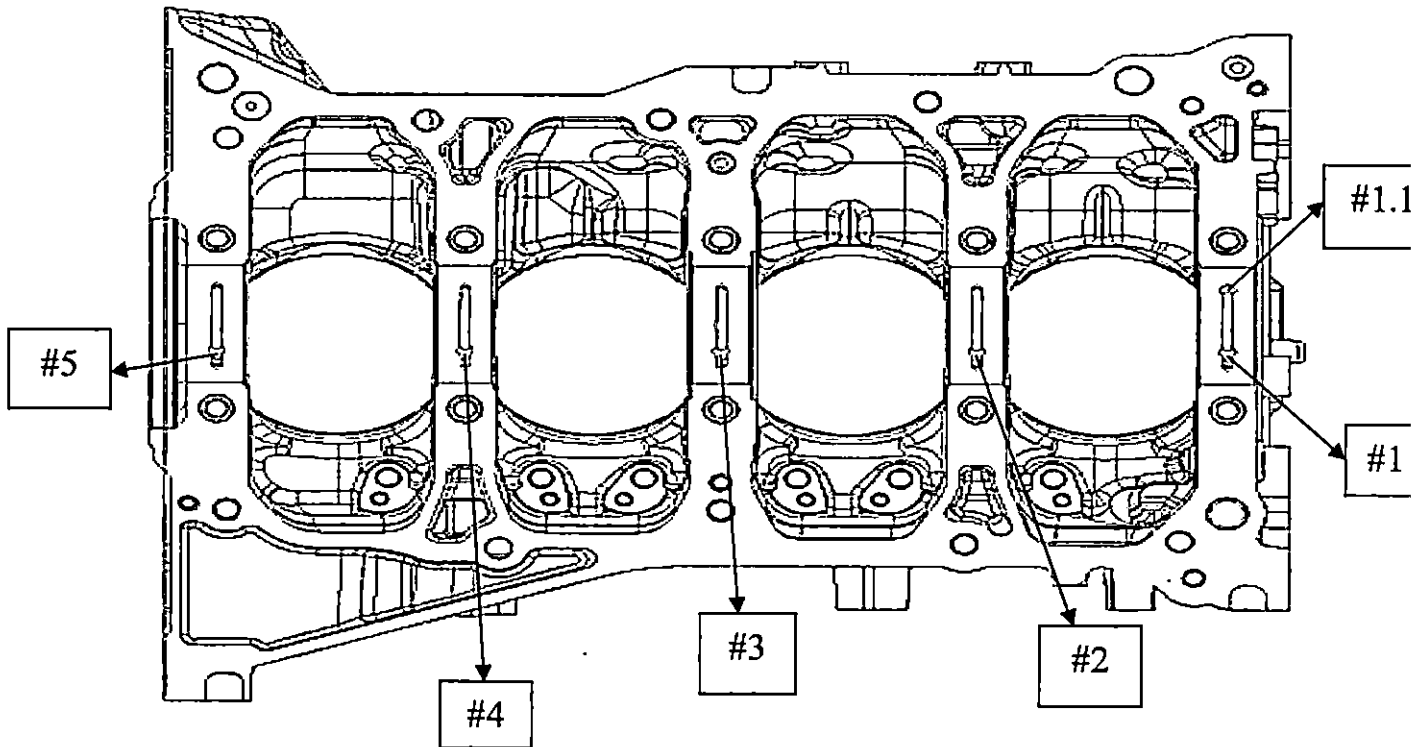


FIG. 16

Top view of AR block

#1.1, #1 to #5 represents journal holes

Research Procedure:

The methods used in drilling journal holes are as follows

- 1) Notched Drill trial:** In this method, the research team took 25 AR blocks and drilled journal holes by using Notched drill. This type of drill has scratches on the tip of the tool made purposely so that the chips break into smaller chips. This will allow us to flush the chips easily.
- 2) 2 second dwell:** In this method, while drilling the journal holes, the researcher sets a 2 second dwell time at the distance of 4mm from the tip of the running tool to target end so that high pressure (290 psi) coolant can be supplied. This high pressure coolant will flush the chips through flutes that stick to the tool from the opposite end, and thus do not settle into the porosities of the journal holes. Therefore, the 2 second dwell helps to flush the chips with high pressure coolant that sticks to the tool.
- 3) Increase drill point angle:** By increasing the drill point angle from 140° to 160° , the research team can drill the journal holes and create bigger chips (larger than the typical porosity) so that the chips do not fit into the porosities. This will allow cleaning the chips with air pressure or by a using manual brush. Therefore, the purpose of increase in the drill point angle is to make bigger chips.
- 4) Change in Feed rate:** In this method, the research team increased the feed rate from 570mm/min to 1140mm/min so that the chips will break into bigger size which will not have room to fit into the porosities of journal holes. By doing so, it will be easy to flush the chips by high air pressure or by using manual brush to clean the

chips inside the journal holes. So, the increase in feed rate is another method to make the chips bigger in size.

5) Decrease tool retract speed: In this method, the research team decreased the retract speed (bringing back the cutting tool after drilling the journal holes) from 5000mm/min to 1000mm/min. By decreasing the retraction speed, the coolant will flush out more chips that will stick to the tool, away from the journal holes. Thus, this technique ensures that the chips do not settle into the porosities.

In all five methods, journal holes #1 through #5 are drilled on one machine and journal hole #1.1 drilled on another machine.

The results of the research methods are explained in the Findings chapter.

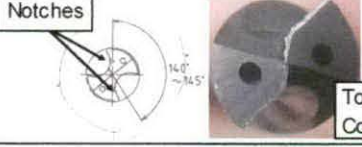

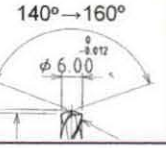


1	Notch added by Sumitomo on both cutting edges to create smaller chips	<table border="1"> <tr><td>tool type</td><td>notch drill</td></tr> <tr><td>dwell</td><td>none</td></tr> <tr><td>feed</td><td>570 mm/min</td></tr> <tr><td>speed</td><td>3800 rpm</td></tr> <tr><td>retract</td><td>rapid</td></tr> <tr><td>c/t</td><td>45sec (OK)</td></tr> </table>	tool type	notch drill	dwell	none	feed	570 mm/min	speed	3800 rpm	retract	rapid	c/t	45sec (OK)		<table border="1"> <tr><td>Tool Wear</td><td>○</td></tr> <tr><td>Condition:</td><td></td></tr> </table>	Tool Wear	○	Condition:	
tool type	notch drill																			
dwell	none																			
feed	570 mm/min																			
speed	3800 rpm																			
retract	rapid																			
c/t	45sec (OK)																			
Tool Wear	○																			
Condition:																				
2	2 second dwell added 4mm from break-through allowing time for chips to be flushed out through flutes	<table border="1"> <tr><td>tool type</td><td>standard</td></tr> <tr><td>dwell</td><td>2 sec</td></tr> <tr><td>feed</td><td>570 mm/min</td></tr> <tr><td>speed</td><td>3800 rpm</td></tr> <tr><td>retract</td><td>rapid</td></tr> <tr><td>c/t</td><td>47sec (OK)</td></tr> </table>	tool type	standard	dwell	2 sec	feed	570 mm/min	speed	3800 rpm	retract	rapid	c/t	47sec (OK)		<table border="1"> <tr><td>Tool Wear</td><td>○</td></tr> <tr><td>Condition:</td><td></td></tr> </table>	Tool Wear	○	Condition:	
tool type	standard																			
dwell	2 sec																			
feed	570 mm/min																			
speed	3800 rpm																			
retract	rapid																			
c/t	47sec (OK)																			
Tool Wear	○																			
Condition:																				
3	Original 140° point angle reground to 160° (in-house) to produce chips potentially larger than porosity	<table border="1"> <tr><td>tool type</td><td>standard</td></tr> <tr><td>dwell</td><td>none</td></tr> <tr><td>feed</td><td>1140 mm/min</td></tr> <tr><td>speed</td><td>3800 rpm</td></tr> <tr><td>retract</td><td>rapid</td></tr> <tr><td>c/t</td><td>40sec (OK)</td></tr> </table>	tool type	standard	dwell	none	feed	1140 mm/min	speed	3800 rpm	retract	rapid	c/t	40sec (OK)		<table border="1"> <tr><td>Tool Wear</td><td>○</td></tr> <tr><td>Condition:</td><td></td></tr> </table>	Tool Wear	○	Condition:	
tool type	standard																			
dwell	none																			
feed	1140 mm/min																			
speed	3800 rpm																			
retract	rapid																			
c/t	40sec (OK)																			
Tool Wear	○																			
Condition:																				
4	Increased feed rate to increase chip size Current: $f=0.15$ mm/rev, $F=570$ mm/min Trial: $f=0.3$ mm/rev, $F=1140$ mm/min	<table border="1"> <tr><td>tool type</td><td>standard</td></tr> <tr><td>dwell</td><td>none</td></tr> <tr><td>feed</td><td>1140 mm/min</td></tr> <tr><td>speed</td><td>3800 rpm</td></tr> <tr><td>retract</td><td>rapid</td></tr> <tr><td>c/t</td><td>40sec (OK)</td></tr> </table>	tool type	standard	dwell	none	feed	1140 mm/min	speed	3800 rpm	retract	rapid	c/t	40sec (OK)		<table border="1"> <tr><td>Tool Wear</td><td>○</td></tr> <tr><td>Condition:</td><td></td></tr> </table>	Tool Wear	○	Condition:	
tool type	standard																			
dwell	none																			
feed	1140 mm/min																			
speed	3800 rpm																			
retract	rapid																			
c/t	40sec (OK)																			
Tool Wear	○																			
Condition:																				
5	Change rapid retract to slow retract to flush out more chips Current: $F=5000$ mm/min Trial: $F=1000$ mm/min	<table border="1"> <tr><td>tool type</td><td>standard</td></tr> <tr><td>dwell</td><td>none</td></tr> <tr><td>feed</td><td>570 mm/min</td></tr> <tr><td>speed</td><td>3800 rpm</td></tr> <tr><td>retract</td><td>1000 mm/min</td></tr> <tr><td>c/t</td><td>51sec (NG)</td></tr> </table>	tool type	standard	dwell	none	feed	570 mm/min	speed	3800 rpm	retract	1000 mm/min	c/t	51sec (NG)		<table border="1"> <tr><td>Tool Wear</td><td>○</td></tr> <tr><td>Condition:</td><td></td></tr> </table>	Tool Wear	○	Condition:	
tool type	standard																			
dwell	none																			
feed	570 mm/min																			
speed	3800 rpm																			
retract	1000 mm/min																			
c/t	51sec (NG)																			
Tool Wear	○																			
Condition:																				

FIG. 17

The above figure explains the research methods used to decrease the machining chips while drilling journal holes and also show the tool wear condition in each process. From the above table, the tool wear condition is good in all the methods and no damage has been done.

Chapter IV

Findings:

The finding of research methods are

1) Notched Drill trial: In this method, the research team took 25 AR blocks and drilled journal holes using a Notched drill tool. After Borescope inspection, the team found that there were 10 AR blocks in which they found chips remaining in all holes and 6 AR blocks that have chips in #1 to #5.

- a. N (no. of AR blocks) =25
- b. Chips remaining in all holes (#1 through #5, #1.1) = 10
- c. Chips in #1 through #5=6
- d. Therefore, 40% of the blocks that have chips in the entire journal holes (25% blocks have chips in #1 to #5) and all the chips were removed by using air pressure and by manual brush.
- e. 100% of blocks were good after the process.

A sampling of picture images with the chips inside the journal holes of an AR block follows. The dots on the circle below the top view of an AR block indicate the location of chips inside journal holes and A, B, C, D, and E are the pictures of the chips inside the porosities that are viewed and captured by the Borescope.

The number 080903D41067 represents the part number and will be different for all the AR blocks.

A. Shot No. 080903D41067



C. Shot No. 080828D41017



E. Shot No. 080828D41006



B. Shot No. 080903D41082



D. Shot No. 080828D41010

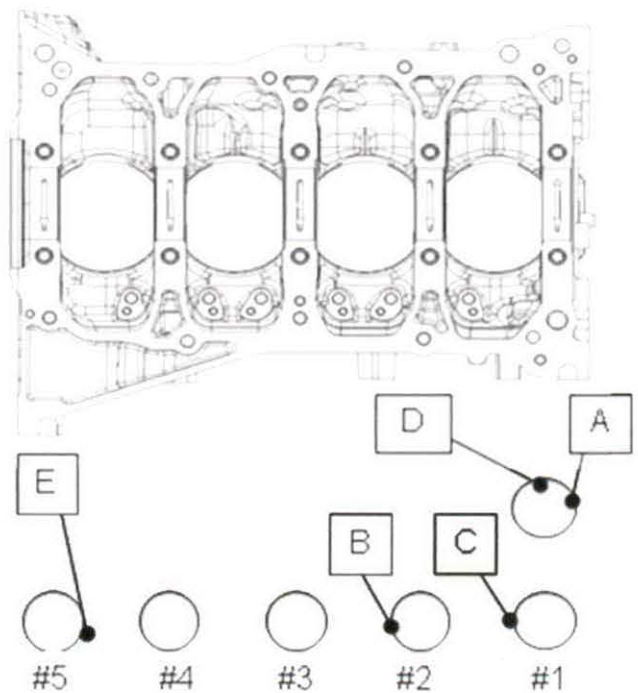


FIG. 18

2) 2 second dwell: In this method, the research team tested 25 AR blocks and found that 8 blocks had chips inside the porosities of all journal holes and 6 blocks that had chips in #1 through #5.

- a. Number of AR blocks, $N=25$
- b. Chips remaining in all holes (#1 through #5, #1.1) =8
- c. Chips remaining in #1 through #5=6
- d. Therefore, 32% of the blocks have chips in all holes (24% of AR blocks have chips in #1 through #5) and they were removed by using manual brush and air pressure.
- e. 100% of the blocks were good after the process.

A sampling of picture images with the chips inside the journal holes of an AR block follows. The dots on the circle below the top view of AR block indicate the location of chips inside the journal holes.

A. Shot No.080911D41008



C. Shot No. 080827D41029



E. Shot No. 080827D41090



B. Shot No. 080827D41061



D. Shot No. 080911D41013

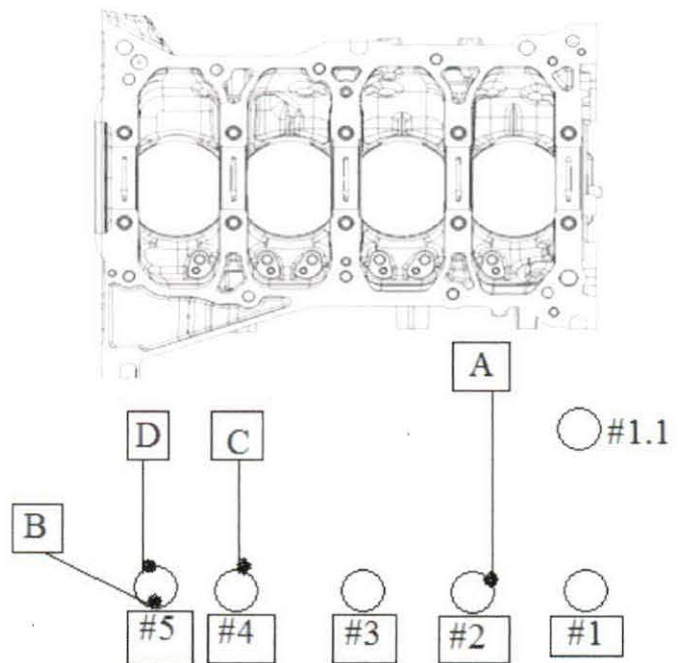


FIG. 19

3) Increase Drill Point Angle:

- a. Number of AR blocks used in this procedure are, $N=24$
- b. Chips remaining in all holes (#1 through #5, #1.1) =7
- c. Chips remaining in #1 through #5=3
- d. Therefore, 29% of the blocks have chips in all holes and 13% of the blocks have chips in #1 through #5 which were removed by air pressure and by using a manual brush.
- e. 100% of the AR blocks were good after the process.

A sampling of picture images with the chips inside the journal holes of an AR block as follows.

A. Shot No. 080911D41009



B. Shot No. 080911D41028



C. Shot No. 080910D41139



another view of C (part 080910D41139)



D. Shot No. 080910D41143

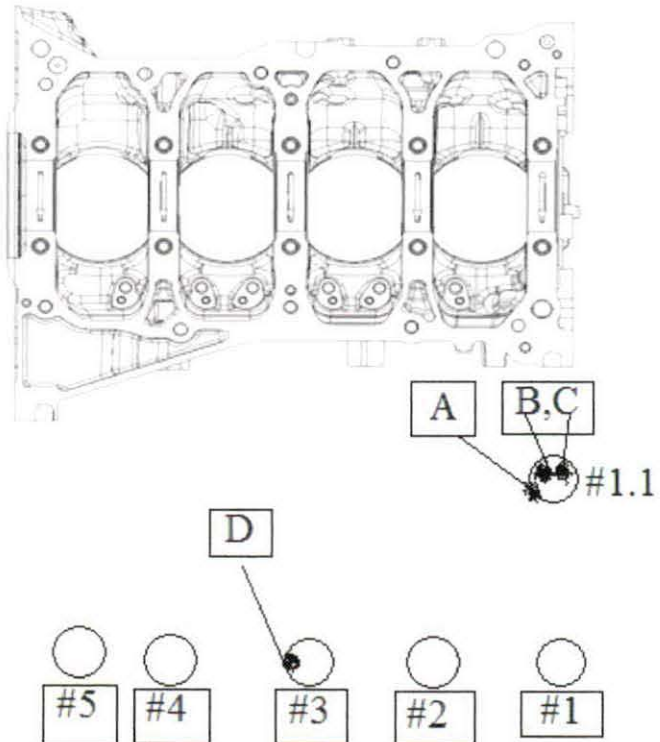


FIG. 20

4) Increased Feed Rate: Increased feed rate is applied to increase the chip size so that the chips do not fit into the porosity and can be cleaned by air pressure.

- a. Number of AR blocks used in this method, $N=25$
- b. Chips remaining in all holes (#1 through #5, #1.1) = 9
- c. Chips remaining in #1 through #5 = 8
- d. Therefore, 36% of the AR blocks have chips in all blocks and 32% of the blocks have chips in #1 through #5.
- e. 100% of the AR blocks were good after process.

A sampling of picture images with the chips inside the journal holes of an AR block follows.

A. Shot No. 0910D41130



C. Shot No. 080910D41133



E. Shot No. 080910D41142



B. Shot No. 080903D41064



D. Shot No. 080828D41016

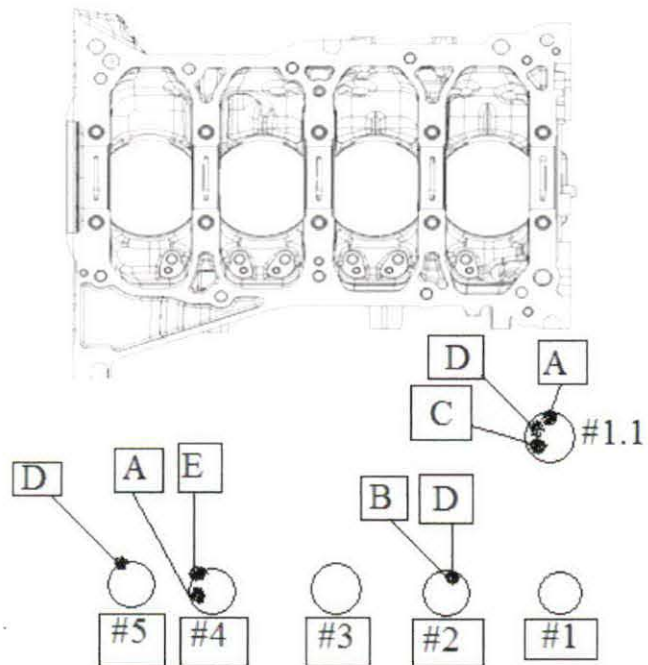


FIG. 21

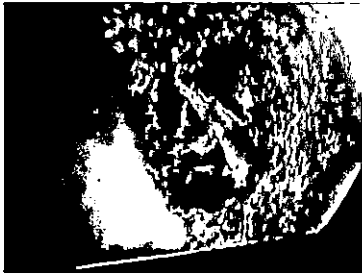
5) Decrease tool retraction speed: In this method, the research team inspected 24 AR blocks to drill the journal holes and found that only 3 blocks have chips in all holes (#1 through #5, #1.1) and one AR block have chips in #1 through #5.

- a. N=24
- b. Chips remaining in all holes (#1 through #5, #1.1) =3
- c. Chips remaining in #1 through #5 = 1
- d. 13% of the blocks have chips in all holes and 4% of the AR blocks have chips in #1 through #5 which were removed by using a manual brush and by air pressure.
- e. 100% of the AR blocks were good after the process.

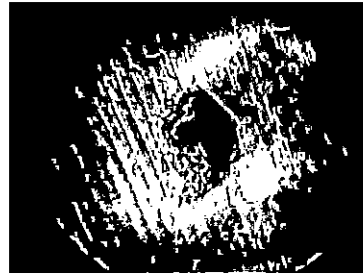
A sampling of picture images with the chips inside the journal holes of an AR block follows.

The dots on the circle indicate the location of chips inside the journal holes.

A. Shot No. 080903D41097



B. Shot No. 080910D41121



C. Shot No. 080910D41122

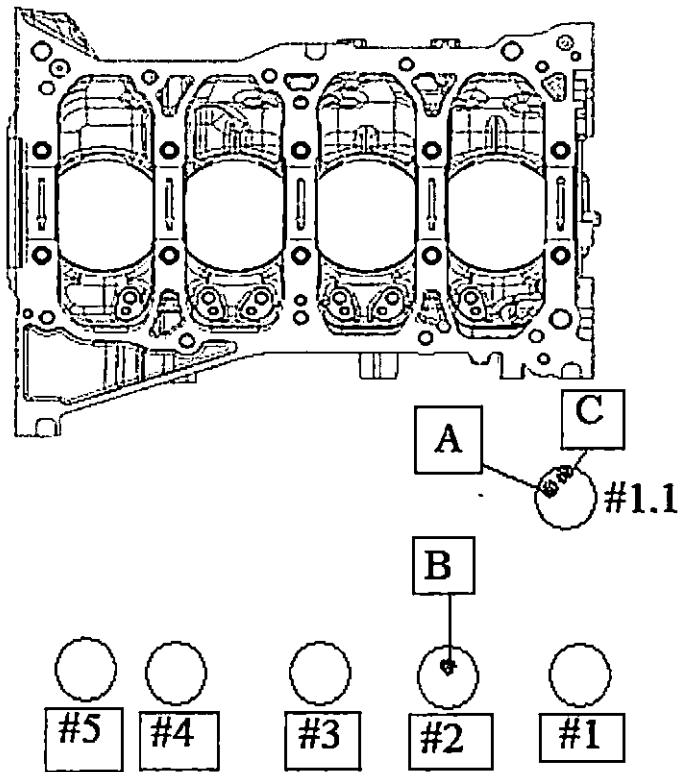


FIG. 22

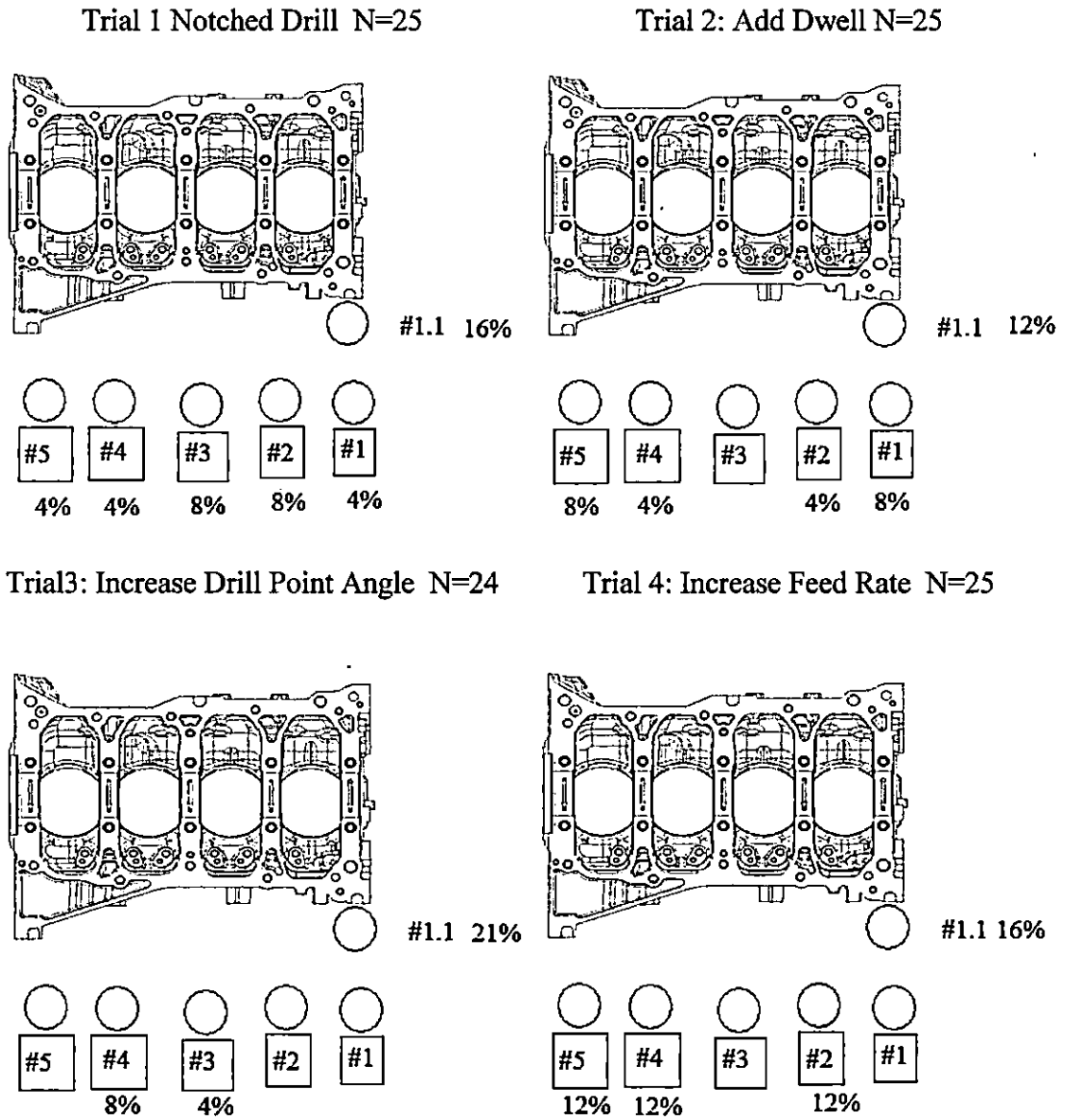


FIG. 23

The percentages below the square boxes or adjacent to the hole (#1.1) indicate the percentage of AR blocks that have chips in the specified journal holes.

Trial 5: Decrease Retraction Speed N=24

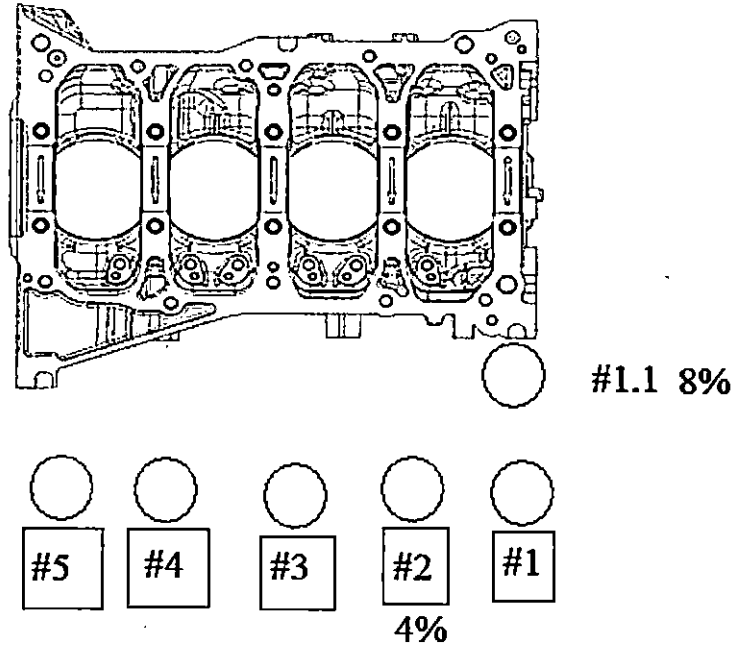


FIG. 24

The percentages below the square boxes or adjacent to the hole (#1.1) indicate the percentage of AR blocks that have chips in the specified journal holes.

Data Analyses and Results:

The results of all trials to reduce the machining chips inside the porosities of journal holes are tabulated below. In the below figure, J1~5 represents journal holes #1 through #5 and J1.1 represents #1.1

Trial	N=	Chip Rem. N=	Chip Rem. J1~5 N=	NG
1	25	10	6	0
2	25	8	6	0
3	24	7	3	0
4	25	9	8	0
5	24	3	1	0
Total	123	37	24	0

Table 1

Trial 1: Notched Drill Method

Trial 2: 2sec Dwell

Trial 3: Increase in Drill Point Angle

Trial 4: Increase in Feed Rate

Trial 5: Decrease Retraction Method

NG: Not Good

Tooling Chips Remaining

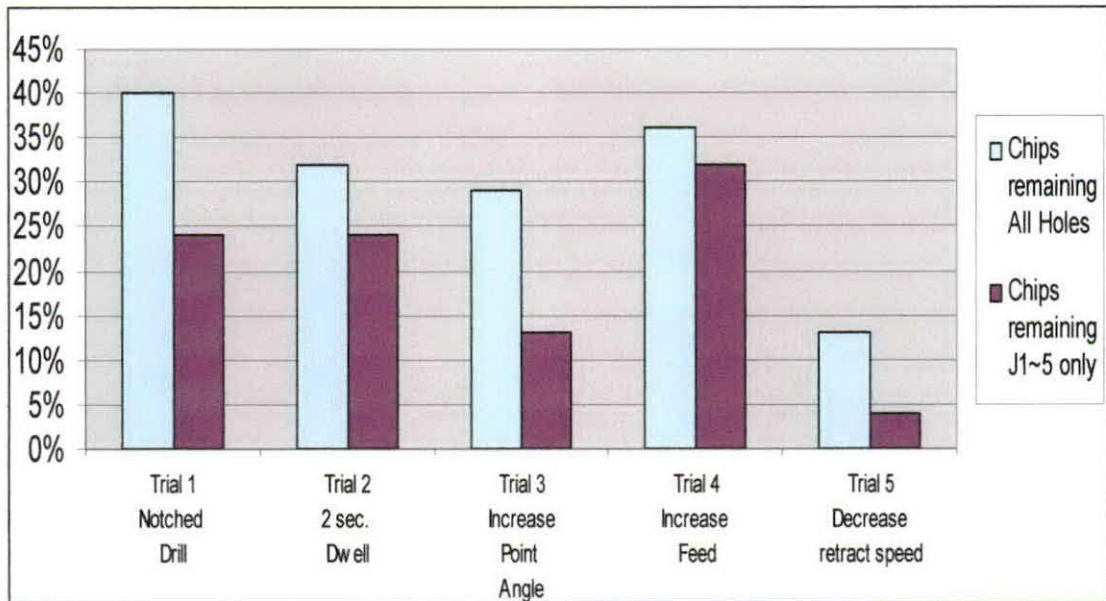


Table 2

From table 2, the research team concluded that the slow or decrease retraction method seemed best. As an aside, that journal hole #1.1 always have more chips than other journal holes. This is because the journal hole #1.1 is the last part of the casting that solidifies.

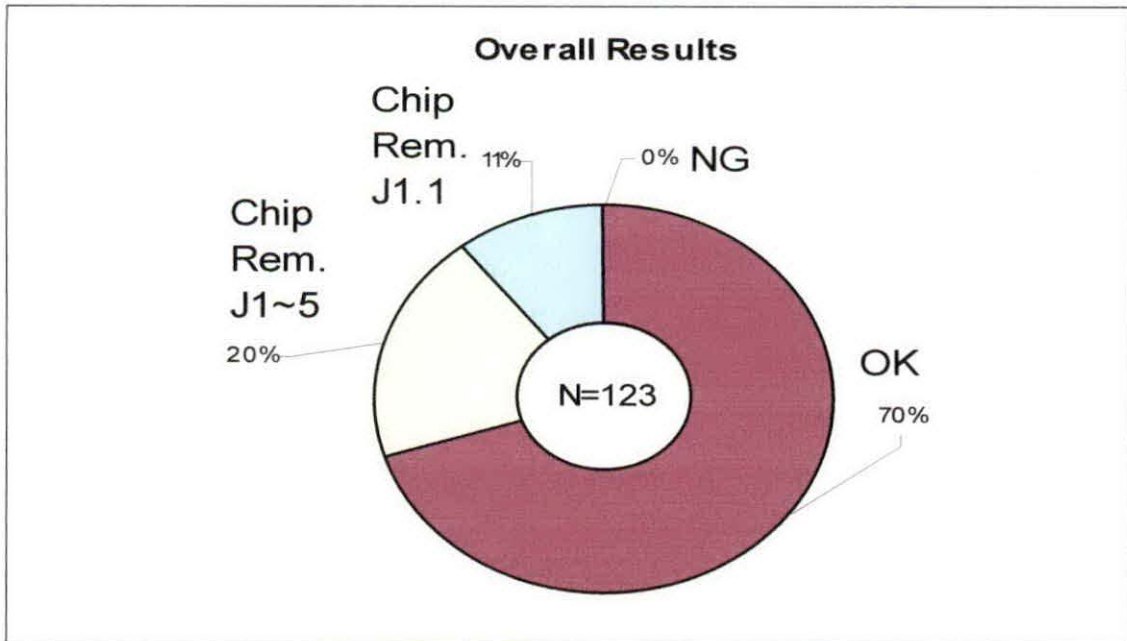


Table 3

Pie chart showing analysis

As show in table, J1~5 represents journal holes #1 through #5 and J1.1 represents #1.1

- Total number of AR blocks in all trials used are, N=123
- Chips remaining in all holes (#1 through #5, #1.1) =37
- Chips remaining in #1 through #5 = 24
- Therefore, 70% of the blocks were without machining chips after drilling journal holes in all trials.
- Percentage of Chips remaining in only #1.1=11
- Percentage of Chips remaining in #1 through #5 = 20

Chapter V

Conclusions

The purpose of this research method is to reduce the number of machining chips while drilling the journal holes for an AR block. The machining chips finally settle into the porosities while drilling and these chips can cause oil leaks from the engine cylinder, block oil holes, and can also subsequently move into the bearings causing engine failure. Elimination of all porosities is impossible because of various constraints like air bubbles, type of material, cost, etc., which cannot be eliminated while casting. Therefore, the research team concentrated on reducing the machining chips by using various methods to drill journal holes so that the machining chips would not fit into the porosities. The research team drilled journal holes using five different methods, and concluded from its data that the decrease (slow) retraction method was the most effective, as the team found only three blocks that had chips in all holes.

Implications:

From the results, the research team has concluded that Slow Retraction Method was the most effective one. After implementing this research procedure, there was an increase in the rate of production. As the number of scraps was reduced, the production cost was also reduced.

Future Recommendations:

Toyota Motor Manufacturing Kentucky needs a Borescope to inspect AR block after drilling journal holes and detect whether there are any machining chips left over inside the porosities. This Borescope inspection is time consuming and requires eight people to inspect each block before moving to the next step. It takes 54 to 90 seconds to inspect each journal hole of an AR block. In order to save money and time, an automated inspection machine for the AR blocks will save both money and time.

References:

Atkinson, L. (2008, January 24). *Borescope Application.png*. (Wikipedia, the free encyclopedia) Retrieved November 28, 2008, from Wikipedia:

<http://en.wikipedia.org/wiki/File:BorescopeApplication.png>

Basic Principles of Ultrasonic Testing. (n.d.). Retrieved December 15, 2008, from

NDT Resource center: <http://www.ndt->

[ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/description.htm](http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/description.htm)

Confocal chromatic sensors for displacement and position. (n.d.). (MICRO-

EPSILON MESSTECHNIK GmbH & Co. KG.) Retrieved October 15, 2008,

from Micro-Epsilon: <http://www.me-us.com/>

D'Orazio, T. L. M. (2008). Automatic ultrasonic inspection for internal defect

detection in composite materials. *NDT international*, 41 (2), 145-154.

Suresh Palanisamy (CAST,). A. (2009, January). Ultrasonic Inspection of Sub-

Surface Defects in Aluminium Die Castings. 71-76.

Ultrasonic Inspection. (2002). Retrieved November 1, 2008, from About.Com:

<http://metals.about.com/library/bldef-Ultrasonic-Inspection.htm>

Ultrasonic testing. (2008, December 10). Retrieved January 9, 2009, from Wikipedia:

http://en.wikipedia.org/wiki/Ultrasonic_testing

Yinggan Tang, X. Z. (2008, August 15). Application of a new image segmentation method to detection of defects in castings. *Int J Adv Manuf Technol* , 1-9.

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