NONDESTRUCTIVE EVALUATION: POSITIVE CONTRIBUTIONS TO SAFETY, RELIABILITY, AND ECONOMICS

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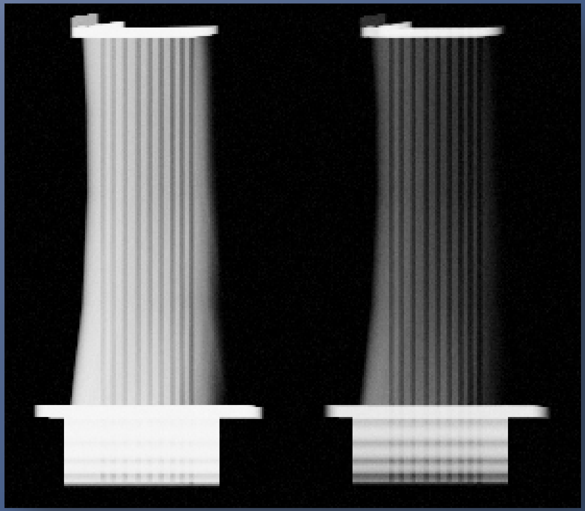
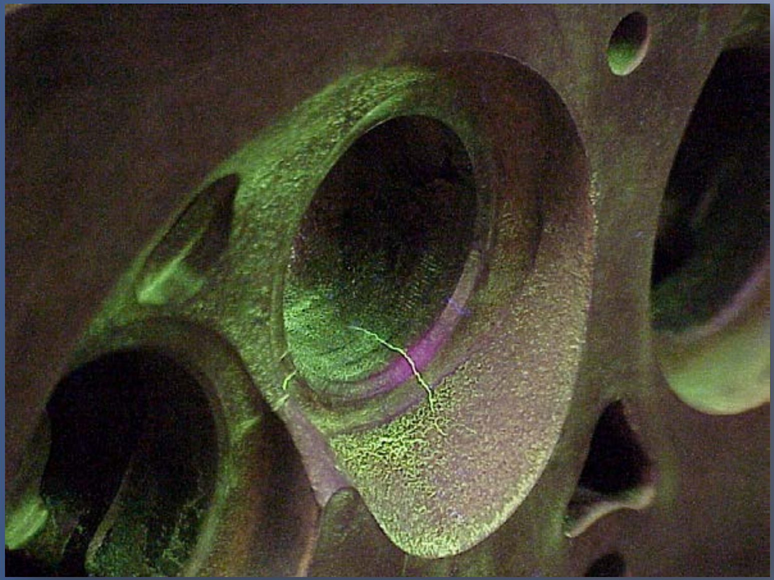
WHAT IS NDE?

- Use of noninvasive technologies for the detection/characterization of engineered structures to enable decisions regarding fitness for service and support lifecycle management
  - Aviation (commercial, military, space)
  - Energy (wind, fossil, nuclear)
  - Manufacturing/transportation
  - Infrastructure (highways, bridges, etc.)
  - Petroleum/chemical
- Also referred to as nondestructive inspection, nondestructive evaluation and nondestructive characterization



WHY IS NDE USED?



- *Safety*
- *Product quality*
- *Reliability*
- *Economics*
- *Lifecycle management*

FAILURE PREVENTION


...of aircraft



...of engines

...of pipelines

...of
highways
and bridges

...and
wind
turbines

WHEN IS NDE USED?

NDT can be applied at any stage in the production or life cycle of a material or component

- *Screening or sorting incoming materials*
- *Monitor, improve or control manufacturing processes*
- *Assisting product development*
- *Verify proper processing such as composite cure state, heat treatment, etc.*
- *Verify proper assembly*
- *Inspecting for inservice damage or use degradation*

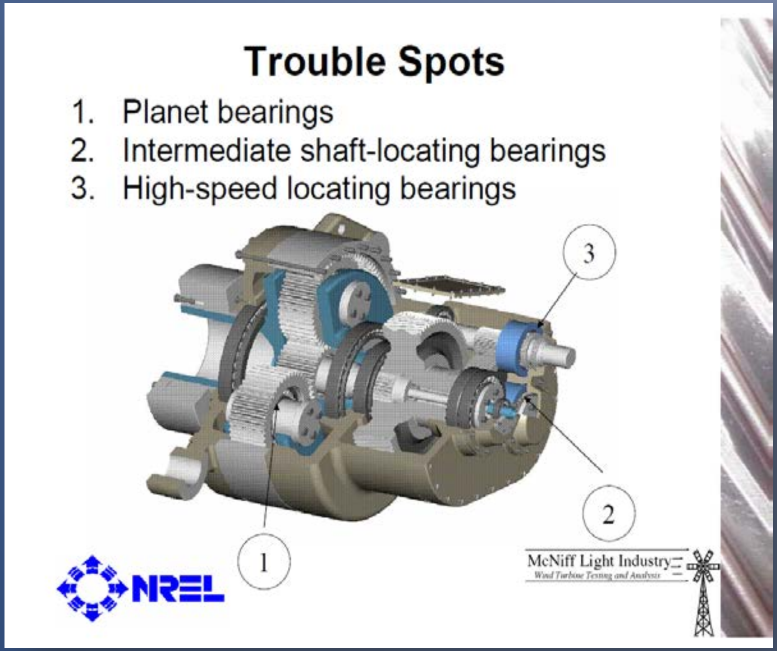
VISUAL INSPECTION

- *Similar to medical applications to look inside the body*
- *Most basic and common inspection method*
- *Must have good lighting and vision for best sensitivity*
- *Tools include fiberscopes, borescopes, magnifying glasses and mirrors*

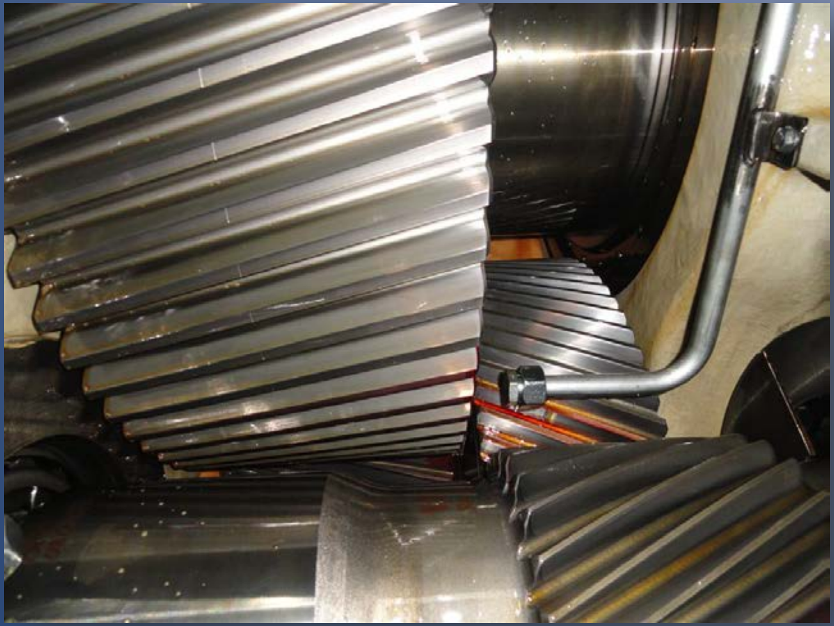
Inspector using fiberscope to inspect internal regions of jet engine

Common tools are borescopes, which can be rigid or flexible (fiberscopes)

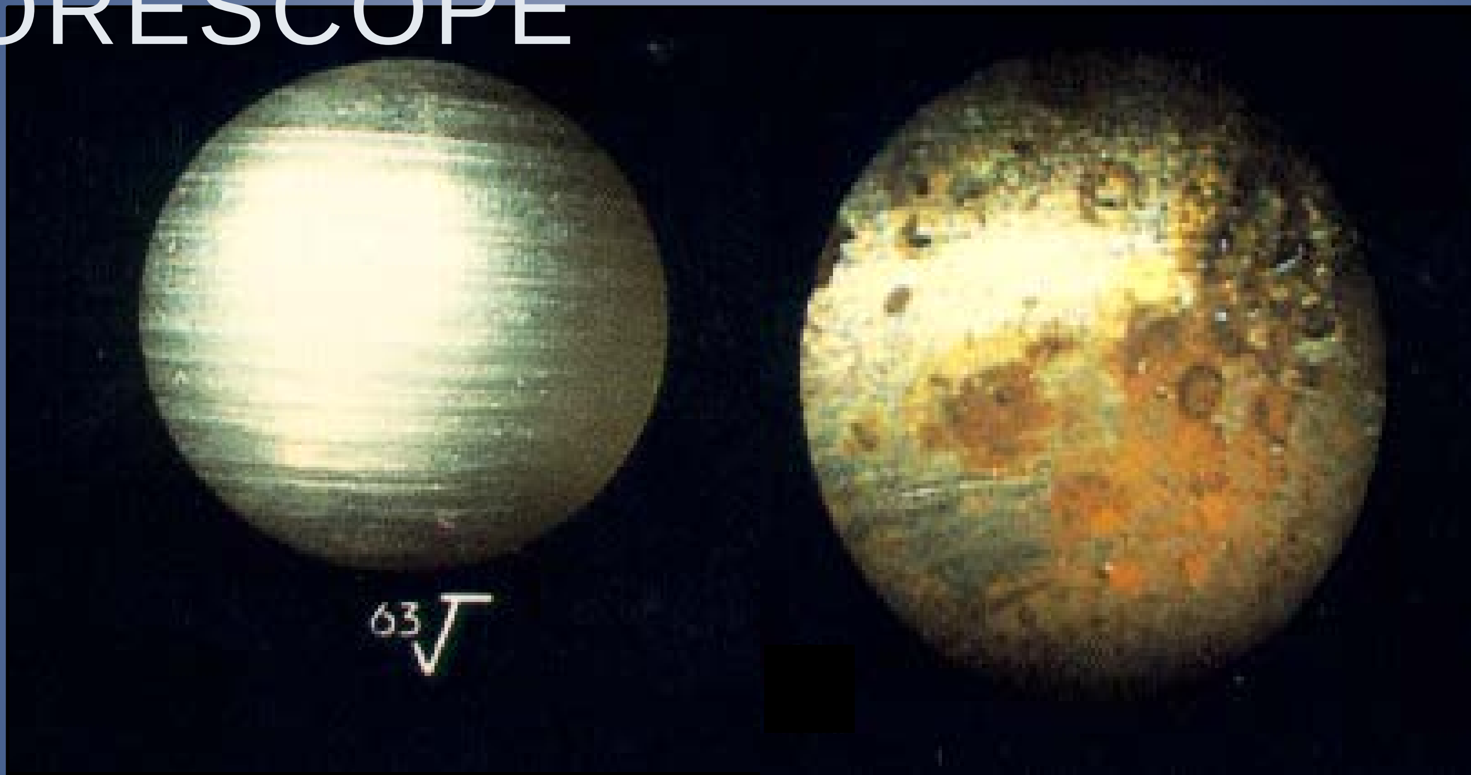
www.copperline.com



Visual inspection involves getting the inspector to "see" where one normally couldn't



VISUAL INSPECTION USING BORESCOPE

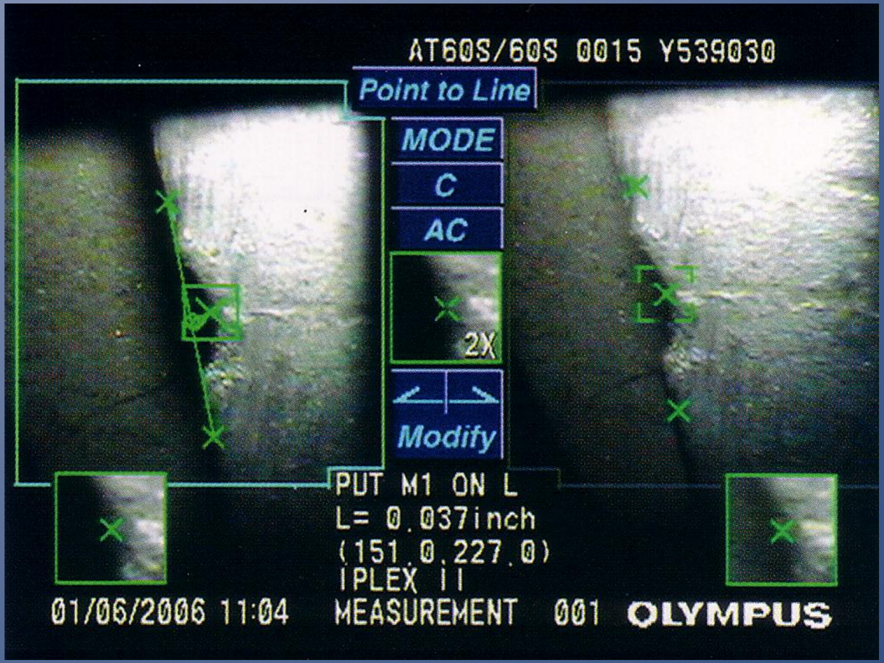


Clean Surface Corrosion Damage

Training & experience are vital for accurate interpretation of features viewed through fiberscopes

More sophisticated equipment offers the ability to make quantitative measurements on remote images viewed at magnification

Dacon Inspection

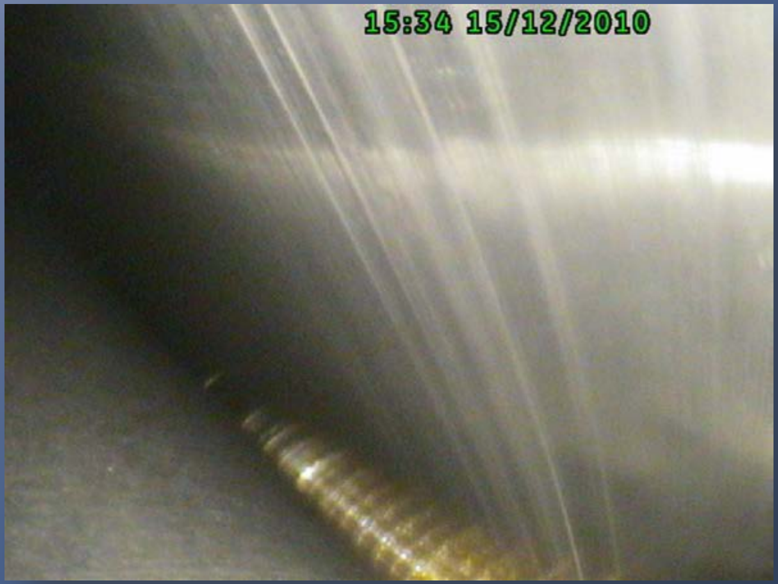


Olympus

ADVANTAGES OF VISUAL INSPECTION

- *Inspection performed rapidly and at low cost*
- *Ability to inspect complex sizes and shapes of any material*
- *Minimum part preparation required*

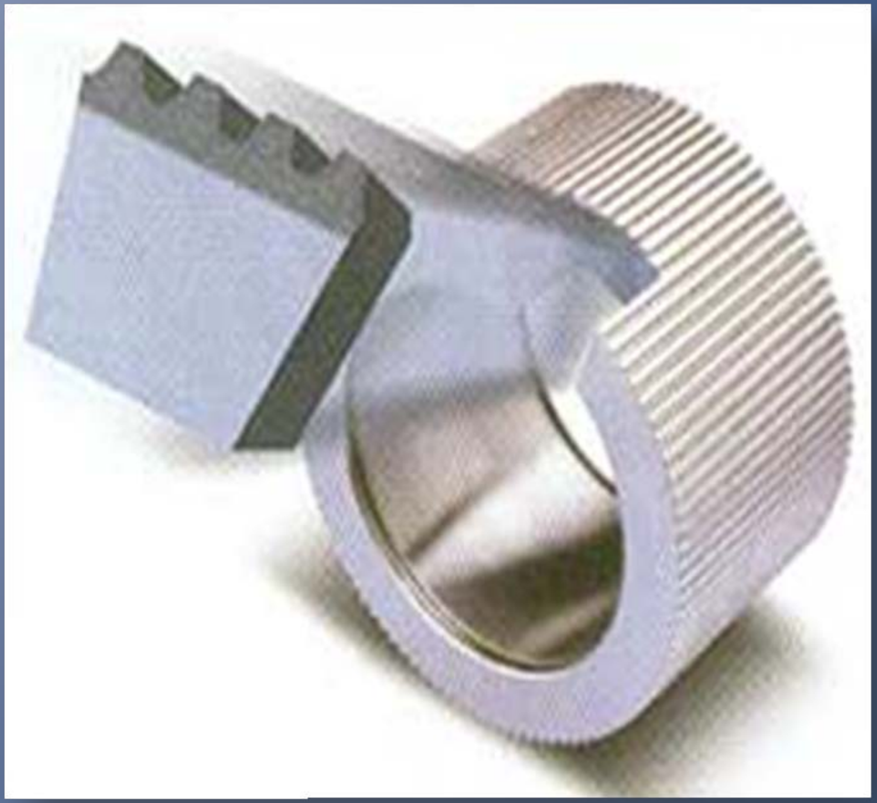
LIMITATIONS OF VISUAL INSPECTION



- *Surface must be accessible to inspector or visual aids*
- *Surface finish and roughness can interfere with inspections*
  - *rough surfaces can mask defects*
  - *smooth surfaces can cause glare*
- *Only surface defects are detectable*

PROBLEM DESCRIPTION

- *A company induction heat-treats large round steel components to ensure the wear properties needed for their application*
- *Field failures indicated that a manufacturing problem may exist, but they had no way to evaluate product quality*
- *The parts exhibited no problems that were visible to the naked eye*



Large 80 pound steel part heat-treated to a 0.180” depth

SOLUTION

- *Several inspection options exist that could be used on this part; magnetic particle inspection was selected based on cost and speed of inspection*
- *This method can find defects in ferrous parts when they lie at the surface, or even slightly below*

No problems were visible to the unaided eye

HOW WAS IT PERFORMED?

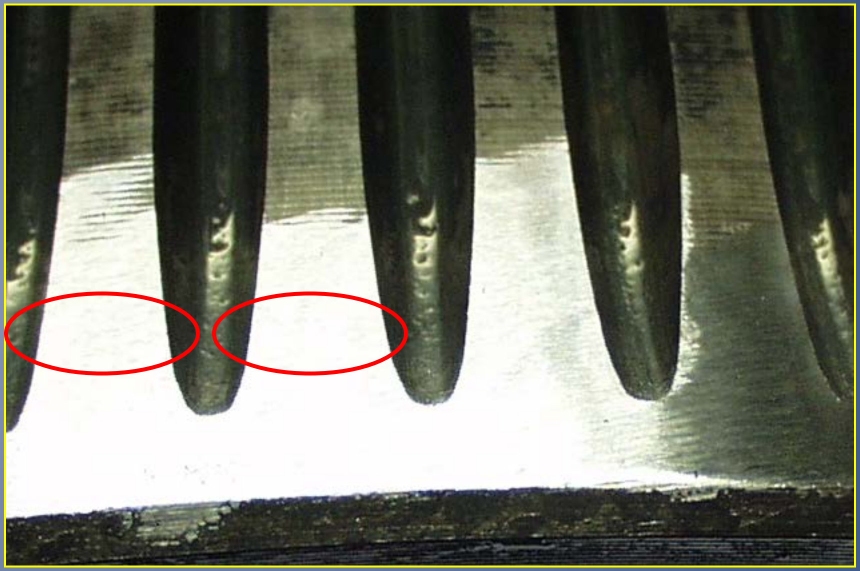
- *Portable AC contour probe was used with fluorescent particles*
- *Inspection was then performed under UV-A (black light) irradiation*
- *Indications from defects were clearly visible directly on the surface of the part*

A complete kit could be purchased for less than $1,200, allowing for regular internal quality checks

RESULTS

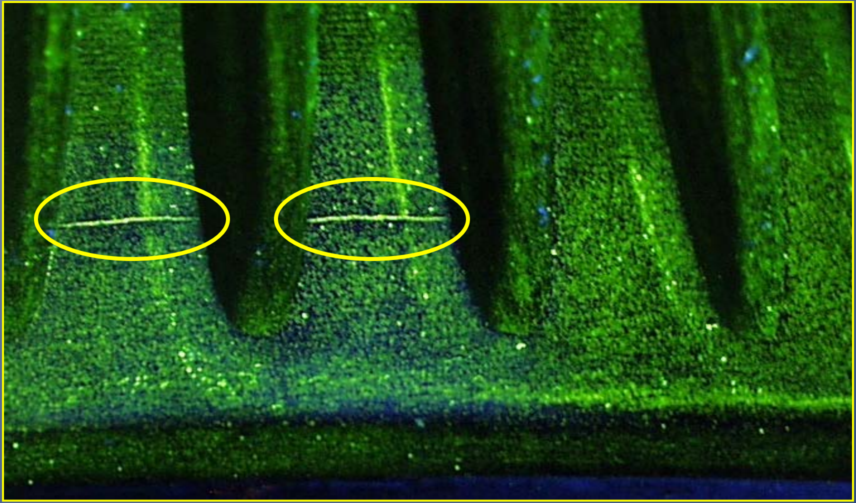
Prior to testing:

No cracks are visible under ambient lighting



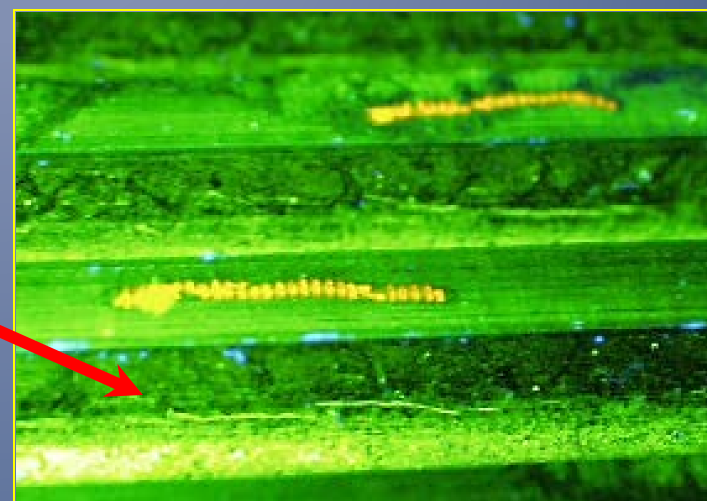
After testing:

Crack indications were clearly visible under UV-A irradiation

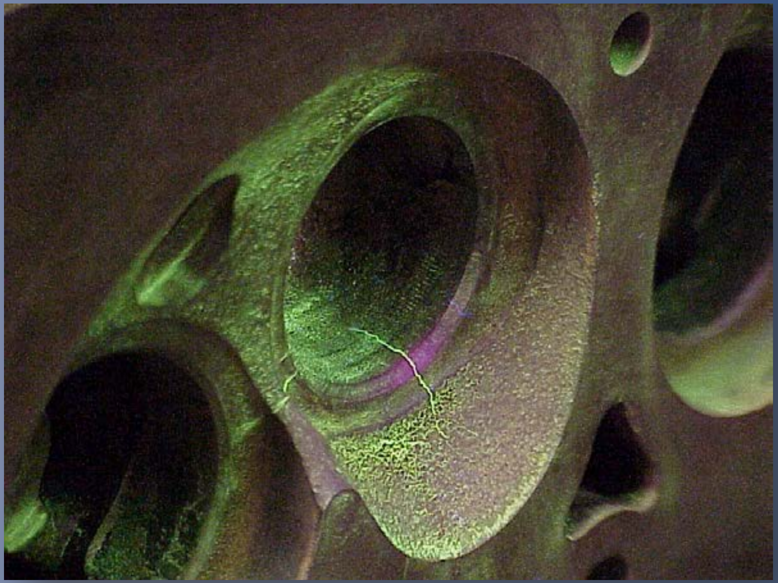


RESULTS

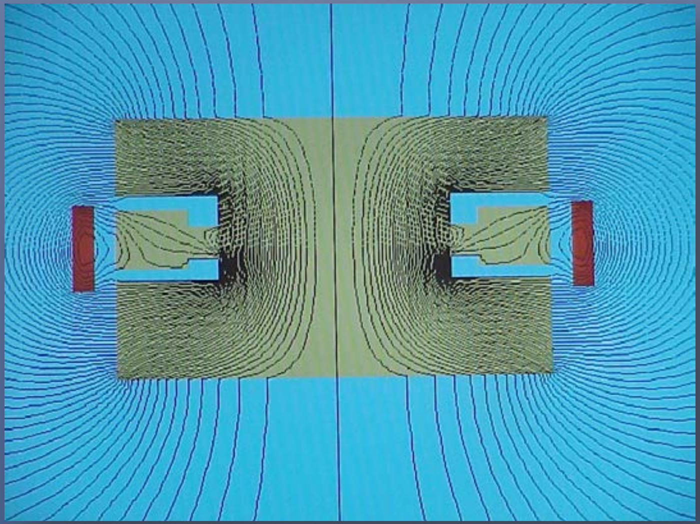
A poor induction heat-treating setup resulted in a multitude of cracks running along, and across the machined grooves



Defects that would have gone undetected were located and sized using magnetic particle inspection



Magnetic Particle Inspection

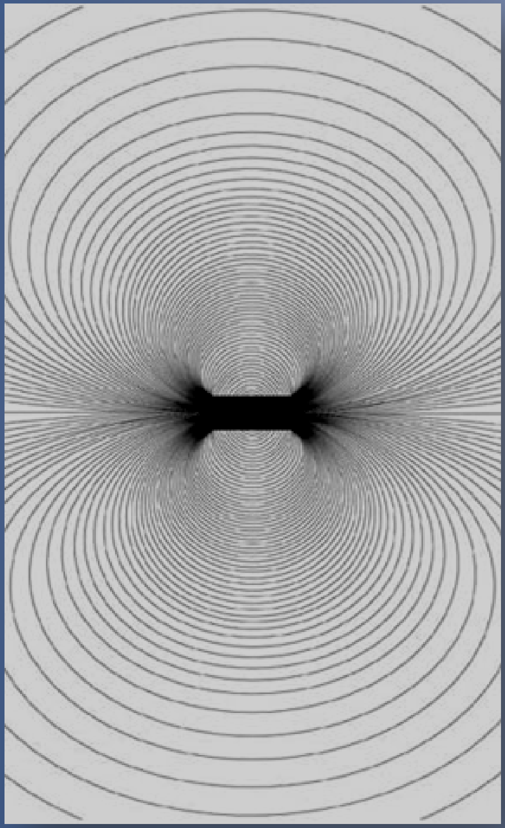


OVERVIEW

Magnetic Particle Inspection (MPI) is performed in four steps:

1. *Introduce a magnetic field into the specimen*
2. *Introduce magnetic particles to the specimen’s surface*
3. *View the surface, looking for particle groupings that are caused by defects*
4. *Demagnetize and clean the specimen*

INTRODUCTION TO MAGNETISM



Magnetic fields are composed of flux lines which:

- *Take the path of least resistance*
- *Do not cross each other*
- *All have the same strength*
- *Decrease in density away from the poles*

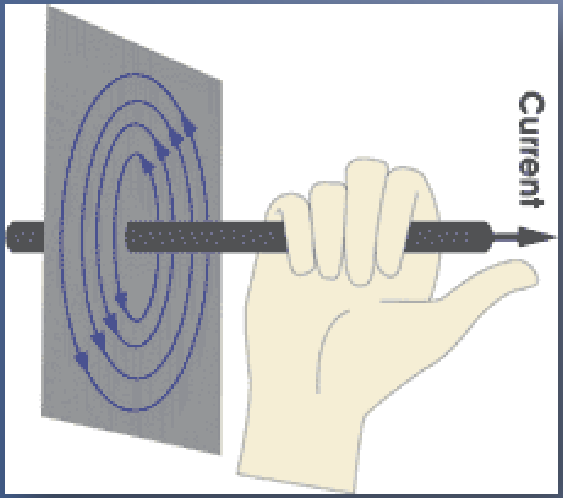
INTRODUCTION TO MAGNETISM

Closed loops of magnetic flux	Opposite poles attracting	Similar poles repelling

- *Like poles repel, and opposite poles attract*

INTRODUCTION TO MAGNETISM

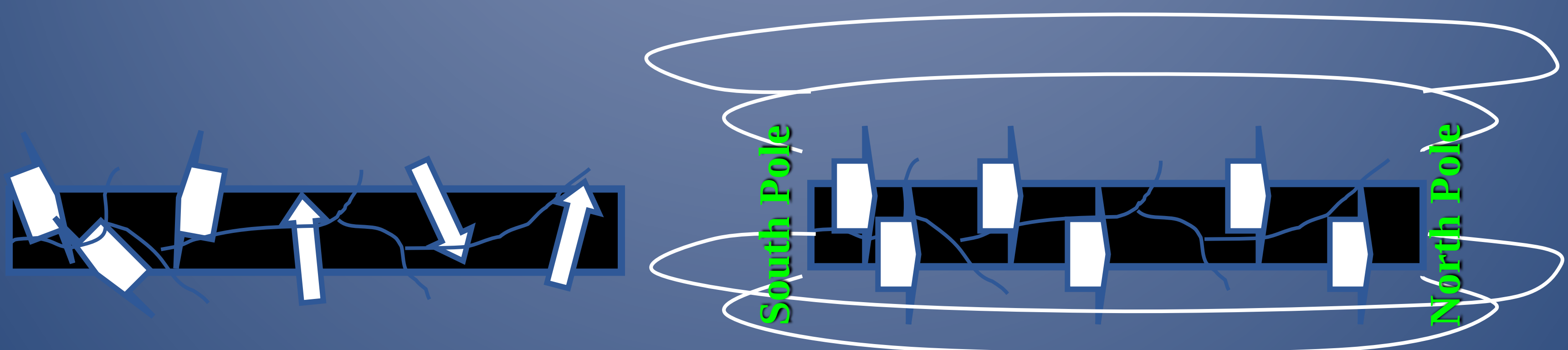
- *In addition to permanent bar magnets, the flow of electric current can also cause a magnetic field*



Magnetic field around an electrical conductor

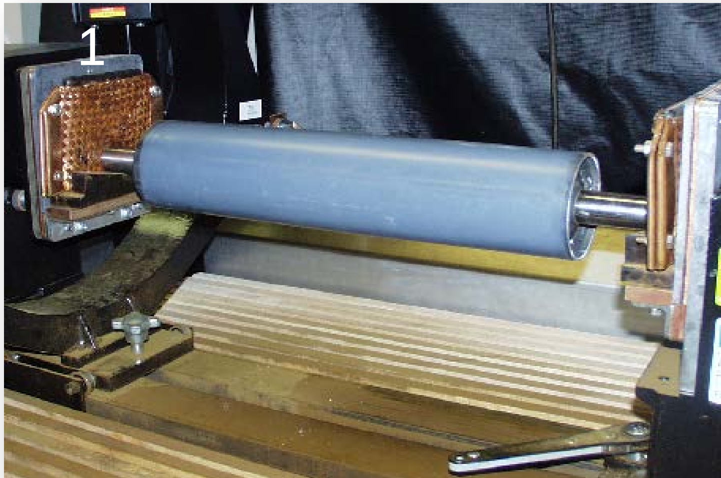
MAGNETISM IN MATERIALS

- *Parts <u>must</u> be ferromagnetic for this test*
- *A ferromagnetic material, such as iron, steel, or nickel is one that may be magnetized*
- *Ferromagnetic materials are made up of many magnetic domains in the crystal structure of the material*
- *The domains point randomly in a non-magnetized material, but they may be aligned so that the material becomes magnetic.*

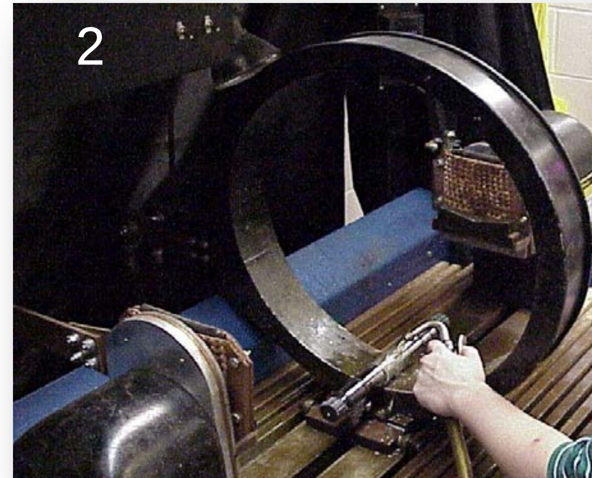


Non-Magnetic **Magnetic**

MAGNETIZING THE SPECIMEN



Passing a high current through the specimen



Passing current through a coil of wire around the part

Using a current-carrying threader bar

Using an electromagnet that contacts the test piece

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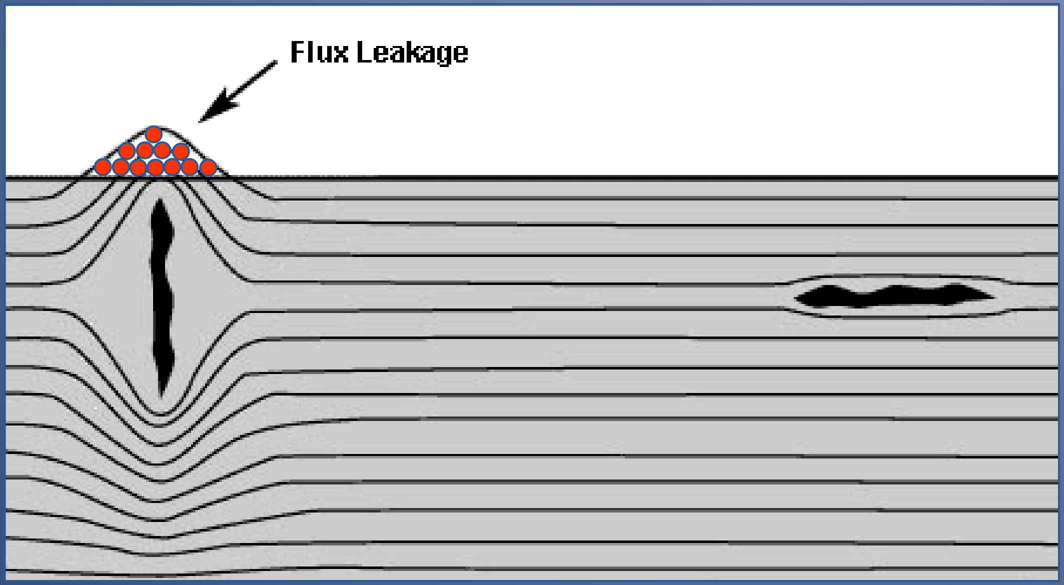
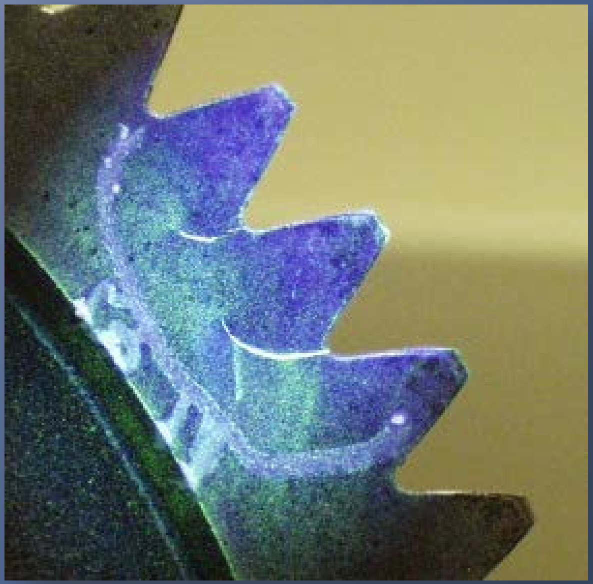
FORMING AN INDICATION

- *When flux lines flowing through the magnetized specimen reach a flaw they may deflect*
- *If the magnetic field and defect are properly aligned the deflection will cause flux leakage on the surface*
- *Orientation plays a greater role than defect size*
- *Flux leakage attracts particles, which cluster to form an indication*





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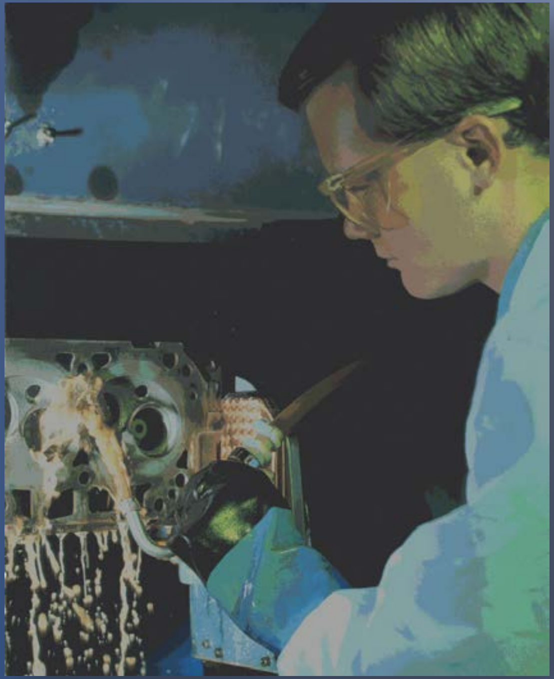
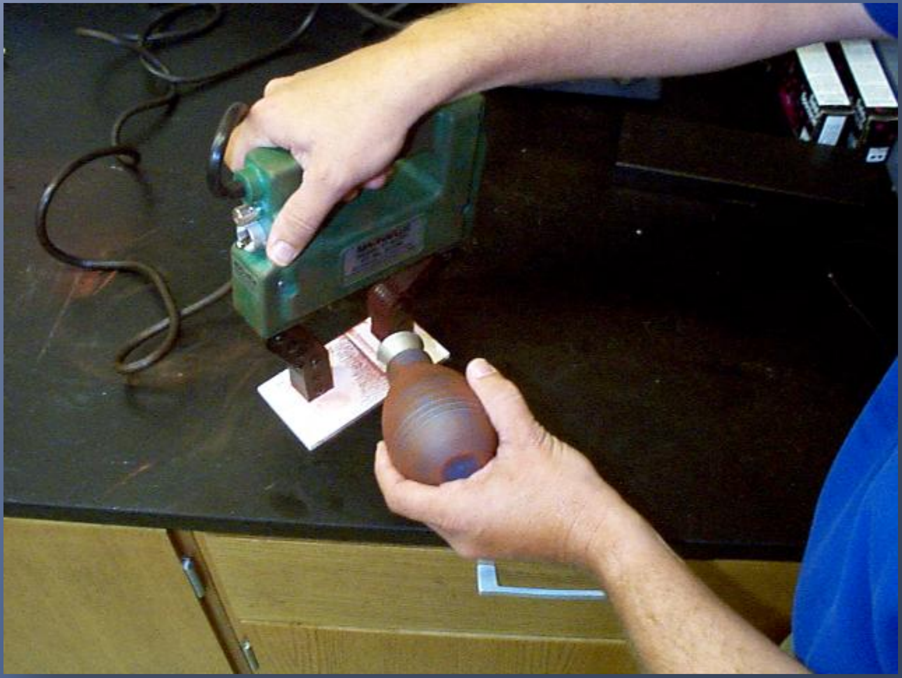
PARTICLES

- ***This method can be performed using either dry powder, or a powder suspended in a liquid.***
- ***The particles may be gray, or they could be painted red, black, or fluorescent yellow to provide good visibility against the specimen surface.***





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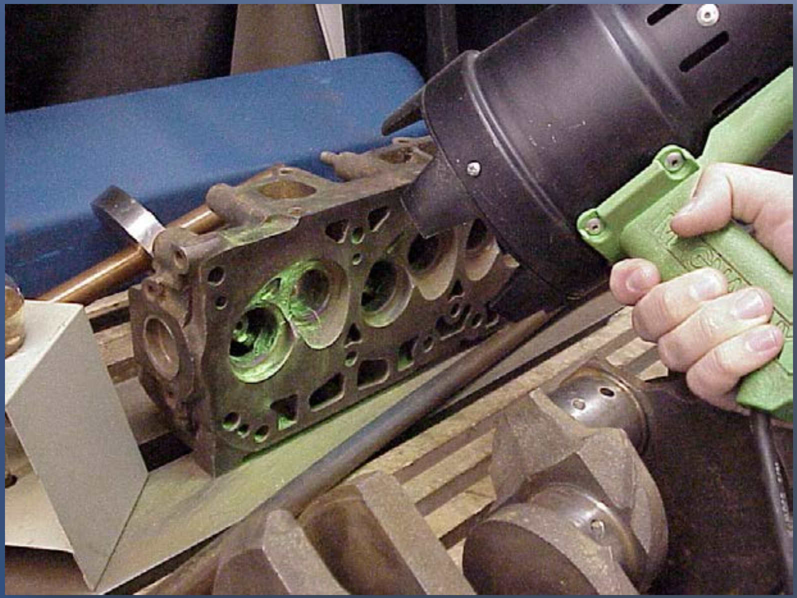
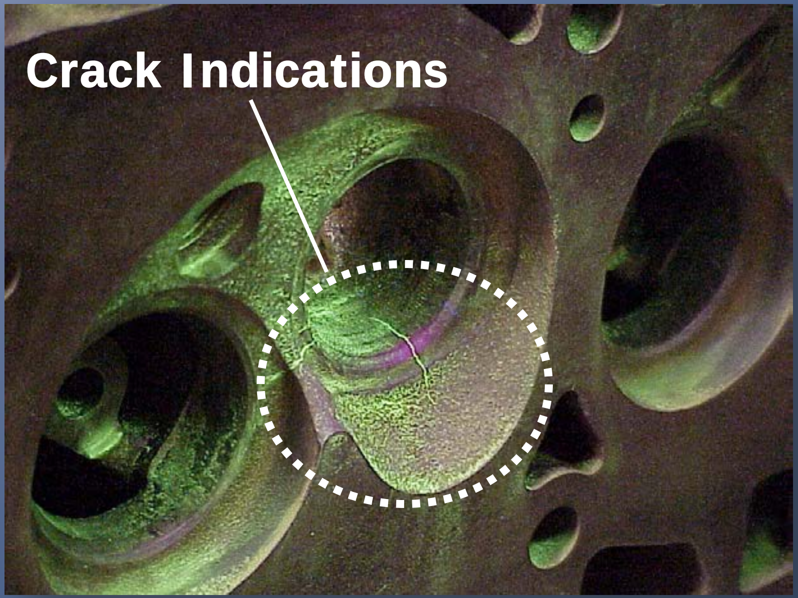
LOOKING FOR INDICATIONS

- *When wet fluorescent particles are used, a blacklight (UVA) must be used to view the indications.*
- *When dry powder (gray, black, or red) is used, then white light is used to view the indications.*





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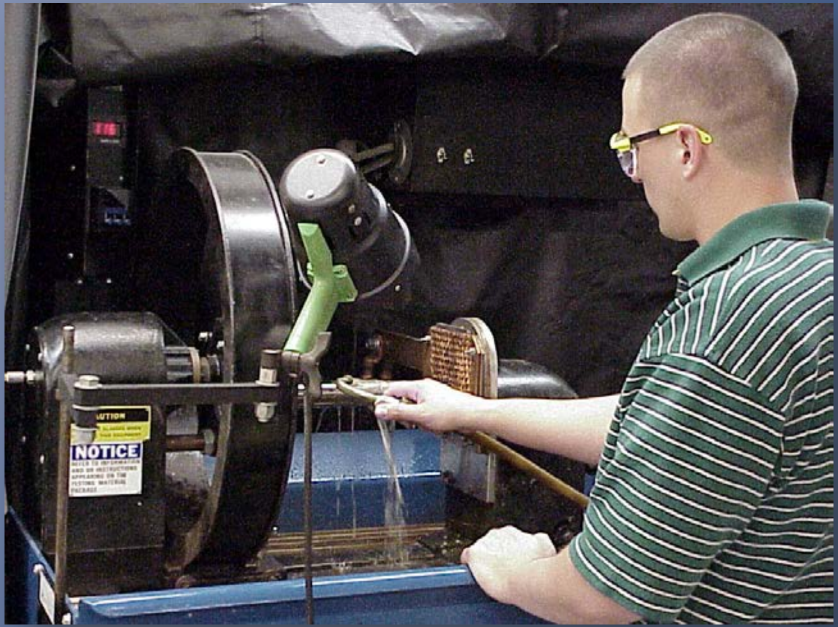


ADVANTAGES

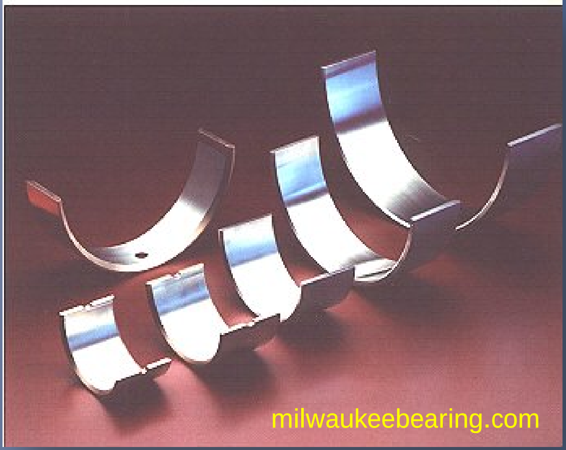
- *Can find both surface and near sub-surface defects*
- *Some forms are extremely portable and low cost*
- *Rapid inspection with immediate results*
- *Indications are visible to the inspector directly on the specimen surface*
- *Can detect defects that have been smeared over*
- *Can inspect parts with irregular shapes easily (external splines, crankshafts, connecting rods, metal injection molded parts, etc.)*

LIMITATIONS

- *Specimen must be ferromagnetic (steel, cast iron, etc.)*
- *Paint thicker than about 0.005" must be removed before inspection*
- *Post cleaning, and post demagnetization is often necessary*
- *Alignment between magnetic flux and defect is important*

PROBLEM DESCRIPTION

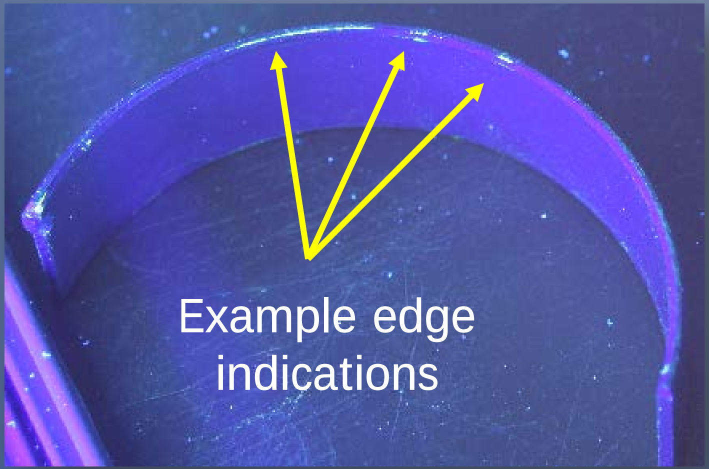
- *A manufacturer of bearing shells was recently experiencing field failures*
- *Shells were made from a steel and leaded bronze bi-metallic sheet that undergoes several fabrication steps, including final plating*
- *If cracking was noted in their final product they would incorporate a change to production steps*

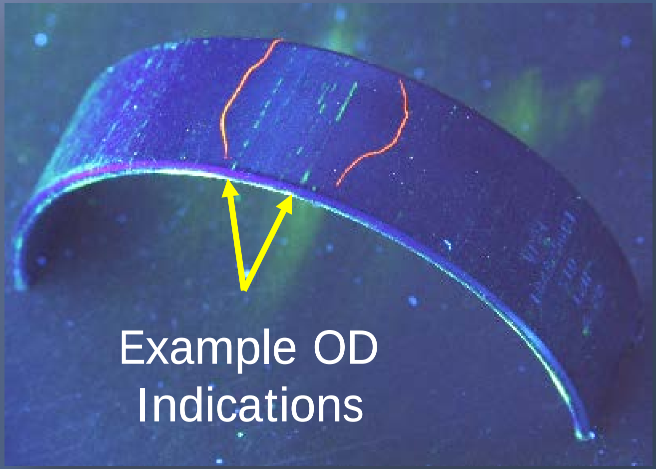


HOW WAS IT PERFORMED?

- *Liquid penetrant inspection was the most cost-effective of available options, and would be easy to implement on the shop floor*
- *A highly-visible dye seeps into surface-breaking flaws, and forms obvious indications on part surface*
- *Indications were verified through destructive testing*

Typical fluorescent indications noted on the shells

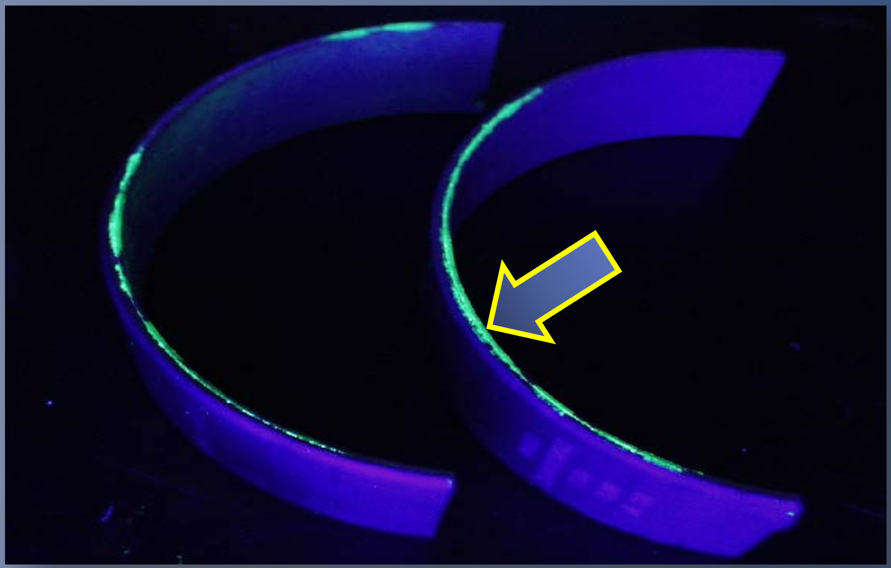




RESULTS

Liquid Penetrant Testing:

Showed that cracks were present along the edge of the shells



After testing:

Cracks were verified by metallography, and process was altered to remedy the situation

LIQUID PENETRANT INSPECTION

OVERVIEW

- *Liquid Penetrant Inspection is the most widely used method*
- *Method may be used in a shop, or in the field far from electricity*
- *Penetrant may be used on any non-porous material*
- *Can be as simple as a collection of aerosol spray cans, or may be a fully automated inspection system*

www.cnde.iastate.edu/faa-casr/fpi

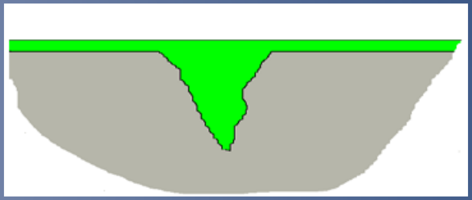
OVERVIEW

Liquid Penetrant Inspection (LPI) is performed in six steps:

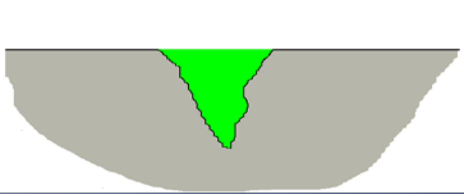
1. Pre-clean and dry the specimen
2. Apply penetrant to the area of interest
3. Remove excess penetrant so dye is left only in defects
4. Apply developer to draw penetrant out and form indication
5. View specimen
6. Post-clean (if necessary)

1) Clean Surface

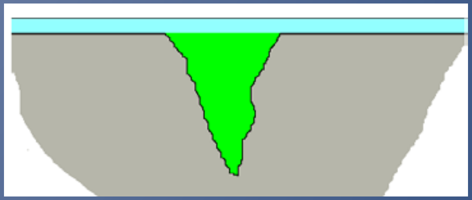
2) Apply Penetrant



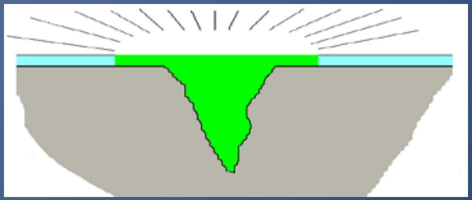
3) Remove Excess



4) Apply Developer



5) Visual Inspection



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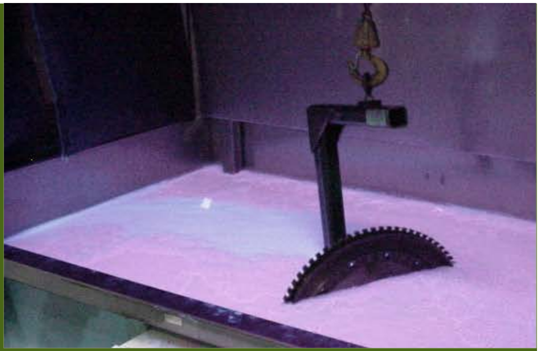
LIQUID PENENTRANT INSPECTION - AEROSPACE

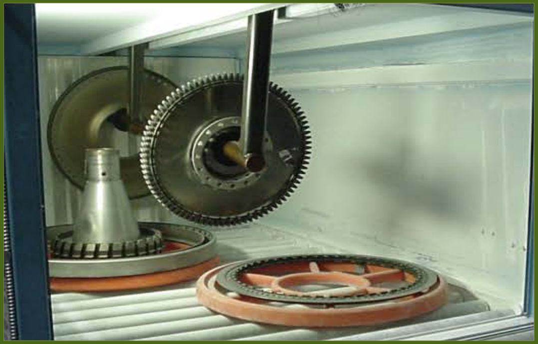
The process begins with a clean, dry part to which the penetrant is applied. Aerospace applications utilize the fluorescent penetrant method, typically in a dip tank.

After the specified dwell time, excess penetrant is removed typically using a spray pre-rinse of acceptable temperature and pressure.



If the post-emulsifiable process is being used, the part is then dipped in the emulsification bath to make the oil-based penetrant water washable.

The emulsification step is followed by a post-rinse step.

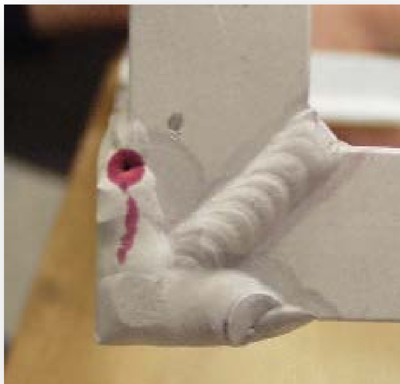


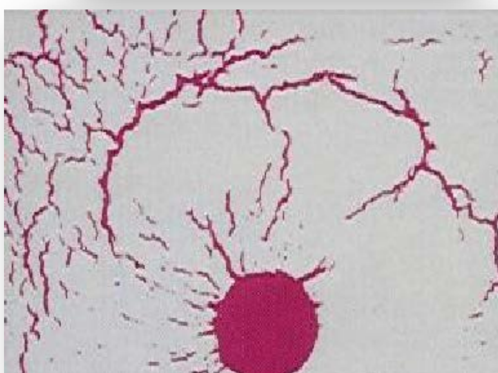
After a drying step, developer is applied, typically using either a spray application or developer chamber as shown here.

Upon completion of adequate developer dwell time, the component is inspected under blacklight in a darkened room or booth.

Penetrant Types

VISIBLE AND FLUORESCENT INDICATIONS



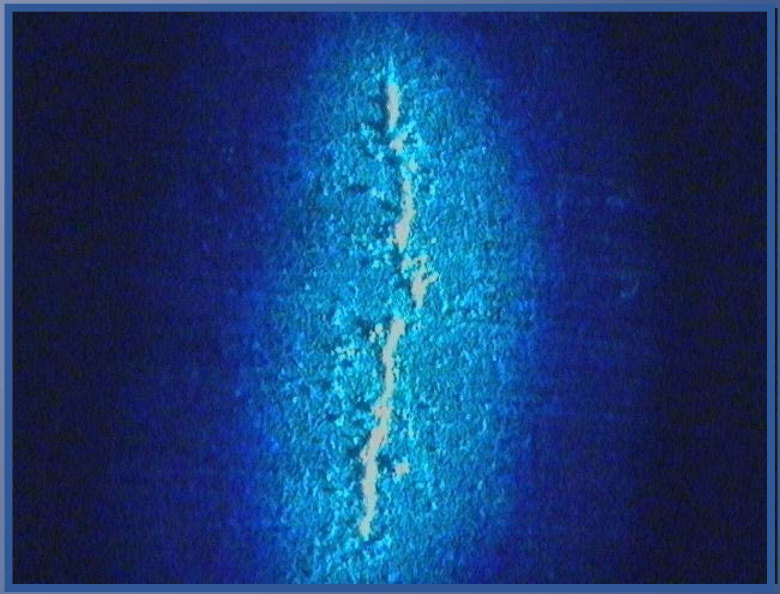


Visible Light Inspection (daylight)

UVA Illumination (blacklight)

OVERVIEW

1. *Begin with a clean and dry part*
2. *Apply penetrant to the area of interest*
3. *Remove excess penetrant so dye is left only in defects*
4. *Apply developer to draw penetrant out and form indication*
5. *View specimen under proper lighting conditions*



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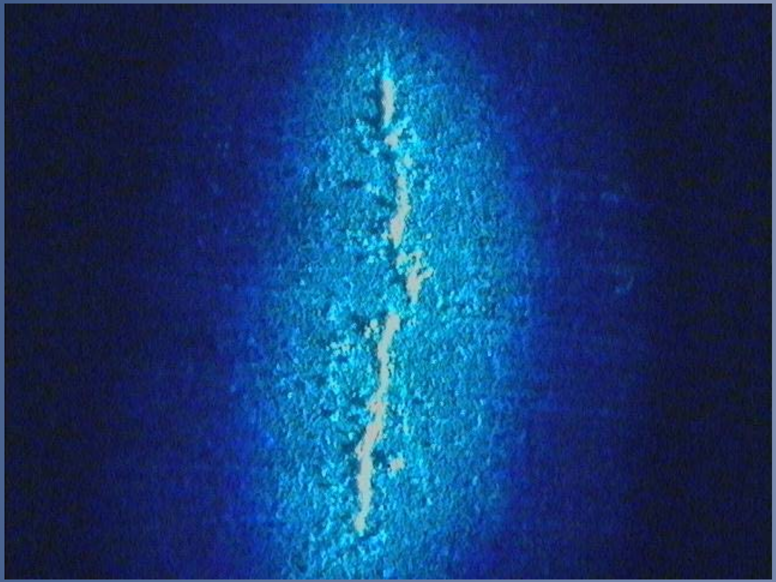
ADVANTAGES

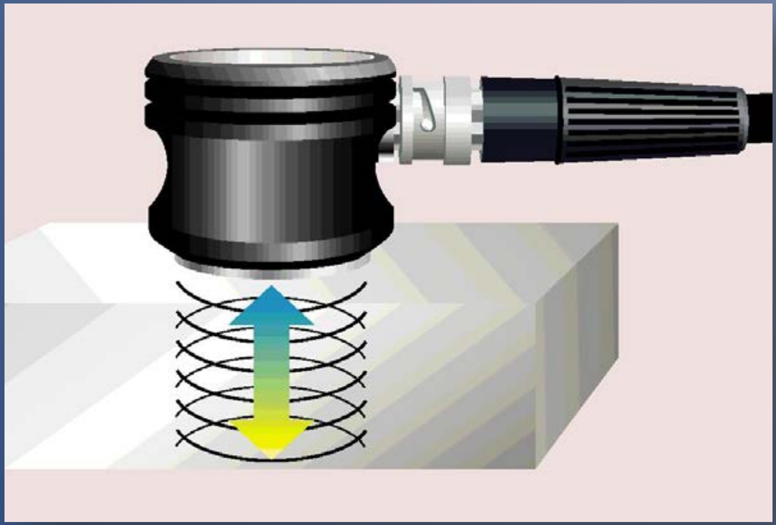


- *Large areas/volumes of parts/materials can be inspected rapidly and at low cost*
- *Parts with complex geometries are routinely inspected*
- *Indications are produced directly on surface of the part providing a visual image of the discontinuity*
- *Initial equipment investment is low*
- *Aerosol spray cans can make equipment very portable*

LIMITATIONS

- *Only detects surface breaking defects*
- *Test material must be nonporous material*
- *Precleaning is critical. Contaminants can mask defects*
- *Post cleaning is necessary to remove chemicals*
- *Requires multiple operations under controlled conditions*
- *Chemical handling precautions may be necessary*
- *Metal smearing from machining, grinding and other operations inhibits detection. Some materials may need to be etched prior to inspection*

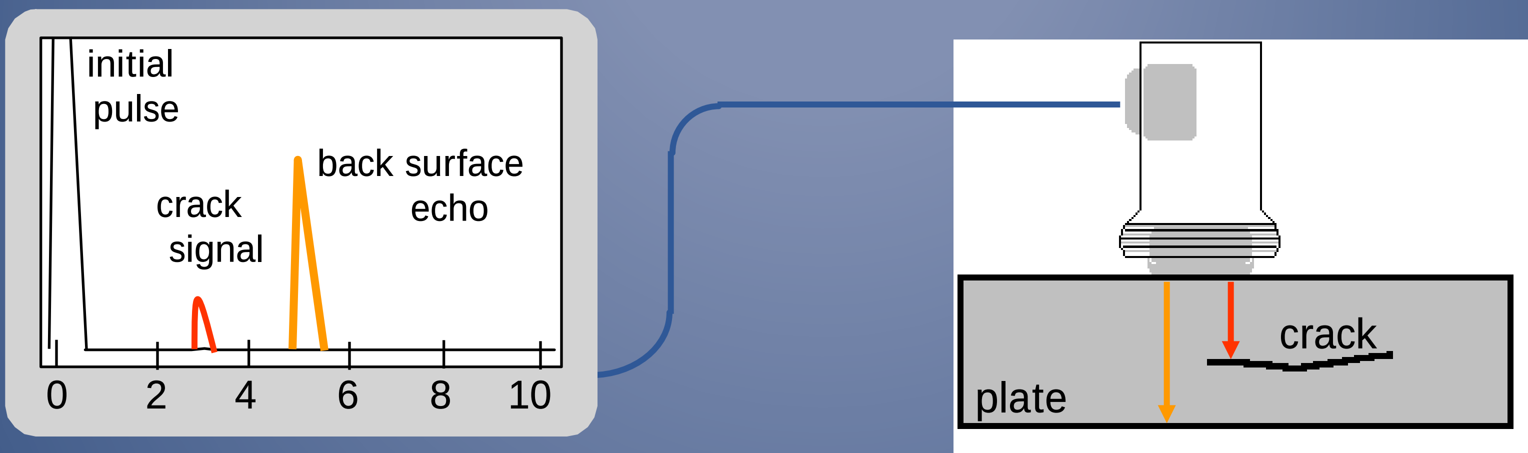
ULTRASONIC INSPECTION



- Same technology as used in fetal monitoring and other ultrasound medical applications
- A piezoelectric element converts electrical energy into mechanical vibrations and vice versa
- Contact transducer touches the test piece, and both transmits and receives the ultrasonic waves

ULTRASONIC TESTING – COMPARISON OF CONTACT METHOD TO PULSE/ECHO MODE

Sound waves travel through the material and are reflected back from surfaces or flaws.

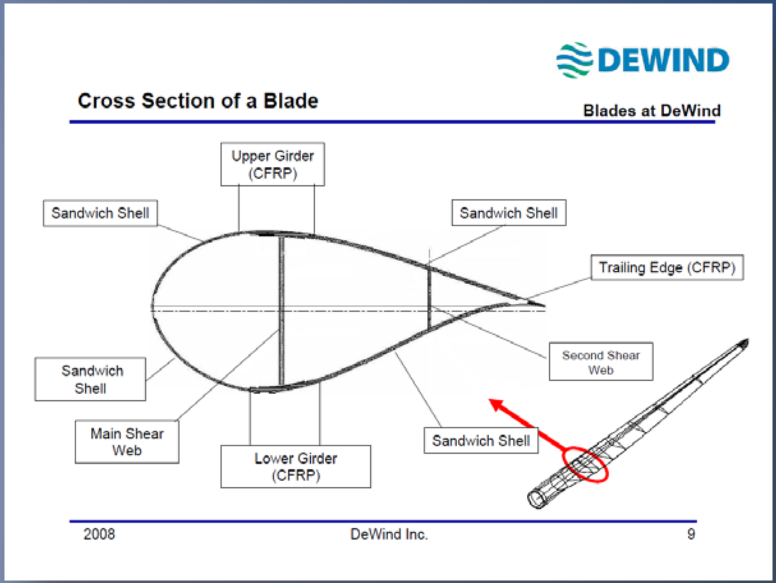


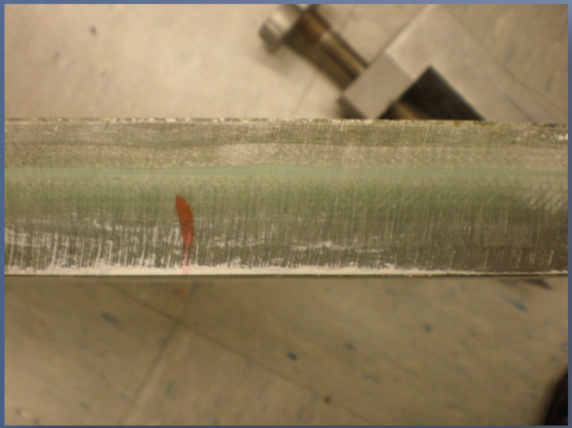
Oscilloscope, or flaw detector screen

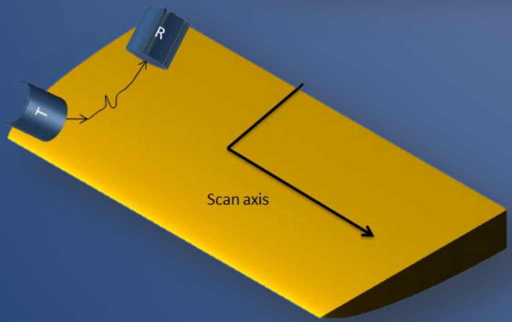
Reflected sound energy is displayed versus time, and inspector can visualize a cross section of the specimen revealing the depth of features that reflect sound.

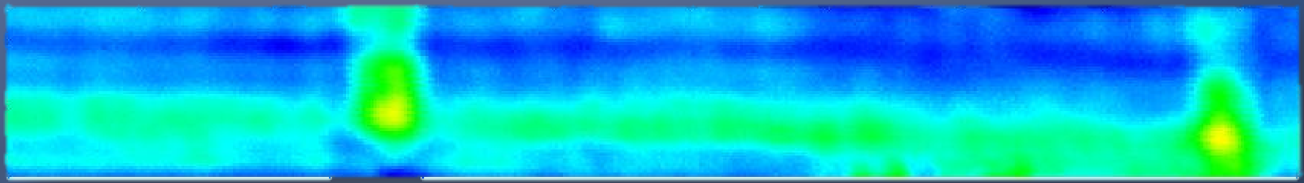
BLADE INSPECTION

- *Current inspection involves looking for disbonds between upper and lower blade halves*
- *Other defect types could be critical*
  - *Fiber layup issues in fiberglass blades*









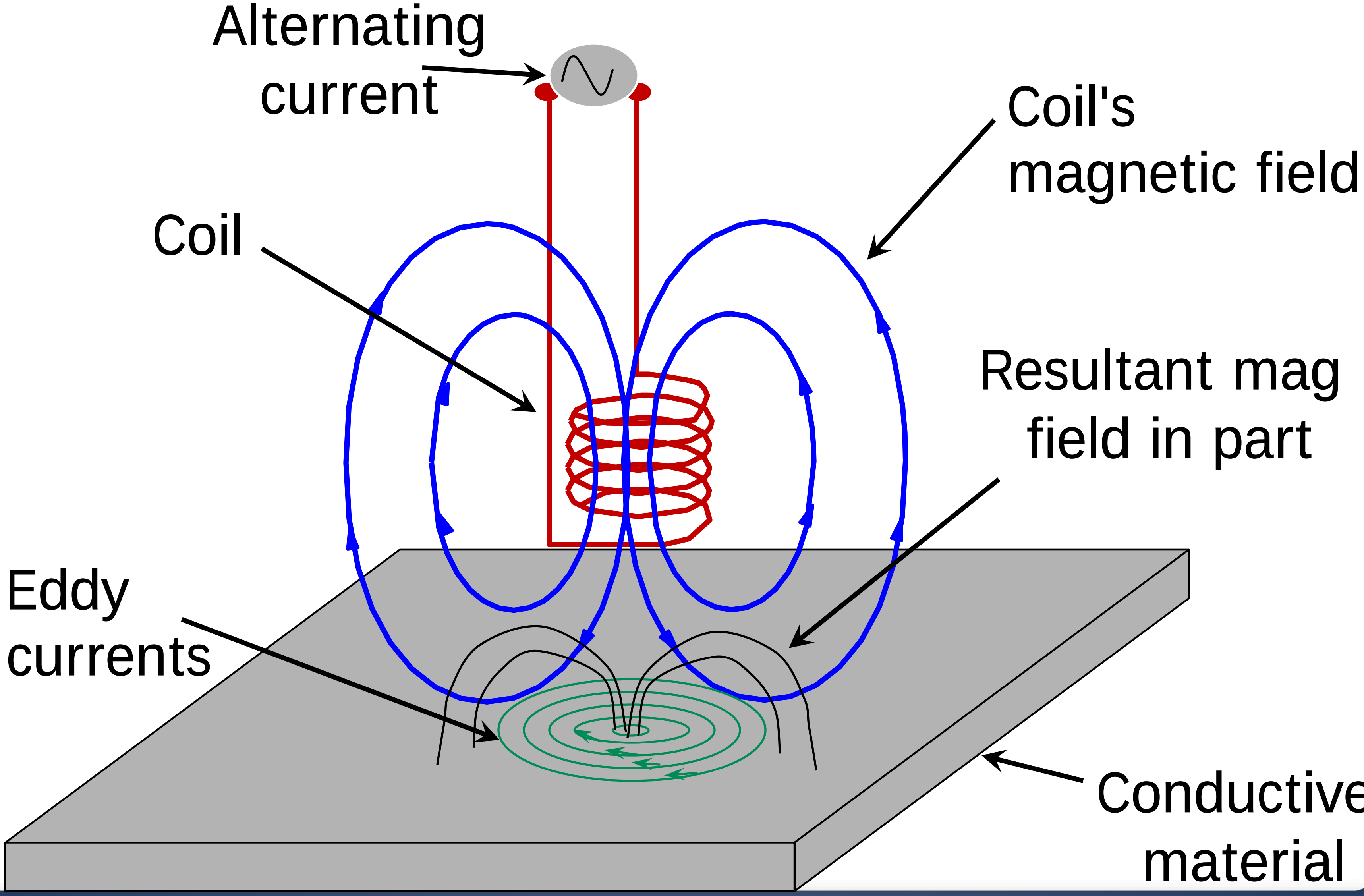
ADVANTAGES

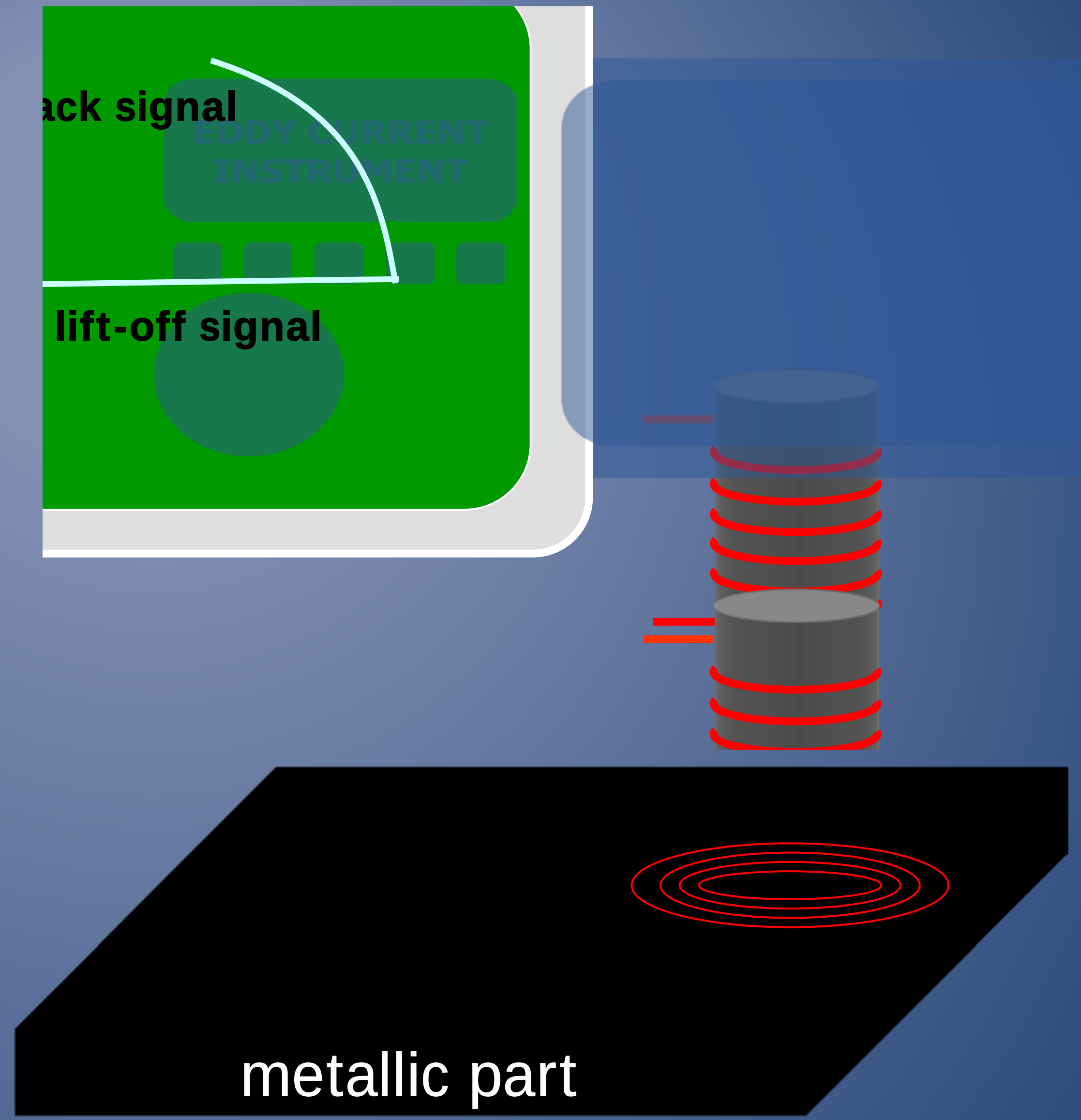
- *Used for detection of wide array of defects*
- *Portable equipment for immediate results*
- *Inspect complex shapes, large sizes and many materials*
- *Only single sided access is required*
- *Inspection can be automated*
- *Minimum part preparation*
- *Superior penetrating power*

LIMITATIONS

- *Surface must be accessible to probe, and couplant is required*
- *Extensive skill and training required*
- *Surface finish and roughness can interfere with inspection*
- *Thin parts may be difficult to inspect*
- *Reference standards are typically needed*

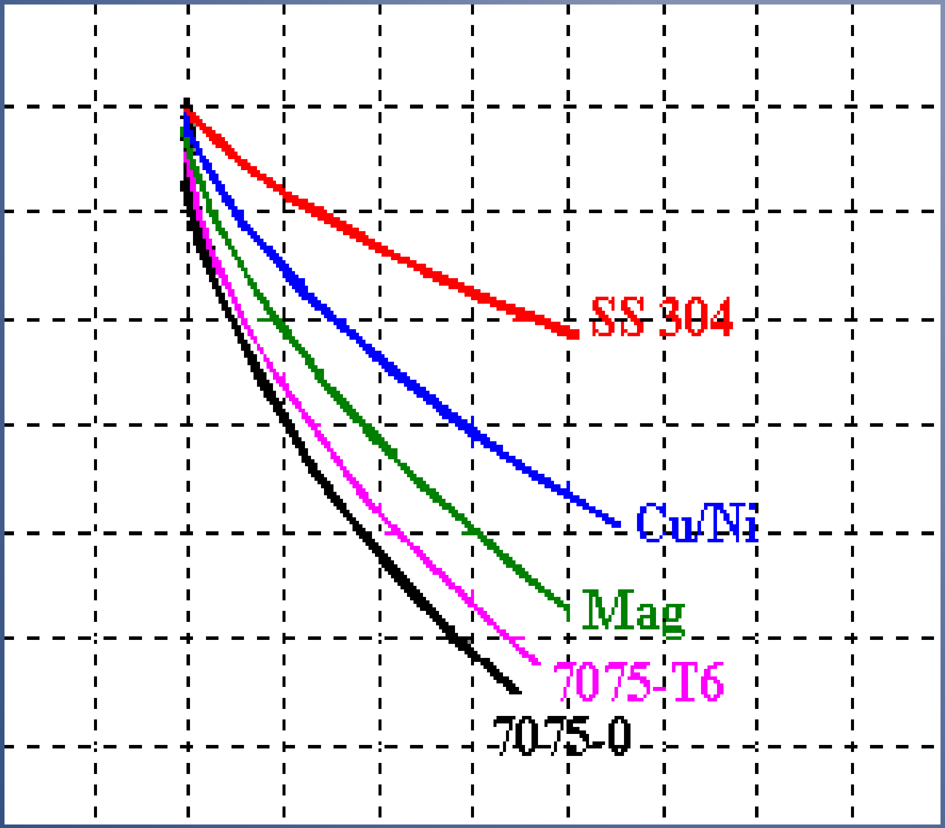
EDDY CURRENT INSPECTION




ack signal
EDDY CURRENT
INSTRUMENT
lift-off signal
metallic part


Impedance plane
imaginary part wL
real part R

EDDY CURRENT TECHNIQUE FOR METAL SORTING



Eddy current testing can be used to sort materials

Differences in conductivity cause different signals on impedance-plane display

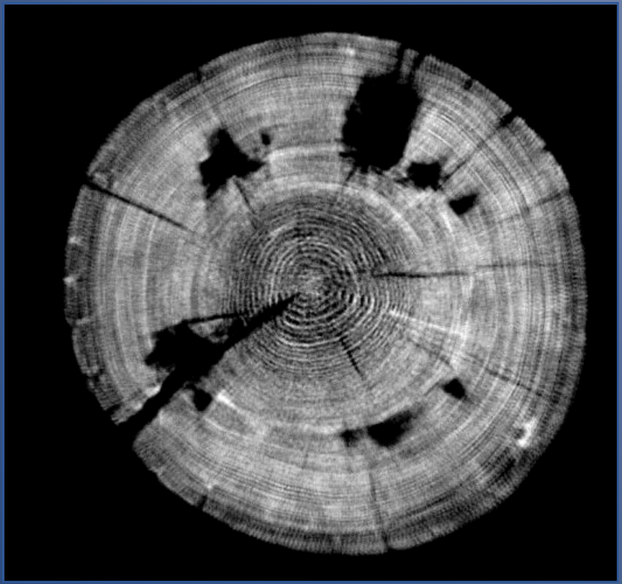
ADVANTAGES

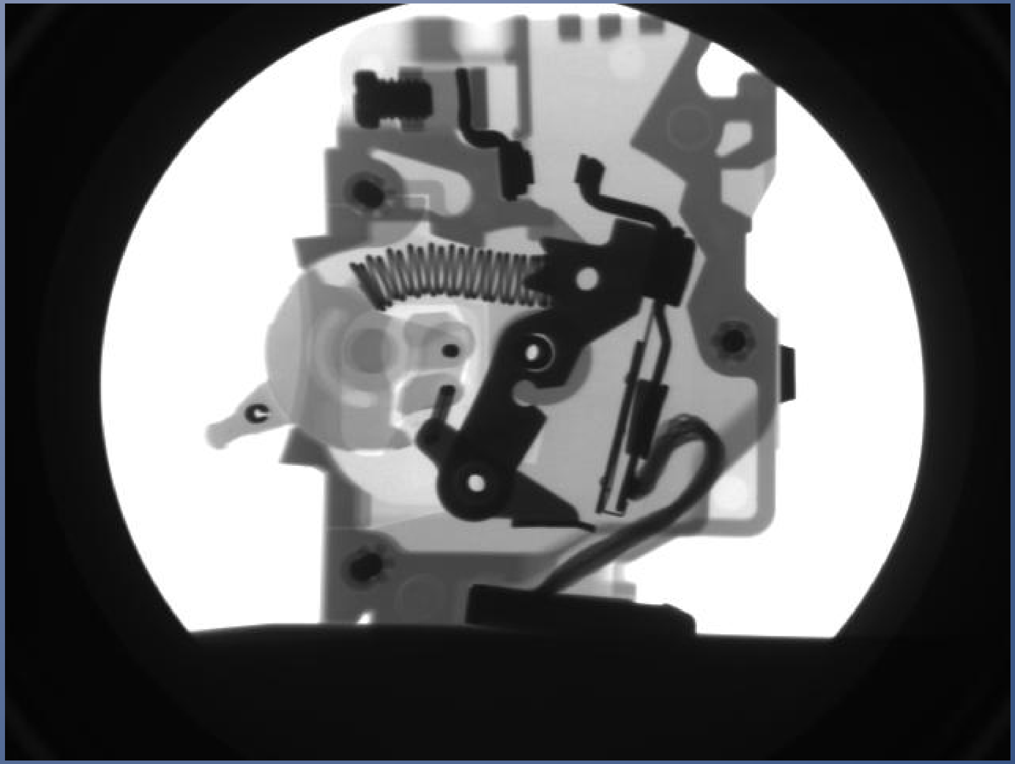
- *Sensitive to small cracks and other defects*
- *Detects surface and near surface defects*
- *Inspection gives immediate results*
- *Equipment is very portable*
- *Method can be used for more than flaw detection*
- *Minimum part preparation*
- *Test probe does not need to contact the part*

LIMITATIONS

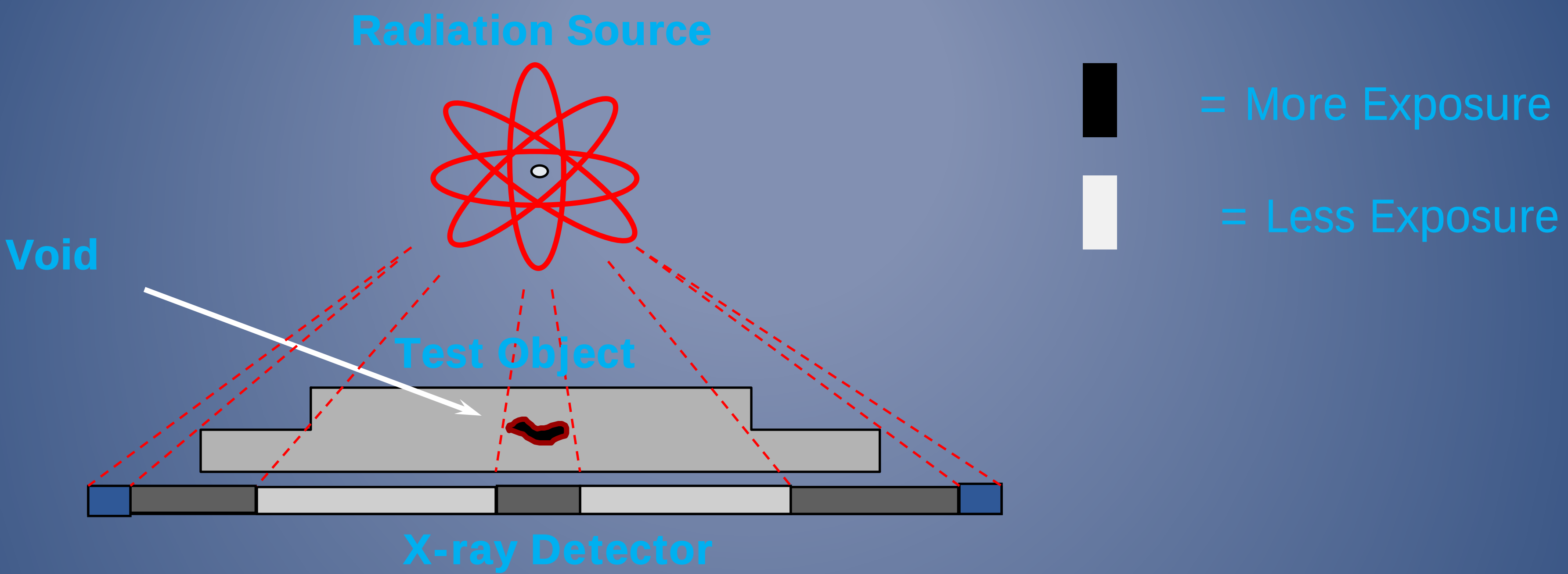
- *Only conductive materials can be inspected*
- *Ferromagnetic materials require special treatment to address permeability effects*
- *Skill and training required is more extensive than other techniques*
- *Surface finish and roughness problematic*
- *Reference standards needed for setup*
- *Depth of penetration is limited*

RADIOGRAPHIC TESTING





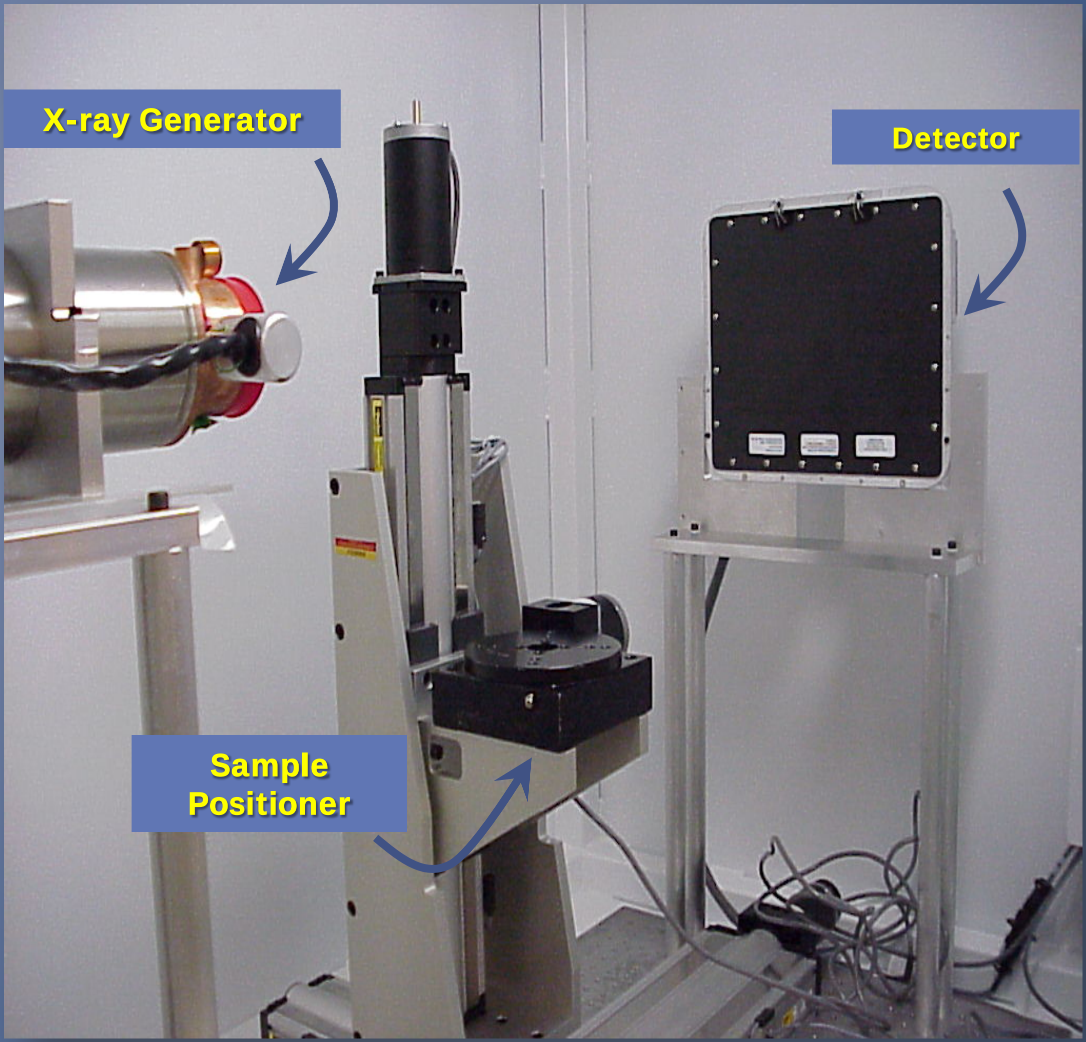
HOW DOES RADIOGRAPHIC INSPECTION WORK?



Top view

RESULTS

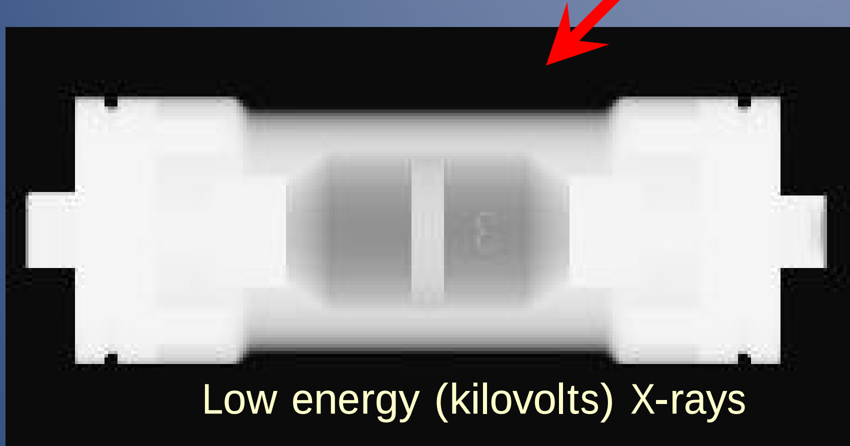
Real-time radiography setup



RADIOGRAPHIC INSPECTION

- *As radiation penetrates the specimen, the sample material stops a percentage of the incident amount from reaching the detector. The energy of the radiation affects its penetrating power, while density and thickness of the material governs its stopping power.*

Thin Walled Area with Film Radiography



ADVANTAGES:

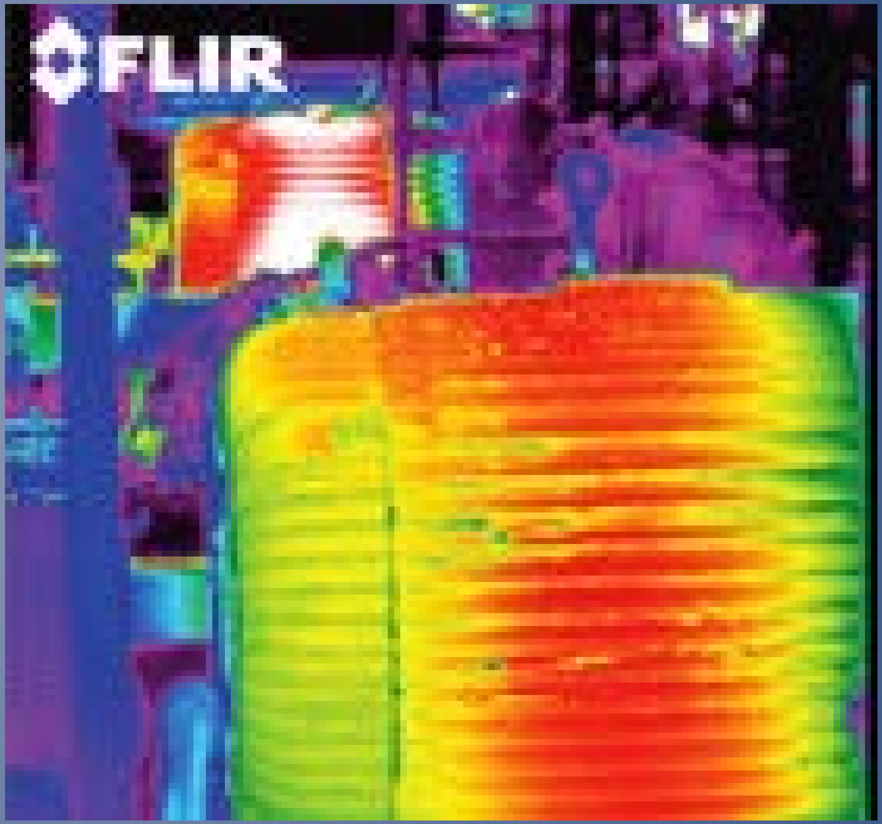
- *Technique is not limited by material type*
- *Can inspect assembled components intact (like a full suitcase)*
- *Minimum surface preparation required*
- *Tests the full thickness at once*
- *Sensitive to changes in thickness and density*
- *A permanent record of the result is obtained*

LIMITATIONS:

- *Many safety precautions for the use of high intensity radiation*
- *Orientation between incident x-ray and flaw is critical*
- *Many hours of technician training prior to use*
- *Access to both sides of sample required*
- *Determining flaw depth is impossible without additional angled exposures*
- *Expensive initial equipment cost, especially for thick parts*

THERMAL INSPECTION

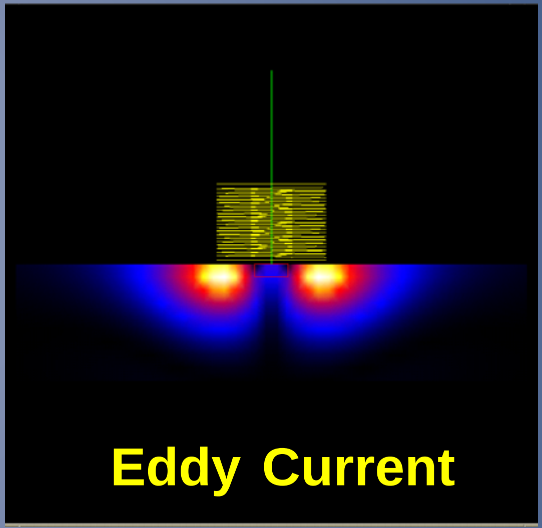
- *Largest reliability debit comes from poor gearbox performance*
- *Much cheaper to plan for maintenance than react because waited to late*
- *Significant issue for offshore installations which are likely to provide increasing proportion of wind energy*
- *Sensors*
  - *Vibration*
  - *Alignment*
  - *Oil Filtration*
  - *Temperature*

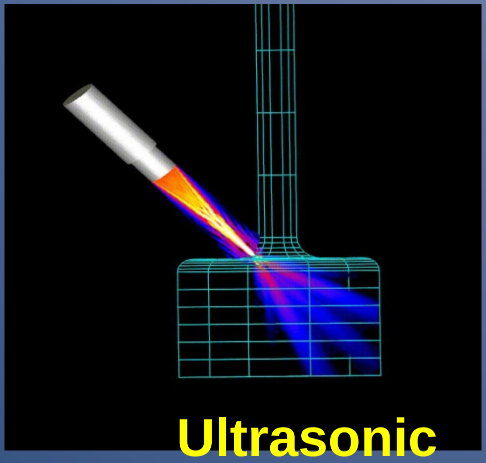


The portion of O&M costs associated with unscheduled maintenance is between 30% and 60% of the total, and generally increases as the project matures and equipment failure rates increase.

INSPECTION METHODS

- *Numerous inspection methods exist*
    - *Visual inspection*
    - *Penetrant testing*
    - *Magnetic particle*
    - *Eddy current inspection*
    - *Ultrasonic inspection*
    - *Radiographic inspection*
    - *Thermographic inspection*
- *Selection of the method depends on the material, the inspection need, the accessibility, and many other factors*





ADDITIONAL MATERIALS

www.asnt.org

www.ndt-ed.org