Condition Assessment for Mining
Reliability, and Asset Optimization

New ASTM Standard for Mill and Kiln Ring Gear Cleaning and Inspections

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ABSTRACT

- ASTM International Standard E2905 was written for mill and kiln ring gear teeth cleaning and inspection.
- It will scan the addendum, dedendum and root of a gear tooth in 15 seconds.
- With 2 and 3D dimensional isometric displays, the defect can be seen electronically as it is on the gear flank and root surface.
- This improves inspection reliability by reducing reliance on the inspector.

- Crack detection of mill gears is fairly important from an insurer's business interruption perspective.
- However, presentation is everything and so is visualization - particularly when the maintenance personnel are trying to explain a problem (or lack of a problem) to management.
- The main advantages are - not only can the defects be characterized, they can also be sized accurately faster and more effectively than other methods.
- The whole depth of a tooth including the root can be scanned in one pass. This method will benefit both the manufacturing and the aftermarket service sectors.

INTRODUCTION

- To understand operational behavior of operating machinery, a data collection and inspection process must be established.
- This data collection process, referred to as “trending”, may show a pattern signifying developing issues.
- ASTM E2905 addresses both of these concepts.
- There are two electromagnetic methods that are the basis of this standard:
- Eddy Current Array (ECA) ASTM E2884 and Alternating Current Field Measurement (ACFM) ASTM E2261.

TECHNOLOGY

- Currently, there are four types of inspections used for gearing, besides visual.
- Magnetic Particle (MT) - ASTM E709. Electromagnetic. Slow process, can miss indications and gear teeth have to be wiped clean to remove any residue.
- Dye Penetrant (LT) - ASTM E1417. Same issues as Magnetic Particle.
- At best, these two methods can determine whether a flaw exists, but are unable to provide information on defect severity such as sizing – length and depth.
- Ultrasonics (UT) ASTM A609. Requires couplant - faster than the above two methods, has a “blind” spot for surface, but can see depth. (Fig. 1)
- Eddy Current (ET) Pencil Probe. It is faster than MT, LT & UT but is very time consuming as the pencil probe must be moved rapidly to cover the entire flank surface. (Fig. 2) Interpretation of results rely solely on the inspector.

COMPARISON OF COVERAGE BETWEEN ECA AND UT

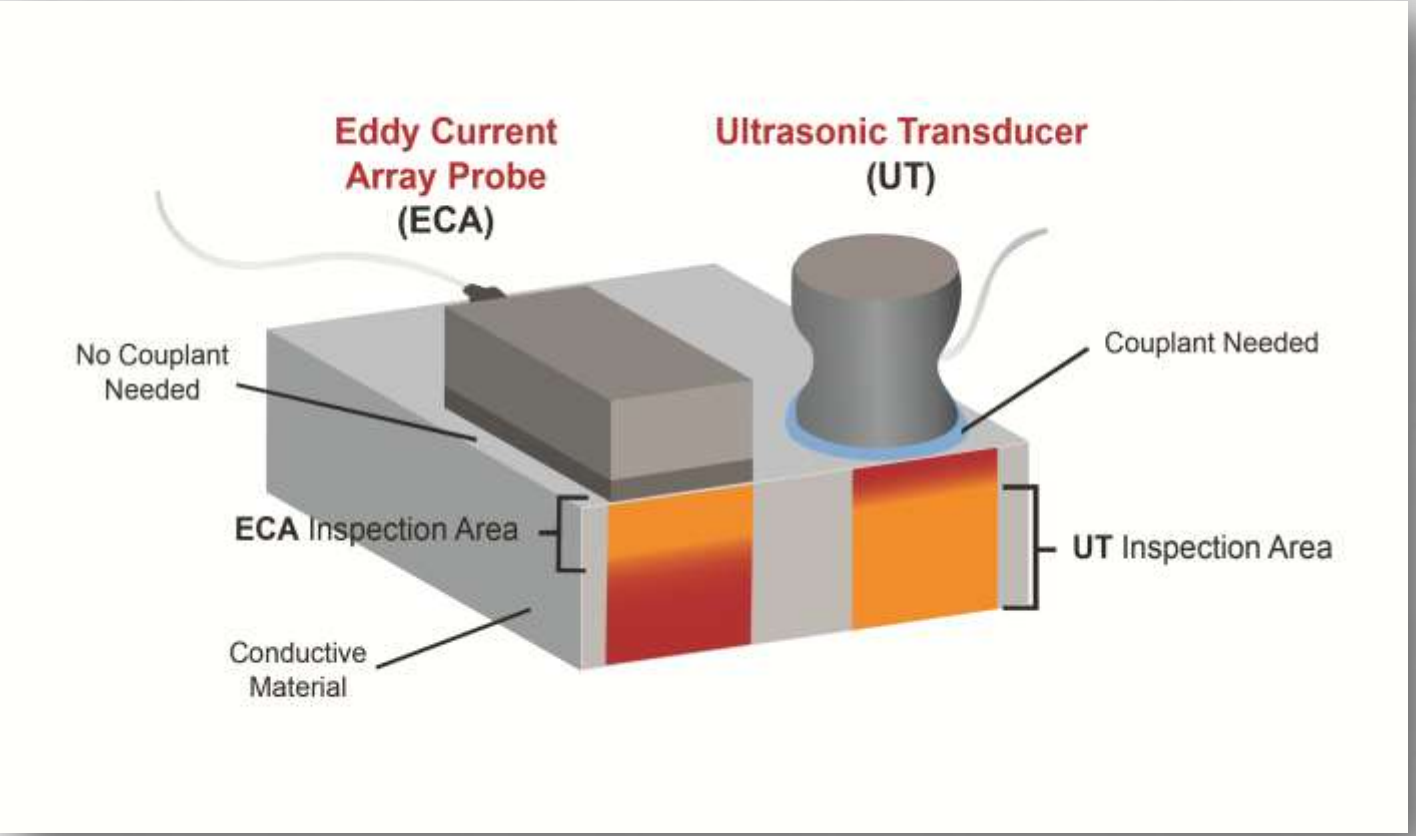

Figure 1: The different inspection areas between ECA and UT

An argument can be made using Ultrasonics for finding casting imperfections:

- Cracks are developed from sharp edges of pits on the tooth surface.
- E2905 provides 100% coverage of all gear teeth surface indications greater than .038mm.
- The reason why casting imperfections are not as important is because there is no way to repair them.
- Its only when the casting imperfection creates a crack that propagates to the surface, that it becomes a problem.
- Any casting imperfections deep in the cast should identified by the manufacturer’s Quality Control Program before the gear leaves the plant.

BRIEF HISTORY ON EDDY CURRENT (ET)

- Eddy current inspection is based on Faraday's electromagnetic induction law.
- Eddy currents are created through a process called electromagnetic induction.
- The encircling eddy currents are induced into the test material and are concentrated on the surface.
- Any flaws on the surface of the test material will disturb the eddy currents, changing the impedance of the coils in the probe. This change in impedance will show any flaws on the surface of the test material.

BRIEF HISTORY OF EDDY CURRENT ARRAY (ECA)

- ECA was developed just before the 20th century. ECA technology provides the ability to drive electronically multiple eddy current coils placed side by side in the same probe assembly (Fig. 2)
- General Electric was the first to use ECA on gearing in the late 1980’s.
- ECA has been used for years in the aircraft and nuclear sectors plus numerous other applications that require fast and accurate surface inspections.
- This practice will help to standardize the use of this nondestructive testing approach for large ring gear inspections.

- Selection of the proper probe is critical. The probe should fit the geometry of gear teeth. For pinions, a flexible probe is required because of the various helix angles of the teeth. (Figure 3)

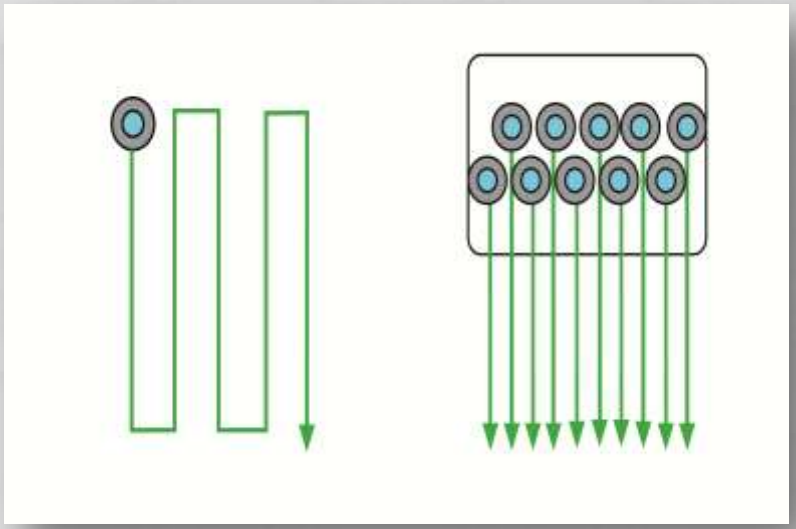

FIGURE 2: Eddy Current Single Coil Probe compared to Eddy Current Array Coil Probe

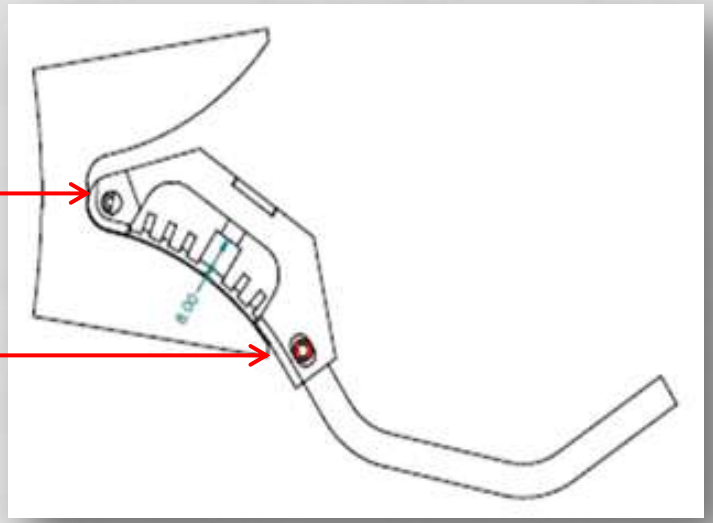

FIGURE 3: Coverage of the flexible probe

- The addendum, dedendum and root are scanned in one pass (Fig. 4,5).

FIGURE 4: Coverage of the ECA Scan

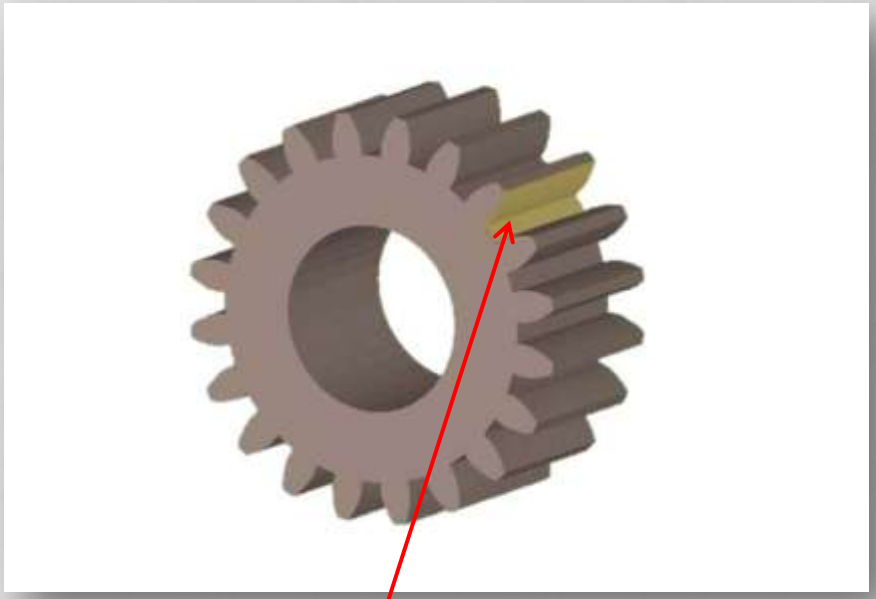

FIGURE 5: Coverage of the ECA Scan

BENEFITS FOR GEAR MANUFACTURERS

- Figure 7 is an example of scanned tooth in good condition. The blue areas of the scan represent liftoff showing each end of the tooth. The green area shows a clean tooth with no defects and the red shows a small shallow defect in the middle of the tooth. The bottom screen shows the 3D image that shows different amplitudes in defect severity.

- Much faster than Magnetic Particle and Dye Penetrant as a final inspection.

- Allows manufacturing to provide the client with an electronic map of addendum, dedendum and root area of each gear tooth before it leaves the plant. (Fig. 7)

FIGURE 6: Gear flank in good condition

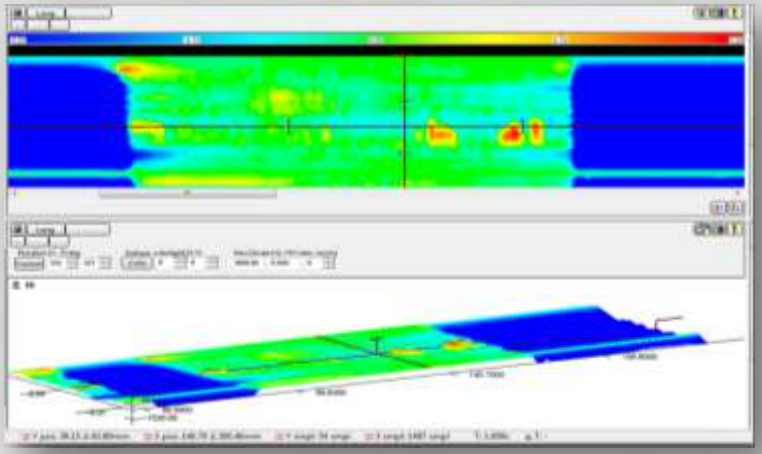

FIGURE 7: C-Scan Image of Figure 6

- Allows manufacturing to have a complete electronic record of all gear teeth scans for future reference. (Fig. 8,9)

FIGURE 8: Gear Scan File Flank # 1 A Side

FIGURE 9: Gear Scan File Flank # 1 B Side

- For example, a 316 tooth gear will have 632 files in total. 316 A Side and 316 B Side. (A Side is drive side – B Side is non-drive side)

BENEFITS FOR AFTERMARKET SERVICES

- E2905 is an excellent NDT electromagnetic method for the aftermarket service sector.
- **Cleaning** - has never been easier. 36’ diameter ring gears can be cleaned in less than an hour. There is no need to wipe the gear teeth down after the cleaning, saving numerous person hours.
- **Inspection** – E2905 is cleaner, faster, documentable, and covers a larger area in less inspection time and greatly improves Probability of Detection better than any other traditional Non-Destructive Testing methods today for gearing applications.
- Once the ring gear is inspected and leaves the factory, follow up inspections will deliver consistency, efficiency and standardization, a service valued by customers worldwide.

THE EASE OF RING GEAR CLEANING

- Over the years, ring gear cleaning, that use high viscosity, asphaltic based lubricants has become something to be avoided at all costs.
- There is now a ring gear cleaning procedure that not only simplifies the cleaning process, but reduces numerous hours of labour. The exception to this is if the lubrication is an oil bath system. In this case, no cleaning is required.
  - The actual time of cleaning a ring gear is under an hour.
  - There is no need to wipe the gear teeth down after by hand to remove residue as in Magnetic Particle or Dye Penetrant inspections.
- The ability to fully visualize the gear teeth is critical for a true gear inspection or audit. (Fig. 10)

- As visual interpretation is the method used to analyze the gear tooth condition, such as contact patterns and wear patterns, a cleaned gear is a must.

- Another reason for clean gear teeth, it is very hard for the probe to maintain the geometry of a gear tooth that has high viscosity lubrication present.

- For gears that are lubricated with a drip system, no cleaning is required.

FIGURE 10: Clean Ring Gear and Pinion

Notice how the friction force increases and the coefficient of friction decreases while the temperature stays constant. The load increases slightly over a two hour period.

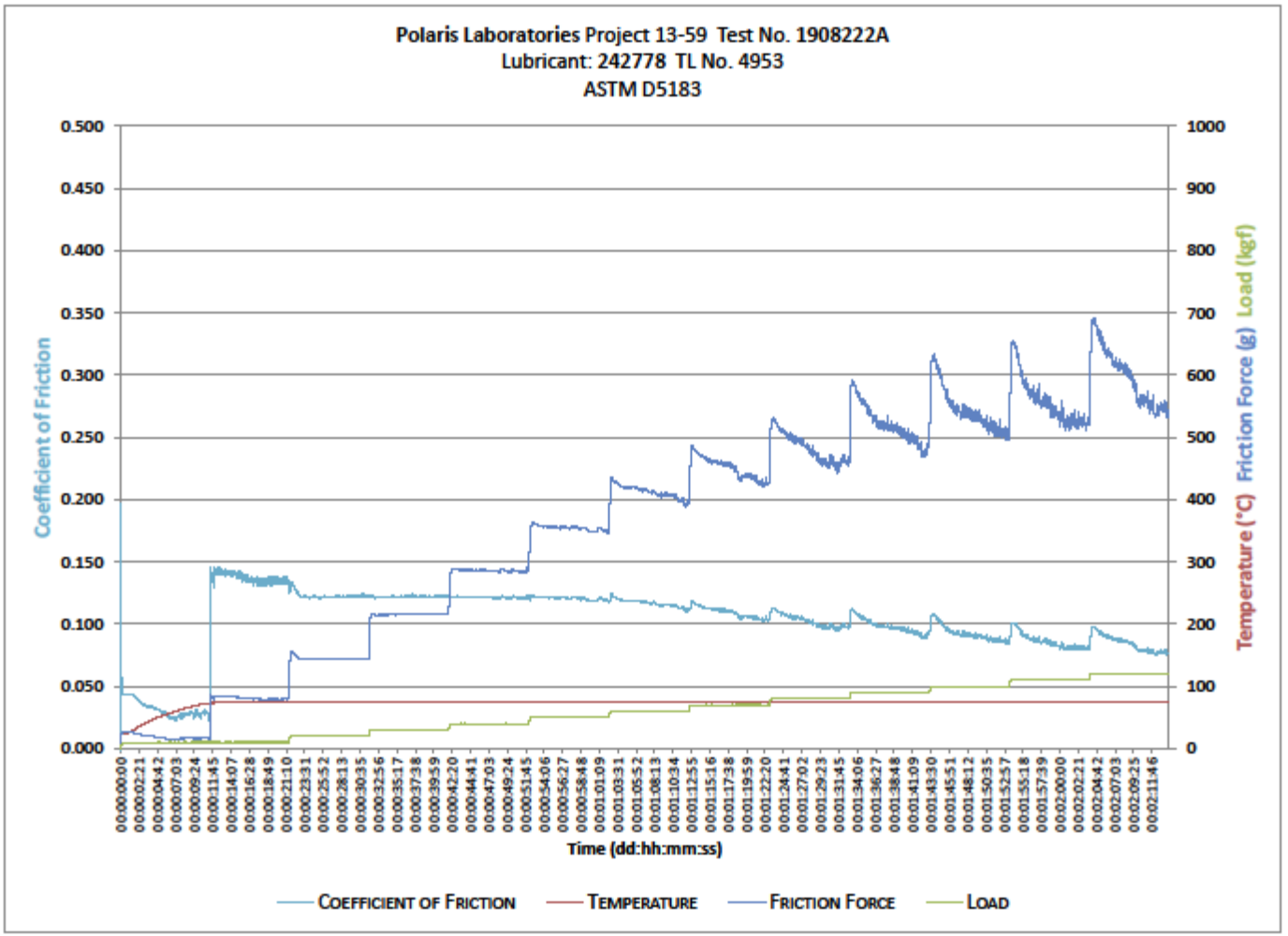

FIGURE 11: ASTM D5183 Results

FIGURE 12 – Crack found in the root that could not be visualized.
C-Scan image in Figure 13

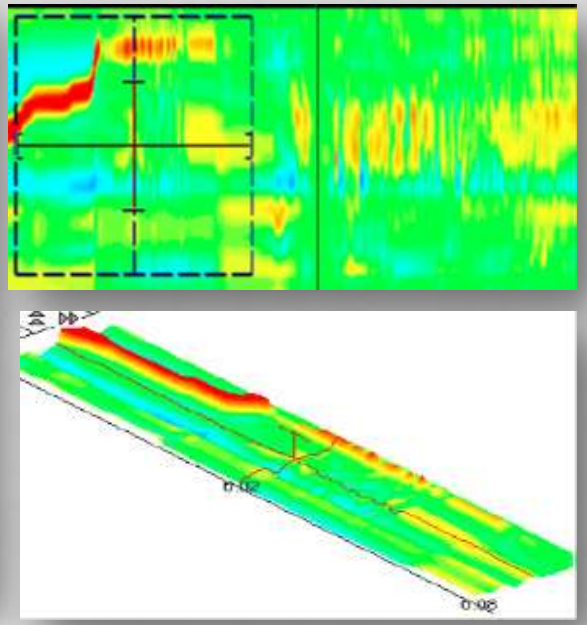

FIGURE 13 – C-Scan image of Figure 12

FIGURE 14 – This root cannot be inspected because of the presence of lubricant

- Looking at Figures 12, a clean root, using E2905 as the inspection standard, reveals a critical crack shown in Figure 13. This crack could not be visualized.

- In Figure 14, the crack in Figure 12, obviously, could not be visualized. It also couldn't be detected using E2905 or any inspection method because of the presence of lubricant.

EXAMPLE OF DETECTION OF A CRACK ON A GEAR FLANK

FIGURE 15 – Crack on a Gear Flank

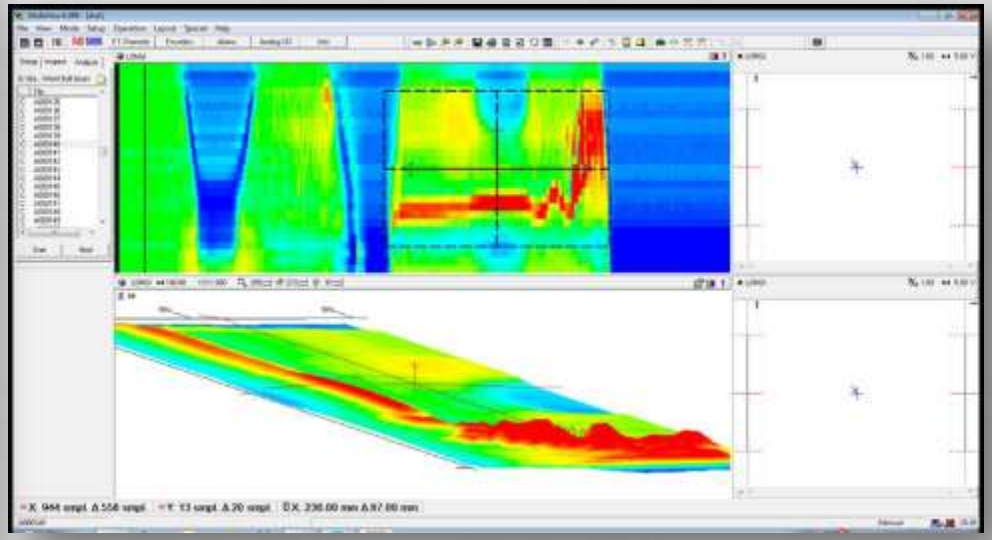

FIGURE 16 – Figure 15 screen shot

- Colours and 3D relief that help with visualization are absolutely invaluable.
- Notice the cleanliness of the gears allowing to visually analyze the gear teeth.

CASE STUDY

FIGURE 17 – Crack on tooth 244A - near the root – could not be visualized

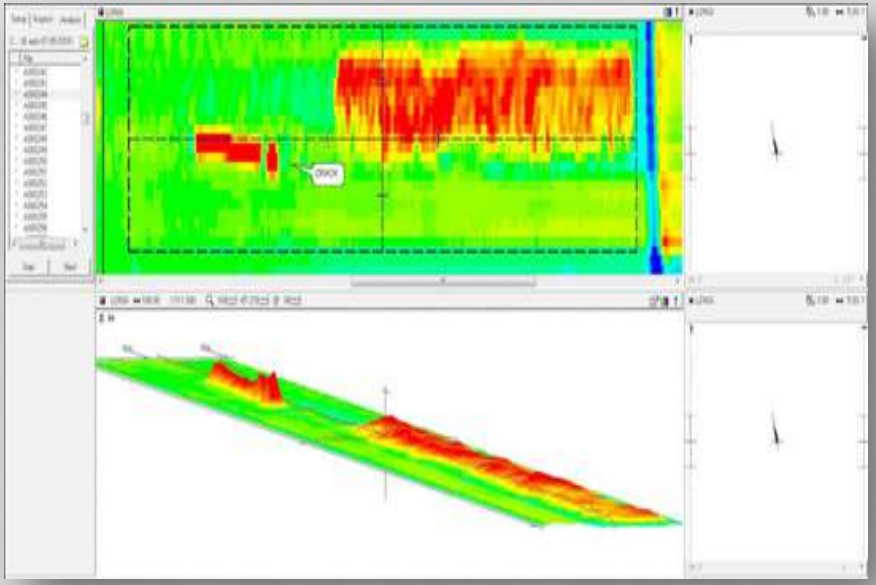

FIGURE 18 - C-Scan image of tooth in Figure 17

- (Fig. 18) is the C-Scan image of Fig. 17.

CASE STUDY

- An excellent example of the benefits of this method is shown on the following page. The client requested an inspection on a 34’ diameter ring gear.

- Once again, the gear teeth are visually inspected as the teeth are scanned. On tooth 244A, (Figure 17) E2905 detected two cracks that could not be visualized.

- The next step was to size the cracks. Utilizing Alternating Field Current Measurement (ACFM), both cracks were sized. The larger crack, was sized at 3.63” L x .68” deep.

- The sizing took less than three minutes.
- To further validate the characteristics of the crack, MT was used to visualize the crack and to document it.
- Moving forward, these cracks can be monitored through the inspection hole, on the gear guard, in less than fifteen minutes.
- Typically this mill would go down for scheduled maintenance four times a year, thus providing a comfort level to the client that any propagation of the cracks can be monitored.

GEAR BLANK PROGRAM

- Program reduces lead time from 45-50 weeks down to 14-18 weeks.
- Gear rim plate can be purchased as insurance against any gear with known defect/s. One gear rim plate can be used for multiple gears.
- Before the forged plate is placed into stock it undergoes a detailed inspection.
- Manufacturer holds stock of this material to enable immediate manufacture to commence without having to wait the current 20 weeks for a gear casting. Having pre-qualified forged material also overcomes the problems of casting porosity or defects that ultrasonic examination of the raw casting may reveal.
- Straight forged plate in section thicknesses up to 220mm can be rolled into any desired radius using a 5,000 tonne vertical roll press. The standard thickness of forged plate can be made into any required gear size.

Estimated Savings Obtained from Utilizing E2905 Compared to Traditional Inspection Methods

Lost Production Revenue Calculator

Inputs	0.4		Grade %Cu
	0.015		Grade %Mo
	1000		Tonnes per hour
	85		Recovery - Copper
	65		Recovery - Moly
	95		Mill availability
	3.00		Assumed price Copper ($/lb)
	11.00		Assume price Moly ($/1b)
	0.97		Payable pounds factor
Outputs	$	497,317	Lost Revenue $ Copper per day (24hr)
	$	53,909	Lost Revenue $ Moly per day (24hr)
Totals	$	4,973,175	Lost Revenue $ - 10 Day period - Copper
Totals	$	539,087	Lost Revenue $ - 10 Day period - Moly
	$	20,722	Lost Revenue $ Copper per hour
	$	2,246	Lost Revenue $ Moly per hour
	$	22,968	Total Lost Revenue $ per hour hour

To the left is the estimated cost of a catastrophic gear failure, over a 10 day period, providing there is a spare gear onsite.

Totals	$	689,033	Lost Revenue Total based on 30 hrs cleaning and inspection using conventional methods
Totals	$	183,742	Lost Revenue Total based on 8 hrs cleaning and inspection utilizing E2905
Totals	$	505,291	Recovered Production Revenue for Customer utilizing E2905

Above, is a typical scenario for customers that inspect using Magnetic Particle and/or Dye Penetrant, assuming the customer is taking 30 hours to clean and inspect. This is typical for these type of methods. Notice the difference and savings using E2905.

SUMMARY OF THE BENEFITS USING E2905

- Drastically reduces inspection time.
- Covers a large area in one single pass.
- Compliments any Plant Asset Management program.
- Unlike some other inspection methods, this will electronically size cracks accurately.
- The gear cleaning program can completely clean a mill gear, including the root, within an hour.
- This technique does not require the gear to be wiped down completely after cleaning, therefore reducing the number of person-hours to prepare the gear for inspection.
- All of the data is electronically archived for future trending.

CONCLUSION

- The inspection can take place alongside other maintenance personnel.
- E2905 will allow SAG and ball mill maintenance planners to reduce the time it takes to perform gear inspections.
- Planners that use to allow 36 hours to inspect the gear set, now allow 6 to 8 hours for this job.
- It is conceivable to clean and inspect four Mills (2 x 34’) and (2 x 24’) in two days.
- This process provides comprehensive and accurate inspection data. This is very important in determining the integrity of the gear set.

- It reduces the reliance on human interpretation using other inspection methods.
- Insurance companies have acknowledged the benefits of this method and some are now requesting their clients to inspect to E2905.
- Some OEM’s are discussing the possibility of manufacturers utilizing E2905 as a final inspection method.
- This method provides real-time mapping of the inspected region, facilitating data interpretation, improving Reliability and Probability of Detection (POD).
- All of this helps in minimizing catastrophic failures, resulting in reduced maintenance costs and increased uptime.

THANK YOU

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