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### Welcome! "NDT Applications" Webinar Series

May 13, 2021 Host: Toni Bailey Owner, TB3 NDT Consulting LLC

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Reducing measurement error in the MPI of metal castings

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[1] https://www.magnaflux.com/NA/EN/Products/Magnetic-Particle-Inspection/Equipment/Database-System.htm#group-1
[2] https://www.dcm-tech.com/products/magnetic-particle-inspection/
[3] https://www.magnumpdt.com/a brief bittory of ndt whiteboard animation blog

[3] https://www.magnumndt.com/a-brief-history-of-ndt-whiteboard-animation-blog

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## Background

- Nondestructive testing (NDT) methods are used in the steel casting industry to test the quality of parts
- Magnetic particle inspection (MPI) is used to detect surface-breaking and subsurface discontinuities
- This work evaluates measurement error in wet MPI



Fig. 1 Example steel casting



## **Basic Principles**

- MPI is a combination of two NDT methods [1]
  - Magnetic flux leakage testing
  - Visual testing



Fig. 1 Flux leakage present due to crack [2]

D. J. Eisenmann, D. D. Enyart, D. Kosaka, and C. Lo, "Fundamental Engineering Studies of Magnetic Particle Inspection and Impact on Standards and Industrial Practice," 2014.
"Basic Principles of MPI," NDT Resource C. [Online]. Available: <u>https://www.nde-ed.org/EducationResources/CommunityCollege/MagParticle/Introduction/basicprinciples.htm.</u>

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Surface Roughness Geometry

[1] https://www.magnaflux.com/NA/EN/Products/Magnetic-Particle-Inspection/Equipment/Database-System.htm#group-1

[2] https://www.dcm-tech.com/products/magnetic-particle-inspection/

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## Variability due to tested part



Fig. 1 Geometry

Fig. 2 Surface Roughness



## Geometry

- Magnetic field strength was measured for:
  - Three geometries
  - Two orientations



Fig. 1 Curved inward radius



Fig. 2 Flat surface



Fig. 3 Curved outward radius

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## **Geometry – Curved inward**

#### **ORIENTATION 1**





#### **ORIENTATION 2**



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## **Geometry – Conclusion**

- Magnetic field strength decreases as curved inward radius increases
- Flat regions/corners did not show difference
- Curved outward radius did not show any meaningful trends
- Defects usually occur in curved inward radius in casting



## **Surface Roughness**

- Do particles tend to collect more on rougher surfaces?
- How does this affect the effectiveness of detecting defects?





$$\bar{G} = \frac{\sum_{i=1}^{n} G_i}{n}$$

- *G<sub>i</sub>* = the green value of the i<sup>th</sup> pixel from the RGB
- *n* = the total number of pixels in the image

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## **Surface Roughness**

- Do particles tend to collect more on rougher surfaces?
- How does this affect the effectiveness of detecting defects?





$$Pi = \begin{cases} 0, Gi \le t \\ 1, Gi > t \end{cases}$$

• Gi = the green value of the i<sup>th</sup> pixel from the RGB

Noise Area Percentage, 
$$\% = \frac{\sum_{i=1}^{n} Pi}{n} * 100$$

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Instructions X Y G value Pixels with G values less than Noise Area Percentage
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## **Surface Roughness - Classification**

- ASTM A802
  - Visual and tactile comparison with standards
  - Subjective



Fig. 1 Example steel casting



Fig. 2 ASTM A802 Surface Roughness Standard



Fig. 3 An example of classified regions with A1, A2, and A3 roughness

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### **Surface Roughness - Results**



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## **Surface Roughness - Conclusion**

- Surface roughness influences the collection of particles
- A general increase in noise area percentage was observed as surface roughness increases
- It may be harder to detect defects in rougher surface textures



## Survey Question

For the industry I am currently in, I work with

- A) Machined surfaces
- B) Mixture of machined surfaces and cast surfaces
- C) Cast surfaces





[3] https://www.magnumndt.com/a-brief-history-of-ndt-whiteboard-animation-blog

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## Variability due to human inspector





Fig. 1 Level of Expertise [2]

[1] https://blog.creativesafetysupply.com/fatigue-causing-increase-workplace-injuries/
[2] https://www.lynda.com/Business-tutorials/Levels-expertise/439681/2280594-4.html

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### Human error

- Percent match Repeatability and reproducibility (3 foundries)
- Used magnets to identify where operators find defects
- Blast parts in between sets (Foundry 2&3)

Repeatability = 40% because 2 out of 5 match



Figure 1. Blue "x" represents Operator 1 Part 1 Trial 1 Red circles represent Operator 1 Part 1 Trial 2





Figure 2. Blue "x" represents the union of Operator 1 Part 1 all Trials Red circles represent the union Operator 2 Part 1 all Trials

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## **Human error - Results**

- Foundry 1 (3 op, 6 parts, 2 times) 73% for repeatability and 48% for reproducibility
- Foundry 2 (2 op, 6 parts, 2 times) 33% for repeatability and 25% for reproducibility
- Foundry 3 (1 op, 4 parts, 2 times) 15% for repeatability



Figure 1. A) Trial 1 Area X1 and B) Trial 2 Area X1



Figure 2. A) Trial 1 Area X2 and B) Trial 2 Area X2

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## Human error - Conclusion

- Low repeatability and reproducibility
  - Supports the need for an inspector aid
- Disappearing indication between Trial 1 and Trial 2
  - Supports further investigation into factors involved in inspection process



## Survey Question

For the industry I am currently in, we perform gauge R&R for wet MPI

- A) Yes
- B) No





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## Variability due to inspection process





Fig. 2 Magnetic Field Strength [1]





Fig. 3 Current Type [2]

Fig. 1 Orientation



Fig. 4 Magnetization Type [1]

https://www.nde-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/FieldOrientation.htm
https://www.nde-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/MagnetizingCurrent.htm

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## **Inspection Process**

- 2<sup>4</sup> 2 levels, 4 factors, 2 replicates
- 32 runs

#### Explanatory variables

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#### Response variable

Factors	Low	High
Orientation	0°	90°
Field Strength	15	45
Magnetization	Longitudinal	Circular
Current	Alternating	Direct



Noise Area Percentage 8.22 %

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## **Inspection process - Conclusion**

- Orientation and Magnetization were found to be significant
- Results seem to be binary (close to 0 or 1)
- Next, more levels for orientation and magnetic field strength will be investigated



#### 

#### Explanatory variables

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### **Human error - Results**

- Foundry 1 (3 op, 6 parts, 2 times) 73% for repeatability and 48% for reproducibility
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Figure 1. Operator 2 identified crack



Figure 2. Operator 1 after blast, crack is there but not identified



### **Our proposed solution**



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## Challenges



Training data

Teach model

Inspector aid system



## **Predictions**







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## **Inspector Aid Project - Conclusion**

- Work in progress
- Requires a lot of images
- Data labeling takes a lot of time
- We will be gathering more images over the summer
  - If you have (or could gather) MPI images and would like to contribute to this research please email me



Min size 1024 by 1024 Not zoomed in to the crack

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## Survey Question

- For the industry I am currently in, this proposed inspector aid solution for wet MPI would be beneficial
  - A) Yes
  - B) No



## **Key Takeaways**

- Lower magnetic field strength was found in curved inward regions where defects are typically located
- It may be harder to detect defects in rougher surface textures
- Percent match R&R average were 25% and 25%
- Orientation and magnetization type were found to be important process parameters
- Development of an inspector aid system could help improve R&R



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Thank you

## **Questions?**

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# **Additional Questions?**

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## Thank you for participating!

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