Factors that affect the defect sizing capabilities of the Magnetic Flux Leakage Technique

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Abstract

This paper is concerned with investigating inherent Magnetic Flux Leakage (MFL) technology variables that affect the reliability, repeatability and accurate sizing of defects. External defect sizing factors such as a clean inspection environment are not considered. With such extraneous variables removed the effects on the MFL signal due to magnetic saturation, the calibration process and of defect geometry can be investigated. The results presented herein confirm that an under-saturated inspection surface is a major limiting factor in defect sizing. Consequently to overcome the limitations presented by under-saturation a new calibration procedure is proposed and investigated. Further suppositions that pertain to defect sizing, due to defect geometry, are also explored and verified empirically.

1 Introduction

The Magnetic Flux Leakage approach is extensively used for the non-destructive testing (NDT) inspection of Aboveground Storage Tanks (ASTs). MFL testing is perfectly suited to the inspection of AST floors due to its ability to cover large areas quickly. This means that MFL equipment is capable of rapidly providing detailed positional and defect severity information. However, it is the accuracy, repeatability and reliability of MFL's defect sizing that is a concern of the MFL community. The co-dependence and consequences of the calibration process, induced magnetism and defect geometry are empirically and theoretically investigated in this paper. Addressing these factors may lead to greatly improved and reliable defect sizing.

To begin, the MFL principle as applied to AST floors is revealed. Then calibration, induced magnetism and defect geometry is discussed in general terms. Continuing, two specific calibration procedures are described and investigated. For each calibration routine results are presented and discussed in turn with the aim of identifying procedures to account for variation in induced magnetism.

Assuming saturation the effect of defect geometry and its impact on MFL defect sizing is subsequently considered. A simple geometry analysis reveals that improved defect sizing accuracies are possible if defect geometry can be learnt. The paper concludes with some final remarks and suggestions for further research.

2 The MFL principle and factors that affect defect sizing

Herein the MFL setup considered is in the context of AST floor scanning. The setup consists of a Yoke mounted on a carriage that induces a magnetic field, via a permanent magnet, into the inspection surface. Ideally this induced field saturates the inspection surface.

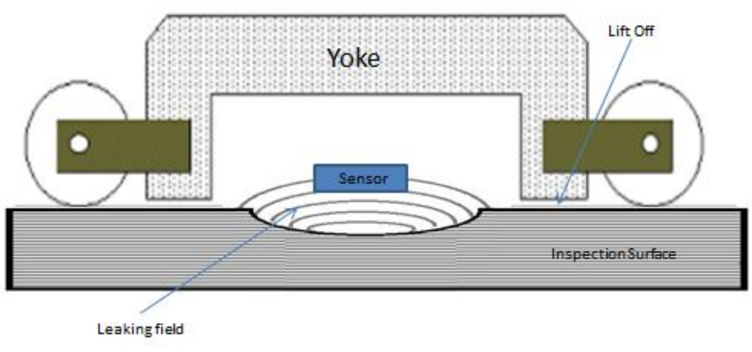


Figure 1: A representation of the MFL principle.

In the vicinity of a defect, a magnetic flux leakage field forms outside of the inspection surface [1]. A sensor array is positioned between the poles of the magnetic Yoke to detect this flux leakage and convert it into a signal. Ideally, the size of the defect generally dictates the amount of leaking field. A calibration based on the leaking signals then determines defect sizing.
Based on experience, related literature and the work performed for this paper, three factors that are known to affect defect sizing, namely calibration, induced magnetism and defect geometry, are now presented and discussed with the aim of improving defect sizing [2,3].

2.1 Calibration

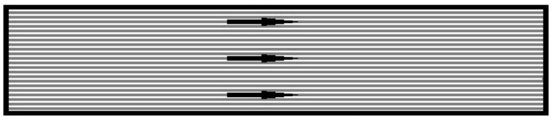
A calibration establishes a relationship between a leaking magnetic field and a defect's depth[1]. For an unknown defect detected during an inspection this relationship is used to estimate its depth, the critical parameter in tank floor inspections. Clearly, as defect geometry can influence the nature of the leaking field this relationship is only valid for defects with a similar geometry. If sizing inaccuracies are observed but the calibration is valid, then other factors, such as induced levels of magnetism and / or defect geometry will likely be the cause of the defect sizing errors[2].

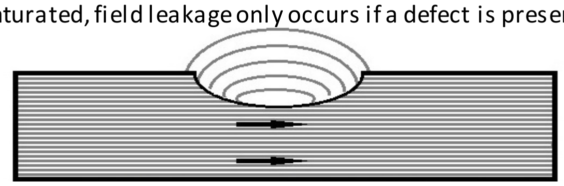
2.2 Induced Magnetism

If permanent magnets are used as the magnetising source then controlling the level of induced magnetism imparted into the inspection surface is a challenge. For one, a change in inspection surface thickness may result in variations to the levels of induced magnetism. The extant level of magnetism in the inspection surface is a key factor that may influences the calibration process by affecting the nature of the leaking field. If magnetism levels during calibration differ to those present in the inspection surface then defect sizing inaccuracies will likely occur.
After one traverse (scan) of an inspection surface, that surface can exist in either one of three induced magnetic states; it can either be ideally-, under- or over-saturated, depending upon the magnetising power of the MFL technology. Below a series of diagrams and accompanying descriptions illustrate and describe the three states in which an inspection surface can exist:

2.2.1 Ideal-Saturation

Magnetism is a function of permeability and as such is reluctant to leave the inspection surface unless into a more permeable material. When an inspection surface is ideally saturated, field leakage only occurs if a defect is present.

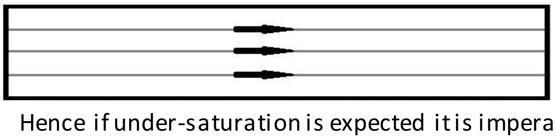


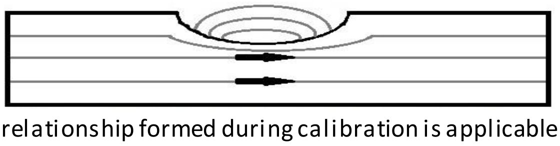


If each scan of an MFL tool can achieve ideal-saturation the immediately preceding scan occurrence (scan history) is unimportant and the magnetic fields leaking from symmetric defects contained therein will be consistent. Ensuing errors in defect sizing are likely due to defect geometry. Seldom are inspection surfaces ideally-saturated hence the other two remaining magnetic states must be accounted for.

2.2.2 Under-Saturation

Varying degrees of under-saturation can exist until ideal saturation is achieved. If unaccounted for, and depending upon its extent, under-saturation is at least a serious defect sizing and repeatability limiting factor[3]. For under-saturated inspection surfaces the leaking fields created by defects can vary if the same area of the inspection surface is rescanned. Opposing scans performed on the same inspection area result in larger leaking fields when compared with repeated scans performed in the same direction. This variation is due to the extent of the magnetic field contained within the inspection surface; its position on the B-H hysteresis curve is variable and, critically for the MFL process, it is not at saturation point meaning scan history can affect the leaking field from future scans [4].





Hence if under-saturation is expected it is imperative that the relationship formed during calibration is applicable to the inspection surface.

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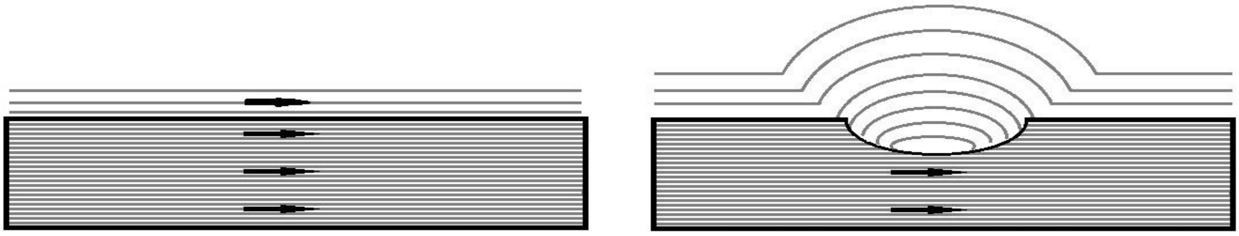
1 Calibrations that clearly result in defect sizing inaccuracies are not explored.
2 Defect origin, top surface or bottom surface is also a factor together with defect orientation.
3 Clearly detection is questionable in severely under-saturated inspection surfaces.

2.2.3 Over-Saturation
Over-saturation occurs when magnetic flux leaks from the inspection surface regardless of defect presence. It has been empirically proved that if an inspection surface is over-saturated, repeated scans of a symmetric defect will result in a consistent leaking field regardless of scan direction i.e. scan history is unimportant.



Moderate over-saturation is preferable because deformations in the leaking fields are likely to be easier to detect in real world applications[4] as any added defect will accentuate the already leaking field in that area.

Knowledge concerning inspection surface saturation levels can explain many occurrences but the main objective for this work is to understand how under-saturation affects defect sizing and therefore how important it is to account for a lack of saturation during the calibration process.

For under-saturated inspection surfaces in particular, it is imperative that the MFL operator understands the calibration and saturation relationship due to the potential variability in defect sizing. The results and discussions to follow show that, if during the calibration process, suitable provisions can be made for under-saturation then accurate defect sizing is readily achievable. However if on the same area of inspection surface repeat direction and opposing scans are compared then defect sizing variability will still be evident, this is unavoidable and a consequence of under-saturation.
The main problem for under-saturated inspection surfaces is that the magnetic state of the inspection surface during calibration is changeable. Furthermore the inspection surface to which the calibration is applied (i.e. an AST floor) is assumed to be free of magnetism. Same direction scans performed during the calibration process may account for this assumption by fixing the level of magnetism in the calibration surface to some still unknown point.

2.3 Defect Geometry
Variations in defect geometry alone will also affect defect sizing accuracies. The relationship between defect geometry and the corresponding leaking magnetic fields is complex and non-linear [5]. In ideal-, over- and near-saturated inspection surfaces defect geometries of equivalent volume can provide different corresponding MFL signals. It is also possible that defects larger in volume, compared with other defects of a different geometry, can emit a smaller leaking field due to the level of magnetism in the inspection surface[5].
Surface origin is yet another size affecting variable, however ascertaining defect surface origin is out of the scope of this paper, and to reduce variables its knowledge is assumed[6].

3 Defect Sizing Findings

To understand how calibration, induced magnetism and defect geometry effect defect sizing two separate investigations were performed. The first investigation negated the effect of defect geometry by considering geometrically invariant defects so that the calibration process and induced levels of magnetism could be examined. The second investigation assumed ideal saturation so that the effects of defect geometry could be explored.

3.1 Induced Magnetism and Calibration Investigation

To investigate the induced magnetism and calibration relationship two calibrations were trialled: *Standard* and *New.* The *Standard* calibration does not consider under-saturated inspection surfaces. The *New* calibration routine takes into account the possibility of under-saturation.
The inspection surface on which this investigation was performed is now described.

[4] Sensor height distance may be increased (compared with ideal- or under-saturated surfaces).
[5] Consider 80% deep pipe like defects and similar through hole type defects.
[6] Recently MFL-based technologies have been able to identify surface origin and size accordingly.

3.1.1 Reference Plate Composition

Mild steel plates 6mm, 8mm, 10mm, 12mm and 16mm thick were used as both calibration and inspection surfaces. The defects contained within these plates were created with a 22mm ball-end cutter[7] and situated laterally in the middle of each plate with sufficient distance between them. Four depths have been used that constitute a standard reference plate for the Silverwing Floormap machine used to scan inspection surfaces in this investigation. The size of each defect is as indicated in the diagram below.

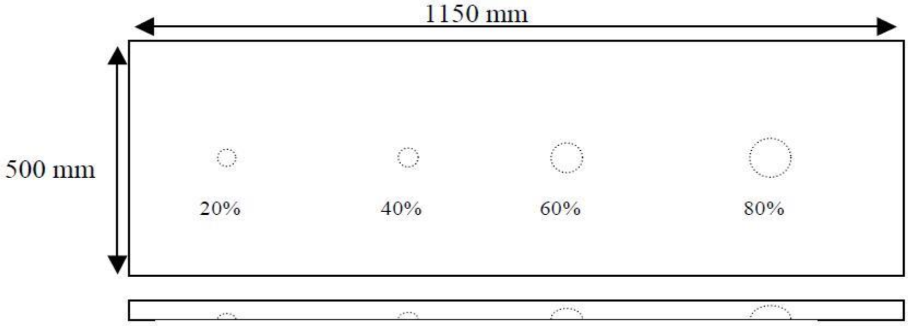


Figure 2 standard reference plate

In the industry these plates are known as reference plates (or sometimes as calibration plates) and are used to create a mapping between defects of known geometry and MFL signal amplitude.

3.1.2 Test Procedure

For both the *New* and *Standard* calibrations the test involved scanning the applicable reference plate a total of 16 times (excluding calibration scans). For all of the first eight scans the reference plate was placed with the defects located on the top surface and so visible. For the first four scans, the scan direction was from the 20% defect to the 80% defect i.e. the scan began at the beginning of the reference plate ran over the 20% defect so that the defect was detected in the middle of the scanner and continued toward the 80% defect. The scan concludes when the scanner reaches the opposite end of the reference plate. Scans five to eight involved a similar scan but in the opposite direction, from the 80% defect to the 20% defect. The reference plate was then turned over (defects now not visible) and four further scans, scans 9-12, were performed in the 20% to 80% direction. Finally the last four scans were again performed with the defects located on the bottom surface but the scan direction this time was from the 80% defect to the 20% defect. This procedure was performed three times in total with an average taken to ensure a fair result.
Each calibration routine will now be described in turn with results and discussion presented where relevant.

3.2 *Standard* Calibration

A *Standard* calibration is achieved by performing the following scans on any one of the above reference plates.

i. Scan 20% to 80% top surface and capture data.
ii. Scan 80% to 20% top surface.
iii. Turn plate over so defects are on the bottom surface.
iv. Scan 20% to 80% bottom surface and capture data.
v. Scan 80% to 20% bottom surface.

Top surface data is not presented herein due to space constraints; however suppositions pertaining to top surface defects are now made. Findings relating to these suppositions will be contained within the relevant results section[8].

For under-saturated calibration surfaces a *Standard* calibration will size top surface defects depending upon the unknown magnetic state of the reference plate before the calibration was performed. For top surface defects based on such a procedure, without external verification, there is no way of determining how this calibration will perform on an under-saturated inspection surface.
Under-saturated inspection surface defect under sizing is inevitable for bottom surface defects using the *Standard* calibration. This is because the scan direction preceding the scan that captures leaking field data is in the opposing direction, thereby creating an enhanced leaking field emanating from the calibration defects that will not reoccur in an inspection surface unless it is first scanned in the opposite direction.

[7] Ball-end cutters are believed to be the best representation of true corrosion.
[8] All graphs are available on demand.

Furthermore repeat direction scans, utilising a *Standard* calibration on an under-saturated inspection surface, are meaningless for both top and bottom surface defects and will **not** result in accurate defect sizing or inspection surface composition information. This is because the induced magnetism in the reference plate is unknown prior to calibration. Opposing scans will provide limited bottom surface information[9].

In summary for under-saturated inspection surfaces a *Standard* calibration will result in:-

- Unknown top-side performance that may undersize, oversize or accurately size top surface defects, to confirm which will require external verification.
- Undersized bottom surface defects.
- No reliable inspection surface composition information.

However accurate defect sizing will result if, for each scan, the inspection surface is ideally- or over-saturated.

3.2.1 *Standard* Calibration Results

Bottom surface analysis on (ideal- or over-) saturated Inspection Surfaces

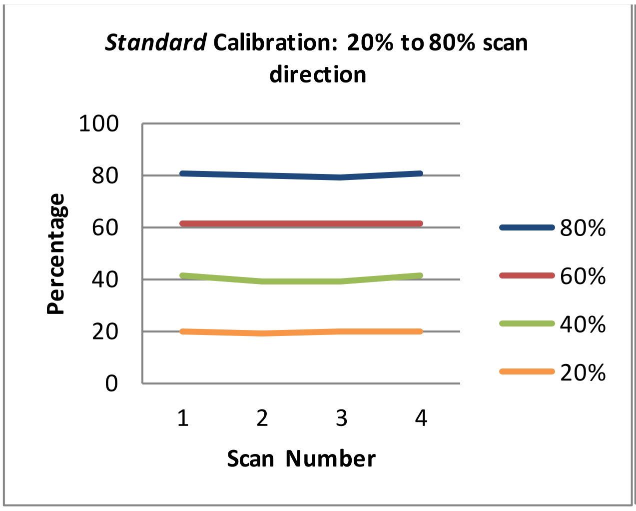


Figure 3 6mm plate

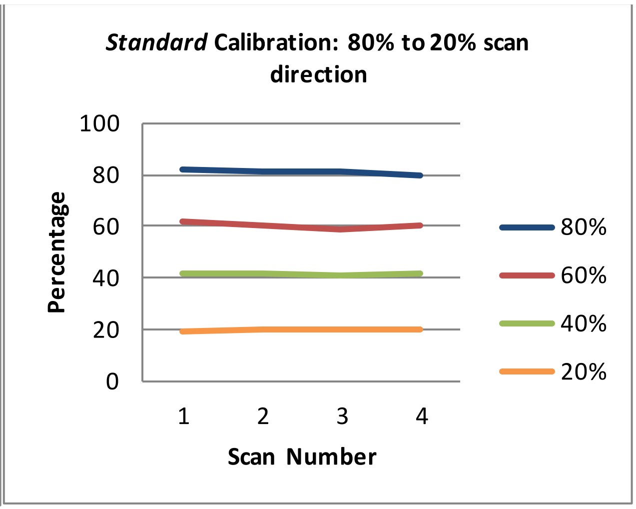


Figure 4 6mm plate

Bottom surface analysis on under-saturated inspection surface

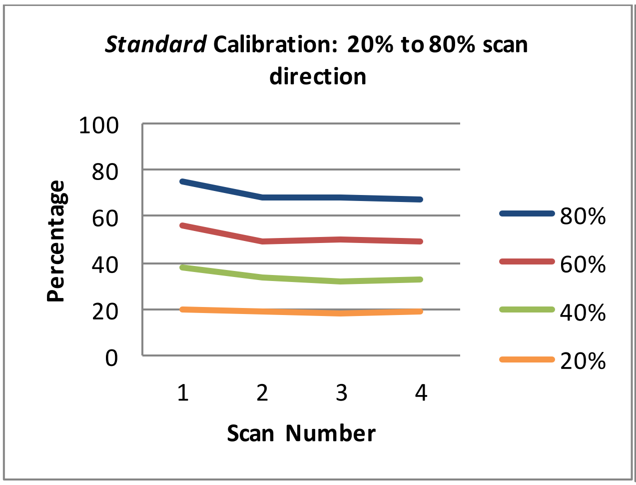


Figure 5 12mm plate

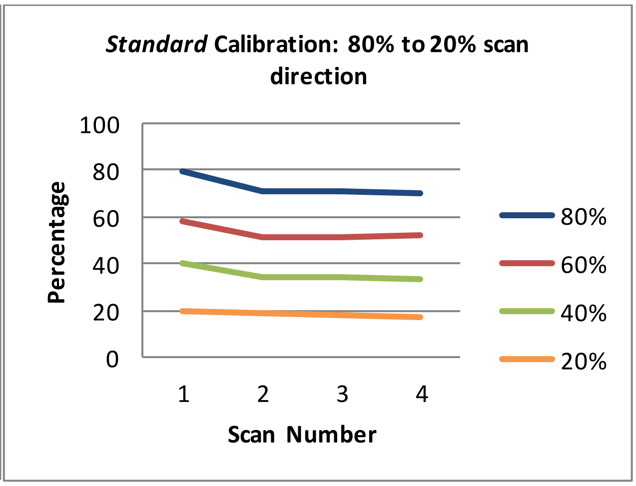


Figure 6 12mm plate

3.2.2 *Standard* Calibration Results and Comments

- From Figures 3 and 4 it can be seen that when an inspection surface achieves at least ideal-saturation with each scan, a calibration that considers scan under-saturation is not required.

[9] Due to the fact that the scan preceding the bottom capture is a top surface scan in the opposite direction.

- From scans 1 and 2 in Figures 5 and 6 it can be seen that when the inspection surface is under-saturated then previous imparted levels of magnetism are an influencing factor that can result in variable defect sizing.
- From Figure 5 it can be seen that defect under sizing must occur if such a calibration as *Standard* is used on an under-saturated inspection surface unless the unlikely scenario of a scan in an opposite direction is performed first and even this is may result in defect sizing inaccuracies as the scan in the opposite direction was performed on the top surface of the defect. Defects that should be sized at 80% are at best sized at 72% and are consistently sized at approximately 70%.
- From Figure 6 it can be seen that accurate bottom surface defect sizing is only possible on under-saturated inspection surfaces if the inspection surface is first scanned in the opposite direction (Scan Number 1 the first scan in the opposite direction does provide accurate results). Otherwise 80% defects are consistently sized at approximately 70%.
- From Figures 5 and 6 repeated scans in the same direction (Scan Numbers 2, 3 and 4) on under-saturated inspection surfaces result in consistent but reduced defect under sizing except for the 20% defects.
- For under-saturated inspection surfaces if three scans are performed, one from the 20% defect to the 80% defect, then two from the 80% defect to the 20% defect then the defect sizing discrepancies are most noticeable for larger defects.
- Regarding the equivalent top surface findings not presented here, all suppositions were proved correct. However accurate top surface defect sizing is possible on under-saturated surfaces if before the calibration process is begun a scan is performed in the 20% to 80% direction. All other scans performed prior to calibration will result in calibrations that will under-size defects.

3.3 *New* Calibration

The *New* calibration is performed in a similar manner but importantly the scan direction of second and fourth scans is different. When the data is captured is also different.

i. Scan 20% to 80% top surface
ii. Scan 20% to 80% top surface and capture data
iii. Turn plate over so defects are on the bottom surface
iv. Scan 20% to 80% bottom surface
v. Scan 20% to 80% bottom surface and capture data

The levels of magnetism induced during calibration are now manipulated and fixed meaning the entire calibration routine is controlled and no longer variable nor subject to previously existing levels of induced magnetism. As opposing scans are avoided the levels of induced magnetism will be similar to those expected during an inspection of an AST floor. It can therefore be assumed that:-

- The calibration will be applicable to the magnetism free inspection surface.

Both of these assumptions, calibration applicability and a magnetism free AST inspection surface, can be verified. If a *New* calibration is used to inspect an equivalent magnetism free surface and provides the desired results then the calibration is applicable. The magnetism free inspection surface assumption can be verified by performing a repeat scan in the same direction. If consistent results are achieved then the assumption is correct. If a difference in sizing results is observed then this will infer that there magnetism did exist in the inspection surface prior to scanning and, consequently, the magnetisation levels employed during the calibration process are not akin to those within the inspection surface meaning sizing must be suitably amended. For this scenario it is possible that the discrepancy can be factored in or alternatively, for increased defect sizing confidence, repeated scans in the same direction will result in the equivalent levels of induced magnetism seen during calibration, meaning that the inspection procedure may require defect detection first and then a rescan for sizing (still a benefit over using other time expensive techniques).

It will be shown that the *New* calibration eradicates all of the *Standard* calibration concerns by providing a calibration that, when applied to an AST floor for an inspection, results in:-

- Accurately sized defects, if for each scan, the inspection surface is ideally-, over-saturated or under-saturated.
- Accurately sized top and bottom defects the first time of scanning under-saturated surfaces if no magnetism is assumed present.
- Defect sizing that can be verified by performing a repeat direction scan (i.e. *New* calibration provides a calibration applicability check by confirming that the induced levels of magnetism match those experienced during the calibration process).

- A calibration applicability option. Via a repeated scan, the applicability of the *New* calibration process can be assessed. If the magnetic state of the inspection surface is comparable to the magnetic state created during calibration then the first scan should be similar to the second scan.
- Inspection surface composition knowledge. If a-similar-to-calibration defect is detected on an AST floor and a second scan in the same direction reports that defect to be, say, 50% but external verification (pit-gauging or ultrasonic testing) reveals the defect, to be 40% then as calibration and defect geometry are not the cause of the sizing inconsistency it must be concluded that the material composition of the inspection surface is different to that calibrated for and thus must be accounted for.
- Will purposefully[10] oversize defects the first time the scan is performed in the opposite direction but then upon repeated scans provide consistent results[11].

3.3.1 *New* Calibration Results

Bottom surface analysis on (ideal- or over-) saturated Inspection Surfaces

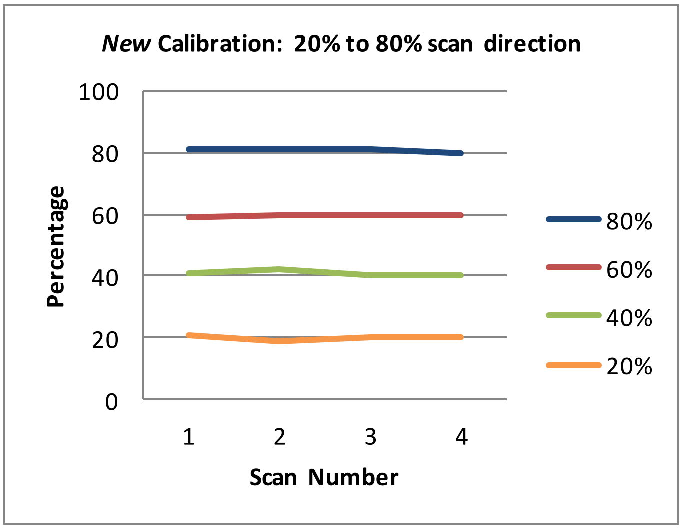


Figure 7 6mm plate

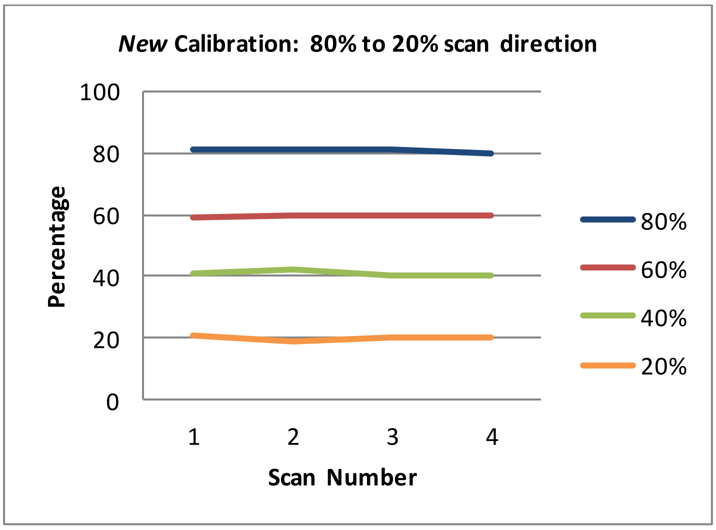


Figure 8 6mm plate

Bottom surface analysis on under-saturated inspection surface

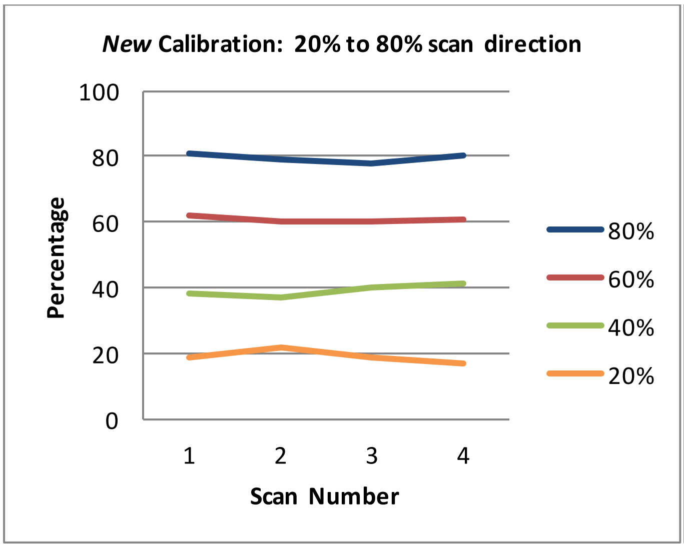


Figure 9 12mm plate

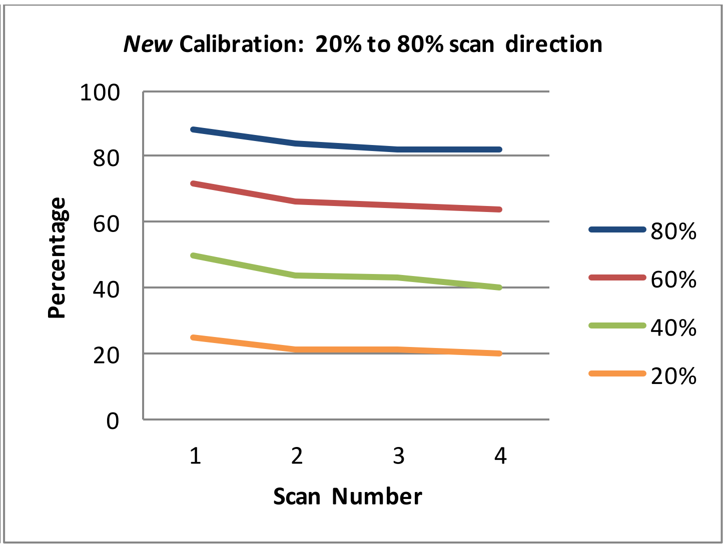


Figure 10 12mm plate

[10] It is possible to undersize but practical considerations dictate that oversizing is the better option.
[11] Note that an inspection should consist of one scan only and not involve a scan in the opposite direction. If verification scans are required then if they are performed in the same direction then this *New* calibration accounts for that.

3.3.2 *New* Calibration Results and Comments

- From Figures 7 and 8 it can be seen when saturation is achieved previous scan occurrences do not affect defect sizing (as evident in Figures 3 and 4).
- From Figure 9 it can be seen that if this calibration were to be used on an inspection surface with a similar induced level of magnetism then bottom-surface defect sizing is likely to be accurate (compare with Figure 5).
- From Figure 10 it can be seen that the first scan in the opposite direction results in defect over-sizing; 80% defects are sized, on average, at 89%. But defect accuracy is retrieved if the surface is again scanned in that direction (compare with Figure 6).
- From Figures 9 and 10 it can be seen that if a scan has been performed in the opposite direction then it requires two scans to be performed in the same direction to return to the imparted levels of magnetism present during calibration. This means that during an inspection upon detection of a defect if that defect is scanned again in the same direction and the result is consistent then the levels of magnetism imparted in the inspection surface are akin to those during the calibration process. This means that, in ideal conditions, if defect sizing inaccuracies do occur it must be the result of some other factor such as defect geometry (discussed below). If the second scan results in lower defect recording then this can be factored into the inspection.

It must be stated here that equivalent magnetism free inspection surfaces were used to validate the calibration process. The results achieved were exactly as expected defect sizing was identical to that exhibited in Figure 9.

3.4 Variation Graphs

Result achieved on under-saturated inspection surface

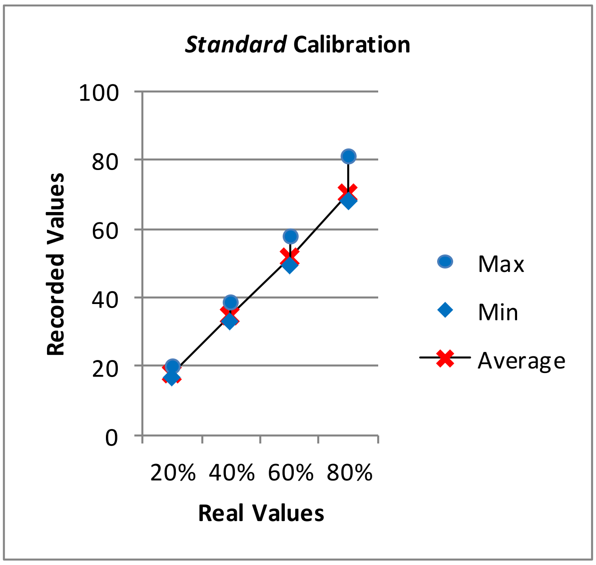


Figure 11: *Standard* - Low average undersized defects

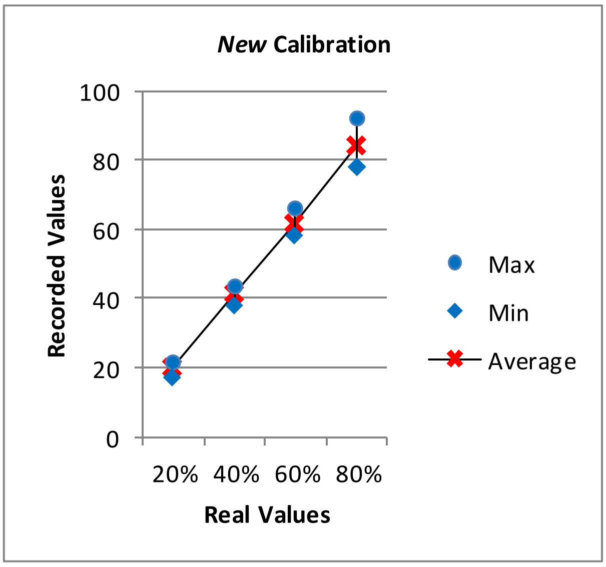


Figure 12: *New* – slightly oversized defects

3.4.1 Variation Graph Comments

Due to under-saturation and opposing scans a variation margin, greater than that seen for saturated surfaces, must exist for both calibration process. If opposing scans were excluded (reasonable as opposing scans are unlikely in a true inspection environment) the amount of variation would be greatly reduced.

From Figure 11 it can be seen that the *Standard* calibration results in a considerably lower defect average, for example the 60% defect is averagely sized at 51.3%.

- From Figure 11 it can be seen that the *Standard* calibration *Max for each defect* is equivalent to the actual defect value. Unfortunately this *Max* value is highly unlikely to be achieved during AST floor scanning.
- From Figure 12 it can be seen that the *New* calibration results in improved defect sizing averages.
- From Figure 12 it can be seen that the *New* calibration margin of variation is centred just above each the required value.

- For both Figures 11 and 12 the *Max* value recorded can be considered an extremely unlikely occurrence as it is a consequence of capturing data after an opposing scan is performed - an event that is unlikely to occur during AST floor scanning. Therefore it is perfectly reasonable to remove the *Max* value. Removing the *Max* value would:
    - Reduce the margin of variation for both *Standard* and *New*, with *New* benefiting and *Standard* deteriorating.
    - Improve the average for *New*, moving it closer to the true value.
    - Deteriorate the average for *Standard* with the average reducing further from the true value.
- As the *Max* value for the *Standard* calibration is unlikely to be achieved the true variation can be thought of as existing between the *Average* and the *Min* values, meaning that in reality defects are likely to be undersized.
- Again, and for the reasons given above, the true variation for the *New* calibration can be considered as being between the *Average* and the *Min* value resulting in further improved defect sizing.

3.5 Calibration and Induced Magnetism Conclusions

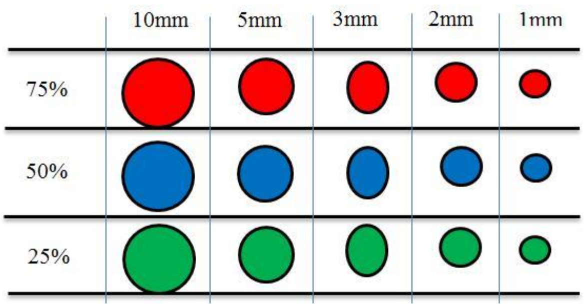
Clearly scan history is irrelevant on inspection surfaces that are locally saturated in the area of interest with each traverse of the MFL equipment. It is only when the MFL technology fails to locally saturate the inspection surface that scan history and scan direction must be taken into account during the calibration process [12].
The new calibration (*New*) offers a substantial improvement in under-saturated inspection surface defect sizing. Instead of unknown equipment performance on under-saturated surfaces, as offered by a *Standard* calibration, it is likely that accurate defect sizing will occur.
During AST floor scanning the inspection surface is assumed to be free of magnetism and the *New* calibration has been designed for such inspection surfaces [13]**. Importantly results performed on virgin (no scan ever performed) reference plates have provided confirmation that the *New* calibration does indeed result in more reliable defect sizing data**.
The *New* calibration also offers a means of investigating the levels of induced magnetism and material composition via a repeated scan performed on the same inspection surface area. This self-verification ability to ensure that the levels of induced magnetism match those experienced during the calibration process is important because:

- Variations in standards of steel exist throughout the world could be investigated. Therefore identifying inspection surfaces whose composition differs from the calibration reference plate is a real possibility. This ability to identify different composition surfaces needs confirming and is thus an area for further research.
- The assumption that the scanned surface is free of magnetism could be verified.

Clearly the *New* calibration procedure can help improve defect sizing on under-saturated inspection surfaces.

4 Defect Geometry

To ensure saturation and so only investigate the effects of defect geometry, the investigation was performed, after suitable calibration and saturation, on a 6mm thick inspection surface.
The inspection plate was dimensionally similar to the reference plate shown in the Figure 2 but the defects contained therein were, what is referred to as, machine drilled flat bottomed pipe-like defects, so unlike those calibrated for. The defects were split into five columns of three rows. Each row had defects that contained 1mm, 2mm, 3mm, 5mm and 10mm drilled holes and each column had defects sized at 25%, 50% and 75%, see the figure below for clarity:



[12] An area for further research is how induced magnetism varies across the width of the magnetic yoke.
[13] In-house experiments on virgin reference plates have shown that the calibration process does indeed size defects well.

4.1 Defect sizing results tables

Defect Diameter	10mm	5mm	3mm	2mm	1mm
75%	75%	43%	27%	25%	0%
50%	65%	36%	21%	19%	0%
25%	44%	23%	0%	0%	0%

Table 1 Bottom surface sizing results

Defect Diameter	10mm	5mm	3mm	2mm	1mm
75%	81%	48%	28%	21%	0%
50%	70%	40%	21%	18%	0%
25%	40%	27%	0%	0%	0%

Table 2 Top surface sizing results

4.1.1 Defect Geometry Comments

Both tables reveal that defect geometry has affected defect sizing. The sizing inaccuracies are the result of a calibration not tailored to the geometry of the defects. This makes the *Standard* calibration not applicable because the leaking field from the inspection defects is different to the equivalent leaking fields from the calibration defects. This clearly suggests that the greater the difference in defect geometry, when compared to the calibration defects, the greater the variation in sizing.

If, prior to scanning, it was known that the defects were so comprised then a calibration could have been performed on a suitable reference plate that contains similar geometry defects to those expected during the inspection thereby creating an applicable calibration that would result in accurate defect sizing. However this process is impractical as defect geometry is generally unknown prior to detection. Therefore it is clear that defect geometry knowledge must become known immediately after defect detection so that suitable re-sizing techniques can be employed. To quickly ascertain defect geometry knowledge, accurate defect display or representation of the MFL signals themselves is essential to ascertain if the defects MFL signature differs from those exhibited during calibration. Given defect geometry information it is then possible to confirm initial defect sizing or perform re-sizing if required.

4.2 Defect Shape and Re-sizing

To investigate defect geometry and representation further, two individual defects of equal depth but different geometry were considered. The defects are sited on the top surface of a 6mm plate and are defined as follows:

- The first defect is rectangular, 3.0mm deep and 10mm wide. The volume of this defect is 300mm^3.
- The second defect is a cylindrical cone, 3.0mm deep with a diameter of 10mm. The volume of this defect is 78.54mm^3.

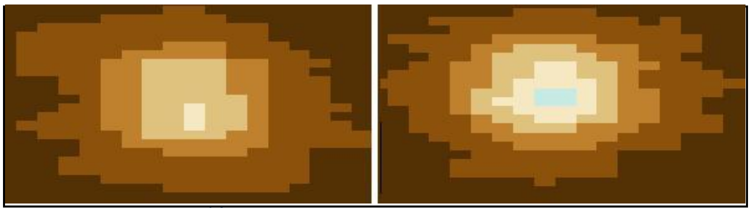


Figure 13 MFLi[14] image of defects: clearly different geometries.

4.2.1 Defect Shape and Re-sizing Comments

As expected the defect unlike the calibration defect was incorrectly sized. However it can be seen from Figure 13 that if the MFL technology is capable of accurate defect representation the MFL scanner operator could possible identify defect geometries that are different to those calibrated for and so perform on the spot defect re-sizing[15].

4.3 Defect Geometry Conclusions

Defect geometry clearly affects defect sizing. If defect re-sizing procedures are to be developed then accurate defect depiction and representation is essential.

[14] MFLi is a new search tool developed by the MFL technology company.
[15] Training will be required.

If defect geometry knowledge could be acquired then re-sizing could be performed. For example it is known that traditionally MFL over sizes large shallow lake-like defects and under sizes narrow but deep pipe-like defects. If defect shape can be identified and categorised then this knowledge can be incorporated into a defect re-sizing procedure. Detailed geometry analysis has been performed with lake-like defects and pipe-like defects now beginning to be readily identified, this is an area for further research[16].

4 Final Remarks

Saturation and Calibration

Regardless of magnetisation levels, the results reveal that accurate and repeatable defect sizing is possible on a range of inspection surfaces[17], if defect geometry is reminiscent of the calibration defects and if a suitable calibration process is employed. Succinctly, if saturation levels can be accounted for, defect sizing inaccuracies are a consequence of defect geometry alone[18].

Regarding the *New* calibration process it is clear that, up to a certain limit, accurate defect sizing is possible on under-saturated inspection surfaces. For the MFL technology herein it could be that an initial 5% of AST defect findings are verified with another technology such as UT to confirm defect sizing accuracy. Furthermore the *New* calibration can possibly inform on inspection surface levels of magnetism and composition.

It is believed that the newly proposed calibration procedure is a great improvement on any calibration routine that does not consider under-saturation conditions.

It must also be noted that the biggest variation in defect sizing is witnessed for the largest defects. This is due to the volumes involved. Larger defect volumes are, by nature, capable of increased leaking field. This outcome is important for in-the-field practises as a lot of maintenance strategies rely on information between the 30%-40% defect range.

Saturated surfaces were shown to be indignant to scan history and scan direction. This is important because if saturated surfaces exhibit sizing issues it is likely a consequence of defect geometry (or external variables).

Inspection surface coating can affect defect sizing by influencing sensor height and by increasing the distance between the inspection surface and the carriage thereby reducing the amount of magnetism imparted into the plate. Coatings must be accounted for during calibration. These sizing errors can be addressed if the coating thickness is known. This is an area for further research.

Defect Geometry

Defect geometry was shown to be a defect sizing variation contributor. However tools are emerging that provide on-the-spot defect geometry information; MFLi was shown to be such a tool. In the near future it is hoped that with the advent and development of this and other tools, defects will be sized with better accuracy and increased confidence – this is a very definite area of further research.

To conclude, in the context of MFL AST floor inspection it has been shown that defect geometry, calibration and saturation are very important factors in defect sizing repeatability.

References

1. Y. Sun and Y. Kang. Magnetic mechanisms of the magnetic flux leakage nondestructive testing. *Appl. Phys. Lett.* 2013; 103184104.
2. J. C. Drury and A. Marino Procontrol, *A comparison of the Magnetic Flux Leakage and Ultrasonic methods in the detection and measurement of corrosion pitting in ferrous plate and pipe*. Presented at the 15th World Conference in Rome 2000.
3. J. C. Drury, *MAGNETIC FLUX LEAKAGE TECHNOLOGY*.
4. Thomas L. Gilbert. *A Phenomenological Theory of Damping in Ferromagnetic Materials*. IEEE TRANSACTIONS ON MAGNETICS vol 40. No. 6. November 2004.
5. P. C. Charlton. *A theoretical and experimental study of the magnetic flux leakage method for the analysis of corrosion defects in carbon steel plate*. PhD Thesis, Swansea institute of higher education, 1995.

[16] Contact the writers for details.
[17] All graphs available on request
[18] Clearly a major sizing influence is also operator skill and inspection environment.