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Induction Active Thermography as an alternative to Magnetic Particle Inspection

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Abstract

Magnetic particle inspection and dye penetrant inspection are conventional non-destructive testing methods used to inspect metallic materials. These methods are highly efficient and, consequently, widely used in the industrial sector. But they are also highly energy-intensive and waste-generating methods, and furthermore they induce possible risks for operators' health. As they are getting aware of the constraints related to conventional inspection methods, increasing numbers of industrialists try to turn to alternative, more environmentally-friendly inspection methods capable of giving comparable results. In this work, we will present a study developed by CETIM in cooperation with the University of Reims Champagne Ardenne. The purpose of this study is to determine the capabilities of induction-stimulated infrared thermography for non-destructive testing of forged parts. We will demonstrate that, during the analysis of a car ball joint, this method makes it possible to obtain experimental results which are very similar to the results given by magnetic particle inspection or dye penetrant inspection.

1) Introduction

Forging consists in forming a malleable material by impact or pressing. On the one hand, this method has the advantage of being performed at a temperature less than the melting temperature of the material. On the other hand, it makes it possible to form a part while improving locally its mechanical properties. This is why this method is widely used in the automotive industry to manufacture ball joints, hubs or control arms (suspension).

During the forging process, various flaws, such as cold shuts or cracks can appear on the produced part. For obvious safety reasons, for example in the automotive industry, it is absolutely necessary to inspect 100% of the parts produced. Then the inspection methods generally used are magnetic particle inspection and dye penetrant inspection. Their principles are as follows:

Magnetic particle inspection consists in generating an intense magnetic flux inside a ferromagnetic material and then in observing the field lines on its surface using a developing product which contains coloured or fluorescent particles. If a flaw is present, these field lines are disturbed. The analysis of these signatures allows the flaws to be detected. These can be surface or subsurface flaws (Figure 1).

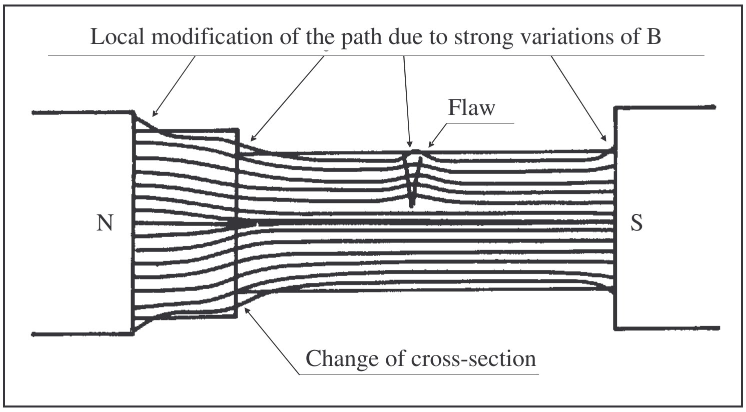

Figure 1: Non-destructive testing principle - Magnetic particle inspection

Dye penetrant inspection consists in applying a penetrant liquid which contains coloured or fluorescent markers onto the surface of the part to be inspected. The liquid penetrates by capillarity into all the open flaws. After removal of the excess penetrant, a developer is then applied onto the examined part. The developer sucks the liquid which remains in the cracks like a blotting paper and reveals them. Therefore, dye penetrant inspection allows detection of open flaws only (Figure 2).

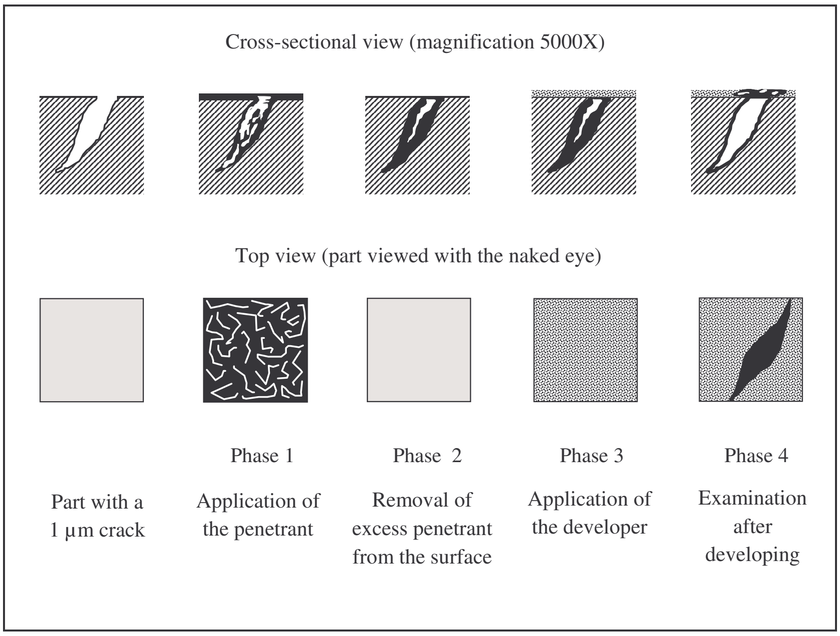

Figure 2: Non-destructive testing principle - Dye penetrant inspection

Magnetic particle inspection and dye penetrant inspection are easy-to-use non-destructive testing methods. And furthermore, they are highly efficient. They have thus become widely used in the industrial sector. Unfortunately, they have a few drawbacks. On the one hand, they require the use of cleaning solvents and aqueous-based or petroleum-based products (red or fluorescent penetrant products plus developers for dye penetrant inspection, magnetic products for magnetic particle inspection). And these products are not very environmentally-friendly. On the other hand, the drying, magnetisation and demagnetisation operations carried out on the parts require large amounts of energy. Cleaning of parts and removal of the excess penetrant generate more effluents which will have to be treated. And at last, these two methods have a significant impact on operators' health. On the one hand, operators are exposed to solvent vapours, and on the other hand they are exposed to organic products and electromagnetic fields. It would be interesting to reduce these drawbacks or even to introduce, in the forging industry, new non-destructive inspection methods which would not have such drawbacks.

The new European Directives adopted this position. They are aimed at reducing the use of energy-intensive, waste-generating methods potentially hazardous to operators' health. Increasing numbers of industrialists have become aware of the constraints associated with conventional inspection methods and they try to turn to alternative, more environmentally-friendly methods capable of giving comparable results. This explains why CETIM and the University of Reims Champagne Ardenne have been studying for several years the possibilities of infrared thermography for non-destructive inspection of forged parts. In this document, we will present examples of results obtained within this scope. These results concern the inspection of ball joints by induction stimulated infrared thermography.

We will first present the studied specimen.

Then we will present the results obtained by magnetic particle inspection and by dye penetrant inspection.

In the third step, we will present the induction stimulated infrared thermography system that we implemented for this study.

And finally we will demonstrate that the induction active method gives access to experimental results which are very close to those obtained with conventional non-destructive testing methods.

2) Studied specimen and results obtained with magnetic particle inspection and dye penetrant inspection

The specimen studied in this work is a forged ball joint. It was produced for the automotive industry. It is made of 20Mn5 and has a complex shape. Its length is 110 mm. On an industrial site, this type of specimen is usually checked by magnetic particle inspection. The ball joint we studied has a longitudinal flaw, which is a cold shut. (Figure 3).

Figure 3: Studied sample

In order to obtain a reference record, we first studied this ball joint with the conventional magnetic particle inspection method. This inspection was carried out by a COFREND certified agent. The part was inspected on a magnetic particle inspection bench through current passage. First circumferential magnetic fields were used in order to detect longitudinal flaws, and then longitudinal fields were used to detect transverse flaws. A magnetic fluorescent developer was sprayed to reveal the flaws in ultraviolet light.

An example of result obtained is presented in Figure 4. It clearly shows a continuous line all over the length of the ball joint. This line corresponds to the cold shut. This is the flaw that we will try to detect again with induction stimulated infrared thermography.

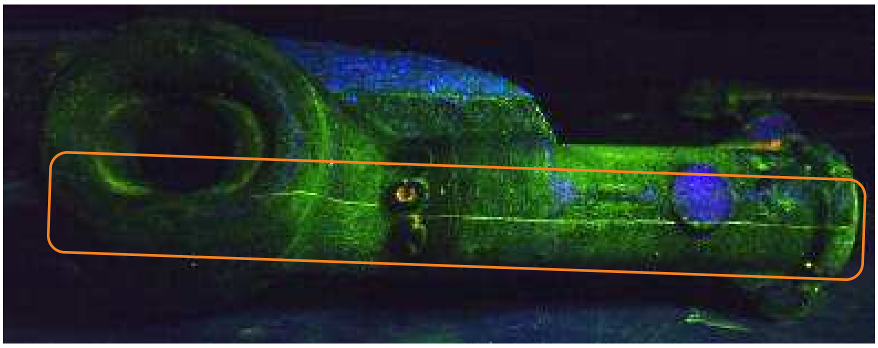

Figure 4: Example of result obtained with magnetic particle inspection

In a second step, for our study, we also carried out a dye penetrant inspection on this ball joint. The purpose of this study was to determine whether de flaw detected by magnetic particle inspection was open or not open. As a matter of fact, magnetic particle inspection is sensitive to open and non-open flaws while dye penetrant inspection is sensitive to open flaws only. The comparison of the results obtained with both methods will then allow us to have data as to the position of the studied flaw with respect to the surface. Again, the inspection was carried out by a COFREND certified agent. The agent first sprayed a fluorescent penetrant. Then, after removal of the excess penetrant, he sprayed the developer. Finally he carried out an examination under UV lighting. An example of result obtained is presented on Figure 5. This shows a bright signature on a portion of the length of the ball joint, this being typical of the presence of an open flaw. However, there is no indication on the ball joint head. In this zone, the indication revealed by the magnetic particle inspection therefore seems to correspond to a non-open flaw.

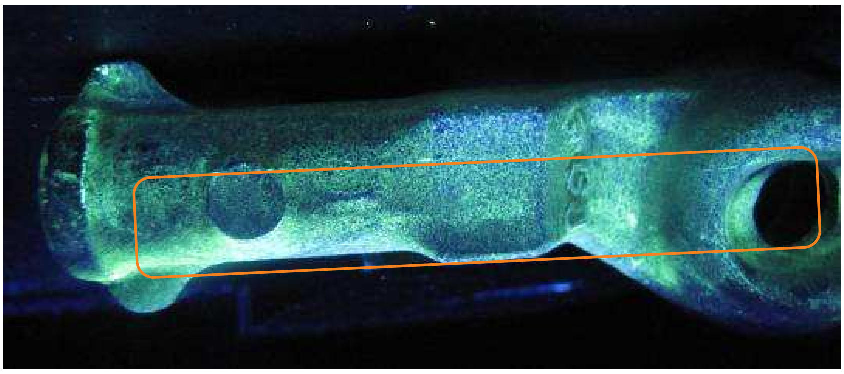

Figure 5: Example of result obtained by dye penetrant inspection

3) Stimulated infrared thermography experimental system used for the study

The stimulated infrared thermography experimental system used for this study is an induction thermography system. It is presented on Figure 6.

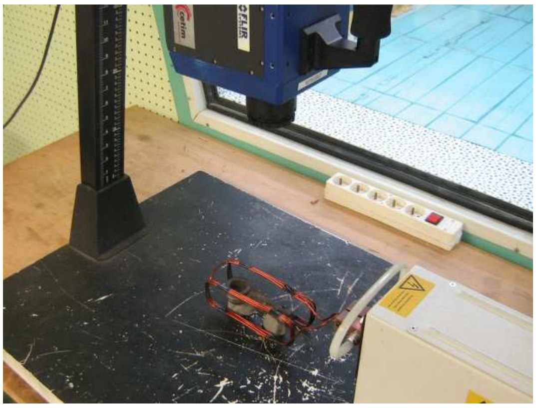

Figure 6: Induction stimulated infrared thermography system used for the study

The system is comprised of three parts. The first part corresponds to the excitation source. This is an inductor supplied by a control electronic system. The inductor is adapted to the inspection of the ball joint and composed of two rectangular coils made up of 3 turns of copper wire. They are 150 mm long and 50 mm wide. The coils are positioned on both sides of the analysed specimen and 45 mm apart. This configuration gives easy access to the ball joint, for example to turn it by 90 degrees to allow the analysis of its entire surface (Figure 7).

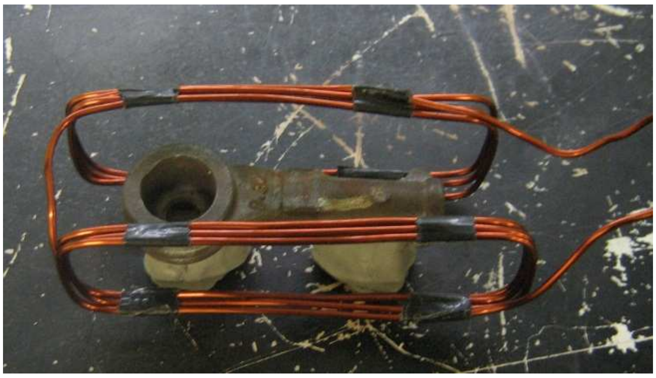

Figure 7: Inductor used for the study

The current is supplied by a generator adjusted to deliver a current equal to 35 amperes for 70 ms (square pulse excitation).

The second part of the experimental system used for this study is an infrared optical detection chain. It is composed of an SC7600 SW camera equipped with an F2 lens, with focal length of 25 mm. It is positioned at approximately 30 cm from the studied ball joint. The camera was adjusted so as to operate at an acquisition frequency of 100 Hz. Furthermore, its operation is synchronised with the excitation.

Finally the last part of the experimental system used for the study is a post-processing computer tool. This tool makes it possible to carry out a temporal Fourier analysis of the thermographic film obtained. It gives access to a frequency representation of the amplitude and phase of the thermographic response obtained. In our case study, we more specifically used the phase parameter. As a matter of fact, this parameter is less susceptible to the lack of homogeneity of the heating and to the variations of geometry of the studied part. This choice allows better detection of the flaws than a simple temporal analysis.

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4) Experimental results obtained

In order to experimentally approach the possibilities of induction infrared thermography for non-destructive testing of car ball joints, we carried out the work in two stages. First we studied a sample ball joint in laboratory; this ball joint was the one previously analysed by magnetic particle inspection and dye penetrant inspection. We analysed it with the experimental system and the experimental conditions previously described. An example of result obtained in this scope is presented in Figure 8. This is the phase image of the thermal induction signal obtained for a frequency of 7 Hz. It clearly shows a stronger infrared signature in the area of the cold shut previously detected by magnetic particle inspection. This is due to the presence of a thin air film below the cold shut, and this air film locally disturbs the internal conduction fluxes generated by the induction excitation. This signature is very similar to that obtained during magnetic particle inspection. This demonstrates the capabilities of the thermographic method for the detection of this type of flaw. Furthermore, it is worth noting that the thermal induction method allows quick analysis on the one hand, and this is an advantage at industrial level. On the other hand it seems to give access to a good spatial resolution, which is also an important advantage.

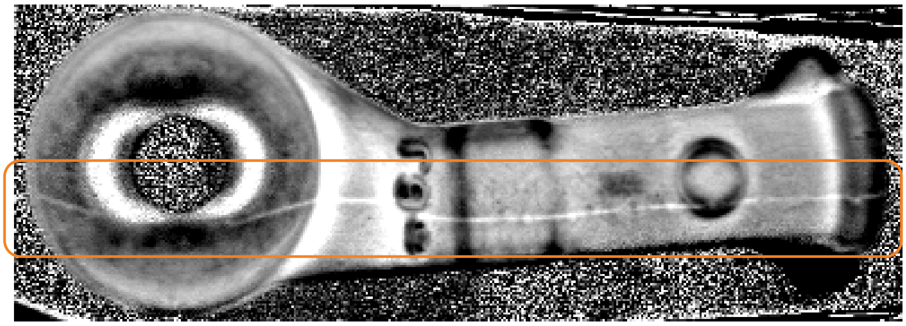

Figure 8: Example of phase thermal induction image obtained (7 Hz)

Following this - rather positive - laboratory study, we developed an inspection in an industrial forging plant. First we selected 63 defective ball joints by means of a magnetic particle inspection analysis. Then we analysed those ball joints by induction infrared thermography. The experimental protocol applied was the same as in the first study. Among these 63 defective ball joints, 53 were also declared defective following the thermographic analysis. For the remaining 10 ball joints for which the conclusions were different, some of them were analysed with metallographic sections. An example of result obtained is presented on Figure 9. It shows that the type of flaw detected by magnetic particle inspection and not by induction infrared thermography is in fact an appearance flaw. This is a surface asperity and not an actual cold shut. When compared to magnetic particle inspection, induction infrared thermography seems to allow finer detection of cold shut type flaws. This is also an interesting result.

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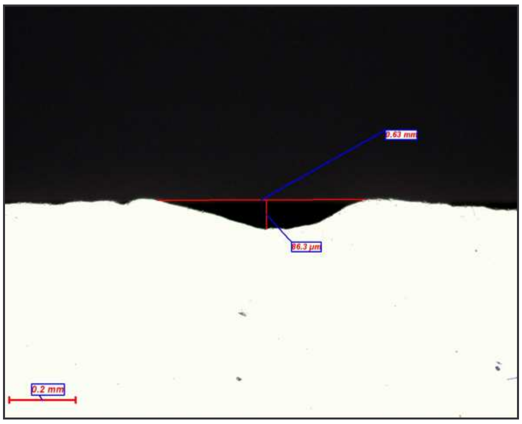
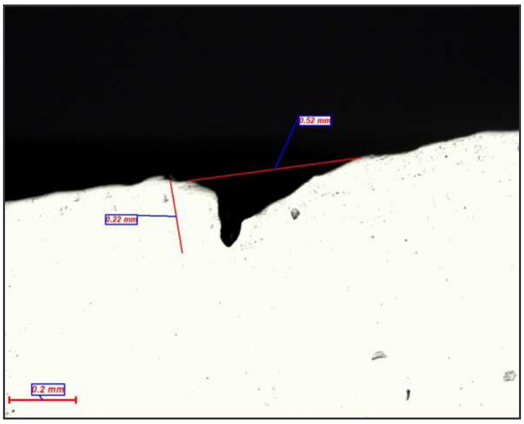


a) Type of indication detected during magnetic particle inspection and not detected by infrared thermography



b) Type of indication detected during magnetic particle inspection and by infrared thermography

Figure 9: Example of metallographic sections obtained

4) Conclusion

In this work we approached the capabilities of induction stimulated infrared thermography for the detection of cold shuts on a car ball joint.

We first studied a test specimen in laboratory. In this scope we first demonstrated that the infrared method gives results very similar to those obtained with magnetic particle inspection which is the method generally used in the industrial sector. Therefore the infrared method can be used to detect cold shuts. Then we also demonstrated that induction active thermography seems to allow the analysis of subsurface and surface flaws, just as magnetic particle inspection, when dye penetrant inspection is rather restricted to the analysis of open flaws. Finally, we can add that induction active thermography is fast and environmentally-friendly; it requires little energy and introduces less restriction for the operators. And finally it seems to give access to a good spatial resolution. These are significant advantages!

Then we carried out tests in a forging plant. During these tests, we inspected 63 defective ball joints, first by magnetic particle inspection then by induction active thermography. We then demonstrated that among these samples the infrared method found 53 defective specimens and 10 sound specimens. In order to understand this difference of interpretation, we carried out metallographic sections on some of these specimens. The sections showed that, for these specimens, the magnetic indication revealed an appearance flaw and not a cold shut. When compared to magnetic particle inspection, induction active thermography therefore seems to allow finer detection of cold shut type flaws. This is also a very interesting result.

Now, these positive results, obtained on a specific specimen, need to be generalised. Furthermore, it would be interesting to study the capabilities of the method in terms of automated interpretation of the results (this being difficult in dye penetrant inspection and in magnetic particle inspection). And finally, it is advisable to optimise the experimental protocol in order to lead to the instrumentation which gives the best possible results. Studies on this subject are in progress.

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Reference documents

[1] S. Maillard, J. Cadith, W. Walaszek, A. Dillenz, J.L. Bodnar, Stimulated infrared thermography, a new inspection technique on production lines?, COFREND congress proceedings, Toulouse (France), 2008
[2] S. Maillard, J. Cadith, D. Eschimese, H. Walaszek, H. Mooshofer, J.C. Candore, J.L. Bodnar, Towards the use of passive and active infrared thermography to inspect metallic components in the mechanical industry, QIRT congress proceedings, Laval (Quebec), 2010
[3] S. Maillard, J. Cadith, G. Legros, P. Bouteille, H. Walaszek, J.L. Bodnar, Inspection of metallic materials by infrared thermography, Thermogram congress proceedings, Châlons-en-Champagne (France), 2011
[4] J.L. Bodnar, M. Egée, Wear characterization by photothermal radiometry, Wear, Vol. 196, 54-59, 1996
[5] J.L. Bodnar, M. Edée, C. Menu, R. Besnard, A. Le Blanc, M. Pigeon, J.Y. Sellier, Cracks detection by a moving photothermal probe, Journal de Physique IV, C7-592, 1994
[6] H.G. Walther, D. Fournier, J.C. Krapez, M. Luukkala, B. Schmitz, C. Sibilia, H. Stamm, J. Thoen, Photothermal Steel Hardness Measurements - Results and Perspectives, Analytical sciences, Vol.17, Special Issue, 2001
[7] J. Vrana, M. Goldammer, J. Baumann, M. Rothenfusser, W. Arnold, Mechanisms and Models for Crack Detection with Induction Thermography, Review of Progress in QNDE 27, pp. 475-482, 2008
[8] H. Mooshofer, M. Goldammer, W. Heine, M. Rothenfusser, J. Bass, E. Lombardo E., J. Vrana, Induktionsthermographie zur automatischen Prüfung von Generatorkomponenten, DGZfP-Jahrestagung 2009, Munster (Germany), 2009
[9] J. Bamberg, G. Erbeck, G. Zenzinger, Ein Verfahren zur bildgebenden Rißprüfung metallischer Bauteile, ZfP-Zeitung 68, 1999, p. 60 - 62
[10] G. Riegert, Th. Zweschper, A. Dillenz, G. Busse, Wirbelstromangeregte Lockin-Thermografie - Prinzip und Anwendungen, DACH - Jahrestagung 2004 Salzburg (Germany),