

Automated System for Crack Detection Using Infrared Thermographic Testing

Stanislav ŠTARMAN and Václav MATZ

STARMANS electronics s.r.o.

V Zahradach 24/836, Prague 8, 180 00

Tel: +420 283 842 063, Fax: +420 283 841 067

E-mail: ndt@starmans.net Www: www.starmans.net

Czech Republic

Abstract

The objective of this study was the development of the automated system for crack detection on square steel bars used in the automotive industry for axle and shaft construction. The automated system for thermographic crack detection uses brief pulsed eddy currents to heat steel components under inspection. Cracks, if present, will disturb the current flow and so generate changes in the temperature profile in the crack area. These changes of temperature are visualized using an infrared camera. The image acquired by the infrared camera is evaluated through an image processing system. The advantages afforded by the system are its inspection times, its excellent flaw detection sensitivity and its ability to detect hidden, subsurface cracks. The automated system consists of four IR cameras (each side of steel bar is evaluated at a time), coil, high frequency generator, and control place with computers. The system is a part of the inspection line where the subsurface and surface cracks are searched. If the crack is present, the cracked place is automatically marked. The components without cracks are then deposited apart from defective blocks. The system is fully automated and its ability is to evaluate four meter blocks within 20 seconds. This is the real reason for using this system in real industrial applications.

Keywords: Thermographic testing, Image processing algorithms, Crack detection.

1. Introduction

Infrared thermography is one of several non-destructive testing techniques which can be used for defect or crack detection. Infrared thermography is a technique of producing a live thermal picture of an object based on the infrared radiation received from it (emitted by any object). In pulse thermography, a thermal pulse is applied to the material to be inspected. Following the application of this thermal pulse, a measurement of the temporal evolution of the specimen surface temperature is performed with an infrared camera allowing subsurface defects to be revealed. The temperature of the material changes rapidly after the initial thermal perturbation because the thermal front propagates, by diffusion, under the surface and also because of radiation and convection losses. The presence of a defect reduces the diffusion rate so that when observing the surface temperature, defects appear as areas of different temperatures with respect to surrounding sound areas once the thermal front has reached them. Consequently, deeper defects will be observed later and with a reduced contrast. Many methods and systems using thermographic inspection have already been proposed. In general, the thermographic testing is commonly used for inspecting solder joints on a surface [1], [3], [4]. Methods used for capturing in real-time thermal images are used and the solution for real-time defect detection is searched [1], [3], [4].

The objective of this paper is to present our proposed and designed automated system for crack detection using the infrared thermographic testing method. The system consists of a circular coil where the metallic material is passed through. By passing the material through the coil, the material is heated and the temperature changes are consequently measured with four infrared cameras. The cameras were designed during our research when the best parameters for material surface scanning were searched. The reason to use four infrared digital cameras is to scan each surface of balk steel material separately and, in the following, to have the testing process more precise and faster. The main advantages of the IR method are that no contacts and wearing surfaces between material being inspected and testing equipment and accessories. Thus, service life and reliability of testing system based on IR principle is much better than using other nondestructive methods (i.e. eddy current). Moreover, IR system is not likely to be affected by irregularities and condition of the surface under inspection.

This paper also addresses the application of the thermographic system used in industry. The detection of cracks (defects) in balk steel bars is very important because it can damage the final product and finally cause huge misery. The created infrared cameras are very sensitive in temperature range and proposed software with implemented algorithms is simple and user friendly. Each detected crack is indicated and evaluated. Based on this evaluation, the statistics of damaged and correct blocks are considered.

This paper is structured as follows. First section describes the final construction of the automated infrared thermographic system. The system is generally described and different reasons are addressed for the correct structure. Next section describes our proposed software used for measurement, display, evaluation and database storing of measured data. The software was created regarding user friendly controlling. In the fourth section, the application of our system in environmental industrial application is mentioned. Finally, the proposed system is concluded and future work briefly described.

2. Construction of automated infrared thermography system

The automated system for infrared thermographic testing was proposed and finally developed in Starmans company Ltd. First of all, the construction of the system was discussed. The goal of the proposed system was to test the square steel blocks created by hot rolling. After the rolling the steel blocks were cut and finally shaped into quadruples. These were tested in our automated system to detect cracks or defects.

In general, the system consists of the following main parts: high frequency generator, high frequency coils, signal processing units, IR detectors (cameras), equipment and software for displaying and evaluation of indications, complete equipment for defect marking, wetting unit, mechanical parts as mechanical frame for fixing of IR detectors, mechanical frame for HF coils.

The high frequency coils are power supplied by the high frequency generator. The coils are used for steel block heating. Blocks were automatically moved onto the belt and wheels, and introduced to the coil place. Generally, the blocks speed depends on the viewing field of the IR camera and used computer system. Both used components allow to achieve linear testing speed of more than 0,2 m/s.

When the steel block was heated, it was automatically scanned by infrared cameras. The whole system contains four IR cameras. Each camera scans one side of quadruple block. The block drawing of the main part of automated thermographic system can be seen in fig.1.

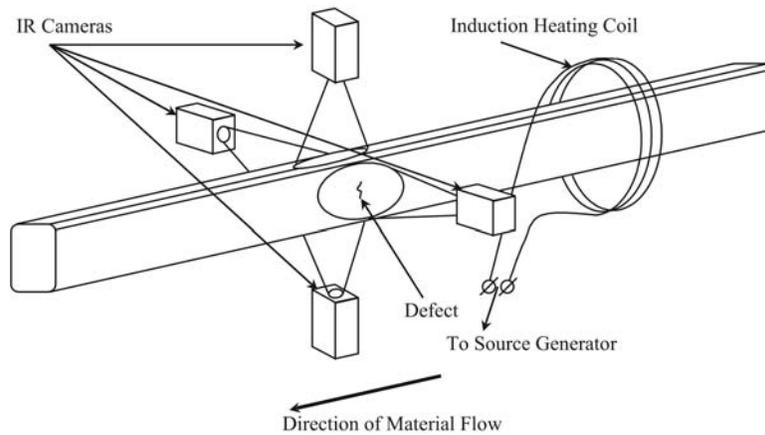


Fig. 1. 3D-visualization of proposed thermographic system

Based on drawings and visualizations, the system was constructed and technical parts were solved. As can be see in fig. 1 and fig. 2, the system contains a huge mechanical frame, with mounted infrared cameras (detectors). The main advantage of the mounted cameras is that these can be automatically adjusted. For the appropriate heating of material surface, the coil has to be in the center of the material. For this requirement the frame is automatically adjusted. All adjustments are engaged in the software. Before the material is introduced in to the coil, the surface is wet by steam.

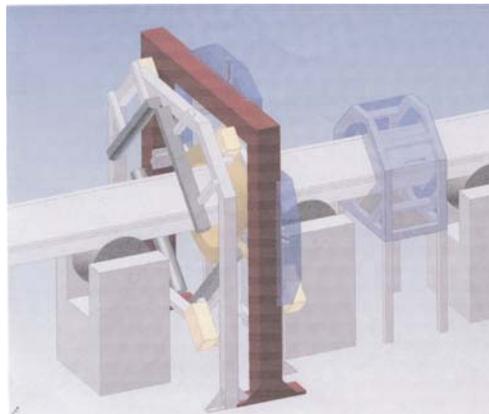


Fig. 2. 3D-visualization of proposed thermographic system

This makes the homogenous distribution of the magnetic field and homogenous heating of the material surface. By passing the steel blocks through the coil the material surface is scanned by infrared cameras and acquired images are sent to PC. At the end of the system, detected cracks are automatically marked with a special marking device. This feature makes it easier for attendants.



Fig. 3. Automated thermographic system overview

Principle of material surface heating is based on induction heating. For the safe material surface heating, the special high frequency generator for induction heating was designed.

4. Software

Created hardware mechanical parts were placed as a part of the full inspection system (infrared + ultrasonic for subsurface flaw detection). When the material is wet, passed through the coils and heated, the IR detectors (cameras) are used for each surface scanning. Measured data is sent to industrial PC through USB port and processed and evaluated in software DIO5000. The software DIO5000 contains basic control functions. The basic display of the software can be seen in fig. 4.

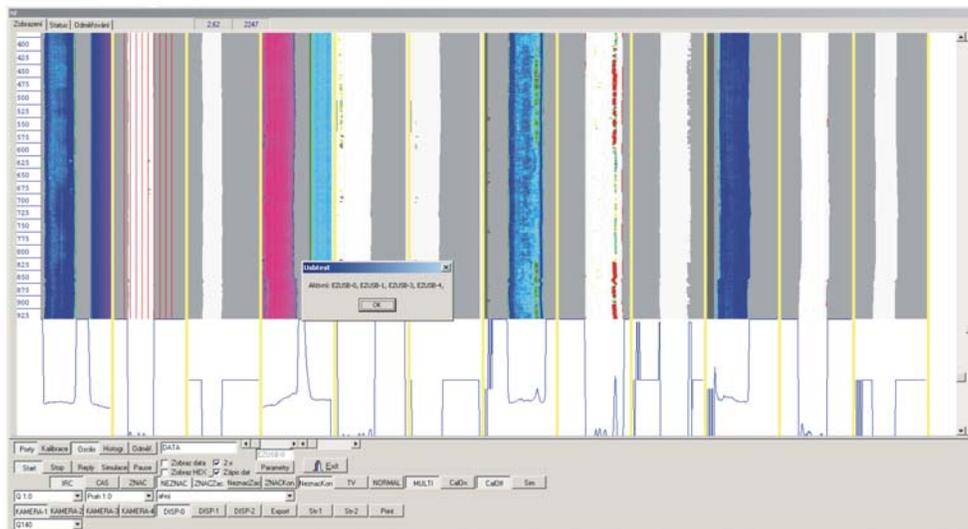


Fig. 4. Basic display of software for data evaluation

In general, the basic display can be divided into two parts. The first part (bottom in fig. 4) contains basic control buttons. Control buttons enable: to detect connected USB ports, calibration of IR cameras, data saving, different modes of data displaying, choosing of predefined square steel blocks shape (for coil adjustment), buttons for defect marking and database generating. The second part allows measured data displaying based on chosen display mode (TV mode, MULTI mode). As can be seen in fig. 4, data is displayed in TV mode, where each colour corresponds to the different temperatures. Part of this window is the oscillogram where the amplitudes of each row is visible. This feature is really important, because the defect amplitude is higher than the background amplitudes. This allows indication of the amplitudes in case of defect presence. For

this reason, it is very important to have IR camera very sensitive. This IR camera is capable of detecting a discontinuity with dimension of less than 0,3 mm, i.e. less than 0,3 % of thickness of the thinnest bar mentioned. The defect detection algorithm uses threshold value, which is derived from dynamic range within amplitudes of measured sample. The defect is indicated in case the defect amplitude is higher than the derived threshold. As can be seen in fig. 5b, the background amplitude is sometimes similar to defect amplitude. In this case, it is very important to consider only the amplitudes within range of the raw signal. The amplitudes of background have to be suppressed and are not considered. This implemented feature makes the defect detection process more efficient. Another issue arised at the edges of the squared steel bars. In case of defect presence at the adge, the amplitudes are also higher, but lower than the background. For this reason, we change the position of IR cameras for scanning the surface under the specific angle. In this configuration, the surface of squared steel bars is efficiently scanned.

6. Application

Based on the proposal and theoretical analysis, the automated thermographic system using infrared detectors were designed and installed in industrial applications. This system as a part of the automated non-destructive line was used for the suface detection on square steel bars. Square steel bars can be used for the axle or shaft construction in automotive industry hence the system has to be acurate and reliable in terms of defect detection. The system was successfully installed and the first test was accomplished on the calibration gauge containing small and large defects. Besides the small changes and parameter settings (hardware and software) on the system, the system reliably marked all defects on the calibration gauge (see fig. 5a).



Fig. 5a. Surface defect detection

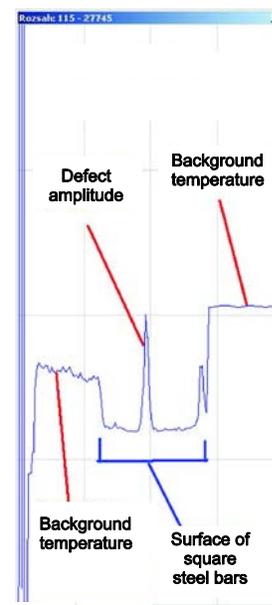


Fig. 5b. Surface amplitude visualization

After these initial tests, real testing of squared steel bars was performed. For the succesful defect detection it was necessary to set appropriate threshold. The threshold is based on a dynamic range of amplitudes within a certain range (see fig. 5b). Based on this threshold, the defects were detected, saved and finally statistical analysis was performed. The statistical analysis can be seen in Tab. 1.

Tab. 1. Statistical analysis of defect detection

	Defect ≥ threshold	Defect < threshold			Defect in edge	No defect
		Total	z toho			
			o -0,05	o > -0,05		
Marked defects ELKEM system	64	159	—	—	24	67
Marked defects DIO5000 system	75	244	18	7	39	68
Equally marked defects	44	104	—	—	13	10
Unmarked defects	5	2	—	—	0	0

Based on the analysis in Tab. 1., the comparison between already existing thermographic ELKEM system and our proposed Starmans DIO5000 system, it can be seen that defect detection ability is better with Starmans DIO5000 system. In present, the proposed system is almost completely installed and squared steel bars containing defects are repeatedly melted.

7. Conclusion

This paper presents our proposed and developed fully automated robust system for crack detection on steel blocks used for axle construction in the automotive industry. This proposed system consists of a circular coil where the steel blocks are passed through and heated; self designed infrared cameras and software with implemented evaluation algorithms. The system is fully automated and in case there is a different material size, it can be easily transposed by coil changing. Developed infrared cameras involve implemented signal processing algorithms. By theoretical and experimental measurements, the methods for efficient noise suppression and crack detection were proposed. The presence of surface and subsurface flaws is automatically indicated and finally evaluated on display monitor. The presence of ambient light noise is suppressed by algorithms based on simple mathematical equations using square average. In future the system can be extended by adding of algorithms used for automated crack recognition.

References

- [1] Maldague X.P.V. Nondestructive evaluation of materials by infrared thermography, Springer Verlag, 1993, London, ISBN 3-540-19769-9.
- [2] Maldague, Xavier P.V., “Theory and Practice of Infrared Technology for Nondestructive Testing,” May 2001.
- [3] Giovanni M. Carlomagno, Carosena Meola: Comparison between thermographic techniques for frescoes *NDT & E International*, Volume 35, Issue 8, December 2002, Pages 559-565.
- [4] Hartless, P.C.M.; Whalley, D.C .Automated thermographic inspection of surface mount solder joints. *Automotive Electronics*, 1991., Eighth International Conference on Volume , Issue , 28-31 Oct 1991 Page(s):178 – 181.
- [5] X. Maldague, J. Cote, D. Poussart, V. Valvilov “Thermal Tomography for NDT of industrial materials” *Canadian Society of Nondestructive Testing Journal* pp. 22-32, May-Jun. 1992.