Vibration Induced Disturbances in Automatic Non-destructive Testing

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Abstract
The interest in automatic inspection of welds has increased during the last decade. An automatic inspection cell is self-acting both by scanning the inspected test piece and by evaluation of the resulting images. For automatic evaluation, high quality of the resulting images is essential. The non-smooth movement of the NDT-sensor when mounted on a robot-arm will have influence on the results. This paper focus on evaluation of the vibration induced disturbances due to the mounting of the sensor and the movement of the robot in an automatic cell. A thermography system detecting the geometry of welds is used in this study and both stationary and continuous movement of the IR camera are studied. The vibration due to the mounting on a robot arm are quantified and compared.

Keywords: Vibration disturbances, weld inspection, thermography, automatic inspection

1. Introduction
Manufacturing industries are heading for full automation in order to be competitive. In parallel non-destructive inspection has become more and more important in order to keep the quality but also to assure reliability. Today automotive and aeronautics products are getting lighter and lighter due to environmental concerns. With reduced structural weight, the local tension will increase. Since the fatigue limit is reciprocally proportional to the size of the defects, the production quality has to increase and the control of the quality is crucial. To fulfil high quality in parallel with low cost for production the interest in automatic inspection has consequently increased.

Full automatic testing and inspection is not an obvious activity. Several problems need to be solved in order to achieve a robust and reliable automatic non-destructive cell (NDT-cell). In an automatic NDT-cell the movement of the sensor during the scanning may introduce vibration disturbances to the measurement signal. This will reduce the signal to noise ratio and influence negatively on the quality of the measurement results. For an automatic NDT-cell the knowledge of the movement may be used to interpret the noise in the signal and accordingly increase the signal to noise ratio. As a step towards a full automatic inspection, the knowledge of the introduced vibration disturbances is of importance.

This paper investigates if an ordinary industry robot is stable enough to be used as scanning equipment in an automatic NDT-cell and focus on evaluation of the vibration induced disturbances due to the mounting of the sensor and the movement of the robot. A thermography system developed for detecting the diameter of a spot weld is used in this study and both stationary and continuous movement of the IR camera are studied. The signal to noise ratio due to the mounting on a robot arm are quantified and compared.

2. Automatic Non-destructive testing
A fully automatic NDT-cell includes both automatic scanning of the test piece and automatic analysis of the test results. An automatic NDT-cell can schematically be divided in two parts;
mechanisation and analysis, see Figure 1 where the mechanisation is the scanning equipment. To achieve a full automatic inspection both parts as well as the interaction between them need to be automatic. Today several commercial systems are available where the mechanisation is automatic. The analyses are in some systems performed automatically, but the interpretations of the results are most often performed by a skilled technician. Today there are research going on to achieve higher level of automatic analysis and interpretation of NDT-signals and results, some examples are presented in Ref. [1-3].

![Schematic set up of automatic NDT cell. A NDT sensor is connected to a scanning equipment and an analyse equipment. The scanning equipment and the analyse equipment are also connected. A read out receives signals both from the scanning equipment as from the analyse equipment.](image)

For a NDT-cell to be used in a manufacturing industry the scanning equipment can be of different types. A common industrial 6-axis robot offers great flexibility, excellent support organization and the know-how about such equipment is also high. Another benefit is that a robot can carry different inspection equipment. In an automatic NDT-cell with an industry robot used for scanning, the robot needs to be connected to a computer for adapt the results and report OK/NOK for the tested part. The robot will be used for the mechanisation of the NDT-cell, and the computer handles the analysis and reports the output.

To reach high quality result from any measuring set-up, high signal to noise ratio is important. When it comes to automatic analysis of NDT results, the signal to noise ratio is even more important in order to distinguish between signal noise and variation in the tested material. For a NDT inspection where a well-trained technician interprets the results, the noise in the signal may be understood, by experience from the technician. However if the signal to noise ratio is to low, the results may be misinterpreted.

Thermography is a relatively novel method within NDT, it is mainly used for inspection of ceramics, plastics and composites [4]. Lately inspection of metal structures and welds are reported [5-7]. Thermography has the advantages that it is relatively fast, non-contact and provides full field information; therefore it is suitable for an automatic NDT-cell. During the investigation presented here a thermography system was used.

### 3. Experiments

To investigate the influence of the vibration to the NDT equipment an ABB robot (IRB 2400) was used as scanning equipment. A thermography system was mounted onto the robot arm
including an IR-camera and a flash light, see Figure 2. The thermography system is developed for measure the diameter of spot welds.

![Figure 2. The robot arm with the IR-camera and the flash light mounted. An accelerometer was attached in order to analyse the vibration during movement in x-direction.](image)

A 3-axis accelerometer (Kistler 5015A) was mounted onto the fixture for the IR-camera to measure the vibration amplitude during movement, see Figure 2. The amplitude of the vibration, both in x- and y- axis direction, was measured when the robot arm was moving in the x-direction. Frequencies in the range of 0 - 5000 Hz were analysed.

The influence of the vibrations due to movement of the thermography system was analysed by studying the thermography results from a test plate with varying geometry. The test plate was a 5 mm thick metal plate with a flat bottom hole on the back side. The hole had a diameter of 9 mm, and a depth 4 mm, see Figure 3. This test plate was produced in order to have a well-known diameter to measure from the back side in order to evaluate the possibility to use the thermography system for measure the diameter of a spot weld. The test plate will simulate the spot weld, or rather the inverse of the geometry of a spot weld (even though this 9 mm hole is wider than an ordinary spot weld).

![Figure 3. The test plate used during the investigation. A flat bottom hole with a diameter of 9 mm where drilled on the back side of the plate. The depth of the hole was 4 mm and the plate thickness was 5 mm.](image)

The test plate was mounted in front of the thermography system with the flat bottom hole on the back side of the plate, not visible from the position of the camera. Using the thermography system, a flash light excited the surface of the test plate, and the variation in temperature of
the surface was measured by the IR camera. The flash light used gave a 2 ms short light pulse at 6kJ and the IR camera was a FLIR SC5650 with a frame rate of 300 Hz.

Studying the first derivative of the temperature variation, the flat bottom hole appears as an area with lower cooling rate. The thermography system was capturing images of the test piece both at rest and immediately after the stop of the robot movement, i.e. at the settling time.

4. Results and discussion

The amplitude of the vibration of the fixture for the thermography system during movement of the robot is presented in Figure 4. The robot was started to move in x-direction at 1.5 s and was programmed to move during 2 s. It is obvious that the amplitude is larger in the moving direction of the robot than in the perpendicular direction, compare red and white curve in Figure 4. It is also clear that the amplitude is highest immediately after the start and during the retardation of the robot arm. For measuring with the thermography system during the movement, one should be aware of the start and stop position, i.e. the acceleration and retardation interval of the robot. It is also shown in Figure 4, that the settling time of the vibration is about 0.25 s. During the movement of the robot arm, the speed is almost constant (time 2 – 3.25 s in Figure 4) and it is shown that the amplitude of the vibration is rather low, but noticeable and in the same range as the amplitude during the settling time. It could therefore be assumed that the influence of the vibration is in the same range during the continuous movement as during the settling time of the robot arm.

![Image](image)

Figure 4. Amplitude plot for the vibration measurement during the robot movement. The movement of the robot in the x-direction was started at 1.5 s and continued during 2 s. White and red curves are the x- and y-axis vibration respectively. Amplitudes are in [mm] and time in [s].

In Figure 5 and 6 results from the thermography system are presented. The cooling rate of the surface is shown as a colour-plot in Figure 5 with high cooling rate as yellow and low cooling rate as blue. The images are captured 0.1 s after the heating with the flash light. Since the temperature distribution is rather high in metal, the surface will cool quickly. In the vicinity to the centre of the flat bottom hole, the cooling rate will be in the same order as outside the flat bottom hole. That is since the cooling rate is proportional to the second derivative of the temperature distribution according to the heat equation;

\[
\frac{\partial T}{\partial t} = k\nabla^2 T,
\]

where \(T(x,y,z,t)\) is the temperature, \(k\) is the thermal diffusivity, and \(\nabla^2\) denotes the Laplace operator.
Figure 5. Results from Thermography equipment when (a) the IR-camera is mounted fixed and (b) the IR-camera is mounted on the robot arm and the results are captured 0.1 s after the stop of the robot.

In Figure 6 a plot of the cooling rate along a cross section above the flat bottom hole is presented. The position of the flat bottom hole is clearly visible as an abrupt change in cooling rate. The results presented are not filtered and includes some noise. Even without filtering the signal, the diameter of the hole is visible as a change in the cooling rate.

Figure 6. Plot of the first derivative of the cooling at the surface of the test piece along a line right above the flat bottom hole. The IR-camera is mounted fixed (a) and on the robot arm (b) and the results are captured 0.1 s after the stop of the robot in (b). Compare Figure 5.

Figure 5 and 6 compares the results from the thermography system when the IR-camera is mounted fixed, Figure 5a and 6a, and on the robot arm, Figure 5b and 6b. The results in Figure 5b and 6b is captured immediately after the stop of the robot, which is during the settling time, compare Figure 4. Comparing Figure 5a and 5b the image captured during the settling time of the robot, Figure 5b, is a little bit more blurred than the one captured with the IR-camera fixed, Figure 5a. That is due to the influence of the vibration. The blurriness is even though rather low and it is clear that it is possible to measure with the thermography system even during disturbances of the moving robot. Comparing the Figure 6a and 6b, the noise is higher in the results with the IR-camera mounted on the vibration robot arm, Figure
than for the situation when the IR-camera is fixed, Figure 6a. The signal to noise ratio is about 4 for the fixed camera and 2.5 for the situation with the moving camera. Still the signal is strong enough and using a robot as scanning equipment in an NDT-cell looks promising.

5. Conclusions

This paper focuses on evaluation of the vibration induced disturbances due to the mounting of a NDT-sensor on a moving robot. A thermography system was mounted on an ordinary industrial robot and used as scanning equipment in an automatic NDT-cell for spot weld inspection. The system was intended for measure the diameter of spot welds. For evaluating the influence of the vibration due to the robot movement the vibration at the mounting position of the thermography system was measured with a piezo electric accelerometer. The vibration amplitude during movement was found to be rather low, but during the acceleration and retardation of the movement, the vibration amplitude was significant. This investigation was performed on an ABB (IRB 2400) robot, other types of robots may have different stability and influence differently on the NDT system.

It is obvious that care should be taken to the vibration disturbances when setting up an automatic NDT-cell. The signal to noise ratio in the measurement results did increase when the thermography system was used during movement. Due to more noise in the results, the evaluation will be less accurate, and when it comes to automatic evaluation it is even more important to keep the noise level as low as possible. Even if the vibration was significant during the motion of the robot, it is found that an ordinary industry robot is possible to use as scanning equipment in an automatic NDT-cell.

References