AUTOMATED SYSTEM FOR MAGNETIC PARTICLE INSPECTION OF RAILWAY WHEELS

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Abstract
This paper presents a new developed automated system used for flaw detection and classification on railway wheels. The described system uses the principle of non-destructive method based magnetic particle inspection. Our proposed and finally constructed automated system is used in industrial applications where non-destructive testing of railway wheels is desired. As a part of testing line, it is possible to detect both surface and subsurface flaws. Using this system, it is possible to test about 15 wheels per hour. The system consists of mechanical parts (frame), inspection parts (cameras) and application software. Application software includes advanced signal and image processing methods used for efficient flaw detection. Using our proposed automated system it is possible to safely detect flaws presented at any part of railway wheel.

Introduction
High safety standards required in the management of railroad lines demand the inspection of railway wheels directly after production in order to detect the presence of surface cracks that could seriously affect the integrity of the railway, and therefore passengers' safety.
During the last two years, we have been developing an automatic system for surface defect detection on railway wheels. The main goal was to develop the highly reliable system based on image processing algorithms that gives a warning of surface flaws to prevent possible future accidents. The system is based on magnetic inspection where the railway wheel is put into the magnetic field and the cracks cause a magnetic stray field. By this technique the cracks are visible and they can be easily recorded using high speed digital camera. The mentioned testing of railroad wheels is based on magnetic particle inspection.

Magnetic Particle Testing
Magnetic particle inspection (MT) processes are non-destructive methods [1] for the detection of surface and sub-surface defects in ferrous materials [2]. They make use of an externally applied magnetic field or electric current through the material, and the principle that the magnetic flux will leave the part at the area of the flaw. The presence of a surface or near surface flaw in the material causes distortion in the magnetic flux through it, which in turn causes leakage of the magnetic fields at the flaw. This deformation of the magnetic field is not limited to the immediate locality of the defect but extends for a considerable distance; even through the surface and into the air if the magnetism is intense enough. Thus the size of the distortion is much larger than that of the defect and is made visible at the surface of the part by means of the tiny particles that are attracted to the leakage fields. Magnetic particles are usually applied as a suspension in water or paraffin. This enables the particles to flow over the surface and to migrate to any flaws. The most sensitive technique, however, is to use fluorescent particles viewed under UV (ultraviolet) light.
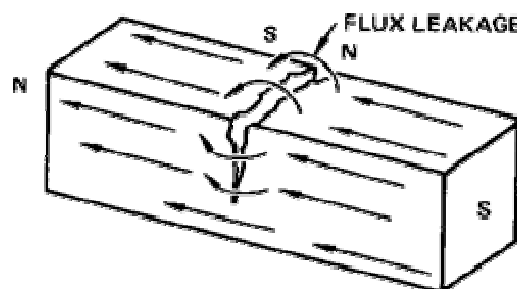

Fig. 1. Magnetic flux flow

System proposal

As described in previous section, our system is based on magnetic particle testing. As our system is developed for inspection purposes of railway wheels we set initial requirements that have to be finally fulfilled. The first requirement was to scan the whole surface of railway wheel in different wheel diameters. The desired wheel diameter is within 500 – 1300 mm. In general, the system had to be flexible to scan the surface in different volumes. This also corresponds to magnetization. Different wheel diameters require different magnetization current. Another requirement was to scan the surface automatically, without human intervene. For this reason we proposed new high-resolution digital cameras that were automatically driven and scanned the surface of the wheel. With these cameras, it was necessary to scan all corners and drapes of the wheels. The last main requirement was to propose and implement efficient signal processing methods used to safely detect all flaws in exact sizes. The minimal size of detected flaw was determined to 1 mm in length and 0.3 mm in thickness. These values are based on standards defined in rail industry. As described system was as a part of complex inspection line used for subsurface defect detection using ultrasonic non-destructive testing it has to be also prepared to inspect wheels in adequate speed.

System overview

The system requirements mentioned above have been kept in mind during the system proposal. As a basis for railway wheel inspection was the magnetic particle method. Based on this, we propose settings of inspection line. The main part of proposed inspection line the coil used for magnetization of inspected wheels was used.
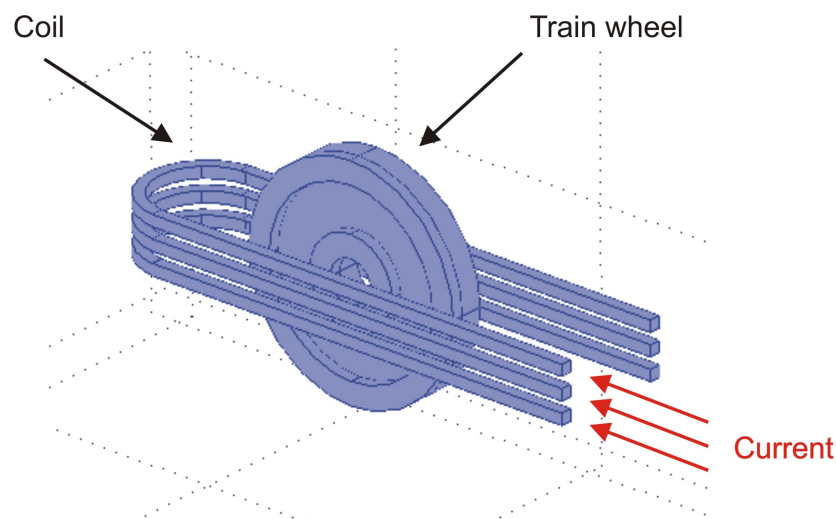

Fig. 1. System configuration for railway wheel testing

The configuration of used coil has to correspond to correct magnetization [3] of railway wheel. The whole volume of railway wheel has to be magnetized. To obtain such magnetization we decided to rotate the railway wheel during the magnetization process (i.e. during the current was applied to the coil). The Fig. 1 shows the proposal of coil configuration and location of railway wheel in the coil.

In the developing stage, we simulated the magnetic field to find out the optimal position of railway wheel in magnetic field for the best defect visibility. In Fig. 3., the streamlines of magnetic flux density represents the magnetic field. The strongest magnetic field (flux density) can be visible at the bending of coil. It means, in case the railway wheel has sizable diameter than is better magnetized. As we need to reach the appropriate magnetization of all predefined wheels (all required diameters), it was necessary to use the second spiraled coil located near
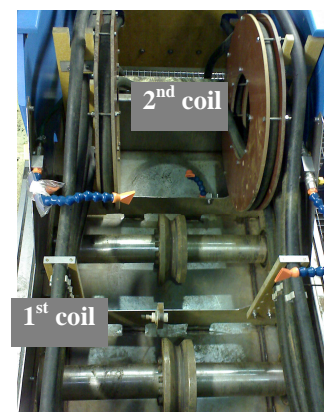

Fig. 2. Configuration of coils

to the centre of the railway wheel (see Fig. 2.). The second spiraled coil was used to improve the total magnetization of railway wheel and make the magnetic field stronger in relation to definitions mentioned in standards. Finally, the main goal was to detect flaws in all directions
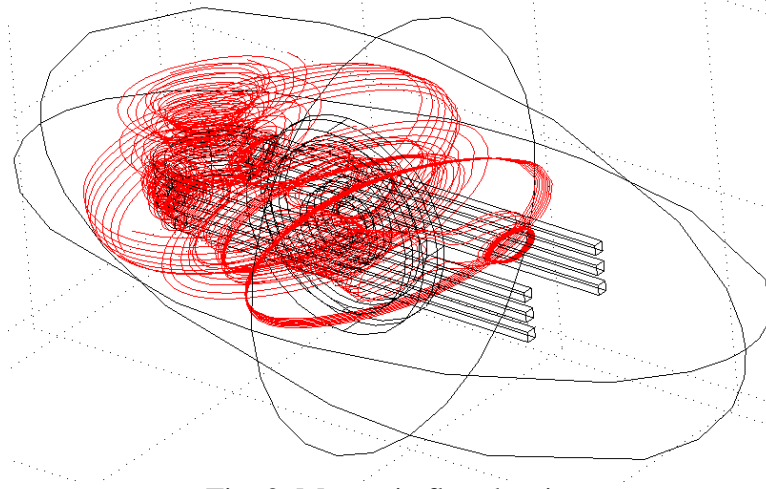

Fig. 3. Magnetic flux density

To make the decision about the proper configuration of coils and location of railway wheel, the first measurements were performed. For measurement, six measured points was determined. These can be seen in Fig. 4a. The results of magnetic intensity H measurement are visible in Fig. 4b..

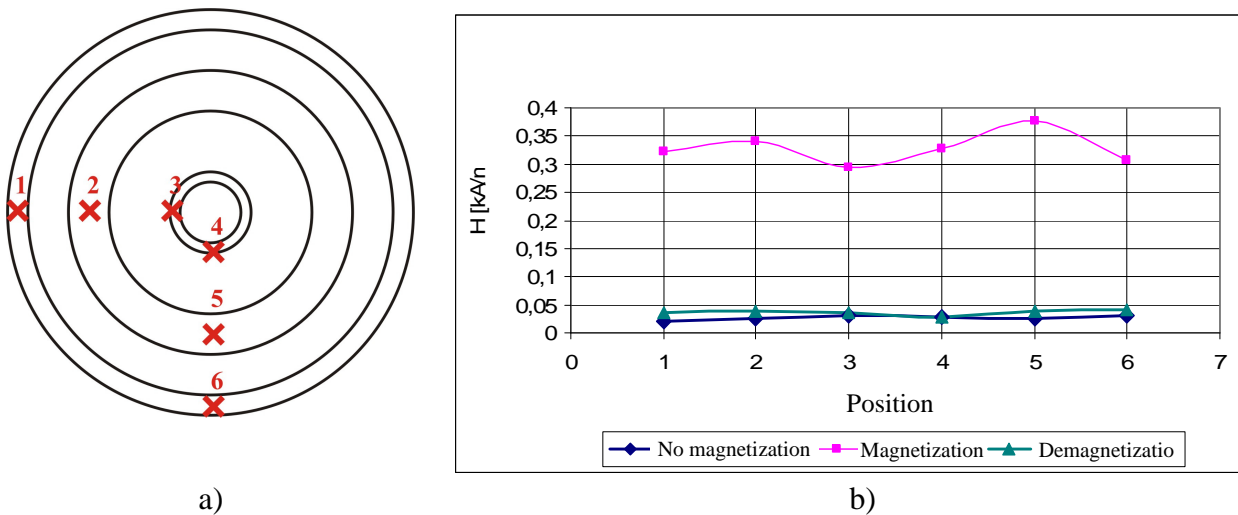a)   b)

Fig. 4. Magnetic intensity measurement, a) locations, b) results

As can be seen in Fig. 4., the minimal intensity was reached near to the center (locations 3 and 4) of railway wheel (about 300 A/m). On the other hand, the maximal intensity was reached in place 5 ($H = 376$ A/m). This value of intensity was reached due to overlay of both coils.

As railway wheels were successfully magnetized we resolved the second step. As second step, we consider the dousing of railway wheel by liquid containing ferrous fluorescent particles [4]. In case, the wheel is covered by ferrous fluorescent particles the flaws are consequently easily visible. During this step we had to find out at which phase the liquid needed to be spout on the inspected wheel. The best time we found was the time during magnetization. This led to certain time that wheel needed to be magnetized and covered with fluorescent liquid simultaneously.

When the inspected railway wheel was magnetized and covered with fluorescent liquid, the flaws and cracks had to be found. All recent lines used for this inspection employed operator. Defects and cracks were found using ultraviolet lights. As our goal was to develop automated inspection line, we used for defect detection our developed cameras. During the magnetic inspection of railway wheel, the railway wheel surface was scanned by digital camera. Each place of inspected

wheel was inspected on-line. Digital camera (see Fig. 5.) scanned the whole surface and all recorded pictures were promptly evaluated using our proposed image processing algorithms. Whole surface and different sizes of railway wheels can be inspected.

Defect detection and classification
As was mentioned before, for defect detection we proposed simple signal processing algorithms. The defect detection process can be briefly described in the three following main steps:

Fig. 5. Digital camera with UV light

1. Noise reduction
The recorded picture is corrupted (see Fig. 6a.) with relatively high noise level (see Fig. 6b.) and detection process is more difficult. As a noise suppression technique, we used simple mathematical processing algorithm based on space pixel averaging. Each pixel of recorded picture has certain amplitude level. By application of space averaging moving along the picture, the places with high amplitudes represent flaws and places with random amplitudes represent noise. It means places with random amplitudes were suppressed.

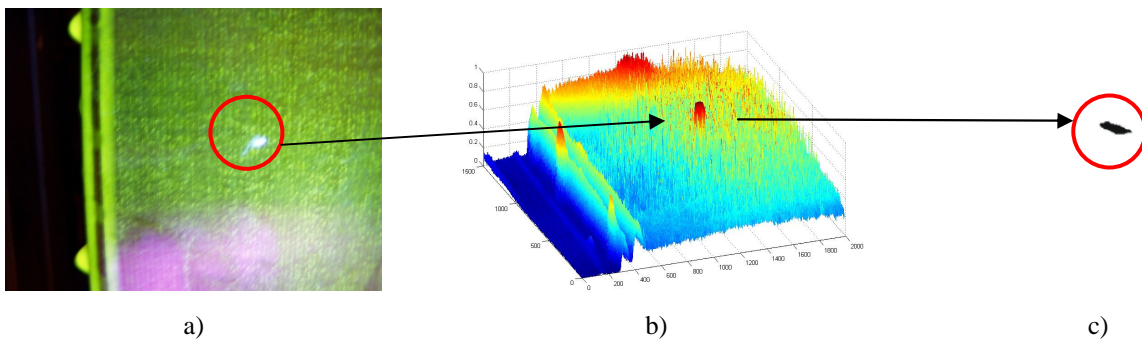a)   b)   c)
Fig. 6. Defect detection algorithm, a) recorded picture, b) flaw amplitude level, c) detected flaw

2. Defect detection
Defects have to be recognized from scratchy surface of railway wheel. By using our signal processing algorithm, defects are recognized from noise. The final pictures contain amplitudes representing flaws only (see Fig. 6c.). In case the defect appears, it was automatically marked on pictures. All pictures containing flaws were stored.

3. Defect classification
The defects most commonly occurring on railway wheels are similar to straight line. With proposed algorithm we are able to recognize the flaw shape and consequently classified as a linear object in various slope or as an object with distinct shape (drop of magnetic particles).

System construction
The previous sections describe system proposal, coil configuration, and defect detection algorithm. Our proposed inspection system focused on surface defect detection on railway wheels uses magnetic particle testing method. To have all adequate system parts working together and with no influence the control system (PLC - Programmable logic controllers) were used. These systems controlled all processes to successfully detect flaws on railway wheels. In general, our system cooperates with ultrasonic inspection line (also developed by our company). In technical standpoint, the inspected wheel is automatically put into the inspection area (to the center of coils). Using

automated holding system, the wheel is rotated all around. During the rotation, the wheel is magnetized and covered with fluorescent liquid. In following, the surface of railway wheel is scanned by digital camera and flaws are on-line recognized. In case the flaw is detected, picture is automatically saved and operator is acoustically warned of flaw presence. Operator than can consequently check the flaw location. The overview of our developed inspection system is in Fig. 7.
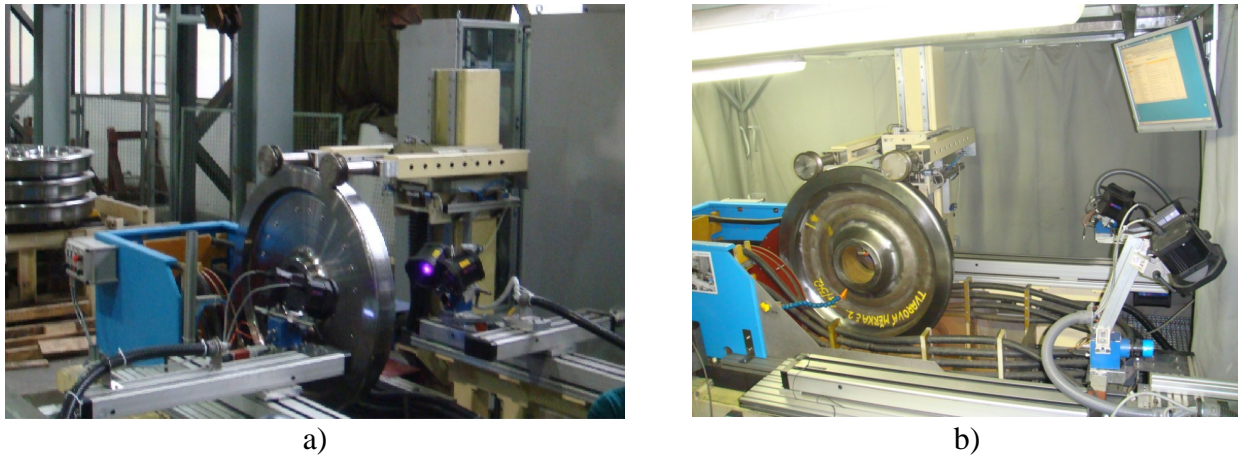

a)   b)

Fig. 7. Developed inspection system, a) wheel under inspection, b) magnetization process

Conclusion

This paper presents our developed system used for surface defect detection on railway wheels based on magnetic particle testing method. With this system it is possible to on-line detect the surface flaws on railway wheels. The digital camera with adequate resolution was developed for the surface scanning and proposed digital image processing algorithms are implemented both in hardware and software parts. In case of flaw detection, it is possible to detect the flaws in length of 1 mm and thickness (width) of 0.3 mm. The proposed system is fully automatic and it is able to successfully detect and classified flaws. The presented system is as a part of complex inspection line and can be easily modified for special desired industrial applications.

Acknowledgement

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