Abstract

Industry 4.0 is, with ongoing digitization and internet abilities, assumed to become the fourth industrial revolution after the first which is based on mechanical manufacturing driven by water and steam power, the second which comprises mass production with electrical energy and the third revolution is determined by digital systems and robotics. The aim of the project Industry 4.0 is to support plant manufacturing of the future in Germany to make the production faster, more efficient and highly flexible. It comprehends complete networks within industrial processes, from raw materials to the finished product, including design with consideration to Non-Destructive Testing (NDT, or NDE, Non-Destructive Evaluation), inspection, production, central quality control and Structural Health Monitoring (SHM).

Today Industry 4.0 still is the relevant idea to be defined and promoted by state institutions. However with available network possibilities it will in addition be a self-fulfilling future aspect in industrial processes. It is believed, that nearly all areas involved in the industrial process are affected.

The question arises as to which extent it will influence the area and profession of NDT as a technique and its related human resources. What would be the requirements and challenges for NDT4.0?

Some aspects of the integration of the inspection results and quality control and online information to the production department are not really new for NDT. The overall networking of NDT 4.0, including all aspects within the industrial process however requires more comprehensive information on the automation of NDT test procedures to be applied and at the same time provide information to all interested parties.

Intelligent sensors are guiding the component through the production process. Relevant information has to be provided online to the quality and back to the production department and as well to the customer. This obviously will require additional demands to the performance of NDT systems. Structural Health Monitoring (SHM) of the finished components or integrated into the complete system during operation is offering additional perspectives and surveillance.

In this paper a completely automated system for magnetic particle inspection of steering knuckles, tubes and round bars is described as an example.
Introduction

The availability of Internet of Things (IOT), Cyber Systems, Cloud Formation, Digital Platforms, and Artificial Intelligence including Neural Networking in future will offer great possibilities and challenges in all areas of production, services and society. In order to promote the introduction of these features in manufacturing plants the German Government Ministry for Education and Research (BMBF) has developed a project named Industry 4.0. [1]

Industry 4.0 is assumed to become or still is the forth industrial revolution after the first which is based on mechanical manufacturing driven by water and steam power, the second comprises mass production with electrical energy and the third through digital systems and robotics. The aim of the project Industry 4.0 is to support plant manufacturing of the future in Germany to make the production faster, more efficient and highly flexible.

Industry 4.0 in SMS Companies

The support from BMBF should especially enable small and medium sized companies (SMS) with up to 100 employees to participate within the progress in order to apply all aspects as mentioned above.

Up to date however there is still a lack of support for SMS companies. In addition CEOs are still reluctant to engage in this project because of required investment in equipment as well as in personal with adequate qualification.

In addition the promises of this forth industrial revolution sometimes are considered as hype. Often it is believed that one can postpone the decision to integrate the requirements of Industry 4.0 until the real advantages can be shown up for production, or for marketing with new business e. g. in servicing the products. Or to wait until the customers require the implementation of different aspects of Industry 4.0.

But further developments within the digital world will revolutionize our world in society and industry and subsequently NDT.

It would lead too far to mention and explain all aspects in this paper. There are a lot of publications and books on this subject (see literature at the end of this paper).

NDT 4.0

NDT 4.0 comprises all aspects within Industry 4.0 for the inspection of the material from raw to machined, inspected and classified until delivery to the customer and during its operational lifetime. Relevant information through the whole process of production, quality assurance to customers is provided. During its lifetime sensors provide information with respect to Structural Health Monitoring (SHM).

The material from the beginning of the process might be equipped with a sensor, which keeps all information about its future, choosing its way through manufacturing and inspection.

The following graph is showing this procedure and relations schematically.
The most important part of the integration of NDT 4.0 is the Automated Evaluation of the workpiece under consideration.

There have been several systems even in the nineties of last century [2,6,7]. Completely automated handling, image processing and image evaluation systems e. g. were delivered to Ford Company in Wülfrath, Germany, for identification of surface cracks by Magnetic Particle Technique for the inspection of steering knuckles. Today such a system for automated evaluation of the crack indications can be designed more easily as is shown in figure 2.

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**Figure 1: Schematic drawing of an NDT 4.0 Process**

**Figure 2: Automated Evaluation System for Magnetic Particle Inspection**
Automated Evaluation

One of the most essential aspects of NDT 4.0 within Industry 4.0 is the possibility of automated evaluation and decision.

Using the Image processing part of the drawing in figure 2, we have evaluated many components in the laboratories of the Helling Company, using the image processing system of the Federal Institute of Material Research and Testing, BAM, Germany [3].

One example is shown in figure 3a and 3b for a pipe inspected with Magnetic Particle Testing.

To date the detection and classification of surface defects by Magnetic Particle or Penetrant Inspection is not a very severe task for an automated image processing system.

But according to our experience it is not so easy for radioscopic weld inspection for example. Even Neural Network Systems mostly are at their limit.

Nevertheless, even complicated situations might be solved in future by image processing algorithms, especially handling big data. It might be further in future however for complex situations, which are often leading to chaotic results if algorithms are used, until they could be solved by real Artificial Intelligence.

![Figure 3a: Raw Image](image1)
![Figure 3b: Evaluated Image for Decision](image2)

From our experience it is obvious, that for different work pieces to be inspected, different image processing algorithms have to be applied, whereby the inspected component might carry with it the correct image processing procedure and therefore choosing the appropriate inspection system.

Information on the inspection results directly to the production and quality assurance department with the corresponding statistics can easily be provided, even to the customer through internet, cloud or digital platforms.

For time being, completely automated system will to our opinion only be applied for the inspection of large number of more or less identical items.

Integrating all aspects of Industry 4.0 within NDT 4.0 to date is reluctantly treated by CEOs of SMS companies. They fear the release of Know How to the Cloud, making it accessible to customers or suppliers and eventually to competitors. IOT and Cloud Computing are still considered as not very trustful.
Conclusion

Summarizing our paper on NDT 4.0, we would cover some aspects of a SWOT Analysis, although we are aware that the list will not be complete.

The strength of NDT 4.0 is:
- Products can be individualized
- All parameters relevant to NDT are digitized and can be provided for all interested parties
- Clouds and platforms are available for horizontal and vertical exchange of information
- Inclusion of all processing steps from raw material to components in operation

Weaknesses are:
- Connectivity between personal and machinery
- Standardization of digital connections
- Available personal with adequate qualification
- Lack of support for SMS companies
- Cost for personal and investment for equipment

Opportunities offer:
- Increase of production
- Digital connection within all internal and external procedures
- Completely Automated NDT Systems
- Real time analysis of all data including big data analysis algorithms
- Detection of strength and weaknesses in development, production, inspection procedures
- New service activities through structural health analysis (SHM)
- New training and education tasks

Of course, as always, there are threats associated with such an industrial revolution:
- Acceptance by society and individuals
- Increase of unemployment
- Potential loss of know how through internet connectivity by clouds and/or platforms to competition, suppliers and customers
- Lack of qualified personal
- Hacker attacks

For further reading there are several papers which are explicitly dealing with the implementation of NDT 4.0 and its consequences especially Iowa State University Center for NDE [4].
So far however there is – to our knowledge - no real system described which is implementing all features of NDT within Industry 4.0 in practical applications.
[1] [https://www.bmbf.de/de/zukunftsprojekt-industrie-4-0-848.html]
[2] [H. Busse et al., Materialprüfung 1989, No. 4, Automatisches Erkennen von Oberflächenrissen bei der Magnetpulverprüfung]
[4] IOWA State University, Center for Nondestructive Evaluation: “Next Generation NDT, NDT for Industry 4.0 and NDE for Everybody”
[5] Meyendorf et al., Addressing Human Factors in NDE by Using Remote NDE, Iowa State University, Center for NDE