Ergonomics as a Relevant Factor in the Field of Nondestructive Testing (NDT)

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Abstract **– NDT testing is a mandatory procedure in the manufacture of structures and equipment. It is a very useful procedure that embeds quality into the production process itself. It can be an automatic procedure, but for the most part it is a procedure carried out by an operator. The quality of the examination depends on the operator, and possible omissions. Ergonomics therefore plays an important role in the final result and is the subject of research in this paper. Ergonomics plays a significant role, especially in conditions where testing equipment is at a height, located in difficult-to-access spaces, confined spaces, or when using test equipment that requires engagement of muscular structure and the eyes.**

Keywords **– ergonomics, non-destructive testing methods, NDT operators.**

1. Introduction

To identify any defects or faults on specimens and other parts during or at the end of the production process, NDT is a regular method to reduce risks and increase product quality. Although artificial intelligence gains practical importance to secure quality standards in producing firms, the human factor is still playing a major role.

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Even though mechanized and semi-automated NDT methods still involve in one or another way human operators at almost all stages of an inspection process, starting from setting up software and equipment, over the carry out of measurement, up to the data evaluation process.

The reliability and effectiveness of NDT examination results do not only depend on improving accuracy and quality of applied equipment, but also and still on the "human factor" itself and how the equipment and surrounding conditions fit to it. The human factor in turn is a name for a bunch of different components, where ergonomics is one of them. It does not only affect the matters of health and safety but also affects directly on work results, efficiency and costs. And most of all it is one component that at least can be optimized to achieve improvements of the outcome in every area of the process, from redesigned equipment to modified surrounding working conditions.

2. Ergonomics as a Matter of Health and Economical Reason

The International Standard Organization in ISO 9241 11:2018 and ISO 26800:2011 defines ergonomics and integration of ergonomics in human –system interaction, as scientific discipline which deals with the understanding of interactions among human and other elements of a system and optimizing human well-being and system performance [1], [2].

The basic task is the adaptation of the work and surrounding conditions on NDT operators by designing an entire work system from workplace, work equipment, work area environmental conditions and the design of the organization processes. Or in short terms: Ergonomics is about ensuring a good 'fit' between the operator, the surrounding conditions and the equipment he uses. The ergonomics therefore build a segment derived originally from the question, how to improve and implement better health of employees. Developed already in the 1970s under the concept of "salutogenesis" the idea of eligibility and the eligibility of individuals for support of health occurred; a development based on studies by Antonowsky, [3].

Health promotion is therefore aimed at a process that reaches out for a higher standard for all people which enables them for self-determination about their health and makes health possible and thereby strengthens and improves it. Antonowsky's three criteria were understandability, manageability and meaningfulness, which Antonowsky once called "the sense of coherence", from nowadays a cornerstone of the efforts that are considered as operational health promotions. Transferred on the level of a company this means: If all processes in the company are transparent, then employees can develop a feeling of trust in the understandability of their surroundings. If tasks are organized in a way that working processes are clear, tools reliable and easy to operate, employees gain trust in their work and surroundings. This reduces mental stress as a source of wrong behavior and accidents as well as wrong results [4].

3. NDT and Its Broad Variety of Application Areas

Nondestructive testing represents an examination without damaging the test piece with one goal, to determine presence or absence of any defect of the test piece [5].

NDT control can minimize the possibilities of failure with a wide variety of NDT methods [6]. NDT can be used from examination raw materials prior to processing, during an enduring process, when the product is finished and of course in case of damage to analyze the source of defect in regards of further production.

Besides the decision which NDT method and which equipment to choose to get best possible results, the human factor plays an important role in the process of detecting faults. The field of NDT is wide as the applied method depends on what defect we search for. On-site hardness testing (HT) is utilized for measuring hardness and performing positive material identification directly at the testing site. Surface-replica testing is employed for surface inspection and documentation purposes, providing a detailed replica of the surface under examination. On-site metallography serves the dual purpose of microstructure examination and replication technique. Surface roughness measurement is employed for assessing surface roughness and overall surface quality. Coating-thickness measurement is crucial for determining the thickness of coatings and metallic plating layers on surfaces. Leak testing (LT) is utilized for crack detection and identifying leakages in components. Thermographic testing (TT) involves the measurement and visualization of surface temperatures, enabling the detection of temperature anomalies caused by factors such as corrosion. Positive material identification methods (PMI), such as X-ray fluorescence analysis, optical emission spectrometry, and infrared spectrometry, are utilized for accurate material identification purposes. Table 1 presents further NDT methods [7], outlining their respective applications and limitations.

Relevant factors in NDT tests are the specimen itself, the equipment, the surrounding work conditions in the broader sense of place and time and the individual human factor. They all have to fit together to obtain the correct and best possible results at low costs.

Table 1. Different NDT methods and their applications and limitations

NDT methods	Capabilities	Limitations
Visual Testing (VT)	Suitable for surface inspection and monitoring manufacturing stages of a product.	Only restricted to surface flaws. Highly dependent upon the inspector's experience.
Penetrant Testing (PT)	Suitable for surface inspection of mass-manufactured products.	Limited to surface anomalies. Too many variables affecting the test. Messy process.
Magnetic Particle Inspection (MPI)	Capable of detecting anomalies on or close to the surface in ferromagnetic materials.	Limited to anomalies in the vicinity of the surface. Can only be used for testing ferromagnetic materials. Testing of complex shapes may not be possible. Removal of any coatings is required.
Radiographic Inspection (RI)	Capable of detecting surface and subsurface anomalies.	Safety hazards and waste disposal issues. Time-consuming and expensive. Dependent upon the orientation of anomalies.
Ultrasonic Testing (UT)	Capable of detecting surface and subsurface anomalies	Anomalies smaller than grain structure can go undetected. Largely manual, therefore highly dependent upon the inspector's skill and experience. Misinterpretations of signals can occur.
Eddy Current Testing (ECT)	Capable of detecting flaws on or close to the surface in materials that are electrically conductive with or without coating (e.g. paint).	Limited to the testing of electrically conductive materials. Assessment of subsurface anomalies in ferromagnetic materials is limited by this technique. Complicated theory of eddy currents.
Acoustic Emission (AE)	Capable of detecting surface and subsurface flaws with information about the propagation of the anomaly.	Structure under testing will attenuate stress waves. Extrinsic sounds can cause misinterpretation.

4. Understanding of the Human Body as Integrated Part of NDT Process

As a human factor in broader sense the human body can also be described as a tool itself in regard to NDT. According to L. Hasan [5] the human body is in the center of the test, wherever a human is involved, enabling with his senses to be the most unique nondestructive testing instrument.

An examination in nearly all fields of NDT begins therefore with the approach to the specimen under the existing surrounding conditions. Regularly an inspection begins on a visual base in order to plan next steps. The visual component is mostly followed by the approach to the specimen in a range of simply standing in front of it, or in nearly worst case the tester being wedged into a pipe, hanging down a rope of an oil rig in the middle of the sea or taking turns in kneeling and standing up.

After having found the optimal position the operator/tester has to hold and use the tools in the correct position to get the data required. Maybe he/she has to bend over, turn his wrist and hold a less or more heavy examination tool to fulfill his task for best possible results. In some cases the tester needs to document the results immediately with the same or other tools and switch between them.

As we can see, the human body has to adapt to many positions while head, arms, legs and the rest of the body are trying to adapt themselves to partly unpleasant surrounding conditions and not optimized tools. Therefore, the body itself is a necessary tool for inspection. It is a valuable tool and binding part between the process steering brain and specimen.

5. Visual Testing (VT)

The most common method of NDT is visual testing. It should be obvious that the first visual impression has a significant impact on further testing decisions. This is particularly true when determining further test steps and selecting or using additional test methods. The point at which the inspection should be carried out and to what extent also depends largely on the first impression, because where gaps are already visible, it is important to examine them closely in order to prove or disprove the suspicion. On the other hand, visual testing is far more than just getting a first impression.

Two studies were conducted that deal directly with the ergonomics of light and visual components. It is determined that position and posture of the tester have an influence on the outcome and efficiency of results.

In the first study the focus was in the influence of viewing distance and individual differences in the oculomotor resting states on both the visual fatigue and inspection performance. Participants also reported greater visual fatigue in the near condition than in the far condition. Result was that participants who experienced large inward shifts in dark vergence also tended to be slow inspectors regardless of the viewing distances. On the other hand, neither inspection performance nor measures of fatigue were related to dark focus. These results support existing evidence against the use of near viewing distances and suggest that an oculomotor mechanism links inspection performance and visual fatigue to viewing distance [8].

Best and Littleton [9] investigated whether individual differences in the oculomotor resting states (dark focus, dark vergence) are linked to subjective and visual consequences of close visual work. Their experiment evaluated whether these resting states are also related to performance on a close visual inspection task and suggest that the performance of visual inspectors is maximized when the mismatch between the task distance and their dark vergence posture is minimized.

Also, “new” techniques gained more influence and need higher skills, especially in the field of remote visual testing. To mention endoscopic examinations, computer based optical enlargements instead of simple endoscopist ocular enlargements and of course the use of drones.

Endoscopic examinations require higher skills in handling, but have the advantage to see places of the specimen that cannot get with a direct visual view as there is not enough space or because things are too small. The advantage is that the test piece remains the same after testing. It is a minimal invasive way of examination, especially in pipes to find the leaking spot. For the visual tester person this means a shift to a more computer-based working, just like the examination with drones. In order to carry out the inspection, the handling of the endoscope requires not only higher knowledge of how to use it, but also an easy and haptic fluent way to handle the instrument so that the operator can focus on the examination process rather than on how to handle “the machine”.

6. Radiographic Testing and Digital Radioscopy (RT/DR)−Working with Dangerous Materials

With the Radiographic Testing (RT) is evaluated the complete volume of the test piece. The method uses X-rays or Gamma rays to produce a radiograph of the test piece to display defects and changes in thickness of the piece. Radiographic testing is used for welded joints where porosity, cracks, voids in weld interiors can be detected [10]. When it comes to health and safety, numerous national institutions, authorities, and laws come into play.

For instance, in some US States, there is the NRC and 10 CFR, while in Germany, there is the Strahlenschutzverordnung, and in the U.K., there is the NAIR by NRPB, all implemented to reduce long-term defects on the tester. Especially on the field of radioactive materials, laws were established to provide acceptable conditions for the staff.

Another field of health issues in the field of radiation, but which does not fall directly under the NDT RT method, is the exposure of materials which concern radioactive specimen and materials with higher the risks of causing cancer on non-radiation base. Welding fumes are the reason for causing acute and chronic health risk such as lung cancer, irritation of the eyes and skin, especially when using consumables containing Nickel. There is also a significant risk from asphyxiation when welding in confined spaces [11]. Therefore, NDT staff is exposed to these dangers as well when they do the testing in working places where welding is happening, e.g. testing welds of box girders of steal bridges.

Both, radiation, and exposure of materials, are relevant factors on the human body and issues NDT testers have to deal with in one or the other way. Regarding radiation, the NDT tester may either have to work in a radiation-relevant area or carry out a radiation test with isotopes himself. In the event of exposure to hazardous dusts and carcinogenic materials, the tester is at risk due to the test workspace surrounding people. For example, when one cleans weld seams on steel constructions in welding halls and comes into contact with the dust. This contact can be made by breathing in the air, but also through purely physical contact with the material itself or unavoidable environmental conditions. In this context, the tester has to use certain protective equipment, such as masks, gloves or special clothing. These in turn have a necessary influence on his posture, his movements and the resulting restrictions on his motoric freedom of action. For example, anyone who has to wear a radiation protection suit is restricted in their movements and feels restricted or even annoyed by the constraints imposed on them. In certain circumstances, a purely physical restriction may result in psychological stress, even if it is just in the form of feeling annoyed or uncomfortable. Anyone who is psychologically stressed may tend to finish the exam as quickly as possible and thus quickly escape the stressful situation. This affects the effectiveness of the exam, its depth and professionalism, as well as its effectiveness and the results to be achieved. So, to stay with the example, if the gloves are ergonomically adapted to the person being tested, this improves the effectiveness of the test, but also leads to a physical relief on the body and, as a result, to a reduction in psychological stress.

Ergonomics in RT-NDT therefore mostly is rather seen under the aspects of safety and health protection, which is ergonomics in the broader sense. This article rather wants to address more to the edge area of ergonomics and focus on ergonomics in regard to optimize the results of work due to better ergonomical equipment and surrounding conditions.

When it comes to ergonomic equipment, improvements also include issues like lighter mobile equipment other X-ray cabinets with optimum radiation protection and adjustable positions as well as additional lightning, door safety contacts. Ergonomic and intuitive design with simple operation devices and easy to move designs are only some part of ergonomic improvements manufacturer develop in order to praise better their products. Nowadays, manufacturers advertise the ergonomic advantages of their products, from which the conclusion can be drawn that the topic of ergonomics not only seems to have growing importance in the field of NDT, but that there is now an awareness of its advantages.

Besides that, the technology of image building concerning quality and high resolution, fast image acquisition and ease integration into the used program, are strongly promoted and lead not only to an easier handling and discharge (especially the eyes), but also seek for better results in the outcome of finding flaws.

Especially as in the past – and still today in many areas – films had/have to be developed, analyzed and evaluated in dark rooms (analog RT) as this was the standard method. This also included the process of developing photo images with all its chemical issues and were a point of improvement [12]. The modern DR method gained some advantages over the films but still cannot be applied everywhere. So technological improvements had the side effect advantage of ergonomic changes for the better. The handling got easier and safer e.g. to move the specimen in its position in order to get a better angle and a variation of ray intensity under relatively safe conditions, while film development takes us from comfort back into the last century. But not only the handling was improved by the upcoming shift from dark rooms towards screen work. These new techniques reduced stress and eye fatigue. Also the “body work” to put the equipment in different positions eased the examination, as the DR-machines mostly are able -within a certain range- to adjust the specimen by simply using a joystick or some buttons to find hidden flaws.

7. Magnetic Particle Testing (MT)

The magnetic particle testing method is used for detecting surface flaws in ferromagnetic materials. The specimen is magnetized and uses the effect of an implied magnetic field, in which field lines run through the test part and parallel to the surface. The material generates then a magnetic "flux" on the area where a discontinuity on the surface is located. To identify the defect area, fine ferromagnetic particles are applied to the surface which will be attracted to the flux leakage [13].

In opposite to an ordinary VT inspection or a PT testing, MT faces the additional difficulty when magnets are used. It has a certain weight. In order to get the full spectrum, the magnet yoke is turned by 90 degrees while examination. Mostly only one hand is needed for the yoke as the other is needed to apply the suspension. Even if the tester does not face challenging surrounding conditions, but is standing in front of an examination table in the laboratory, sometimes not only the weight of the yoke is stressing the wrists but to hold the specimen can be a heavy task as it has to be put or holden in a special position while examination. So, wrist fatigue, arm strain, back pain and physical stress are typical issues of MT-NDT operators.

The musculoskeletal disorders (MSD) like lower back pain, neck strain, herniated, ruptured discs, wrist tinnitus, elbow strain and shoulder/rotator cuff injuries can be reduced by better equipment, especially tool design but also by optimizing knowledge of positioning during the exercise of the tasks. To minimize wrist deviation e.g., positioning and tool design may help to reduce such risks as shown in Figure 1, showing the development of yokes.

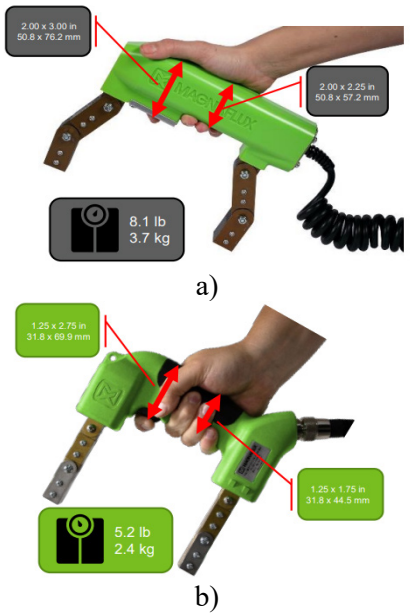

Figure 1. a) Standard yoke, b) Ergonomic design of yoke by Magnaflux

8. Dye Penetrant Inspection (PT)

Dye penetrant inspection is a method for revealing surface cracks by using color dye. Into the prepared test piece a liquid is drawn, showing the flaws and imperfections by capillary effect, Figure 2. Like the MT testing procedure, the ways the operator has to examine the specimen with the aforementioned PT procedure is nearly the same, so that the focus lies more on the surrounding conditions under which the tester has to operate. In opposite to an MT test, the equipment is much lighter, but to move the (sometimes heavy) specimen in the right position may cause musculoskeletal disorders (MSD).

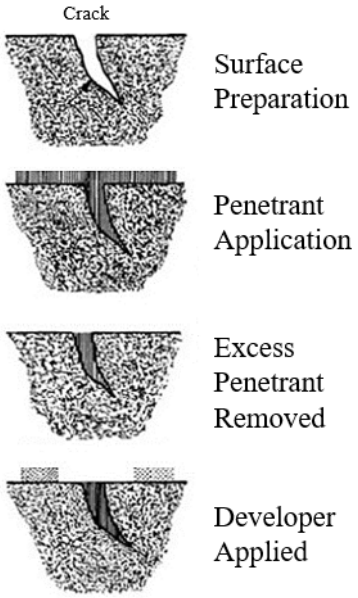

Figure 2. PT steps

9. Other NDT Methods

Beside the named methods, other NDT methods like e.g. Eddy Current Test (ET), Leak Test (LT), Thermographic Testing (TT) and Acoustic Emission Test (AT) or Vibration Analysis (VA) [14] are also often used to detect flaws and damages depending on the fields where they work as best method in regard to results. They all have in common that the human body has to adapt the surrounding conditions while the inspection itself stays mainly the same. Fatigue and MDT related injuries are not unusual. In this respect, reference can be made to the above statements accordingly.

10. Conclusion

Each area of work at NDT is special and has its own characteristics and particular risks. What they all have in common, however, is that in one way or another and depending on the technology used, there are risks to the human body.

Any NDT testing may cause injuries, but MSD risks cannot be completely eliminated. In this respect, ergonomics should not be seen as a panacea, but rather as an ongoing process to optimize processes to reduce dangers and stress on the body of a NDT-inspector. Ergonomics requires constant review and adjustment as work processes and technologies used change and new medical knowledge is gained based on new studies. Finally, we should not ignore the fact that, outside of mandatory statutory regulations, ergonomics is largely always subject to a business cost-benefit assessment. Be it in the context of assessing consequential risks due to injuries or in the pursuit of ways to optimize work processes and their outcomes.

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