Automatic Wheel Inspection Using Building Blocks

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Abstract. Light-alloy wheels must be inspected 100%. High throughput and a low false-reject rate are thus the major prerequisites for automatic X-ray inspection systems. Due to the widespread variety of wheel designs and ever-increasing size of new wheel types, improvements on automatic inspection systems must be made regularly. To reduce costs and safeguard assembly, a building-block concept is being applied in mechanical construction as well as in software design that provides flexible solutions.

In contrast to traditional systems, the latest generation of automatic wheel inspection systems increases throughput by using the latest digital camera technology offering maximum image-frame rates above 60 frames per second, which is also important for superior live image display. Wheels are moreover tested and identified on a parallel basis. These systems therefore also benefit directly from faster positioning times for the manipulator system. The manipulator itself has additionally become much more robust and system downtime is minimal because of the built-in, high-end components and a user-friendly maintenance concept. Last of all, several significant improvements have been implemented to decrease the false-reject rate to a minimum. For instance, new algorithms for image registration (position correction) and image filters that determine the exact defect size are being applied. The intensity resolution of digital images and precision of positioning have been increased on the hardware side, too.

In this article we are going to show how the latest generation of wheel inspection systems makes use of hardware and software building blocks to constantly take advantage of recent improvements in hardware and software technology.

Introduction

Fully automated X-ray inspection systems for the latest generation of non-destructive testing (NDT) have been developed to fulfill the manifold requirements of today's modern casting industry. One-hundred percent inspection has become the standard, especially for light alloy wheels in the automotive industry.

Both hardware and software building blocks toward realizing the basics of an automatic wheel inspection system are being explained in the following section. Additional optional building blocks and special functional extensions will lead to a flexible and user-friendly automatic defect recognition (ADR) system that has been configured to provide exactly the required functionality for actual wheel inspection tasks. This kind of flexibility moreover allows the ADR system to keep up with new requirements via minimal investments in the future.

1. Building Blocks

1.1 Hardware Building Blocks

An automatic wheel inspection system is normally designed as a high-throughput system, i.e. the wheels to be inspected are conveyed automatically through the inspection system. Depending on the individual foundry and end customer, there are different conditions in terms of how many wheels should be tested and in which ways. Moreover, the space for such an inspection system may be limited. All of these reasons make a flexible hardware layout necessary. We are therefore going to introduce a component system, i.e. the building blocks of typical wheel inspection systems, which can be combined with a specially customized solution to cope exactly with the actual requirements of a particular casting foundry. We shall discuss examples of hardware building blocks for a basic wheel inspection system and for a fully equipped system in the following.

All wheels to be inspected must be positioned within the system. There are different methods for positioning to choose from, e.g. wheels could be positioned using a so-called roller-chain manipulator, or even with a so-called bevel wheel manipulator. The positioning assembly using a roller-chain manipulator is the standard for the basic and the full system. There the wheels are rotated and moved through two chains clamping the wheel. By contrast, the bevel wheel manipulator uses four bevel wheels for holding and positioning the wheel to be inspected.

As a result of the X-ray radiation involved, a wheel inspection system requires a special housing that is shielded against radiation. A standard-size radiation-shielded cabinet for inspecting wheels up to a diameter of 20” can be enhanced via radiation-shielded entrances and exits to increase throughput. For larger-sized wheels, an extra-large radiation-shielded cabinet is available that can also be combined with radiation-shielded entrances and exits. These kinds of entrance and exit baffles are not available for the basic minimum system. The radiation-shielded cabinet is mandatory for both the minimum and the full system, at least in the standard size.

Another important area of components is covered by building blocks related to the imaging system. Here an X-ray system is essentially needed. An X-ray tube with 160kV tube voltage and 1000W tube power is standard for the inspection of light alloy wheels. A minimally equipped system will use an industrial-grade image intensifier with an input field diameter of 9 inches, whereas an image intensifier with a 12-inch diameter is usually used in a fully equipped system to depict the wheel using fewer images than is the case with the 9-inch image intensifier. The industrial image intensifier uses either an analog or digital camera to capture and display the “live” X-ray image on a monitor. A high frame rate greater than 50 fps is necessary for visual inspection, whereas a higher geometrical resolution is used for the recognition of very small defects. Moreover, with 12 bits or 10 bits respectively, the intensity resolution of digital cameras is higher than the 8 bits converted by the analog camera. Both the basic and full systems are thus usually equipped with the fast digital camera with a frame rate of 60 fps, an intensity resolution of 10 bits, and a geometrical resolution of 640 x 480 pixel.

Although wheel inspection is performed automatically, the need still exists to control the settings and the inspection process itself interactively. Each wheel inspection system is therefore equipped with a control desk consisting of an operating console and one monitor. The control desk can be optionally enlarged by adding extension trays and upgraded by adding a second or even a third monitor. A fully equipped system usually contains a control desk with additional extension trays and two monitors.

The hardware building blocks mentioned above are listed in Table 1. The building blocks are listed in the first column. The second column lists the mandatory '✓', the impracticable '–' or even optional building blocks within a basic, minimum system, while building blocks for a fully equipped system are marked in the third column.

Table 1. Hardware building blocks of a wheel inspection system and the equipping level.

Positioning System		
Building block	**Minimum**	**Full**
Roller-chain manipulator	✓	✓
Bevel wheel manipulator	–[1]	–[1]
Housing		
Building block	**Minimum**	**Full**
Radiation-shielded cabinet – standard	✓	✓
Radiation-shielded cabinet – extra-large	–[1]	–[1]
Radiation-shielded entrance and exit baffles	–	✓
Imaging System		
Building block	**Minimum**	**Full**
X-ray system, 160kV, 1000W	✓	✓
Image intensifier 9"	✓	–[1]
Image intensifier 12"	–[1]	✓
Analog camera, PAL/CCIR 768x572, 8bit	–[1]	–[1]
Digital camera, 2/3" CCD, 1004x1004, 30fps, 12bit	–[1]	–[1]
Digital camera, ½" CCD, 640x480, 60fps, 10bit	✓	✓
Control Desk		
Building block	**Minimum**	**Full**
Operating console with monitor	✓	✓
Extension trays for the console	–[1]	✓
2nd monitor	–[1]	✓
3rd monitor	–	–[1]

✓ mandatory, – impracticable, –[1]optional

1.2 Software Building Blocks

In the following we are going to focus on the software part of X-ray inspection systems, including ADR systems [1], and especially on the software building blocks of a wheel inspection system.

X-ray inspection systems for wheel inspection differ regarding their modes of operation (e.g. manual, semi-automated or fully automated) and the number of different pre-processing and post-processing steps involved.

The *manual mode* is the underlying operational mode for testing wheels. The software only performs tasks passively in the manual mode. On the one hand these involve tasks to control machinery, e.g. setting the right voltage and current or positioning the wheel. The other hand revolves around tasks toward displaying acquired X-ray images. In order to display X-ray images in superior quality, image enhancement algorithms can be used to ensure optimal defect recognition by the human operator. The operator makes the final decision and is responsible for final classification of the wheel. Usually the operator just makes a good/bad decision, but different decision levels are conceivable. The test results may then be stored, as well as the display parameters. After that the operator has to induce unloading of the tested wheel depending on its test result.

In the so-called *semi-automated mode*, general control tasks for machinery are shifted to the ADR software system, but the human operator still makes the final test decision. The ADR software merely provides decision support by highlighting potential defects in the X-ray image. Parameters to control machinery are thus teachable, e.g. during online testing the learned parameters concerning voltage and current and the dedicated position can be recalled to capture an X-ray image automatically. It is therefore possible to test wheels from low to high-volume production lines consistently using the same view. An X-ray image analysis is performed additionally in order to recognize potential defects automatically and highlight those defects in the displayed X-ray image. With the aid of such highlighted defects in the X-ray image, the human operator's attention is turned to critical positions that represent potential defects. Yet the operator still remains responsible for classification of any defects found, and must induce unloading of the tested wheel in an adequate way, i.e. in the simplest case, the operator must make a good/bad decision.

The *automated mode* means that both the control of machinery and the test decision are made by the ADR software on a fully automated basis. The loading and unloading of wheels to be inspected is furthermore done fully automatically during the batch-testing process. Recognized defects in wheels are classified via a given test specification. The test results of the automatic defect recognition step are usually compiled in a statistic. The possibility also exists to review the test process or to compare the test result with reference results from a previous test, e.g. for auditing purposes, although an inspection program has to be trained to learn all needed parameters for controlling machinery and performing defect recognition automatically in the course of a setup phase. If several different wheels are to be tested within the same ADR system, part-type recognition for wheels is needed. Furthermore, a hardware guard must verify that the general image quality is still applicable for the testing process, e.g. when intensity of the X-ray beam varies or there has been an error during image acquisition. To be avoided no matter what the case is that the X-ray image analysis becomes 'blind'.

The necessary tasks toward enacting the three different operational modes explained above are listed in Table 2 under the headings *Hardware Control* and *Image Processing*. A specialized software building block is being listed as an example in the section *Special Image Processing* (Table 2). For instance, if the real type (e.g. gas hole, shrinkage etc.) of a recognized defect is supposed to be specified, then a detailed classification method must be used in addition to standard classification.

X-ray inspection systems also differ due to the manifold requirements of casting foundries and their special mechanical environment before and after actual X-ray image analysis in the radiation-shielded cabinet. As examples we are going to introduce optional scenarios, each of which can be handled by a certain software building block (see Table 2, section *Additional Pre- and Post-Processing*).

Molds for the same type of wheels may differ in their construction, e.g. due to optimization of the casting process. Mold recognition may thus be necessary in order to adapt selected parameters of X-ray image analysis automatically.

In the case of a detailed classification of defect type, it would make sense to sort the tested wheels coming out by their type class. Moreover, a detailed classification of defect type makes it possible to conclude the cause of the defect directly from the type class. The latest generation of automated X-ray wheel inspection systems will also detect anomalies that lie below a certain test specification. Process feedback of the test results to the casting process would thus enable the caster to initiate countermeasures, even before the size of detected anomalies exceeds the test specifications for the cast wheel. That saves resources and leads to a minimum rate of rejects.

Similar to Table 1, the mandatory tasks or building blocks for each mode (manual, semi-automated, automated) are marked with a '✓' in Table 2; impossible or optional tasks are respectively marked with a '–'. It is therefore possible to configure several different X-ray inspection systems by combining certain software building blocks that are not restricted to a wheel application [1]. In combination with the hardware building blocks mentioned above, a completely customized and extendable automated wheel inspection system is obtained that constantly takes advantage of recent improvements in hardware and software technology.

Table 2. Tasks (software building blocks) and modes of operation of wheel inspection system.

Hardware Control			
Task	**Manual**	**Semi-automated**	**Automated**
Load / unload wheels – interactively	✓	✓	–[1]
Load / unload wheels – automatically	–[1]	–[1]	✓
Control of X-ray tube – interactively	✓	✓	✓
Control of X-ray tube – teachable	–	✓	✓
Control of manipulator – interactively	✓	✓	✓
Control of manipulator – teachable	–	✓	✓
Setup imaging device	✓	✓	✓
Image Processing			
Task	**Manual**	**Semi-automated**	**Automated**
Image display	✓	✓	✓
Automatic image acquisition	–	✓	✓
Image enhancement	✓	✓	✓
X-ray image analysis – defect recognition	–	✓	✓
Load / save parameters	✓	✓	✓
Load / save test results	✓	✓	✓
Definition of test specification	–	–[1]	✓
Classification by test specification	–	–[1]	✓
Statistic of test results	–	–[1]	✓
Process review	–	–[1]	✓
Part-type recognition for wheels	–	–[1]	✓
Hardware guard	–	–[1]	✓
Special Image Processing			
Task	**Manual**	**Semi-automated**	**Automated**
Detailed type classification of defects	–	–[1]	–[1]
Additional Pre- and Post-Processing			
Task	**Manual**	**Semi-automated**	**Automated**
Mold recognition	–	–[1]	–[1]
Part sorter	–	–[1]	–[1]
Feedback to casting process	–	–	–[1]

✓ mandatory, – impossible, –[1]optional

2. Results

The latest generation of automatic wheel inspection systems can be configured through a combination of hardware and software building blocks. An example of a fully equipped system is given in Figure 1, including a roller-chain manipulator and a control desk with two monitors as shown in Table 1. For wheels with diameters greater than 20”, an extra-large radiation-shielded cabinet is used to handle a wider range of wheel types (see Figure 2). By comparison, Figure 2 shows two housing variations. The standard-size radiation-shielded cabinet with additional entrance and exit baffles is depicted on the left, the extra-large radiation-shielded cabinet, also with entrance and exit baffles, is being shown on the right.

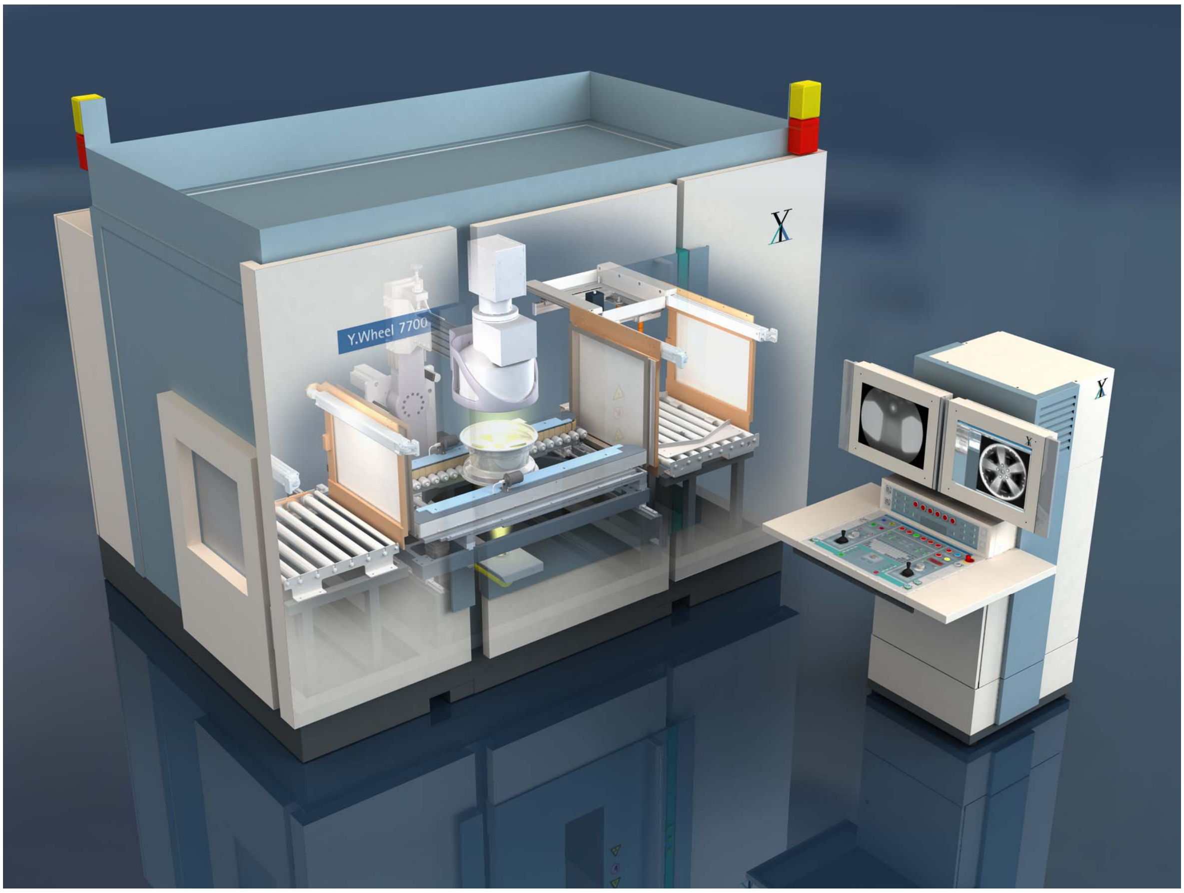

Figure 1. Example of full system, YXLON Y.Wheel 7700.

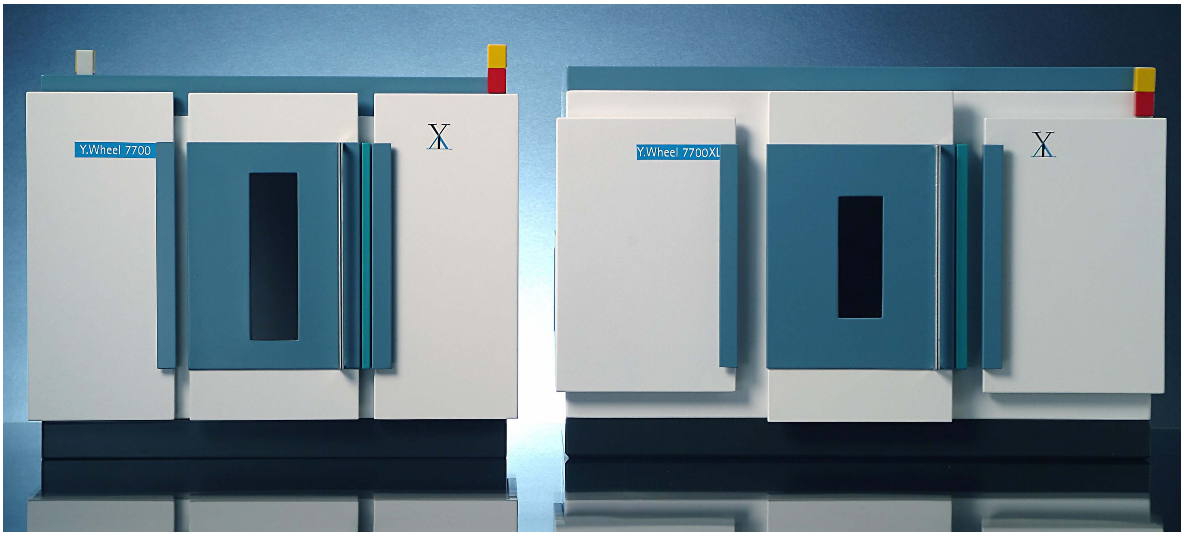

Figure 2. Examples of different X-ray cabinets, Y.Wheel 7700 and Y.Wheel 7700XL.

In Figure 3, three control desks are being depicted as examples that differ in the number of monitors and the kind of optional extension trays used, illustrating different combinations of hardware building blocks. As can be seen in Figures 1 and 3, the wheel inspection software shown on the monitor screens is integrated into the look and feel of particular hardware building blocks. Yet the tasks necessary for wheel inspection are manifold, too. Depending on the software building blocks chosen, the separate views are generated dynamically depending on the current context. Figure 4 shows a view for testing the standard classification. The view is split into navigation in the left-hand column, the resulting image in the right-hand column, and detailed information about defects in between.

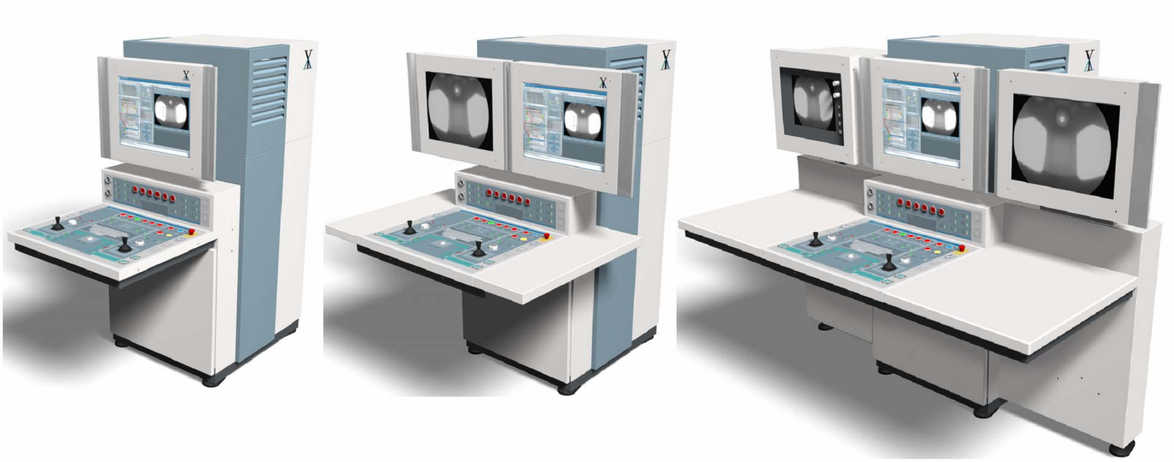

Figure 3. Examples of different YXLON operator consoles.

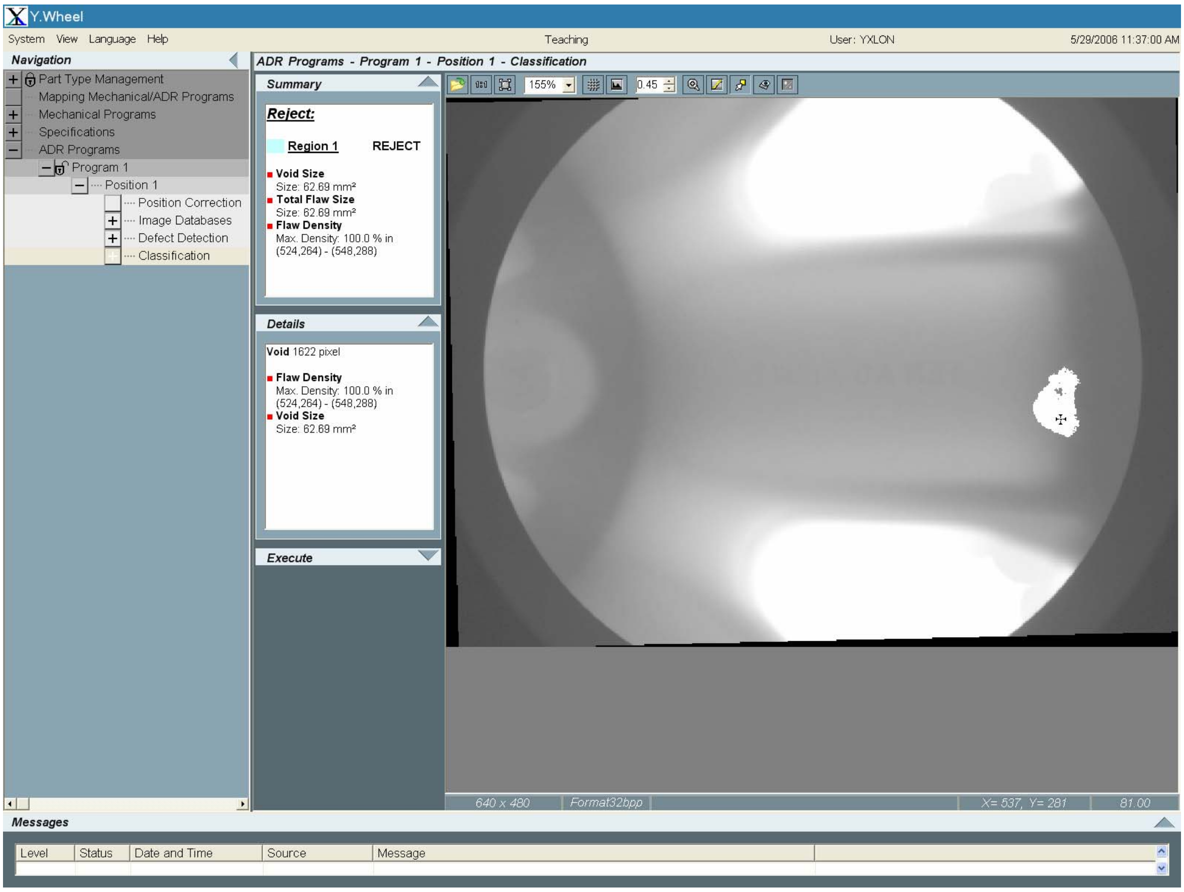

Figure 4. Use of software building blocks: dynamically generated view for testing the classification.

3. Conclusion

A full-scale and individualized automatic wheel inspection system of the latest generation can be configured with the support of hardware and software building blocks. A well-configured wheel inspection system like this can be expanded further to provide exactly the functionality required. Moreover, this flexibility also makes it possible to satisfy future requirements by extending the basic building blocks to include an added or even new functionality. Flexible configuration of the existing ADR system is useful for these kinds of purposes, besides increasing uptime and saving costs.
When upgrading a building block in an existing system, the operator will furthermore be able to gain from the experiences made. Thus, only the additional operational modes or system features require training, yet without starting from scratch. This can be seen in Table 1 and Table 2 because the building blocks build on top of each other.
The use of standard building blocks, both in hardware and software, ensures a high operational availability of the entire system while safeguarding the initial investment at the same time.

References

[1] F. Herold, S. Frantz, K. Bavendiek, R.-R. Grigat, “Building Blocks of a third generation Automatic Defect Recognition system”, 9th European Conference on NDT, September 25-29, 2006, Berlin, Germany.