Automatic Scanning System for Non-destructive Testing of Vertical and Bottom Surfaces

Marcus SCHUBERT, Markus STOPPEL*, Herbert WIGGENHAUSER
BAM, Federal Institute for Materials Research and Testing, Division 8.2: Non-destructive Damage Assessment and Environmental Measurement Methods, Unter den Eichen 87, 12205 Berlin, Germany
Phone: +49 30 8104 4262, Fax: +49 30 8104 1447; e-mail: marcus.schubert@bam.de, herbert.wiggenhauser@bam.de

Abstract
Non-destructive investigations of vertical and bottom surfaces as cooling towers, dam walls or undersides of bridges is very demanding with regard to accessibility and safety aspects.
An automated scanner for free motion on concrete surfaces has been developed. The system is based on a six-feet-vacuum construction. Respectively three feet are grouped together – linked by a solid metal connection. These two groups are slidable to each other. In addition, each foot can be individually attached to the surface and establish a separate vacuum. By displacing, attaching and removing the two groups, the scanner can vary its position (in steps of about 5 cm). The resulting movement speed is slow. The scanner is used as a carrier of one or more non-destructive testing (NDT) methods. Due to the low speed, especially contacting methods such as ultrasonic echo or impact-echo are suitable.

Keywords: NDT scanner, carrier system, automation, free motion, remote control, laser tracking

1. Introduction
Detailed non-destructive testing (NDT) with dense measurement grid of a few centimeters on large or elongated structures, e.g. bridges or dams, is practically hard to perform manually. The use of scanner systems or robots and the integration of different NDT methods allow an economic investigation of these areas and improve the reliability of the measurement results. In recent years, especially for horizontal investigations (park or bridge decks) several automation systems were developed ([1], [2], [3]).

In contrast, vertical or hanging testing issues for example wind turbines, cooling towers, box girders or bridge ceilings are much more complex and very demanding due to challenging accessibility and high safety requirements (Figure 1). Such investigations are...
typically carried out manually or semi-automated using a dual-axis scanner system, which is attached using vacuum suction feet to the surface and is moved to the next test position manually after measurement completion ([4], [5], [6]). In studies of narrow, elongated structures\(^3\), e.g. for evaluation of grouting conditions inside post-tensioned tendon ducts, the overhead is very high due to the displacement effort and the needed accessibility associated with it. As a further development of the BAM scanner concept - NDT carrier system with vacuum suction feet for surface attachment - a free motion automated system was designed and realized as a prototype.

In this contribution, the functional requirements for an automatic scanning system for NDT of vertical and bottom surfaces are presented. Based on this characterization, the system features and the automation concept of the developed scanner are described in detail. The integration of NDT methods into the scanning system is included into the discussion in chapter 3.

2. System design

The functional features for the climbing robot were defined as follows:

- climbing on vertical or bottom surfaces (fair-faced concrete) in free motion
- investigation of narrow, elongated structures with a path width of about 50 cm (straight forward or curved)
- carrier of one or more NDT methods (especially contacting methods like ultrasonic echo or impact-echo)
- simultaneous position recording
- power supply and fall protection through an umbilical cable
- light weight
- remote control of all scanner movements and NDT settings
- graphic user interface (GUI) to configure scanner / NDT settings

2.1 Framework

The current BAM scanner concept is based on a frame construction that can be attached with four suction feet on the surface (Figure 2). The distance to the measurement area is manually adjustable. A freely movable axis positions the NDT method within the framework in any desired pattern (usually in a meandering pattern). In the case of using a contacting method, the sensor is pressed to the surface in pre-defined point intervals via a pneumatic unit.

The movement concept of the new scanner copies the standard measurement procedure with the BAM scanner (attach the system to the object, perform the measurement(s), detach the system, displace system to the next measuring field). In order to eliminate the manual relocation of the frame, we have designed a dual-frame structure consisting of two BAM scanner frames, which are interconnected by a sliding unit (Figure 3(a)).

\(^3\)path width between 20 - 40 cm and a path length of several meters (> 4 m)
A major goal of the system development is the lowest possible weight to facilitate the subsequent handling and to reduce the necessary holding force. For this reason, we have reduced the foot number to three feet per frame. In addition, the design has been adapted to a desired measurement width\(^4\) of about 45 cm and a length of about 90 cm. The single-frame connections have been replaced by a more massive carrier construction. This structure serves also as a mounting platform for the control unit and for the NDT method(s). The design is shown in Figure 3(b). As framework material has been used aluminum primarily.

2.2 Movement concept

The new scanner system is based on the BAM suction-foot-construction (Figure 2). Three feet are grouped together. These two groups are slidable against each other. In addition, each foot can be individually attached to the surface via a pneumatic cylinder and establish a separate vacuum\(^5\). By displacing, attaching and removing the two groups, the scanner can vary its position (Figure 4). The sliding unit integrates two pneumatic cylinders to shift the groups in X- and Y-direction. The shift distance (step width) is hardcoded, but can be changed manually (maximal about 5 cm).

\(^4\)The scanner should be able to carry the ultrasonic tomograph A1040 MIRA of Acoustic Control Systems. For more details refer to www.acsys.ru/eng/.

\(^5\)A digital controllable vacuum generator creates by means of compressed air a vacuum.
In order to make slight positional correction, the groups are rotatable in a small range (± 2.5°). This make it possible to adjust the scanner alignment to slightly curved paths.

The movement concept with its multistage motion sequences and in particular the vacuum generation make the system slow. Initial tests yielded a speed of approximately 5 mm/s or 300 mm/min. Moreover, it has been shown that defective surfaces (e.g., cracks) or joints prevent the vacuum generation and thus make the locomotion impossible. The development of a more robust suction foot design, for example by using a multi-chamber design for the suction cups or by using multiple suction cups per foot, is desirable. A climbing robot for inspecting aircraft components is introduced in [7]. Its movement concept is similar to the presented motion design (two groups relocatable to each other). The holding concept bases on twelve feet. Each of them has four suction cups.

The BAM prototype for NDT of vertical and bottom surfaces (called "Crawler") is shown in Figure 5. The scanner characteristics are summarized at the end of this section in Table 1.

Figure 5. Scanner system "Crawler". (a) construction plan with group arrangement. (b) vertical test at BAM NDT-hall with ultrasonic transducer.
2.3 Local and remote control

The new scanner integrates only the most essential control components, in order to save weight. All electrical assemblies (microcontroller, cylinder and vacuum control, communication system, motor control for group alignment, user interface with a display and five buttons) are situated centrally in an housing above the sliding unit (refer to Figure 5). Because of the inaccessibility during a measurement, the scanner is controlled remotely by an external personal computer. In order to simplify the control, some basic procedures are stored in the microcontroller (e.g. move a step upwards) and might be executed on demand by transmitting a command to the scanner. The communication can be established via a wired or wireless connection.

The entire measurement planning and control is implemented in software.

2.4 Position evaluation

A spatially accurate data recording is a prerequisite for data processing methods like the Synthetic Aperture Focusing Technique (SAFT) and for a proper imaging [8]. Positioning systems can be divided in active and passive recording techniques. In the case of the active variants, the scanner determines its current position based on the evaluation of one or more on-board sensors. These include for example the utilization of local wheel encoders [9] or the Global Positioning System (GPS) [2] as well as the position calibration on the basis of reference objects by a laser distance measurement system [1]. The passive variants need only reference markings / elements. An external device ascertain the position via these objects. Photogrammetry or the position tracking with a total station belong to the passive methods.

The total station has been chosen as position evaluation system, because a high accuracy and a lowest possible scanner weight should be achieved. Moreover, the system already

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Footnote: system design tool of National Instruments (include basic interfaces, visualization and control elements for a GUI).
provides coordinate information and can be triggered simultaneously with the measurement. With the help of the automatic prism tracking, the position determination can be done without further user input at any time.

The following listing outlines some total station features (Leica TPS1200+):

- internal motors enable automatic horizontal and vertical turning
- automatic prism search, Automatic Target Recognition (ATR) and prism tracking
- remote control via communication protocol called GeoCOM
- wired or wireless\(^7\) connection between measurement computer and total station

Figure 6 illustrates the total station and the remote control software.

### Table 1. Characteristics of the scanner system "Crawler"

<table>
<thead>
<tr>
<th>scanner control system</th>
<th>microcontroller with several standard interfaces like LCD-port and Inter-Integrated Circuit (IIC)-interface; electrical assemblies for scanner subsystems (e.g. pneumatics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>propulsion system</td>
<td>two groups with three feet linked together; groups slidable by two orthogonal mounted pneumatic cylinders; separate vacuum for each foot</td>
</tr>
<tr>
<td>group alignment</td>
<td>± 2.5° (adjustable by motor)</td>
</tr>
<tr>
<td>step size</td>
<td>max. 50 mm (hardcoded, but manually adjustable)</td>
</tr>
<tr>
<td>speed</td>
<td>slow (5 mm/s or 300 mm/min)</td>
</tr>
<tr>
<td>position evaluation</td>
<td>Leica TPS1200+, Leica RX1250 (external) and 360° surveying prism (mounted on scanner); remote control via GeoCOM commands</td>
</tr>
<tr>
<td>communication system</td>
<td>WLAN communication with a proprietary protocol (command based); additional WLAN router to increase remote distance</td>
</tr>
<tr>
<td>user control system</td>
<td>software for scanner remote control (LabVIEW program) for motion control, position evaluation, NDT configuration</td>
</tr>
<tr>
<td>supply system (external)</td>
<td>12 and 24 Volts</td>
</tr>
<tr>
<td>framework, housing</td>
<td>maximal 7 bar</td>
</tr>
<tr>
<td>outer dimensions</td>
<td>900 x 450 x 550 mm (L x W x H)</td>
</tr>
<tr>
<td>NDT assembly area (max.)</td>
<td>450 x 140 x 150 mm (L x W x H)</td>
</tr>
<tr>
<td>weight (without load)</td>
<td>20 kg</td>
</tr>
</tbody>
</table>

\(^7\)The remote control handle Leica RH1200 and the handheld device Leica RX1200 are needed to establish a wireless connection.
3. NDT methods and their requirements

A single NDT method typically is not sufficient to meet the testing requirements, which cover different areas, such as material and structural properties. Measuring geometrical properties require other test methods than e.g. the evaluation of the grouting condition inside a tendon duct [4]. The use of as many methods as possible is not target-aimed due to the weight requirements of the scanner and the limited assembly area. The examiner should be aware of what kind of NDT is the proper method for the investigation.

Commercial handheld devices are ideal for scanner applications, because they have light weight and a compact design as well as a proven reliability. To integrate the devices in the system the automation of the measuring method and opened interfaces in the handhelds have to be assured. Most handheld devices are designed for manual measurements and therefore do not provide a corresponding automation and remote control interface. Using commercial sensor in combination with suitable data acquisition systems is a feasible approach to integrate a NDT method in a compact way. In addition, the connection and the interface between the NDT and the controller / software can be freely selected, thus enabling an easier system integration.

4. Conclusion

A prototype of an automatic scanning system for NDT of vertical and bottom surfaces has been developed. Initial tests at BAM NDT-hall proved the design in terms of stability. The total weight of about 20 kg may be reduced in order to facilitate the handling and to diminish the strain on the suction cups. Moreover, the test has shown that the suction feet could no longer build the necessary vacuum in poor surface condition. A redesign is desirable. The movement concept with the alternating group displacing and attaching was successfully tested. The resulting movement speed is slow. Especially contacting method such as ultrasonic echo or impact-echo are suitable. Commercial equipment can rarely be integrated into the scanner due to the lack of remote control interfaces. The application of commercial sensors with a suitable data acquisition system would be sensible, since this would provide better integration possibilities. The position determination by means of a total station could be realized completely remotely. The automatic prism tracking enables a coordinate capture at any time. The control of the scanner and the total station is implemented in two separated software applications. An integration into a complete program is still pending.

Acknowledgements

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References