Robotised UT Transmission NDT of Composite Complex Shaped Parts

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Abstract. Due to increasingly strict quality standards in all industrial sectors for both production and maintenance, non-destructive testing must be used along with C-scan mapping. The flaws detected can then be monitored throughout the service life of the device or component. Automated testing is more efficient and reliable, and it considerably boosts productivity, thus keeping our industries competitive. Automated gantry systems can fulfill the automation requirements in a number of applications. Six-axis industrial robots can be used for automated inspection of complex-shaped parts, as long as you take the constraints that are specific to non-destructive testing (NDT) into account, e.g. C-scan mapping accuracy or inspection programming.

Introduction

Many automated NDT systems, whether based on ultrasound or on eddy currents, use automated gantry systems. These usually consist of two or three linear axes (X, Y and Z), to which may be added rotary axes (rotary table, probe orientation).

The use of these systems to inspect parts with noncomplex shapes (planes, cylinders or cones) and no adaptive arts (rotational, helical, etc.) is widespread. These systems usually consist of specific machines or machines which are used uniquely to inspect identically shaped and/or sized parts.

Whatever the NDT method used, the quality of C-scan mapping depends on signal acquisition and the position of the probe(s) when the signal is captured. Most automated gantry systems are equipped with stepper motors or programmers that give the signal position in quasi real time, so that their performance in terms of accuracy, resolution and inspection rate complies with manufacturer requirements. They have limited flexibility, however, in terms of use and adaptability to parts with complex shapes.
Six-axis industrial robots

To simplify inspection operations on complex adaptive parts, you need to add a 6-axis industrial robot. Unlike with an automated gantry system, however, it is not possible to identify probe position in real time when using a 6-axis industrial robot. Standard robots give their position only every 2 to 8 (or more) milliseconds, so data concerning the probe’s true position can only be captured at frequency rates from 100 to 500 hertz.

By interpolating, it is possible to create virtual positions in between the known positions. The interpolation algorithms are relatively easy to develop and set up, but there is a major inconvenience with the solution in that two conditions must be fulfilled:

- The signal acquisition frequency must be constant;
- The robot’s probe speed must be constant.

The acquisition frequency can be controlled quite well on most systems. The probe speed can be considered as constant in only two cases:

- Outside the acceleration and deceleration phases (at the start and end of the C-scan acquisition lines). The scanning area must therefore be extended beyond the zone that needs to be inspected;
- In the zones where the changes in direction are not too extreme. However, by their very nature, complex-geometry parts have zones that require significant changes in path direction.

Profile Contrôles Industriels used these findings to launch development of a system to correct these problems and improve inspection quality.

Sysaxe® – Robotics and nondestructive testing

Together with robot manufacturer Adept, Profile Contrôles Industriels tackled the issue of high-speed transmission of robot positioning data, the objective being to achieve data acquisition frequencies compatible with non-destructive testing (NDT) requirements. The system also had to be operable and programmable by an operator with little or no experience in robotics, and it needed to be compatible with any ultrasound or eddy-current inspection device equipped with at least two TTL encoder inputs.
**Interfacing with the NDT device**

A three-stage solution was chosen:

1 – Retrieval of axis position data: the angular positions of each of the robot’s six axes are needed for accurate following of the programmed paths. These positions are known to the robot’s motion controller station. Profile Contrôles worked with Adept to develop and implement the motion controller station, which is a software module that captures the axis position data at a frequency rate of 8 KHz. The positions are then sent in numerical form at the same frequency to a programmable electronic device for processing by group of three axes.

2 – Conversion into Cartesian coordinates: the axis data in numerical form are converted into Cartesian coordinates using the inverse kinematic model for the robot used. These coordinates are available in different reference systems (machine, NDT cell, part) and in different forms (X-Y-Z or X-Y-Z-Ø1- Ø2- Ø3), curvilinear abscissa (X’-Y’), or a combination of both (X’-Y’-X-Y-Z-Ø). Then they are sent to the testing system in the form of TTL signals (incremental encoders). A curvilinear abscissa is not equivalent to a coordinate along an axis (X, Y or Z), but rather to a path travelled in the scanning direction (X’) or the scanning step orientation (Y’). Acquisitions with curvilinear abscissa allow:

- Spatial position data acquisition with a device that has only two encoder inputs,
- Real-time C-scan imaging using curvilinear abscissa instead of projection onto the scanning/step plane.

3 – Transmission of coordinates in TTL format (incremental encoders): the electronic device converts the numerical data into TTL signals (incremental encoders) that can be used directly by most NDT systems.

Profile Contrôles Industriels has patented this technology.

**The technology’s advantages**

The technology enables real-position acquisition (see fig.2), with all the associated advantages:

- C-scan mapping accuracy,
- No hysteresis phenomenon,
- Acquisition during acceleration/deceleration phases,
- Accepting acceleration in case of path change during contour following,
- Depending on the utilized UT device, possibility to return to a specific point.
Robots Calibrating

The Cartesian coordinates are deduced from the robot’s axis positions using its inverse kinematic model. These are theoretical positions linked to the accuracy of the inverse model. The robot’s manufacturing tolerances can lead to millimeter-scale positional errors, which is not acceptable in the present applications.

To eliminate any chance of positioning error, you have to calibrate the robot precisely using a laser system.

Path definition

In the simplest cases, paths are defined based on elementary surfaces such as right-or left-handed rectangles, cylinders, cones, etc., that can be concatenated to obtain the surface to be scanned (see fig.3).
In the case of parts with more complex shapes, the paths are defined based on CAD files obtained in various ways and using robotic simulation software that is adapted to NDT applications.

1.1 Simulation

The path definition process was simplified by integrating robotic simulation software that was developed by Applied Computing Engineering (ACE). All three companies – Profile, Adept and ACE – worked together to develop the NDT functions. The NDT laboratories of a number of large industrial groups also participated.

Besides the design of the NDT cell and the optimum position of the robot(s), three other objectives of the simulation process were to:

- define the scanning paths,
- verify that the robot does not collide with the part or the NDT cell,
- verify that there are no singular or inaccessible robot positions.

1.2 Trying out the paths

A teach-and-learn mode is used to inspect parts that are not very complex but which are non-adaptive and cannot be broken down into elementary surfaces.

The operator uses a joystick to record a number of carefully chosen points on the surface. The file containing these points is exported to CAD format and transferred to the robotic simulation software and processed in the same way as CAD manufacturing files or 3D scan files (see next).

1.3 CAD manufacturing files

For production controls, the CAD data required for manufacturing the part are often available. The simulation software can use these data directly, as long as the proper format is selected (Catia, Step, Iges, etc.).
The operator imports the file, positions the part in the defined NDT cell, enters the scanning parameters, e.g. path-following accuracy or the scanning step, verifies inspection feasibility in terms of accessibility, singular zones, etc., then validates the parameters (see fig.4).

![Fig. 4: Screen view of Robotic simulation](image)

This stage considerably reduces the risks of collision during inspections.

As soon as feasible and satisfactory paths have been achieved, the system creates a file that is transmitted to the robot control, which is on standby for the inspection.

### 1.4 3D retro-designing

When inspecting parts with complex but unknown contours (for maintenance, non-CAD-manufactured parts, etc.), the operator has no data available for a simulation or for path definition.

The proposed solution is to 3D-scan the contour to be inspected. Here, a Konica Minolta VI-910 laser scanner was used for the tests. For a surface roughly of a square meter, it only takes a few seconds to generate the images.

For larger surfaces, the scanning is done in multiple images. The software assembles these automatically to obtain a scatter diagram that can be transformed, exported to CAD format, and transferred to the simulation software (see fig.5).

![Fig. 5: Scatter plot obtained with a Laser scanning](image)

The operator is in much the same situation as if he had the original data at his disposal, but he also has the exact contour of the part to be inspected.
1.5 Zero shifting

Sometimes accurate positioning or repositioning of parts is not possible – with composite parts, for example. In this case, a zero shift is necessary for the part and/or the scan path origins.

This is done using the coordinates of three points on the part to be inspected. The operator uses the joystick to position the robot on the three reference points. Once these three positions have been validated, the origins are automatically shifted back to zero. If the parts to be inspected are of different shapes, the zero shifting can be achieved by doing a cursory ultrasonic “pre-scan” to define the part surface (by measuring the height of the water column) and determine the new paths.

However, the use of zero shift corrections for either position or shape should not be abused, in order to avoid placing the robot and the movements associated with it in singular zones (see fig.6).

![Fig. 6: C-scan in amplitude obtained with the Sysaxe® Single 850 work cell](image)

1.6 Inspection by pulse-echo ultrasound or by eddy currents

The probes are mounted on the end of the robot arm.

Several different ultrasonic techniques can be applied:

- Contact: in this case, the probe is mounted on a base equipped with a water coupling feed (and possibly suction) system;
- Local immersion: coupling is carried out by a micro-nozzle that travels over the surface of the part being inspected at a constant distance and tilt with respect to the surface.
- Total immersion: the part is immersed in a tank and the probe is moved with a constant water column height.

The robot’s level of protection against humidity varies as a function of the technique used (protection against water spraying or immersion). These systems are equipped with a single six-axis industrial robot.
Ultrasonic transmission NDT, synchronizing two robots

There are several techniques for automated ultrasonic transmission inspection. The simplest involves a fork with a squirter at the end of each branch.

Since there is only one movement to be managed, only one robot is required. This method is suitable for simple-geometry parts (flat or rotational), but not for complex geometries. For such parts, you have to use two robots that travel opposite each other. The axes of the ultrasonic beams on the transmitter and receiver probes must be secant and coaxial.

The tolerable error for positioning, depending on the size of the robots used, is at the millimetre scale, and the coaxial tolerance should not exceed a few degrees. We made use of the possibilities of Sysaxe® technology for fast robot position data acquisition, among other things, to achieve synchronization in conformity with the above-described requirements (see fig.7).

Fig. 7: Sysaxe® Dual 850 – Synchronized Twin robots NDT work cell
With the courtesy of Fraunhofer IZFP of Saarbrücken

External axes

It is possible to add one or more external axes to increase the system’s capacity, whether the system has a single robot or two robots:

- For rotational parts (cylindrical, elliptical, ovoid, etc.), a rotary table is added;
- For extra-long parts, a linear axis is added.

These systems are programmed and controlled in the same way as for single robots. This type of robotized system and its variants have applications in various industrial sectors:

- Aviation (composite or metal components),
- Sheet metal work and welds inspections in the nuclear, chemical and petrochemical industries,
- Shipbuilding,
- Iron and steel industry (ironworks, casting, etc.).