AUTOMATIC MEASUREMENTS WITH FLEXIBLE PROGRAMMABLE X-RAY IMAGE EVALUATION ROUTINES (Xe²)

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Abstract
The diversity of applications in industrial X-ray inspection requires for automatic measurements a flexible image processing tool. This tool is realized by Xe² (“X-ray image Evaluation Environment”), a graphical development system for measurement scenarios in the X-ray-image. Xe² is a part of phoenix quality|assurance and phoenix x|act, the inspection software of GE Sensing & Inspection Technologies.
Within this development environment the user can choose between a lot of different image processing algorithms, which can be combined with almost no limitation. The algorithms in use are for example edge detection, greyscale analysis, pattern matching or void detection. After executing the image processing algorithms it is possible to run geometrical or statistical functions on the extracted features like the fit of geometric principles, data rows, Boolian operators, etc. There are also tasks for visualization and machine operation available. Every single task can be used for an automated error detection by using free variable thresholds. Depending on the result of a measurement, following tasks can be activated or deactivated. The basics for an automated inspection must be a high quality and high resolved X-ray image. Xe² allows easy programming of automatic measurement and failure analysis tasks, e.g. for atypical solder joints which can not be evaluated with standard inspection programs. Therefore, the Xe² user benefits from an highly efficient and repeatable automated X-ray inspection ensuring to meet his quality standards.

Due to the modular structure of Xe² the user can react fast and easy on new inspection tasks. He can create a new inspection module or he can modify or develop an existing module. In the paper we will give a short overview about the functional principle Xe² is an optimal tool for automatic measurements of internal geometries and distances of any kind of synthetic or metallic samples or assembled components which are detectable in the X-ray image.

Introduction
Right after discovering the radiation, which later in the German speaking countries was given his name to, W.C. Röntgen realized its benefits for non-destructive testing. In his publication „Über eine neue Art von Strahlen“ (“On a new kind of rays”, Würzburg 1895) he mentions a photograph of a piece of metal, “the inhomogenety of which becomes noticeable through the X-rays”[1].
In 1951 V.E. Cosslett und W.C. Nixon (Cambridge) reported about an “X-ray shadow-microscope”[2], which they had constructed utilising a magnetic electron-lens as proposed earlier by M. v. Ardenne. Another two decades later this technique found its first industrial applications when micrometer scale defects became an issue due to miniaturisation of electronic devices and assemblies as well as increased reliability requirements.

Functional Principle
In a microfocus X-ray inspection system the specimen is irradiated by a fan-shaped X-ray beam which generates a magnified X-ray image on a detector which presently, in most cases, is still an image intensifier. The detectability of a defect through the image is ruled by three quantities: magnification, resolution and contrast.

The *resolution* (image sharpness) achievable by the system is mainly determined by the size of the X-ray source which is in the range of a few microns for microfocus X-ray tubes. The *geometric magnification* is given by the geometry of the beam as illustrated in figure 1 and can be as high as 1000 to 2500fold at practicable distances. Apart from resolution and magnification, the recognition of a individual object feature depends on the *contrast* induced by this feature to the image. Physically, the contrast originates from different X-ray absorptions of different object areas and can be caused by varying thickness (e.g. shape of a solder joint) as well as by varying material (e.g. copper conductor in a printed circuit board), see figure 2.

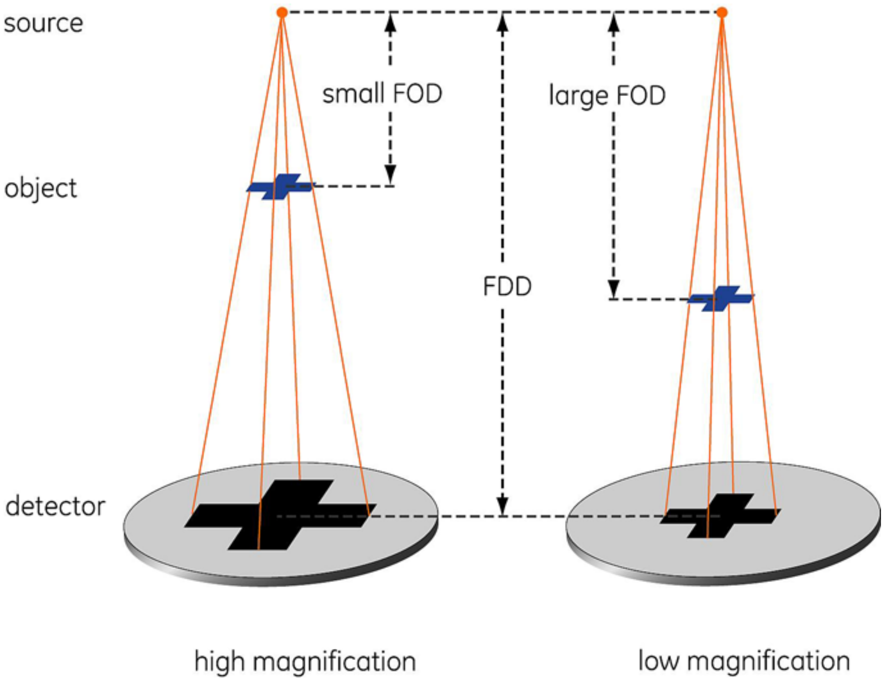

Fig. 1: Function principle of microfocus X-ray inspection. The geometric magnification is M= FDD / FOD. The resolution is determined by the size of the X-ray source, i.e., the focal spot size of the X-ray tube.

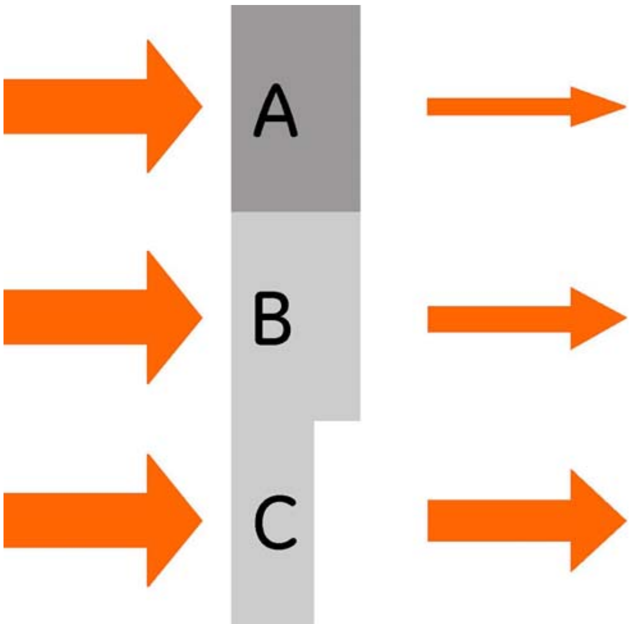

Fig. 2: Contrast generation in the X-ray image: Object A is of the same thickness as object B but yields a higher absorption due to higher density or higher atomic number. Object C consists of the same material as object B but absorbs less radiation than the thicker object B.

X-ray tubes
X-radiation is produced by abruptly braking swift charged particles such as electrons. To realise this in a simple X-ray tube, the electrons are emitted from a heated cathode and are accelerated by means of an electric field towards the anode. When impinging on the anode the electrons are stopped and emit X-radiation.

In a microfocus X-ray tube the electrons pass through a hole in the anode and enter a magnetic lens. The magnetic field focuses the electron beam onto a target in a very small spot. In this way, the diameter of the X-ray source becomes as small as several microns and sharp images can be recorded even at highest magnification. Novel nanofocus tubes using multiple focussing lenses achieve a resolution down to 500 nanometres (= 0.5 microns) (figure 3).

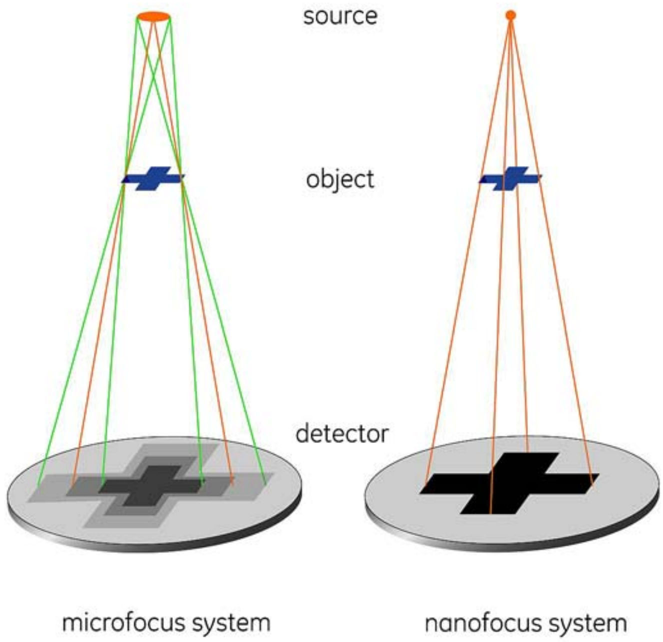

Fig. 3: From microfocus to nanofocus. The penumbra effect: source size limits resolution.

Detectors
The classical detector for X-ray images is the radioscopic film which is still frequently used in non-destructive testing (e.g. of weld seams) because of its high spatial resolution of several tens of microns and its excellent contrast resolution of about 0.5 %. Moreover, a radiograph represents a durable documentation of the inspection result and its application is regulated by comprehensive European, American and international standards. Main disadvantage of the radiograph is the time consumption for film exposure and development of some minutes whereas the image intensifier with image chain provides a live image, however, at relatively low contrast and spatial resolution. Inspecting microscopic object details the lack of spatial resolution can be compensated by the microfocus or nanofocus technique: at sufficient geometric magnification (see figure 1) solely the size of the X-ray source determines the remaining blur of the image so that even finest object details can be sharply imaged.
The strengths of both above detection methods are unified ideally in digital detectors which provide a live image at a contrast resolution which is - at least for the harder part of the radiation - comparable to that of a radiographic film. With up to 65.000 grey values the dynamics of such detectors surpasses the specifications of image intensifiers by orders of magnitude, which helps to avoid oversaturation effects in the image. The latest digital detector generation is like the GE DXR detector active temperature stabilized ensuring a very low

noise live imaging. Due to its high dynamic, these detectors show a brilliant live image with 30 frames per second at full resolution.

Applications

Today, process control and failure analysis in the electronic industries are the predominating applications of microfocus X-ray systems [3]. In printed circuit board assembly mainly hidden solder joints such as those of Ball-Grid-Array (BGA) packages are inspected for voids, wetting failure and solder bridges and other criteria including amount of solder and misregistration. [4][5]. To the semiconductor industry X-ray inspection is an established method for non-destructive testing of the internal interconnections in IC packages. Due to the high resolution even finest cracks in bond wires -which themselves are merely 25 microns (figure 4) in diameter - can be detected, or voids in the die-attach can be revealed and analysed.

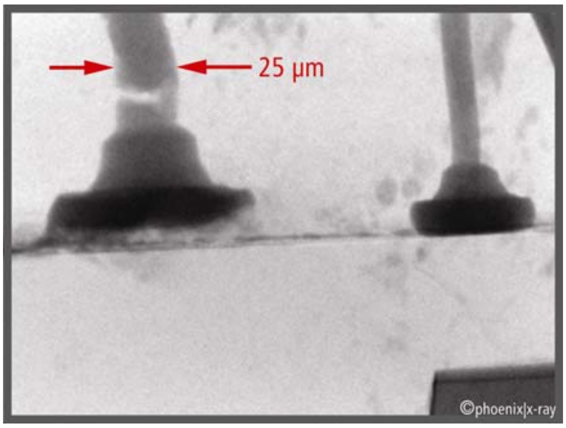

Fig. 4: Nanofocus X-ray image of two ball bonds at the chip in an IC-package (side view, resolution 500 nm). The wire at the left has been destroyed by overcurrent and shows a crack which is about 2 microns wide. Note that finest details are sharply displayed.

With growing quality and reliability requirements also automotive subcontractors take advantage of microfocus X-ray systems. In particular for moulded or encapsuled components such as connectors, plugs, sensors, switches etc. X-ray inspection can at least partially substitute time consuming or destructive methods like mechanical slices (figure 5).

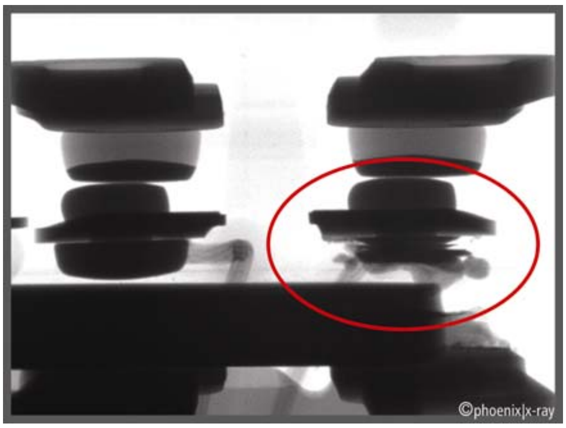

Fig. 5: Microfocus X-ray image of two contact springs in a relay (resolution 2 microns). The lower contact of the right spring is burned. Connecting the relay to a control unit, the movements during switching may be observed in the live X-ray image.

Besides quality check it’s also possible to measure dimension within the X-ray image. By knowing the exact geometry of the system and aligning the sample in a repeatable position distances, radii or angles can be measured (figures 6). For more or less flat objects a quantitative analysis of voiding can be performed.

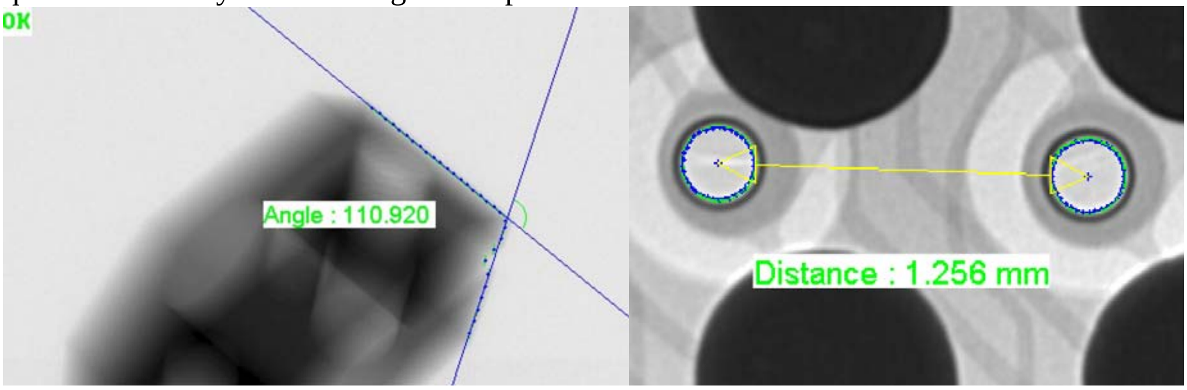

Fig 6: Angle measurement between two fitted lines along two edges of an aluminium sample. Distance measurement between two through holes below a PCBA.

Xe²

Xe² (X-ray image Evaluation Environment) is a modular part within the imaging software phoenix x|act of GE Sensing & Inspection Technologies. It is a graphical development system, which creates various measurement scenarios for analyzing 2D X-ray images in real time.

Xe² allows an interactive setup of four different classes of tasks: measurement tasks, statistical tasks, graphical tasks and image processing tasks. Within the measurement tasks the user can choose between grey value measurements, edge finding routines, voiding calculation or a pattern matching. The measurement results can be reviewed by absolute (user defined) thresholds or feed into statistical tasks for combination of results. Statistical tasks are for example formulas, data rows, fit of geometric principles, Boolean operators, etc. The visualization of the results can be done with the graphical tasks. These tasks can show result values, fitted geometries or other annotations to help the user to interpret the X-ray image. For some measurements it's important to modify the image by applying image filters like smoothing, noise reduction or contrast enhancement. All operation on the image itself can be done with image processing tasks.

Depending on measurement or statistical results following tasks can be activated or deactivated. The inspection routine itself makes a decision on the visual content, which measurements should be performed on the image.

Application example

As an example distance and angle measurements on two different samples are done. The first sample is an injection molded plastic part with a length of 71 mm. Parts of the sample were magnified to measure the angles between the edges. Besides the angle measurement also voids in the bulk material become visible (figures 7).

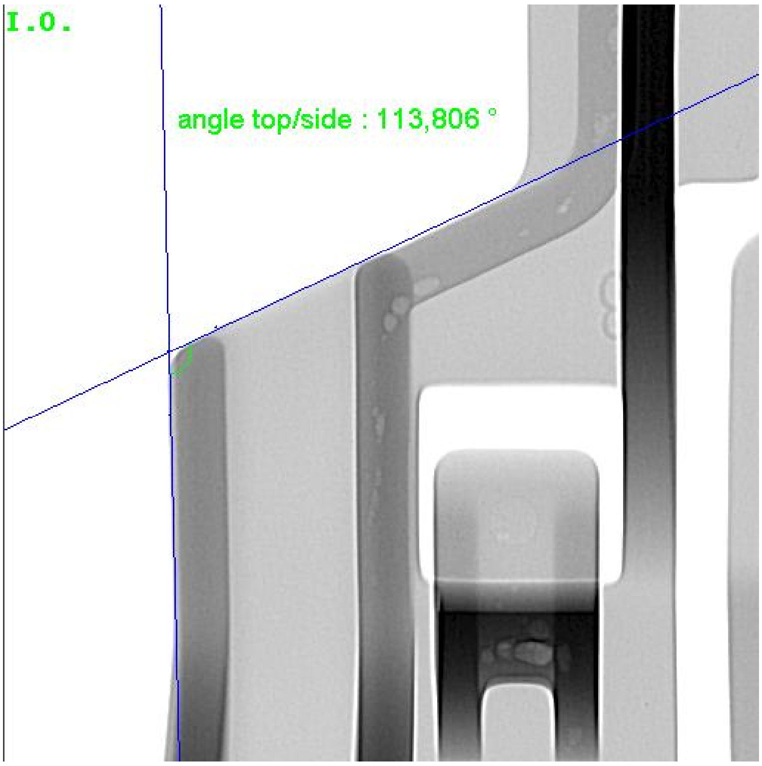

Fig 7: Angle measurement at a plastic sample. Voids are clearly visible.

For the angle measurement a set of points is created by an edge finder, which is moving from a start to an end point (figure 8). Lines are fitted in the points with the least square method. The angle is calculated at the cross section of two fitted lines (figure 11).

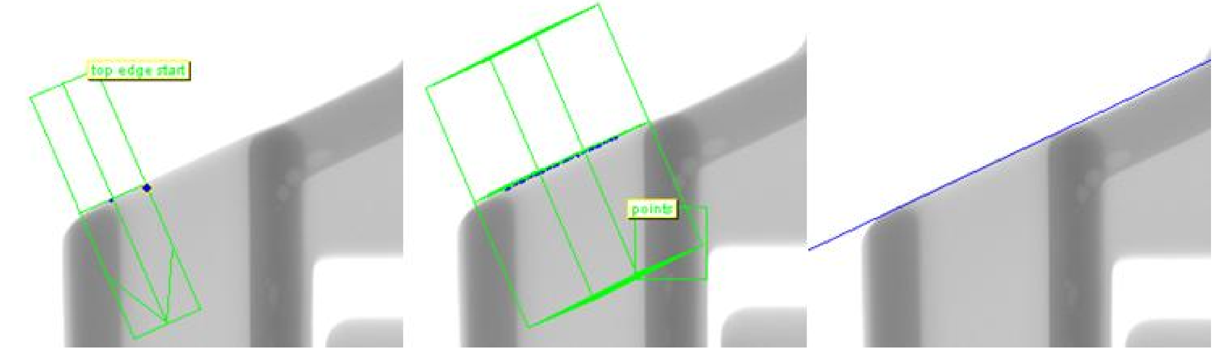

Fig 8: Measurement tasks to fit a line.

The second sample is an aircraft aluminium valve block (courtesy of Continental AG Frankfurt) with an edge length of 130 mm. In the X-ray image a lot of holes and internal structures become visible (figure 9).

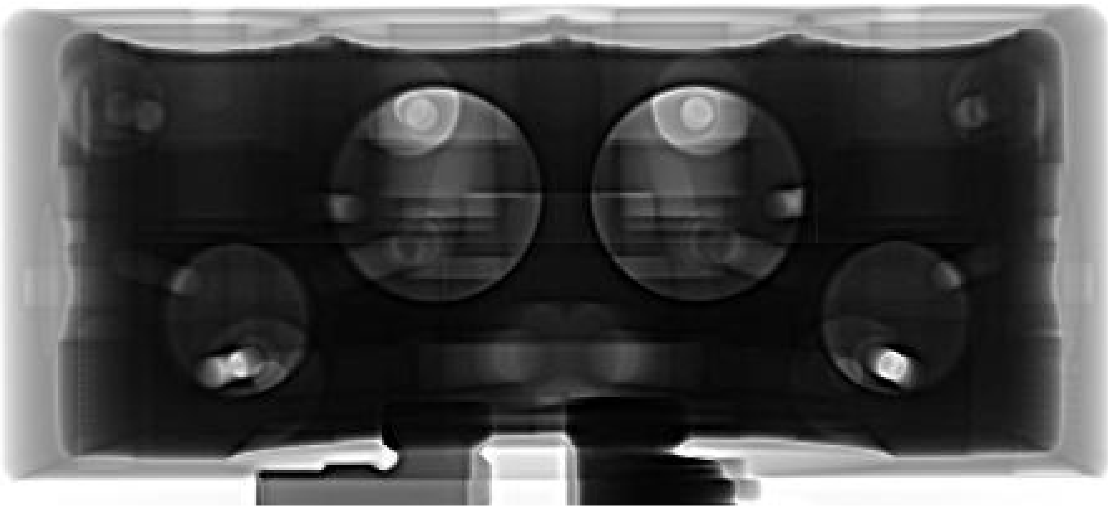

Fig 9: Aircraft aluminium valve block, 2D projection image.

The distances between the four big holes were measured from the 2D projection image with Xe². For all four holes the same set of tasks is used (figure 10): 1. locator (circle finder/measurement), 2. points on the edge of the hole (edge finder/measurement, than data row/statistics), 3. circle fit (statistics).

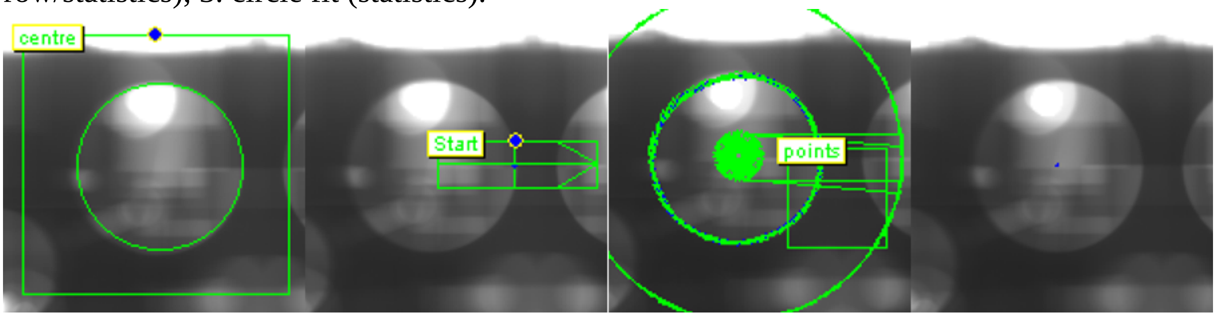

Fig 10: Measurements tasks to find the centre of the hole.

The centre points of the holes can now be used to measure distances or angles in the image (figure 11). All measurements results are initially in pixel dimension. In the case of fitted geometries (like circles, lines or cross sections) the result is in the sub pixel range. By knowing the exact geometry of the X-ray system the dimension in mm can be calculated. The accuracy depends on the pixel size.

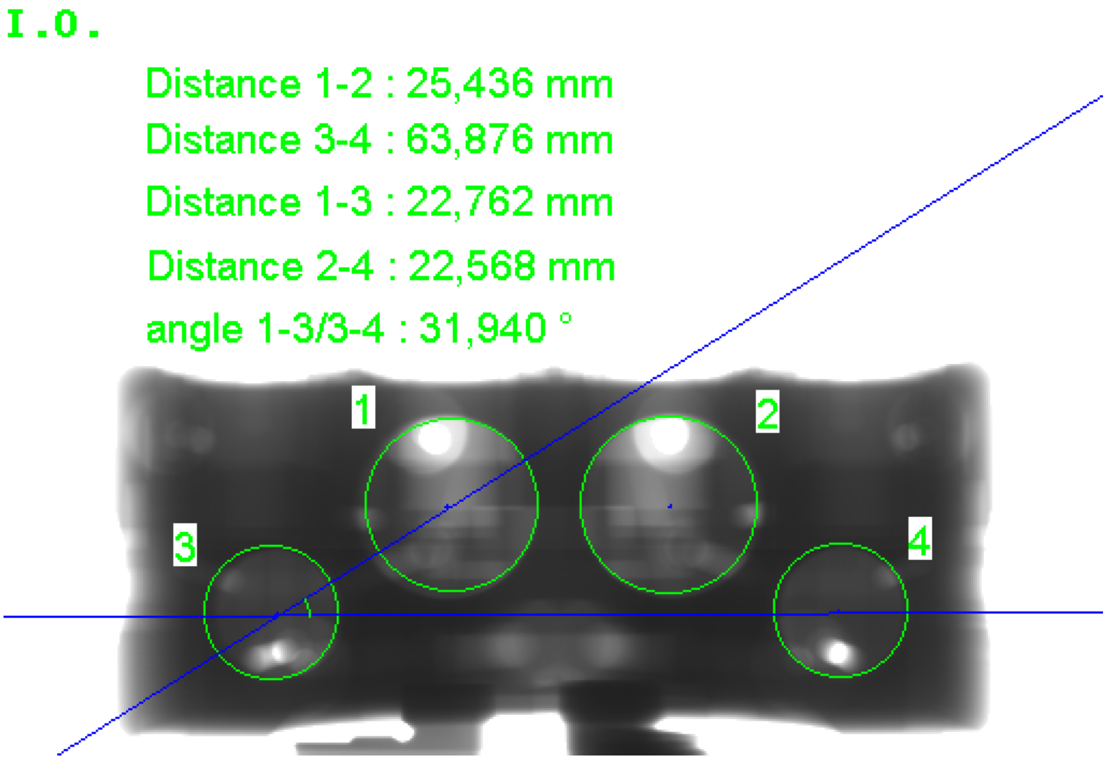

Fig 11: Results of 2D measurements within the projection image.

Conclusion

Microfocus X-ray systems are useful in failure analysis and for measurement functions. Xe² is a tool to extract features from 2D X-ray projection images. The programmability and the possibility to combine the available tasks allow the user to create fast new measurement solutions on changing requirements. Xe² opens the X-ray system for a wide range of applications.

[1] S.z.B.: *A. Fölsing*, Wilhelm Conrad Röntgen, Hanser, München1995
[2] *V.E. Coslett*, -*W.C. Nixon*, Nature 168, 1951, pp. 24-25
[3] www.microfocus-x-ray.com, siehe „Applications“
[4] *H. Roth*, More than counting black dots, EPP inspection special, pp. 2-4
[5] *T. Ahrens*, Non-destructive tests fort he quality control of electronic assemblies- The principles of inspection and X-ray evaluation techniques, VTE 4/2001, pp. E49-65