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Evaluation of the CCD scanner "Vidar NDT Pro”

Scanner : CCD Scanner "Vidar NDT Pro"

Producer : Vidar Systems Corporation, Hemdon, VA, USA (www.vidar.com)

Provided by: Lariviere Gesellschaft für digitale Präsentationssysteme mbH, Bremen

Aim of the evaluation : Investigation of system classification according to EN ISO 14096 “Non-destructive testing (NDT): qualification of radiographic film digitisation systems”

Basis : EPRI test film according to ASTM E 1936 and EN ISO 14096 - 1,
serial number E-099

Test device : Delivered and installed at BAM Berlin in January 2013 by Lariviere GmbH
serial number : 370023
software used : 19454-001 Rev A VIDARscanNDTPRO.exe from Vidar
DarkNoiseFilter Installation: VIDARscanNDTPRODNF.exe
Vidar Twain 7.1.65.0
ISee! Version 1.11.1 from BAM on Win7SP1 32 bit system

Speciality : No scanning options are available, all parameters beside the data depth (8,12 or 16 Bit data can be generated, only 16 bit data depth was used here) are fixed. The pixel size was 570 dpi = 44,56 µm

Scan speed: 92 lines per second, i.e.4 mm/s, a film length of 10 cm is scanned in 25 s.

Test Set-up at BAM:

Results of this evaluation:

All evaluation procedures have been done according the description in EN ISO 14096. The software "ISee!" was used for data analysis, which is a 16 bit image data application for viewing, processing and analysis and is developed at BAM for digital industrial radiology (see http://dir.bam.de/ic.html for more information and program download). The scanner was accessed through the standard TWAIN interface (see fig. 1), which can be called directly from “ISee!” and supports full 16 bit gray scale resolution. The communication via TWAIN and USB-2 interface to the scanner worked well without any problem.

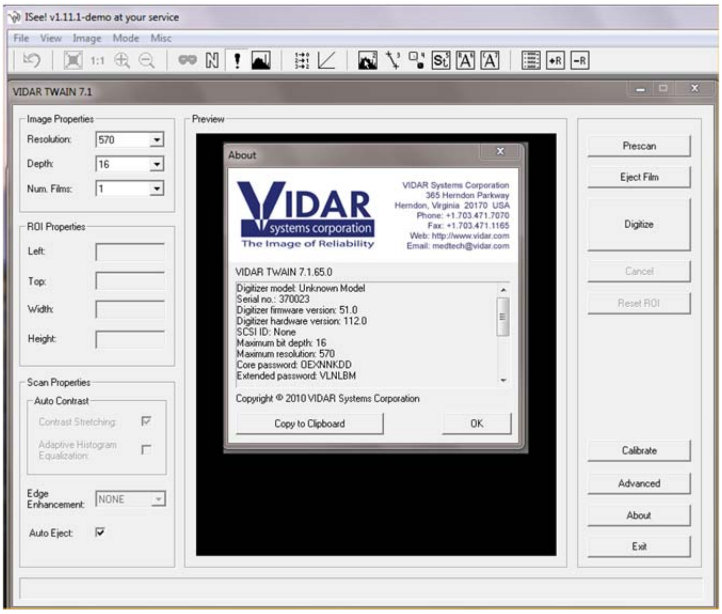


Fig.1: The TWAIN interface used for image acquisition from the scanner “Vidar NDT Pro”.

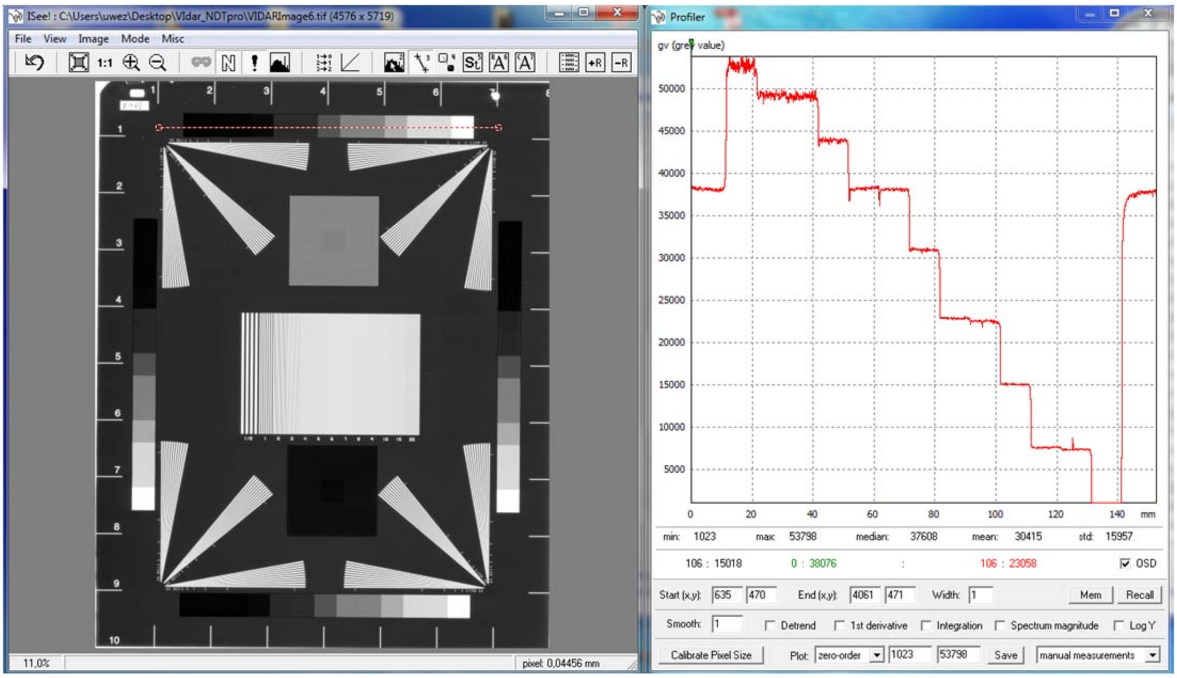


Fig.2: The digitized EPRI test film and the raw data created by the CCD scanner "Vidar NDT Pro". The single line profile of the raw data is shown at the right side with a resolution of 570 dpi across the stepped density target H of the test film (position of the profile indicated by the red line in the left image, the profile width was 1 pixel).

In fig. 2 the raw data output is shown. For the first time a CCD scanner was tested from the worldwide market, which allows to handle the full density range specified in EN 14096 (D = 0,5 … 4,5) in one working range of one scanned image. Clearly all features of the stepped density target can be resolved. Also the typical increase of the noise level with the optical density is shown. The scanner output is roughly proportional to the optical density. All gray values below an optical density of ca. D < 0,5 is clipped and represented by a gray value of 1023.

Characteristic Transfer Curve (CTC)

The following CTC was created starting from the raw data shown in fig. 2 and all further data analysis was done using this CTC for the scanner gray value calibration:

The scanner delivers 16 Bit gray values (Gv) depending on the diffuse optical Density (D) of the digitized film. A Look up table (LUT) was generated and following loaded into the viewer program “ISee!” to generate a signal response directly proportional to the optical density D for further data analysis according to EN ISO 14096-1:

$$LUT(Gv) = 10000 * D \tag{1}$$

All following data analysis is done on the LUT-corrected gray values according to equation (1).

This LUT was generated by fitting a polynomial of third order of the raw gray values from the scanner using the measured diffuse optical densities of the stepped density target H as shown in fig. 2. These optical densities can be found for each density target of the EPRI reference film in the certificate accompanying this film. In fig. 3 the measured mean gray values and their corresponding optical densities are shown as well as the fitted polynomial for LUT generation. Excel was used to generate a 16 bit LUT from the given formula and the LUT was used to convert the gray values into diffuse optical densities according to equation (1). In this way a linear CTC was achieved proportional to the optical density of the film.

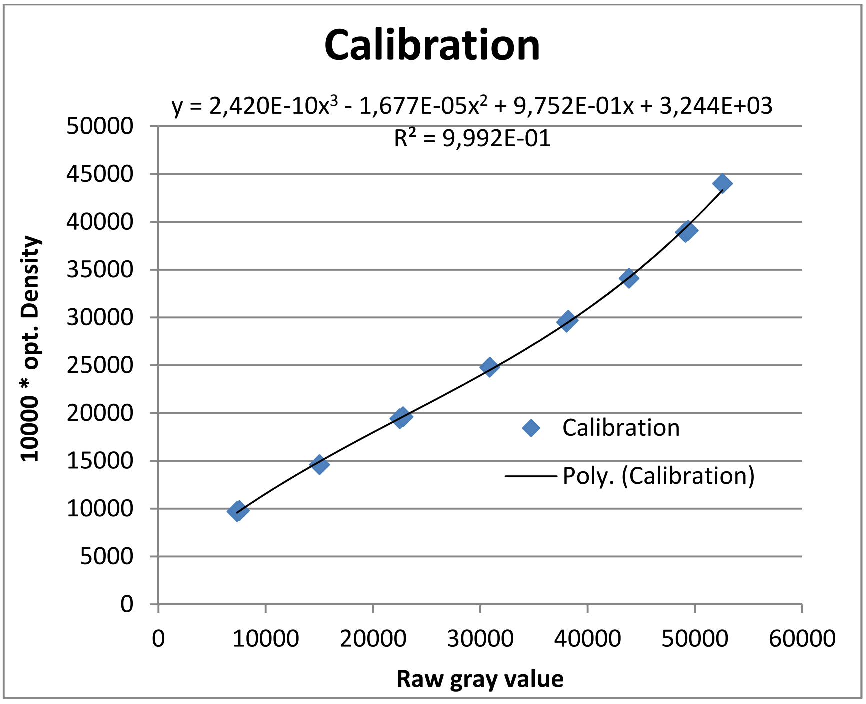


Fig. 3: Generation of a LUT for scanner calibration according to equation 1. The fitted LUT is slightly non-linear, which is considered by a polynomial of 3rd order. The given

formula was used for LUT generation to convert the raw data output of the scanner into a density proportional signal response.

In fig. 4 the result is shown when using this generated LUT according to the formula given in fig. 3 on the same stepped density target H as shown in fig. 2 for the raw data. Now the optical density of the digitized film is represented by a truly density proportional gray value according to equation (1). Nevertheless, all images shown in this report are displayed in the negative mode as they appear on the film.

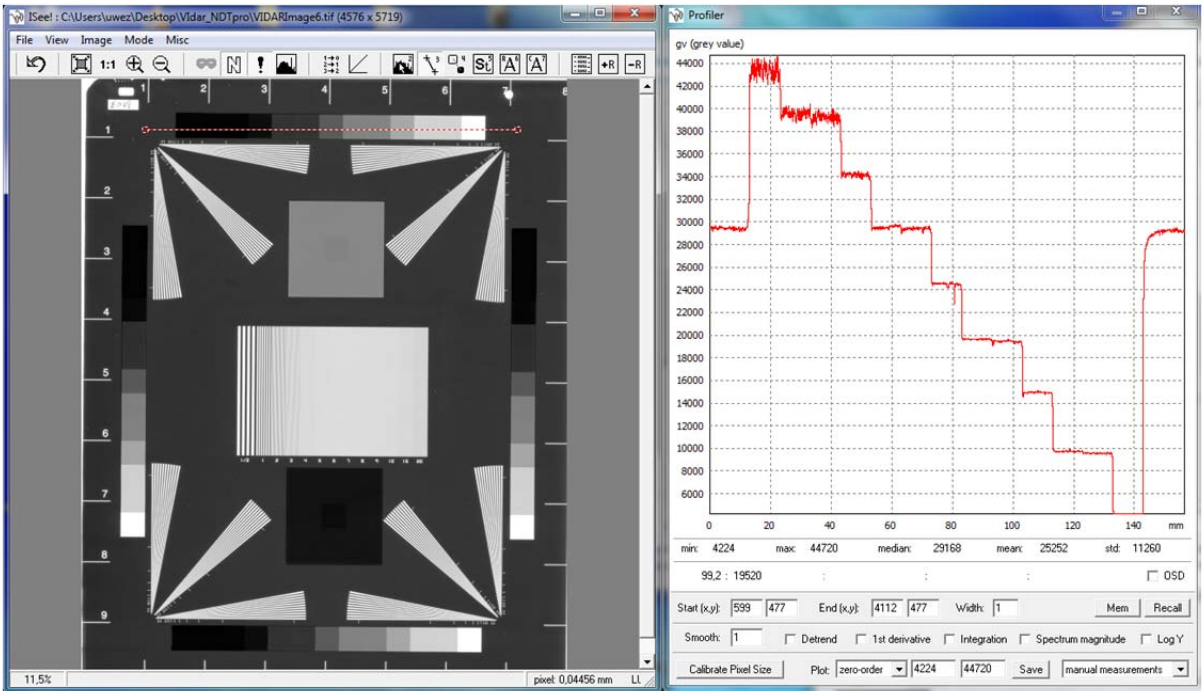


Fig.4: The digitized EPRI test film and the density-linear Characteristic Transfer Curve created for the CCD scanner "Vidar NDT Pro" shown by a single line profile (right) at full resolution (570 dpi) along the stepped density target H of the test film (position of the profile indicated by the red line in the left image, the profile width was 1 pixel).

A common problem of NDT film digitization is the huge light intensity range of 5 orders of light intensities to be handled by the light detector, when the optical density D is in the range $0 < D < 5$ (D is a logarithmic measure of light intensities behind film). The sensitivity of the light detector (here a CCD line) for optical and electronic flare, especially when low optical densities surround a region with a high optical density, will reduce the density readings of the high densities depending on its surrounding.
Looking at the other stepped density targets of the EPRI test film and analyzing their deviation in optical densities when using the LUT shown in fig. 3 (generated only from the target H) reveal deviations $\Delta D < 0{,}05$, which is an excellent value and represents the stability of the scanner calibration.
An extreme example for this effect is shown in fig. 5. Here the scanning device is clearly driven to the physical limits. A calibrated BAM stepped density tablet contains 16 density steps with $0{,}2 < D < 5$, surrounded by only the film density of the base with $D < 0{,}2$. Up to an density of $D = 4$ the deviation by flare from the surrounding is $\Delta D < 0{,}1$. Only for $D > 4$ remarkable deviations were found. This is an impressive step forward in scanner technology for NDT films, other scanners can have density differences $\Delta D > 0{,}5$ caused by flare already at densities $D > 3$.

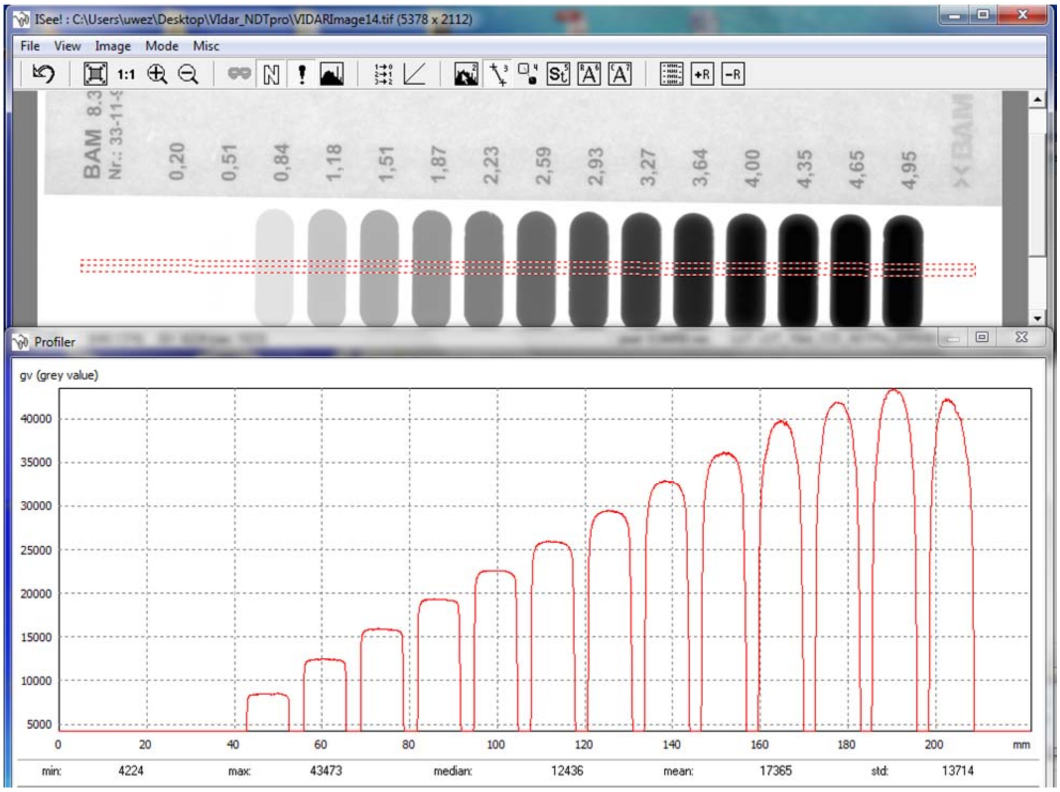


Fig. 5: Density profile of a stepped density target ("BAM-Treppe") in the density range 0,2 < D < 5. Only for D > 4 deviations are visible in the scanner output from the calibrated values caused by the optical flare of the surrounding film base with D < 0,2.

Summary :
A large dynamic range of 0,5 < D < 4,5 can be calibrated very linearly with a stepped density target, but for higher densities D > 4 this calibration depends on surrounding film densities. Deviations higher then ΔD > 0,5 have been observed for densities D > 4,5. It is assumed that this represents a limit of the today scanning technology. The scanner software delivered by Vidar should be extended to include a scanner calibration using the EPRI test film to acquire directly calibrated gray values according to equation (1). Otherwise, an external LUT table can be created and used together with "ISee!" for calibration of the scanner raw data.

Density Contrast Sensitivity (DCS)

The estimation of the density contrast sensitivity is based on the evaluation of the standard deviation of the calibrated gray value of a step on the stepped density target of the EPRI test film as shown in fig. 4. To exclude extra noise from dust and scratches on the film it is important to visually check the image on the monitor at a zooming factor of 1, i.e. each pixel in the data file is displayed on the monitor. Contrast and brightness have to be adjusted accordingly to see the image noise from each step during the measurement. Our software ensures undistorted standard deviations by an additional check of the median S/N (signal to noise ratio), calculated independently for each line in the selected rectangle. A correct estimation of the standard deviation of the selected scan area is done, if the S/N calculated by the quotient of mean data value and the standard deviation is equal to the mean S/N of the lines. The standard deviation STD is measured in a ROI of 15x15 pixels in each step.

It is expected from physics that the noise level increases with increasing film density. The evaluation of the standard deviation STD was done for all steps of the stepped density target H on the LUT calibrated raw data at a pixel size of 44,56 µm (570 dpi). The density contrast sensitivity (DCS) on a pixel size corrected scale (scanning aperture with 100 micron diameter, see EN 14096 - 1) was calculated according to:

$$DCS = 0{,}0002 * STD * \text{pixel size} / 88{,}6\ \mu m \qquad (2)$$

The results of this evaluation are shown in fig. 6.

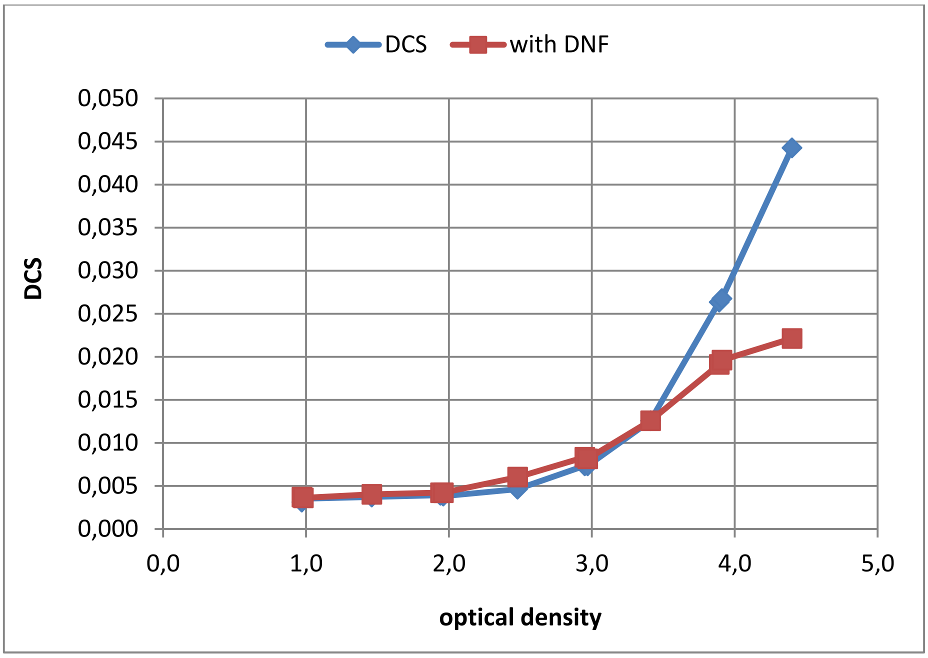
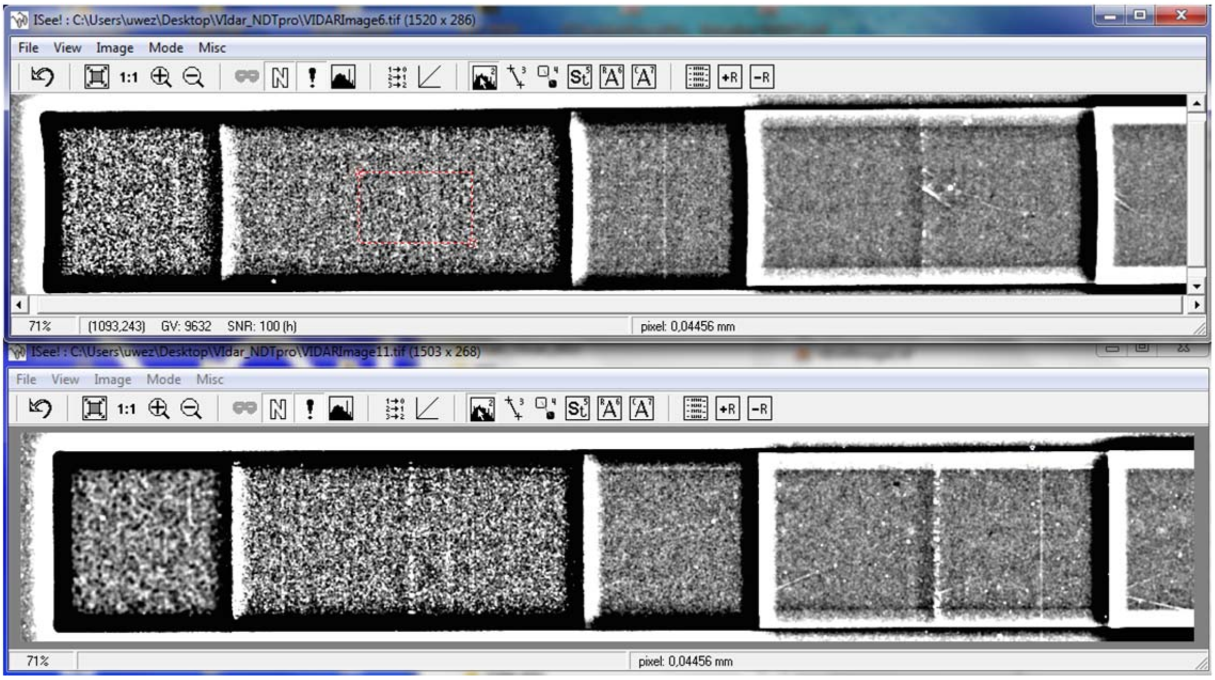


Fig. 6: Density contrast sensitivity DCS for scans with 44,56 µm pixel size for the standard mode (blue “DCS” line) and after installation of the “Dark Noise Filter”(red “DNS” line) in an optical density range 1 < D < 4,5 for the scanner “Vidar NDT Pro”.

For the standard scanning mode (no DNF filter activated) at 570 dpi and 16 bit data depth the scanner “Vidar NDT Pro” has a DCS < 0,02 in a density range 0,5 < D < 3,5. This corresponds to the scanning class “DA” according to EN ISO 14096.
After installation of the “Dark Noise Filter” DNF the noise at high film densities is reduced and the DCS performance is improved. Now the scanner has a DCS < 0,02 in a density range of 0,5 < D < 4,0, which corresponds to the better scanning class “DB”.
The best scanning class “DS” requires a DCS < 0,02 in the full density range 0,5 < D < 4,5, which cannot be reached with the tested scanner model.

High-pass filtered images of the stepped density target H (the part with densities D > 2,4) are shown in fig. 7. The high-pass filtering allows evaluating the noise visually inside the steps, simultaneously for all densities. With increasing density the visual noise impression is changed with the DNF filter activated in the scanner, i.e. especially for densities D > 3,5. A bandwidth limitation of the DNF filter is clearly visible. This is the result of a low-pass filtering for noise reduction at higher densities. In this way the measured DCS is improved as shown in fig. 6.



<u>Fig. 7:</u> High-pass filtered images (moving average by 49x49 pixel subtracted from original image) showing the noise distribution in the stepped density targets for density steps D=2,5 (right) up to D=4,5 (left). The upper target shows the noise impression for the standard scanning mode, the lower target the DNF mode. For density steps D = 4 and D = 4,5 high frequency noise is reduced resulting reduced DCS values. Pixel size is 44,56 µm.

Summary:
The standard scanning mode fulfils the requirement DCS < 0,02 according to EN ISO 14096 (within the measuring error) in a density range 0,5 < D < 3,5, which results in a digitization class “DA”. The activated DNF mode enlarges the DCS < 0,02 for a density range 0,5 < D < 4,0, which corresponds to the digitization class “DB”. The best digitization class “DS” cannot be reached with this scanner model, this would require a DCS < 0,02 at densities up to D = 4.5.

<u>Pixel size</u>

The true pixel size in line and scanning direction was measured using the linearity scales at the EPRI test film. These scales have exact distance markers in inches, in this way the measured number of pixels between them provide directly the resolution in dpi in horizontal and vertical direction. No deviations along the axes (e.g. between left and right hand side of the full scanning area) have been found.

The measured pixel size in vertical direction is exactly the 44,56 µm as stated by the manufacturer (i.e. 570 dpi). In horizontal direction 567 dpi were measured, which corresponds to a pixel size of 44,80 µm, a deviation of +0,5 %. This deviation can be reduced by adjustments of the CCD line position, which was not done here.

Summary:
The measured scanner pixel size is within +/- 0,5 % of the manufacturer specification and is constant across the complete scanning area.

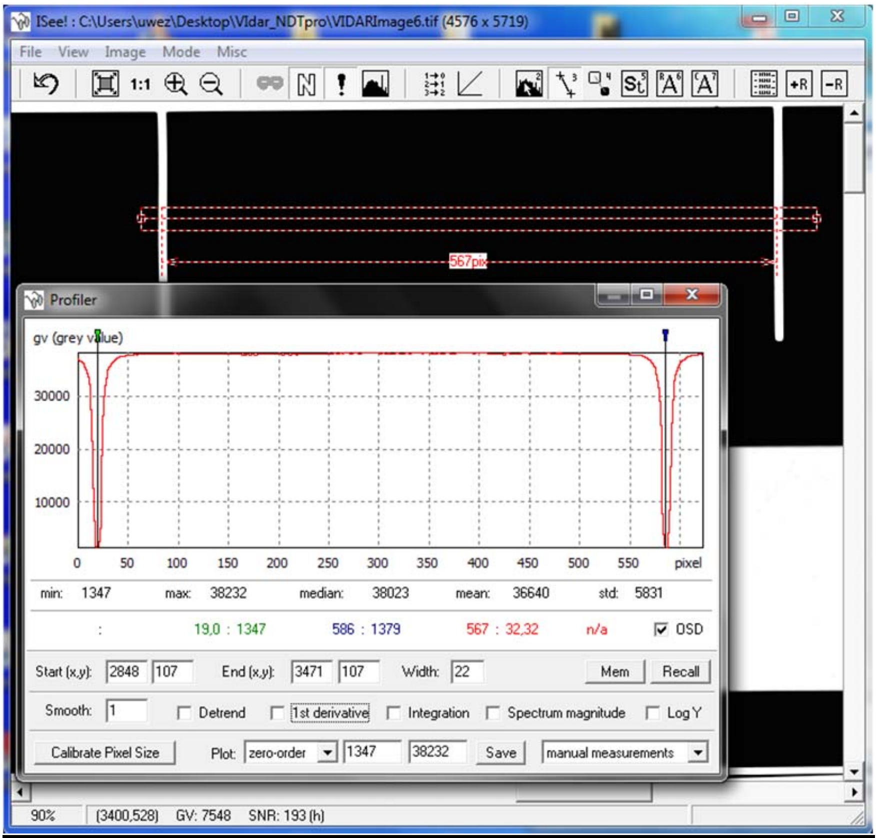


Fig.8: Measurement of the horizontal scanning resolution of 567 dpi using a linearity scale of the EPRI test film.

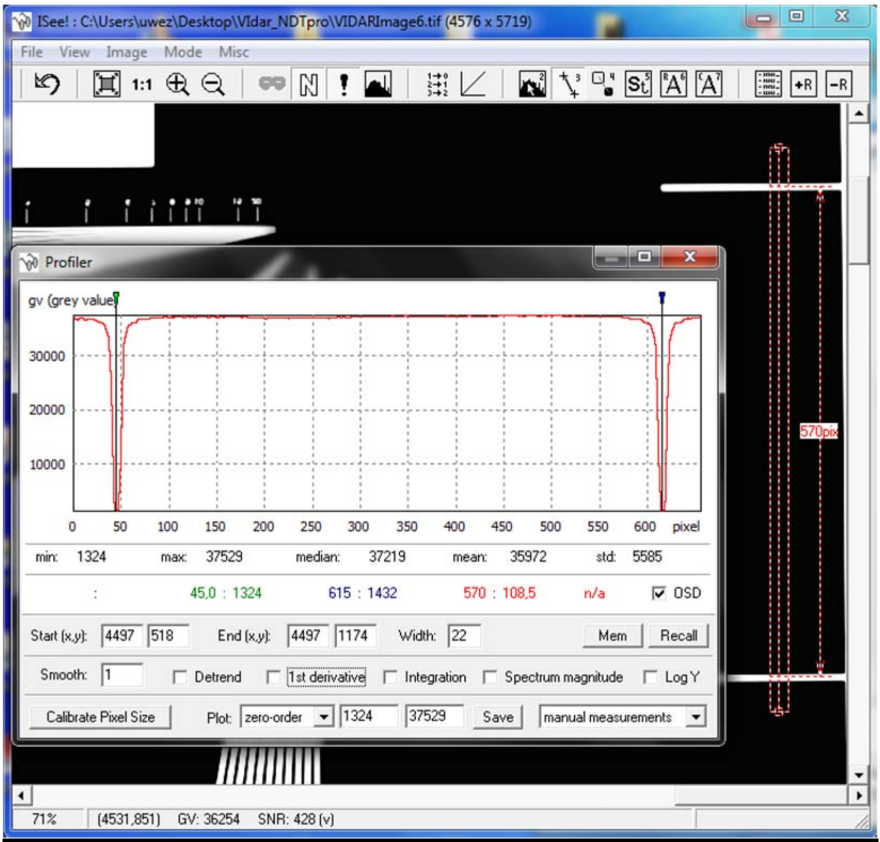


Fig.9: Measurement of the vertical scanning resolution of 570 dpi using a linearity scale of the EPRI test film.

Modulation Transfer Curve (MTF)

For the calculation of the MTF a profile across the sharp edge target of the test film is used (see figs. 10 & 11). To reduce noise effects 22 neighboured profiles are integrated for MTF calculation according to EN ISO 14096. After differentiation and FFT the magnitude spectrum shows the MTF of these step responses directly in the profiler window of “ISee!”.
According to EN ISO 14096 the edges of the stepped density targets with an density of D=0,5 tp the background density of D = 3 should be used. This is not possible at the tested scanner, because the optical density step at D=0,5 is already clipped with a constant raw gray value of 1023. Therefore, the sharp edge of the density targets between D=1,0 and D=1,5 was used (see figs. 10 &11). For correct MTF measurement according to EN ISO 14096 a strictly density proportional response across the edge has to be observed.

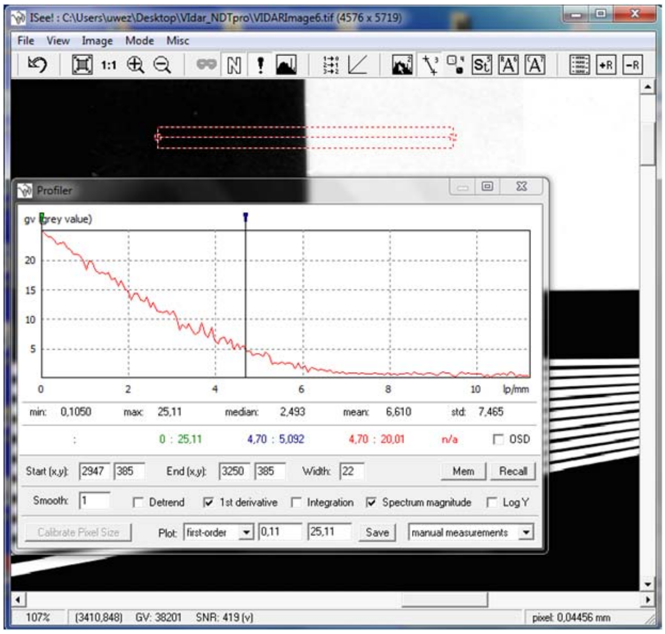


Fig.10: Extraction of an integrated edge profile and MTF calculation (horizontal direction). The 20% MTF value is above 4,7 LP/mm.

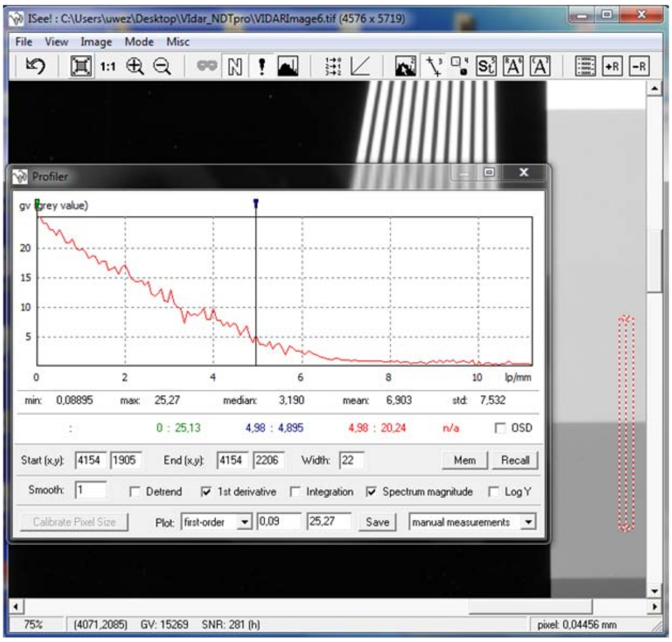


Fig.11: Extraction of an integrated edge profile and MTF calculation (vertical direction). The 20% MTF value is at 5 LP/mm.

Summary :

The scanner “Vidar NDTPro” has a maximal spatial resolution of 5 LP/mm (rounded MTF 20% value). The MTF in vertical and horizontal direction is nearly identical. The CCD sensor and its optics do not show any aliasing, The MTF is Zero above 7 LP/mm up to the Nyquist frequency (11,2 LP/mm). This indicates some space for optimization of the optics. A sharper optics will increase the MTF, but also the measured DCS values, because more high frequency noise from the film will be detected.

Other investigations

Another test film was scanned, a typical weld image with a variety of welding flaw indications from the BAM test weld plate “BAM5” (8mm steel plate with V weldment, see fig. 12). This film fulfil the requirements of testing class B according to EN ISO 17636 and has a background density of D=4,9 in the base material. Digital data without severe scanning artefacts can only be produced by film scanners adapted to the NDT film market. Scanners from the medical market or office scanners will show only scanner noise and no flaw indications in the weldment caused by the high film densities used in the NDT film market.

The tested scanner “Vidar NDT Pro” passed this test successfully (see fig. 12), whereas a slight degradation of the resolution at film densities D>4,5 was observed (see fig.13).

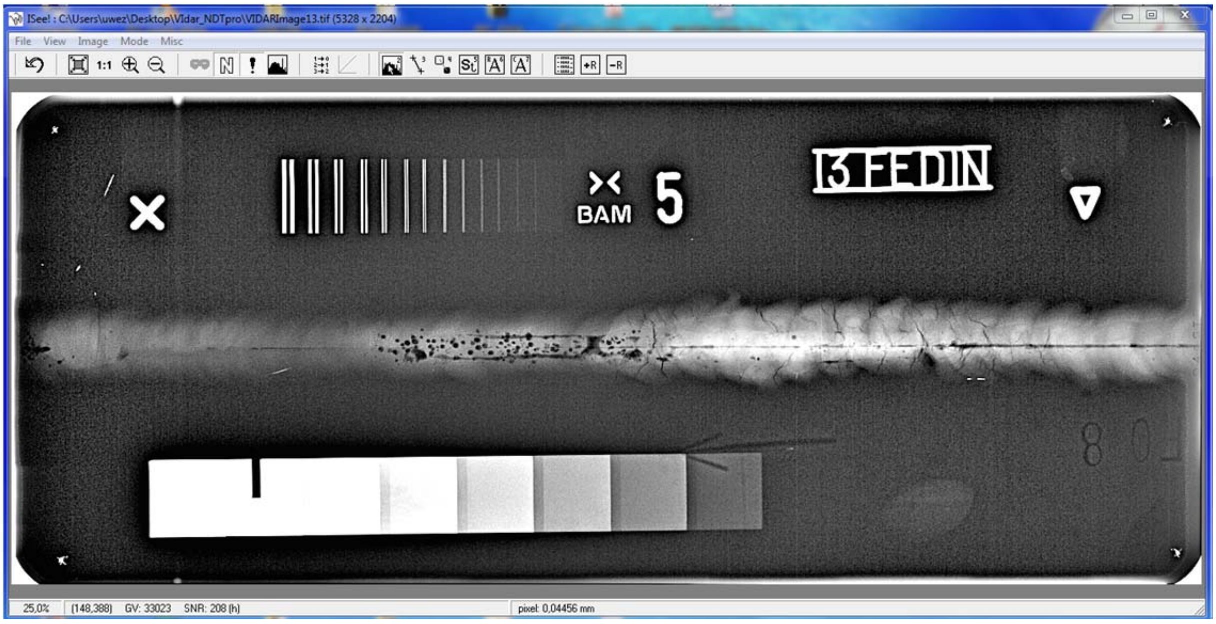


Fig. 12: Image of a scanned test film of the test weldment “BAM 5”. This film has a background density of D=4,9 and fulfils testing class B according to EN ISO 17636. Digitization with the scanner “Vidar NDTPro” preserves this testing class B also in the digital data using the DNF mode. All flaw indications are visible in the digital data, for better image reproduction the shown image is high-pass filtered using “Enhance details” of “ISee!”.

<u>Fig.13:</u> Enlarged ROI of fig.12 showing the finest duplex wires merged together, which are all resolved on the original film. The film density at the background is D=4,9. The upper image is the standard scanning mode, the lower image the DNF mode. The observed reduced resolution of the duplex wires is a result of the limited DCS at high film density and scanning at 570 dpi, high-pass filtered with “Enhance details”.

<u>Conclusions :</u>

The evaluated CCD scanner "VIDAR NDT Pro" fulfils the basic requirements for density contrast sensitivity for NDT applications (DCS < 0,02 with 16 bits data depth). At a pixel size of 44,6 µm all requirements according to EN ISO 14096 are fulfilled and the scanner can be classified to the digitization class:

(standard installation):	**DA 5**
(with Dark Noise Filter installed):	**DB 5**

The scanner class DB according to EN ISO 14096 part 2 require a sensitivity of DCS ≤ 0,02 in the density range from D = 0,5 to D = 4,0. The scanner is able to handle the full dynamic range of D = 0,.5 up to D = 4,5 in one working range, an impressive step forward compared with all the other CCD scanners tested before.

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