British Standard

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23 July 2003

Non-destructive testing — Qualification of radiographic film digitisation systems —

Part 1: Definitions, quantitative measurements of image quality parameters, standard reference film and qualitative control

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ICS 01.040.19; 01.040.37; 19.100; 37.040.25

British Standards

National foreword

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The UK participation in its preparation was entrusted to Technical Committee Wee/46, Non-destructive testing, which has the responsibility to:

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Non-destructive testing - Qualification of radiographic film digitisation systems - Part 1: Definitions, quantitative measurements of image quality parameters, standard reference film and qualitative control

Essais non destructifs - Qualification des systèmes de numérisation des films radiographiques - Partie 1: Définitions, mesures quantitatives des paramètres de qualité d'image, film de référence normalisé et contrôle qualitatif

Zerstörungsfreie Prüfung - Qualifizierung von Röntgenfilm-Digitalisierungssystemen - Teil 1: Definitionen, quantitative Messung von Bildqualitätsparametern, Standard-Referenzfilm und Qualitätssicherung

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Foreword

This document (EN 14096-1:2003) has been prepared by Technical Committee CEN /TC 138, "Non-destructive testing", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2003, and conflicting national standards shall be withdrawn at the latest by October 2003.

EN 14096 comprises a series of European Standards for radiographic film digitisation systems which is made up of the following:

EN 14096-1 Non-destructive testing – Qualification of radiographic film digitisation systems – Part 1: Definitions, quantitative measurements of image quality parameters, standard reference film and qualitative control

EN 14096-2 Non-destructive testing – Qualification of radiographic film digitisation systems – Part 2: Minimum requirements

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

Radiographic film systems are used for industrial inspection by X- and gamma rays. To apply modern means of computer support for analysis, transmission and storage the information stored in the radiographic film should be converted into digital data (digitisation). This European Standard defines minimum requirements to ensure that the relevant information for evaluation of the digital data is preserved during the film digitisation process.

1 Scope

This European Standard specifies procedures for the evaluation of basic performance parameters of the radiographic film digitisation process such as spatial resolution and spatial linearity, density range, density contrast sensitivity and characteristic transfer curve. They can be integrated into the system software and together with a standard reference film (as described in clause 5) used for quality control of the digitisation process. This reference film provides a series of test targets for performance evaluation. The test targets are suitable for evaluating a digitisation system with a spatial resolution down to 25 µm, a density contrast sensitivity down to 0,02 optical density, a density range of 0,5 to 4,5 and a film size capacity of (350 x 430) mm². This standard does not address signal processing and display of the digitised data.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 584-1, *Non-destructive testing — Industrial radiographic film — Part 1: Classification of film systems for industrial radiography.*

EN 14096-2, *Non-destructive testing — Qualification of radiographic film digitisation systems — Part 2: Minimum requirements.*

3 Terms and definitions

For the purposes of this European Standard, the following terms and definitions apply.

3.1
radiographic film digitisation system
digitiser
sequential application of the two functions below:

a) detection of the diffuse transmittance of a small unit area of the film (pixel, picture element) by means of an optical detector, giving an electric output signal (geometrical digitisation);

b) conversion of the above electrical signal into a numerical value (densitometrical digitisation)

3.2
scanning aperture
S_A
spatial extension (area) on the radiographic film through which the digitiser performs the scanning of one pixel for geometrical digitisation

The size of the scanning aperture corresponds:

— in the case of rectangular aperture: to the longer side,

— in the case of circular aperture: to the diameter.

The scanning aperture limits the spatial resolution of the digitiser.

3.3
pixel size
P
geometrical centre-to-centre distance between adjacent pixels in a row (horizontal pitch) or column (vertical pitch) of the scanned image

3.4
optical density
D
logarithmic value to the base 10 of the diffuse light intensity ratio in front of (I_0) and behind (I_D) the radiographic film according to equation (1):

$$D = \lg \frac{I_0}{I_D} \tag{1}$$

3.5
edge spread function
ESF
resulting profile across a step function after digitisation

NOTE This function can be either as light intensity or optical density.

3.6
digitiser unsharpness
U_D
blurring of sharp edges by the scanning aperture, scattered light, flare or electronic bandwidth

It is determined from the geometrical distance of the 10% and 90% point of the Edge Spread Function (ESF) from a light intensity step function.

3.7
spatial frequency
f
described by a sinusoidal intensity variation along a geometrical axis

The period of this function is measured in number of line pairs per millimetre (lp/mm).

3.8
spatial frequency maximum value
f_c
in theory, this value, in number of line pairs per millimetre, is given by the Nyquist sampling theorem, see equation (2):

$$f_c = 1 / (2 * P) \tag{2}$$

Practically, the scanning aperture, the mechanics and the electronics of the digitiser reduce this theoretical value.

3.9
modulation transfer function
MTF
normalised magnitude of the Fourier-transform (FT) of the differentiated spatial optical density edge spread function (ESF) (see Figure 1)

It describes the unsharpness function of the digitiser (contrast transmission as a function of the object size).

NOTE This MTF calculation is based on optical densities, which correspond to the X-ray dose.

3.10
density range
D_R
range of maximum and minimum optical densities, which can be measured by the digitiser

Depending on the construction of the digitiser, this density range can be split into several working ranges (e.g. by a different illumination power and/or a different detector integration time).

3.11
characteristic transfer curve
CTC
relationship between the optical density of the film and the digitised data

3.12
digital resolution in bit
number of bits provided by the analogue-to-digital converter of the digitiser used for densitometrical digitisation

NOTE A digital resolution of N bits corresponds to 2^N digital values.

3.13
density sampling pitch
ΔD_{SP}
optical density variation corresponding to an increase of 1 in the digitised value

NOTE This density variation depends on the characteristic transfer curve of the digitiser. The density sampling pitch can be a function of the density.

3.14
density contrast sensitivity
ΔD_{CS}
minimum density variation of the film, which is resolved by the digitiser

This is mostly determined by the digitisation noise of the digitiser (quantum noise of the light detector).

3.15
working range
D_{WR}
range of optical densities, where the digitiser guarantees a minimum density contrast sensitivity in one single acquisition

Only in this density range the digitised data can be used for evaluation. Depending on the digitiser construction there can be more than one working range, e.g. for brighter or darker films.

3.16
single acquisition
digitisation of one radiographic film performed with one single scan

The result of which is a collection of data not subject to any type of further processing. A unique set of parameters of the digitisation system is used for this acquisition.

3.17
standard reference film
photographic image on an industrial radiographic film containing all of the reference targets described in this document

3.18
targets
physical patterns on the standard reference film which are used to evaluate the digitiser

4 Evaluation procedures

4.1 Evaluation of the characteristic transfer curve, density range, pixel size and density contrast sensitivity

4.1.1 Stepped density target

For the measurement of the characteristic transfer curve, the density range and the density contrast sensitivity of the digitiser a stepped density target on a reference radiograph (standard reference film) is required with the following requirements:

— to cover the optical density interval between D = 0,5 and D = 4,5;

— the optical density spacing between 2 adjacent steps is not greater than ΔD = 0,5;

— the area of each step is at least 100 mm²;

— a fine grain type film (system class C1 in EN 584-1) with light exposure shall be used to achieve a fine granularity resulting into a film noise less than ΔD = 0,01 (at 88,6 µm pixel size).

4.1.2 Characteristic transfer curve (CTC)

For a unique set of digitiser parameters, an acquisition of the stepped density target on the reference film is performed. For each density step D_{i} the arithmetic mean value $\overline{gl}_{\mathrm{i}}$ of the digitised data values $gl_{\mathrm{j,i}}$ for an area of (15 x 15) pixel shall be determined according to equation (3):

$$\overline{gl}_{\mathrm{i}} = \frac{1}{225} \times \sum_{\mathrm{j}=1}^{225} gl_{\mathrm{j,i}} \qquad (3)$$

The characteristic transfer curve of the digitiser is constructed from the table of D_{i} versus $\overline{gl}_{\mathrm{i}}$.

Missing density values between the measured density steps can be interpolated in compliance with the following conditions:

— for linear systems (digital data proportional to light intensity) the curve shall be logarithmic,

— for logarithmic systems (digital data proportional to optical film density, provided by electronic log-amplifiers or digital LUT) the curve shall be linear.

The digital data provided by the digitiser and the corresponding optical density values shall be reported in a table and/or a diagram.

The discrete density values expressed by the digital data shall be named $D(gl)$.

Depending on the construction of the digitiser, the CTC can be different for the stepped density target in scanning direction and perpendicular to it.

4.1.3 Density range (D_{R})

The density range of the digitiser is determined by the characteristic transfer curve. It is the difference between the minimum and maximum optical density, which can be resolved by the digitiser. The minimum and maximum optical density for a given parameter set of the digitiser can be found from the corresponding characteristic transfer curve. But there can be digitiser parameters which select a different CTC. Then the density range is calculated from the maximum and minimum optical density values of all possible CTC's.

4.1.4 Pixel size (P)

The pixel size is determined by evaluating the spatial linearity targets of the standard reference film. By dividing the known distance of these targets by the number of pixels found in the digitised image the pixel size P can be calculated. This has to be performed in row and column direction of the image.

4.1.5 Density contrast sensitivity (ΔD_{CS})

The evaluation of the density contrast sensitivity ΔD_{CS} is based on a calculation of the standard deviation σ_D of adjacent pixels in a film region with constant optical density. This calculation has to be performed on the digitised values of the calibrated optical film density $D(gl)$. For convenience, it is defined that a neighbourhood of 225 pixels is considered for all following cases. The standard deviation σ_D of the calibrated density $D(gl_i)$ is calculated for these 225 values at a given density step according to equation (4):

$$\sigma_D = \frac{1}{\sqrt{224}} \cdot \sqrt{\sum_{n=1}^{225} \left[D(gl_n) - \frac{1}{225} \cdot \sum_{m=1}^{225} (D(gl_m)) \right]^2} \quad (4)$$

The σ_D represents the noise of the digitiser itself at the density value considered. So it follows for the density contrast sensitivity (scaled to 88,6 µm pixel size, P – actual pixel size of the digitiser), equation (5):

$$\Delta D_{CS} = 2\sigma_D \times (P / 88{,}6\ \mu m) \quad (5)$$

To compare the density contrast sensitivity of digitisers with different pixel sizes, the value of ΔD_{CS} is referred to a square pixel size of 88,6 µm. This corresponds to the 100 µm diameter of the microdensitometer aperture used for film granularity measurements in EN 584-1.

The practical determination of the standard deviation should be carried out as follows:

for every density step of the stepped density target of the standard reference film a square matrix of 15 x 15 neighbouring pixels can be evaluated. The standard deviation of the calibrated density $D(gl_i)$ of this set of 225 values can be calculated as above, giving the noise of the digitiser itself at this density value. This method gives only correct results when the film noise of the stepped density target is lower than the digitisation noise from the scanner.

NOTE It should be checked visually, by display of the evaluated regions, that no dust or scratches of the standard reference film disturb this evaluation.

4.2 Evaluation of the spatial frequency maximum value, digitiser unsharpness and modulation transfer function

4.2.1 General

The spatial resolution of the digitiser is affected by the optical aperture of the system, the response of the electronics and the accuracy of the mechanical system. The optical aperture gives generally a linear, space invariant response whose total effect is image blurring. This blurring is independent of the density. Some equipment, like uncorrected flying spot flat bed scanners, have a spatial resolution depending on the position on the film.

4.2.2 Spatial frequency maximum value (f_c)

Using the converging line pairs or parallel line pair test targets (see 5.1.1 for description) the highest indicated spatial frequency in line pairs per millimetre (lp/mm) can be determined, where all of the lighter lines are seen to be separated by the darker lines.

NOTE Caution ! Due to digitisation artefacts (Aliasing !) it can be difficult to distinguish the correct maximum value especially for the parallel line pair test target. A small misalignment of the test pattern to the scanning direction can change the Moiré patterns considerably.

4.2.3 Digitiser unsharpness (U_D)

For the measurement of the digitiser unsharpness (in millimetres) a density step function is used from the stepped density test target (see 5.1). The edge spread function (ESF) of the scanned density step determines the digitiser unsharpness. The unsharpness is the geometrical distance of the 10% and 90% value of the ESF in light intensity units . The ESF should be determined in the scanning direction and perpendicular to it. The ESF used for MTF calculation shall be derived from the calibrated density axis.

4.2.4 Determination of the modulation transfer function (MTF)

The starting point of the MTF-calculation is the ESF from the unsharpness evaluation (see Figure 1). It is useful to average at least nine ESF's from adjacent lines perpendicular to the density step for noise suppression. In the next step the averaged ESF shall be differentiated numerically (e.g. the calculation of the differences of following points) to obtain the line spread function LSF, see equation (6):

$$\mathrm{LSF}_i = \mathrm{ESF}_i - \mathrm{ESF}_{i-1} \tag{6}$$

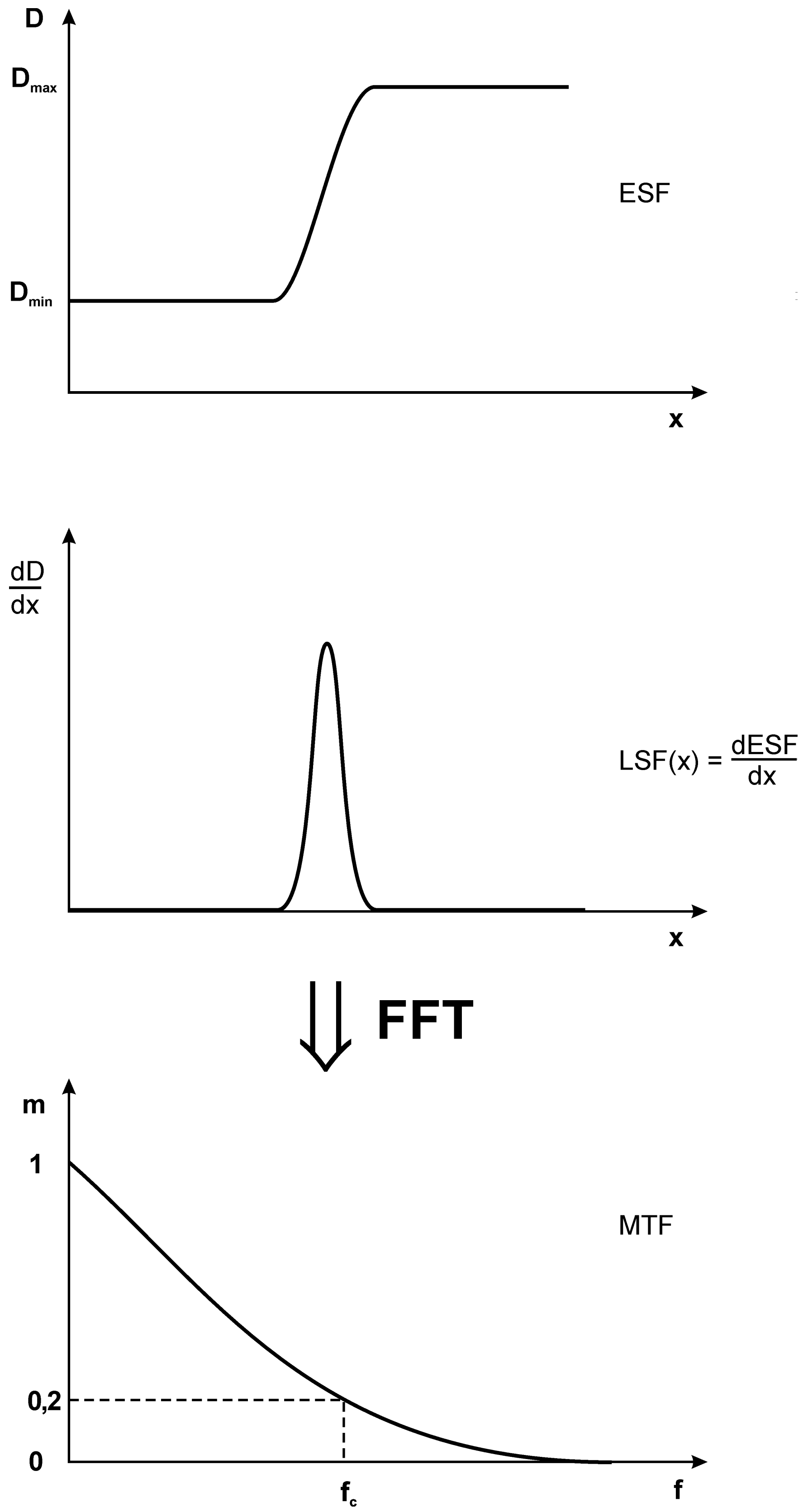
In the last step the MTF can be calculated from a Fourier transformation (FT) of the LSF according to equation (7):

$$\mathrm{MTF}_m = \frac{1}{\sum_{n=0}^{N-1} \mathrm{LSF}_n} \left| \cdot \sum_{n=0}^{N-1} \mathrm{LSF}_n \cdot \exp\left(\frac{2\pi\ \mathrm{i} n m}{N}\right) \right| \tag{7}$$

The MTF describes the contrast transmission as a function of the object size. It is a sensitive function for the image quality of the digitiser.

NOTE 1 The MTF resolution (f_c – spatial frequency maximum value) should be taken from the 20 % value (MTF_{fc} = 0,2).

NOTE 2 Normally CCD scanners have a stronger decaying MTF than Laser scanners with the same rated spatial resolution.



Key

m Modulation

f Spatial frequency

Figure 1 — Principle of MTF determination

4.3 Other evaluations

4.3.1 Blooming or flare

Examine the digitised standard reference film (as described in clause 5) for the evidence of light overshoot or streaking in areas with high density contrast (e.g. in the surrounding of the stepped density target). This can be caused by saturation of the light detector, or intensity transfer from regions with high light intensities into dark regions with a low intensity and is measured by 4.2.2 or 4.2.3.

4.3.2 Digitisation artefacts

The acquired image shall be examined for the evidence of artefacts which are not present on the scanned film (e.g. vertical or horizontal lines or streaks, dust or dirt specks, etc).

The film should be checked after scanning for possible scratching from the film transport mechanism of the digitiser.

4.3.3 Geometric distortions

The spatial linearity of the digitiser shall be checked by the scale (spatial linearity targets, see 5.1.4.) in x- and y-direction on the standard reference film. The film transport system should not allow the film to tilt or twist during the scan resulting in a geometrical image distortion.

5 Standard reference film

5.1 General

The standard reference film has five types of targets which may be used to evaluate various parameters of the digitisation system. The targets are located within a background density of $D = 3$. The standard reference film is divided into 3 areas with sizes of (200 x 250) mm², (280 x 350) mm² and (350 x 430) mm². These have been created for digitisers unable to accommodate a maximum film size of (350 x 430) mm². The standard reference film may be cut to custom fit a particular digitiser and still contain all of the necessary targets within each of these areas (see Figure 2 for an image of this film).

NOTE This European standard describes the same standard reference film as used in ASTM E 1936.

1.2 Description of test targets

5.2.1 Converging spatial resolution targets

These consists of 3 identical groups of at least 6 converging line pairs. The targets have a maximum resolution of at least 20 lp/mm, a minimum resolution of 1 lp/mm and a density contrast of $\Delta D = 2{,}5 \pm 0{,}5$ with a maximum density of $D = 0{,}5$ of the bright lines. These three targets are oriented in the 0°, 45° and 90° positions. The maximum resolution is oriented toward the corners of the reference test film. Reference marks are provided to indicate spatial resolution at levels of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15 and 20 lp/mm.

5.2.2 Density contrast sensitivity targets

These consist of (10 x 10) mm² fields centred in (40 x 40) mm² blocks of a slighter different density. Two series of blocks will be used, one block series with an optical density of $D = 2{,}00$ on a background of $D = 1{,}95$. The second block series will have $D = 3{,}50$ on a background of $D = 3{,}40$. The relative density change is more important than the absolute density. These 2 blocks series are located in 6 areas on the reference test film.

5.2.3 Stepped density targets

These targets are to be used to determine density range, density contrast sensitivity and MTF. They consist of a series of (10 x 10) mm² blocks with densities of $D = 0{,}5$ to $D = 4{,}5$. There are 13 blocks aligned in a row with the following approximate densities:

4,50; 4,02; 4,00; 3,50; 3,02; 3,00; 2,50; 2,02; 2,00; 1,5; 1,02; 1,00 and 0,5.

These blocks are grouped in 8 areas on the reference film.

All outer edges of the stepped density targets shall have sharp edges (unsharpness < 10 µm) for the digitiser unsharpness and MTF evaluation (see 4.2.2 and 4.2.3).

5.2.4 Spatial linearity targets

These targets provide 25,4 mm units of measure. They shall be located in horizontal and vertical directions. The spatial linearity targets, or measurement scale, divides the standard reference film into 3 distinct film sizes (200 x 250) mm² , (280 x 350) mm² and (350 x 430) mm².

5.2.5 Parallel line pair target

This target consists of a parallel line pair gauge with a spatial resolution starting at no greater than 0,5 lp/mm and increases to a resolution of no less than 20 lp/mm and a density contrast of ΔD = 2,5 ± 0,5 with a maximum density of D = 0,5 of the bright lines. It is positioned near the centre of the (200 x 250) mm² area on the standard reference film.

5.2.6 Additional targets

Additional targets may be located on the standard reference film as long as they do not interfere with the targets as described in 5.1.1 to 5.1.5.

5.3 Preparation of the standard reference film

The standard reference film is made on a high-quality industrial radiographic film which has been exposed with visible light to reduce the granularity of the density targets. The optical densities specified in 5.1 of this standard are determined by using calibrated densitometry equipment and are supplied with the standard reference film. Optical densities are recorded in the centre of each of the density step targets (± 1,5 mm).

The tolerance of the optical density changes of ΔD = 0,02; 0,05 and 0,1 in the test targets according to 5.1.2 and 5.1.3 shall be ± 0,005.

The densities shall be within ± 0,15 of the values stated in 5.1.2 and 5.1.3. The actual densities shall be recorded and furnished with the standard reference film.

The background density, where no targets are located, shall have an optical density of D = 3 ± 0,5.

The standard reference film shall have a unique identification which appears in the image when digitised.

5.4 Storage and handling of the standard reference film

5.4.1 Storage

Radiographic film is subject to wear and tear from handling and use. The extent to which the image deteriorates over time is a function of storage conditions, care in handling and amount of use. The film shall be protected against light, heat and contamination.

5.4.2 Handling

The standard reference film may exhibit a loss if image quality over time. The film should therefore be examined each time it is used for signs of wear and tear, including scratches, abrasions, stains etc. A standard reference film which shows signs of excessive wear and tear, which could influence the evaluation results, should be replaced.

5.5 Documentation of the standard reference film

The supplier of the standard reference film shall provide a certificate of conformity to this standard, which shall include the following data:

— a serial number on film and certificate;

— strip designations and the optical densities of each step;

— guidelines for usage, storage and handling;

— date of certification and expiration date;

NOTE The certificate of the standard reference film should be valid for three years starting from the date of first use.

— deviation from this standard, if any;

— the certificate shall be signed.

6 Qualitative control and long term stability of the digitisation system

6.1 Normal check

The user shall verify the following parameters of the digitisation system in the specified range, determined from:

a) converging spatial resolution targets – spatial frequency maximum value (f_C);

b) density targets (with ΔD = 0,02; 0,05 and 0,1 separation) – density contrast sensitivity (targets separable or not on the monitor);

c) spatial linearity target - dimensional stability in number of pixels for reference length and width (i.e. in x- and y-direction);

d) stepped density target – the density range (max. and min. density) recognised.

The verification method can be using a software module that generates the data from the digitised standard reference film or alternatively viewing the digitised standard reference film on a monitor capable of displaying the sensitivity and resolution of the image as well as measuring software tools. In this case, contrast and brightness adjustments can be used.

6.2 Extended check

The extended check contains all procedures as described in 4.1 to 4.3.

The check shall be done at the maximum spatial resolution specified for the digitisation system and in all working modes used.

The extended check shall be done to ensure that the minimum requirements for the digitisation system are fulfilled as specified in EN 14096-2. The extended check will determine the class of the digitisation system (as specified in EN 14096-2).

6.3 Test periods and long term stability

The extended check should be carried out directly after installation and repair of the digitisation system. The results shall be documented for long term stability tests. The periods for normal check and extended check as well as acceptance levels should be specified by a quality assurance system.

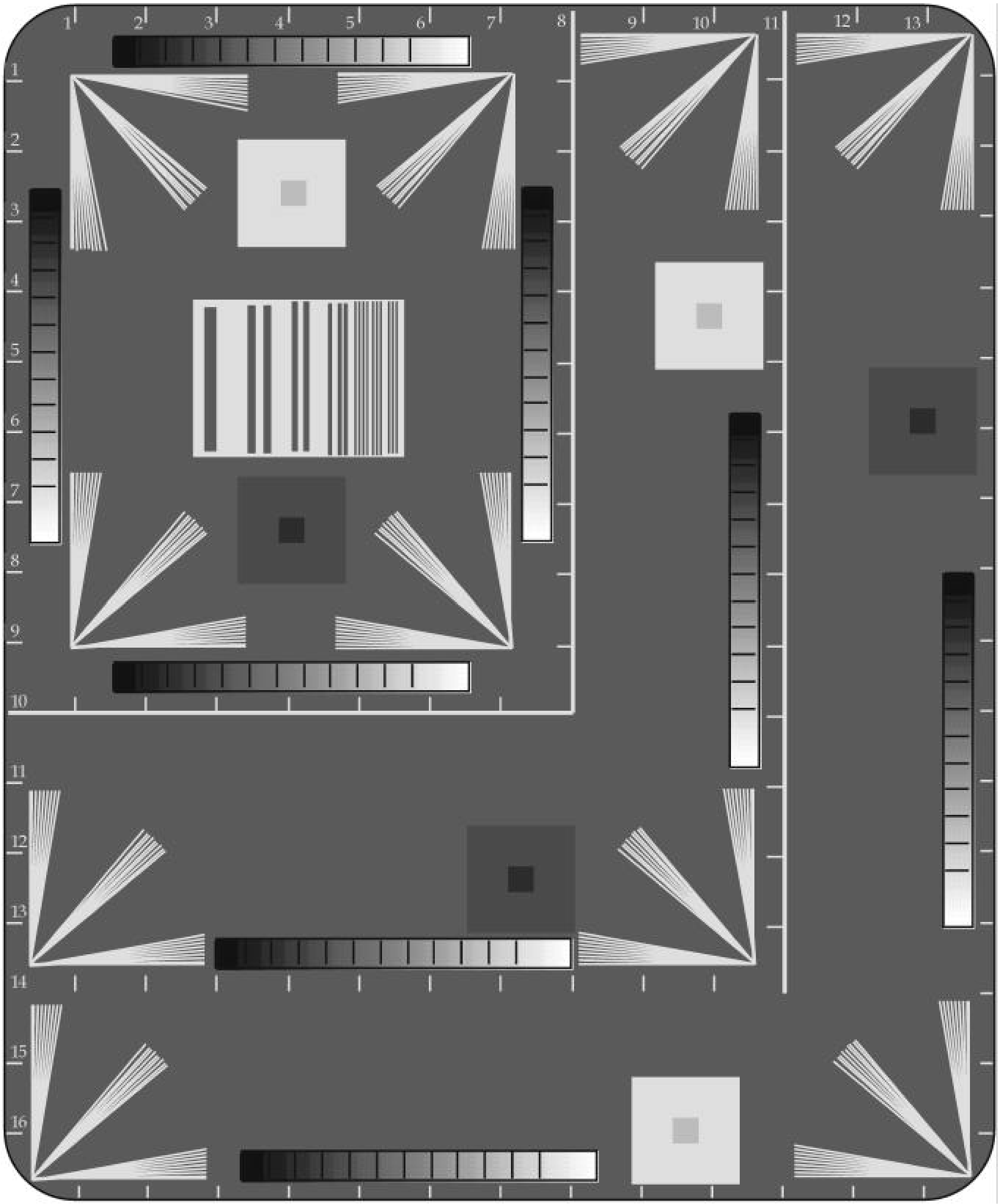


Figure 2 — Standard reference film

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