INTERNATIONAL STANDARD

ISO 8721

Second edition
2010-09-01

Road vehicles — Measurement techniques in impact tests — Optical instrumentation

Véhicules routiers — Techniques de mesure lors des essais de chocs — Instrumentation optique

Reference number
ISO 8721:2010(E)

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Published in Switzerland

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8721 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems*.

This second edition cancels and replaces the first edition (ISO 8721:1987), which has been technically revised.

Road vehicles — Measurement techniques in impact tests — Optical instrumentation

1 Scope

This International Standard defines performance criteria for an optical data channel used in impact tests on road vehicles, when numerical time and space data are taken from images to analyse impact test results.

The objective of this International Standard is to facilitate comparison between results obtained by different laboratories by specifying minimum quality criteria.

Annexes A, B, C and D present a method of measuring several indices like quality parameters of subprocesses of the optical data channel, using a calibration target, reference distances and analysis systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

3 Terms and definitions

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

3.1
analysis system
system to measure and collect the coordinates of target points in image space as a function of time

NOTE The calculation results of the analysis system are 3D coordinates in object space, whereas in the case of 2D analysis, the depth of the target points is known and considered.

3.2
cell size
distance of neighbouring pixels on the sensor of an image recording device

NOTE If there are different distance values in the two main directions of the image, the cell size is the maximum of these values.

3.3
control point
point that was determined with a higher accuracy and is further accepted as an error-free point

3.4
frame rate
f_r
frequency of renewal of information for a given point, expressed in renewals per second, or in images per second if all points of the image are renewed simultaneously

3.5
image recording device
system composed of a camera/lens unit together with a recording system

3.6
location accuracy
a_{loc}
desired accuracy of the object or target being measured

3.7
optical data channel
system composed of one or more image recording devices and a system for analysing the images, including any analysis procedure and data correction that validate and modify the content of the data

3.8
reference distance
known distance between a validation target pair

3.9
synchronism device
device to identify the synchronism effect in two or more corresponding image recording devices

3.10
time base system
device allowing determination of the time interval elapses between any two recorded events for each image recording device

3.11
time origin identification device
device to identify the instant chosen as the time origin, usually the contact between the test objects

3.12
validation target pair
pair of targets placed in the field of view so that the distance separating them remains constant

NOTE Both of them are visible during the impact test.

3.13
accuracy value
a
value that represents the relative overall accuracy of any point measurement within the optical data channel when the performance value is satisfied

3.14
accuracy value limit
r_{avl}
user-defined limit for the accuracy value that represents the relative overall accuracy of any point measurement within the optical data channel when the performance value is satisfied

3.15
camera position calculation index
i_{cpc}
index that gives the possibility to evaluate whether the accuracy of the optical data channel determined from one time step is representative for the entire sequence

3.16
camera set-up index
i_{cs}
index that makes it possible to evaluate whether the set-up of the camera with respect to the movement plane permits a reliable analysis

NOTE Only for 2D film analysis.

3.17
control point distribution index
i_{cpd}
index that makes it possible to evaluate whether the distribution of the control points in the image permits a reliable orientation of the used images

3.18
distortion index
i_d
index that makes it possible to evaluate whether the interior orientation parameters of the used camera are still valid

3.19
focal length index
i_{fl}
index that makes it possible to evaluate whether the focal length of the used image recording device is still valid

3.20
index value
value that is determined by the index calculation equation

NOTE 1 See Annex A.

NOTE 2 The index value is the result of the index determination and is a floating point number.

3.21
index condition
condition of the check of the index

NOTE The index condition can be true (value 1) or false (value 0). The condition true means that the index check is fulfilled and the condition false means that the index check is not fulfilled.

3.22
intersection index
i_i
index that makes it possible to evaluate the intersection geometry of the rays from the image recording devices to the object points

NOTE Only for 3D film analysis.

3.23
length measurement error
value that represents the absolute overall accuracy of any point measurement within the optical data channel when the performance value is satisfied

3.24
motion blur index
i_{mb}
index that allows one to evaluate whether the exposure time used in the test is small enough with respect to the appropriate object movement, in order to ensure a reliable point identification and point measurement in the images

3.25
performance value
value that guarantees suitable general conditions for the estimation of the accuracy of the optical data channel

NOTE It is derived from all indices which describe the performance of the optical data channel.

3.26
plane scale index
i_{ps}
index that makes it possible to evaluate whether there is the possibility to calculate the scale in each movement plane

NOTE Only for 2D film analysis.

3.27
point motion index
i_{pm}
index that makes it possible to estimate whether the selected frame rate is high enough, in order to correspond to the test requirements

3.28
scale index
i_s
index that gives the possibility to evaluate whether there are enough independent reference distances to control the system scale

3.29
synchronism index
i_{sy}
index that makes it possible to estimate whether the data produced in the test can be regarded as synchronous

NOTE Only for 3D film analysis.

3.30
target detection index
i_{td}
index that makes it possible to evaluate whether the measuring accuracy of the image coordinates is small enough, in order to correspond to the test requirements

3.31
target size index
i_{ts}
index that makes it possible to evaluate whether the signalized points, used in the test, are large enough, in order to ensure a reliable point identification and point measurement in the images

3.32
time base index
i_{tb}
index that makes it possible to evaluate whether the time accuracy of the used time base system corresponds to the test requirements

3.33
time origin identification index
i_{toi}
index that makes it possible to evaluate whether the time accuracy of the used time origin identification device corresponds to the test requirements

4 Symbols

Symbol	Definition
A_{cf}	control point formed area
A_{i}	image area
a	accuracy value of the optical data channel
a_{alaid}	allowed location accuracy in depth
a_{clad}	current location accuracy (distortion)
a_{claf}	current location accuracy (focal length)
a_{clai}	current location accuracy (intersection)
a_{claid}	current location accuracy in depth
a_{clat}	current location accuracy (target)
a_{clatb}	current location accuracy (time base)
a_{clatoi}	current location accuracy (time origin identification)
a_{d}	distortion accuracy
a_{fl}	focal length accuracy
a_{fr}	frame rate accuracy
a_{loc}	location accuracy
$a_{refdist,r}$	accuracy value of the reference distance, r
a_{td}	target detection accuracy
d	object distance
e	exposure time
f	focal length
f_{r}	frame rate
i_{cpc}	camera position calculation index
i_{cpd}	control point distribution index
i_{cs}	camera set-up index
i_{d}	distortion index
i_{fl}	focal length index
i_{i}	intersection index
i_{mb}	motion blur index
i_{pm}	point motion index
i_{ps}	plane scale index

Symbol	Definition
i_{s}	scale index
i_{sy}	synchronism index
i_{tb}	time base index
i_{td}	target detection index
i_{toi}	time origin identification index
i_{ts}	target size index
ΔL	length measurement error of the optical data channel
Δl_r	length measurement error of reference distance, r
l_{aed}	asynchronism effect in viewing direction
l_{aep}	asynchronism effect perpendicular to the viewing direction
l_{apm}	allowed point motion between two sequenced images in object space
$l_{\text{c},r}$	calibrated length of reference distance, r
l_{cb}	camera base
l_{cmbv}	current motion blur value
l_{cpm}	current point motion between two sequenced images in object space
l_{cs}	cell size
l_{ctd}	current target diameter
l_{dco}	distance camera base to object
l_{fpd}	fix point distance
l_{ih}	image height
l_{iw}	image width
$l_{\text{m},r}(t)$	measured length of reference distance, r, as a function of time
l_{mdi}	maximum displacement in image space
l_{mdo}	maximum displacement in object space
l_{rtd}	required target diameter
l_{ttd}	theoretical target diameter
p	3D performance value of the optical data channel
p_{cpa}	control point area
p_{cpd}	control point distribution
$p_{\text{dtp},i}$	distance to plane of motion i
p_{np}	number of planes of motion
$p_{\text{rd},r}$	reference distance
$p_{\text{rd},i}$	reference distance in direction i
$p_{\text{rdp},i}$	reference distance in plane of motion i
p_{siap}	scale information in all planes of motion
$p_{\text{sip},i}$	scale information in plane of motion i

Symbol	Definition
p_{syd}	synchronism index in viewing direction
p_{syp}	synchronism index perpendicular to the viewing direction
$p_{t,i}$	target in image section i
p_{tpc}	type of camera set-up
p_{tpd}	type of position determination
Q	performance value of the optical data channel
q_i	2D performance value of the image recording device i
r_{aar}	allowed accuracy relation
r_{avl}	accuracy value limit
r_{car}	current accuracy relation
t_b	beginning of the analysed time interval
t_c	user-defined time within the analysed time interval
t_{ca}	current asynchronism
t_{dtz}	difference between t_0-image and -signal
t_e	end of the analysed time interval
t_{int}	time interval
t_{td}	time drift
t_{ttd}	total time drift
v	velocity

5 Performance

5.1 General requirements

The performance of the optical data channel shall be evaluated initially to establish performance levels. This evaluation shall be repeated whenever the system is modified to an extent which could cause a change in accuracy. This shall be done with an offline procedure.

It is also possible to measure the performance of the optical data channel during an impact test. This is called the online procedure.

The performance of the optical data channel shall be estimated using 2D performance values, or 3D performance values, or both. These values consist of different performance indices depending on the test constellation. To verify the estimated performance values, an accuracy value shall be determined using two or more reference distances.

If a film analysis is carried out using the image sequences of onboard cameras, the used equipment (camera and lens) shall correspond to the expected shock.

5.2 Reference distance

The reference distances shall be determined ten times more precisely than the desired location accuracy. The determination of the reference distances should be done before the test.

The reference distances shall be located on approximately perpendicular (90 ± 10)° lines (see A.3.2). For 3D analysis, all three directions in space shall be covered.

5.3 Time base system

The time base shall be determined ten times more precisely than the desired time accuracy.

5.4 Performance of the optical data channel

5.4.1 General

The performance of the optical data channel consists of different indices (see Table 1). The determination depends on the application (2D or 3D).

5.4.2 Performance indices

Each index value shall be at least 0,5. If this minimum requirement is not fulfilled for every index, then the impact test does not conform to this International Standard. The index condition of a certain index is 0 if the requirements for this index (see Annex A) are not fulfilled; otherwise the index condition is 1.

Table 1 — Performance indices

Index	2D	3D	Number per optical data channel	Comment
Focal length index	[a]	[a]	one per image recording device	in a suitable image
Distortion index	[a]	[a]	one per image recording device	in a suitable image
Target detection index	[a]	[a]	one per image recording device	worst target used in the analysis
Target size index	[a]	[a]	one per image recording device	worst target used in the analysis
Motion blur index	[a]	[a]	one per image recording device	at maximum object speed
Point motion index	[a]	[a]	one per image recording device	at maximum object speed
Control point distribution index	[a]	[a]	one per image recording device	in a suitable image
Time base index	[a]	[a]	one per image recording device	—
Time origin identification index	[a]	[a]	one per image recording device	—
Camera set-up index	[a]	[b]	one per image recording device	—
Plane scale index	[a]	[b]	one per image recording device	—
Intersection index	[b]	[a]	one	best pair of image recording devices
Synchronism index	[b]	[a]	one	worst pair of image recording devices

[a] Index value is used for the performance value.

[b] Index value is not used for the performance value.

5.4.3 2D performance value

The performance value for every image recording device is estimated by all 2D related index conditions (see Table 1). The 2D performance value, q_i, is the ratio of the achieved sum to the possible sum of index conditions with respect to the test requirements, and is calculated as shown in Equation (1):

$$q_i = \frac{\sum_{j=1}^{n} x_{ji}}{n} \tag{1}$$

where

i is the image recording device number;

j is the 2D performance index number;

x_{ji} is the index condition of the 2D performance index, j, of the image recording device, i;

n is the number of 2D performance indices (2D film analysis: $n = 11$; 3D film analysis: $n = 9$).

5.4.4 3D performance value

The 3D performance value of the optical data channel, p, is calculated as shown in Equation (2):

$$p = \sum_{k=1}^{m} y_k \tag{2}$$

where

k is the 3D performance index number;

y_k is the index condition of the 3D performance index, k, of the optical data channel;

m is the number of 3D performance indices ($m = 2$).

5.4.5 Performance value of the optical data channel

For 2D analysis, the performance value of the optical data channel, Q, is identical to the 2D performance value, q_1, as shown in Equation (3):

$$Q = q_1 \tag{3}$$

For 3D analysis with only one image recording device, the intersection index and the synchronism index are not defined. In this case, the performance value of the optical data channel, Q, is equal to the 2D performance value, q_1.

For 3D analysis, the performance value of the optical data channel, Q, is the ratio of the achieved sum to the possible sum of all index conditions, calculated according to Equation (4):

$$Q = \frac{\left(n \times \sum_{i=1}^{u} q_i\right) + (p \times u)}{(n \times u) + (m \times u)} = \frac{\left(\frac{n}{u} \times \sum_{i=1}^{u} q_i\right) + p}{n + m} \tag{4}$$

where

i is the image recording device number;

q_i is the 2D performance value of the image recording device, i;

u is the number of image recording devices;

n is the number of 2D performance indices (2D film analysis: $n = 11$; 3D film analysis: $n = 9$);

m is the number of 3D performance indices ($m = 2$);

p is the 3D performance value of the optical data channel.

5.5 Accuracy of the optical data channel

5.5.1 Accuracy indices

The accuracy indices are shown in Table 2.

Table 2 — Accuracy indices

Index	Number per optical data channel	Comment
Camera position calculation index	one per image recording device	—
Scale index	one	indispensable index

5.5.2 Length measurement error and accuracy value of a reference distance

The length measurement error and accuracy value of a reference distance are defined as follows:

— the length measurement error, Δl_r, of the reference distance, r, is the maximum difference between the measured length, $l_{m,r}(t)$, and the calibrated length, $l_{c,r}$, within the analysed time interval;

— the accuracy value, $a_{refdist,r}$, of the reference distance, r, is the maximum relative difference between the measured length, $l_{m,r}(t)$, and the calibrated length, $l_{c,r}$, within the analysed time interval.

All used image recording devices shall be used for the calculation of the reference distances.

If the index condition of the camera position calculation index, i_{cpc}, of all used image recording devices is fulfilled, the length measurement error, Δl_r, can be determined at a single time step within the analysed time interval. If the index condition of only one image recording device is not fulfilled, the length measurement error, Δl_r, shall be calculated for every time step within the analysed time interval. The accuracy value, $a_{refdist,r}$, of the reference distance, r, is the ratio between the length measurement error, Δl_r, and the calibrated length, $l_{c,r}$.

If every $i_{cpc,i} \geqslant 1$, then the length measurement error, Δl_r, is calculated according to Equation (5):

$$\Delta l_r = \left| l_{m,r}(t_c) - l_{c,r} \right| \quad (5)$$

where

$i_{cpc,i}$ is the index value of the camera position calculation index of the image recording device, i;

i is the image recording device number;

r is the reference distance number;

$l_{m,r}(t)$ is the measured length of reference distance, r, as a function of time;

$l_{c,r}$ is the calibrated length of reference distance, r.

If any $i_{cpc,i} < 1$, then the length measurement error, Δl_r, is calculated according to Equation (6):

$$\Delta l_r = \max \left| l_{m,r}(t) - l_{c,r} \right|_{t_b}^{t_e} \quad (6)$$

where

t_b is the beginning of the analysed time interval;

t_e is the end of the analysed time interval;

t_c is a user-defined time within the analysed time interval.

The accuracy value, $a_{refdist,r}$, is calculated according to Equation (7):

$$a_{refdist,r} = \frac{\Delta l_r}{l_{c,r}} \tag{7}$$

5.5.3 Length measurement error and accuracy value of the optical data channel

— The length measurement error of the optical data channel, ΔL, is the maximum of the length measurement errors, Δl_r, of all reference distances, r.

— The accuracy value of the optical data channel, a, is the maximum of the accuracy values, $a_{refdist,r}$, of all reference distances, r.

$$\Delta L = \max\left(\Delta l_r\right) \tag{8}$$

$$a = \max\left(a_{refdist,r}\right) \tag{9}$$

5.6 Types of procedure

5.6.1 General

Conformity with this International Standard can be verified by different types of procedure, depending on the desired complexity. The different types of procedure are shown in Table 3.

Table 3 — Types of procedure

Type of procedure	Before the real impact test		During the real impact test	
	Performance value	Accuracy value	Performance value	Accuracy value
Online	—	—	$Q \geqslant 0{,}7$	$\Delta L \leqslant a_{loc}$ $a \leqslant r_{avl}$
Offline	$Q \geqslant 0{,}8$	$\Delta L \leqslant a_{loc}$ $a \leqslant r_{avl}$	Synchronism index $i_{sy} \geqslant 1$ (only 3D analysis)	$\Delta L \leqslant a_{loc}$ $a \leqslant r_{avl}$

Key

Q performance value of the optical data channel

ΔL length measurement error of the optical data channel

a accuracy value of the optical data channel

r_{avl} user-defined accuracy value limit of the optical data channel

a_{loc} user-defined location accuracy of the optical data channel

5.6.2 Type of procedure — Online

5.6.2.1 The online procedure is of the highest complexity. All work shall be done for every impact test. The performance and the accuracy of the optical data channel can be checked during the test.

This procedure can be used, if the equipment of the optical data channel will often be changed essentially between the impact tests, or if no prior information about the optical data channel is available.

The user has the possibility to evaluate every component of the optical data channel for every impact test.

5.6.2.2 Tasks during the impact test are specified below.

— All described performance and accuracy indices shall be calculated during the real impact test.

— All described performance index values shall be at least 0,5.

— The performance value of the optical data channel, Q, shall be greater than 0,7.

— The length measurement error of the optical data channel, ΔL, shall be lower than the location accuracy, a_{loc}.

— The accuracy value of the optical data channel, a, shall be lower than the accuracy value limit, r_{avl}.

5.6.3 Type of Procedure — Offline

5.6.3.1 The offline procedure is of middle complexity. The main part of the calculation shall be done once in the preliminary test. The performance of the optical data channel can only be checked in this test. During the impact test, only the accuracy can be calculated. For a 3D analysis, the synchronism shall be checked.

This procedure can be used if the equipment of the optical data channel will not be changed, or if only minor changes will be done.

The user has the possibility to evaluate every component of the optical data channel once in the preliminary test. For every impact test, the user only has the possibility to evaluate the overall result of the optical data channel.

5.6.3.2 Tasks in the preliminary test are specified below.

— The lighting and the frame rates of the image recording devices in the preliminary test shall be similar to an impact test. The using of a VDI/VDE 1634 Part 1 artefact is recommended (see Reference [2]). The size of the artefact should correspond to the size of the measuring area of the impact test.

— All described performance index values shall be at least 0,5.

— The performance value of the optical data channel, Q, shall be greater than 0,8.

— The length measurement error of the optical data channel, ΔL, shall be lower than the location accuracy, a_{loc}.

— The accuracy value of the optical data channel, a, shall be lower than the accuracy value limit, r_{avl}.

5.6.3.3 Tasks during the impact test are specified below.

— For 3D analysis, the synchronism index shall be fulfilled, $i_{\text{sy}} \geqslant 1$.

— The length measurement error of the optical data channel, ΔL, shall be lower than the location accuracy, a_{loc}.

— The accuracy value of the optical data channel, a, shall be lower than the accuracy value limit, r_{avl}.

5.7 Conformity statement

The accuracy value represents the overall accuracy of any point measurement within the optical data channel when suitable general conditions are valid. This is guaranteed by the performance value.

An optical data channel conforms to this International Standard if the index value of the scale index is 1 and the accuracy value and the performance value fit the requirements of the used procedure.

5.8 Derived quantities

For derived computed quantities, the requests for the digital signal processing of a data channel shall be considered in accordance with ISO 6487.

5.9 User-defined variables

The user is able to influence the results of the testing procedure by the specification of user-defined variables. The conformity or non-conformity of this International Standard depends on these user-defined variables. They shall be listed in the inspection record. With these variables, the user specifies his desired measurement accuracy.

User-defined variables are given in Table 4.

Table 4 — User-defined variables

Variable	Symbol	Definition	Unit
location accuracy	a_{loc}	desired accuracy of the object or target being measured (target detection index, focal length index, distortion index, motion blur index, length measurement error)	length unit
allowed point motion	l_{apm}	allowed point motion between two sequenced images in object space (point motion index)	length unit
allowed accuracy relation	r_{aar}	allowed accuracy relation between the accuracy perpendicular to the camera base in the direction to the object and the accuracy in the other two directions (intersection index)	—
accuracy value limit	r_{avl}	desired accuracy relation of the reference distances being measured (accuracy value)	—

6 Documentation

For the interpretation of the accuracy and performance values, it is necessary to specify the used type of procedure (online/offline), the type of analysis (2D/3D), the number of image recording devices and the time interval used for the evaluation. All user-specific input values and all index values shall be recorded.

If the frame rate is not constant over the time interval, the time vector shall be recorded.

For the documentation of the performance of an optical data channel, an inspection record is recommended (see Clause A.4).

Annex A
(normative)

Index determination methods

A.1 2D performance indices

A.1.1 Focal length index, i_{fl}

The focal length index determines the influence of an incorrect focal length on the location accuracy. The accuracy of the determined focal length is calculated by algorithms determining the camera internal parameters.

For a 2D film analysis using a perpendicular set-up of the camera with respect to the movement plane (see A.1.8), and if reference distances are available in each motion plane (see A.1.9), the index value of the focal length index is 1. Otherwise, the index value shall be calculated by Equations (A.1) and (A.2), using the parameters in Table A.1.

Table A.1 — Parameters to determine focal length index

Parameter		Symbol	Definition	Unit
Input parameters	focal length	f	focal length of the used image recording device	length unit
	object distance	d	distance between object and image recording device	length unit
	focal length accuracy	a_{fl}	accuracy of the determined focal length	length unit
User-defined variables	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current location accuracy	a_{claf}	current accuracy of the object or target being measured	length unit

The functional connection is as shown in Equation (A.1):

$$a_{claf} = \frac{d}{f} \times a_{fl} \tag{A.1}$$

The requirement for the parameter focal length index, i_{fl}, is as shown in Equation (A.2):

$$i_{fl} = \frac{a_{loc}}{a_{claf}} \geqslant 1 \tag{A.2}$$

EXAMPLE If $f = 16$ mm, $d = 5\,000$ mm, $a_{loc} = 10$ mm and $a_{fl} = 0{,}02$ mm, then

$a_{claf} = (5\,000 \text{ mm}/16 \text{ mm}) \times 0{,}02 \text{ mm} = 6{,}25 \text{ mm}$

$i_{fl} = 10 \text{ mm}/6{,}25 \text{ mm} = 1{,}6$

$i_{fl} \geqslant 1$ ✓

A.1.2 Distortion index, i_d

The distortion index determines the influence of incorrect distortion parameters of the interior orientation on the location accuracy. The distortion accuracy is the remaining maximum residual of the process of determining the internal camera parameters. The distortion index value shall be calculated by Equations (A.3) and (A.4), using the parameters in Table A.2.

Table A.2 — Parameters to determine distortion index

Parameter		Symbol	Definition	Unit
Input parameters	focal length	f	focal length of the used image recording device	length unit
	object distance	d	distance between object and image recording device	length unit
	distortion accuracy	a_d	accuracy of the determined distortion parameters (maximum residuals)	pixel
	cell size	l_{cs}	cell size of the digital image	length unit/pixel
User-defined variables	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current location accuracy (distortion)	a_{clad}	current accuracy of the object or target being measured	length unit

The functional connection is as shown in Equation (A.3):

$$a_{clad} = \frac{d}{f} \times a_d \times l_{cs} \quad \text{(A.3)}$$

The requirement for the parameter distortion index, i_d, is as shown in Equation (A.4):

$$i_d = \frac{a_{loc}}{a_{clad}} \geqslant 1 \quad \text{(A.4)}$$

EXAMPLE If $f = 16$ mm, $d = 5\,000$ mm, $a_{loc} = 10$ mm, $a_d = 1$ pixel and $l_{cs} = 0{,}016$ mm/pixel, then

$a_{clad} = (5\,000 \text{ mm}/16 \text{ mm}) \times 1 \text{ pixel} \times 0{,}016 \text{ mm/pixel} = 5 \text{ mm}$

$i_d = 10 \text{ mm}/5 \text{ mm} = 2{,}0$

$i_d \geqslant 1$ ✓

A.1.3 Target detection index, i_{td}

The target detection index determines the influence of the target detection accuracy on the location accuracy. The worst target used in the analysis shall be used for the determination of the target detection index. The target detection index value shall be calculated by Equations (A.5) and (A.6), using the parameters in Table A.3.

Table A.3 — Parameters to determine target detection index

Parameter		Symbol	Definition	Unit
Input parameters	focal length	f	focal length of the used image recording device	length unit
	object distance	d	distance between object and image recording device	length unit
	target detection accuracy	a_{td}	target detection accuracy (e.g. determined by measurement on similar target type and target size of known location)	pixel
	cell size	l_{cs}	cell size of the digital image	length unit/pixel
User-defined variables	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current location accuracy (target)	a_{clat}	current accuracy of the object or target being measured	length unit

The functional connection is as shown in Equation (A.5):

$$a_{clat} = \frac{d}{f} \times a_{td} \times l_{cs} \tag{A.5}$$

The requirement for the parameter target detection index, i_{td}, is as shown in Equation (A.6):

$$i_{td} = \frac{a_{loc}}{a_{clat}} \geqslant 1 \tag{A.6}$$

EXAMPLE If $f = 16$ mm, $d = 8\ 000$ mm, $a_{loc} = 10$ mm, $a_{td} = 0{,}1$ pixel and $l_{cs} = 0{,}016$ mm/pixel, then

$a_{clad} = (8\ 000$ mm/16 mm$) \times 0{,}1$ pixel $\times 0{,}016$ mm/pixel $= 0{,}8$ mm

$i_{td} = 10$ mm/0,8 mm $= 12{,}5$

$i_{td} \geqslant 1$ ✓

A.1.4 Target size index, i_{ts}

The target size index compares the current and the required diameter of the targets in object space. The worst target used in the analysis shall be used for the determination of the target size index. The target size index value shall be calculated by Equations (A.7) and (A.8), using the parameters in Table A.4.

Table A.4 — Parameters to determine target size index

Parameter		Symbol	Definition	Unit
Input parameters	focal length	f	focal length of the used image recording device	length unit
	object distance	d	distance between object and image recording device	length unit
	required target diameter	l_{rtd}	required target diameter in image space (required by the analysis system developer)	pixel
	cell size	l_{cs}	cell size of the digital image	length unit/pixel
	current target diameter	l_{ctd}	real target diameter in object space	length unit
Derived values	theoretical target diameter	l_{ttd}	theoretical target diameter in object space	length unit

The functional connection is as shown in Equation (A.7):

$$l_{\text{ttd}} = \frac{d}{f} \times l_{\text{rtd}} \times l_{\text{cs}} \tag{A.7}$$

The requirement for the parameter target size index, i_{ts}, is as shown in Equation (A.8):

$$i_{\text{ts}} = \frac{l_{\text{ctd}}}{l_{\text{ttd}}} \geqslant 1 \tag{A.8}$$

EXAMPLE If f = 25 mm, d = 5 000 mm, l_{rtd} = 10 pixel and l_{cs} = 0,016 mm/pixel and l_{ctd} = 35 mm, then

l_{ttd} = (5 000 mm/25 mm) × 10 pixel × 0,016 mm/pixel = 32 mm

i_{ts} = 35 mm/32 mm = 1,09

$i_{\text{ts}} \geqslant 1$ ✓

A.1.5 Motion blur index, i_{mb}

The motion blur index determines the influence of the motion blur on the location accuracy. The motion blur index value shall be calculated by Equations (A.9) and (A.10), using the parameters in Table A.5.

Table A.5 — Parameters to determine motion blur index

Parameter		Symbol	Definition	Unit
Input parameters	object speed	v	maximum speed of the object perpendicular to the optical axis	length unit/time unit
	exposure time	e	exposure time of the used image recording device	time unit
User-defined variables	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current motion blur value	l_{cmbv}	current motion blur value at the object	length unit

The functional connection is as shown in Equation (A.9):

$$l_{\text{cmbv}} = 0{,}5 \times v \times e \tag{A.9}$$

The requirement for the parameter motion blur index, i_{mb}, is as shown in Equation (A.10):

$$i_{\text{mb}} = \frac{a_{\text{loc}}}{l_{\text{cmbv}}} \geqslant 1 \tag{A.10}$$

EXAMPLE If v = 18 m/s, e = 0,4 ms and a_{loc} = 5 mm, then

l_{cmbv} = 0,5 × 18 mm/ms × 0,4 ms = 3,6 mm

i_{mb} = 5,0 mm/3,6 mm = 1,39

$i_{\text{mb}} \geqslant 1$ ✓

A.1.6 Point motion index, i_{pm}

The point motion index determines the current point motion between two images of a sequence with respect to the test requirements. The point motion index value shall be calculated by Equations (A.11) and (A.12), using the parameters in Table A.6.

Table A.6 — Parameters to determine point motion index

Parameter		Symbol	Definition	Unit
Input parameters	object speed	v	maximum speed of the object perpendicular to the optical axis	length unit/time unit
	frame rate	f_r	frame rate of the image recording device during the test	1/time unit
User-defined variables	allowed point motion	l_{apm}	allowed point motion between two sequenced images in object space	length unit
Derived values	current point motion	l_{cpm}	current point motion between two sequenced images in object space	length unit

The functional connection is as shown in Equation (A.11):

$$l_{cpm} = v \times \frac{1}{f_r} \tag{A.11}$$

The requirement for the parameter point motion index, i_{pm}, is as shown in Equation (A.12):

$$i_{pm} = \frac{l_{apm}}{l_{cpm}} \geqslant 1 \tag{A.12}$$

EXAMPLE If $v = 14$ m/s, $f_r = 1\,000$ Hz and $l_{apm} = 15$ mm, then

$l_{cpm} = 14$ mm/ms $\times$ 1 ms $= 14$ mm

$i_{pm} = 15$ mm/14 mm $= 1{,}07$

$i_{pm} \geqslant 1$ ✓

A.1.7 Control point distribution index, i_{cpd}

The control point distribution index determines the number of control points in the different image sections (see Figure A.1) and the percentage coverage of the control point area over the image.

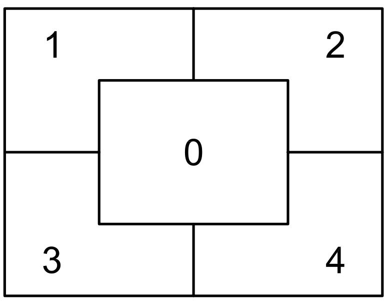


Figure A.1 — Sections of the image (specifications in accordance with Clause A.12 and Figure A.2)

For a 2D film analysis using a perpendicular set-up of the camera with respect to the movement plane (see A.1.8), the index value of the control point distribution index is 1. Otherwise, the index value shall be calculated by Equations (A.13) and (A.14), using the parameters in Table A.7.

Table A.7 — Parameters to determine control point distribution index

Parameter		Symbol	Definition	Unit
Input parameters	target in image section i	$p_{t,i}$	presence of targets in the special image sections	—
	image width	l_{iw}	width of the digital image	pixel
	image height	l_{ih}	height of the digital image	pixel
	control point formed area	A_{cf}	area which is formed by the control points (e.g. a triangle, if three points are used)	pixel × pixel
Derived values	control point distribution	p_{cpd}	parameter for the distribution of the control points	—
	control point area	p_{cpa}	parameter for the area of the control points	—
	image area	A_i	area of the digital image	pixel × pixel

The functional connection is as shown in Equation (A.13):

$$p_{t,i} = 1 \text{ if at least one target exists in image section } i$$

$$p_{t,i} = 0 \text{ if no target exists in image section } i$$

$$p_{cpd} = p_{t,1} + p_{t,2} + p_{t,3} + p_{t,4}$$

$$A_i = l_{iw} \times l_{ih}$$

$$\text{if } \frac{A_{cf}}{A_i} > 10\,\% \text{, then } p_{cpa} = 1$$

$$\text{if } \frac{A_{cf}}{A_i} \leqslant 10\,\% \text{, then } p_{cpa} = 0 \qquad \text{(A.13)}$$

The requirement for the parameter control point distribution index, i_{cpd}, is as shown in Equation (A.14):

$$i_{cpd} = \frac{p_{cpd} \times p_{cpa}}{3} \geqslant 1 \qquad \text{(A.14)}$$

EXAMPLE During the exposure, five control points are visible in the image: one is in section 2 ($p_{t,2} = 1$), one in section 3 ($p_{t,3} = 1$), two are in section 4 ($p_{t,4} = 1$) and one is in the centre of the image in section 0 (no effect).

If $l_{iw} = 768$ pixel, $l_{ih} = 512$ pixel and $A_{cf} = 122\,290{,}3$ pixel^2, then

$$p_{cpd} = 0 + 1 + 1 + 1 = 3$$

$$A_i = 768 \text{ pixel} \times 512 \text{ pixel} = 393\,216 \text{ pixel}^2$$

$$\frac{A_{cf}}{A_i} = \frac{122\,290 \text{ pix}^2}{393\,216 \text{ pix}^2} = 0{,}311 = 31{,}1\,\% > 10\,\% : p_{cpa} = 1$$

$i_{cpd} = (3 \times 1)/3 = 1$

$i_{cpd} \geqslant 1$ ✓

A.1.8 Camera set-up index, i_{cs} (only for 2D film analysis)

The camera set-up index describes the requirements to the orientation of the camera with respect to the plane of motion, which can be perpendicular or non-perpendicular.

Using the perpendicular set-up, the camera shall be oriented precisely perpendicular to the plane of motion.

A non-perpendicular set-up of the motion plane with respect to the optical axis of the camera is only allowed if all measured objects only move in the considered plane of motion. Using the non-perpendicular set-up the camera position and orientation shall be calculated with respect to the plane of motion and a perspective correction of the measurements shall be carried out. Furthermore, the control point distribution index and the focal length index shall be calculated and fulfilled.

The camera set-up index value shall be calculated by Equations (A.15) and (A.16), using the parameters in Table A.8.

Table A.8 — Parameters to determine camera set-up index

Parameter		Symbol	Definition	Unit
Input parameters	type of camera set-up	p_{tpc}	type of the set-up of the camera with respect to the plane of motion (perpendicular or non-perpendicular)	—
	index value of the focal length index	i_{fl}	all parameters for the focal length index (see A.1.1)	—
	index value of the control point distribution index	i_{cpd}	all parameters for the camera position calculation index (see A.1.7)	—

The functional connection is as shown in Equation (A.15):

$p_{tpc} = 1$ if the camera set-up is perpendicular to the plane of motion

$$p_{tpc} = 0 \text{ if the camera set-up is non-perpendicular to the plane of motion} \quad \text{(A.15)}$$

The requirement for the parameter camera set-up index, i_{cs}, is as shown in Equation (A.16):

$i_{fl} \geqslant 1$ and $i_{cpd} \geqslant 1$

$$i_{cs} = p_{tpc} + \left(i_{fl} \times i_{cpd}\right) \geqslant 1 \quad \text{(A.16)}$$

A.1.9 Plane scale index, i_{ps} (only for 2D film analysis)

The plane scale index describes the requirements to the scale information in each plane of motion. If not all objects are moving in one plane of motion, the scale information shall be determined in each additional plane of motion.

Then the scale information can be obtained by the use of an additional reference distance in that plane. The other possibility is to use the precise distance between the additional plane of motion and the reference plane to obtain the scale information.

The plane scale index value shall be calculated by Equations (A.17) and (A.18), using the parameters in Table A.9.

Table A.9 — Parameters to determine plane scale index

Parameter		Symbol	Definition	Unit
Input parameters	number of planes of motion	p_{np}	number of additional planes of motion	—
	reference distance in plane of motion i	$p_{rdp,i}$	presence of a reference distance in the plane of motion	—
	distance to plane of motion i	$p_{dtp,i}$	distance between the additional plane of motion and the reference plane	—
Derived values	scale information in plane of motion i	$p_{sip,i}$	parameter for the availability of the scale information in the plane of motion	—
	scale information in all planes of motion	p_{siap}	parameter for the availability of the scale information in all planes of motion	—

The functional connection is as shown in Equation (A.17):

$p_{rdp,i} = 1$ if a reference distance is present in the plane of motion

$p_{rdp,i} = 0$ if no reference distance is present in the plane of motion

$p_{dtp,i} = 1$ if the distance between reference plane and plane of motion has been measured

$p_{dtp,i} = 0$ if the distance between reference plane and plane of motion has not been measured

if $p_{rdp,i} = 1$ or $p_{dtp,i} = 1$, then $p_{sip,i} = 1$

if $p_{rdp,i} = 0$ and $p_{dtp,i} = 0$, then $p_{sip,i} = 0$

$$p_{siap} = \sum_{i=1}^{p_{np}} p_{sip,i} \tag{A.17}$$

The requirement for the parameter plane scale index, i_{ps}, is as shown in Equation (A.18):

$$i_{ps} = \frac{p_{siap}}{p_{np}} = 1 \tag{A.18}$$

EXAMPLE Using 2D film analysis, two object points are measured which move in two planes parallel to the reference plane. In the plane in which the first object point moves, a reference distance is placed. In the plane in which the second point moves, no reference distances are available, but the distance to the reference plane is measured precisely.

If $p_{np} = 2$, $p_{rdp,1} = 1$, $p_{dtp,1} = 0$, $p_{rdp,2} = 0$, $p_{dtp,2} = 1$, then

$p_{sip,1} = 1$, $p_{sip,2} = 1$, $p_{siap} = 2$

$i_{ps} = 2/2 = 1$

$i_{ps} = 1$ ✓

A.1.10 Time base index, i_{tb}

The time base index determines the influence of the time base accuracy on the location accuracy.

The time base index value shall be calculated by Equations (A.19) and (A.20), using the parameters in Table A.10.

Table A.10 — Parameters to determine time base index

Parameter		Symbol	Definition	Unit
Input parameters	frame rate	f_r	frame rate of the image recording device during the test	1/time unit
	object speed	v	maximum speed of the object	length unit/time unit
	time interval	t_{int}	analysed time interval of the test	time unit
	frame rate accuracy	a_{fr}	accuracy of the frame rate	—
User-defined values	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current location accuracy (time base)	a_{clatb}	current accuracy of the object or target being measured	length unit
	time drift	t_{td}	time drift of each time step	time unit
	total time drift	t_{ttd}	time drift of the entire time interval	time unit

The functional connection is as shown in Equation (A.19):

$$t_{td} = \frac{1}{f_r} \times a_{fr}$$

$$t_{ttd} = t_{td} \times t_{int} \times f_r$$

$$a_{clatb} = t_{ttd} \times v \qquad \text{(A.19)}$$

The requirement for the parameter time base index, i_{tb}, is as shown in Equation (A.20):

$$i_{tb} = \frac{a_{loc}}{a_{clatb}} \geqslant 1 \qquad \text{(A.20)}$$

EXAMPLE If f_r = 1 000 Hz, v = 18 m/s, a_{loc} = 10 mm, t_{int} = 140 ms and a_{fr} = 0,003, then

t_{td} = 1/1 000 Hz × 0,003 = 0,003 ms

t_{ttd} = 0,003 ms × 140 ms × 1 000 Hz = 0,42 ms

a_{clatb} = 0,42 ms × 18 m/s = 7,56 mm

i_{tb} = 10 mm/7,56 mm = 1,32

$i_{tb} \geqslant 1$ ✓

A.1.11 Time origin identification index, i_{toi}

The time origin identification index determines the influence of the time origin identification accuracy on the location accuracy.

The time origin identification index value shall be calculated by Equations (A.21) and (A.22), using the parameters in Table A.11.

Table A.11 — Parameters to determine time origin identification index

Parameter		Symbol	Definition	Unit
Input parameters	frame rate	f_r	frame rate of the image recording device during the test	1/time unit
	object speed	v	maximum speed of the object	length unit/time unit
	difference between t_0-image and -signal	t_{dtz}	time difference between the t_0-image and the t_0-signal	time unit
User-defined values	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current location accuracy (time orig.)	a_{clatoi}	current accuracy of the object or target being measured	length unit

The functional connection is as shown in Equation (A.21):

$$a_{clatoi} = t_{dtz} \times v$$

If t_{dtz} is unknown

$$a_{clatoi} = \frac{1}{f_r} \times v \tag{A.21}$$

The requirement for the parameter time origin identification index, i_{toi}, is as shown in Equation (A.22):

$$i_{toi} = \frac{a_{loc}}{a_{clatoi}} \geqslant 1 \tag{A.22}$$

EXAMPLE If f_r = 1 000 Hz, v = 18 m/s, a_{loc} = 10 mm, and t_{dtz} = 0,2 ms, then

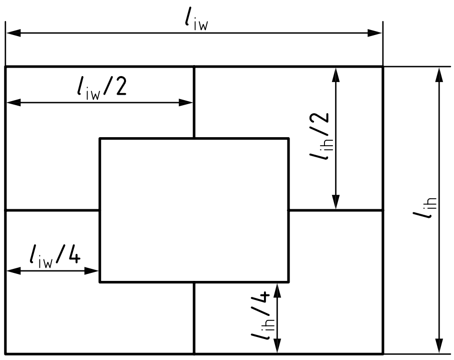
a_{clatoi} = 0,2 ms × 18 mm/ms = 3,6 mm

i_{toi} = 10 mm/3,6 mm = 2,78

$i_{toi} \geqslant 1$ ✓

A.1.12 Sections of the image

For the distortion index and the control point distribution index, the image shall be divided into five sections. The arrangement of these sections of the image is shown in Figure A.2.



Key

l_{iw} image width

l_{ih} image height

Figure A.2 — Definition of the image sections

A.2 3D performances indices

A.2.1 Intersection index, i_i

The intersection index compares the current and the allowed location accuracy in the direction to the object. The worst triangulation configuration for one object point should be used for index calculation. If this worst constellation consists of three or more cameras, the pair with the best configuration should be used.

The intersection index value shall be calculated by Equations (A.23) and (A.24), using the parameters in Table A.12.

Table A.12 — Parameters to determine intersection index

Parameter		Symbol	Definition	Unit
Input parameters	distance camera base to object	l_{dco}	distance between the object and the middle of the camera base	length unit
	camera base	l_{cb}	length of the camera base	length unit
	target detection accuracy	a_{td}	target detection accuracy (e.g. indicated by the developer of the detection algorithm and/or effect of compression – decompression)	pixel
	object distance of camera 1/2	d_1/d_2	distance between object and image recording devices	length unit
	focal length of camera 1/2	f_1/f_2	focal length of the used image recording devices	length unit
	cell size of camera 1/2	$l_{cs,1}/l_{cs,2}$	cell size of the digital images	length unit/pixel
User-defined values	allowed accuracy relation	r_{aar}	allowed relation between the accuracy perpendicular to the camera base in the direction to the object and the accuracy in the other two directions (worst case)	—
	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	current accuracy relation	r_{car}	current relation between the accuracy perpendicular to the camera base in the direction to the object and the accuracy in the other two directions	—
	current location accuracy (intersection)	a_{clai}	current accuracy of the object or target being measured	length unit
	allowed location accuracy in depth	a_{alaid}	allowed accuracy in the direction to the object	length unit
	current location accuracy in depth	a_{claid}	current accuracy in the direction to the object	length unit

The functional connection is as shown in Equation (A.23):

$$r_{car} = \frac{2 \times l_{dco}}{l_{cb}}$$

$$a_{clai} = \max\left[\left(\frac{d_1}{f_1}\right) \times \left(a_{td} \times l_{cs,1}\right); \left(\frac{d_2}{f_2}\right) \times \left(a_{td} \times l_{cs,2}\right)\right]$$

$$a_{claid} = r_{car} \times a_{clai}$$

$$a_{alaid} = a_{loc} \times r_{aar} \qquad \text{(A.23)}$$

The requirement for the parameter intersection index, i_i, is as shown in Equation (A.24):

$$i_i = \frac{a_{alaid}}{a_{claid}} \geqslant 1 \qquad \text{(A.24)}$$

EXAMPLE If d_1 = 8 000 mm, f_1 = 16 mm, $l_{cs,1}$ = 0,016 mm/pixel, d_2 = 7 800 mm, f_2 = 20 mm, $l_{cs,2}$ = 0,016 mm/pixel, a_{td} = 0,1 pixel, a_{loc} = 10 mm, l_{dco} = 7 900 mm, l_{cb} = 1 500 mm and r_{aar} = 3, then

r_{car} = (2 × 7 900 mm)/1 500 mm = 10,533

a_{clai} = max[(8 000 mm/16 mm) × (0,1 pixel × 0,016 mm/pixel);
(7 800 mm/20 mm) × (0,1 pixel × 0,016 mm/pixel)] = 0,8 mm

$a_{claid} = 10{,}667 \times 0{,}8 \text{ mm} = 8{,}427 \text{ mm}$

$a_{alaid} = 10 \text{ mm} \times 3 = 30 \text{ mm}$

$i_i = 30 \text{ mm}/8{,}427 \text{ mm} = 3{,}56$

$i_i \geqslant 1$ ✓

A.2.2 Synchronism index, i_{sy}

The synchronism index determines the influence of the asynchronism between the cameras on the location accuracy. The measurements of the image coordinates can also be corrected by interpolation with respect to a known asynchronism. Then the current asynchronism is the accuracy of the calculated asynchronism. At least the worst pair of image recording devices shall be used for the determination of the synchronism index.

The synchronism index value shall be calculated by Equations (A.25) and (A.26), using the parameters in Table A.13.

Table A.13 — Parameters to determine synchronism index

Parameter		Symbol	Definition	Unit
Input parameters	object speed	v	maximum object speed	length unit/time unit
	current asynchronism	t_{ca}	current asynchronism between the image recording devices (e.g. measured with a time base system)	time unit
	distance camera base to object	l_{dco}	distance between the object and the middle of the camera base	length unit
	camera base	l_{cb}	length of the camera base	length unit
User-defined values	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
	allowed accuracy relation	r_{aar}	allowed relation between the accuracy perpendicular to the camera base in the direction to the object and the accuracy in the other two directions (worst case)	—
Derived values	allowed location accuracy in depth	a_{alaid}	allowed accuracy in the direction to the object	length unit
	asynchronism effect perpendicular to the viewing direction	l_{aep}	asynchronism effect perpendicular to the viewing direction to the object	length unit
	asynchronism effect in viewing direction	l_{aed}	asynchronism effect in viewing direction to the object	length unit
	synchronism index perpendicular to the viewing direction	p_{syp}	synchronism index perpendicular to the viewing direction to the object	—
	synchronism index in viewing direction	p_{syd}	synchronism index in viewing direction to the object	—

The functional connection is as shown in Equation (A.25):

$$a_{alaid} = a_{loc} \times r_{aar}$$

$$l_{aep} = \frac{t_{ca} \times v}{2}$$

$$l_{aed} = \frac{t_{ca} \times v \times l_{dco}}{l_{cb}}$$

$$p_{syp} = \frac{a_{loc}}{l_{aep}}$$

$$p_{syd} = \frac{a_{alaid}}{l_{aed}} \qquad \text{(A.25)}$$

The requirement for the parameter synchronism index, i_{sy}, is as shown in Equation (A.26):

$$i_{sy} = \min\left(p_{syp}; p_{syd}\right) \geqslant 1 \qquad \text{(A.26)}$$

EXAMPLE If v = 18 m/s, t_{ca} = 0,2 ms, a_{loc} = 10 mm, l_{dco} = 8 000 mm, l_{cb} = 2 000 mm; r_{aar} = 3, then

a_{alaid} = 10 mm × 3 = 30 mm

l_{aep} = (0,2 ms × 18 m/s)/2 = 1,8 mm

l_{aed} = (0,2 ms × 18 m/s × 8 000 mm)/2 000 mm = 14,4 mm

p_{syp} = 10 mm/1,8 mm = 5,56

p_{syd} = 30 mm/14,4 mm = 2,08

i_{sy} = min (5,56; 2,08) = 2,08

$i_{sy} \geqslant 1$ ✓

A.3 Accuracy indices

A.3.1 Camera position calculation index, i_{cpc}

The camera position calculation index determines the influence of the camera position calculation method on the location accuracy.

The camera position calculation index value shall be calculated by Equations (A.27) and (A.28), using the parameters in Table A.14.

Table A.14 — Parameters to determine camera position calculation index

Parameter		Symbol	Definition	Unit
Input parameters	type of position determination	p_{tpd}	type of the determination procedure of the position of the image recording device (static or dynamic)	—
	maximum displacement in image space	l_{mdi}	maximum displacement of a fix point in image space	pixel
	cell size	l_{cs}	cell size of the digital image	length unit/pixel
	fix point distance	l_{fpd}	distance between the camera and a fix point	length unit
	focal length	f	focal length of the used image recording device	length unit
User-defined values	location accuracy	a_{loc}	desired accuracy of the object or target being measured	length unit
Derived values	maximum displacement of a fix point in object space	l_{mdo}	maximum displacement of a fix point in object space	length unit

The functional connection is as shown in Equation (A.27):

$p_{tpd} = 1$ if the position of the image recording device is determined dynamically

$p_{tpd} = 0$ if the position of the image recording device is determined only in one image

$p_{tpd} = 0$ if the position of the image recording device is not determined in a 2D film analysis

$$l_{mdo} = \frac{l_{mdi} \times l_{cs} \times l_{fdp}}{f} \quad \text{(A.27)}$$

The requirement for the parameter camera position calculation index, i_{cpc}, is as shown in Equation (A.28):

if $p_{tpd} = 1$, then $i_{cpc} = 1$

$$\text{if } p_{tpd} = 0 \text{, then } i_{cpc} = \frac{a_{loc}}{l_{mdo}} \geqslant 1 \quad \text{(A.28)}$$

EXAMPLE The position of the image recording device is determined only in one image.

If l_{mdi} = 1,3 pixel, l_{cs} = 0,016 mm/pixel, l_{fpd} = 5 000 mm, f = 25 mm and a_{loc} = 5 mm, then

$p_{tpd} = 0$

l_{mdo} = (1,3 pixel × 0,016 mm/pixel × 5 000 mm)/25 mm = 4,16 mm

i_{cpc} = 5 mm/4,16 mm = 1,20

$i_{cpc} \geqslant 1$ ✓

A.3.2 Scale index, i_s

The scale index determines the existence of the required reference distance in the different object space directions.

For a 2D film analysis, at least two reference distances are required which should be perpendicular to each other (90° ± 10°). They define a reference plane and shall be placed within the plane of motion or at a well known distance parallel to the plane of motion.

For a 3D film analysis, at least three reference distances which are perpendicular to each other (90° ± 10°) shall be placed in the measuring volume.

The scale index value shall be calculated by Equations (A.29) and (A.30), using the parameters in Table A.15.

Table A.15 — Parameters to determine scale index

Parameter		Symbol	Definition	Unit
Input parameters	reference distance in direction i	$p_{rd,i}$	presence of calibrated reference distances in the specified object space directions	—

The functional connection is as shown in Equation (A.29):

$p_{rd,i} = 1$ if at least one reference distance exists in direction i

$p_{rd,i} = 0$ if no reference distance exists in direction i

$$i_s = p_{rd,1} + p_{rd,2} + p_{rd,3} \tag{A.29}$$

The requirement for the parameter scale index, i_s, is as shown in Equation (A.30):

for 2D analysis, $i_s \geqslant 2$

for 3D analysis, $i_s = 3$ (A.30)

EXAMPLE In a 3D analysis, a system scale is specified in the images; furthermore, three more reference distances are visible in the images and are located in the object area at an angle of in each case 80° to each other.

If $p_{rd,1} = 1$, $p_{rd,2} = 1$ and $p_{rd,3} = 1$, then

$i_s = 1 + 1 + 1 = 3$

$i_s = 3$ ✓

A.4 Inspection record

A.4.1 General

The inspection record shall document all required aspects which are needed to control and reproduce the results of the testing procedure in accordance with this International Standard.

The inspection record consists of the following parts:

— main part with results;

— performance values (2D/3D);

— length measurement error and accuracy value;

— indices of all image recording devices;

— 3D indices (for 3D analysis only).

A.4.2 Main part with results

In this main part of the inspection record, the main information and the main results of the testing procedure are represented as shown in the example below.

EXAMPLE **Main part**

Laboratory test ref. number:	FR123456
Laboratory name:	Crash Inc.
Date of the test:	2003-09-10
Type of procedure:	Online

Type of analysis:	3D
Number of image recording devices:	6
Time interval:	0 ms to 140 ms

User-defined variables:

Location accuracy:	$a_{loc} = 10$ mm
Allowed point motion:	$l_{apm} = 18$ mm
Allowed accuracy relation:	$r_{aar} = 3$
Accuracy value limit:	$r_{avl} = 0{,}01$

Results and requirements with respect to the type of procedure and type of analysis:

Scale index:	$i_s = 3$	ok (= 3)
Performance value:	$Q = 0{,}94$	ok (⩾ 0,7)
Length measurement error:	$\Delta L = 4{,}43$ mm	ok (⩽ 10 mm)
Accuracy value:	$a = 0{,}003$	ok (⩽ 0,01)

Conformity with this International Standard: ok

A.4.3 Performance value

In this part of the inspection record, the determination of the 2D/3D performance value is listed in detail, as shown in the example below and summarized in Table A.16.

EXAMPLE **Performance value**

Type of procedure:	Online	
Type of analysis:	3D	
Number of image recording devices:	$u = 6$	
Number of 2D performance indices:	$n = 10$	
Number of 3D performance indices:	$m = 2$	
Number of index values ≤ 0,5:	$N = 0$	ok (= 0)
Performance value of the optical data channel:	$Q = 0{,}924$	ok (⩾ 0,70)

Table A.16 — Example of an overview of the performance value

ID	Name of image recording device	2D performance value q_i	Number of index values $\leqslant$ 0,5	Minimum requirement fulfilled
1	Left_Total.avi	1,00	0	ok
2	Left_Front.avi	1,00	0	ok
3	Top.avi	0,80	0	ok
4	Right_Total.avi	1,00	0	ok
5	Right_Rear.avi	0,80	0	ok
6	Front_Top.avi	1,00	0	ok

A.4.4 Length measurement error and accuracy value

In this part of the inspection record, the determination of the length measurement error and the accuracy value are listed in detail, as shown in the example below.

EXAMPLE **Length measurement and accuracy value**

Number of reference distances: $i = 3$

Beginning of the analysed time interval: $t_\mathrm{b} = 0$ ms

End of the analysed time interval: $t_\mathrm{e} = 140$ ms

Time of the accuracy calculation: $t_\mathrm{c} = 0$ ms

Length measurement error of the optical data channel: $\Delta L = 4{,}43$ mm ok ($\leqslant$ 10 mm)

Accuracy value of the optical data channel: $a = 0{,}003$ ok ($\leqslant$ 0,01)

Table A.17 — Example of an overview of the length measurement error and accuracy value

Reference distance $p_{\mathrm{rd},r}$	Calibrated length $l_{\mathrm{c},r}$	Measured length $l_{\mathrm{m},r}(t)$	Length measurement error Δl_r	Accuracy value $a_{\mathrm{refdist},r}$
1	1 136,79 mm	1 139 mm	2,21 mm	0,001 9
2	2 674,43 mm	2 670 mm	4,43 mm	0,000 9
3	861,22 mm	859 mm	2,22 mm	0,002 6

Camera position calculation indices:

The type of camera position calculation is reliable.

The lengths of the reference distances can be measured at an arbitrary time step.

Table A.18 — Example of an overview of the camera position calculation indices

Image recording device	Type of position calculation	Maximum displacement in object space l_{mdo}	Camera position calculation index	Result value
1	dynamic	—	1,000	ok
2	dynamic	—	1,000	ok
3	dynamic	—	1,000	ok
4	static	5,607	1,783	ok
5	dynamic	—	1,000	ok
6	dynamic	—	1,000	ok

Input parameters:

camera (1): l_{mdi} = — l_{fpd} = —

camera (2): l_{mdi} = — l_{fpd} = —

camera (3): l_{mdi} = — l_{fpd} = —

camera (4): l_{mdi} = 0,800 pixel l_{fpd} = 7 600 mm

camera (5): l_{mdi} = — l_{fpd} = —

camera (6): l_{mdi} = — l_{fpd} = —

A.4.5 2D indices

In this part of the inspection record, all parameters and results of the image recording devices are represented in summary. For each image recording device, there shall be one paragraph, as shown in the examples below.

EXAMPLE

2D indices of image recording device 1

Table A.19 — Example of an overview of 2D indices of an image recording device

	Index	Index value	Requirement	Index condition
1	Focal length index	1,078	⩾ 1	1
2	Distortion index	1,348	⩾ 1	1
3	Target detection index	13,480	⩾ 1	1
4	Target size index	1,078	⩾ 1	1
5	Motion blur index	3,210	⩾ 1	1
6	Point motion index	1,011	⩾ 1	1
7	Control point distribution index	1,333	⩾ 1	1
8	Time base index	1,338	⩾ 1	1
9	Time origin identification index	5,618	⩾ 1	1

Results:

Sum of the index conditions	$s = 9$
Number of 2D performance indices	$n = 9$
2D performance value of image recording device 1	$q_1 = 1{,}0$

User-defined variables:

location accuracy	$a_{\text{loc}} = 10{,}0$ mm
allowed point motion	$l_{\text{apm}} = 18{,}0$ mm

Input parameters:

focal length	$f = 17{,}254$ mm
object distance	$d = 8\ 000$ mm
focal length accuracy	$a_{\text{fl}} = 0{,}02$ mm
cell size	$l_{\text{cs}} = 0{,}016$ mm/pixel
distortion accuracy	$a_{\text{d}} = 1{,}0$ pixel
target detection accuracy	$a_{\text{td}} = 0{,}1$ pixel
required target diameter	$l_{\text{rtd}} = 5$ pixel
current target diameter	$l_{\text{ctd}} = 40$ mm
object speed	$v = 17{,}8$ m/s
exposure time	$e = 0{,}350$ ms
frame rate	$f_{\text{r}} = 1\ 000$ Hz
target exists in section 1	$p_{\text{t},1} =$ true
target exists in section 2	$p_{\text{t},2} =$ true
target exists in section 3	$p_{\text{t},3} =$ true
target exists in section 4	$p_{\text{t},4} =$ true
width of the digital image	$l_{\text{iw}} = 512$ pixel
height of the digital image	$l_{\text{ih}} = 384$ pixel
control point formed area	$A_{\text{cf}} = 58\ 530{,}7$ pixel^2
time interval	$t_{\text{int}} = 140$ ms
frame rate accuracy	$a_{\text{fr}} = 3$ ppm
time difference between t_0-image and t_0-signal	$t_{\text{dtz}} = 0{,}100$ ms

2D indices of image recording device 2

…

A.4.6 3D indices

In this part of the inspection record, the 3D indices are listed in detail. This part of the inspection record is only needed if the type of analysis is 3D, as shown in the example below.

EXAMPLE

3D indices of the optical data channel

Table A.20 — Example of an overview of 3D indices of the optical data channel

Index		Index value	Requirement	Index condition
1	Intersection index	4,676	⩾ 1	1
2	Synchronism index	4,242	⩾ 1	1

Results:

3D performance value of the optical data channel $p = 2$

Number of 3D performance indices $m = 2$

User-defined variables:

location accuracy $a_{loc} = 10,0$ mm

allowed accuracy relation $r_{aar} = 3$

Input parameters:

distance camera base (4 - 5) to object $l_{dco} = 8\ 000$ mm

camera base (4 - 5) $l_{cb} = 2\ 014$ mm

current asynchronism (4 - 5) $t_{ca} = 0,10$ ms

A.5 Examples

A.5.1 Type of procedure — Online/3D

A.5.1.1 Test description

A 3D film analysis of a vehicle impact crash test shall be verified for conformity with this International Standard. Image sequences of six digital high-speed cameras in a circular set-up are used for the 3D film analysis of the frontal crash test.

The user-defined variables for this analysis are as follows:

— location accuracy: $a_{loc} = 10$ mm

— allowed point motion: $l_{apm} = 18$ mm

— allowed accuracy relation: $r_{aar} = 3$

— accuracy value limit: $r_{avl} = 0,01$

The input parameters of the six digital high-speed cameras are listed in Table A.21.

Table A.21 — Example of an overview of the input parameters of six digital high-speed cameras

Input parameters			Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
focal length	f	mm	8	10	16	17	16	17
object distance	d	mm	2 500	5 000	8 000	8 000	8 000	8 000
focal length accuracy	a_{fl}	mm	0,02	0,02	0,02	0,02	0,02	0,02
cell size	l_{cs}	mm/pixel	0,016	0,016	0,016	0,016	0,016	0,016
distortion accuracy	a_d	pixel	1,0	1,0	1,0	1,0	1,0	1,0
target detection accuracy	a_{td}	pixel	0,1	0,1	0,1	0,1	0,1	0,1
required target diameter	l_{rtd}	pixel	5	5	5	5	5	5
current target diameter	l_{ctd}	mm	40	40	40	40	40	40
object speed	v	m/s	17,6	17,6	17,6	17,6	17,6	17,6
exposure time	e	µs	250	250	250	250	250	250
frame rate	f_r	Hz	1 000	1 000	1 000	1 000	1 000	1 000
target exists in section 1	$p_{t,1}$	—	true	true	true	true	true	true
target exists in section 2	$p_{t,2}$	—	false	true	true	true	false	true
target exists in section 3	$p_{t,3}$	—	true	true	false	true	true	true
target exists in section 4	$p_{t,4}$	—	false	false	true	true	true	true
width of the digital image	l_{iw}	pixel	512	512	512	512	512	512
height of the digital image	l_{ih}	pixel	384	384	384	384	384	384
control point formed area	A_{cf}	pixel^2	58 530,7	58 520,7	58 540,7	58 510,7	58 550,7	58 560,7
time interval	t_{int}	ms	150	150	150	150	150	150
frame rate accuracy	a_{fr}	ppm	3	3	3	3	3	3
time difference t_0	t_{dtz}	ms	0,1	0,1	0,1	0,1	0,1	0,1

A.5.1.2 Determination of the test results

The determination of the conformity check can be subdivided into three main parts.

a) Calculation of the performance of the optical data channel (see 5.4).

The performance of the optical data channel shall be calculated using the following workflow:

— calculation of all 2D performance indices of each camera (see 5.4.2 and Clause A.1);

— calculation of the 3D performance indices for the test (see 5.4.2 and Clause A.2);

— calculation of the 2D performance value of each camera (see 5.4.3);

— calculation of the 3D performance value for the test (see 5.4.4);

— calculation of the performance value of the optical data channel (see 5.4.5).

b) Calculation of the accuracy of the optical data channel (see 5.5).

The accuracy of the optical data channel shall be calculated using the following workflow:

— calculation of all accuracy indices (see 5.5.1 and Clause A.3);

— calculation of the length measurement error and the accuracy value of each reference scale (see 5.5.2);

— calculation of the length measurement error and the accuracy value of the optical data channel (see 5.5.3).

c) Conformity check for the impact test.

The decision of the conformity check for the impact test shall be made with respect to the limits of the online procedure (see 5.6.1 and 5.6.2).

A.5.1.3 Documentation of the conformity check results

The results should be documented in an inspection record (see Clause A.4). Extracts of the inspection record of this conformity check are shown in Clause A.4.

A.5.2 Type of procedure — Offline/3D

A.5.2.1 Test description

The same impact test as described in A.5.1 is analysed using an offline procedure. A preliminary test is carried out acquiring a test artefact as described in Reference [2]. The equipment and the camera constellation used in the impact test shall be the same as in the preliminary test.

The user-defined variables for this analysis are as follows:

— location accuracy: $a_{loc} = 10$ mm

— allowed point motion: $l_{apm} = 18$ mm

— allowed accuracy relation: $r_{aar} = 3$

— accuracy value limit: $r_{avl} = 0{,}01$

The input parameters of the six digital high-speed cameras are listed in Table A.21.

A.5.2.2 Determination of the results of the preliminary test

The conformity check of the preliminary test can be subdivided into three main parts.

a) Calculation of the performance of the optical data channel (see 5.4).

The performance of the optical data channel shall be calculated using the following workflow:

— calculation of all 2D performance indices of each camera (see 5.4.2 and Clause A.1);

— calculation of the 3D performance indices for the test (see 5.4.2 and Clause A.2);

— calculation of the 2D performance value of each camera (see 5.4.3);

— calculation of the 3D performance value for the test (see 5.4.4);

— calculation of the performance value of the optical data channel (see 5.4.5).

b) Calculation of the accuracy of the optical data channel (see 5.5).

The accuracy of the optical data channel shall be calculated using the following workflow:

— calculation of all accuracy indices (see 5.5.1 and Clause A.3);

— calculation of the length measurement error and the accuracy value of each reference scale (see 5.5.2);

— calculation of the length measurement error and the accuracy value of the optical data channel (see 5.5.3).

c) Conformity check for the impact test.

The decision of the conformity check for the preliminary test shall be made with respect to the limits of the offline procedure (see 5.6.1 and 5.6.3).

A.5.2.3 Determination of the results of the impact test

The conformity check of the impact test can be subdivided into three main parts.

a) Calculation of the synchronism index (see A.2.2).

b) Calculation of the accuracy of the optical data channel (see 5.5).

The accuracy of the optical data channel shall be calculated using the following workflow:

— calculation of all accuracy indices (see 5.5.1 and Clause A.3);

— calculation of the length measurement error and the accuracy value of each reference scale (see 5.5.2);

— calculation of the length measurement error and the accuracy value of the optical data channel (see 5.5.3).

c) Conformity check for the impact test.

The decision of the conformity check for the impact test shall be made with respect to the limits of the offline procedure (see 5.6.1 and 5.6.3). For a conformity check of an offline procedure, the preliminary test and the impact test shall fulfil the conformity requirements.

A.5.2.4 Documentation of the conformity check results

The results of the preliminary test and of the impact test should be documented in inspection records (see Clause A.4).

A.5.3 Type of procedure — Online/2D

A.5.3.1 Test description

A 2D film analysis of a vehicle impact crash test shall be verified for conformity with this International Standard. The movement of the steering wheel during a 0° passive frontal crash shall be measured. Only one camera with the total view from the left side was analysed for this test.