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Pumps — Minimum required efficiency of rotodynamic water pumps

National foreword

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Pumps - Minimum required efficiency of rotodynamic water pumps

Pompes - Rendement minimum requis des pompes à eau rotodynamiques

Pumpen - Geforderte Mindesteffizienz bei Kreiselpumpen für Wasser

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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European foreword

This document (EN 16480:2016) has been prepared by Technical Committee CEN/TC 197 “Pumps - Minimum required efficiency of rotodynamic water pumps”, 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of an identical text or by endorsement, at the latest by November 2016, and conflicting national standards shall be withdrawn at the latest by November 2016.

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This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 2009/125/EC.

For relationship with EU Directive 2009/125/EC, see informative Annex ZA, which is an integral part of this document.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

Purpose and content of the standard

The water pumps within the scope of this European Standard are typically produced and sold by pump manufacturers as series of large to very large numbers. The performance characteristics of pumps of one size produced by a manufacturer show some scatter caused by manufacturing tolerances, but are described by mean values and curves which represent that size.

The total consumption of electric energy by water pumps installed in applications within the scope of this European Standard depends on the total number of installed pumps of each size and on its mean efficiency. The quality of a size in respect to its mean efficiency is quantitatively described by the Minimum Efficiency Index (MEI) which is defined and used in this standard. To achieve a certain value of the Minimum Efficiency Index (MEI), a corresponding minimum value of the mean efficiency of a size is required.

This European Standard defines – for each pump type and size within the scope of the standard - the minimum required value of efficiency depending on the value of the Minimum Efficiency Index (MEI). Also, this standard prescribes how the value of the Minimum Efficiency Index (MEI) of a pump size indicated by the manufacturer can be verified by an independent institution (e.g. in the frame of market surveillance). For the manufacturer of the pump size it is generally left free how to prove the indicated value of the Minimum Efficiency Index (MEI) of a size. Nevertheless, this standard describes also a method to prove by the manufacturer that the mean values of efficiency meet the requirements for indicating a certain value of the Minimum Efficiency Index (MEI).

Normally, the qualification of a pump size for a certain MEI value done by the manufacturer will be based on tests and evaluations made on a sample of pumps of this size. It is essential that tests and evaluations carried out for the purpose of qualifying the corresponding size fulfil certain requirements:

— From the tests on the sample pumps, it becomes possible to predict for the corresponding size the confidence intervals within which the true mean values of efficiencies which are relevant for the qualification are enclosed with a sufficiently high probability. Only in that way, the qualification of the size in respect to a required and/or indicated value of Minimum Efficiency Index (MEI) will make sure that the aspired effect of energy saving will be reached.

— If a pump size has been qualified according to the criteria described in this European Standard, every test on one or more test pump(s) of the same size (with a full impeller diameter) which is carried out in the frame of a verification procedure shall result with a very high probability in a confirmation of the qualification.

Caused by technical alignment procedures of the single pump components, e.g. bearings or shaft seals, the performance of the pump is gained after a certain running-in time.

Ways to prove and to verify the Minimum Efficiency Index (MEI) of a pump size

This European Standard describes different ways how manufacturers can achieve the qualification of a pump size for a certain value of the Minimum Efficiency Index (MEI) and how this qualification can be verified by an independent institution.

For the <u>manufacturer</u>, it is generally left free to choose and apply appropriate methods to prove that the mean efficiency values of a size are at least equal to or higher than particular threshold values of efficiency. These particular threshold values of efficiency are related to the value of the Minimum Efficiency Index (MEI) to be indicated for the size. The way to determine these values of efficiency is described in this standard. If the way chosen by the manufacturer to prove the MEI value of a size deviates from the way mentioned in the next paragraph, the manufacturer has to document all tests, evaluations and/or calculations which are carried out and the methods which are applied to prove the justification of the indicated MEI value.

If the manufacturer decides to determine the mean performance values of the size by one of the methods described in Annex D of this standard, he has to carry out tests according to the requirements given in Annex C of this standard and evaluations as described in Annex C of this standard and to prove – as described in Clause 7 of this standard – that the criteria for the achievement of a certain value of the Minimum Efficiency Index (MEI) of the size are fulfilled. The test conditions, the results of test evaluation and the fulfilment of the criteria are documented and stored. The time period to keep documentation available for the authorities to prove conformity is fixed by the legal text.

The independent institution carries out tests on pumps of the size in question according to the requirements given in 5.2 to 5.4 of this standard as well as evaluations as described in 5.5 of this standard and applies the methodology and procedure described in Clause 4 of this standard.

For an independent institution, two ways are possible and specified by this standard to verify the value of Minimum Efficiency Index (MEI) indicated by the manufacturer:

a) If the documentation of the qualification is presented by the manufacturer to the independent institution on request, the procedure of verification executed by the independent institution is based on the documentation of tests and evaluations done and documented by the manufacturer. In this case, the documentation will be checked by the independent institution in respect to being in accordance with requirements and criteria given in this standard.

b) If no documentation is presented by the manufacturer on request or if the documentation presented by the manufacturer on request is not accepted as proof of the indicated value of MEI, the independent institution carries out tests on pumps of the size in question according to the requirements given in Annex C of this standard as well as evaluations as described in 5.5 of this standard and applies the methodology and procedure described in Clause 4 of this standard.

Relevance of Sections of this standard for manufacturers or independent institutions

Clause 4 describes nominal values of minimum required efficiency for a certain value of the Minimum Efficiency Index (MEI) and is generally relevant when applying this standard.

Clause 5 specifies test procedures, test conditions and evaluations and has to be applied

— by a manufacturer in the case that he decides to determine mean values of a size by tests on sample pumps of this size (e.g. by methods described in Annex D),

— by an independent institution in the case that the Minimum Efficiency Index (MEI) of a pump size shall be verified by the procedure described in Clause 7.

Clause 6 describes the procedure to be applied by a manufacturer in order to determine particular threshold values of efficiency for a certain value of the Minimum Efficiency Index (MEI) of a size and to prove the justification of this MEI value by the fulfilment of criteria for the mean efficiency values.

Clause 7 describes the methodology and procedure to be applied by an independent institution in the case that the Minimum Efficiency Index (MEI) of a size indicated by the manufacturer shall be verified by third party tests on pumps of this size.

Annex C is concerned with mean values of a pump size which are relevant for manufacturers to prove that a pump size achieves a certain value of the Minimum Efficiency Index (MEI).

1 Scope

This European Standard specifies performance requirements (methods and procedures for testing and calculating) for determining the Minimum Efficiency Index (MEI) of rotodynamic glanded water pumps for pumping clean water, including where integrated in other products.

The pump types and sizes covered by this standard are described in the Annex A. These pumps are designed and produced as duty pumps for pressures up to 16 bar for end suction pumps and up to 25 bar for multistage pumps, temperatures between -10 °C and +120 °C and 4” or 6” size for submersible multistage pumps at operating temperatures within a range of 0 °C and 90 °C.

In addition, this standard specifies how the value of the Minimum Efficiency Index (MEI) of a pump size indicated by the manufacturer can be checked by market surveillance.

Even if it is left free to the manufacturer of a pump size how to prove the rated value of the Minimum Efficiency Index (MEI), nevertheless this standard specifies a method to prove that this rated value meets the requirements within the confidence intervals with a sufficiently high probability.

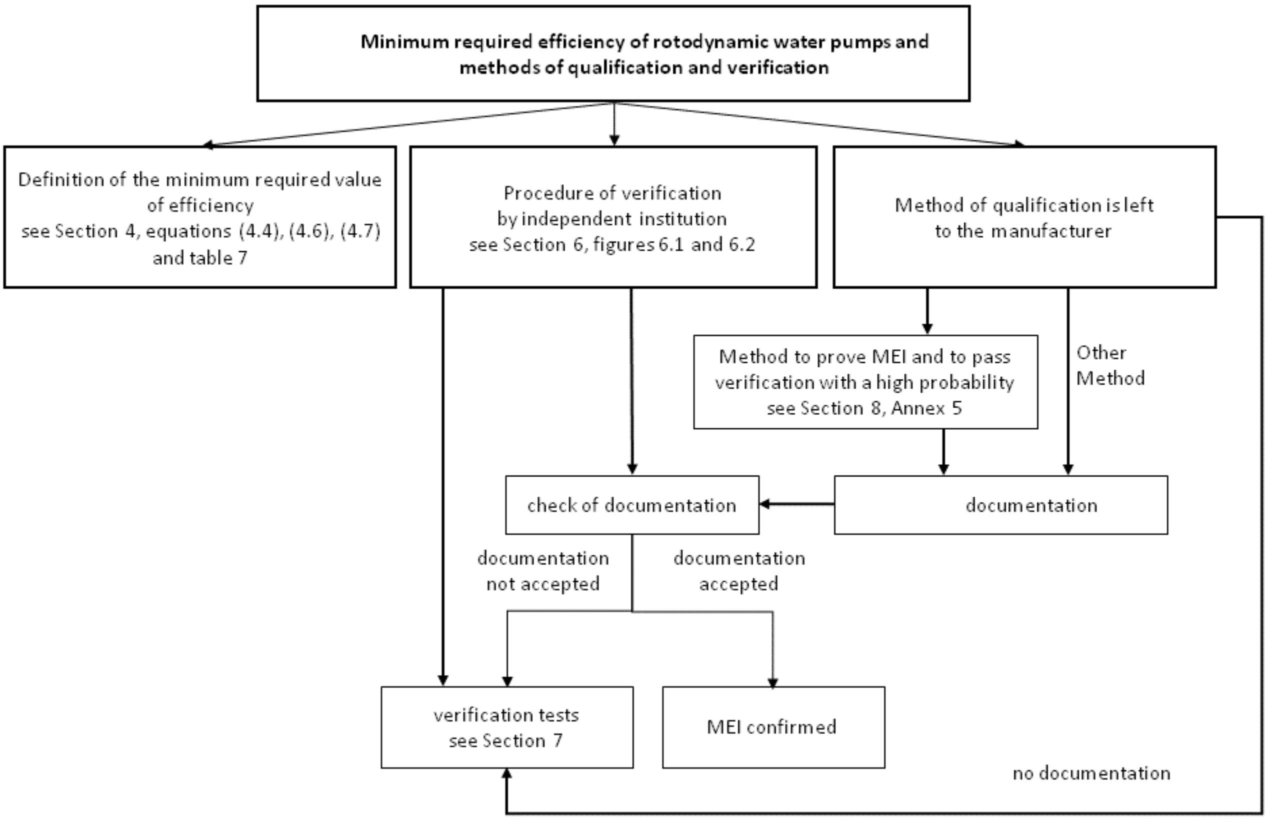


Figure 1 — Scheme of application of this standard

2 Normative references

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

EN ISO 9906:2012, *Rotodynamic pumps — Hydraulic performance acceptance tests — Grades 1, 2 and 3 (ISO 9906:2012)*

3 Terms and definitions

3.1 General

For the purposes of this European Standard, the quantities, definitions, symbols and units given in EN ISO 9906 and in 3.2 apply. 3.2 gives specific definitions of terms - in deviation of EN ISO 9906 - used in this European Standard, together with any associated symbols which have been allocated and is based on ISO 80000.

Table 1 gives an alphabetical list of symbols used and Table 2 gives a list of subscripts. As far as possible, the quantities, definitions and symbols used in this standard comply with those used in EN ISO 9906. Quantities, definitions and symbols used in EN ISO 9906, but not needed in this standard are not contained in 3.2 and Tables 1 and 2, while these tables contain some quantities, definitions and symbols which are not used in EN ISO 9906.

In this European Standard, all formulae are given in coherent SI-units.

3.2 List of quantities with definitions

For the purposes of this document, the following terms and definitions apply. Most of the terms and definitions come from EN ISO 9906, except for the definition of MEI.

3.2.1
Reynolds number
dimension less number that gives a measure of the ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for given flow conditions. In this standard, it is defined by the relation:

$$\mathrm{Re} = \frac{D_{imp} \cdot u}{\nu}$$

where u is the peripheral velocity at the outer impeller diameter D_{imp}

3.2.2
(volume) rate of flow
external rate of flow of the pump, i.e. the rate of flow discharged into the pipe from the outlet branch of the pump

Note 1 to entry: Losses or abstractions inherent to the pump, i.e.:

— discharge necessary for hydraulic balancing of axial thrust;

— cooling of bearings of the pump itself;

— water seal to the packing.

Note 2 to entry: Leakage from the fittings, internal leakage, etc. is not to be reckoned in the rate of flow. On the contrary, all derived flows for other purposes, such as cooling of the motor bearings; cooling of a gear box (bearings, oil cooler), etc. are to be reckoned in the rate of flow.

Note 3 to entry: Whether and how these flows shall be taken into account depends on the location of their derivation and of the section of flow-measurement respectively.

3.2.3
driver power input
power absorbed by the pump driver

3.2.4
pump efficiency

$$\eta = \frac{P_{\text{hyd}}}{P_2} = \frac{\textit{Hydraulic output}}{\textit{Pump power input}}$$

3.2.5
driver efficiency

$$\eta_{\text{dr}} = \frac{P_2}{P_1} = \frac{\textit{Pump power input}}{\textit{Driver power input}}$$

3.2.6
overall efficiency

$$\eta_{\text{tot}} = \frac{P_{\text{hyd}}}{P_1} = \frac{\textit{Pump power output}}{\textit{Driver power input}}$$

3.2.7
specific speed
dimensional number characterizing the impeller type (radial, semi-axial, axial) of rotodynamic pumps

$$n_s = n_N \cdot \frac{\sqrt{Q_{BEP}}}{H_{BEP}^{0.75}}$$

Note 1 to entry: For multistage pumps, H_{BEP} is the head per stage which results from dividing the total pump head at the point of best efficiency by the number of stages.

Note 2 to entry: The specific speed of an individual pump or the mean specific speed of a pump size is a (dimensional) value which characterizes the impeller shape (radial, semi-axial, axial) of the pump or the size. The numerical value of the specific speed is defined by an equation given in 3.2.7 by using special units for the quantities contained in this equation. As described in Clause 4, the specific speed is one of the parameters which the nominal values of minimum required efficiency depend on.

3.2.8
minimum efficiency index
MEI
value which determines the minimum required efficiency for the qualification criteria and, thereby, is a measure of the quality of a pump size in respect to efficiency

Note 1 to entry: Dimensionless scale unit for hydraulic pump efficiency at BEP, PL and OL.

Note 2 to entry: The MEI is the result of a statistical analysis of the performances of a large number of commercial pump sizes, and corresponds to the various “quartiles” of the statistical distribution.

For example, MEI = 0,40 corresponds to the efficiency performance level that 40 % of the pumps on the market do not meet.

3.3 Lists of basic letters and subscripts

Table 1 — Alphabetical list of basic letters used as symbols

Symbol	Quantity	Unit
A	Area	m^2
C	Constant	pure number
D	Diameter	m
e	Measurement uncertainty, relative value	pure number
f	Frequency	s^{-1}, Hz
g	Acceleration due to gravity	m/s^2
H	Pump total head	m
k	Number of instrument readings or sample pumps	pure number
m	Mass	kg
M	Number of pumps of a sample	pure number
n	Speed of rotation	s^{-1}, min^{-1}
N	Number of instrument readings	pure number
n_s	Specific speed	min^{-1}
p	Pressure	Pa
p	Probability	pure number
P	Power	W
Q	(Volume) rate of flow	m^3/s
s	Standard deviation of a sample	according to special quantity
t	Tolerance factor, relative value	pure number
t	Time	s
t	Student´s factor	pure number
T	Torque	Nm
u	Peripheral velocity	m/s
U	Mean velocity	m/s
U	Voltage	V
v	Local velocity	m/s
V	Volume	m^3
x	General quantity	according to special quantity

Symbol	Quantity	Unit
y	General quantity	according to special quantity
z	Height above reference plane	m
z	Number of produced pumps	pure number
η	Efficiency	pure number
θ	Temperature	°C
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
ω	Angular velocity	rad/s
σ	Standard deviation of normal distribution	according to special quantity

For a list of concise designations (short term description) of pump types in scope, see Annex B.

Table 2 — List of letters and figures used as subscripts

Subscript	Meaning
1	electrical
2	mechanical
abs	absolute
amb	ambient
annual	per year
curve	on fitting curve
BEP	at best efficiency point
dr	driver
D	datum
exp	experimentally determined
G	guaranteed
H	pump total head
I	numbering index
J	numbering index
imp	impeller
man	manufacturing
max	maximum permissible
mean	mean value of pump series
min,requ	minimum required
N	nominal
OL	overload
Pd	pre-defined

Subscript	Meaning
P	power
PL	part load
Q	(volume) flow rate
R	random
S	specific, systematic
sync	synchronous
tot	total, overall
true	true value
T	torque
T	translated
v	vapour
x	of quantity x
y %	for probability of y %
η	efficiency
hyd	hydraulic

3.4 General definitions

3.4.1
qualification
procedure where the manufacturer of the pump size proves, by appropriate methods, the fulfilment of the efficiency criteria defined in this standard

Note 1 to entry: Generally, the qualification criteria refer to the mean values of the size which are valid for the full impeller diameter and which will be determined by tests and evaluations on pumps of the respective size. These mean efficiency values and their confidence intervals are compared to nominal values of minimum required efficiency. Also, these values depend on parameters (see Clause 4) the values of which partly result from the tests and are determined with some uncertainty or tolerance. Therefore, so-called particular threshold values of efficiency are determined and used in the frame of the qualification procedure for comparison with the mean values.

3.4.2
verification
procedure where an independent institution checks the result of the qualification procedure, in the frame of market surveillance

Note 1 to entry: In this case, the tests and the evaluation of the test data are carried out according to Clause 5 of this European Standard. The approval decision is taken according to the procedure described in Clause 7 of this European Standard.

3.4.3
independent institution/market surveillance
organization mandated by the market surveillance for verification of MEI values indicated by manufacturers

Note 1 to entry: These organizations are generally called independent institutions whatever the special type of the institution (non-governmental organization (NGO), neutral institute, market surveillance authorities or similar) may be.

Note 2 to entry: Neutral institutions or similar organizations can also be mandated by a manufacturer for the qualification procedure, in this case they are not considered as independent institution when applying this standard.

3.4.4
minimum required efficiency
$\eta_{min,requ}$
value of efficiency that have to be reached in order to fulfil a particular MEI value

Note 1 to entry: The value of minimum required efficiency depends on certain properties of the pump size (pump type, nominal speed of rotation, flow rate at best efficiency point and specific speed) and on the Minimum Efficiency Index (MEI). For one size, different minimum required efficiencies are relevant at best efficiency point, at specified part load and overload operating points, respectively.

3.4.5
particular threshold values of efficiency
$\eta_{threshhold}$
values calculated from the minimum required efficiency by subtracting a total tolerance

3.4.6
pump size
range of pumps characterized by certain dimensions (e.g. nominal diameter of discharge flange and nominal impeller diameter for end-suction and multistage pumps, nominal outer casing diameter in the case of submersible multistage pumps) and given in his catalogues by the manufacturer

Note 1 to entry: In a Q-H-chart each pump size covers a certain range of Q- and H-values. Within this range, each duty point can be served by a pump of the corresponding pump size by adapting its Q-H-curve by impeller trimming, i.e. by cutting down the outer impeller diameter to an appropriate value. The upper limit of the Q-H-range covered by one pump size is determined by the full diameter of the impeller corresponding to this size.

3.4.7
full impeller diameter of a pump size
impeller with the maximum diameter for which performance characteristics are given for a pump size in the catalogues of a water pump manufacturer

3.4.8
best efficiency point
BEP
operating point where the greatest value of pumps efficiency is obtained, at nominal speed of rotation

3.4.9
part load
PL
particular operating point in the range of operating points with lower flow than best efficiency point, at nominal speed of rotation

3.4.10
overload
OL
particular operating point in the range of operating points with higher flow than best efficiency point, at nominal speed of rotation

4 Minimum Required Efficiencies and Minimum Efficiency Index

4.1 The concept of "house of efficiency"

To achieve the goal of energy saving by replacing less energy efficient pumps by pumps which are qualified in respect to fulfilling criteria of minimum required efficiency, two important aspects have to be taken into account:

a) The required minimum values of η_{BEP} shall be fulfilled by the mean values of the qualified pump sizes which are produced and sold in large numbers. Therefore, these mean values shall be determined by appropriate methods and then be compared to minimum required values which are based on general physical interrelations (see Annex B) as well as on a statistical evaluation of existing pumps of "state of the art" design and manufacturing quality (see 4.2 and 4.3).

b) Not only the value of η_{BEP} is relevant for energy consumption and saving by pumps, but also the efficiency in the part load and overload ranges of operation. This is caused by two reasons:

The product program of pump manufacturers for a certain pump type is – from economic reasons – subdivided into a limited number of different pump sizes which each cover a certain range of flow rate Q and pump head H. This leads to the effect that not for any Q-H duty point (i.e. the operating point specified by the pump user which normally is the most probable point of operation) for a pump application, a pump size will exist for which its best efficiency point is identical to the required duty point. The selection of the "best choice" size for a given application will most often cause the duty point to be a slight "off-design", i.e. part load or overload, point of the selected size. (For more information to aspects of pump selection, see Annex B.)

Even if the best efficiency point of a pump size fits exactly to a required duty point, the pump will normally be operated in a range of operation and not only at its duty point. This can result from changes or variations of the hydraulic resistance of the circuit (caused either by varying demand of system flow rate or by long time effects as, e.g. internal incrustation of pipes) or, in the case of parallel operation of pumps, from variable operation conditions when different numbers of pumps are running.

Therefore, the qualification of a pump size in respect to minimum required efficiency is based on the so-called concept "house of efficiency" which includes two criteria A and B.

Criterion A is the minimum efficiency requirement at the best efficiency point (BEP) of the pump size:

A.

$$(\eta_{BEP})_{mean} \geq (\eta_{BEP})_{\min,\, requ} \tag{1}$$

Criterion B is the minimum efficiency requirement at specified part load (PL) and overload (OL) operating points of the pump size:

B.

$$(\eta_{PL})_{mean} \geq (\eta_{PL})_{\min, requ} \tag{2}$$

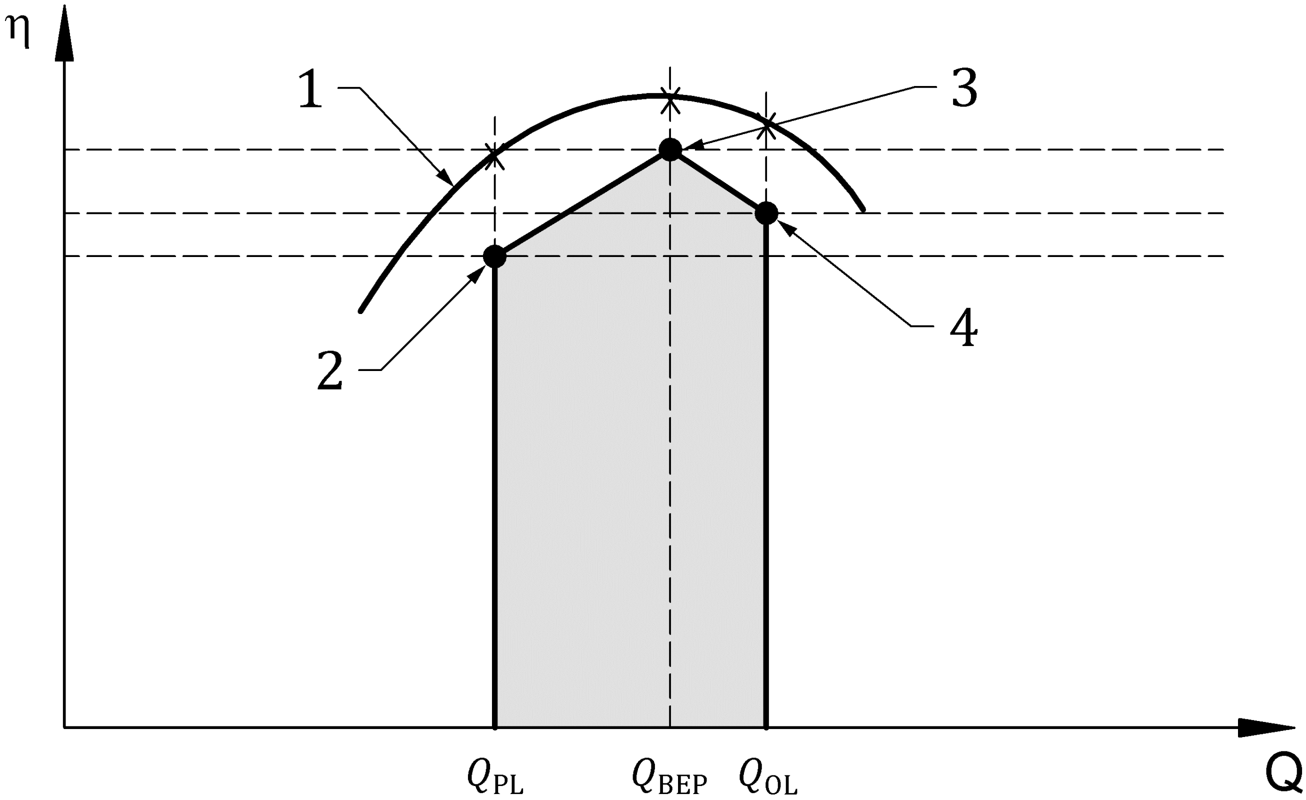
$$(\eta_{OL})_{mean} \geq (\eta_{OL})_{\min, requ} \tag{3}$$

In this standard, the operating points which shall be representative for the efficiency in the part load and overload range are fixed at Q_{PL} = 0,75 Q_{BEP} and Q_{OL} = 1,1 Q_{BEP}.

All efficiency values in the criteria given above are mean values of the pump size and are to be taken for pumps of this size with full impeller diameter.

As a result, the mean efficiency curve of the size has to show a high maximum and a broad width to fulfil the criteria for qualification.

In Figure 2 the representation of the two criteria is shown in a *Q-η* diagram. To be qualified, the mean efficiency curve of the size with its maximum at the best efficiency point shall not penetrate into the "roof" of the "house of efficiency".



Key

η pump efficiency

Figure 2 — 'House of Efficiency' - explanatory representation

4.2 Mathematical representation of minimum required efficiency

The minimum required efficiency values for pump sizes fulfilling the qualification criteria A and B are based on scientific analyses of the attainable efficiency of rotodynamic pumps as well on a statistical evaluation of data collected from several questionnaires sent to European pump manufacturers in 2007.

The collected data comprises all pump types within the scope of this European Standard. The specific speed n_s of the pumps forming the data base ranges from 6 to 110,5 min^{-1} and the range of flow rate at best efficiency Q_{BEP} is from 1,8 to 1200 m^3/h. The performance data supplied by the European manufacturers were assumed to be valid for the full diameter of the respective pump sizes.

In respect of the general physical dependency of attainable mean values of efficiency on main parameters (see Annex B), the collected data have been ordered according to a representation in the form $\eta_{BEP} = f(n_s, Q_{BEP})$ for each pump type and nominal speed within the scope. This correlation is described by a mathematical formula (see below). The form of the formula is based on previous investigations. The various steps to come from the collected data to the quantitative description of the relation $\eta_{BEP} = f(n_s, Q_{BEP})$ in the form of a 3-dimensional quadratic polynomial approximation are presented in more detail in the final report of the evaluation study.

The mathematical formula describing the relation η_{BEP} = f (n_s, Q_{BEP}) is:

$$\eta_{BEP} = -11,48\left(\ln\left(n_s\right)\right)^2 - 0,85\cdot\left(\ln\left(Q_{BEP}\right)\right)^2 - 0,38\cdot\ln\left(n_s\right)\cdot\ln\left(Q_{BEP}\right) + 88,59\ln\left(n_s\right) + 13,46\cdot\ln\left(Q_{BEP}\right) - C \quad (4)$$

with

η_{BEP} in [%];

n_s in [min^{-1}];

Q_{BEP} in [m^3/h];

C: constant in [%], depending on Minimum Efficiency Index (MEI), see 4.4.

The result calculated from Formula (4) has to be rounded to the 1st digit after the decimal point.

The mathematical range of validity of the formula is:

6 min^{-1} ≤ n_s ≤ 120 min^{-1}

2 m^3/h ≤ Q_{BEP} ≤ 1 000 m^3/h.

The physical range of validity of the formula is

η_{BEP} ≤ 88 %

NOTE 1 The limitation of the physical range of validity to a maximum value of η_{BEP} results from the fact that the hydraulic and mechanical losses in commercially designed and manufactured rotodynamic pumps cannot fall below a lower limit.

NOTE 2 Further reduction of losses would need special measures in design and manufacturing which would lead to unacceptable efforts and costs and/or would be incompatible with other pump operating requirements as, for example, good cavitation performance, low noise and vibration levels.

Assuming that there are no other constraints, Formula (4) is valid for all pump types within the scope of this European Standard pumping clean cold water. In the case of multistage pumps (MS), it is valid for a minimum stage number of 3, in the case of submersible multistage pumps (MSS) for a minimum stage number of 9. Generally, the equation is valid for the full impeller diameter of a pump size.

The efficiency values concern only pump efficiency, not the overall efficiency even in the case of close coupled pump-motor units.

4.3 Minimum efficiency at part load and overload

The pump data given by the manufacturers was also evaluated at selected part load (0,75 $Q_{BEP.}$) and overload (1,10 Q_{BEP}) operating points.

Part load and overload coefficients defined by:

$$x_{PL} = \frac{\eta_{PL}}{\eta_{BEP}}; \quad x_{OL} = \frac{\eta_{OL}}{\eta_{BEP}} \quad (5)$$

were calculated for each pump type. The mean value of these coefficients were found to be x_{PL} = 0,947 and x_{OL} = 0,985 for all pump types in good approximation.

Using the relation described in 4.2 for η_{BEP}, the minimum efficiency requirements for the selected operating points at part load and overload are

$$(\eta_{PL})_{\min,\,requ} = 0{,}947 \cdot (\eta_{BEP})_{\min,\,requ} \tag{6}$$

$$(\eta_{OL})_{\min,\,requ} = 0{,}985 \cdot (\eta_{BEP})_{\min,requ} \tag{7}$$

4.4 Minimum Efficiency Index

By varying the constant C in the equation for η_{BEP}, the curves resulting from Formula (4) and plotted in a n_s-$\eta_{min,requ}$ - diagram for constant values of Q_{BEP} are shifted in the vertical direction (see Figure 3 as an example). With a chosen value of C for a pump type and rotational speed within the scope, the existing pumps of this type produced by the European manufacturers are split into a percentage of the total number of pump sizes which already fulfil the corresponding minimum efficiency requirement (in respect to criteria A and B) and the (complementary) percentage of those which do not fulfil this requirement yet and, therefore, will be replaced on the market by pumps which are qualified in respect to the criteria A and B. The quantitative effect of the qualification criteria (finally determined by the value C) on the market and energy saving effect is characterized by the Minimum Efficiency Index (MEI). In the statistical evaluation, the Minimum Efficiency Index (MEI) was determined such that its value, multiplied by 100, indicates the percentage of existing pump sizes which do not fulfil the qualification criteria A and B for the corresponding value of C. To come to these results, the data for each pump given by the pump manufacturer were taken as being representative for the total number of pumps of the corresponding size with full impeller diameter.

The Minimum Efficiency Index (defined as described above) is a measure for the quality of a pump size in respect to efficiency. At the lower limit MEI = 0, the corresponding efficiencies of pump sizes can be achieved on a low level of design and manufacturing. For values of MEI > 0,7 the corresponding efficiencies of pump sizes can only be achieved by a very special hydraulic design which only aims at high efficiency and does not respect other hydraulic aspects as, e.g., good cavitation performance, and additionally by exceptional measures in mechanical design and manufacturing. Therefore, values of MEI higher than 0, 7 are not practically attainable for mass produced pumps.

NOTE 1 The maximum effect of reducing energy consumption by using pumps with high MEI will only be achieved if the pumps are carefully selected for required duties (see Annex B).

Table 3 shows the values of C for the pump types within the scope and for different values of the Minimum Efficiency Index (MEI).

Table 3 — Values of the constant C for different values of the Minimum Efficiency Index (MEI)

	Minimum Efficiency Index						
	0,10	0,20	0,30	0,40	0,50	0,60	0,70
C (ESOB 1450)	132,58	130,68	129,35	128,07	126,97	126,10	124,85
C (ESOB 2900)	135,60	133,43	131,61	130,27	129,18	128,12	127,06
C (ESCC 1450)	132,74	131,20	129,77	128,46	127,38	126,57	125,46
C (ESCC 2900)	135,93	133,82	132,23	130,77	129,86	128,80	127,75
C (ESCCi 1450)	136,67	134,60	133,44	132,30	131,00	130,32	128,98
C (ESCCi 2900)	139,45	136,53	134,91	133,69	132,65	131,34	129,83
C (MS-V 2900)	138,19	135,41	134,89	133,95	133,43	131,87	130,37
C (MSS 2900)	134,31	132,43	130,94	128,79	127,27	125,22	123,84

Examples of efficiency values resulting from Formula (4) for certain values of MEI are shown in Figures 3 and 4.

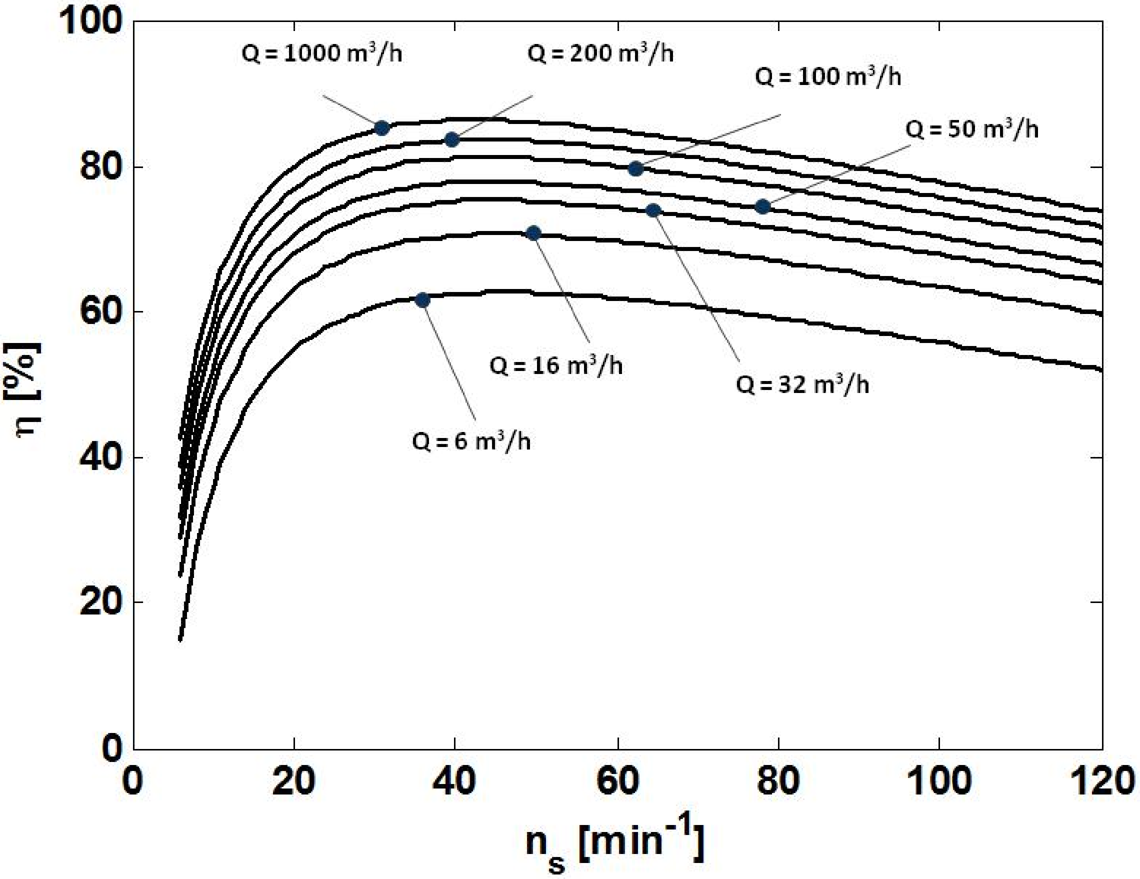


Figure 3 — Two-dimensional representation of ηBEP = f (ns,QBEP) for ESOB, n= 2 900 min-1 and MEI = 0,70 (see Table 3)

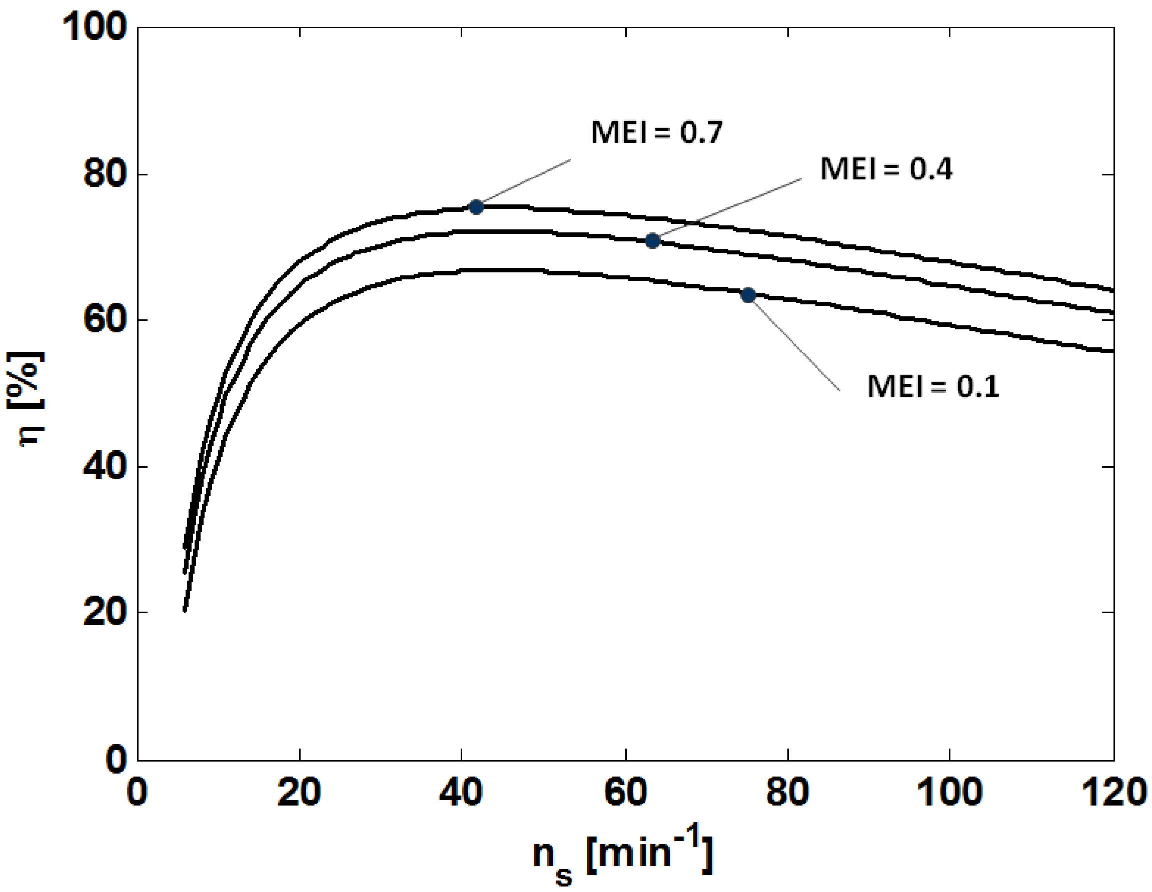


Figure 4 — ηBEP = f (ns) for ESOB with QBEP = 32 m^3/h, 2 900 min-1 and for different values of MEI (see Table 3)

For the choice of the value of MEI within the qualification procedure, the following applies:

a) The value of the Minimum Efficiency Index (MEI) can be chosen (and proven by a qualification procedure) by the pump manufacturer to indicate the quality of a pump size in respect to efficiency.

b) Minimum values of MEI might be fixed by law, governmental or EU regulations for market acceptance in order to reduce overall energy consumption

Examples of graphical representations for one pump type and rotational speed are given in Figures 3 and 4. Figure 3 shows the principal dependence of $\eta_{min,requ}$ on the specific speed n_s and on the flow rate at best efficiency Q_{BEP}. In Figure 4, the effect of varying the value of MEI on $\eta_{min,requ}$ is demonstrated.

In the frame of qualification or verification of a pump size, the values of Q_{BEP} and n_s - which $\eta_{min,requ}$ depends on - shall themselves be determined by tests on sample pumps and are not known *a priori* nor do they result from the tests as exact or true values. The determination of Q_{BEP} and n_s from tests on sample pumps is subjected to effects of manufacturing tolerances within the size (see Annex C) and of measurement uncertainties (see Clause 5). Therefore, the values of Q_{BEP} and n_s can only be determined to be confined to corresponding tolerance or confidence intervals. When calculating $\eta_{min,requ}$ by the means of Formula (4), the uncertainties of Q_{BEP} and n_s propagate into the result. In this standard, the value of $\eta_{min,requ}$ which is calculated by the means of Formula (4) using as input the measured (and – in the case of a sample of M > 1 pumps – arithmetically averaged) values of Q_{BEP} and n_s is called nominal value of minimum required efficiency. The combined effects of manufacturing tolerances within the size and of measurement uncertainties are taken into account by applying a total negative tolerance on the nominal value of minimum required efficiency $\eta_{min,requ}$. The values resulting from the application of the total negative tolerance on the values $\eta_{min,requ}$ are called particular threshold values of efficiency and are used in the qualification and verification procedures specified in this standard for comparison with the actual efficiencies of pumps of the size in question.

NOTE 2 The application of a total negative tolerance on the nominal values of minimum required efficiency is in close correspondence to the application of a total tolerance on guaranteed values of hydraulic quantities as in the method described in EN ISO 9906. The difference is the fact that in this European Standard the values on which the total tolerance is applied result from tests while they are fixed in a contract in the case of EN ISO 9906.

5 Determination of the Efficiency of a Test Pump

5.1 General

This clause specifies performance tests and evaluations on test pumps drawn at random out of a size which are carried out

— by an independent institution (for example in the frame of market surveillance) in order to verify the value of the Minimum Efficiency Index (MEI) indicated by the manufacturer,

— by a manufacturer in the case he has decided to qualify this size in respect to a certain value of Minimum Efficiency Index (MEI) by applying these tests and evaluations.

Such tests and evaluations shall provide the necessary information on the actual performance values of test pumps needed for the verification procedure described in Clause 6 or for the qualification procedure described in Clause 7. These values comprise:

a) the flow rate at best efficiency point Q_{BEP} from which also the values of flow rate Q_{PL} and Q_{OL} at specified part load and overload operating points (defined in 4.1), respectively, can be derived,

b) the maximum efficiency η_{BEP} at Q_{BEP} and the values of efficiency η_{PL} and η_{OL} at the corresponding values of flow rate Q_{PL} and Q_{OL} ,

c) the specific speed n_s which is needed to determine the minimum required efficiencies (see 4.2 to 4.4).

Regarding the requirements on test installations and measuring equipment, EN ISO 9906 is to be applied.

5.2 Test Procedures

Test shall be provided in accordance with EN ISO 9906 grade 2B. The exception for input power of 10 kW and below (see EN ISO 9906:2012, 4.4.2) shall not be considered.

For pumps (P2) < 1KW it is recommended to test a sample number higher than 3 in order to ensure a higher reliability to determine mean values.

a) Tests shall be carried out on test stands of the manufacturer or of laboratories in accordance to the methods and in the test arrangements specified in EN ISO 9906,

b) the pump performance shall be determined between the pump's inlet flange and discharge flange.

The conditions necessary to ensure satisfactory measurement of the performance characteristics are defined in 5.3.

NOTE 1 Recommendations and general guidance about suitable pipe arrangements to ensure satisfactory measurements for flow and head are given in EN ISO 9906:2012, Annex A and, if necessary, they can be used in conjunction with the ISO Standards on measurement of flow rates in closed conduits concerning the different methods (see EN ISO 9906:2012, Annex A).

As explained in EN ISO 9906:2012, A.1.4, the pump power input which is needed to determine the pump efficiency can be experimentally determined

— either by measurements of rotational speed and torque,

— or by electric power measurements.

In the case of determining by electric power measurements the pump power input of test pumps taken out of a size, an electric motor shall be used which is calibrated according to the IEC- or IEEE-Standards cited in EN ISO 9906:2012, A.1.4.3 and which is operated only under conditions where the motor efficiency is known with sufficient accuracy.

In the case of testing a pump with an integrated electric motor (as for pump types ESCC or MSS) in the frame of the verification procedure, the motor efficiency dependent on the motor load shall be found out in a suitable way, e.g. by information given by the motor manufacturer or by disassembling the test pump and calibrating the motor according to the IEC- or IEEE-Standards cited in of EN ISO 9906:2012, A.1.4.3.

For sizes of multistage pumps which are offered and sold by the manufacturer with different numbers of stages, the tests on test pumps which should be representative (in respect to the efficiency) for the size shall be carried out on pump versions with at least 3 stages for (not submersible) multistage pumps (MS-V) and with at least 9 stages for submersible multistage pumps (MSS).

The test pumps taken out of a pump size shall have an impeller with the full diameter of the corresponding pump size.

NOTE 2 Trimming a pump of a given size by cutting down the impeller diameter will reduce the pump efficiency compared to the efficiency of the same pump size with full diameter.

The test results shall be summarized in a report. Further guidance regarding the contents of a test report and a suitable pump test sheet is given in EN ISO 9906:2012, Annex F.

5.3 Test conditions

Tests shall be carried out with clean cold water. The duration of the test shall be sufficient to obtain repeatable results; especially run-in effects shall be considered.

NOTE 1 Run-in effects may take up to one day operating time.

All measurements shall be made under steady state conditions (see 5.4).

The tests should be conducted under conditions where cavitation does not affect the performance of the pump.

NOTE 2 If cavitation exists to a remarkable extent in the test pump during the test, not only the pump head but also the pump efficiency can deteriorate which leads to an underestimation of the pump efficiency.

A minimum of seven test points shall be taken for all performance tests within the range of 60 % to 120 % around the expected value of flow at the BEP. Four of these points shall be spaced between 60 % and 95 %, two between 105 % and 120 %, and one point chosen within 95 % to 105 % of the expected flow at the BEP. Preferably, tests should be carried at speeds of rotation n close to the nominal speed of rotation n_N which is given in the technical documentation of the manufacturer. Under some circumstances, e.g. if the electric motor is running at a constant frequency and its speed of rotation varies with the loading by the test pump which depends on the pump operating point, tests may be carried out at values of speed of rotation different from the nominal value. In this case, the speed of rotation at test should be within the range 80 % to 110 % of the nominal speed of rotation to establish rate of flow, pump total head and power input. If testing at different speeds the efficiency may be affected. However, in the case the variation of speed is within 20 % of the nominal speed the efficiency change is considered negligible.

In certain cases, the pump shaft is not accessible for the measurement of the rotational speed, e.g. in the case of submersible multistage pumps, and/or a nominal electric frequency f_N is given in the technical documentation of the manufacturer for the pump size instead of a nominal speed of rotation. In these cases, the tests shall be carried out at a frequency f of the electric supply which does not deviate from the nominal frequency f_N by more than 1 %. The voltage U of the electric supply used in the test shall be no more than 5 % above or below the voltage on which the characteristics given in the technical documentation of the manufacturer of the manufacturers are based.

5.4 Measuring uncertainties

5.4.1 Relevance

In Tables 5 and respectively Tables 6 and 7, maximum permissible values of measurement device uncertainty and overall uncertainty are given. The values given in these tables are set in analogy to the values given in EN ISO 9906, grade 2, for pump acceptance tests. They have to be met when performing tests according to Clause 7 of this European Standard.

For tests done by a pump manufacturer which aim at the qualification of a size, it is obvious from the criteria and procedures described in Clause 6, that it is advantageous – in respect to the fulfilment of the qualification criteria - to have a width of the confidence interval of the mean efficiencies of the size as small as possible. Whichever method is used by the manufacturer to determine the mean values and their confidence intervals needed to prove the fulfilment of qualification criteria, it is advisable to the manufacturer to achieve random and systematic measurement uncertainties (see Annex G) as small as possible.

For tests done by an independent institution in the frame of the verification procedure which is described in Clause 6, the situation is different. Each test pump selected for the verification test(s) has to be evaluated and assessed individually in respect to its efficiency. The efficiencies resulting from the test(s) have to be compared to corresponding particular minimum (threshold) values partly resulting from the same test(s). In this case, the “pass-or-fail” result is strongly dependent on the total measurement uncertainties. Therefore, to neutralize the influence of measurement uncertainties on the verification result, the maximum permissible measurement uncertainties specified in this European Standard have to be met and proven in tests aiming at the verification of the value of Minimum Efficiency Index (MEI) indicated by the manufacturer.

5.4.2 Fluctuations

The fluctuations stated in Table 4 shall not be exceeded. If a damping device is used it shall provide integration over at least one complete cycle of fluctuations.

Table 4 — Permissible amplitude of fluctuation as a percentage of mean value of quantity being measured

Measured quantity	Permissible amplitude of fluctuations %
Rate of flow	±3
Differential pressure	±4
Discharge pressure	±3
Suction pressure	±3
Driver power input	±3
Speed of rotation	±1
Torque	±3
Temperature	0,3 °C

5.4.3 Statistical evaluation of overall measurement uncertainty

The random component due either to the characteristics of the measuring system or to variations of the measured quantity or both appears directly as a scatter of the measurements. Unlike the systematic uncertainty, the random component can be reduced by increasing the number of measurements of the same quantity under the same conditions.

The random uncertainty shall permit the overall uncertainty *e* not exceeding the limits given in Table 6.

5.4.4 Maximum permissible measurement device (systematic) uncertainty

5.4.4.1 General

For tests according to Clause 5 of this standard, Table 5 below gives values of maximum permissible (relative) measurement device uncertainty $e_{s,max}$.

The values in Table 5 have to be applied for all operating points of the tests.

NOTE The values in Table 5 correspond to the values given for the relative measurement device uncertainties in EN ISO 9906:2012, Table 5 for acceptance tests according to class 2.

EN ISO 9906:2012, A.1 describes different methods of measurement as well as devices that typically are used to determine rate of flow, pump total head, speed of rotation and pump power input in the range of required accuracy.

Table 5 — Maximum permissible measurement device uncertainty es,max as a percentage of the arithmetically averaged value of the measured quantity

Measured Quantity	Maximum permissible measurement device uncertainty $e_{s,max}$
Rate of flow	± 2,5 %
Differential pressure	± 2,5 %
Discharge pressure	± 2,5 %
Suction pressure	± 2,5 %
Driver power input	± 2,0 %
Speed of rotation	± 1,4 %
Torque	± 2,0 %
Temperature	± 1,0 °C

5.4.4.2 The overall uncertainty

The value for overall uncertainty, e, is given by:

$$e = \sqrt{e_R^2 + e_S^2} \tag{8}$$

Permissible values of overall measurement uncertainties, e, are given in Table 6.

Table 6 — Permissible values of overall uncertainties

Quantity	Symbol	%
Flow rate	e_Q	±3,5
Speed of rotation	e_n	±2,0
Torque	e_{T}	±3,0
Pump total head	e_H	±3,5
Driver power input	e_{P1}	±3,5
Pump power input (computed from driver power and motor efficiency)	e_P	±4,0

5.4.4.3 Determination of overall uncertainty of efficiency

If efficiency is computed from torque and speed of rotation:

$$e_l = \sqrt{e_Q^2 + e_H^2 + e_{\mathrm{T}}^2 + e_n^2}$$

If efficiency is computed from pump power input:

$$e_l = \sqrt{e_Q^2 + e_H^2 + e_P^2}$$

Using the values given in Table 6, the calculations lead to the results given in Table 7.

Table 7 — Resulting largest values of the overall uncertainties of efficiency

Quantity	Symbol	%
Pump efficiency (computed from Q, H, M, n)	e_l	±6,1
Pump efficiency (computed from Q, H, P_1, l_{dr})	e_l	±6,4

5.5 Evaluation of test data

5.5.1 Conversion of the test results to the nominal speed of rotation or to the nominal electric frequency

Conversion of the test results to the nominal speed of rotation or to the nominal electric frequency shall be in accordance with EN ISO 9906.

Case 1: A nominal speed of rotation n_N is given in the catalogues of the manufacturer:

All test data obtained at an actual speed of rotation n in deviation from the nominal speed of rotation n_N shall be converted to the nominal speed of rotation n_N.

If the deviation of the test speed of rotation n from the nominal speed of rotation n_N does not exceed the permissible variations stated in 5.3, the measured data on the rate of flow Q, the pump total head H, the pump power input P and the pump efficiency η can be converted (according to the hydrodynamic similarity laws) by means of the following formulae:

$$Q_t = Q \cdot \frac{n_N}{n} \tag{9}$$

$$H_t = H \cdot \left(\frac{n_N}{n}\right)^2 \tag{10}$$

$$P_t = P \cdot \left(\frac{n_N}{n}\right)^3 \tag{11}$$

$$\eta_t = \eta \tag{12}$$

<u>Case 2:</u> A nominal frequency f_N and voltage U_N of electric supply is given in the catalogues of the manufacturer:

All test data obtained at an actual electric frequency f at the pump test in deviation from the nominal electric frequency f_N shall be converted to the nominal frequency f_N.

If the deviations of the electric frequency f at the pump test from the nominal frequency f_N and of the electric voltage U at the pump test to the value given in the catalogues do not exceed the permissible variations stated in 5.3, the measured data on the rate of flow Q, the pump total head H, the pump power input P and the pump efficiency η can be converted (according to the hydrodynamic similarity laws) by means of the following formulae:

$$Q_t = Q \cdot \frac{f_N}{f} \tag{13}$$

$$H_t = H \cdot \left(\frac{f_N}{f}\right)^2 \tag{14}$$

$$P_t = P \cdot \left(\frac{f_N}{f}\right)^3 \tag{15}$$

$$\eta_t = \eta \tag{16}$$

5.5.2 Performance curves

In order to determine the data which are needed for the qualification or verification procedure (Q_{BEP}, Q_{PL}, Q_{OL}, the corresponding values of efficiency η_{BEP}, η_{PL} *and* η_{OL} and the specific speed n_s), performance curves for head H versus flow rate Q and efficiency η versus flow rate Q have first to be established. These shall be best-fit curves in relation to the measured points.

These curves shall fulfil the condition of "least squares", i.e. the condition that the sum of the squared deviations of the measured values of H and η, respectively, from the corresponding values on the fitting curve at the same flow rates is at minimum:

$$\sum_{j=1}^{k}\left[H_j\left(Q_j\right) - H_{curve}\left(Q_j\right)\right]^2 = \min \tag{17}$$

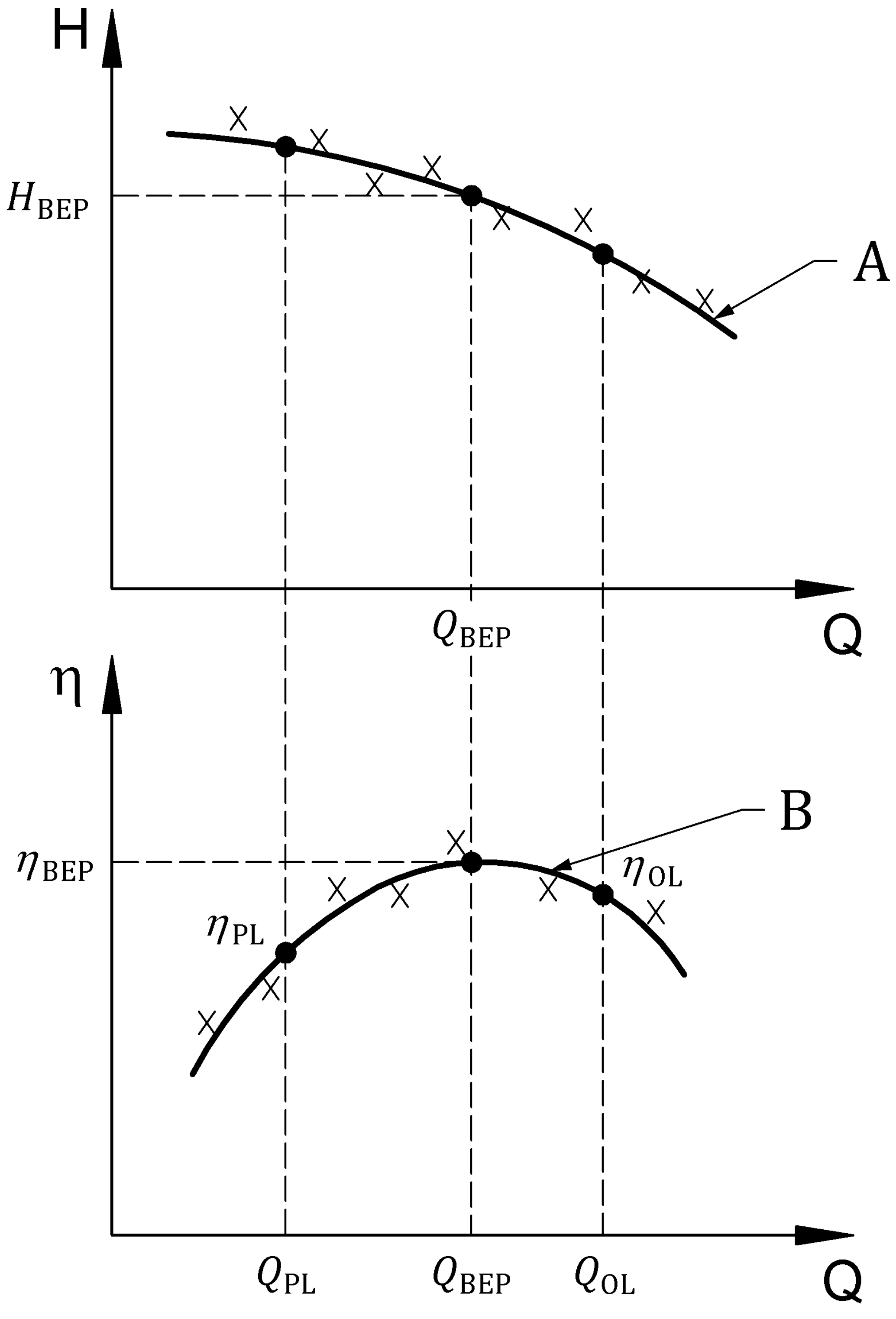
$$\sum_{j=1}^{k}\left[\eta_j\left(Q_j\right)-\eta_{curve}\left(Q_j\right)\right]^2=\min \qquad (18)$$

For the determination of the flow corresponding to BEP, PL, and OL, the flow- efficiency fitting curve shall be represented by an appropriate mathematical expression. In the range of flow rates from PL to OL, the curve represented by the mathematical expression shall have only one maximum, and the second derivative of the mathematical expression shall be negative. Appropriate methods for drawing the flow-efficiency fitting curve are, e.g. polynomials of third order or spline functions. Alternatively, the nominal best flow value from the manufacturer's test reports can be chosen if provided. The mathematical expression has to fulfil the following conditions:

— in the range of flow rates from $Q = Q_{PL}$ to $Q = Q_{OL}$, the curve represented by the mathematical expression shall have only one maximum,

— in the range of flow rates from $Q = Q_{PL}$ to $Q = Q_{OL}$, the 2nd derivative of the mathematical expression shall be negative.

After having determined the fitting curves, these shall be plotted together with the measured test points in a Q-H- and in a Q-η-diagram, see Figure 5.



Key

X	measured points	•	values relevant for the qualification or verification
A	Q-H fitting curve		
B	Q-η fitting curve		

Figure 5 — Performance curves with values relevant for the qualification or verification

5.5.3 Determination of the values relevant for the qualification or verification

The next step consists in the determination of Q_{BEP} and η_{BEP}. Q_{BEP} is found as the value of the flow rate which corresponds to the maximum of the fitting curve in the Q-η-diagram. This maximum fulfils the mathematical condition:

$$\frac{d\eta}{dQ}=0 \qquad (19)$$

From the fitting curve (most easily from its mathematical expression), the value η_{BEP} corresponding to Q_{BEP} is determined.

The values of Q_{PL} and Q_{OL} are found by multiplying Q_{BEP} by the factors 0,75 and 1,1, respectively. The corresponding values of η_{PL} and η_{OL} are determined from the fitting curve (most easily from its mathematical expression). These values are also plotted in Figure 5.

For the determination of the specific speed n_s and for the determination of the actual overall measurement uncertainties of the efficiencies η_{BEP} , η_{PL} and η_{OL} (see Annex G), also the values of pump head H_{BEP} at Q_{BEP} , H_{PL} at Q_{PL} and H_{OL} at Q_{OL} are needed. These are found on the Q-H fitting curve at the respective values of flow rate (see Figure 5).

NOTE It is important to note that the values of η_{BEP} , η_{PL} and η_{OL} determined in the manner described above are <u>not</u> the true values of these efficiencies but are the mid-points of the corresponding confidence intervals to which the true values are confined with a probability of 95 %. Within these confidence areas, each value is equally valid. For details of the determination of the actual overall measurement uncertainties and the confidence intervals of efficiencies, see Annex D.

Also, the specific speed n_s is needed to determine the minimum required values of efficiency (see Clauses 4, 6 and 7). The specific speed n_s is defined by the formula

$$n_s = n_N \cdot \frac{\sqrt{Q_{BEP}}}{H_{BEP}^{0.75}}$$

The units are [min^{-1}] for n_s and n_N, [m^3/s] for Q_{BEP} and [m] for H_{BEP}.

H_{BEP} is the value on the Q-H fitting curve at the point where $Q = Q_{BEP}$ (see Figure 5).

For multistage pumps, H_{BEP} is the head per stage, i.e. the pump total head divided by the number of stages i.

If the measurement of the rotational speed is inappropriately difficult, e.g. shaft inaccessible in case of a submersible multistage pump, a slip of 3 % is assumed for the rotational speed at the point of best efficiency of the pump.

5.5.4 Procedures for testing and/or evaluation of special pump types

5.5.4.1 General

For special pump types covered by the scope of this standard, procedure and testing according to 5.5.4.2 to 5.5.4.4 shall be applied, respectively.

5.5.4.2 Other nominal speeds than 1 450 min^{-1} or 2 900 min^{-1}

For those pumps, one of the following two options for testing shall be applied:

a) Pumps are tested at their nominal speed. The calculation of the minimum required efficiency or Minimum Efficiency Index shall be done on the basis of Formula 4.4. The C-value (from Table 3) shall be taken for 1 450 min^{-1} or 2 900 min^{-1} whichever is closer to the nominal speed of the tested pump size.

b) Pumps are tested at 1 450 min^{-1} or 2 900 $min^{-1.}$ The corresponding C values (from Table 3) shall be taken.

NOTE 1 For b) only: Testing and evaluation is done under the assumption that this pump size is designed for the respective test speed.

NOTE 2 Typical examples are pumps driven by six-pole motors or over synchronous permanent magnet motors.

5.5.4.3 Twin head pumps (ESCCi with two impellers)

Twin head pumps shall be tested by incorporating one of the driver/impeller sets into an adequate pump casing of ESCCi type. The C-value (from Table 3) shall be taken for the corresponding ESCCi pump type and speed.

5.5.4.4 Pumps according to more than one type definition

For pump types where more than one type definition is applicable the type of pump casing shall determine which C value (from Table 3) has to be taken.

6 Proving the Minimum Efficiency Index of a pump size

6.1 General remarks

There are two possible cases of information on the Minimum Efficiency Index (MEI) of a pump size which is indicated by the manufacturer on the nameplates and/or in the technical documentation:

a) The conformity to requirements by law in respect to the MEI-value is indicated by the information that MEI is at least equal to or higher than MEI_{min} where MEI_{min} is defined by law (for example "MEI ≥ 0,40" if MEI_{min} = 0,4).

b) The numerical value determined according to this European Standard is indicated (for example "MEI ≥ 0,47").

Both cases of indicated values are valid for the **mean** efficiency values of the size at BEP, PL and OL and the manufacturer has to prove that the values $\eta_{BEP,mean}$, $\eta_{PL,mean}$ and $\eta_{OL,mean}$ fulfil – **with a sufficiently high probability** – the criteria defined in Clause 4.

c) To prove the conformity to requirements by law in respect to the MEI-value, tests and evaluations have to be carried out according to Clause 5 on sample pumps taken randomly out of the size and mean values of efficiency at PL, BEP and OL have to be determined (for example as described in Clause 5). Subsequently, the MEI-value has to be calculated as described in 6.2.

   The conformity to law is than proven if the MEI-value determined in that way fulfils the condition

$$MEI \geq MEI_{min} \qquad (20)$$

   where

   MEI_{min} is prescribed by law.

d) To prove the validity of an indicated numerical value of MEI which is higher than the minimum value required by law, the determination of the indicated value of MEI has to be carried out by tests and evaluations according to Clause 5 and calculations according to 6.2.

NOTE In the verification procedure according to Clause 7, a tolerance t_η = - 5 % is applied to the values of $\eta_{min,requ}$ which are calculated by Formula (4) for the MEI-value required by law or indicated by the manufacturer. This tolerance is **not included** in the method to determine and to prove the MEI-value of a pump size by the manufacturer.

6.2 Determination of the Minimum Efficiency Index of a pump size

The values which are needed to determine the MEI value of a pump size are:

— the nominal rotational speed n_N,

— the mean values of the flow rate $Q_{BEP,mean}$ and the pump head $H_{BEP,mean}$ at best efficiency point BEP, resulting from tests and evaluations carried out according to Clause 5 and – if applied – Annex D,

— the mean values of efficiency $\eta_{BEP,mean}$, $\eta_{PL,mean}$ and $\eta_{OL,,mean}$, resulting from tests and evaluations carried out according to Clause 5 and – if applied – Annex D,

— the specific speed $n_{s,mean}$ calculated from n_N, $Q_{BEP,mean}$ and $H_{BEP,mean}$ according to 5.5.3.

The MEI-value is than determined in the following way:

Step 1: The auxiliary function F_η is calculated from

$$F_\eta = -11{,}48\left(\ln\left(n_{s,mean}\right)\right)^2 - 0{,}85\left(\ln\left(Q_{BEP,mean}\right)\right)^2 - 0{,}38\left(\ln\left(n_{s,mean}\right)\right)\cdot \ln\left(Q_{BEP,mean}\right) + 88{,}59\left(\ln\left(n_{s,mean}\right)\right) + 13{,}46\ln\left(Q_{BEP,mean}\right) \quad (21)$$

with

$n_{s,mean}$ in [min^{-1}]

$Q_{BEP,mean}$ in [m^3/h]

The value of F_η calculated from Formula (21) has to be rounded to the 2nd digit after the decimal point.

Step 2: For each of the values of mean efficiency at BEP, PL and OL, a corresponding value of C is calculated from

$$C_{BEP} = F_\eta - \eta_{BEP,mean} \quad (22)$$

$$C_{PL} = F_\eta - \frac{\eta_{PL,mean}}{0{,}947} \quad (23)$$

$$C_{OL} = F_\eta - \frac{\eta_{OL,mean}}{0{,}985} \quad (24)$$

Step 3: The values calculated from Formulae (22) to (24) have to be rounded to the 2nd digit after the decimal point. The greatest of the 3 values C_{BEP}, C_{PL} and C_{OL} is taken as the value C_{MEI} which serves to calculate the MEI value

$$C_{MEI} = \max(C_{BEP}, C_{PL}, C_{OL}) \quad (25)$$

Step 4: The value of MEI corresponding to C_{MEI} is calculated by linear interpolation between the neighbouring values in Table 3. For this purpose, in the line for the pump type and nominal rotational speed of the pump size the neighbouring values C_{left} and C_{right} to the left and to the right of C_{MEI}, respectively, are taken from Table 3 as well as the values MEI_{left} and MEI_{right} corresponding to C_{left} and C_{right}. Finally, the MEI value of the pump size is calculated from

$$MEI = \left(MEI_{right} - MEI_{left}\right) \cdot \frac{C_{MEI} - C_{left}}{C_{right} - C_{left}} + MEI_{left} \quad (26)$$

Because in Table 3 the difference $MEI_{right} - MEI_{left}$ is generally equal to 0,1, Formula (26) can be simplified to

$$MEI = 0{,}1 \cdot \frac{C_{MEI} - C_{left}}{C_{right} - C_{left}} + MEI_{left} \quad (27)$$

The value of MEI of a pump size calculated from Formulae (26) or (27) shall be rounded to the 2nd digit after the decimal point.

7 Verification of the Minimum Efficiency Index for a pump size

7.1 General remarks

If a manufacturer has qualified a size of a pump as described in Clause 5 a check and a confirmation of the result of the qualification by an independent institution, for example in the frame of market surveillance, may be required. This is called verification of the MEI-value in this European Standard.

Normally, the MEI-value required as a minimum will be prescribed by law as for example MEI ≥ 0,40.

The numerical MEI value indicated by a manufacturer which is higher than the value required by law shall be indicated as a number with two digits after the decimal point as for example MEI ≥ 0,47.

7.2 describes the procedure to be applied in the case that the conformity to the requirements by law in respect to MEI or the validity of the numerical value of MEI indicated by the manufacturer shall be verified by tests on pumps of this size. *This verification procedure uses a limited number of test pumps and tests.*". The procedure is based on simple pass-or-fail tests and a "decision tree". In Annex H, some explanations are given concerning the methodology and the probability of the results.

An alternative to the verification procedure described in 7.2 exists if the manufacturer either has proven that the mean efficiencies of the pump size fulfil the requirements by law in respect to MEI according to Clause 6 or has determined the indicated numerical value of MEI which is higher than the minimum value required by law by applying the method described in Clause 5 and has **completely documented** the whole procedure which was applied. The applied procedure can consist of tests and evaluations according to Clause 5 and application of one of the methods described in Clause 7 or of other methods chosen by the manufacturer. The documentation should be presented by the manufacturer to the independent institution on request for the purpose of verification. If the documentation is approved by the independent institution, the conformity to law in respect to MEI or the validity of the indicated numerical value of MEI shall be confirmed and the qualification of the pump size is regarded as verified.

7.2 Procedure and decision

The whole verification methodology and procedure applies to pumps with full diameter impeller and consists of several steps:

a) An individual pump is drawn at random out of the size, tested, evaluated and assessed in respect to the corresponding Minimum Efficiency Index (MEI) as described below.

b) If the individual pump has passed according to the criterion described below, the value of the Minimum Efficiency Index (MEI) of the investigated size is confirmed.

c) If the efficiency of the first individual pump does not achieve the corresponding threshold values, three other individual pumps are drawn at random out of the size, tested and evaluated as described.

d) The values of Q_{BEP}, η_{BEP}, η_{PL}, η_{OL} and n_s has to be determined for each of the three tested pumps. Out of these values the MEI is determined according to (see Formulae (29) and 30)). The three derived MEI values have to be arithmetically averaged according to Formula (28).

$$\bar{x} = \frac{1}{3} \cdot \sum_{i=1}^{3} x_i \tag{28}$$

e) If the "average-of-three MEIs" has also failed according to the criterion described below, the verification of the investigated size for the Minimum Efficiency Index (MEI) required by law or indicated by the manufacturer is definitely rejected.

f) If the "average-of-three MEIs" has passed according to the criterion described below, the pump size has passed in spite of the fact that the first pump test has failed.

The tests and evaluations on each of the pumps drawn at random and independently from each other out of the size for which the conformity to law in respect to the Minimum Efficiency Index (MEI) or the validity of the numerical value of MEI indicated by a manufacturer shall be verified according to Clause 6 of this standard.

For each of the tested pumps, the Q-η and Q-H fitting curves and from these the values of Q_{BEP} and n_s have to be determined as described in 5.5.2.

The following calculations have to be done for the first test pump and – in the case it fails – also for the "average-of-three" pump (i.e. the "virtual" pump having the averaged hydraulic performance of the three real pumps which were additionally tested).

Using the values Q_{BEP} and n_s or $\bar{Q}_{BEP}$ and $\bar{n}_s$, respectively, determined from the test, the minimum required efficiencies $(\eta_{BEP})_{min,requ}$, $(\eta_{PL})_{min,requ}$ and $(\eta_{OL})_{min,requ}$ for the pump have to be calculated. These calculations are done by the means of Formulae (4), (6) and (7) given in Clause 4 with the C-value taken from Table 3 in 4.4 for the type and nominal speed of the tested pump(s) and for the Minimum Efficiency Index (MEI) as required by law or as indicated by the manufacturer.

If the value of MEI indicated by the manufacturer is a numerical number between the values given in Table 3, the corresponding value of C in Formula (2) shall be determined by linear interpolation in the interval between the neighbouring values given in Table 3.

For this purpose, in the line for the pump type and nominal rotational speed of the pump size the neighbouring values MEI_{left} and MEI_{right} to the left and to the right of the indicated numerical value MEI, respectively, are taken from Table 3 as well as the values C_{left} and C_{right} corresponding to MEI_{left} and MEI_{right}. Finally, the value of C corresponding to the indicated numerical value of MEI of the pump size is calculated from

$$C = C_{left} + \frac{MEI - MEI_{left}}{MEI_{right} - MEI_{left}} \cdot \left(C_{right} - C_{left)}\right) \tag{29}$$

Because in Table 3 the difference MEI_{right} – MEI_{left} is generally equal to 0,1, Formula (22) can be simplified to

$$C = C_{left} + \frac{MEI - MEI_{left}}{0,1} \cdot \left(C_{right} - C_{left)}\right) \tag{30}$$

EXAMPLE For a pump size of the type ESOB and a nominal speed n_N = 2 900 min^{-1}, a manufacturer indicates the numerical value MEI = 0,47. The neighbouring values of MEI given in Table 3 are MEI_{left} = 0,4 and MEI_{right} = 0,5. The corresponding C-values are C_{left} = 130,27 and C_{right} = 129,18. The C-value for MEI = 0,47 is calculated as:

$$\begin{aligned} C &= C_{left} + \frac{MEI - MEI_{left}}{MEI_{right} - MEI_{left}} \cdot \left(C_{right} - C_{left}\right) \\ &= 130,27 + \frac{0,47 - 0,4}{0,5 - 0,4} \cdot (129,18 - 130,27) = 129,51 \end{aligned} \quad (31)$$

As described in Clause 4, the minimum required values of efficiency depends themselves on the quantities Q_{BEP} and n_s which result from tests and evaluations on the test pumps taken as sample. Thereby, they are also subjected to effects of manufacturing tolerances within the size and inevitable measurement uncertainties. To take account of these effects together with the inherent measurement uncertainties of the efficiency values determined by the verification test(s), a tolerance has to be applied also on the minimum required values of efficiency used in the verification procedure. This leads to the particular threshold values which the measured efficiencies of the tested pumps shall exceed. For this purpose, the negative tolerance of t_η = - 0,05 (or - 5 %) is applied to each of the values $(\eta_{BEP})_{min,requ}$, $(\eta_{PL})_{min,requ}$ and $(\eta_{OL})_{min,requ}$ which are calculated by the means of Formulae (4), (6) and (7). By application of the total tolerance on the calculated values (i.e. by multiplying them with the factor $(1 - |t_\eta|) = 0,95$), the particular threshold values result. If plotted in a Q-η-diagram at the flow rates:

— Q_{BEP} or $\overline{Q}_{BEP}$,

— Q_{PL} = 0,75 Q_{BEP} or $\overline{Q}_{PL}$ = 0,75 $\overline{Q}_{BEP}$,

— Q_{OL} = 1,1 Q_{BEP} or $\overline{Q}_{OL}$ = 1,1 $\overline{Q}_{BEP}$.

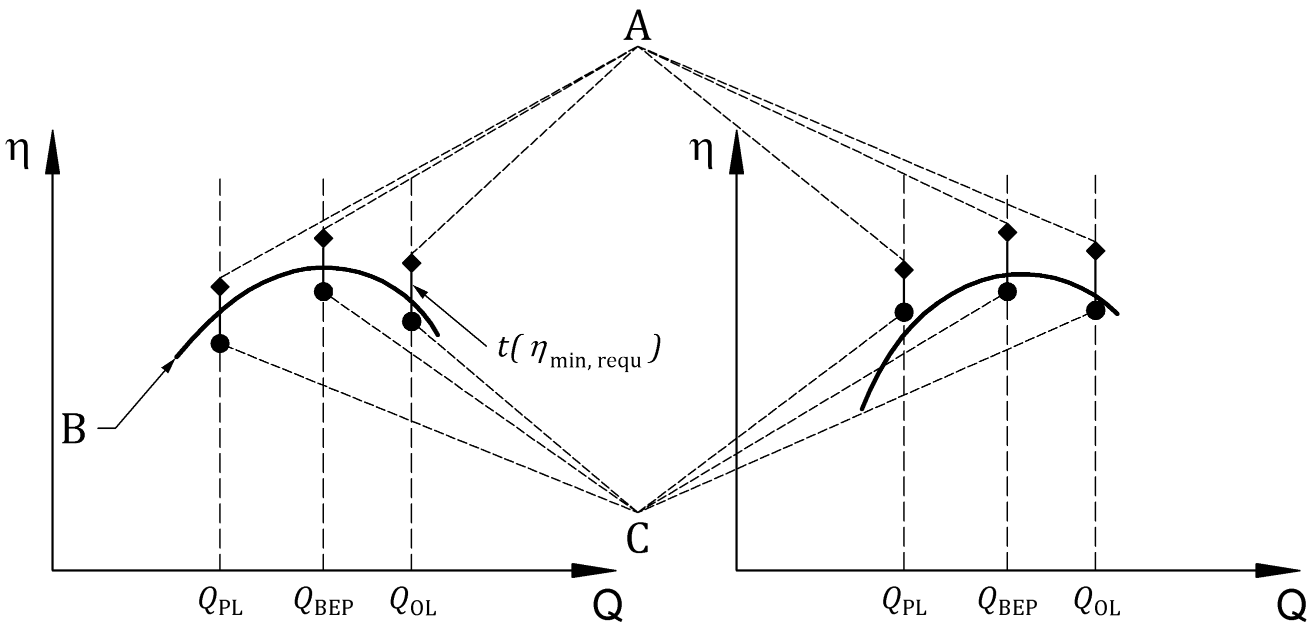
The calculated values, the tolerance bars and the particular threshold values can be visualized (see Figure 6). The points of the particular threshold values form the “house of efficiency” (see Figure 2) being relevant for the first test pump or for the “average-of-three” pump, respectively.

Decision criteria:

The first tested pump or the “average-of-three” pumps has passed in respect to confirming the required or indicated value of the Minimum Efficiency Index (MEI), if all 3 values η_{BEP}, η_{PL} and η_{OL} resulting from the measurements are equal to or higher than the corresponding particular threshold value at BEP, PL and OL.

The first tested pump or the “average-of-three” pumps has failed in respect to confirming the required or indicated value of the Minimum Efficiency Index (MEI), if at least one of the 3 values η_{BEP}, η_{PL} and η_{OL} resulting from the measurements is lower than the corresponding particular threshold value at BEP, PL and OL.

Examples of “passed” or “failed” results are shown schematically in Figure 6.



Key

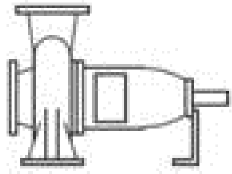
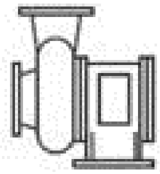
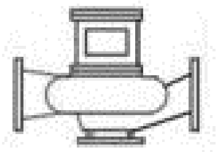
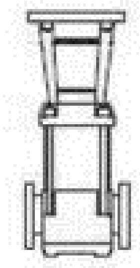
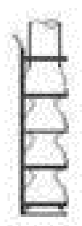
A	calculated minimum required efficiencies at PL, OL and BEP for required or indicated MEI value
B	Q-η fitting curve from test(s)
C	particular threshold values for PL, OL and BEP resulting from A
$t(\eta_{min,requ})$	total tolerance applied to $\eta_{min,requ}$

Figure 6 — Schematic presentation of "pass" (left figure) and "fail" (right figure) results of a test pump for a certain value of the Minimum Efficiency Index (MEI)

Annex A
(normative)

Pump types in scope

Table A.1 — Pump types within the scope

ESOB End Suction Own Bearings pump	
ESCC End Suction Close Coupled pump	
ESCCi Inline End Suction Close Coupled pump	
MS-V Vertical Multistage pump	
MSS Submersible multistage borehole pump	

End suction pumps (ESOB, ESCC and ESSCi).

Glanded single stage end suction rotodynamic water pump in axial-top or in-line arrangement of the pipe connections and with volute casing designed for pressures up to 16 bar.

All pumps made with flanged or threaded nozzles in metric or inch dimensions.

Pump sizes with performance data according to Table A.2.

Vertical Multistage Pumps (MS-V).

Glanded multi stage (i > 1) rotodynamic water pump in which the impellers are assembled on a vertical rotating shaft, which are designed for pressures up to 25 bar.

Pump sizes with performance data according to Table A.2.

The efficiency to be evaluated for being an energy efficient pump is the efficiency of the pump version with 3 stages (pumps with more stages have better efficiency by physical reasons).

Submersible multistage borehole pump (MSS).

Multi stage (i > 1) rotodynamic water pump with a nominal outer diameter of 4″ (10, 16 cm) or 6″ (15,24 cm) designed to be operated in a borehole at operating temperatures within a range of 0 °C and 90 °C;.

The efficiency to be evaluated for being an energy efficient pump is the efficiency of the pump version with 9 stages.

Table A.2 — Pumps within the scope

Pump type	Defined scope				
ESOB ESCC ESCCi	$n = 1\,450\ min^{-1}$	$Q_{BEP} \geq 6\ m^3/h$	$H_{BEP} \leq 90\ m$	$6\ min^{-1} \leq n_s \leq 80\ min^{-1}$	$P_2 \leq 150\ kW$
ESOB ESCC ESCCi	$n = 2\,900\ min^{-1}$	$Q_{BEP} \geq 6\ m^3/h$	$H_{BEP} \leq 140\ m$	$6\ min^{-1} \leq n_s \leq 80\ min^{-1}$	$P_2 \leq 150\ kW$
MS-V	$n = 2\,900\ min^{-1}$			$Q_{BEP} \leq 100\ m^3/h$	
MSS	$n = 2\,900\ min^{-1}$	4′′ and 6′′			

Annex B
(informative)

General remarks on the efficiency of rotodynamic pumps

The efficiency η of each rotodynamic pump, running at constant rotational speed n or driven by an electric motor at constant electric frequency f, depends on the pump flow rate Q. From $\eta = 0$ at $Q = 0$, the efficiency increases with increasing flow rate, reaches a maximum value η_{BEP} and then decreases with further increasing flow rate. The point of best efficiency *"BEP"* with the corresponding values of flow rate Q_{BEP} and pump head H_{BEP} is defined by the condition $\eta = \eta_{BEP}$. Usually and also in this standard, the operating range $Q < Q_{BEP}$ is called *"part load"* (*PL*), while the range $Q > Q_{BEP}$ is called *"overload"* (*OL*).

Rotodynamic pumps cannot be expected to have generally comparable values of η_{BEP}, even if they were designed and manufactured with comparable quality. In contrary, for comparable quality of design and manufacturing the values of η_{BEP} depend on two main hydraulic parameters:

a) The flow rate Q_{BEP} which characterizes the size of the pump (and indirectly the Reynolds number *Re*, a hydrodynamic parameter on which most of the internal hydraulic losses in pumps are dependent).

b) The specific speed n_s (with the unit [min^{-1}]) which characterizes the impeller shape (from radial at the lowest n_s-values to axial at the highest ones) and is calculated by the means of the formula

$$n_s = n \cdot \frac{\sqrt{Q_{BEP}}}{H_{BEP}^{0.75}} \qquad \text{(B.1)}$$

wherein the units [min^{-1}] for n_s and for the rotational speed n, [m^3/s] for Q_{BEP} and [m] for H_{BEP} have to be used. In the case of multistage pumps, H_{BEP} is the head per stage which results from dividing the total pump head by the number of stages i.

Many theoretical considerations and experimental investigations have shown that for rotodynamic pumps of comparable quality of design and manufacturing,

— η_{BEP} increases monotonically with increasing Q_{BEP} where the slope $\partial\eta_{BEP}/\partial Q_{BEP}$ is steepest at the lowest values of Q_{BEP} and flattens down asymptotically to zero for very high values of Q_{BEP},

— η_{BEP} has a maximum at n_s–values in the range between 40 and 50 min^{-1} and decreases for higher and lower n_s–values, especially leading to very low values of η_{BEP} at $n_s \leq 10$ min^{-1}.

This typical dependency of η_{BEP} on Q_{BEP} and n_s can physically be explained by the influence of these two parameters on the various internal hydraulic losses (relative to the power input of a pump) as are flow-through losses, disc friction losses and internal leakage losses. Additionally, the increasingly low values of efficiency at low values of Q_{BEP} and/or n_s – which are typical for small pumps of correspondingly low power input - result from a considerable contribution of mechanical friction losses (arising in shaft sealing and bearings) to the total pump losses.

Compared to single stage pumps (types ESOB, ESCC and ESCCi), the efficiencies of multistage pumps (types MS-V and MSS) with the same values of Q_{BEP} and n_s are generally lower because of additional flow-through losses in the guide vanes and return channels. But multistage pumps have an advantage in respect to efficiency, when the required data of Q, H and n would lead to a very low n_s-value of a single stage pump for this duty point. In this case, the more favourable n_s-value of a multistage pump (calculated and relevant per stage) leads to a considerably higher efficiency compared to a single stage pump. The general dependency of η_{BEP} on Q_{BEP} and n_s for multistage pumps is similar to that one of single stage pumps.

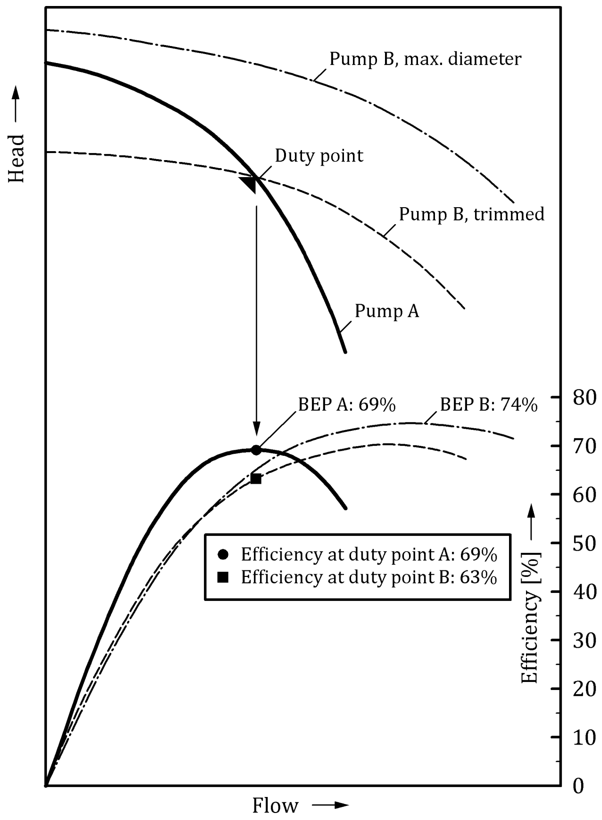


Figure B.1

In Figure B.1, two pumps A and B are compared. Pump B is the better one in respect to the efficiency at BEP. But the required duty point specified by the system designer (customer) differs from the point of best efficiency of pump B. So, pump A with a lower efficiency at BEP but better matching to the required duty point results in a better choice (higher efficiency) for the given application.

In summary it is necessary to underline that a correct and precise dimensioning of parameters such as *H*, *Q* and *NPSH* (et al.) needs to be carried out by the customer quoting the duty point and the manufacturer selecting the right pump for the quoted duty point.

Annex C
(informative)

Mean Values of a Size Relevant for its Minimum Efficiency Index

As explained in Clause 6, in order to achieve a certain value of the Minimum Efficiency Index (MEI) the mean values of efficiency of a pump size shall be at least equal or higher than corresponding minimum required values.

Within one size of mass produced pumps of one manufacturer (with the same full impeller diameter), there is an inevitable scatter of hydraulic performance characteristics including the efficiency and other values (Q_{BEP} and n_s) which are of relevance for the Minimum Efficiency Index (MEI). This scatter of hydraulic performance characteristics results from small differences of hydraulically relevant geometrical dimensions (as e.g. internal flow cross sections, impeller blade angles, gap clearances) among the individual pumps of the same size. These differences are within the range of geometrical or dimensional tolerances which are inherent in every manufacturing process and which cannot be reduced below some economically acceptable limits.

The bandwidth of the hydraulically relevant geometrical tolerances leads to a corresponding bandwidth of hydraulic performance characteristics of individual pumps of the same size.

The size as a whole is characterized by the mean performance data and curves. The mean values of hydraulic quantities relevant for the Minimum Efficiency Index are defined as:

$$x_{mean} = \frac{1}{z} \cdot \sum_{i=1}^{z} x_i \qquad \text{(C.1)}$$

where x is the respective quantity (for example Q, H, η, n_s) and z is the total number of pumps of the same size ever produced by the same manufacturer. For sizes produced in very large numbers, the total number z can be replaced by the number z_{annual} of pumps of the same size produced per year.

NOTE If the number z (or z_{annual}) is large, it can generally be assumed that the geometrical dimensions and, thereby, the hydraulic quantities x depending on these dimensions show normal (Gaussian) distributions (see Figure C.1). For the same impeller diameter – and especially for the full impeller diameter - these distributions are characterized by their true mean value x_{mean} (which is identical to the value defined by the equation above) and the associated bandwidth of scatter. The latter can also be called the actual manufacturing tolerance of a hydraulic quantity or actual hydraulic manufacturing tolerance of a pump size.

For normal distributions, the probability is 95 % that any individual true value x_i of the respective hydraulic quantity x is confined to a confidence interval of ± 1,96·s_x around the mean value x_{mean}

where

$$s_x = \sqrt{\frac{1}{z-1} \cdot \sum_{i=1}^{z} \left(x_i - x_{mean}\right)^2} \qquad \text{(C.2)}$$

is the standard deviation of the quantity x within the same size - see Annex E.

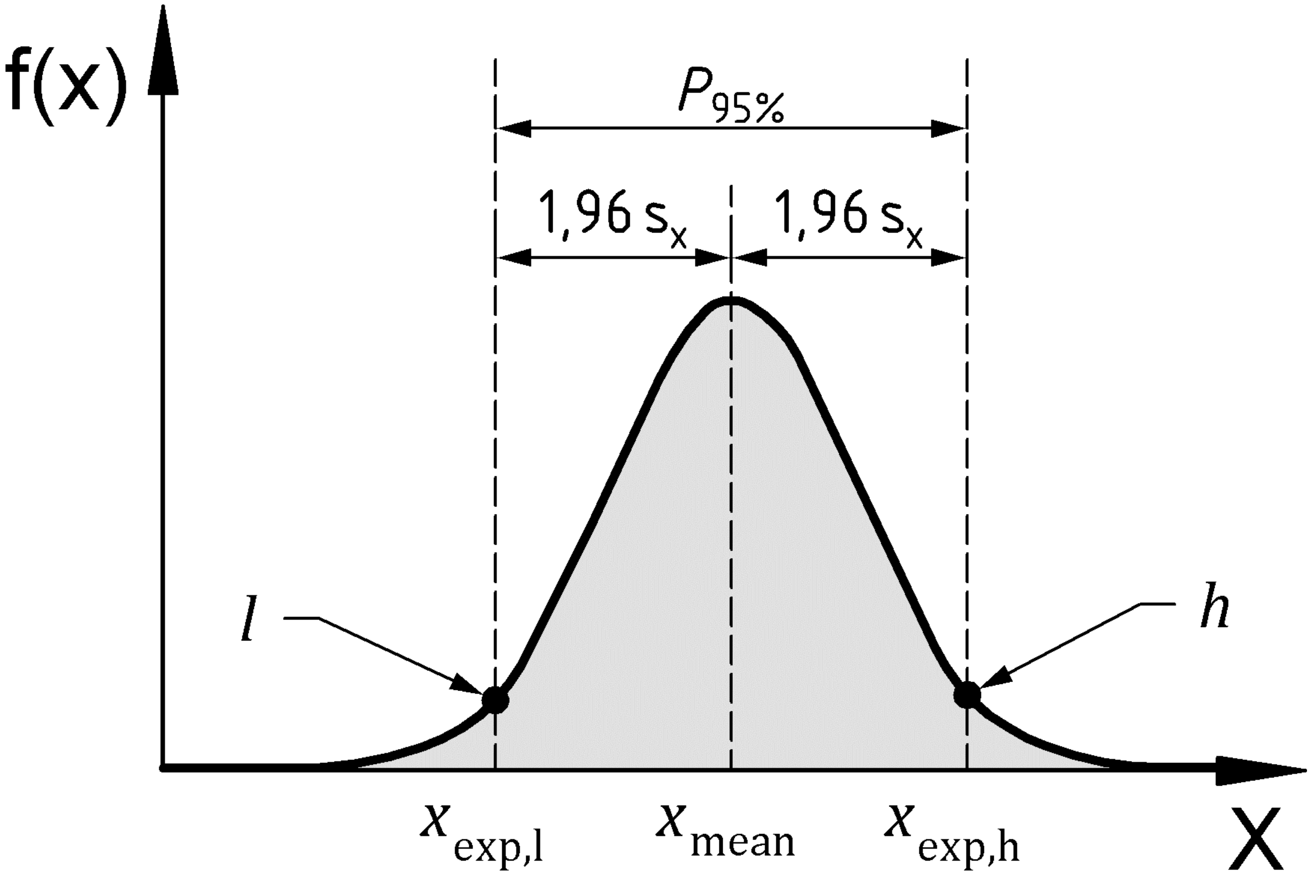
Therefore, the manufacturing tolerance of a quantity x can be defined as ± 1,96 s_x, see Figure C.1.

Furthermore, the true value x_i of any pump of the same size and impeller diameter, produced by the same manufacturer, has a probability of

— 50 % to be equal to or larger than x_{mean},

— 97,5 % to be equal to or larger than x_{mean} – 1,96 s_x .

Because, in most cases, the total numbers z or z_{annual} of pumps of one size within the scope of this European Standard produced by a manufacturer are very large, the mean values of the size can only be determined by performing and evaluating tests on a sample of a number M (typically being very small compared to z or z_{annual}) of test pumps drawn at random out of the production. Thereby, the mean values can only be determined with some remaining uncertainty even if no measurement uncertainties would exist. While the individual true values of efficiency and other relevant quantities evaluated from tests on a sample of test pumps can be expected to be confined to the bandwidth of scatter around the (unknown) true mean values, it is unknown where the individual values are located within the corresponding bandwidth.



Key

f(x)	relative frequency of x
X	hydraulic quantity Q, H, η, …
x_{mean}	mean value of x
s_x	standard deviation of x
l	low
h	high
$P_{95\%}$	probability interval of x_{mean}

Figure C.1 — Normal distribution of a quantity x within a pump size resulting from manufacturing tolerances

For example, a test pump drawn at random out of a size can have any true value of efficiency η_i within the scatter bandwidth, and also, as one of the two possible extreme cases, either the minimum or the maximum value of efficiency on the boundaries "l" (low) and "h" (high) of the bandwidth, see Figure C.1.

To prove for a pump size a certain value of the Minimum Efficiency Index (MEI) by the procedure described in Clause 6, besides the mean efficiency values $(\eta_{BEP})_{mean}$, $(\eta_{PL})_{mean}$ and $(\eta_{OL})_{mean}$ of the size, also the mean values $(Q_{BEP})_{mean}$ and $(n_s)_{mean}$ of the size are needed for the determination of the corresponding nominal values of minimum required efficiency (see Clause 4).

When determining the mean hydraulic values of a size by tests and evaluations on sample pumps, additionally to the bandwidth of the true values caused by hydraulic manufacturing tolerances within the size, the effect of measurement uncertainties shall be taken into account. The bandwidth of true values within a size is only dependent on the quality of manufacturing. The width of the confidence intervals of hydraulic quantities which are experimentally determined are additionally dependent on the accuracy of the measuring methods and devices, i.e. on the actual overall measurement uncertainties (see Annex D).

Therefore, the true mean values of hydraulic quantities of a size, especially of those which are relevant for the Minimum Efficiency Index (MEI), can be determined by tests and evaluations only as being limited to corresponding confidence intervals which can be quantified by total tolerance factors or values. These total tolerance factors can either be based on general experience of the individual manufacturer or can be determined directly from measurements on a sample of several tests pumps of the same size (when applying, for example, the method described in D.3.

To assure a sufficiently high probability that

— the true mean efficiency values of a pump size are at least equal to the threshold values corresponding to the Minimum Efficiency Index (MEI) of this size,

— tests on one or more pump(s) of this size (with a full impeller diameter) which is carried out in the frame of a verification procedure will result in a confirmation of the Minimum Efficiency Index (MEI) indicated by the manufacturer,

it is necessary that the mean efficiency values of $(\eta_{BEP})_{mean}$, $(\eta_{PL})_{mean}$ and $(\eta_{OL})_{mean}$ determined by tests on sample pumps shall have some positive margins (expressed by total tolerances or confidence intervals) relative to the threshold values for the value of the Minimum Efficiency Index (MEI) required by law and/or indicated by the manufacturer.

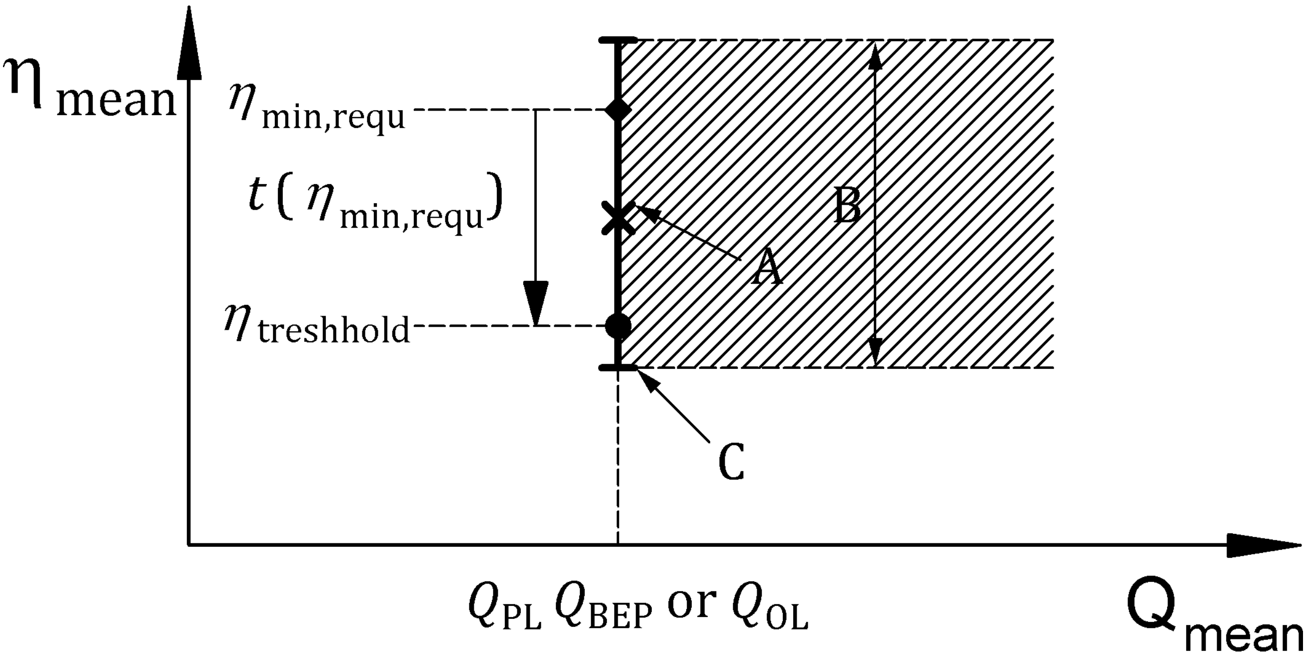
These necessary margins between the mean efficiency values - determined by tests on sample pumps of a size - and the corresponding threshold values of efficiency for a certain value of the Minimum Efficiency Index are the smaller

— the smaller the hydraulic scatter within the size is (→ good manufacturing quality, small manufacturing tolerances),

— the smaller the measurement uncertainties of the measurements on the sample pumps are (→ high accuracy of measuring equipment, small random errors, see Annex H),

— the larger the number M of tested sample pumps is (see Annex G and Annex H).

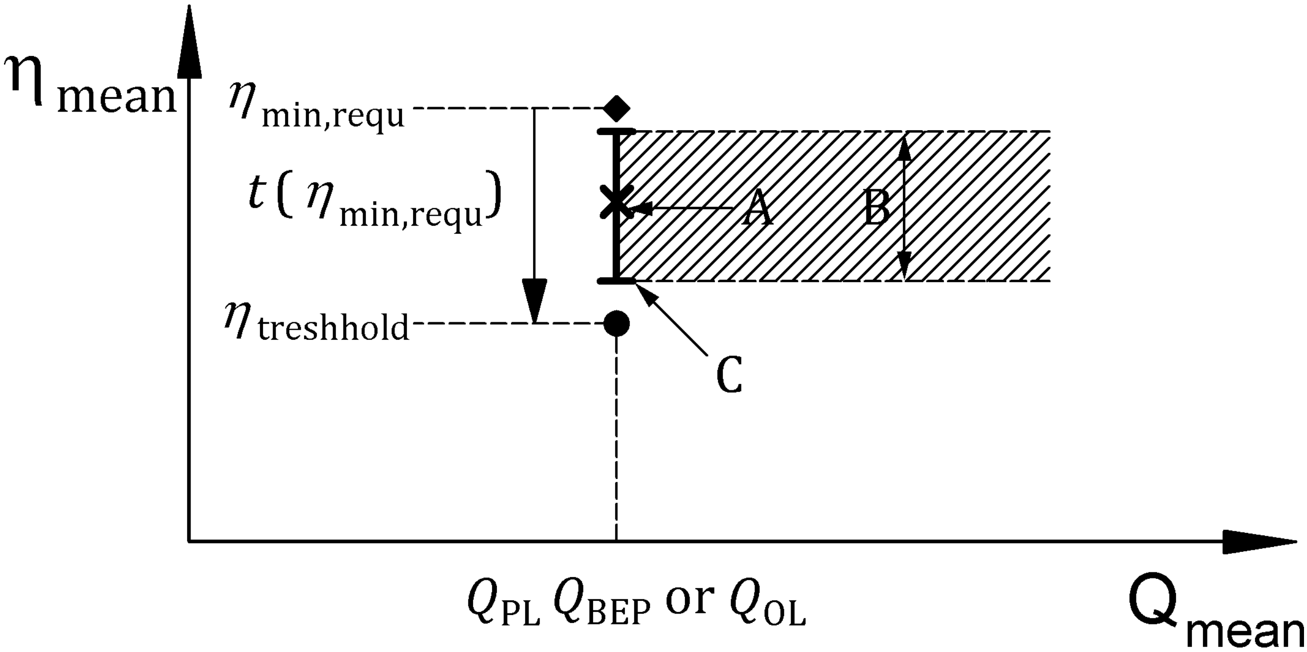
In Figures C.2 and C.3, the effect of the magnitude of the total tolerances (i.e. the width of the confidence intervals) of the mean efficiencies of a size on the comparison with the corresponding threshold values according to Clause 5 is demonstrated. In both cases, the average efficiency resulting from measurements on sample pumps as well as the nominal values of minimum required efficiency and the corresponding threshold values of efficiency are assumed to be the same ones. In the case of larger total tolerances of the measured efficiencies (shown in Figure C.2) the same pump size may miss the criteria (defined in Clause 5) for qualification in respect to a certain value of Minimum Efficiency Index (MEI) while it fulfils the criteria in the case of smaller total tolerances of the measured efficiencies (shown in Figure C.3).



Key

$\eta_{min,requ}$	nominal value of minimum required efficiency (calculated by Formulae (4),(6),(7))
$\eta_{threshold}$	particular threshold value
$t(\eta_{min,requ})$	total tolerance according to EN ISO 9906, grade 2B, applied to $\eta_{min,requ}$
A	η or $\overline{\eta}$ from test(s)
B	95 % confidence interval of η_{mean} from test(s)
C	min. value of true η_{mean} (with 97,5 % probability)

Figure C.2 — Effect of total tolerances of measured efficiencies, case 1



Key

$\eta_{min,requ}$	nominal value of minimum required efficiency (calculated by Formulae (4),(6),(7))
$\eta_{threshold}$	particular threshold value
$t(\eta_{min,requ})$	total tolerance according to EN ISO 9906, grade 2B, applied to $\eta_{min,requ}$
A	η or ..from test(s)
B	95 % confidence interval of η_{mean} from test(s)
C	min. value of true η_{mean} (with 97,5 % probability)

Figure C.3 — Effect of total tolerances of measured efficiencies, case 2

When the procedure described in Clause 6 is applied by a manufacturer in order to prove for a pump size a certain value of the Minimum Efficiency Index (MEI), the determination of the relevant (confidence intervals of the) mean values of this size is generally in the responsibility of the manufacturer.

Two possibilities to determine with sufficient probability for a pump size – on the basis of tests on sample pumps of this size - the mean values of efficiency and the other relevant quantities are described in detail in Annex D.

Annex D
(informative)

Methods recommended for manufacturers to determine the mean values of hydraulic quantities of a size relevant for MEI

D.1 General remarks

To determine mean quantities of a size, two possibilities exist and are recommended to be applied by manufacturers for proving that the size achieves a certain value of the Minimum Efficiency Index (MEI):

1) Only one test on a single test pump drawn at random out of the size is carried out and its efficiency values at BEP, PL and OL are determined by measurements and evaluations as described in Clause 5. The mean efficiency values of the size are calculated by making use of a hydraulic manufacturing tolerance factor $t_{man,\eta}$ which is based on experience of the manufacturer concerning maximum manufacturing tolerances to be expected for the respective pump size. But it is generally not known where the experimentally determined values η_{exp} of the sample pump are located within the bandwidth of scatter caused by manufacturing tolerances. Also the actual magnitude of the bandwidth of scatter is unknown. But the true mean values η_{mean} can be expected to be confined to the interval of $\pm\ t_{man,\eta} \cdot \eta_{exp}$ around the experimentally determined values η_{exp}. To be sure that the requirements mentioned in Annex C are met for the qualification, the extreme case shall be considered that the efficiency of the sample pump is at the high end (point "h" in Figure C.1) of the scatter bandwidth of η. Then, one can be sure that the mean value of efficiency η_{mean} is equal to or higher than $(1 - t_{man,\eta}) \cdot \eta_{exp}$ in any case.

2) Tests are carried out on a sample consisting of *M* test pumps drawn at random out of the size. On the results of these tests, small (or exact) sampling theory is applied. On the basis of the results for the *M* tested pumps, the arithmetically averaged values, the standard deviations of the relevant hydraulic quantities and the actual confidence intervals of the mean efficiencies of the size are calculated.

While the second method needs more experimental effort, it normally will lead to smaller confidence intervals if good manufacturing quality is attained by quality management measures applied by the manufacturer. This is because the magnitude of fixed manufacturing tolerance factors used for the first method is set to cover even cases of poorer manufacturing quality. Therefore, the higher effort when applying the second method is – in most cases – justified by smaller margins (in comparison to the fixed tolerance in the first method) by which the experimentally determined mean values of efficiency shall exceed the corresponding threshold values which are relevant for the verification procedure described in Clause 7. This effect is also demonstrated in Figures C.2 and C.3 in Annex C.

D.2 Determination of the mean efficiency of a pump size from a test on one single test pump

The test on a single pump has to be performed and evaluated as described in Clause 5.

Thereby, the measured values of flow rates Q_{BEP}, Q_{PL} and Q_{OL} and the corresponding values of efficiency η_{BEP}, η_{PL} and η_{OL} as well as the value of specific speed n_s (see 5.5.3) are available for the test pump.

Based on these values, the total tolerance intervals have to be determined to which the values of the mean efficiencies η_{mean} (at BEP, PL and OL) of the size are confined with a high probability. For the determination of the width of these intervals, the total tolerance factor $t_{tot,\eta}$ has to be applied.

Because the scatter of efficiencies within the size and the measurement uncertainties of the test on the selected pump can be assumed to be normally (Gaussian) distributed and statistically independent of each other, the total tolerance factor for the mean efficiencies of the size are calculated by the means of the formula

$$t_{tot,\eta} = \sqrt{e_{tot,\eta}^2 + t_{man,\eta}^2} \qquad \text{(D.1)}$$

In Formula (D.1), $t_{man,\eta}$ is the (relative) hydraulic tolerance resulting from geometrical manufacturing tolerances within the size. The value of $t_{man,\eta}$ has to set on the basis of the manufacturers experience, for example on the basis of data available from quality management. The tolerance interval of ± $t_{man,\eta}$ shall be sufficiently large to enclose about 95 % of the true efficiency values of individual pumps of the size. Only as a default value **$t_{man,\eta}$ = 0,04 (or 4 %)** is recommended for sizes produced with usual quality of manufacturing. Sizes consisting of small pumps with low power input tend to have larger scatter of individual efficiency (and, thereby, larger values of $t_{man,\eta}$) because

— geometrical tolerances have stronger effects on the efficiency,

— mechanical losses in shaft sealings and bearings which can show relative large scatter within the same size contribute more to pump efficiency.

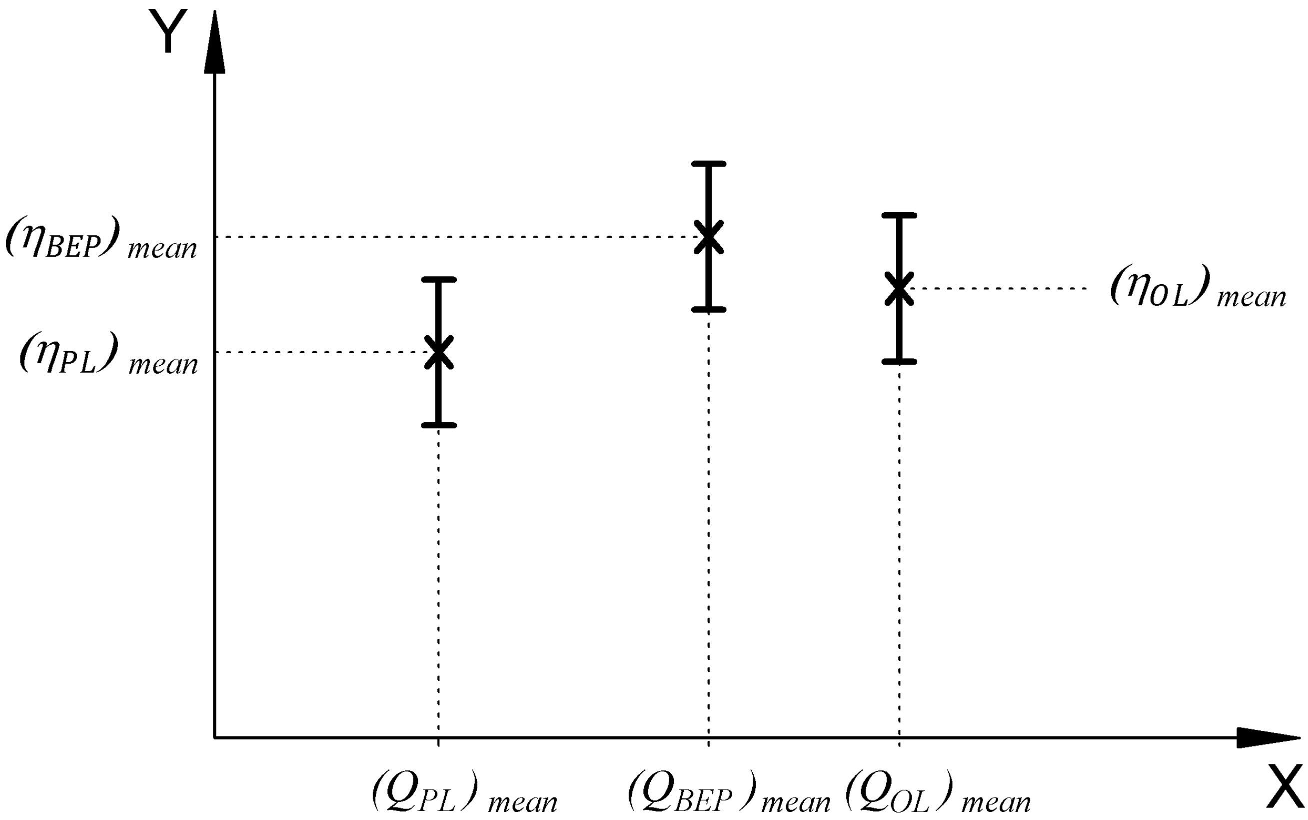
In a Q-η-diagram, the total tolerance intervals of the values of efficiency relevant for the Minimum Efficiency Index (MEI) can be plotted at the values of flow rate determined from the test result (see Figure D.1). The semi-axes of these total tolerance intervals are

at $Q = Q_{BEP}$: $\pm t_{tot,\eta} \cdot \eta_{BEP}$

at $Q = Q_{PL}$: $\pm t_{tot,\eta} \cdot \eta_{PL}$

at $Q = Q_{OL}$: $\pm t_{tot,\eta} \cdot \eta_{OL}$

The true mean values of η of the pump size (which are relevant for the qualification in respect to the Minimum Efficiency Index (MEI)) are confined to the total tolerance intervals. Within these total tolerance intervals, each value of η is equally valid.



Key

95 % confidence interval of η_{mean} from test(s)

Figure D.1 — Graphical presentation of mean efficiencies relevant for the Minimum Efficiency Index (MEI) of a pump size

The mean values of flow rate at best efficiency Q_{BEP} and specific speed n_s of the size which are needed to calculate values of minimum required efficiencies are set to be equal to the values determined for the test pump:

$$Q_{BEP,mean} = Q_{BEP} \tag{D.2}$$

$$n_{s,mean} = n_s \tag{D.3}$$

D.3 Determination of the mean efficiency of a pump size from a sample of M test pumps

A sample of $M > 1$ test pumps is drawn at random out of a pump size. Preferably, the number of test pumps forming the sample should be $M \geq 5$. For each of the sample pumps a test has to be carried out and evaluated as described in Clause 5.

For each test pump of the sample, the values of flow rates Q_{BEP}, Q_{PL} and Q_{OL} and the corresponding values of efficiency η_{BEP}, η_{PL} and η_{OL} as well as the value of the specific speed n_s have to be determined according to 5.5.3.

Then, for each of these hydraulic quantities x the arithmetically averaged value $\overline{x}$ of the sample and the standard deviation s_x of the sample have to be calculated by the means of the following formulae:

$$\overline{x} = \frac{1}{M} \cdot \sum_{i=1}^{M} x_i \qquad \text{(D.4)}$$

$$s_x = \sqrt{\frac{1}{M-1} \cdot \sum_{i=1}^{M} \left(x_i - \overline{x}\right)^2} \qquad \text{(D.5)}$$

If a value of a quantity *x*, especially the value of η_{BEP}, of one of the test pumps, seems to be not plausible or erroneous compared to the values of the other *M-1* pumps of the sample, an outlier test can be conducted according to Annex F. If by this test the value is proven to be an outlier, the results of this test pump should be rejected and

— either the values $\overline{x}$ and s_x have to be recalculated from the test results of the remaining *M-1* test pumps, if *M-1* is still sufficiently large to be statistically significant (see Annex F),

— or the test on the test pump which produced the outlier value may be repeated,

— or another test pump may be tested additionally.

If no measurement uncertainties of the efficiency would exist, the true mean values of efficiency at BEP, PL and OL, respectively, would be confined – with a probability of 95 % - to the confidence interval

$$\overline{\eta} \pm \frac{t(95\%, M) \cdot s_\eta}{\sqrt{M}}$$

using the value of *t(95%,M)* for the number M of test pumps from Table F.1 in Annex F.

However, because of the inevitable measurement uncertainties, the combined effects of hydraulic manufacturing tolerances and measuring uncertainties have to be taken into account. The measurement errors arising at the tests on each of the *M* test pumps can be assumed to be statistically independent from each other. Therefore, the uncertainty of the arithmetically averaged values $\overline{\eta}$ of the sample can be calculated from the total measurement uncertainties $e_{tot,\eta}$ at each of the tests on the *M* test pumps according to the law of error propagation (see Annex F):

$$e_{tot,\overline{\eta}} = \frac{1}{M} \cdot \sqrt{\sum_{i=1}^{M} \left(\frac{\eta_i}{\overline{\eta}} \cdot e_{tot,\eta_i}\right)^2} \qquad \text{(D.6)}$$

In the (probable) case that for each of the tests on one of the M pumps, the values η_i do not differ much from each other (i.e. $\eta_1 \approx \eta_2 \approx .... \approx \overline{\eta}$) and the measurement uncertainties e_{tot,η_i} have nearly the same magnitudes (i.e $e_{tot,\eta_1} \approx e_{tot,\eta_2} \approx ...... \approx e_{tot,\eta}$), it results

$$e_{tot,\overline{\eta}} = \frac{1}{\sqrt{M}} \cdot e_{tot,\eta} \qquad \text{(D.7)}$$

Then, the width of the 95 % confidence interval of the true mean values of efficiency at BEP, PL and OL, respectively, can be calculated by the means of the formula

$$\overline{\eta} \cdot \left(1 - t_{tot,\overline{\eta}}\right) \le \eta_{mean} \le \overline{\eta} \cdot \left(1 + t_{tot,\overline{\eta}}\right) \qquad \text{(D.8)}$$

with

$$t_{tot,\overline{\eta}} = \sqrt{e_{tot,\overline{\eta}}^2 + \frac{1}{M} \cdot \left(t_{95\%} \cdot \frac{s_\eta}{\overline{\eta}} \right)^2} \tag{D.9}$$

The semi-axes of the total tolerance intervals of the true mean values of efficiency relevant for the Minimum Efficiency Index (MEI) are

— at $Q = \overline{Q}_{BEP}$: $\pm t_{tot,\eta_{BEP}} \cdot \overline{\eta}_{BEP}$

— at $Q = \overline{Q}_{PL}$: $\pm t_{tot,\eta_{PL}} \cdot \overline{\eta}_{PL}$

— at $Q = \overline{Q}_{OL}$: $\pm t_{tot,\eta_{OL}} \cdot \overline{\eta}_{OL}$

Figure D.1 shows the graphical presentation of the results in a Q-η diagram. The true mean values of η of the pump size (which are relevant for the Minimum Efficiency Index (MEI)) are confined to the total tolerance intervals. Within these total tolerance intervals, each value of η is equally valid.

The mean values of flow rate at best efficiency Q_{BEP} and specific speed n_s of the size which are needed to calculate values of minimum required efficiencies are set to be equal to the respective arithmetically averaged values:

$$Q_{BEP,mean} = \overline{Q}_{BEP} \tag{D.10}$$

$$n_{s,mean} = \overline{n}_s \tag{D.11}$$

Annex E
(informative)

Numerical example

The numerical example described illustrates the application of the two different methods described in A5.2 and A5.3, to compare the two methods in respect to tolerances and to results in respect to qualification and to demonstrate the advantages of testing a sample of M > 1 pumps in the frame of the qualification procedure.

To simplify the comparison, the numerical example focuses on the mean efficiency values of a size at BEP.

The exemplarily chosen size is a "virtual" one and may be characterized by the following properties and mean values:

— pump type: ESOB, nominal speed of rotation: n = 2 900 min^{-1},

— design flow rate: Q_{BEP} = 19,82 m^3/h, design pump head: H_{BEP} = 24,04 m,

— design specific speed: n_s = 19,82 min^{-1},

— **true mean efficiency of the pump size: $\eta_{BEP,mean}$ = 0,607 p.u. = 60,7 %,**

— mechanical power input: P2 = 2,2 kW.

It is assumed that the true efficiency values $\eta_{BEP,true}$ of the individual pumps within the size show a normal (Gaussian) distribution with the true mean value having the highest probability and with a scatter bandwidth caused by manufacturing tolerances, i.e. 95 % confidence interval, of ± 4 % of $\eta_{BEP,mean}$. (In this example, the actual bandwidth of manufacturing tolerances is the same as the value of $t_{man,\eta}$ = 0,04 which is recommended as a default value when applying the method described in Annex E). The absolute hydraulic manufacturing tolerance is

$\pm t_{man,\eta} \bullet \eta_{BEP,mean} = \pm 0,04 \bullet 0,607 = 0,0243 = 2,43$ %

For the purpose of demonstration, five "virtual" pumps are drawn at random out of the "virtual" size as sample pumps so that their true efficiency values respect their probability resulting from the underlying normal (Gaussian) distribution within the size. This leads to the true values of $\eta_{BEP,true}$ of the exemplarily taken pumps shown in Table E.1:

Table E.1 — "True efficiency values" of sample pumps

n° of test pump i	manufacturing scatter (%)	$\eta_{BEP,true}$ (%)
1	-2,00	58,70
2	0,43	61,13
3	1,22	61,92
4	-0,80	59,90
5	1,35	62,05

Next, "virtual" test results are generated taking into account assumed actual random and systematic measurement uncertainties which are smaller than the maximum permitted values given in Tables 5 and 6 in 5.4.4. The effect of the "virtual" actual measurement uncertainties on the "virtual" measured efficiency values is treated in the following way:

— Efficiency is assumed to be determined by measurement of speed and torque.

— The values of measurement uncertainties of the individual measured quantities (Q, H, T, n) respect probabilities resulting from underlying normal (Gaussian) distributions.

— Individual (and different) values of random uncertainties are assumed for each test pump of the sample.

— Same values of systematic uncertainties (i.e. same accuracy of test equipment) are assumed for all test pumps of the sample:

  — $e_{s,Q}$: 0,01 p.u. =1 %

  — $e_{s,H}$: 0,01 p.u. =1 %

  — $e_{s,n}$: 0,01 p.u. =1 %

  — $e_{s,T}$: 0,01 p.u. =1 %.

— Uncertainties of directly measured quantities are correctly combined when calculating efficiency.

This leads to the "measurement results" for the exemplarily taken pumps shown in Tables E.2 and E.3:

Table E.2 — "Measured values" of sample pumps

n° of test pump i	Flow rate		Total head		Torque		Speed of rotation	
	$Q_{BEP,test}$ (mc/h)	$e_{tot,Q}$ (%)	$H_{BEP,test}$ (m)	$e_{tot,H}$ (%)	$T_{BEP,test}$ (Nm)	$e_{tot,T}$ (%)	$n_{BEP,test}$ (min^-1)	$e_{tot,n}$ (%)
1	20,60	1,12	24,7	2,12	7,76	1,41	2900	1,02
2	19,52	2,69	23,4	3,81	6,69	2,97	2900	1,22
3	19,16	1,41	23,8	2,58	6,59	1,02	2900	1,17
4	20,01	2,06	24,6	1,58	7,36	1,28	2900	1,12
5	19,80	1,56	23,7	3,18	6,77	2,15	2900	1,35

Table E.3 — "Calculation of measured values" of sample pumps

n° of test pump i	Specific speed		Measured efficiency		95 % confidence interval of measured efficiency
	$n_{s,BEP,test}$ (min^-1)	$e_{tot,ns}$ (%)	$\eta_{BEP,test}$ (%)	$e_{tot,\eta}$ (%)	$\eta_{BEP,test}$ (%)
1	19,80	1,97	58,70	2,96	56,96 – 60,44
2	20,07	3,39	61,13	5,66	57,67 – 64,59
3	19,63	2,37	61,92	3,32	59,86 – 63,98
4	19,57	1,93	59,90	3,10	58,04 – 61,76
5	20,02	2,85	62,05	4,36	59,34 – 64,76

If the five pumps are taken together to form a sample of M = 5, averaging of the individual measured values by applying the calculations according to Formulae (A5.4) to (A5.11), the method described in Annex E leads to the following results:

Arithmetically averaged values of the sample:

$Q_{BEP,mean}$ = 19,82 m³/h

$n_{s,mean}$ = 19,82 min⁻¹

$\eta_{BEP,mean}$ = 60,74 %

95 % confidence interval of mean efficiency of the size:

$$58{,}66\ \% \leq \eta_{BEP,mean} \leq 62{,}82\ \%$$

On the other hand, if only one of the five pumps would be taken as a sample with M = 1, if the method described in Annex E with Formulae A5.1 to A5.3 is applied and if the manufacturing tolerance factor is set to the default value of $t_{man,\eta}$ = ± 0,04 = 4 %, the 95 % confidence intervals of the mean efficiency of the size shown in Table E.4 would result from the test results of each individual pump.

Table E.4 — 95 % confidence intervals of mean efficiency resulting from tests on a single pump

n° of test pump i	Flow rate Q_{BEP} (mc/h)	Measured efficiency η_{BEP} (%)	Total tolerance factor t_{tot} (%)	95 % confidence intervals of mean efficiency of the size η_{BEP} (%)
1	20,60	58,70	4,98	55,78 – 61,62
2	19,52	61,13	6,93	56,89 – 65,37
3	19,16	61,92	5,20	58,70 – 65,14
4	20,01	59,90	5,06	56,87 – 62,93
5	19,80	62,05	5,92	58,38 – 65,72
all test pumps combined	19,82	60,74	3,43	58,66 – 62,82

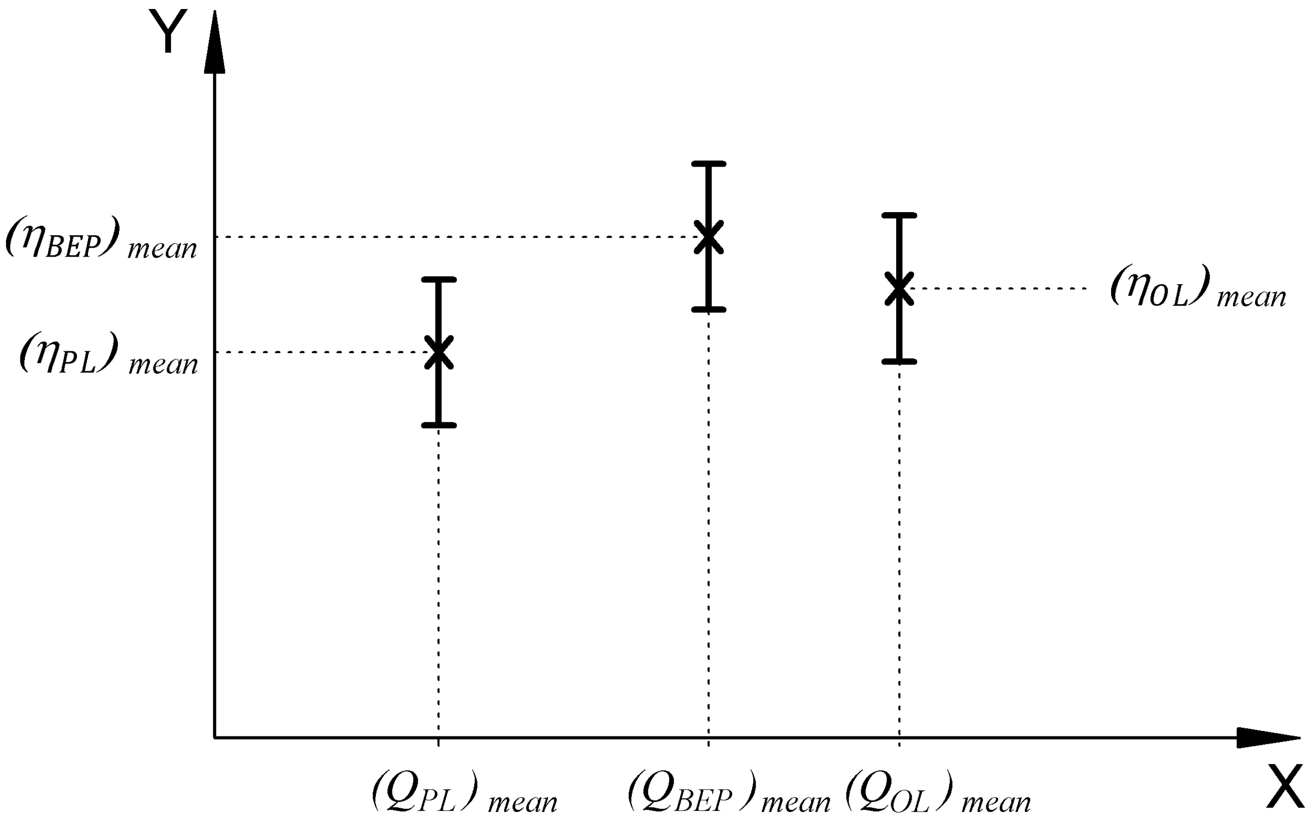


Figure E.1 — Comparison of confidence intervals of mean efficiency

It can clearly be seen from the example that the width of the 95 % confidence intervals of the mean efficiency of the same size and determined with the same measurement accuracy are much larger when testing only one sample pump than when testing a sample of five pumps. (It has to be noted that in the example the default value of $t_{man,\eta}$ = ± 0,04 describes exactly the actual scatter of efficiencies of individual pumps within the size.)

Finally, the results shall serve to prove that for the size a Minimum Efficiency Index of MEI = 0,4 can be indicated. According to Clause 4, the value of η_{mean} has to be compared to the corresponding minimum required value. To fulfill the qualification criterion for MEI = 0,4, the value of η_{mean} shall be equal to or higher than the corresponding minimum required value. To determine the minimum required values of η_{mean}, first the nominal values of minimum required efficiency are calculated by the means of Formula (4) for MEI = 0,4 with the values of

— $Q_{BEP,test}$ and $n_{s,test}$ in the case of M = 1,

— $Q_{BEP,mean}$ and $n_{s,mean}$ in the case of M = 5

as input quantities.

According to Clause 6, the value of η_{mean} within its 95 % confidence interval has to be compared to the corresponding threshold value. To fulfill the verification criterion for MEI = 0,4, the value of η_{mean} shall be equal to or higher than the corresponding particular threshold value. To determine the particular threshold values of η_{mean}, the previous values resulting from Formula (4), is multiplied by the factor 0,95 (which corresponds to the total tolerance t_η = - 5 % in EN ISO 9906, class 2). The mentioned values are shown in Table E.5. In the last column of Table E.5, also the result of the comparison in respect to the fulfillment of the qualification and verification criterion for MEI = 0,4.

Table E.5 — Relevant values and results in respect to qualification of the size

n° of test pump i	Measured efficiency η_{BEP} (%)	Lowest value of 95 % confidence interval η_{BEP}- t_{tot} (%)	Minimum required value $\eta_{BEP,requ}$ (%)	Particular threshold value $\eta_{BEP,threshold}$ (%)	Fullfilled qualificatio n criterion	Fullfilled verification criterion
1	58,70	55,78	60,90	57,86	no	yes
2	61,13	56,89	60,77	57,73	yes	yes
3	61,92	58,70	60,22	57,20	yes	yes
4	59,90	56,87	60,47	57,45	no	yes
5	62,05	58,38	60,83	57,78	yes	yes
all test pumps combined	60,74	58,66	60,64	57,61	yes	yes

Although in this example, the true mean value $\eta_{BEP,mean}$ = 60,74 % is actually higher than the nominal minimum required values (qualification criterion), the results for two of the five pumps – when taken as a single test sample – would not prove that an value of MEI = 0,4 is justified. On the other hand, when all five pumps are taken as a sample of M = 5, the result (qualification criterion) would not only prove clearly that a value of MEI = 0,4 is justified.

NOTE The indication of the value MEI = 0,4 for the size, proven by the manufacturer on the basis of the sample of M = 5 pumps, would be confirmed by an independent institution (applying the procedure described in Clause 6) already with the first test if anyone of the five pumps serving for the example above would be drawn at random out of the size.

Only in cases of very low probability if only one pump is tested for the qualification, a pump chosen for the verification would fail. But also in this cases, the indicated value of MEI = 0,4 would be confirmed with very high probability by tests on three additional sample pumps (see also Annex F).

Annex F
(informative)

Application of mathematical statistics on tests

F.1Purposes of applying statistics in the frame of qualification and verification

The application of this standard needs to perform and evaluate tests on pumps. In the frame of this work, use is made of mathematical statistics for different purposes:

a) To determine the random error of measured hydraulic quantities when tests are carried out according to Clause 5 and to prove that they do not exceed maximum permissible values given in EN ISO 9906.

b) To determine confidence intervals of relevant measured quantities, see Clauses 6 and 7.

c) To determine the total measurement uncertainty of efficiency values, where the law of error propagation has to be applied because the efficiency cannot be directly measured but is calculated from several directly measurable quantities, see Annex G.

d) To qualify a pump size in respect to a certain value of the Minimum Efficiency Index (MEI). For this purpose, mean efficiency values of the size (defined in Annex C) have to be determined. If corresponding tests and evaluations are done on a sample of $1<M<z$ pumps drawn at random out of the z total numbers of pumps of the size, the confidence interval of the mean values can be determined mathematically as described in Annex C.

Normal or Gaussian distribution

The effects of random error of measurements as well as of scatter of hydraulic quantities within a pump size resulting from manufacturing processes can be assumed to be of random nature. For sufficiently large numbers of individual instrument readings for a measured quantity or of individual pumps within a size, the individual values of instrument readings of the same measured quantity or of a hydraulic quantity of the individual pumps within a size will obey in good approximation the so-called normal or Gaussian distribution. This distribution describes the frequency (or probability) with which the individual values will occur within their whole range (see Figure C.1 in Annex C). Mathematically, the normal or Gaussian distribution is described by the formula

$$p(x) = \frac{1}{\sqrt{2\pi} \cdot \sigma_x} \cdot \exp\left(- \frac{(x - x_{mean})^2}{2\sigma_x^2} \right) \quad \text{(F.1)}$$

In Formula (F.1), $p(x)$ is the probability density, x_{mean} is the true mean value and σ_x is the standard deviation of the quantity x which obeys exactly a normal or Gaussian distribution.

Setting

$$Z = \frac{x - x_{mean}}{\sigma_x}, \quad \text{(F.2)}$$

Formula F.1 can be written as

$$p(Z)=\frac{1}{\sqrt{2\pi}}\cdot\exp\left(-\frac{Z^2}{2}\right). \tag{F.3}$$

The integration of the probability density p(Z) from $Z=-\infty$ to Z^* gives the function $P(Z^*)$ which describes the (normalized) probability that any individual value of Z is lower than Z^* while, $1-P(Z^*)$ describes the probability that any individual value of Z is higher than Z^*.

For quantities which obey this distribution, some statements are generally valid:

a) The probability distribution is symmetrical in respect to the mean value x_{mean}. The value $x = x_{mean}$ has the highest frequency or probability. The probability of $x \le x_{mean}$ and of $x \ge x_{mean}$ is equal and is 0,5 (or 50 %).

b) The probability is 0,9 (or 90 %) that any value of x is within the interval $x_{mean} \pm 1{,}65\ \sigma_x$. The probability is 0,95 (or 95 %) that any value of x is within the interval $x_{mean} \pm 1{,}96\ \sigma_x$. The probability is 0,99 (or 99 %) that any value of x is within the interval $x_{mean} \pm 2{,}58\ \sigma_x$.

c) The probability is 0,841 5 (or 84,15 %) that any value of x is $\ge x_{mean} - 1{,}65\ \sigma_x$. . The probability is 0,975 (or 97,5 %) that any value of x is $\ge x_{mean} - 1{,}96\ \sigma_x$. The probability is 0,995 1 (or 99,51 %) that any value of x is $\ge x_{mean} - 2{,}58\ \sigma_x$.

F.2 Confidence interval

If

— only a limited number N of readings of the same measured quantity x is made,

— or only a limited number M of sample pumps of a size is tested and the individual values of a hydraulic quantity x are determined,

neither the true (mean) value x_{mean} nor the true standard deviation σ_x can be determined exactly. In these cases, only a confidence interval of x can be determined to which the true (mean) value x_{mean} is confined with a certain probability. For this aim, the arithmetically averaged value $\overline{x}$ of the N or M x-values is taken as an estimate of the true (mean) value. Depending on the desired probability p, the confidence interval is then defined by $\overline{x}\pm f(p)\cdot\sigma_x$. Most commonly, the desired probability p is chosen as 0,95 (or 95 %) so that $f(p)$ = 1,96. As mentioned, in this case the probability is 0,975 (or 97,5 %) that the true (mean) value is ≥ ($\overline{x}-1{,}96\,\sigma_x/\sqrt{\mathrm{N}}$) (for high numbers of readings) where σ_x is the true but unknown standard deviation of the normal distribution of x. To calculate a confidence interval on the basis of the limited numbers N of readings or M of sample pumps, respectively, the following formula can be used

$$\overline{x}-\frac{t(p,k)\cdot s_x}{\sqrt{k}}\le x_{mean}\le\overline{x}+\frac{t(p,k)\cdot s_x}{\sqrt{k}}. \tag{F.4}$$

In this equation, k is the degree of freedom and is equal to either the number N-1 of instrument readings or the number M-1 of sample pumps. s_x is the standard deviation of the readings of the quantity x or of the values of the quantity x of the individual sample pumps from the arithmetically averaged value $\overline{x}$ and is calculated by the means of the formula

$$s_x = \sqrt{\frac{1}{k-1} \cdot \sum_{i=1}^{k} \left(x_i - \overline{x}\right)^2} \quad \text{(F.5)}$$

t(p,k) is the so-called Student´s factor which depends on the desired probability of the confidence interval *p* and on the number *k*. For a two sided probability of 0,95 (or 95 % or a single sided probability of 97,5%) the values of *t(p,k)* are given in Table F.1.

For increasing *k,* the Student´s factor approaches the value 1,96, the width of the confidence interval goes asymptotically to zero and the arithmetically averaged value $\overline{x}$ approaches the true mean value xmean. In most practical applications, the Student´s factor can be set approximately to 1,96 for k ≥ 30.

Table F.1 — Values of Student`s factor for two sided probability 95 % (single sided with 97,5%)

K= (N-1)	*t(95%,k)*
2	4,303
3	3,182
4	2,776
5	2,571
6	2,447
7	2,365
8	2,306
9	2,262
10	2,228
11	2,201
12	2,179
13	2,160
14	2,145
15	2,131
16	2,120

K= (N-1)	*t(95%,k)*
17	2,110
18	2,101
19	2,093
20	2,086
21	2,080
22	2,074
23	2,069
24	2,064
25	2,060
26	2,056
27	2,052
28	2,048
29	2,045
30	2,042
...	

Outlier test

When sampling N instrument readings of a quantity *x* during its measurement or when determining a quantity *x* of M sample pumps by tests and evaluations, the possibility exists that one reading of *x* or the x-value of one of the sample pumps may deviate much more widely from the arithmetical average $\overline{x}$ than the remainder in the set. This value is called xr. The so-called outlier test can serve to decide whether or not the value x_r is an outlier and may be rejected.

For this purpose, first the arithmetical mean $\overline{x}$ and the standard deviation sx are calculated from the whole set including the suspect value x_r. Then, the ratio

$$R = \frac{\left|x_r - \overline{x}\right|}{s_x} \quad \text{(F.6)}$$

is calculated and compared to the maximum permissible value of R_{max} given in Table F.2. If the actual value of x_r is larger than the maximum permissible value, taken from Table F.2 for the original number N of readings or M sample pumps, the value x_r is rejected. In this case, k is reduced by 1, and .. and s_x are recalculated. If the new number N or M respectively becomes too small (for example < 5 in the case of a sample of pumps), additional readings should be taken or in case of different sample pumps an additional sample pump should be tested.

Table F.2 — Maximum permissible values of ratio R (two sided 95%)

N or M	R_{max}	*N or M*	$R_{max\%}$
3	1,15	17	2,62
4	1,48	18	2,65
5	1,71	19	2,68
67	1,89	20	2,71
8	2,02	21	2,73
9	2,13	22	2,76
10	2,21	23	2,78
11	2,29	24	2,80
12	2,36	25	2,82
13	2,41	26	2,84
14	2,46	27	2,86
15	2,51	28	2,88
16	2,55	29	2,90
	2,59	30	2,91

F.3Law of error propagation

The evaluation of test results often requires the calculation of relevant quantities y as, e.g. the efficiency from other quantities x_i which can be directly measured. The functional dependency is known and is given by the equation

$$y = f\left(x_1, x_2, x_3, ...x_n\right) \tag{F.7}$$

Each of the quantities xi shows a standard deviation s_{x_i}. If the effects causing the deviations from the true mean value (or from the arithmetically averaged value) are of random nature, the measured quantities x_i will obey a normal (Gaussian) distribution. If, additionally, the quantities are statistically independent of each other, the standard deviation s_y of the quantity y is given by

$$s_y = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial y}{\partial x_i}\right)^2 \cdot s_{x_i}^2} \tag{F.8}$$

If f is a linear function (as in case of the efficiency), s_y is given by

$$s_y = \sqrt{\sum_{i=1}^{n} s_{x_i}^2} \tag{F.9}$$

The same relations can be used for the calculation of multiples of the standard deviations, for example for the calculation of the width of the 95 % confidence interval of the quantity y from the 95 % confidence intervals of the quantities x_i.

F.4Numerical example

The numerical example described illustrates the application of the two different methods described in Annexes A5.2 and A5.3, to compare the two methods in respect to tolerances and to results in respect to qualification and to demonstrate the advantages of testing a sample of M > 1 pumps in the frame of the qualification procedure.

To simplify the comparison, the numerical example focuses on the mean efficiency values of a size at BEP.

The exemplarily chosen size is a “virtual” one and may be characterized by the following properties and mean values:

— pump type: ESCC, nominal speed of rotation: $n = 2\,900\ min^{-1}$;

— design flow rate: $Q_{BEP} = 19{,}82\ m^3/h$, design pump head: $H_{BEP} = 24{,}04\ m$;

— design specific speed: $n_s = 19{,}82\ min^{-1}$;

— **<u>true mean</u> efficiency of the pump size: $\eta_{BEP,mean}$ = 0,607 p.u. = 60,7 %**;

— mechanical power input: P2 = 2,2 kW.

It is assumed that the true efficiency values $\eta_{BEP,true}$ of the individual pumps within the size show a normal (Gaussian) distribution with the true mean value having the highest probability and with a scatter bandwidth caused by manufacturing tolerances, i.e. 95 % confidence interval, of ± 4 % of $\eta_{BEP,mean}$. (In this example, the actual bandwidth of manufacturing tolerances is the same as the value of $t_{man,\eta} = 0{,}04$ which is recommended as a default value when applying the method described in Annex E). The absolute hydraulic manufacturing tolerance is

$$\pm\ t_{man,\eta} \bullet \eta_{BEP,mean} = \pm\ 0{,}04 \bullet 0{,}607 = 0{,}024\ 3 = 2{,}43\ \%$$

For the purpose of demonstration, five “virtual” pumps are drawn at random out of the “virtual” size as sample pumps so that their true efficiency values respect their probability resulting from the underlying normal (Gaussian) distribution within the size. This leads to the true values of $\eta_{BEP,true}$ of the exemplarily taken pumps shown in Table F.3:

Table F.3 — “True efficiency values” of sample pumps

n° of test pump i	manufacturing scatter (%)	$\eta_{BEP,true}$ (%)
1	-2,00	58,70
2	0,43	61,13
3	1,22	61,92
4	-0,80	59,90
5	1,35	62,05

Next, “virtual” test results are generated taking into account assumed actual random and systematic measurement uncertainties which are smaller than the maximum permitted values given in Tables 5 and 6 in 5.4.4. The effect of the “virtual” actual measurement uncertainties on the “virtual” measured efficiency values is treated in the following way:

— Efficiency is assumed to be determined by measurement of speed and torque.

— The values of measurement uncertainties of the individual measured quantities (Q, H, T, n) respect probabilities resulting from underlying normal (Gaussian) distributions.

— Individual (and different) values of random uncertainties are assumed for each test pump of the sample.

— Same values of systematic uncertainties (i.e. same accuracy of test equipment) are assumed for all test pumps of the sample:

— $e_{s,Q}$: 0,01 p.u. =1 %;

— $e_{s,H}$: 0,01 p.u. =1 %;

— $e_{s,n}$: 0,01 p.u. =1 %;

— $e_{s,T}$: 0,01 p.u. =1 %.

— Uncertainties of directly measured quantities are correctly combined when calculating efficiency.

This leads to the "measurement results" for the exemplarily taken pumps shown in Table F.4 and F.5:

Table F.4 — "Measured values" of sample pumps —

n° of test pump i	Flow rate		Total head		Torque		Speed of rotation	
	$Q_{BEP,test}$ (mc/h)	$e_{tot,Q}$ (%)	$H_{BEP,test}$ (m)	$e_{tot,H}$ (%)	$T_{BEP,test}$ (Nm)	$e_{tot,T}$ (%)	$n_{BEP,test}$ (min^-1)	$e_{tot,n}$ (%)
1	20,60	1,12	24,7	2,12	7,76	1,41	2 900	1,02
2	19,52	2,69	23,4	3,81	6,69	2,97	2 900	1,22
3	19,16	1,41	23,8	2,58	6,59	1,02	2 900	1,17
4	20,01	2,06	24,6	1,58	7,36	1,28	2 900	1,12
5	19,80	1,56	23,7	3,18	6,77	2,15	2 900	1,35

Table F.5 — "Calculation of measured values" of sample pumps

n° of test pump i	Specific speed		Measured efficiency		95 % confidence interval of measured efficiency
	$n_{s,BEP,test}$ (min^-1)	$e_{tot,ns}$ (%)	$\eta_{BEP,test}$ (%)	$e_{tot,\eta}$ (%)	$\eta_{BEP,test}$ (%)
1	19,80	1,97	58,70	2,96	56,96 – 60,44
2	20,07	3,39	61,13	5,66	57,67 – 64,59
3	19,63	2,37	61,92	3,32	59,86 – 63,98
4	19,57	1,93	59,90	3,10	58,04 – 61,76
5	20,02	2,85	62,05	4,36	59,34 – 64,76

If the five pumps are taken together to form a sample of M = 5, averaging of the individual measured values by applying the calculations according to Formulae (A5.4) to (A5.11), the method described in Annex E leads to the following results:

Arithmetically averaged values of the sample:

$Q_{BEP,mean}$ = 19,82 m^3/h

$n_{s,mean}$ = 19,82 min^{-1}

$\eta_{BEP,mean}$ = 60,74 %

95 % confidence interval of mean efficiency of the size:

- 58,66 % • ≤ $\eta_{BEP,mean}$ ≤ 62,82 %

On the other hand, if only one of the five pumps would be taken as a sample with M = 1, if the method described in Annex E with Formulae A5.1 to A5.3 is applied and if the manufacturing tolerance factor is set to the default value of $t_{man,\eta}$ = ± 0,04 = 4 %, the 95 % confidence intervals of the mean efficiency of the size shown in Table F.1 would result from the test results of each individual pump.

Table F.6 — 95 % confidence intervals of mean efficiency resulting from tests on a single pump

n° of test pump i	Flow rate Q_{BEP} (mc/h)	Measured efficiency η_{BEP} (%)	Total tolerance factor t_{tot} (%)	95 % confidence intervals of mean efficiency of the size η_{BEP} (%)
1	20,60	58,70	4,98	55,78 – 61,62
2	19,52	61,13	6,93	56,89 – 65,37
3	19,16	61,92	5,20	58,70 – 65,14
4	20,01	59,90	5,06	56,87 – 62,93
5	19,80	62,05	5,92	58,38 – 65,72
all test pumps combined	19,82	60,74	3,43	58,66 – 62,82

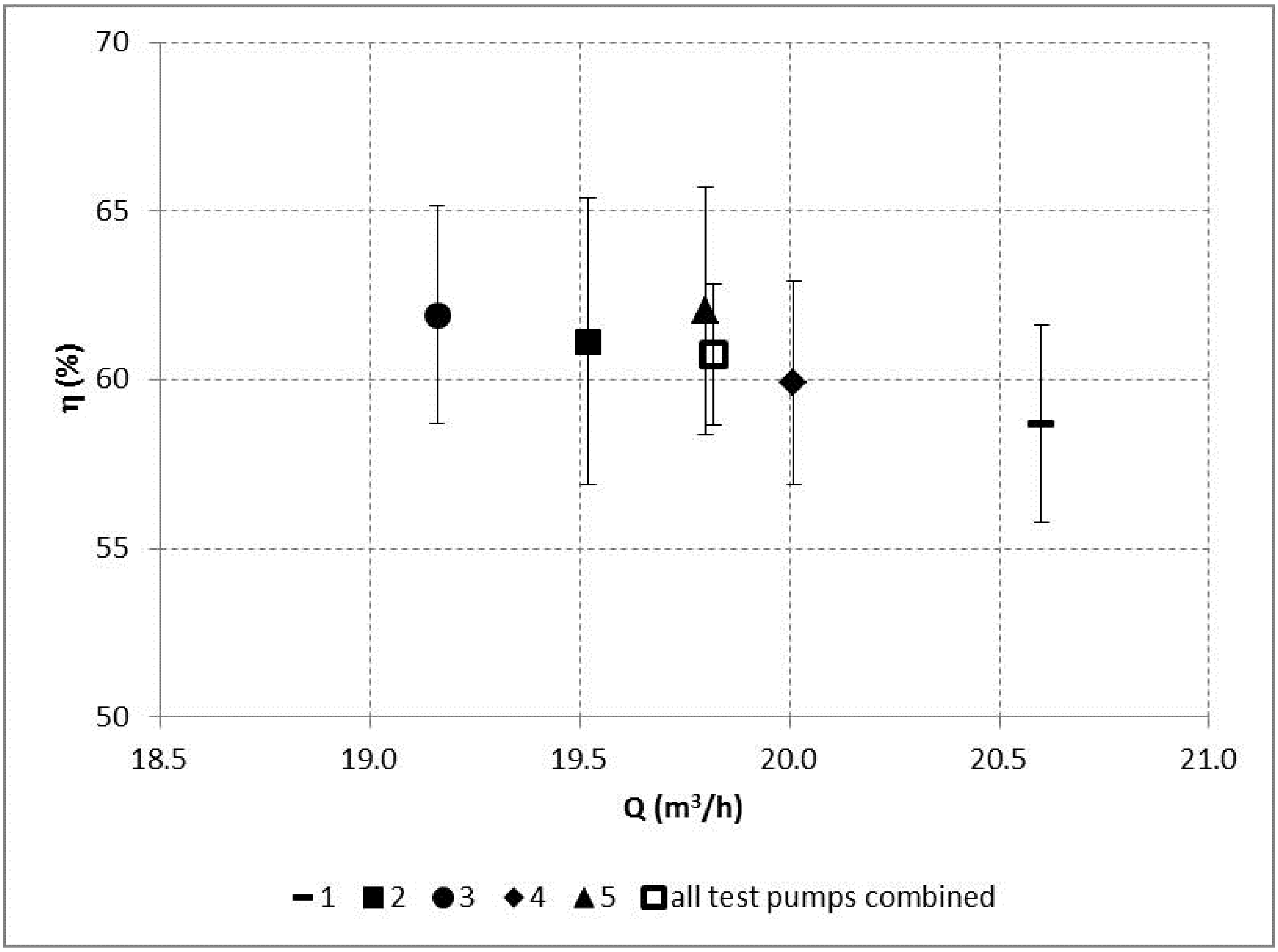


Figure F.1 — Comparison of confidence intervals of mean efficiency resulting from application of different methods

It can clearly be seen from the example that the width of the 95 % confidence intervals of the mean efficiency of the same size and determined with the same measurement accuracy are much larger when testing only one sample pump than when testing a sample of five pumps. (It has to be noted that in the example the default value of $t_{man,\eta}$ = ± 0,04 describes exactly the actual scatter of efficiencies of individual pumps within the size.)

Finally, the results shall serve to prove that for the size a Minimum Efficiency Index of MEI = 0,4 can be indicated. According to Clause 4, the value of η_{mean} has to be compared to the corresponding minimum required value. To fulfill the qualification criterion for MEI = 0,4, the value of η_{mean} shall be equal to or higher than the corresponding minimum required value. To determine the minimum required values of η_{mean}, first the nominal values of minimum required efficiency are calculated by the means of Formula (4) for MEI = 0,4 with the values of

— $Q_{BEP,test}$ and $n_{s,test}$ in the case of M = 1,

— $Q_{BEP,mean}$ and $n_{s,mean}$ in the case of M = 5

as input quantities.

According to Clause 6, the value of η_{mean} within its 95 % confidence interval has to be compared to the corresponding threshold value. To fulfill the verification criterion for MEI = 0,4, the value of η_{mean} shall be equal to or higher than the corresponding particular threshold value. To determine the particular threshold values of η_{mean}, the previous values resulting from Formula (4), is multiplied by the factor 0,95 (which corresponds to the total tolerance t_η = - 5 % in EN ISO 9906, class 2). The mentioned values are shown in Tables F.7 and F.8. In the last column of Tables F.7 and F.8, also the result of the comparison in respect to the fulfillment of the qualification and verification criterion for MEI = 0,4.

Table F.7 — Relevant values and results in respect to qualification of the size

n° of test pump i	Measured efficiency η_{BEP} (%)	Lowest value of 95 % confidence interval η_{BEP}- t_{tot} (%)	Minimum required value $\eta_{BEP,requ}$ (%)	Auxiliary function $F\eta$ (%)	C value tested pump CMEI (%)	Minimum efficiency index of the tested pump MEI	Fullfilled qualification criterion
1	58,70	55,78	60,90	191,67	132,97	0,25	no
2	61,13	56,89	60,77	191,54	130,41	0,44	yes
3	61,92	58,70	60,22	190,99	129,07	0,57	yes
4	59,90	56,87	60,47	191,24	131,34	0,36	no
5	62,05	58,38	60,83	191,60	129,55	0,53	yes
all test pumps combined	60,74	58,66	60,64			0,43	yes

Table F.8 — Relevant values and results in respect to verification of the size

n° of test pump i	Measured efficiency η_{BEP} (%)	Minimum required value $\eta_{BEP,requ}$ (%)	Particular threshold value $\eta_{BEP,threshold}$ (%)	Fullfilled verification criterion
1	58,70	60,90	57,86	yes
2	61,13	60,77	57,73	yes
3	61,92	60,22	57,20	yes
4	59,90	60,47	57,45	yes
5	62,05	60,83	57,78	yes
all test pumps combined	60,74	60,64	57,61	yes

Although in this example, the true mean value $\eta_{BEP,mean}$ = 60,74 % is actually higher than the nominal minimum required values (qualification criterion), the results for two of the five pumps – when taken as a single test sample – would not prove that an value of MEI = 0,4 is justified. On the other hand, when all five pumps are taken as a sample of M = 5, the result (qualification criterion) would not only prove clearly that a value of MEI = 0,4 is justified.

NOTE The indication of the value MEI = 0,4 for the size, proven by the manufacturer on the basis of the sample of M = 5 pumps, would be confirmed by an independent institution (applying the procedure described in Clause 6) already with the first test if anyone of the five pumps serving for the example above would be drawn at random out of the size.

Only in cases of very low probability if only one pump is tested for the qualification, a pump chosen for the verification would fail. But also in this cases, the indicated value of MEI = 0,4 would be confirmed with very high probability by tests on three additional sample pumps (see also Annex F).

Annex G
(informative)

Measurement uncertainties

G.1 General remarks

Every measurement is inevitably subject to some uncertainty, even if the measuring procedures and the instruments used, as well as the methods of analysis, fully comply with good practice and with the requirements of EN ISO 9906 and this European Standard. This uncertainty results from two sources.

a) Even at constant conditions which determine an operating point of a test pump (speed of rotation or frequency of electric supply, hydraulic resistance of test circuit, inlet pressure, liquid properties), inevitable fluctuations of the measured quantities due to the characteristics of the measuring system or to random variations of the measured quantity will occur. These fluctuations cause slightly different values of the instrument readings of the same quantity at the same operating point. Therefore, an averaging of repeated readings is necessary to determine an average value of the measured quantities. The arithmetically averaged value $\overline{x}$ of a set of N instrument readings of the quantity x is calculated as

$$\overline{x} = \frac{1}{N} \cdot \sum_{i=1}^{N} x_i \qquad \text{(G.1)}$$

b) If N increases, the values of $\overline{x}$ tend to approach the true mean value x_{mean} of the instrument readings within its fundamental limits of precision. The bandwidth of variations of the individual readings of the quantity x at the same operating point around the average value $\overline{x}$ is also called random uncertainty. Assumed that the results of repeated measurements of the quantity x show a normal (Gaussian) distribution (see Annex C), the true mean value x_{mean} can be expected with a probability of about 95 % to be confined to a confidence interval of $\overline{x} \pm 1{,}96 \cdot s_x / \sqrt{N}$ where s_x is the standard deviation of the N readings and can be calculated by the means of the following Formula (G.2). (The value 1,96 is to be taken for high numbers of measurements only !)

$$s_x = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} \left(x_i - \overline{x} \right)^2} \qquad \text{(G.2)}$$

Within this confidence interval, every value of x is equally valid.

For values of N less than 30, small (or exact) sampling theory may be applied. Then, the confidence interval is given by $\overline{x} \pm t(p,N) \cdot s_x / \sqrt{N}$ where $t\,(p,N)$ is the so-called Student´s factor for the corresponding probability p. For a probability of 95 %, the values of t (95 %,N) are given in Table F.1 in Annex F. In this European Standard, maximum permissible values of random uncertainty are specified as given in EN ISO 9906, grade 2B. The actual values of random uncertainty have to be determined as $\pm 1{,}96 \cdot s_x / \sqrt{N}$ for N ≥ 30 or as $\pm t\left(95\,\%, N\right)) \cdot s_x / \sqrt{N}$ for N < 30, respectively.

Usually, the random uncertainty is given as a relative value $e_{r,x}$ referred to the arithmetically averaged value $\overline{x}$:

$$e_{r,x} = \pm \frac{1{,}96\, s_x}{\overline{x} \cdot \sqrt{N}} \quad \text{for N} \geq 30 \tag{G.3}$$

$$e_{r,x} = \pm \frac{t(95\,\%, N) \cdot s_x}{\overline{x} \cdot \sqrt{N}} \quad \text{for N} < 30 \tag{G.4}$$

In respect to successfully proving the achievement of a certain value of the Minimum Efficiency Index (MEI) of a size by the procedure and criteria described in Clause 6, it is strongly recommended to the manufacturer to make great effort in order to have random uncertainties as small as possible. This can be reached

1) by providing a damping device in the measuring instruments or in their connecting lines (where use shall be made of symmetrical and linear damping devices, as for example a capillary tube, to not negatively affect the accuracy of instrument readings),

2) by the use of electronic data acquisition systems with appropriate hardware and/or software tools for low pass filtering or by appropriate data sampling and averaging.

c) Even after careful measurement of dimensions, proper installation etc., and if all known corrections (found by calibration) are applied to the value of an instrument reading taken at perfectly steady conditions, the reading may differ from the true value of the measured quantity. This residual uncertainty is called <u>instrument uncertainty</u>, and arises from limitations of the calibration, change of installation compared to calibration conditions, unknown environmental influences, unknown reactions of the measuring installation on the quantity to be measured and inherent and constructional limitations of the measuring chain itself. The instrument uncertainty cannot be avoided or reduced by repeated readings if the same instrument and the same method of measurement are used. It can only be estimated on the basis of information given by the manufacturer of the instruments (instrument accuracy, non-linearity, hysteresis,…), of information given by standards concerning maximum errors of standardized measuring methods, and of experience available at the staff carrying out the measurements. Usually, the instrument uncertainty is given as a relative value $e_{s,x}$ referred to the true value of the measured quantity x_{true}.

In respect to successfully proving the achievement of a certain value of the Minimum Efficiency Index (MEI) of a size by the procedure and criteria described in Clause 6, it is strongly recommended to the manufacturer to make great effort to have instrument uncertainties as small as possible. This can be reached by

1) selection and application of highly accurate instrumentation, data acquisition hardware and software,

2) careful design and construction of test rig details to avoid negative effects on measurement accuracy as for example disturbed flow distribution at pump inlet or at location of flow meter, not standard conform and/or badly manufactured geometry of static pressure taps,

3) careful installation of measuring devices as for example flow meters and torque meters,

4) careful calibration of instruments and/or whole measuring chains at proper intervals (see EN ISO 9906),

5) regular zero adjustment of instruments and/or measuring chains.

In accordance with EN ISO 9906, the relative overall measurement uncertainty $e_{tot,x}$ of a quantity x is calculated by the square root of the sum of the squares of the (relative) random uncertainty $e_{r,x}$ (fluctuations) and the (relative) instrument uncertainty $e_{s,x}$ of the quantity x:

$$e_{tot,x} = \sqrt{e_{r,x}^2 + e_{s,x}^2} \quad \text{(G.5)}$$

The absolute overall measurement uncertainty $E_{tot,x}$ of a quantity x results by multiplying the value of $\overline{x}$ determined from the measurements and evaluations by the relative overall measurement uncertainty $e_{tot,x}$.

$$E_{tot,x} = e_{tot,x} \cdot \overline{x} \quad \text{(G.6)}$$

The 95 % confidence interval of a quantity x is determined by

$$\left(1 - e_{tot,x}\right) \cdot \overline{x} \ \le x \le \left(1 + e_{tot,x}\right) \cdot \overline{x} \quad \text{(G.7)}$$

or

$$\overline{x} - E_{tot,x} \le x \le \cdot \overline{x} + E_{tot,x} \quad \text{(G.8)}$$

G.2 Determination of the overall measurement uncertainty of efficiency

In the equations below, the relative overall measurement uncertainties $e_{tot,x}$ of all quantities x have to be determined at the respective flow rates Q_{BEP} , Q_{PL} and Q_{OL}. Normally, these values can be taken from the measured operating points nearest to the flow rates Q_{BEP} , Q_{PL} and Q_{OL} , respectively.

The overall measurement uncertainty of the pump efficiency η has to be calculated according to the law of error propagation. Under the premise that the errors of the quantities which are directly measured are normally (Gaussian) distributed and statistically independent of each other, the overall measurement uncertainty of the efficiency η (as percentages of the corresponding values of η on the fitting curves) can be calculated by the means of one of the following formulae:

a) In the case that the pump power input P is determined by measuring the speed of rotation n and the shaft torque T:

$$e_{tot,\eta} = \sqrt{e_{tot,Q}^2 + e_{tot,H}^2 + e_{tot,n}^2 + e_{tot,T}^2} \quad \text{(G.9)}$$

b) In the case that the pump power input P is determined by measuring the driver power input P_{gr} and calculating P from P_{gr} by the means of the electric motor efficiency η_{dr} known from calibration:

$$e_{tot,\eta} = \sqrt{e_{tot,Q}^2 + e_{tot,H}^2 + e_{tot,P_{gr}}^2 + e_{tot,\eta_{dr}}^2} \quad \text{(G.10)}$$

In these equations, the relative overall measurement uncertainties $e_{tot,Q}$ of the flow rate Q, $e_{tot,n}$ of the speed of rotation n, $e_{tot,T}$ of the torque T and $e_{tot,Pgr}$ of the driver power input P_{gr} result directly from the relative random and instrument uncertainties of the instrumentation which is used to measure these quantities.

The relative overall measurement uncertainty $e_{tot,H}$ of the pump head H has to be calculated according to the law of error propagation. Under the premise that the errors of the quantities which are directly measured are normally (Gaussian) distributed and statistically independent of each other, the relative overall measurement uncertainty of H (as percentages of the corresponding values of H on the fitting curves) can be calculated by the means of one of the following formulae.

c) In the case that the pump head H is determined by separately measuring the suction pressure p_1 and the discharge pressure p_2 :

$$e_{tot,H} = \sqrt{\left(\frac{p_1}{p_2 - p_1} \cdot e_{tot,p_1}\right)^2 + \left(\frac{p_2}{p_2 - p_1} \cdot e_{tot,p_2}\right)^2} \qquad \text{(G.11)}$$

d) In the case that the pump head H is determined by measuring the pump differential pressure $\Delta p = p_2 - p_1$:

$$e_{tot,H} = e_{tot,\Delta p} \qquad \text{(G.12)}$$

NOTE In the formulae for $e_{tot,H}$, it is assumed that the overall uncertainties of the density ρ and of the acceleration due to gravitation g can be neglected. Additionally, the contributions of the difference of velocity heads $U_2^2/2g - U_1^2/2g$ at pump inlet and outlet as well of the height difference $z_2 - z_1$ of pump inlet and outlet to the pump head are assumed to be sufficiently small so that the effect of their uncertainties on $e_{tot,H}$ can be neglected.

It shall be emphasized that large overall uncertainties of pump H head will result from measuring the suction pressure p_1 and the discharge pressure p_2 separately and calculating their difference, if this difference is much smaller than one or both of the pressures p_1 and p_2. In this case, it is strongly recommended to measure directly the differential pressure Δp with the aid of a differential pressure transducer.

The overall measurement uncertainty $e_{tot,\eta dr}$ of the electric motor efficiency has to be determined separately dependent on the method and instrumentation of motor calibration.

Annex H
(informative)

Explanations concerning the methodology of the verification procedure and the probability of the results

The verification procedure serves to confirm (or reject) the value of the Minimum Efficiency Index (MEI) of a pump size indicated by the manufacturer. Because of the scatter of individual efficiency values among the total number of pumps of the size, the efficiency of a single pump drawn at random out of the size can be lower or higher than the mean efficiency of the size.

Under the assumption of a normal (Gaussian) distribution of the efficiency values (see Annex C)

— the probabilities are both 50 % that the true efficiency of an individual pump drawn at random out of the size is either lower or higher than the true mean efficiency η_{mean} of the size,

— the probability is 95 % that the true efficiency of an individual pump drawn at random out of the size is confined to the range of $\eta_{mean} \pm t_{man,\eta}$, where $t_{man,\eta}$ is the hydraulic tolerance of the individual true efficiency values within the size caused by manufacturing tolerances and is 1,96 times the true standard deviation of efficiency values within the size,

— the probability is 97,5 % that the true efficiency of an individual pump drawn at random out of the size is at least equal to or better than η_{mean} - $t_{man,\eta}$.

From tests on a sample of pumps of the size (done in the frame of the qualification procedure) the true mean efficiency ηmean is only known to be confined to a confidence interval with a certain probability. According to Annex F the half width of the confidence interval of ηmean is ± $t_{tot,\overline{\eta}} \cdot \overline{\eta}$ while the hydraulic tolerance of individual efficiency values within the size (caused by manufacturing tolerances) is $t_{man,\eta} \cdot \eta_{mean} \approx t_{man,\eta} \cdot \overline{\eta}$.

The situation is illustrated in Figure H.1. The maximum (= center) of the normal (Gaussian) distribution of individual efficiency values within the size can be located somewhere within the confidence interval of η_{mean} with the two extreme cases at the lower and upper limit of the interval.

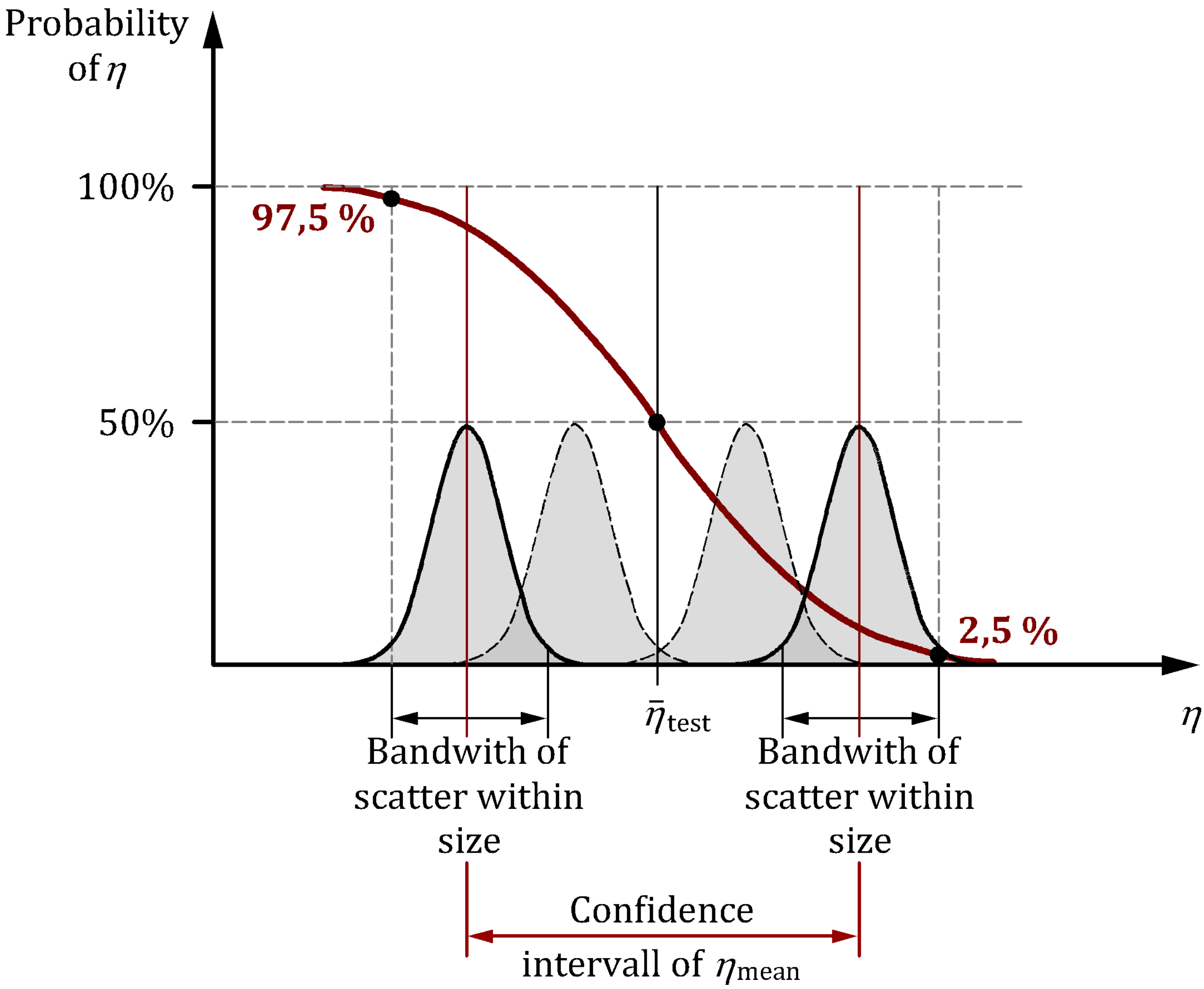


Figure H.1 — Probability of individual efficiency within a size

The probability that an individual pump drawn at random out of the size has a certain true efficiency value η (plotted as the horizontal axis) is qualitatively shown in Figure H.1 and can be mathematically expressed by the probability function.

The probability that the true efficiency of any individual pump drawn at random out of a size will be at least equal to a threshold value $\eta_{threshold}$ depends on

a) the probability that the efficiency of an individual pump is higher than the mean efficiency η_{mean} of this size (50 % for a normal distribution),

b) the location of $\eta_{threshold}$ relative to the confidence interval of η_{mean} which can be described by the "margin" $\overline{\eta} - \eta_{threshold}$.

In the case that $\eta_{threshold}$ is at the lower limit of the confidence interval of η_{mean}, (i.e. that the "margin" which is used for the indication of the MEI-value by the manufacturer is set to $\overline{\eta} - \eta_{threshold} = +\left|t_{tot,\eta}\right| \cdot \overline{\eta}$), there is a high probability that the efficiency of any individual pump will be at least equal to $\eta_{threshold}$. If in this case the ratio of tolerances is for example, $t_{man,\eta}/t_{tot,\eta} \approx 1$, it results from the probability function (shown in Figure H.1) that this probability is about 84 % and the probability to "fail" is only about (100 – 84) % = 16 %.

If, on the other hand, for the same ratio of tolerances $t_{man,\eta}/t_{tot,\eta} \approx 1$, $\eta_{threshold}$ is at the upper limit of the confidence interval of η_{mean}, i.e. $\bar{\eta} - \eta_{benchmark} = -\left| t_{tot,\eta} \right| \cdot \bar{\eta}$, it follows that this probability is only about 16 %, but the probability to "fail" is about (100 – 16) % = 84 %.

According to Clause 7, even if the first pump taken for a verification test will fail, the MEI-value indicated by the manufacturer has to be confirmed if the average efficiency of three additional pumps will "pass". Of course, there is a relation between the probability to pass the whole procedure (including the possibility of testing four pumps in all) and the probability that any individual pump will pass.

Annex I
(informative)

Reporting of Test Results

I.1 Test Report Requirements

When tests are carried out to determine the Minimum Efficiency Index (MEI) the test report shall contain detailed information to identify the tested pump and any other equipment that may be subject to test. The report shall contain the raw test data for all test points taken. A graph shall be drawn where the corrected test points are plotted. A curve fitted to the corrected test points shall be drawn on the graph. The operating points at best efficiency (BEP) as well as at part load (PL) and overload (OL) as specified in Clause 5 of this European Standard shall be determined and documented.

The following information should be included in the report (as applicable):

— test date;

— the tested equipment;

— test facility and location;

— ambient and water temperatures;

— barometric pressure;

— density of Test-Water;

— driver data;

— if test point corrections are made, the correction method shall be outlined;

— the mathematical approximation method used to fit the test data shall be outlined;

— comments pertaining to anything noteworthy about the test.

I.2 Pump test sheet

The pump test sheet illustrated in this Annex is given for guidance for presenting pump test results and to assist in their interpretation. It does not purport to include all the information required from a pump test and modifications may be necessary depending on the type of pump, its application, and the mode of calculation.

Table I.1 — Test report I

Test report / Procès-verbal d´essai / Prüfprotokoll		
Test Record No		Date
Pump Type	Pump Size	Nominal speed
Impeller data	Impeller diameter Ø [mm]	
Test conditions	Test bed type Closed	Test liquid Cold water
	Ø Suction side measuring point [mm]	Ø Discharge side measuring point [mm]
Motor data	Test motor No	
Test speed values		

Measured variable	Measurement point									
	1	2	3	4	5	6	7	8	9	10
n [min^{-1}]										
H_s [m]										
H_d [m]										
$\Delta v^2/2g$ [m]										
H [m]										
Q [m^3/h]										
Q [l / s]										
P_2 [kW]										
P_{hyd} [kW]										
η [%]										
Values at nominal speed										
H_t [m]										
Q_t [m^3/h]										
Q_t [l / s]										
$P_{2,t}$ [kW]										
$P_{hyd,t}$ [kW]										
η_t [%]										

	Values at operating points designated for MEI		
Q/Q_{BEP}	0,75	1,00	1,10
H [m]			
Q [m^3/h]			
P_2 [kW]			
η [%]			
C_{right}			
C_{left}			
C			
MEI			

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2009/125/EC, establishing a framework for the setting of ecodesign requirements of energy related products and implemented by the European Commission Regulation (EU) No. 547/2012

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive 2009/125/EC, establishing a framework for the setting of ecodesign requirements of energy related products implemented by EU Regulation 547/2012.

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

Table ZA.1 — Correspondence between this European Standard and the EU-regulation 547/2012

Clause(s)/sub-clause(s) of this EN	Essential Requirements (ERs) of EU regulation 547/2012 and Commission Communication 2012/C 402/ 07	Qualifying remarks/Notes
4.2; 4.3 and 4.4	Article 3; Annex II, 1a) 1b)	Efficiency requirements
5.1; 5.2, 5.3 and 5.5 Clause 6	Annex III	Measurements and calculations
7.2	Article 5; Annex IV	Verification procedure (e.g. for market surveillance purposes)
Annex I Table I.1	2012/C 402/07 Point 12	Test reports

Bibliography

EN ISO 5198, *Centrifugal, mixed flow and axial pumps — Code for hydraulic performance tests — Precision class (ISO 5198)*

ISO 2602, *Statistical interpretation of test results — Estimation of the mean — Confidence interval*

ISO 80000, *Quantities and units*

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BSI Group Headquarters

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