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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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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of an identical text or by endorsement, at the latest by November 2016, and conflicting national standards shall be withdrawn at the latest by November 2016.

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

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 manufacturer, 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 $+120^{\circ}\text{C}$ 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.

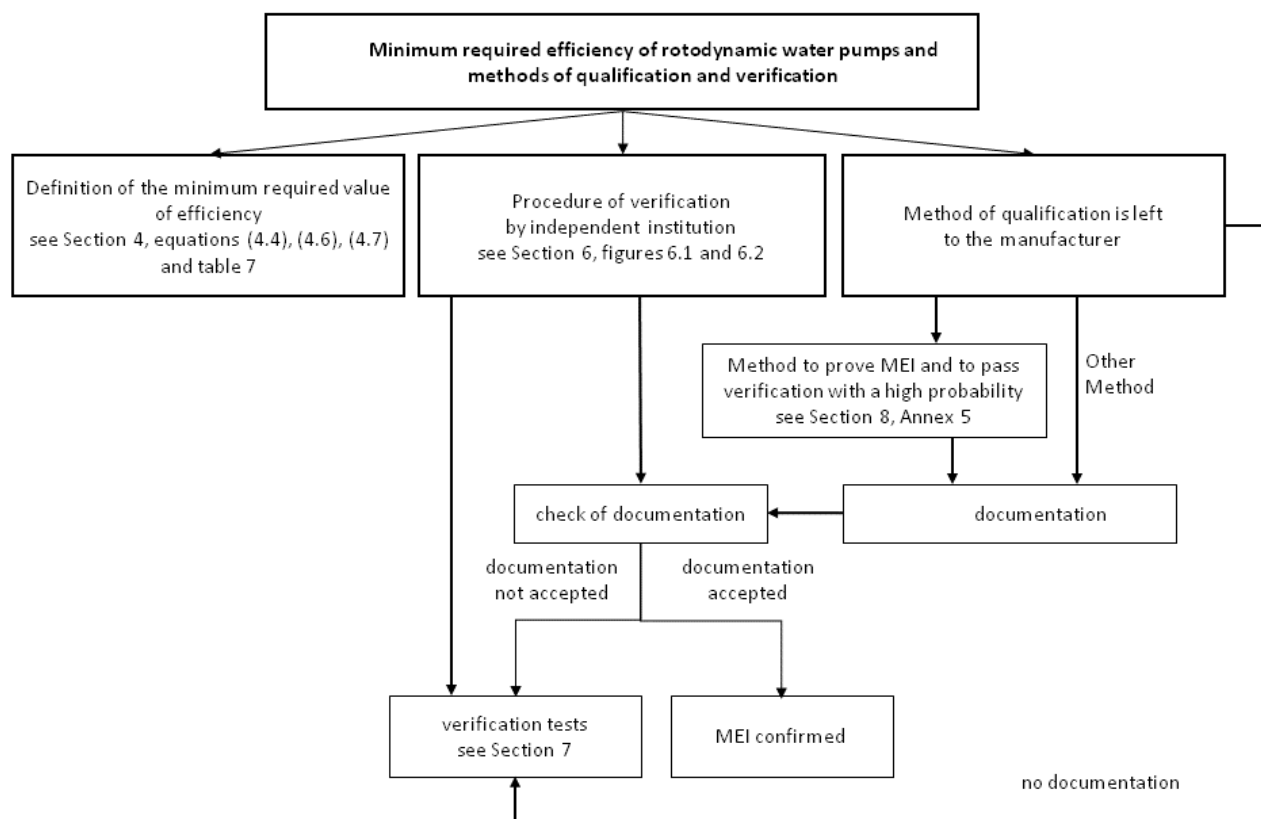


Figure 1 — Scheme of application of this standard

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:

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

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

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

3.2.5

driver efficiency

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

3.2.6

overall efficiency

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

3.2.7

specific speed

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

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

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
<i>A</i>	Area	m ²
<i>C</i>	Constant	pure number
<i>D</i>	Diameter	m
<i>e</i>	Measurement uncertainty, relative value	pure number
<i>f</i>	Frequency	s ⁻¹ , Hz
<i>g</i>	Acceleration due to gravity	m/s ²
<i>H</i>	Pump total head	m
<i>k</i>	Number of instrument readings or sample pumps	pure number
<i>m</i>	Mass	kg
<i>M</i>	Number of pumps of a sample	pure number
<i>n</i>	Speed of rotation	s ⁻¹ , min ⁻¹
<i>N</i>	Number of instrument readings	pure number
<i>n_s</i>	Specific speed	min ⁻¹
<i>p</i>	Pressure	Pa
<i>p</i>	Probability	pure number
<i>P</i>	Power	W
<i>Q</i>	(Volume) rate of flow	m ³ /s
<i>s</i>	Standard deviation of a sample	according to special quantity
<i>t</i>	Tolerance factor, relative value	pure number
<i>t</i>	Time	s
<i>t</i>	Student's factor	pure number
<i>T</i>	Torque	Nm
<i>u</i>	Peripheral velocity	m/s
<i>U</i>	Mean velocity	m/s
<i>U</i>	Voltage	V
<i>v</i>	Local velocity	m/s
<i>V</i>	Volume	m ³
<i>x</i>	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

$\eta_{\min, \text{requ}}$

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

$\eta_{\text{threshold}}$

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.

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

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

B.

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

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

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”.

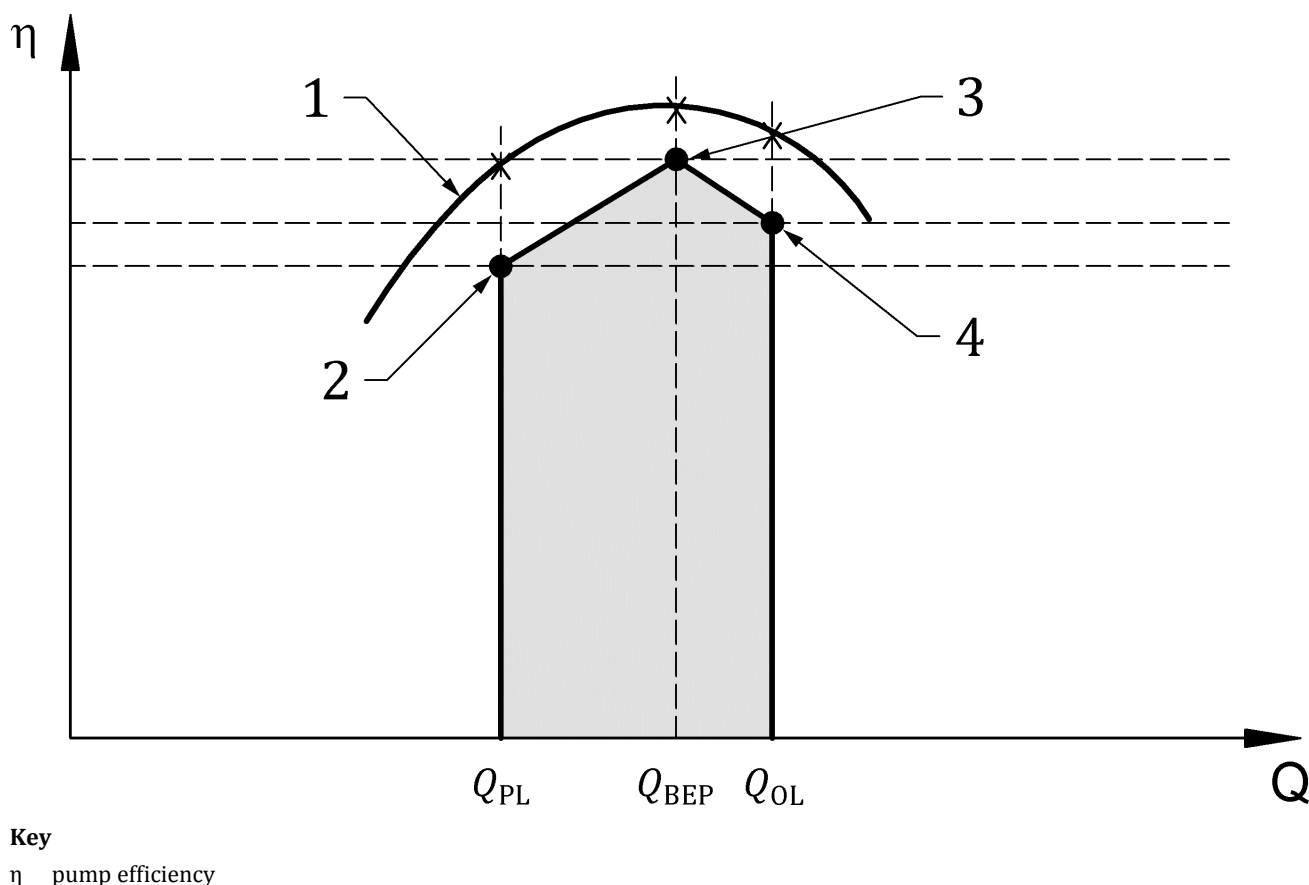


Figure 2 — 'House of Efficiency' - explanatory representation

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 $\eta_{BEP} = f(n_s, Q_{BEP})$ is:

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

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:

$$6 \text{ min}^{-1} \leq n_s \leq 120 \text{ min}^{-1}$$

$$2 \text{ m}^3/\text{h} \leq Q_{BEP} \leq 1\,000 \text{ m}^3/\text{h}.$$

The physical range of validity of the formula is

$$\eta_{BEP} \leq 88 \%$$

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

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

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

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.

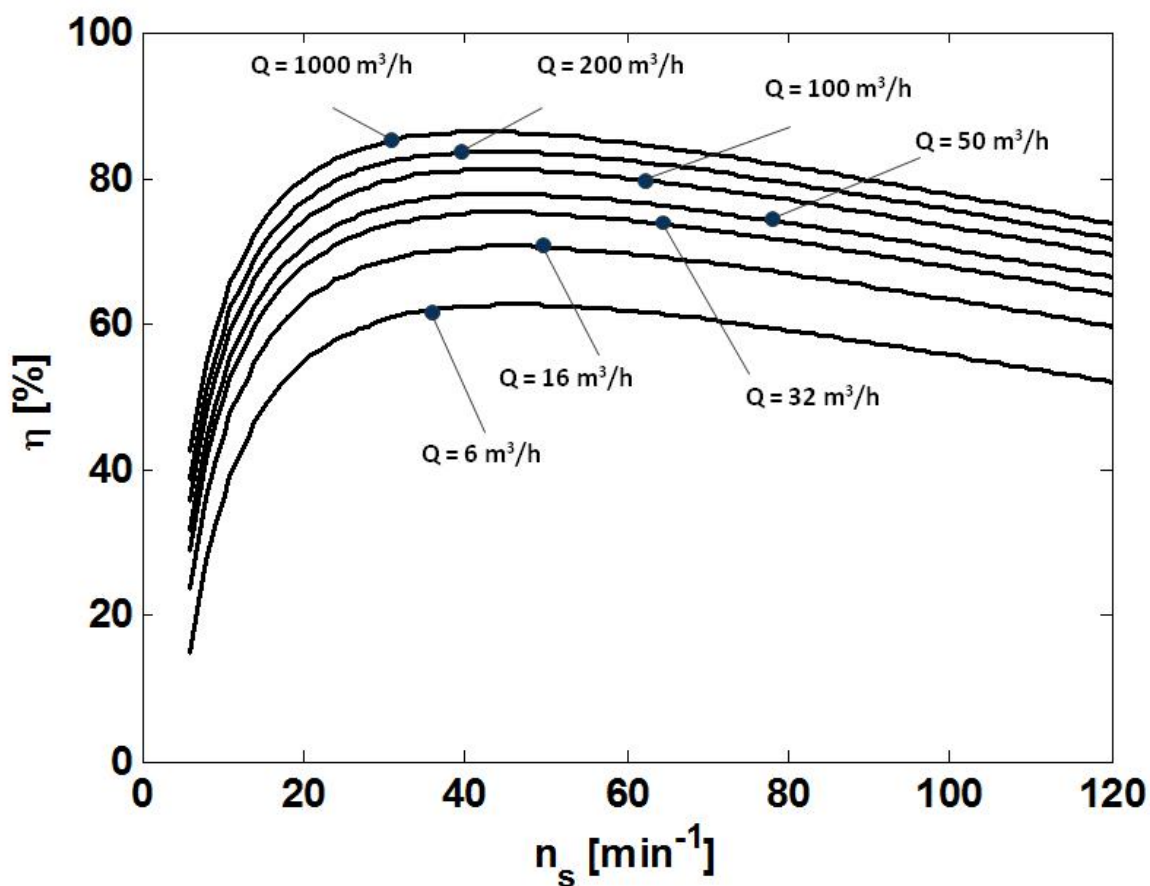


Figure 3 — Two-dimensional representation of $\eta_{\text{BEP}} = f(n_s, Q_{\text{BEP}})$ for ESOB, $n = 2\,900 \text{ min}^{-1}$ and $\text{MEI} = 0,70$ (see Table 3)

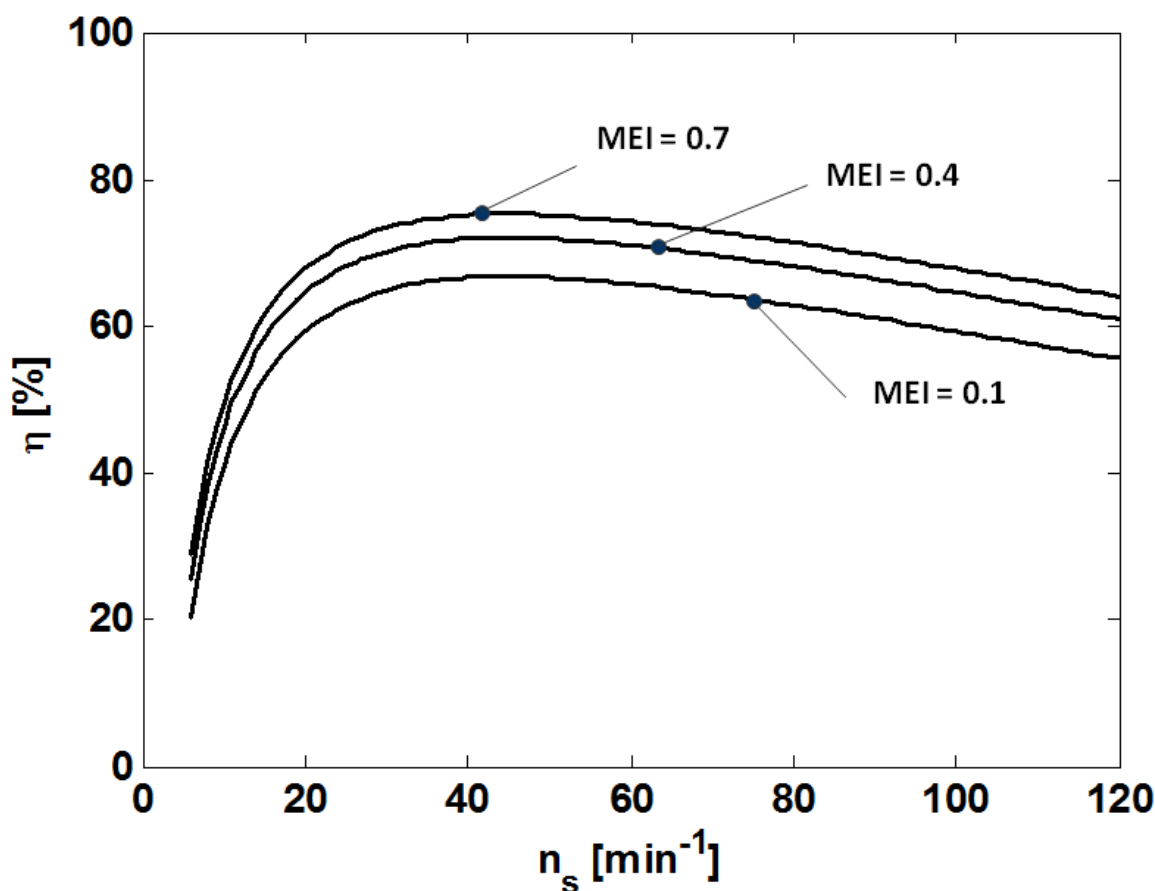


Figure 4 — $\eta_{BEP} = f(n_s)$ for ESOB with $Q_{BEP} = 32 \text{ m}^3/\text{h}$, $2\,900 \text{ min}^{-1}$ and for different values of MEI (see Table 3)

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

- 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.
- 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.