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Črpalke - Rotodinamične črpalke - Indeks energijske učinkovitosti - Metode za kvalifikacijo in verifikacijo - 3. del: Preskušanje in izračun indeksa energijske učinkovitosti (EEI) ojačevalnikov

Pumps - Rotodynamic Pumps - Energy efficiency Index - Methods of qualification and verification - Part 3: Testing and calculation of ener-gy efficiency index (EEI) of booster sets

Pumpen - Kreiselpumpen - Methoden zur Qualifikation und Verifikation - Teil 3: Prüfung und Berechnung des Energieeffizienzindexes (EEI) von Druckerhöhungsanlagen

Pompes - Pompes rotodynamiques - Indice de rendement énergétique - Méthodes de qualification et de vérification - Partie 3 : Essai et calcul de l'indice de rendement énergétique (EEI) des groupes de surpression

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Pumps - Rotodynamic Pumps - Energy efficiency Index - Methods of qualification and verification - Part 3: Testing and calculation of ener-gy efficiency index (EEI) of booster sets

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This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 197.

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European foreword

This document (prEN 17038-3:2017) has been prepared by Technical Committee CEN/TC 197 “Pumps”, the secretariat of which is held by AFNOR.

This document is currently submitted to the CEN Enquiry.

Introduction

This part of the European Standard is the third part of a series of standards describing a methodology to evaluate energy efficiency performance of booster sets, comprising one or more pump(s), the motor(s) with or without frequency converter, and additional components influencing hydraulic performance. It is based on a non-dimensional numerical value called Energy Efficiency Index (*EEI*). An *EEI* allows the comparison of different configurations with one common indicator. Physical influences such as number and size of the incorporated pump(s), pump unit part-load operation, motor-efficiency characteristic and frequency converter influence are implemented into this metric.

Specific requirements for testing and a calculation method for *EEI*, the so called semi-analytical model (SAM) of a complete booster set, a specific flow-time profile and a reference control curve are given in this part of the standard.

EEI is an index to rate booster sets according to their energy efficiency but does not replace the need to do a life-time cost analysis regarding energy consumption over the life time of the booster set.

1 Scope

This documents specifies methods and procedures for testing, calculating and determining the Energy Efficiency Index (*EEI*) of booster sets.

A booster set is either a single pump unit or an assembly of pump units connected in parallel with a maximum hydraulic power of 150 kW, a minimum rated flow of 6 m^3/h (0,001667 m^3/s), to be operated with backflow prevention and additional components influencing hydraulic performance and with components necessary to control pressure or provide flow in open loops inside buildings and which is placed on the market and/or put into service as one single product and its intended use is to pump clean water and does not have a self-priming functionality.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 17769-1, *Liquid pumps and installation - General terms, definitions, quantities, letter symbols and units - Part 1: Liquid pumps (ISO 17769-1)*

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

EN 16480, *Pumps - Minimum required efficiency of rotodynamic water pumps*

EN 60034-1, *Rotating electrical machines - Part 1: Rating and performance*

EN 60034-30-1, *Rotating electrical machines - Part 30-1: Efficiency classes of line operated AC motors (IE code)*

CLC/FprTS 60034-30-2, *Rotating electrical machines - Part 30-2: Efficiency classes of variable speed AC motors (IE-code)*

EN 60034-2-1, *Rotating electrical machines - Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*

EN 60034-2-2, *Rotating electrical machines - Part 2-2: Specific methods for determining separate losses of large machines from tests - Supplement to IEC 60034-2-1*

IEC/TS 60034-2-3, *Rotating electrical machines - Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors*

EN 60038:2011, *CENELEC standard voltages*

EN 61800-2, *Adjustable speed electrical power drive systems - Part 2: General requirements - Rating specifications for low voltage adjustable speed a.c. power drive systems (IEC 61800-2)*

EN 61800-9-1, *Adjustable speed electrical power drive systems - Part 9-1: Ecodesign for power drive systems, motor starters, power electronics and their driven applications - General requirements for setting energy efficiency standards for power driven equipment using the extended product approach (EPA) and semi analytic model (SAM)*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purpose of this document, the terms and definitions given in EN ISO 17769-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
booster set
either a single pump unit or an assembly of pump units connected in parallel with a maximum hydraulic power of 150 kW, a minimum rated flow of 6 m^3/h (0,001667 m^3/s), to be operated with backflow prevention and additional components influencing hydraulic performance and with components necessary to control pressure or provide flow in open loops inside buildings and which is placed on the market and/or put into service as one single product and its intended use is to pump clean water and does not have a self-priming functionality

3.1.2
expansion tank
tank partially filled with air, whose compressibility cushions pressure deviations under balancing small water volumes between the tank and the connected system

3.1.3
fixed-speed pump
pump without an electronic power converter

3.1.4
variable-speed pump
pump equipped with an electronic power converter

3.1.5
jockey pump
pump sized for considerably less flow than other pumps of the booster set and is intended only to handle leakage flows and/or small flows during cut-in of another pump

3.1.6
stand-by pump
pump only used for booster set operation when another pump fails

3.1.7
Complete Drive Module (CDM)
electronic power converter connected between the electric supply and a motor as well as extensions such as protection devices, transformers and auxiliaries (according to EN 61800-2)

3.1.8
Power Drive System (PDS)
combination of a CDM and an electric motor

3.1.9
suction pressure
pressure at the inlet of a booster set

Note 1 to entry: All pressures are gauge pressures (relative to the ambient pressure).

3.1.10
discharge pressure
pressure at the outlet of a booster set

3.1.11
total differential head
the total differential head (or only head) of the booster set is

$$H = \frac{p_d - p_s}{\rho \cdot g} \qquad (1)$$

where

H is the total differential head [m]

p_d is the delivery pressure [bar (g)]

p_s is the suction pressure [bar (g)]

ρ is the density of the test water at 20° C temperature 998,2 kg/m³

g is the gravitational constant of 9,81 m/s²

Note 1 to entry: The differences of dynamic head $v^2/(2 \cdot g)$ and geodetic height z between inlet and outlet of the booster set are typically zero or very small compared to the pressure head and are, therefore, neglected in Formula (1).

3.1.12
hydraulic power
arithmetic product of the flow Q and the head H and a constant

$$P_{hyd} = 2{,}72 \cdot Q \cdot H \qquad (2)$$

where

P_{hyd} is the hydraulic power [W]

Q is the flow [m³/h]

H is the total head [m]

3.1.13
maximum hydraulic power
maximum value of the hydraulic power values of a booster set

Note 1 to entry: The booster set shall be capable and designed to run in maximum hydraulic power continuously

3.1.14
booster set maximum hydraulic power point
booster set operation point leading to maximum hydraulic power

3.1.15
100%-flow rate
flow rate at booster set maximum hydraulic power point

3.1.16
100%-head
total differential head at booster set maximum hydraulic power point

3.1.17
control curve
adjusted delivery pressure dependent on flow rate of a booster set with at least one variable-speed pump

3.1.18
reference control curve
one representative pressure control curve defined relatively to the booster set maximum hydraulic power point

3.1.19
flow-time profile
relation between flow rate intervals and relative operation time

3.1.20
reference flow rate
flow rate defined by the 100%-flow rate and the flow-time profile

3.1.21
reference head
total differential head defined by the reference control curve and the reference flow rate

3.2 Symbols and units

For this document the symbols and units given in Table 1 are valid

Table 1 – Symbols and units

Symbol	Designation	Unit
A	Cross section	m^2
e	Uncertainty	%
g	Gravitational constant	m/s^2
H	(Total differential) head	m
H_L	Internal head loss	m
H_{loop}	Head loss of closed hydraulic loop	m
H_{meas}	Measured head	m
H_{ref}	Reference head	m

$H_{\text{resistance}}$	Head loss of the connected hydraulic system	m
$H_{100\,\%}$	100 %-head	m
i	Consecutive number of load points	-
j	Total number of actually running pumps	-
k	Number of running fixed speed pumps	-
K	Constant in Formula (3)	m/(m³/h)
m	Consecutive number of a time-sample in test	-
$n_{N,PU}$	Nominal rotational speed of a pump	min⁻¹
n_s	Specific speed of a pump	min⁻¹
N	Total number of load points	-
Q	Flow rate	m³/h
$Q_{BEP,PU}$	Flow rate at best efficiency point of a pump	m³/h
Q_{fix}	Flow rate of fixed speed pump	m³/h
Q_{higher}	Next higher adjustable flow rate	m³/h
Q_{lower}	Next lower adjustable flow rate	m³/h
Q_{lower}	Next lower adjustable flow rate	m³/h
Q_{off}	Flow rate at switching off one running pump	m³/h
Q_{on}	Flow rate at switching on one more pump	m³/h
Q_{ref}	Reference flow rate	m³/h
Q_{test}	Flow rate from test	m³/h
Q_{tr}	Flow rate after switching on or off a pump	m³/h
Q_{var}	Flow rate of variable speed pump	m³/h
$Q_{100\,\%}$	100 %-flow rate	m³/h
ΔQ	Switching hysteresis of flow rate	m³/h
p	Pressure	bar (g)
p_s	Suction pressure	bar (g)
p_d	Discharge pressure	bar (g)
$p_{d,100\,\%}$	100 %-discharge pressure	bar (g)
p_{ref}	Reference pressure	bar (g)
P_1	Electric power	W, kW
$P_{1,meas}$	Measured electric power	W, kW
$P_{1,pen}$	Penalty electric power	W, kW

P_2	Shaft power	W, kW
P_L	Power loss	W, kW
t	Manufacturing tolerance	%
tj	Time fraction	-
V_{tank}	Volume of an expansion tank	l
z	Number of pumps incorporated in a booster set	-
ρ	Density	kg/m³
ζ	Loss coefficient	-

4 General conditions for the determination of EEI

4.1 Hydraulic loop

Booster sets are operated in open loop systems with geodetic head. In particular, in the case of large geodetic height not all operating points are accessible for fixed speed pumps due to the switching of the pumps. In order to keep the gaps in the accessible flow as small as possible, a hydraulic loop without geodetic head is used for the determination of *EEI*. Then, the resistance curves which determine the operating points of the booster set are purely parabolic (without geodetic part) and are of the type given by Formula (**3**):

$$H_{resistance} = K \cdot Q^2 \quad (3)$$

where the constant K depends on the setting of the throttle valve.

The booster head is given by Formula (1) in 3.11. To be independent of p_s, for the determination of *EEI* the inlet pressure is defined to be *atmospheric pressure*, i.e. $p_s = 0$. On the other hand, when operating booster sets in a test rig there exists typically a certain (and also slowly varying) inlet pressure p_s. In 8.2.7, a correction for the effect of p_s is described for the experimental determination of *EEI*.

4.2 Booster set

If in the booster set is/are integrated

- an expansion tank
- and/or a "jockey pump" as defined in 3.5

they shall not affect the *EEI* value.

Therefore, it has/they have

- to be deactivated during tests for determining *EEI* except a tank of a volume $V_{tank} \leq 10 + (Q_{100\,\%}/1\text{m}^3/\text{h})$ litres,
- to be neglected in the SAM of the booster set.

NOTE: An expansion tank of the maximum volume defined above may be necessary during tests in respect to the time-transient behaviour of the pressure control of variable speed booster sets.

If a stand-by pump (as defined in 3.6) is integrated in the booster set, it has to be taken as one of the total number of normal operating pumps for the determination of the values of $Q_{100\,\%}$ and *EEI* according to the procedures described in Clauses 8 and 9.

5 Reference flow-time profile and reference pressure control curve

5.1 Reference flow-time profile

The reference flow time profile for booster sets is defined by Table 2.

Table 2— Reference flow-time profile for booster sets

Flow Q in % of $Q_{100\,\%}$	10	20	30	40	50	60	70	80	90	100
Time Δt in % of total operating time	6	21	26	19	12	6	4	3	2	1

The value $Q_{100\,\%}$ is defined by the condition that the corresponding hydraulic power P_{hyd} of the booster set is maximum.

The value $Q_{100\,\%}$ has to be determined by tests or by the SAM, the value written on the nameplate shall not be used.

5.2 Reference pressure control curve

The reference control curve for booster sets is defined by Formula (**4**):

$$H_{ref} / H_{100\%} = 100 \cdot \left[0.75 + 0.25 \cdot \left(Q / Q_{100\%} \right) \right] \quad [\%] \tag{4}$$

The value $H_{100\,\%}$ is the head of the booster set at the operating point $Q = Q_{100\,\%}$. The values $H/H_{100\,\%}$ at the corresponding values of $Q/Q_{100\,\%}$ of the reference flow-time profile are given according to Formula (**4**).

6 Rules to be applied for not accessible load points

For booster sets that are equipped with at least two but only fixed speed pumps, one or more load points defined by Table 2 may not be stably adjustable. This is caused by the “jump” of the operating point along the parabolic hydraulic resistance curve which arises when one of the pumps is switched on or switched off. Then, only flow rates before or after the switching (located on the resulting *Q*-*H* curves of the running pumps) can be adjusted and – in case of testing – the corresponding values of flow rate Q, head H and electric power input P_1 of the booster set can be measured.

In the case that a load point at the flow rate $Q_{ref,i}$ is not accessible within the allowed tolerances (e.g. for fixed speed boosters due to switching), for the calculation of $P_{1,avg}$ (see 8.3 or 9.9, respectively) the electric power input $P_1(Q_{ref,i})$ at that load point has to set

- equal to the electric power input $P_1(Q_{lower})$ (including corrections and penalties) at the nearest lower accessible flow rate Q_{lower} if $Q_{lower} \geq Q_{ref,i} - 0.05 \cdot Q_{100\,\%}$
- otherwise equal to the electric power input $P_1(Q_{higher})$ (including corrections and penalties) at the nearest higher accessible flow rate Q_{higher}

7 Penalties for deviations of the pressure control

In pressurized open loop systems, a proper supply is essential. An oversupply will result in waste of energy, an undersupply will result in a breakdown of the supply. Even a temporal undersupply will not be accepted by the user who would raise the control set point. For both types of pressure deviations at a certain duty point – static and temporal – the procedure given below will introduce a penalty $P_{1,pen}$ which has to be added to the measured electric power input.

In the case of an oversupply, no additional penalty is added to the measured electric power input $P_{1,meas}$. The punishment for an oversupply is inherently given by the increased electric power input.

If the determined head H_{meas} falls below the requested value H_{ref} according to the reference pressure control curve defined in 5.2 the averaged electric power input $P_{1,\text{avg}}$ is underrated as it is shown in Figure 1. This leads to a deviation in *EEI* compared to measurements at values defined by the reference pressure control curve H_{ref}. Hence, a penalty is applied in this case. The electric power input is penalized such as if an undersupply in head by a value ΔH leads to the same electric power input as an oversupply in head by ΔH, see Figure 1.

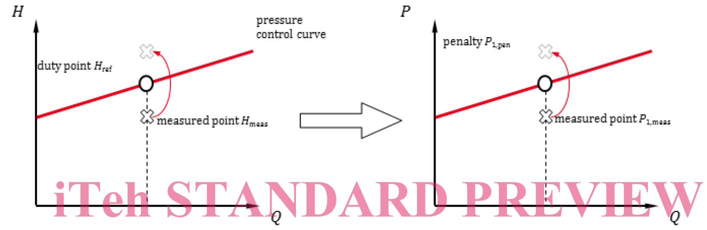

Fig. 1: Visualization of the penalty for booster sets.

Figure 1 — Visualization of the penalty for booster sets

The penalty is calculated by Formula (5):

$$P_{1,pen}\left(Q_i\right) = 2 \cdot \frac{H_{ref}\left(Q_i\right) - H_{meas}\left(Q_i\right)}{H_{meas}\left(Q_i\right)} \cdot P_{1,meas}\left(Q_i\right) \tag{5}$$

with the reference head (as defined in Formula 4)

$$H_{ref}\left(Q_i\right) = \frac{p_{ref}\left(Q_i\right) - p_s\left(Q_i\right)}{\rho \cdot g} \tag{6}$$

≥

and the measured head

$$H_{meas}\left(Q_i\right) = \frac{p_{meas}\left(Q_i\right) - p_s\left(Q_i\right)}{\rho \cdot g} \tag{7}$$