Van Tongeren
kennemer bv
BEVERWIJK

2. Schaalregels
(met beperkingen volgens ISO 5801)

Van Tongeren
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BEVERWIJK

VENTILATOR ~~WETTEN~~ SCHAALREGELS

Zoals in de grafiek te zien is, wordt de werking van de ventilator weergegeven in druk (p) bij een volumestroom (Q) waarvoor een toe te voeren asvermogen (P) benodigd is.

Behalve van de vorm van de waaier en het ventilatorhuis zijn de bedrijfsgegevens van een ventilator o.a. afhankelijk van de volgende drie variabelen :

D = Diameter van de waaier
T = Temperatuur cq dichtheid van het medium in K
n = Toerental

Vanuit de standaard T-ventilatoren kunnen andere bedrijfspunten bereikt worden door deze drie variabelen te wijzigen. Hieronder genoemd staan de formules per variable, maar deze kunnen uiteraard gecombineerd worden.

1. Verandering van toerental n

Volumestroom

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2}$$

Druk

$$\frac{p_1}{p_2} = \left(\frac{n_1}{n_2}\right)^2$$

Asvermogen

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

2. Verandering van temperatuur T [K] en medium dichtheid

Volumestroom

$$Q_1 = Q_2$$

Druk

$$\frac{p_1}{p_2} = \frac{T_2}{T_1}$$

Asvermogen

$$\frac{P_1}{P_2} = \frac{T_2}{T_1}$$

3. Verandering van ventilator grootte (M-getal) $M = \frac{D_1}{D_2}$

Volumestroom

$$\frac{Q_1}{Q_2} = M^3$$

Druk

$$\frac{p_1}{p_2} = M^2$$

Asvermogen

$$\frac{P_1}{P_2} = M^5$$

Voor de beperking op de geldigheid van de schaalregels zie .. o.a BS 5801

ISO 5801

INDUSTRIAL FANS

PERFOMANCE TESTING USING STANDARDIZED AIRWAYS

§ 15 RULES FOR CONVERSION OF TEST RESULTS

15 Rules for conversion of test results

The test results can only be compared directly with the guaranteed values if, during the acceptance tests, the measurements of the performance of the fan are taken under the conditions specified.

In most tests completed on fans, it is not possible to exactly reproduce and maintain the operating and/or driving conditions on the test airway as specified in the operating conditions.

Only the results converted to these operating conditions may be compared with the specified values.

For very large fans, model tests may be conducted in standardized airways when a full-scale test is impracticable owing to the limitations on power supply or dimensions of standardized test airways.

15.1 Laws on fan similarity

15.1.1 Similarity

Two fans which have similar flow conditions will have similar performance characteristics. The degree of similarity of the performance characteristics will depend on the degree of similarity of both the fans and of the flows through the fans.

15.1.1.1 Geometrical similarity

Complete geometrical similarity requires that the ratios of all corresponding dimensions for both fans be equal.

This includes ratios of thickness, clearances and roughness as well as the other linear dimensions for the flow passages.

All corresponding angles shall be equal.

15.1.1.2 Reynolds number similarity

Reynolds number similarity is necessary in order to keep relative thicknesses of boundary layer, velocity profiles and friction losses equal.

$$Re_u = \frac{uD_r\rho_{sg1}}{\mu} = \frac{uD_r p_{sg1}}{\mu R_w \Theta_{sg1}}$$

When the peripheral Reynolds number increases, the friction losses decrease.

Therefore efficiency and possibly performance may increase.

A difference in efficiency of 0,04 (4%) may be obtained for a Reynolds numbers ratio equal to 20.

15.1.1.3 Mach number and similarity of velocity triangles

In order to keep velocity triangles equal, variations of pressure, velocity and temperature through the fan must also be the same.

For peripheral Mach numbers higher than 0,15 important differences may arise if the Mach number is not kept equal for test and specified conditions.

For fans, the peripheral Mach number is given by.

$$Ma_u = \frac{u}{\sqrt{\kappa R_w \Theta_{sg1}}}$$

When this Mach number increases, the peripheral Reynolds number increases, as does the fan pressure.

When the fan pressure increases, ρ_m increases, while k_p and the ratio ρ_{sg1}/ρ_{msg} both decrease. The velocity triangle similarity is no longer respected and losses increase.

This is why, when the Mach number increases, fan performance and efficiency first improve and then tend to deteriorate.

This effect depends on fan type, impeller design and position of the operating point on the characteristic curve of the fan.

As the compressibility coefficient k_p defined in 14.8.2.1 and 14.8.2.2 is close to ρ_{sg1}/ρ_{msg} it can be used to represent the density variation through the fan and to characterize the similarity of the velocity triangles.

NOTE 34 There are never shock waves in fans: $Ma < 0,7$.

15.2 Conversion rules

The subscript Te is applied to the test measurements and test results, and the subscript Gu to the operating conditions and performance guaranteed by contract.

Figure 11 shows the permissible variations of the ratio

$$\frac{Re_{u\text{Te}}}{Re_{u\text{Gu}}}$$

as a function $Re_{u\text{Gu}}$, and figure 12 gives an indication of the variations of the ratio $n_{\text{Gu}}/n_{\text{Te}}$ as a function of k_{pGu} and Δk_{p},

where

$$\Delta k_{\text{p}} = k_{\text{pGu}} - k_{\text{pTe}}$$

15.2.1 Conversion rules for compressible flow

There is insufficient evidence to establish universal rules for the conversion of fan performance from a test to a specified condition involving a change in the compressibility coefficient k_{p} of more than ± 0,01 and which may be as great as 0,06.

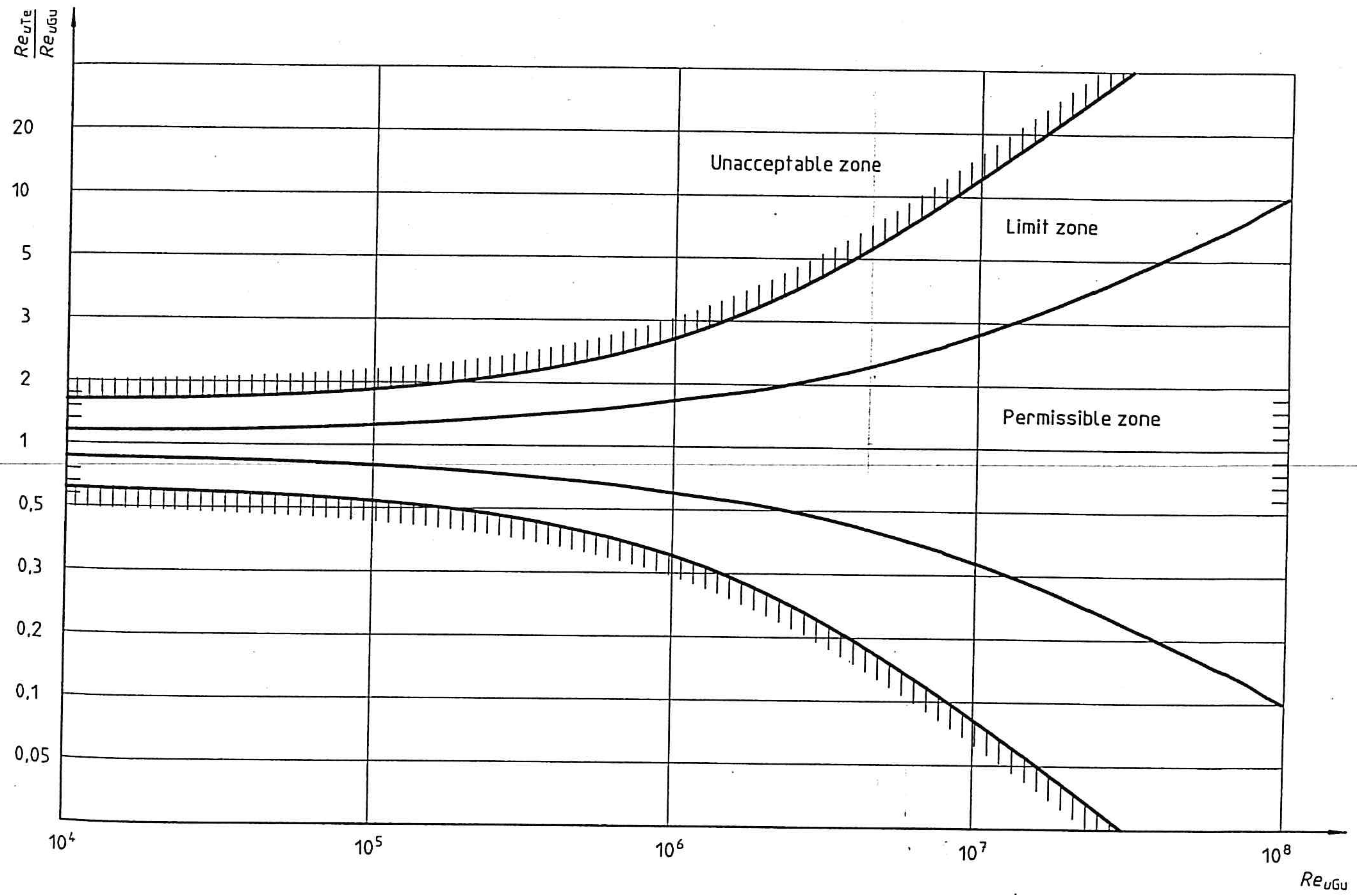
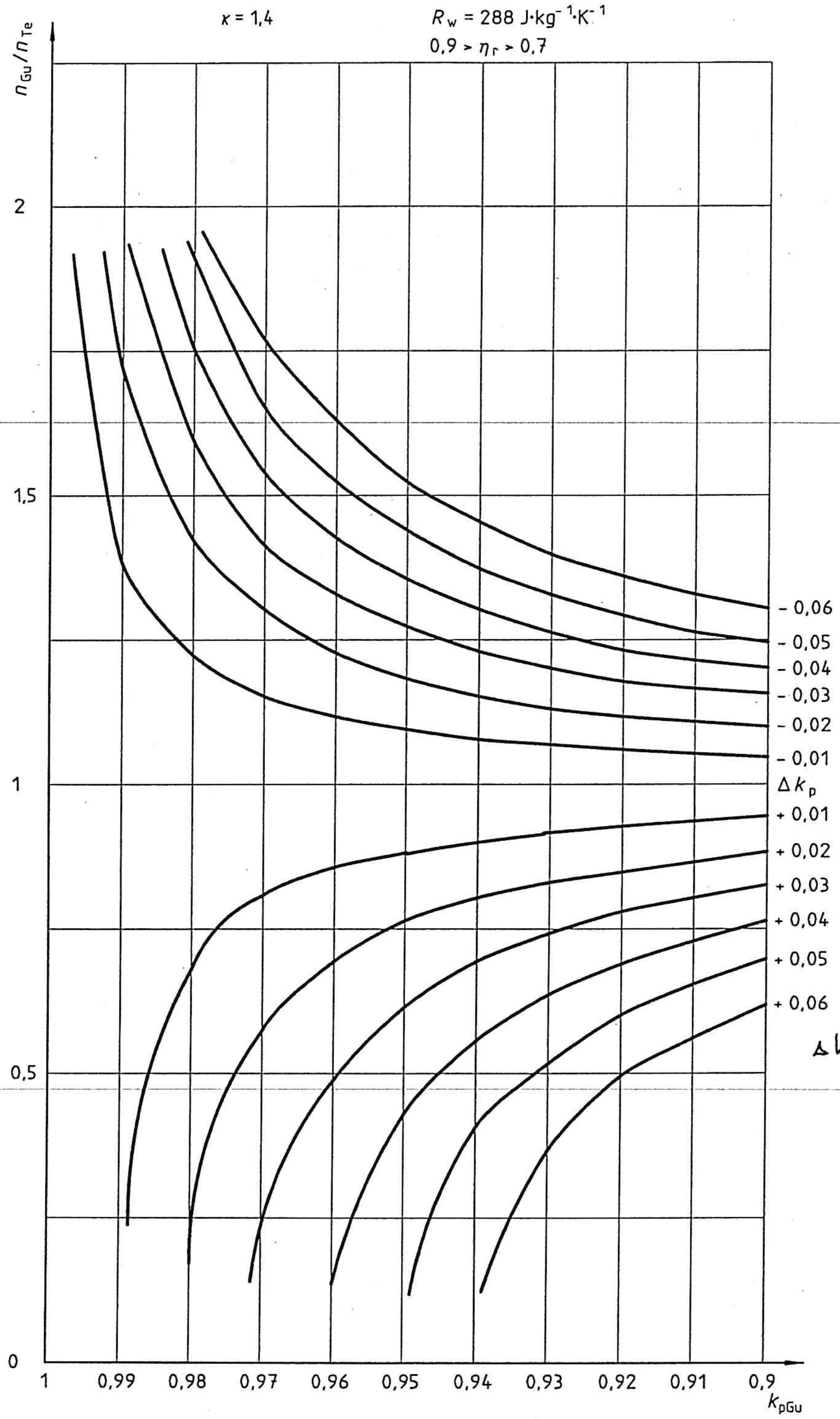


Figure 11 — Permissible variations of $Re_{u\text{Te}}/Re_{u\text{Gu}}$ as function of $Re_{u\text{Gu}}$



$\Delta k_p = k_{pGu} - k_{pTE}$

Figure 12 — Variation of n_{Gu}/n_{Te} as a function of k_{pGu} and Δk_p

15.2.1.1 Conversion rules for a change of more than ± 0,01 in the compressibility coefficient, k_p

These conversion rules can be represented by the following expressions, in which q is an exponent which may vary from one design to another, values from 0 to – 0,5 having been demonstrated.

A type-test is recommended (which may be at model scale) to determine the range of pressure ratio r and the range of fan characteristic on either side of the best efficiency point, over which q may be regarded as constant without unduly increasing the uncertainty of performance prediction.

An agreement between purchaser and manufacturer is needed to apply these conversion rules.

The compressibility coefficient k_{pGu} after conversion may be found from the following approximate formula, which is correct within a few parts per 1 000:

$$\frac{1-k_{pGu}}{1-k_{pTe}}=\left(\frac{n_{Gu}D_{rGu}}{n_{Te}D_{rTe}}\right)^2\left(\frac{R_{wTe}\Theta_{sg1Te}}{R_{wGu}\Theta_{sg1Gu}}\right)\frac{\kappa_{Te}}{\kappa_{Gu}}\left[\frac{1-\kappa_{Gu}(1-\eta)}{1-\kappa_{Te}(1-\eta)}\right]=k^2$$

where η is η_r or η_{sr}.

The fan performance after conversion may then be found from the following expressions:

$$\frac{q_{Vsg1Gu}}{q_{Vsg1Te}}=\frac{n_{Gu}}{n_{Te}}\left(\frac{D_{rGu}}{D_{rTe}}\right)^3\left(\frac{k_{pGu}}{k_{pTe}}\right)^q$$

$$\frac{p_{FGu}}{p_{FTe}}=\left(\frac{n_{Gu}}{n_{Te}}\right)^2\left(\frac{D_{rGu}}{D_{rTe}}\right)^2\left(\frac{\rho_{sg1Gu}}{\rho_{sg1Te}}\right)\left(\frac{k_{pGu}}{k_{pTe}}\right)^{-1}$$

$$\frac{p_{sFGu}}{p_{sFTe}}=\left(\frac{n_{Gu}}{n_{Te}}\right)^2\left(\frac{D_{rGu}}{D_{rTe}}\right)^2\left(\frac{\rho_{sg1Gu}}{\rho_{sg1Te}}\right)\left(\frac{k_{pGu}}{k_{pTe}}\right)^{-1}$$

$$\frac{P_{rGu}}{P_{rTe}}=\left(\frac{n_{Gu}}{n_{Te}}\right)^3\left(\frac{D_{rGu}}{D_{rTe}}\right)^5\left(\frac{\rho_{sg1Gu}}{\rho_{sg1Te}}\right)\left(\frac{k_{pGu}}{k_{pTe}}\right)^q$$

The Reynolds number Re_u shall be within the limits of figure 11.

These expressions are established in the case of change in:

— rotational speed, N, or rotational frequency, n;

— impeller diameter, D_r;

— gas: R_w, κ;

— inlet temperature, Θ_{sg1} and density, ρ_{sg1}.

NOTE 35 Simplifications may be introduced as functions of the parameters which may be regarded as constant.

15.2.1.2 Conversion rules for a change of less than ± 0,01 in compressibility coefficient k_p

In the limits of the peripheral Reynolds number allowed according to figure 11, the following expressions may be applied.

The compressibility coefficient for guaranteed conditions k_{pGu} may be estimated from the formula given in 15.2.1.1.

$$\frac{1-k_{pGu}}{1-k_{pTe}}=\left(\frac{n_{Gu}D_{rGu}}{n_{Te}D_{rTe}}\right)^2\left(\frac{R_{wTe}\Theta_{sg1Te}}{R_{wGu}\Theta_{sg1Gu}}\right)\frac{\kappa_{Te}}{\kappa_{Gu}}\left(\frac{1-\kappa_{Gu}(1-\eta)}{1-\kappa_{Te}(1-\eta)}\right)$$

The fan performance after conversion may then be found using the following expressions:

$$\frac{q_{Vsg1Gu}}{q_{Vsg1Te}}=\frac{n_{Gu}}{n_{Te}}\left(\frac{D_{rGu}}{D_{rTe}}\right)^3\left(\frac{k_{pGu}}{k_{pTe}}\right)^q$$

$$\frac{p_{FGu}}{p_{FTe}}=\left(\frac{n_{Gu}}{n_{Te}}\right)^2\left(\frac{D_{rGu}}{D_{rTe}}\right)^2\left(\frac{\rho_{sg1Gu}}{\rho_{sg1Te}}\right)\left(\frac{k_{pGu}}{k_{pTe}}\right)^{-1}$$

$$\frac{p_{\text{sFGu}}}{p_{\text{sFTe}}} = \left(\frac{n_{\text{Gu}}}{n_{\text{Te}}}\right)^2 \left(\frac{D_{\text{rGu}}}{D_{\text{rTe}}}\right)^2 \left(\frac{\rho_{\text{sg1Gu}}}{\rho_{\text{sg1Te}}}\right)\left(\frac{k_{\text{pGu}}}{k_{\text{pTe}}}\right)^{-1}$$

$$\frac{P_{\text{rGu}}}{P_{\text{rTe}}} = \left(\frac{n_{\text{Gu}}}{n_{\text{Te}}}\right)^3 \left(\frac{D_{\text{rGu}}}{D_{\text{rTe}}}\right)^5 \left(\frac{\rho_{\text{sg1Gu}}}{\rho_{\text{sg1Te}}}\right)\left(\frac{k_{\text{pGu}}}{k_{\text{pTe}}}\right)^{q}$$

where η is η_{r} or η_{sr}, and q is an index which may vary from one design to another, values from 0 to $-0{,}5$ having been demonstrated.

NOTE 36 Simplifications may be introduced as functions of the parameters which may be regarded as constant.

15.2.2 Simplified conversion rules for incompressible flow

When the fan pressure for test and guaranteed conditions is less than 2 000 Pa, k_{p} is close to 1 and the following simplified expressions may be used for the calculation of converted performance.

$$\frac{q_{V\text{sg1Gu}}}{q_{V\text{sg1Te}}} = \left(\frac{n_{\text{Gu}}}{n_{\text{Te}}}\right)\left(\frac{D_{\text{rGu}}}{D_{\text{rTe}}}\right)^3$$

$$\frac{p_{\text{FGu}}}{p_{\text{FTe}}} = \left(\frac{n_{\text{Gu}}}{n_{\text{Te}}}\right)^2 \left(\frac{D_{\text{rGu}}}{D_{\text{rTe}}}\right)^2 \left(\frac{\rho_{\text{sg1Gu}}}{\rho_{\text{sg1Te}}}\right) = \frac{p_{\text{sFGu}}}{p_{\text{sFTe}}}$$

$$\frac{P_{\text{rGu}}}{P_{\text{rTe}}} = \left(\frac{n_{\text{Gu}}}{n_{\text{Te}}}\right)^3 \left(\frac{D_{\text{rGu}}}{D_{\text{rTe}}}\right)^5 \left(\frac{\rho_{\text{sg1Gu}}}{\rho_{\text{sg1Te}}}\right)$$

15.2.3 Shaft power and impeller power

The measured and specified input powers will usually be the fan shaft power P_{aTe} and P_{aGu}.

It may be necessary to estimate the bearing losses P_{bTe} at n_{Te} and P_{bGu} at n_{Gu} and to use the relations

$$P_{\text{rTe}} = P_{\text{aTe}} - P_{\text{bTe}}$$

and

$$P_{\text{aGu}} = P_{\text{rGu}} + P_{\text{bGu}}$$

in order to carry out the conversion specified in 15.2.

However, the error incurred by assuming

$$\frac{P_{\text{rGu}}}{P_{\text{rTe}}}$$

as equal to

$$\frac{P_{\text{aGu}}}{P_{\text{aTe}}}$$

will not exceed the following, in percent,

$$\frac{200\left(n_{\text{Gu}} - n_{\text{Te}}\right)P_{\text{b}}}{n_{\text{Te}}P_{\text{a}}}$$

which is often negligible.