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Guide de charge pour transformateurs de puissance du type sec

Loading guide for dry-type power transformers

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LOADING GUIDE FOR DRY-TYPE POWER TRANSFORMERS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.
3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendations and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This guide has been prepared by IEC Technical Committee No. 14: Power transformers.

The text of this guide is based on the following documents:

Six Months' Rule	Report on Voting
14(CO)60	14(CO)63

Full information on the voting for the approval of this guide can be found in the Voting Report indicated in the above table.

The following IEC Publications are quoted in this guide:

Publications Nos. 76-1 (1976): Power transformers. Part 1: General.
726 (1982): Dry-type power transformers.

LOADING GUIDE FOR DRY-TYPE POWER TRANSFORMERS

1. Scope

This guide is applicable to naturally cooled dry-type power transformers complying with IEC Publication 726 and operated within the limitations referred to in Clause 6. Six different insulation systems are taken into account, identified by their system temperatures.

Because there are numerous combinations of different insulation systems and constructions it is possible to make loading recommendations only of a general nature. For this reason the guide is in two parts:

- the first part makes no loading recommendations, but gives the method of calculating loading conditions when the variable parameters are known as the result of prototype testing of a particular construction and/or insulation system. The calculations are given in the form of an algorithm from which computer programs can be written;
- the second part assumes constant values for the variable parameters, with the exception of the insulation temperature limits (Table I) and the temperature of external cooling air, irrespective of insulation system or construction, thereby enabling load curves to be produced.

The guide indicates how dry-type transformers may be operated without exceeding the acceptable limit of deterioration of insulation through thermal effects. The acceptable limit of deterioration of insulation is defined as that which occurs when the dry-type transformer is operating under rated conditions at the basic temperature of the external cooling air.

2. Object

The object of this guide is to permit the calculation of, and to indicate the permissible loading under certain defined conditions in terms of rated current, for the guidance of users and to help planners to choose the rated power of transformers required for new installations.

The basic temperature of the external cooling air is assumed to be 20 °C. Guidance is given for this temperature, and also for external cooling air temperatures of 10 °C and 30 °C. Deviations from these temperatures are provided for in such a way that the increased use of life when operated with a higher external cooling air temperature is balanced by a reduced use of life with a lower external cooling air temperature.

In practice, uninterrupted continuous operation at full rated current is unusual, and this guide gives recommendations for cyclic daily loads, taking into account seasonal variations of ambient temperature. The daily use of life due to thermal effects is compared with normal daily use of life which results when the dry-type transformer is operating at rated voltage and current, with an external cooling air temperature of 20 °C.

Load curves, Figures 5 (1) to 5 (12) on pages 32 to 43, show the permissible load current which will result in a normal daily use of life for winding insulation systems having insulation system temperatures of 105, 120, 130, 155, 180 and 220 °C in the following two sets of conditions:

a) continuous duty with different temperatures of external cooling air,

b) cyclic duty with different temperatures of external cooling air.

Note. – It is assumed that the transformer is adequately ventilated and the increased losses resulting from an overload do not significantly change the temperature of the cooling air.

3. Symbols

The following symbols are used in this guide:

a = subscript representing "ambient" (external cooling air)

c = subscript representing the "hot spot of the winding" at rated current and basic temperature of external cooling air

cc = subscript representing the highest permissible "hot spot of the winding" according to this guide

d = subscript representing the doubling of the rate of using life

e = subscript representing the final "average of winding" for any value of load current

i = subscript representing the initial "average of winding" for any value of load current

j = integer variable representing the number of the day in the year ($1 \leq j \leq 365$)

$K_1, K_2, \ldots K_n, \ldots K_N$ = load currents as fractions of rated currents

m = subscript representing maximum "average of winding". (Thus for continuous rated current, $\Delta\theta_{mr} = \Delta\theta_c / Z$, and for a short time in excess of rated current, $\Delta\theta_m = \Delta\theta_{cc} / Z$, resulting in a greater than normal rate of using life during this period)

n = subscript representing any one period during the daily load cycle

q = exponent of K by which the average temperature rise varies with load current

r = subscript representing rated value

t = time

t_b = duration, in hours, at any load current K_1 ($t_b \geqslant 24 - t_p$)

t_p = maximum permissible duration, in hours, at any load current K_2

$t_1, t_2, \ldots t_n, \ldots t_N$ = duration of each load condition period

w = subscript representing the winding

wh = subscript representing the "hot spot of winding"

A = amplitude of annual variations in the daily average ambient temperature (sinusoidal variation is assumed)

B = amplitude of daily variations in the ambient temperature (sinusoidal variation is assumed)

I = load current in amperes (any value); I_r = rated current

k = subscript representing any individual load period prior to the start of the load period t_n for which the calculation is being made

L = life consumption in hours

L_{an} = calculated annual use of life

L_R = relative rate of using life

N = number of different load periods for a day

T = sum of the individual load periods t_k prior to the start of the load period t_n for which the calculation is being made

Z = ratio between hot spot and average winding temperature rises (see also explanations to subscript m)

$\propto$ = arbitrary variable used in determining the relative rate of using life

$\Delta\theta$ = temperature rise in kelvins

ε = accuracy factor for estimation of the hot-spot temperature at the beginning of the 24 h period

θ = temperature in degrees Celsius

θ_{ad} = daily average ambient temperature

θ_{ay} = annual average ambient temperature

τ = thermal time constant of windings at rated current, in hours

PART 1

4. Basis of guide

4.1. *Introduction*

The life of a dry-type transformer is related to the deterioration of its insulation through thermal ageing. Experience indicates that the normal life of a transformer is some tens of years. It cannot be stated more precisely, because it may vary even between identical units, owing in particular to operating factors which may differ from one transformer to another.

In practice, uninterrupted continuous operation at full load current is unusual and so account should be taken of the various operating conditions and the subsequent fluctuation of the rate of thermal deterioration of the transformer insulation.

It is necessary therefore:

a) To define "normal" expectation of life as a function of the rated load current and the rated hot spot temperature of the winding insulation.

b) To relate the increase in hot spot winding temperature to the increase in the rate of insulation deterioration.

c) To devise a method of calculating the net effect of variation in the winding hot spot temperature due to changes in load period, load current and ambient temperature, on the thermal ageing of the insulation.

d) To then compare the net "use of life" due to the sum of the different factors in the load cycle, with the definition of "normal use of life". Hence, any of the parameters in the load cycle can be adjusted to give a normal expectation of transformer life.

4.2 *Parameters used in the calculations*

4.2.1 *Temperature limits*

TABLE I

Temperature limits

Insulation system temperature (IEC Publication 726)	Hot spot winding temperature (°C)		Average winding temperature-rise limits at rated current (K) (IEC Publication 726)
	rated	highest permissible	
(°C)	(θ_c)	(θ_{cc})	($\Delta\theta_{wr}$)
105 (A)	95	140	60
120 (E)	110	155	75
130 (B)	120	165	80
155 (F)	145	190	100
180 (H)	175	220	125
220 (C)	210	250	150

4.2.2 The parameter θ_c is used to calculate normal life consumption. Under certain operating conditions in which it is permissible to exceed this normal consumption level, high overloads may be applied, resulting in a hot spot temperature considerably higher than θ_c. Thus a parameter θ_{cc} representing the absolute limit of the hot spot temperature has been introduced. This temperature is that beyond which the rate of deterioration of the insulation becomes inadmissible. (See Table I for values of θ_c and θ_{cc}.)

4.2.3 The value of parameter θ_d is taken as the increase in hot spot temperature which doubles the rate of using life.

4.2.4 The basic value required for calculating the life consumption level is the temperature at the hottest spot. For this purpose, it is necessary to know the temperature rise at this position for each load condition and the ambient temperature. There are at least two methods of obtaining the hot spot temperature rise:

a) $\Delta\theta_{whn}$ can be determined by performing temperature-rise tests with various loads K_n;

b) by using the formula:

$$\Delta\theta_{whn} = Z \cdot \Delta\theta_{wr} \cdot K_n^{q} \tag{1}$$

In this case, it is necessary to know the values of Z, $\Delta\theta_{wr}$ and q.

It is preferable to use, whenever possible, the results of tests giving $\Delta\theta_{whn}$, thus removing any uncertainty regarding the validity of the factor Z and the value of q. Experience shows that q and Z assume different values depending on the type of transformer and the level of the load current at which it operates.

Note. – With some types of winding construction determination of $\Delta\theta_{whn}$ may be possible only on prototype transformers.

On the basis of the test results, a curve can be plotted of $\Delta\theta_{wh} = f(K)$, which can be used to determine the corresponding $\Delta\theta_{whn}$ for each K_n necessary for the calculation.

4.2.5 Values obtained during temperature-rise tests carried out on a prototype under different load conditions:

τ = thermal time constant in hours;

Note. – The winding to be taken into consideration is that with the shortest time constant.

$\Delta\theta_{wr}$ = average winding temperature rise at the assigned rating;

$\Delta\theta_{wh}$ = $f(K)$: temperature rise at the hottest spot, under the established conditions, as a function of the load.

4.2.6 Values obtained by means of ageing tests carried out on models of insulating systems:

θ_c = temperature at which the insulating system has a normal service life;

θ_{cc} = maximum temperature beyond which the rate of deterioration of the insulation is inadmissible;

θ_d = slope of the straight line for the life of the insulation ≡ increase in temperature causing the life consumption rate to double.

4.2.7 Values relating to the conditions of use: See Figure 1, page 17.

θ_{ad} = daily average ambient temperature;

θ_{ay} = annual average ambient temperature;

A = range of annual variations in the daily average ambient temperature (sinusoidal variation assumed);

B = range of variations in the daily ambient temperature (sinusoidal variation assumed);

$K_1, K_2, \ldots K_n, \ldots K_N$ = load conditions;

$t_1, t_2, \ldots t_n, \ldots t_N$ = duration of each load condition (expressed in hours);

N = number of load conditions.

4.3 *Formulae*

4.3.1 For load condition K, the temperature rise at the hottest spot, at the end of period t, is calculated by means of the formula:

$$\Delta\theta^{t}_{wh} = \Delta\theta^{t_{n-1}}_{wh} + (\Delta\theta_{whn} - \Delta\theta^{t_{n-1}}_{wh})\,(1 - e^{-\frac{t}{\tau}}) \qquad (2)$$

that is,

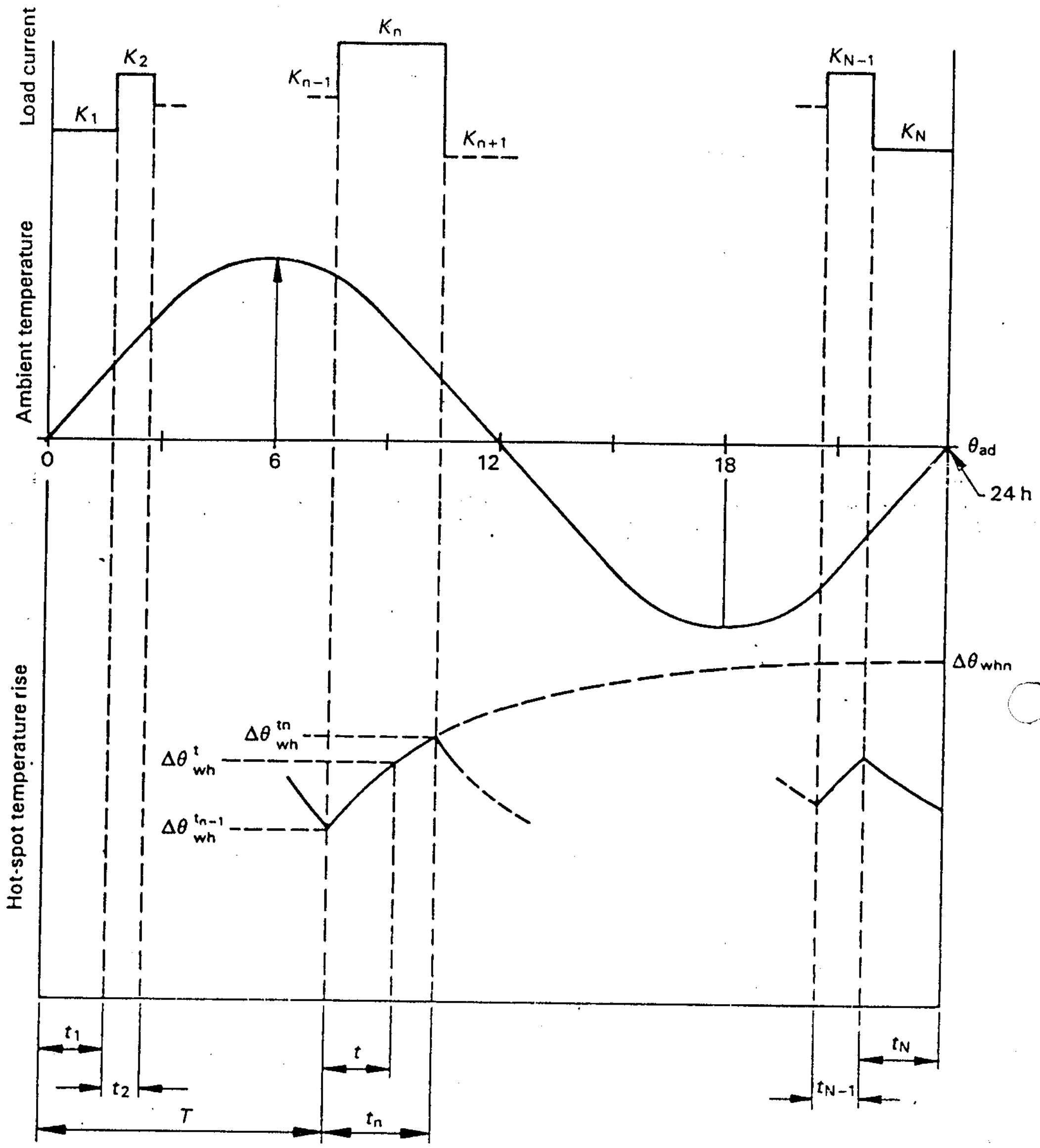
$$\Delta\theta^{t}_{wh} = \Delta\theta_{whn} + (\Delta\theta^{t_{n-1}}_{wh} - \Delta\theta_{whn})\, e^{-\frac{t}{\tau}} \qquad (3)$$

In this formula $\Delta\theta_{whn}$ is either given by the formula:

$$\Delta\theta_{whn} = Z \cdot \Delta\theta_{wr} \cdot K^{q}_{n} \qquad (4)$$

or derived from the function $\Delta\theta_{wh} = f(K)$ resulting from the tests.

The temperature rise at the end of each period t_n is obtained by means of the same formulae by making $t = t_n$.



Note. – Hot-spot winding temperature at any instant = $\Delta\theta^{t}_{wh} + \theta_{ad}$.

FIG. 1. – Load diagram for use in the preparation of computer programs.

4.3.2 The component L_n of daily life consumption due to a load K_n of duration t_n per day is calculated from the expression:

$$L_n = \int_T^{T+t_n} e^{\frac{\ln 2}{\theta_d}\left[\Delta\theta^t_{wh} + B \sin \frac{2\pi}{24}(T+t) + \theta_{ad} - \theta_c\right]} dt \qquad (5)$$

where:

$$T = \sum_{k=1}^{n-1} t_k$$

The annual consumption L_{an}, is obtained by summation of the daily consumptions for 365 days, due to loads of duration t_1 to t_N.

$$L_{an} = \sum_{j=1}^{365} e^{\frac{\ln 2}{\theta_d}\left[\theta_{ay} + A \sin \frac{2\pi}{365} j\right]} \sum_{1}^{N} L_n \text{ (hours)} \qquad (6)$$

This value L_{an} is then compared with the normal consumption for one year:

$$L_{normal} = 24 \times 365 \times e^{\frac{\ln 2}{\theta_d} \cdot (\Delta\theta_{whr} + 20 - \theta_c)} \text{ (hours)} \qquad (7)$$

that is, $L_{normal} = 24 \times 365 \times 1 = 8760$ (hours).

4.4 Determination of the overload applicable to a transformer with a given load diagram, on the basis of normal life consumption:

The load diagram shown in Figure 1, page 17, gives a number of different load currents, the magnitude of which can be adjusted by the use of a common multiplying factor.

The life consumption and the relative rate of using life, L_R, determined for the initial load diagram are calculated by means of a program drawn up in accordance with the algorithm given in Clause 5.

If this L_R is less than 1, the overload which the unit is capable of withstanding is then calculated.

For this purpose, the calculation is made with the values K'_1, K'_2, ... K'_N equal to αK_1, αK_2, ... αK_N, and t_1, t_2, ... t_N remaining unchanged.

The multiplying factor α used is slightly greater than 1 (for example 1.1).

If the relative rate of using life L'_R calculated in this way is less than 1, the adjustment $\alpha + 0.1$ is made and the calculation is repeated until the value for α leading to $L_R \geqslant 1$ is obtained.

The permissible overload is that obtained by means of the penultimate value of α used in the calculation.

If, in the initial calculation, the relative rate of using life L'_R is greater than 1, the calculation is repeated using a lower value of α (e.g. $\alpha = \alpha - 0.01$) etc.

The operation is repeated until the value of α is determined at which the relative rate of using life L'_R is equal to or slightly less than 1.

Note. – If one accepts a level of consumption for the equipment which is in excess of the "normal" level, for a certain period of operation, the same method of calculation is applied, using a value for L_R which is greater than 1.

4.5 Determination of the overload (value or duration) applicable to a transformer with a simplified load diagram, on the basis of a given life consumption.

The load diagram shown in Figure 2, page 23, comprises two load currents K_1 and K_2.

The ambient temperature in the 24 hour period is assumed to be constant.

4.5.1 Calculation of the duration of the overload K'_2 for a given K_1:

By means of an initial calculation programmed in accordance with the algorithm given in Clause 5, the life consumption L is established for the condition (K_1t_1, K_2t_2).

The overload value is fixed at K'_2, and L_1 and L'_2 are calculated for the same times t_1 and t_2. The resulting consumption $L'_1 + L'_2$ is greater than the initial consumption $L_1 + L_2$.

t_2 is reduced to $t_2 - \Delta t$ (which implies t_1 is increased to $t_1 + \Delta t$) and L_1 and L'_2 are calculated, giving a value L' which is lower than the previous value.

This operation is repeated until L' is equal to or slightly less than L.

The value of t for which this result is obtained represents the permissible duration of the overload K'_2.

4.5.2 Calculation of the overload value K'_2 of duration t_2 for given values of K_1 and t_1:

In this case, the method of calculation is the same as that described in Sub-clause 4.4.

The factor α is obtained by which K_2 is multiplied.

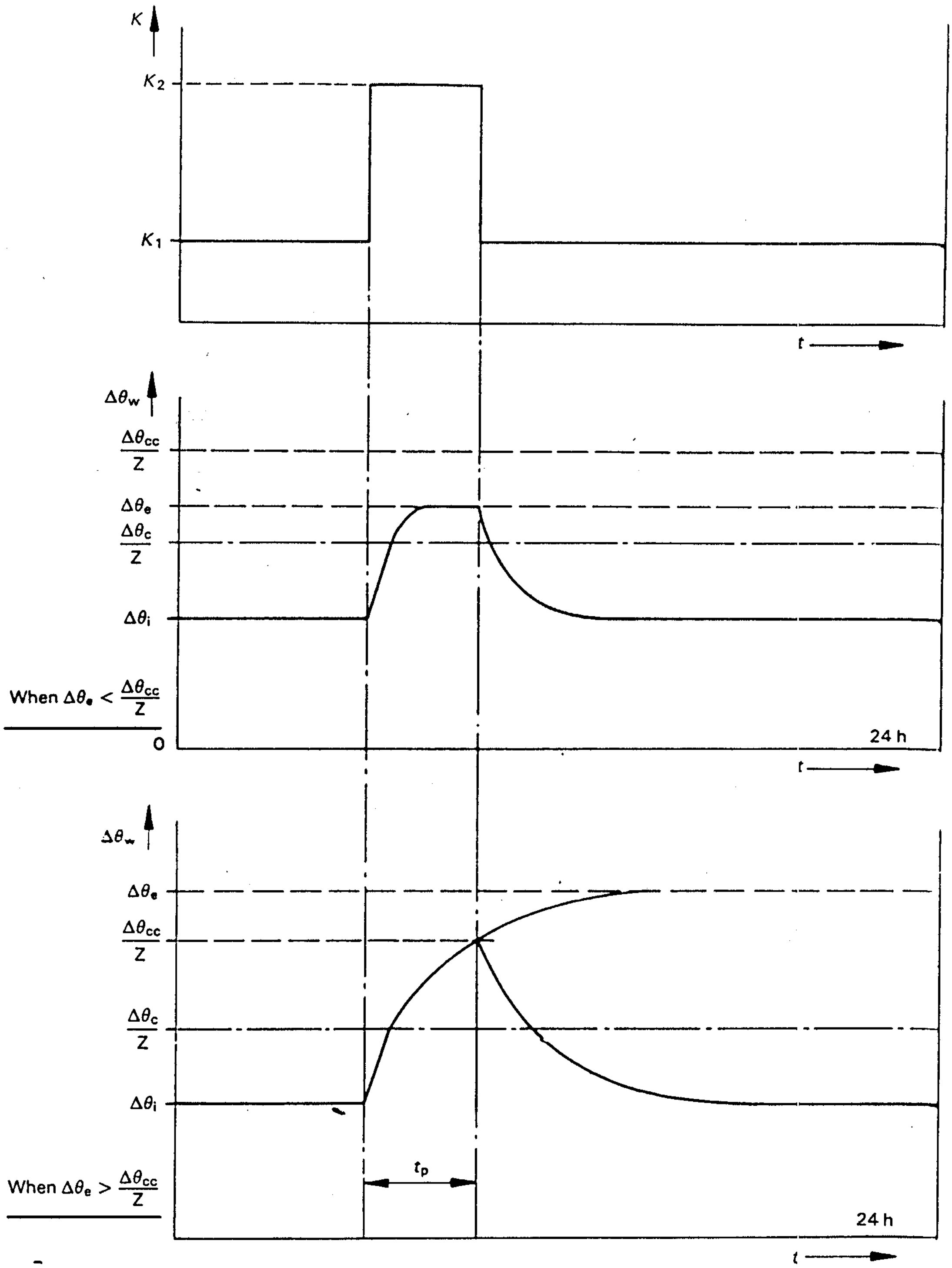
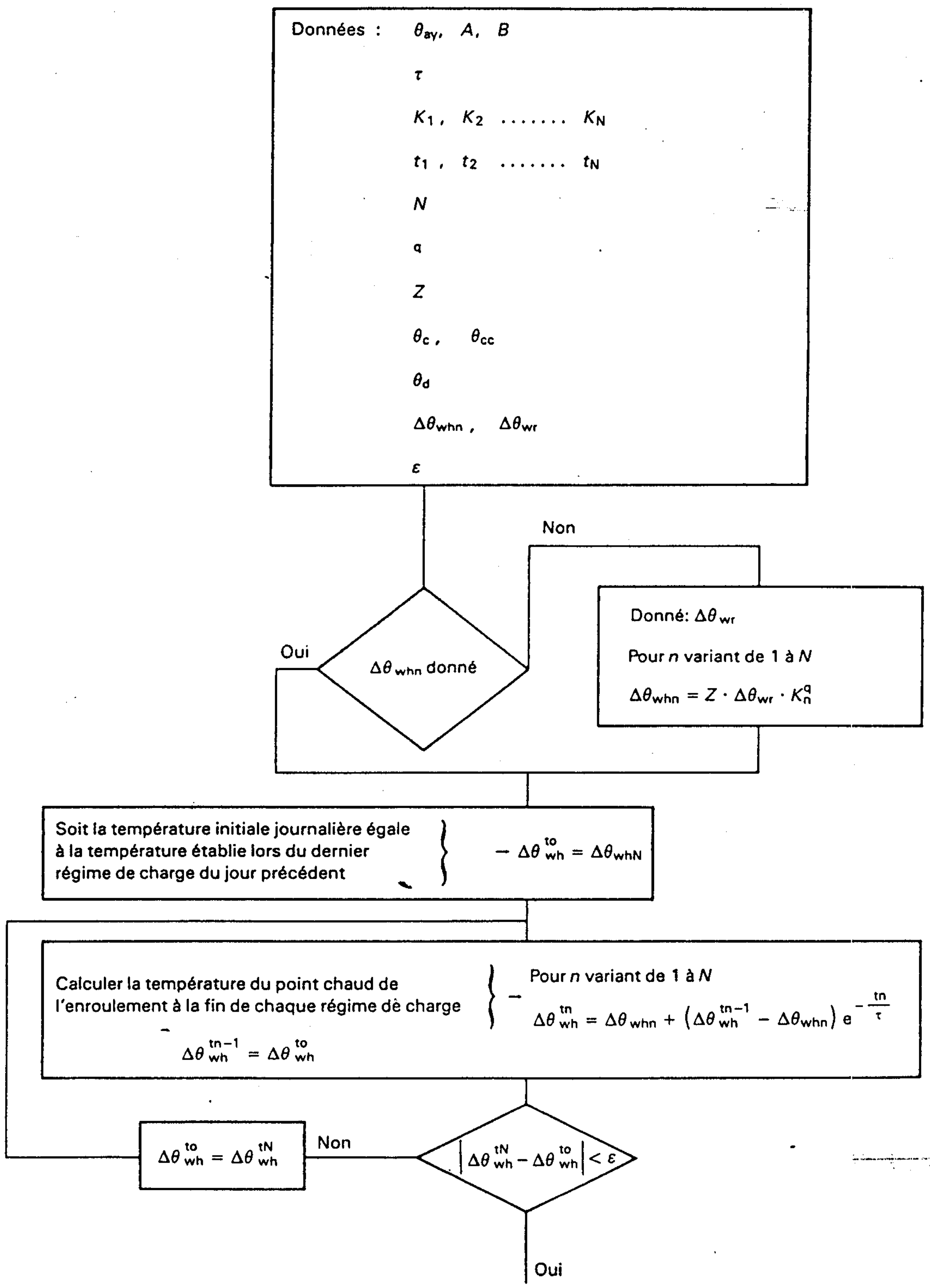


FIG. 2. – Simplified load diagram for cyclic daily duty and corresponding average winding temperature rise.

5. **Algorithme de calcul des «consommations de vie» de base**

L'algorithme de la figure 3 peut être utilisé pour faciliter les calculs de consommation de vie par ordinateur. (Voir paragraphes 4.4 et 4.5.1.)



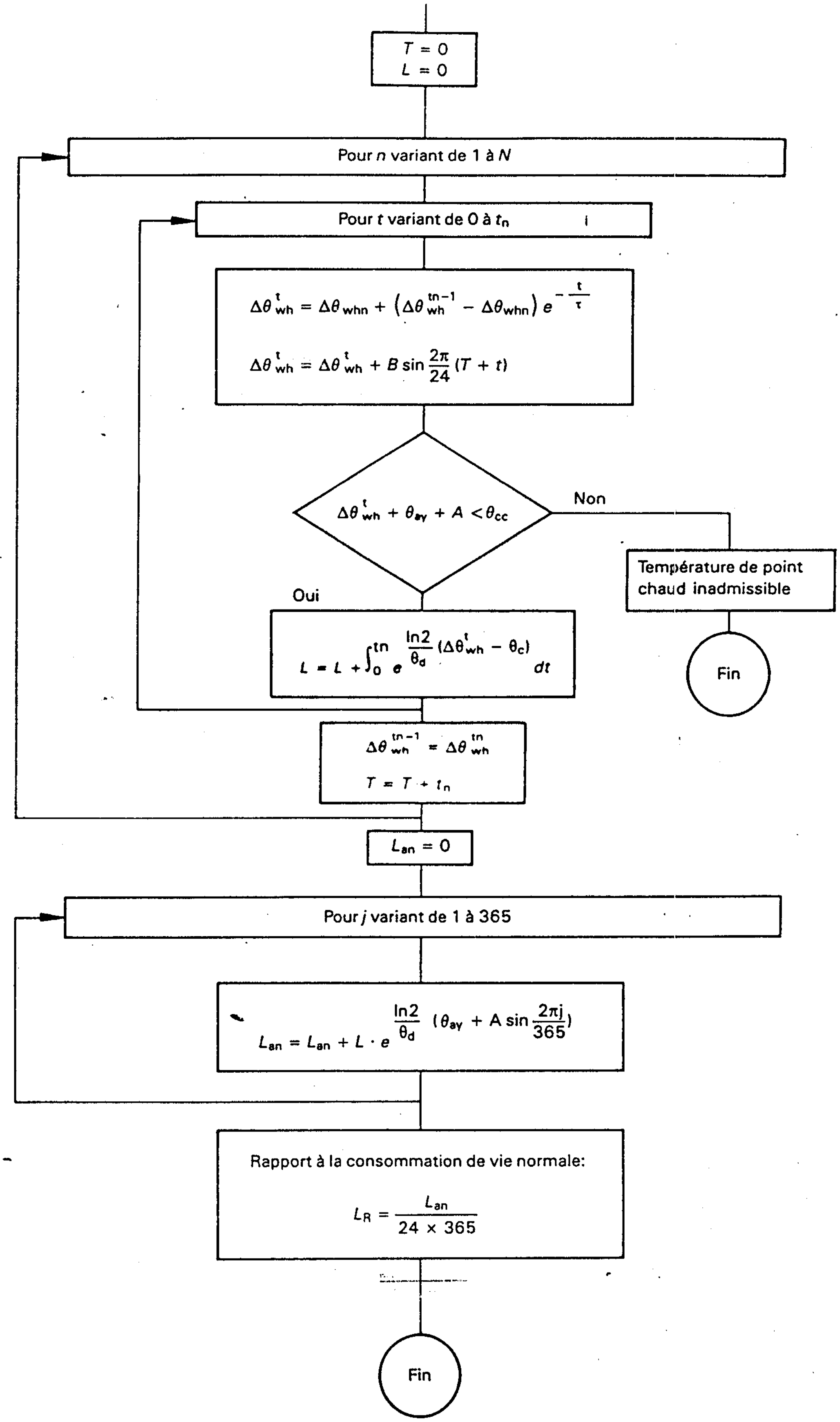
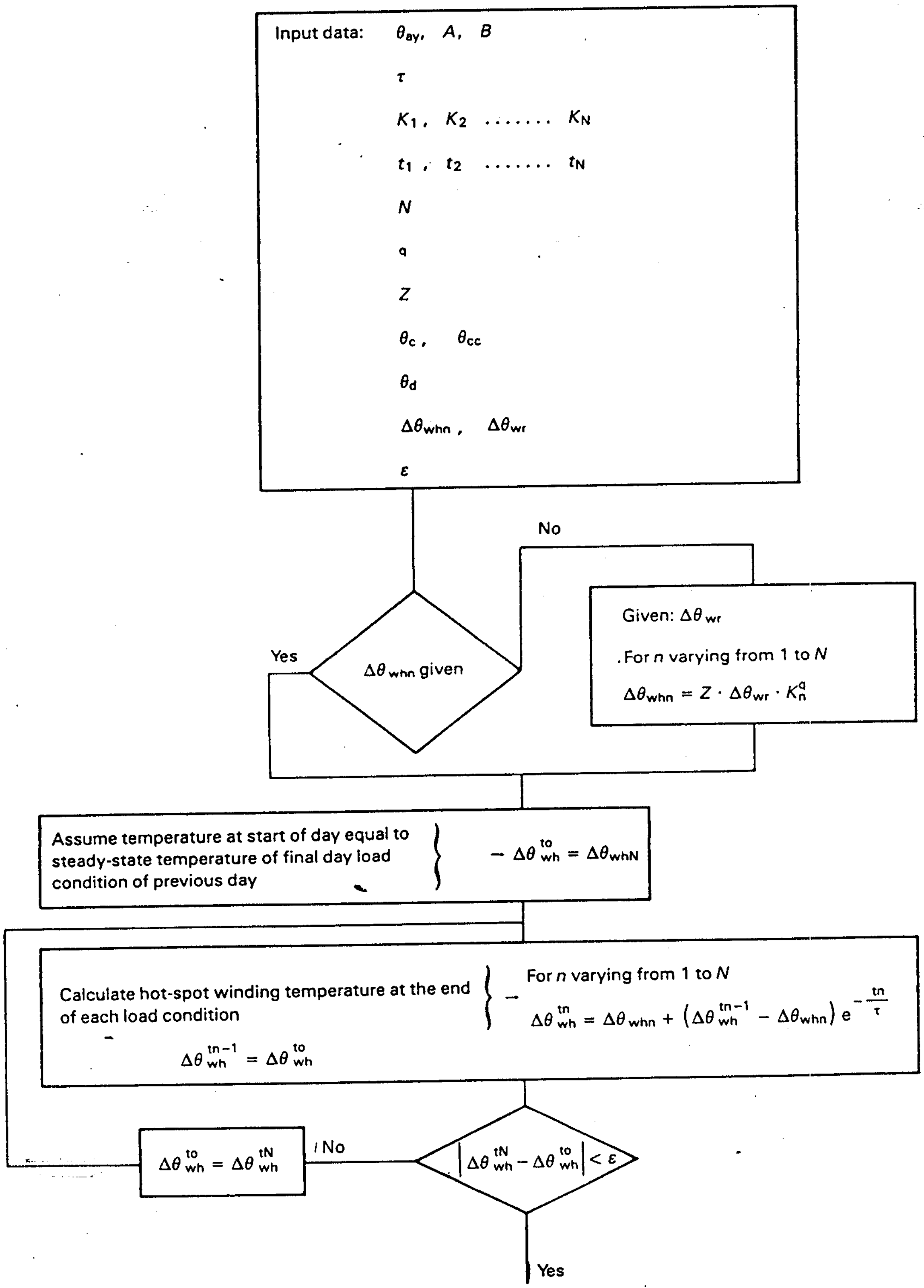


FIG. 3. – Algorithme de calcul des «consommations de vie» de base.

5. Algorithm for basic "use of life" calculations

The algorithm of Figure 3 may be used to facilitate calculation by computer of the life consumption. (See Sub-clauses 4.4 and 4.5.1.)



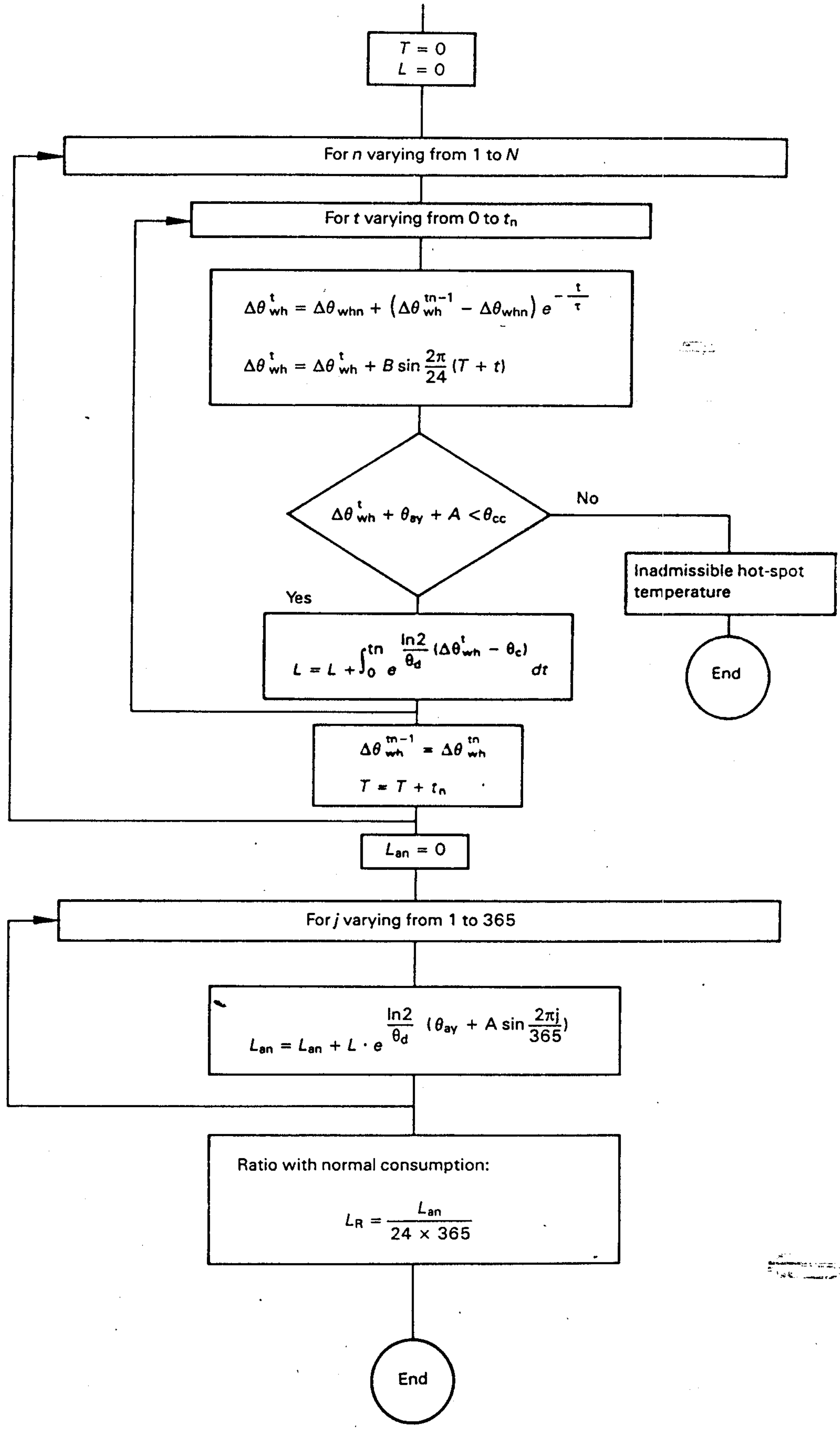


FIG. 3. – Algorithm of basic "use of life" calculations.

6. Limitations

6.1 For normal cyclic duty, the load current does not exceed 1.5 times rated value.

6.2 The hot spot temperature is limited to the value θ_{cc} specified in Table I for each insulation system temperature.

6.3 The influence of the core loss on the temperature rise of the windings is neglected. In addition, any applied voltage in excess of rated voltage is limited according to the formula in Sub-clause 4.4 of IEC Publication 76-1. (See also IEC Publication 726, Sub-clause 7.4.)

PART 2

7. Basis of establishing load curves

7.1 *Typical load diagram*

The simplified load diagram for cyclic duty shown in Figure 2, page 23, has been adopted, where in a daily 24 h period:

– the inital load current $K_1 = \frac{I_1}{I_r}$,

– is followed by a load current $K_2 = \frac{I_2}{I_r}$ of duration t_p h,

– followed by a return to the initial load current K_1 for the remainder of the 24 h period.

7.2 *Parameters of the load curves*

In the preparation of the load curves on pages 32 to 43 the following assumed values are used for ALL insulation system temperatures:

A = 0
B = 0
τ = 0.5 h and 1.0 h
θ_{ay} = 10 °C, 20 °C, 30 °C (constant for 24 h)
q = 1.6 for naturally cooled transformers
Z = 1.25
θ_d = 10 K
N = 2

8. Selection of appropriate load curve with examples

For any load diagram, simplified as described in Sub-clause 7.1, select the load curve corresponding to the insulation system temperature, using the appropriate winding thermal time constant and ambient temperature, θ_a. If the value of θ_a lies between two load curves, either select the nearest one above or interpolate between the two nearest curves.

Exemple 1 – Détermination du courant de charge admissible.

Transformateur 1000 kVA AN, température du système d'isolation 155 °C, constante de temps thermique de l'enroulement 0,5 h, courant de charge initial 722 A. Chercher le courant de charge admissible pendant 2 h à la température ambiante de 20 °C (courant assigné 1444 A).

$$\theta_a = 20\ °C,\ K_1 = \frac{722}{1444} = 0{,}5,\ t_p = 2\ h$$

La figure 5 (7), page 38, donne $K_2 = 1{,}23$.

D'où le courant de charge admissible pendant 2 h est égal à 1776 A (suivi du retour à 722 A pour le reste de la période de 24 h).

Exemple 2 – Détermination de la puissance assignée d'un transformateur nécessaire pour un service donné.

Avec $\theta_a = 10$ °C, une température du système d'isolation de 155 °C, une constante de temps thermique de l'enroulement de 0,5 h, on cherche un transformateur fournissant 2020 A pendant 4 h et 1444 A pendant les 20 h restant chaque jour.

$$\frac{2020}{1444} = \frac{I_2}{I_1} = 1{,}4 \quad \text{(Voir figure 4.)}$$

A partir de la figure 5 (7), page 38, sur la ligne $t_p = 4$ h, les valeurs de K_2 et K_1 donnant $\frac{K_2}{K_1} = 1{,}4$ sont $K_2 = 1{,}175$ et $K_1 = 0{,}84$.

D'où, la charge continue équivalente $= \frac{2020}{1{,}175} = \frac{1444}{0{,}84} = 1720$ A.

Par conséquent, un transformateur triphasé avec une tension secondaire à vide de 400 V, devra avoir une puissance assignée de:

$$\sqrt{3} \times 400 \times 1720 \times 10^{-3} = 1192\ \text{kVA}.$$

La puissance normalisée immédiatement supérieure, par exemple 1250 kVA, devrait être adoptée.

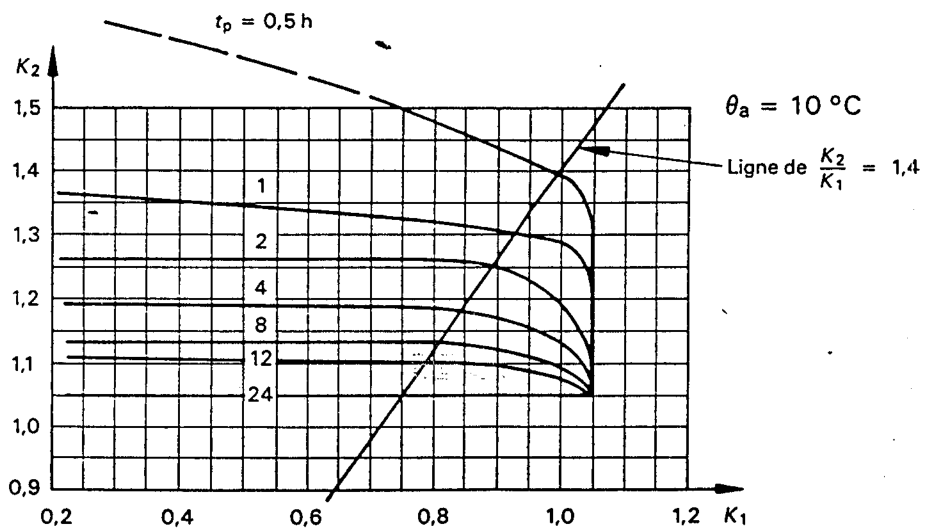


FIG. 4. – Illustration de l'exemple 2.

Example 1 – Determination of the permissible load current.

1000 kVA AN transformer, insulation system temperature 155 °C, winding thermal time constant 0.5 h, initial load current 722 A. Required to find permissible load current for 2 h at an ambient temperature of 20 °C. (Rated current 1444 A.)

$$\theta_a = 20\ °C,\ K_1 = \frac{722}{1444} = 0.5,\ t_p = 2\ h$$

Figure 5 (7), page 38, gives $K_2 = 1.23$.

Therefore the permissible load current for 2 h is 1776 A (then returning to 722 A for the remainder of the 24 h period.)

Example 2 – Determination of the necessary power rating of a transformer suitable for a given duty.

With $\theta_a = 10$ °C, insulation system temperature 155 °C, winding thermal time constant 0.5 h, a transformer is required to deliver 2020 A for 4 h and 1444 A for the remaining 20 h each day.

$$\frac{2020}{1444} = \frac{I_2}{I_1} = 1.4 \quad \text{(See Figure 4.)}$$

From Figure 5 (7), page 38, on the $t_p = 4$ h line, the values of K_2 and K_1 giving $\frac{K_2}{K_1} = 1.4$ are $K_2 = 1.175$ and $K_1 = 0.84$.

Therefore the equivalent continuous current $= \frac{2020}{1.175} = \frac{1444}{0.84} = 1720$ A.

Therefore the power rating required for a transformer with a no load secondary voltage 400 V three-phase is:

$$\sqrt{3} \times 400 \times 1720 \times 10^{-3} = 1192\ \text{kVA}.$$

The standard power immediately above, for example 1250 kVA, should be adopted.

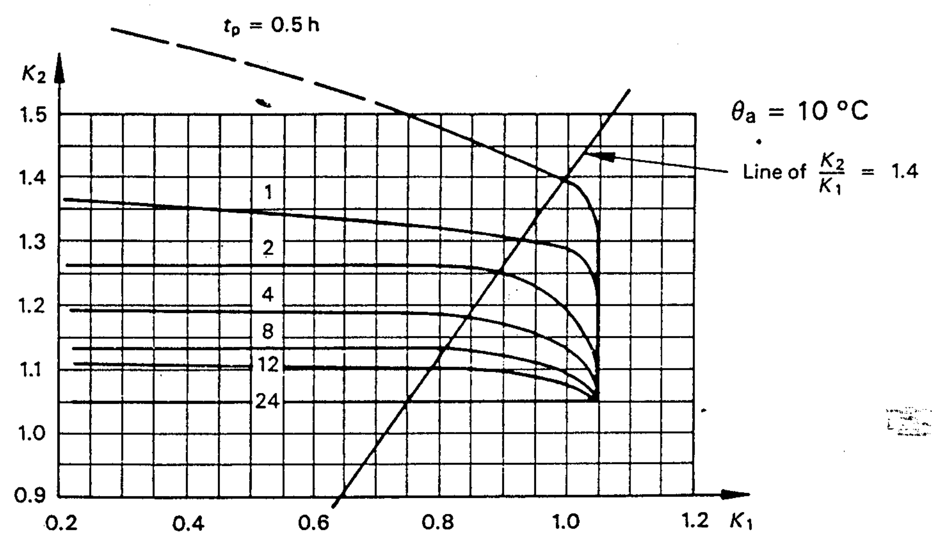
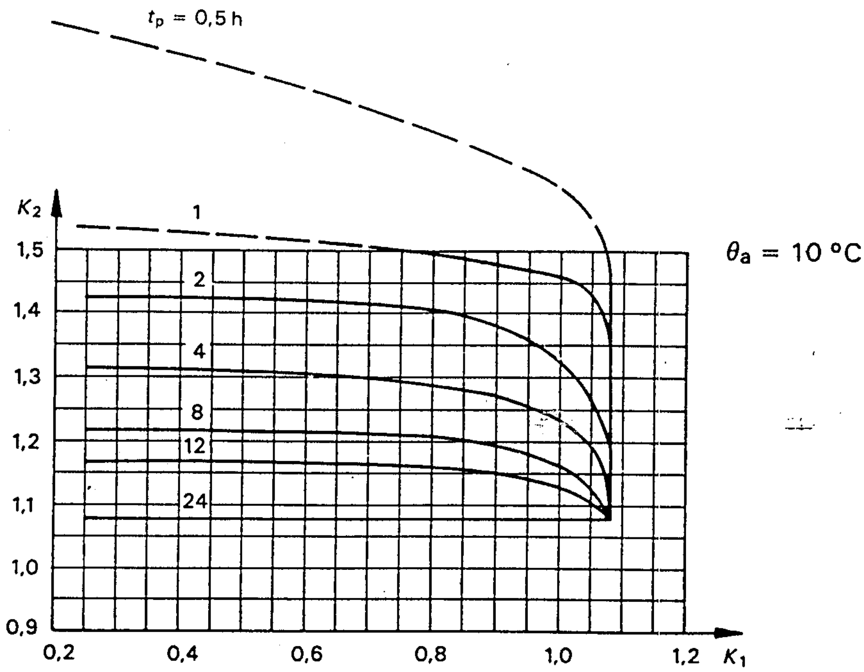
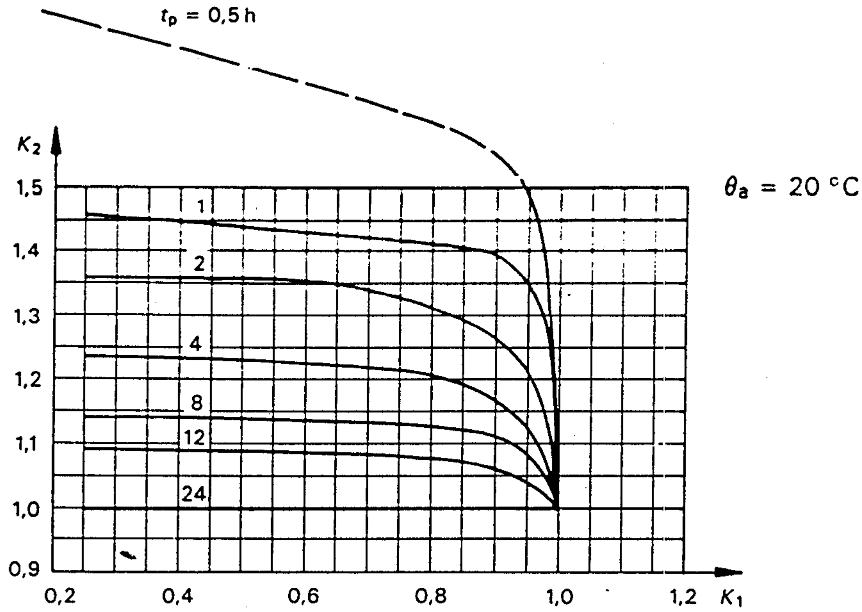


FIG. 4. – Illustration of example 2.





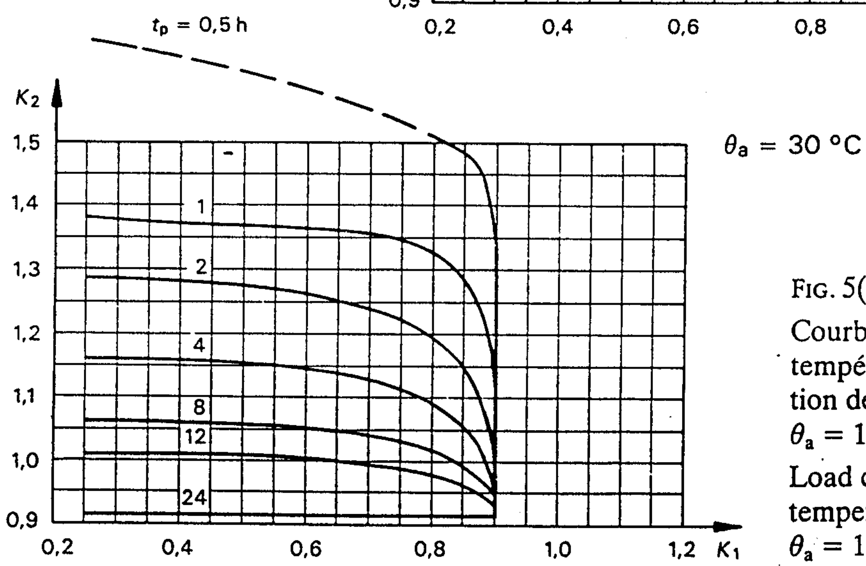
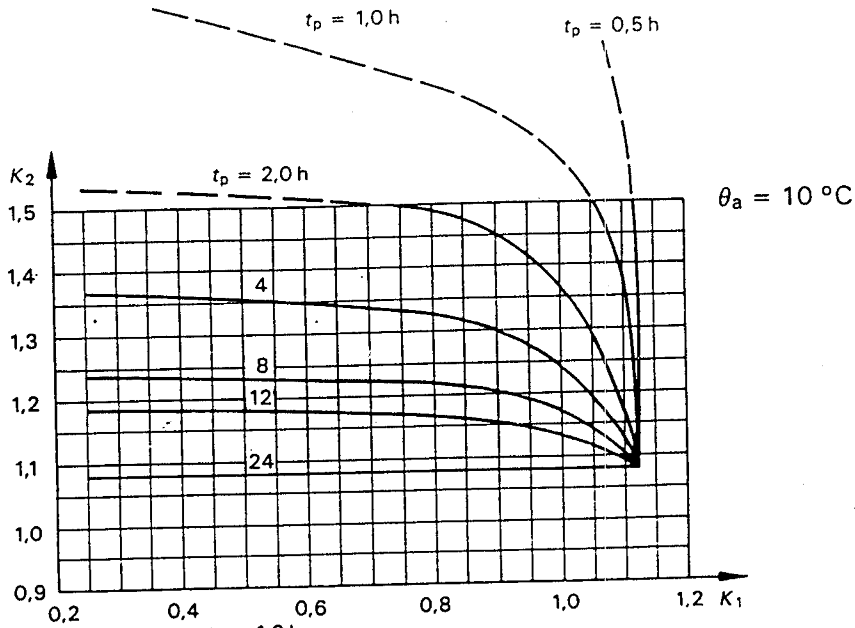
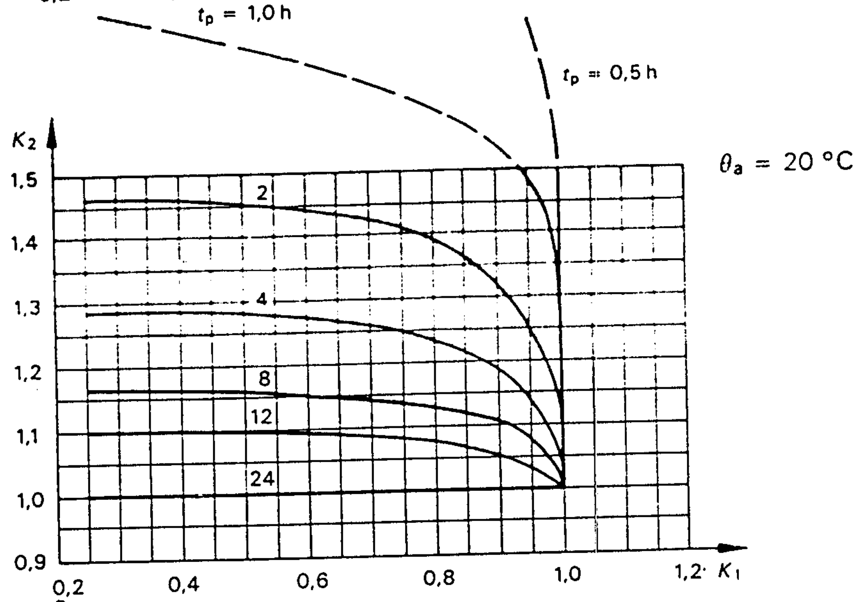


FIG. 5(1).

Courbes des charges pour une température de système d'isolation de 105 °C, τ = 0,5 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 105 °C, τ = 0.5 h
θ_a = 10, 20 and 30 °C.





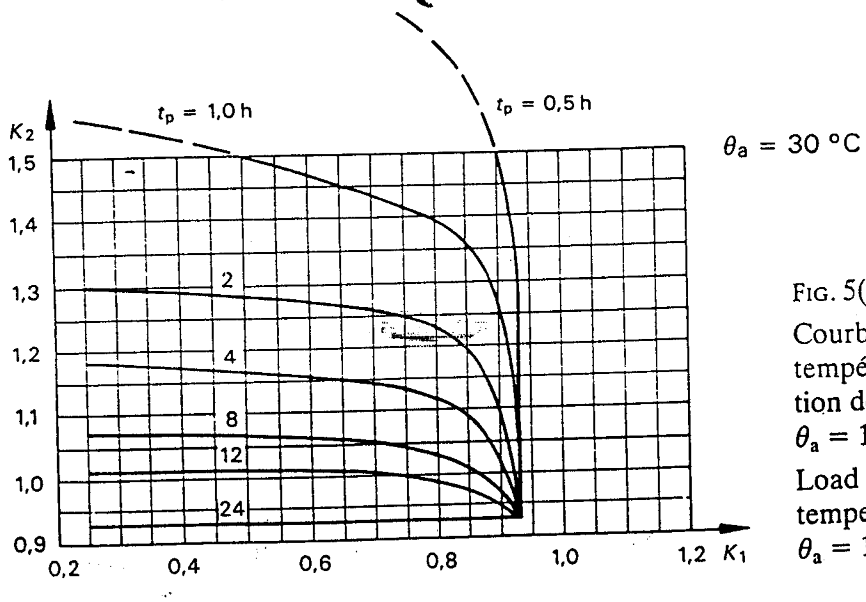
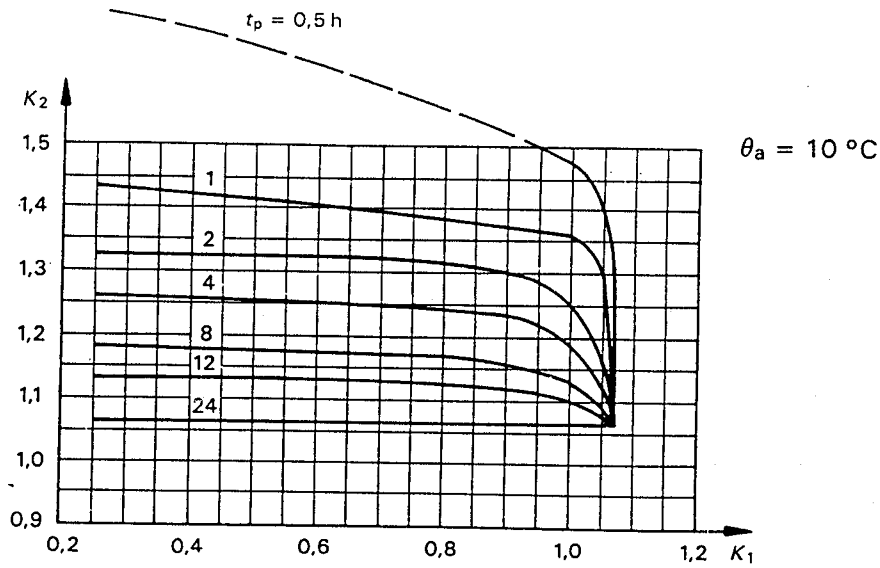
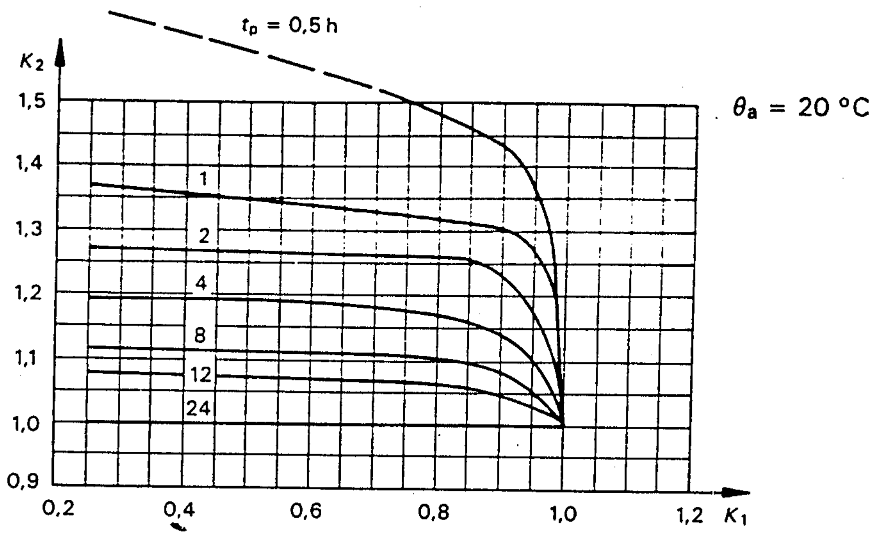


FIG. 5(2).

Courbes des charges pour une température de système d'isolation de 105 °C, τ = 1,0 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 105 °C, τ = 1.0 h
θ_a = 10, 20 and 30 °C.





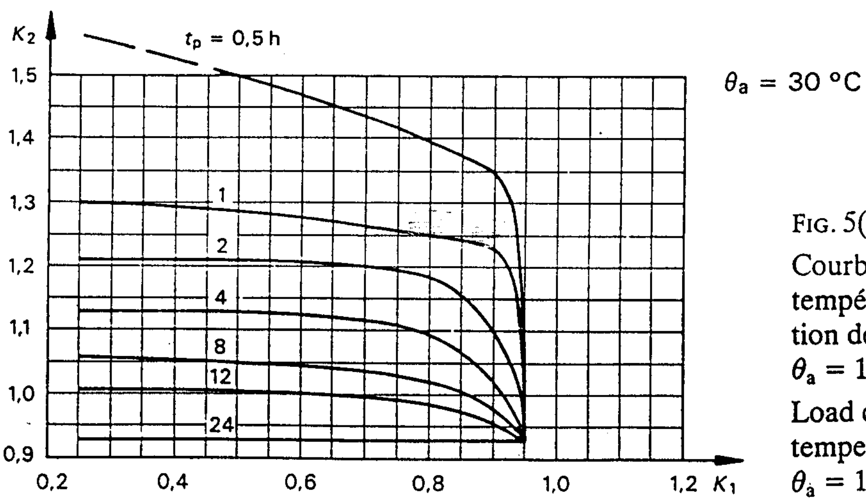


FIG. 5(3).

Courbes des charges pour une température de système d'isolation de 120 °C, $\tau = 0{,}5$ h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 120 °C, $\tau = 0.5$ h
θ_a = 10, 20 and 30 °C.

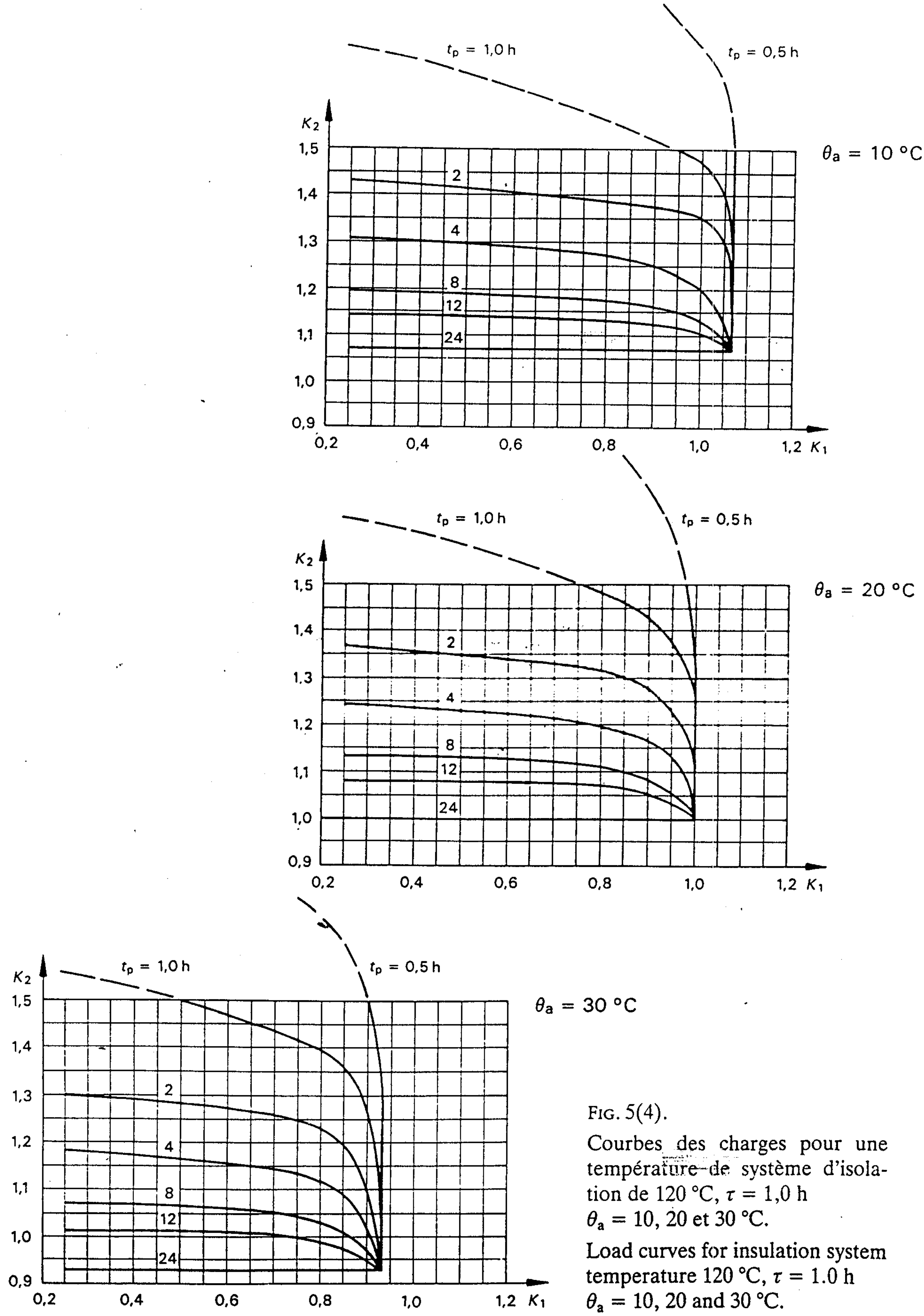
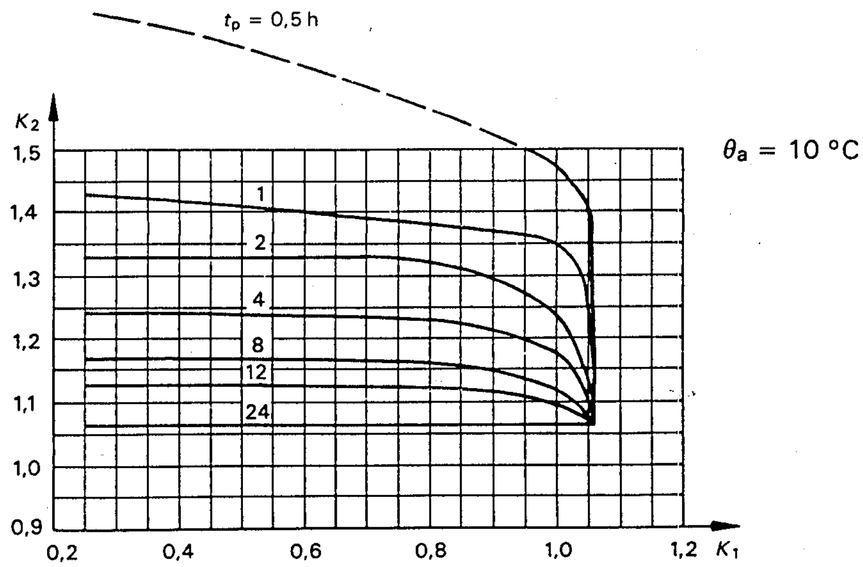
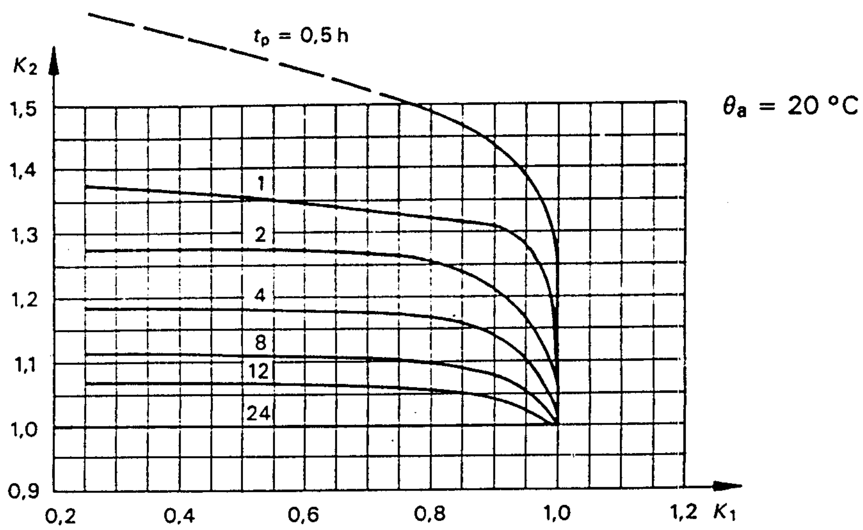


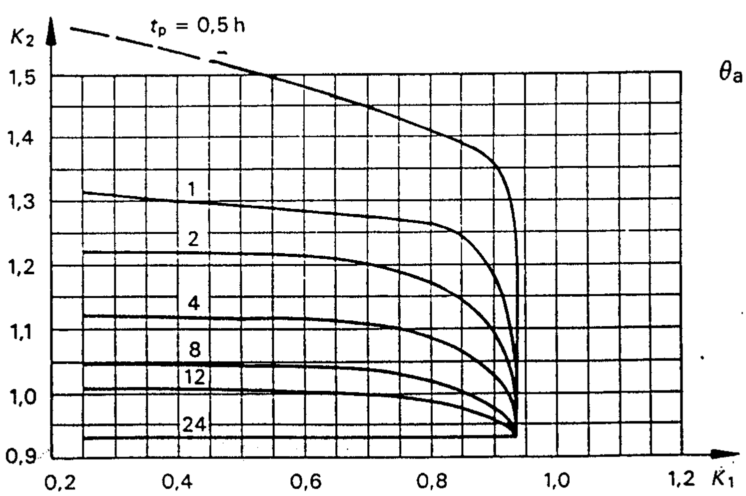
FIG. 5(4).

Courbes des charges pour une température de système d'isolation de 120 °C, τ = 1,0 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 120 °C, τ = 1.0 h
θ_a = 10, 20 and 30 °C.





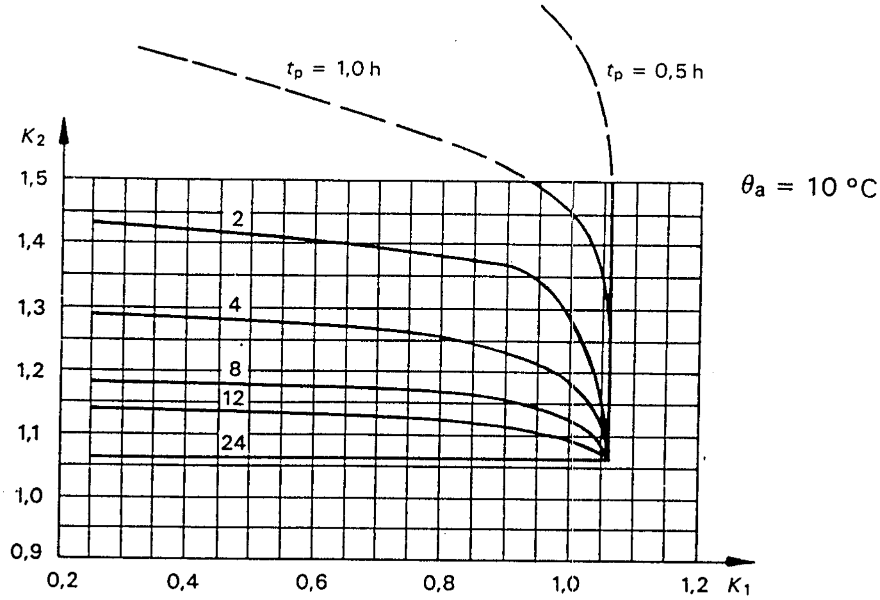


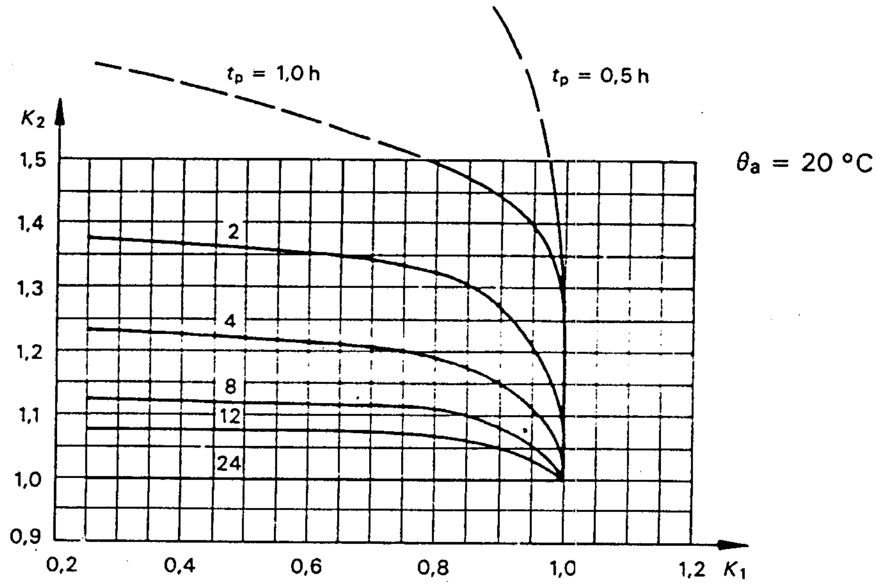
θ_a = 30 °C

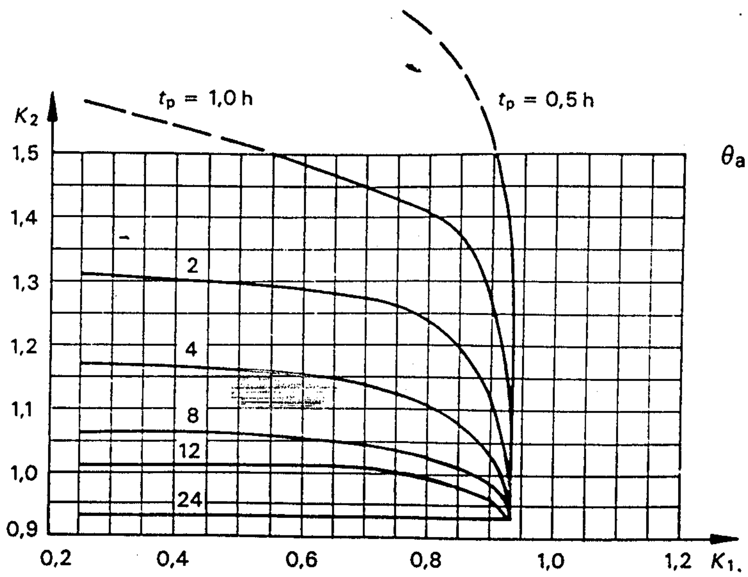
FIG. 5(5).

Courbes des charges pour une température de système d'isolation de 130 °C, τ = 0,5 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 130 °C, τ = 0.5 h
θ_a = 10, 20 and 30 °C.





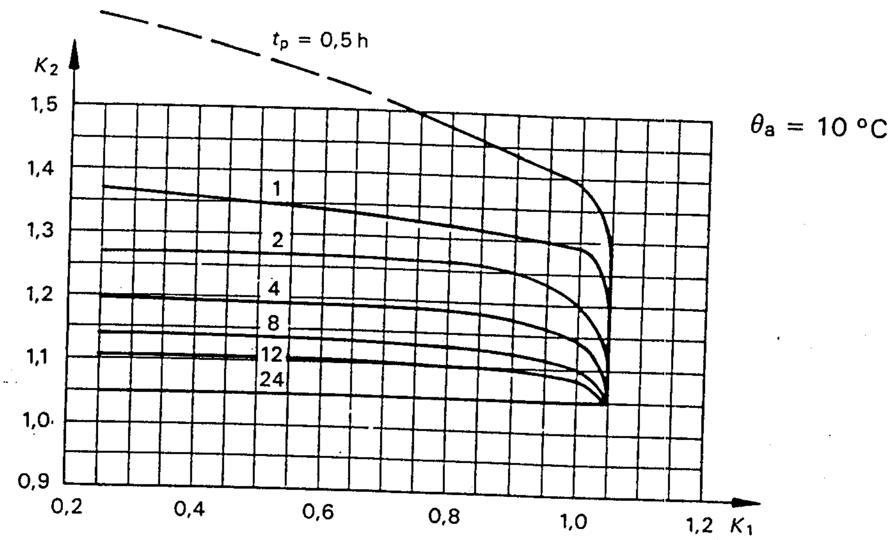


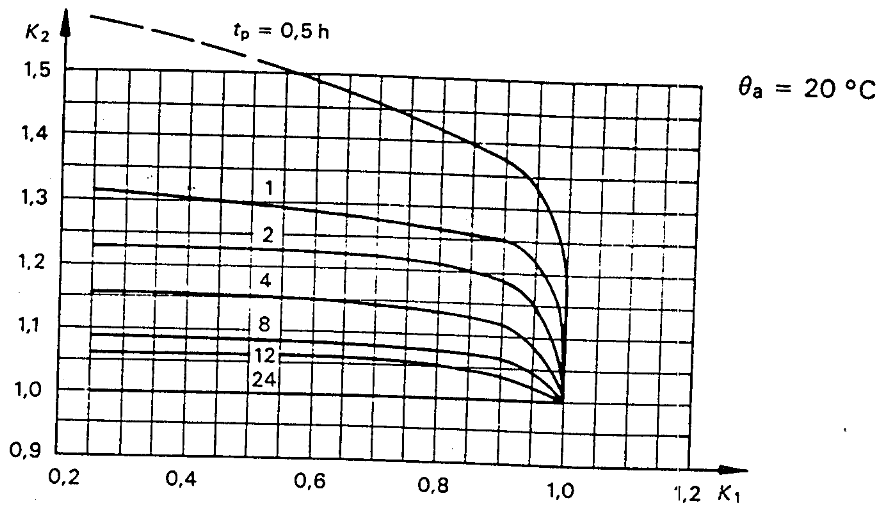
θ_a = 30 °C

FIG. 5(6).

Courbes des charges pour une température de système d'isolation de 130 °C, τ = 1,0 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 130 °C, τ = 1.0 h
θ_a = 10, 20 and 30 °C.





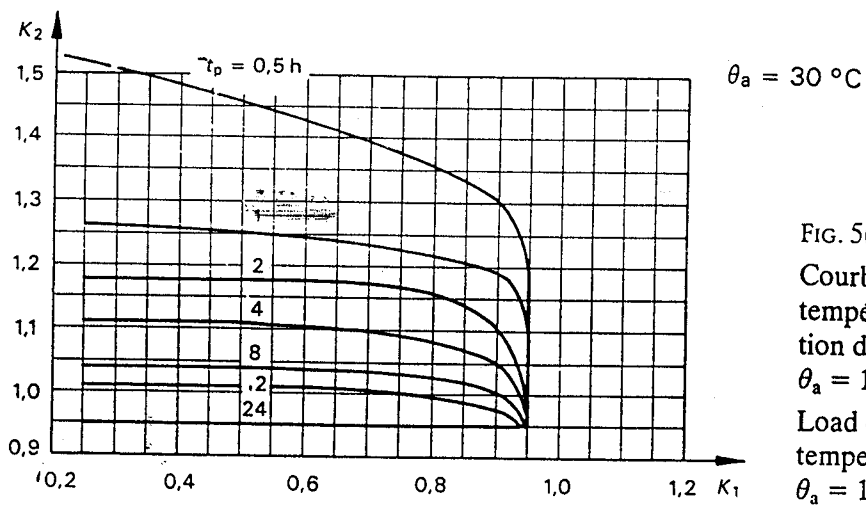


FIG. 5(7).

Courbes des charges pour une température de système d'isolation de 155 °C, τ = 0,5 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 155 °C, τ = 0.5 h
θ_a = 10, 20 and 30 °C.

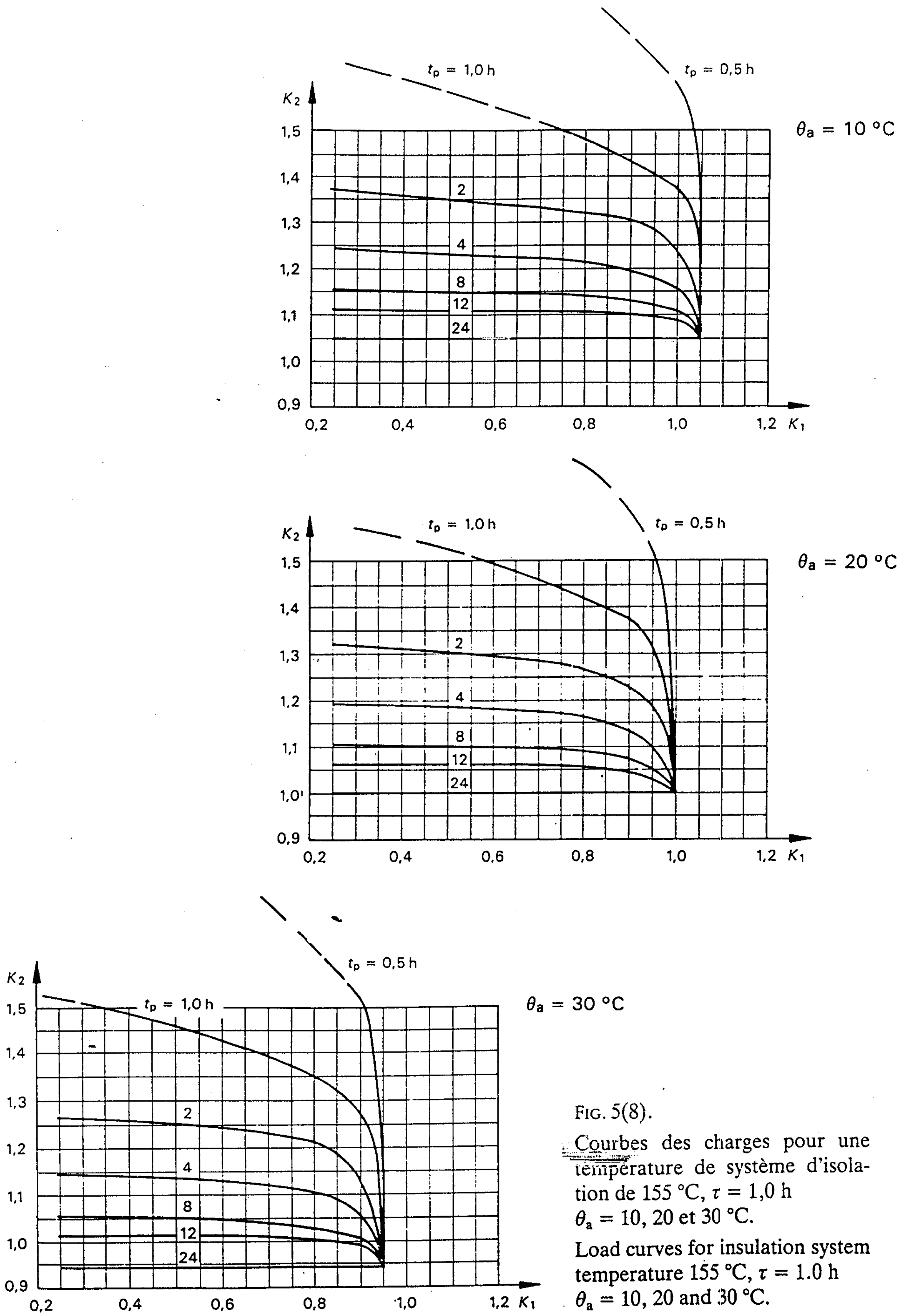
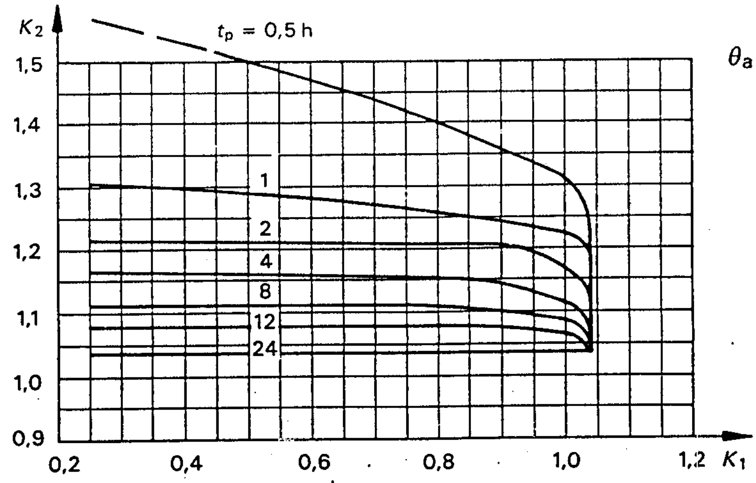


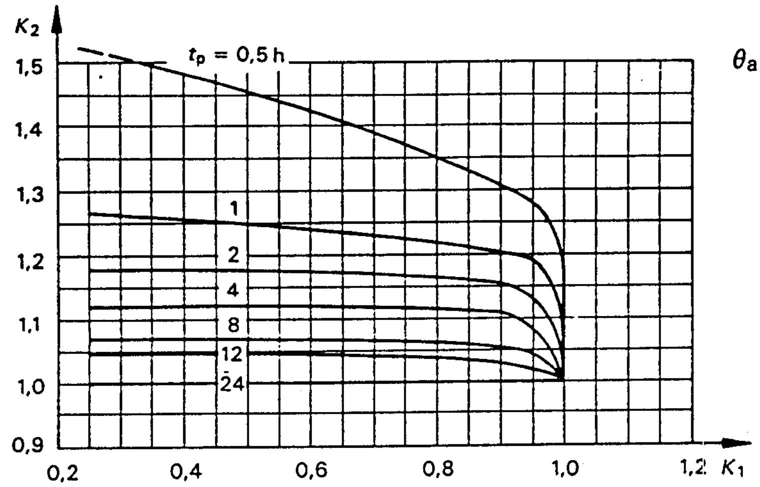
FIG. 5(8).

Courbes des charges pour une température de système d'isolation de 155 °C, τ = 1,0 h
θ_a = 10, 20 et 30 °C.

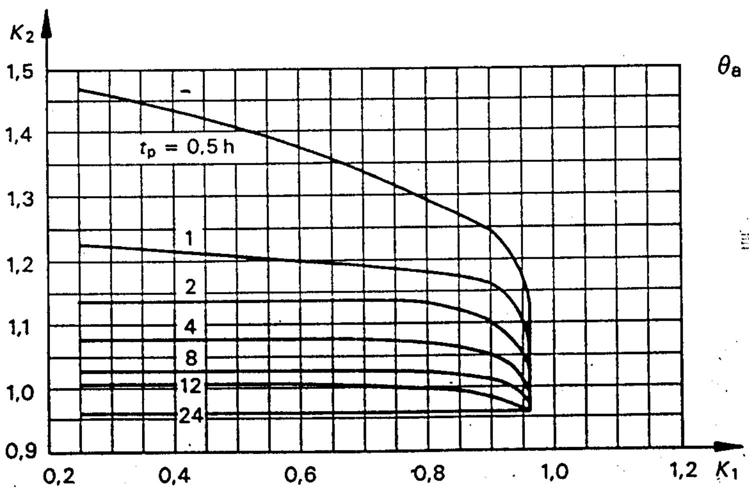
Load curves for insulation system temperature 155 °C, τ = 1.0 h
θ_a = 10, 20 and 30 °C.



θ_a = 10 °C



θ_a = 20 °C

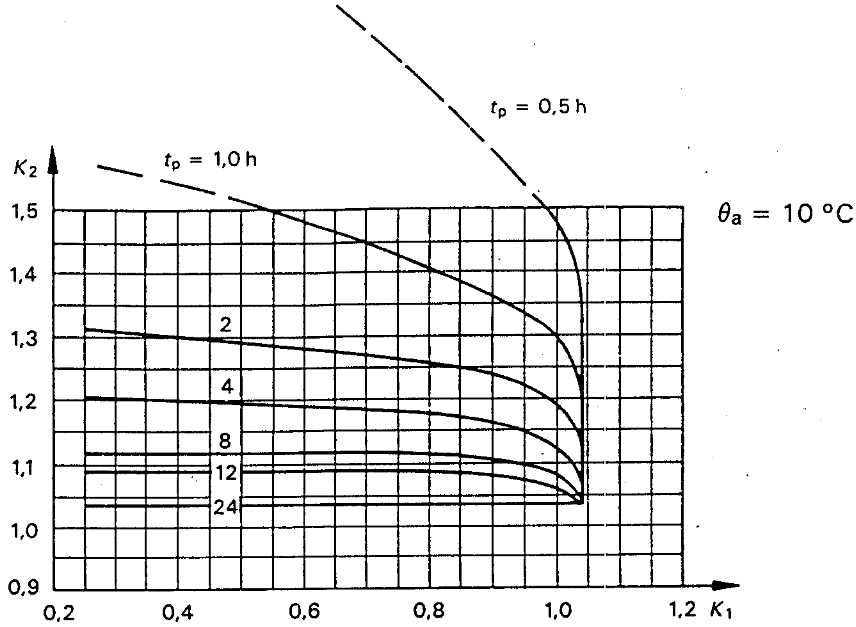


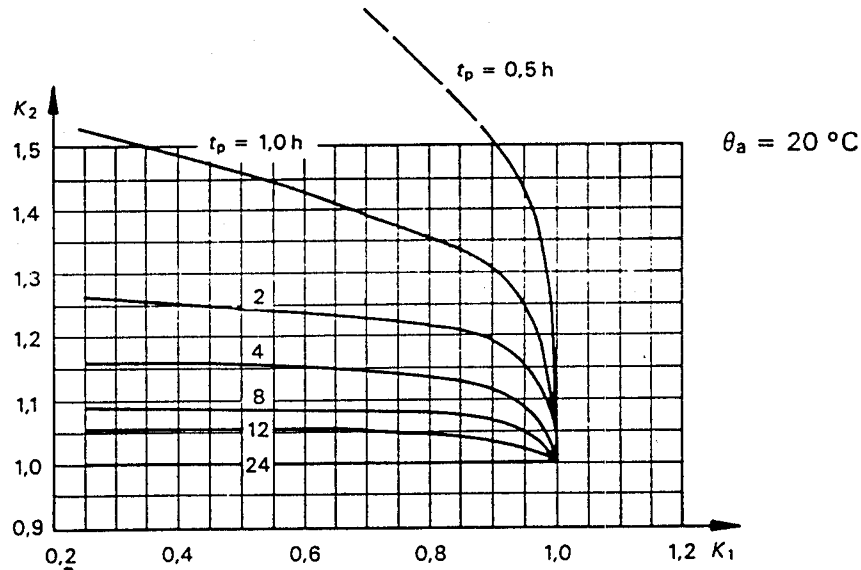
θ_a = 30 °C

FIG. 5(9).

Courbes des charges pour une température de système d'isolation de 180 °C, τ = 0,5 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 180 °C, τ = 0.5 h
θ_a = 10, 20 and 30 °C.





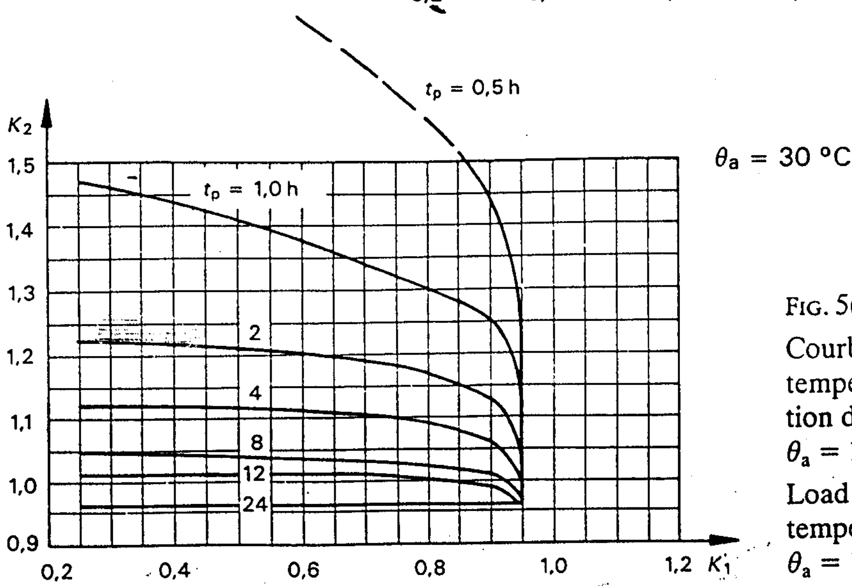
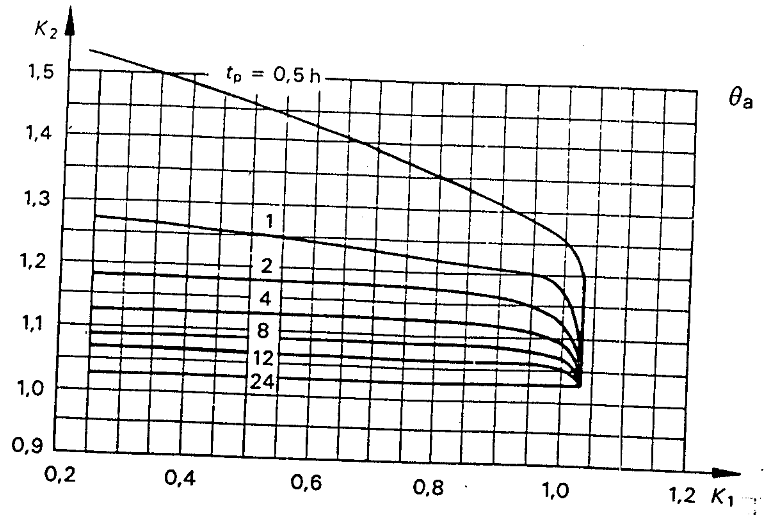


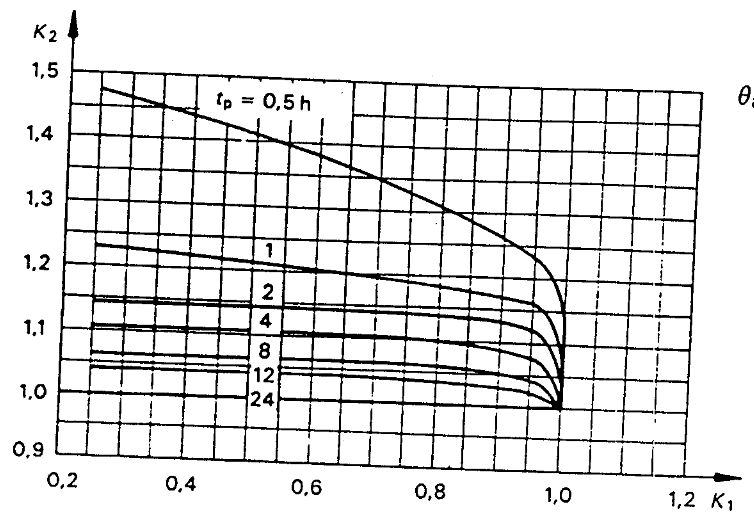
FIG. 5(10).

Courbes des charges pour une température de système d'isolation de 180 °C, τ = 1,0 h
θ_a = 10, 20 et 30 °C.

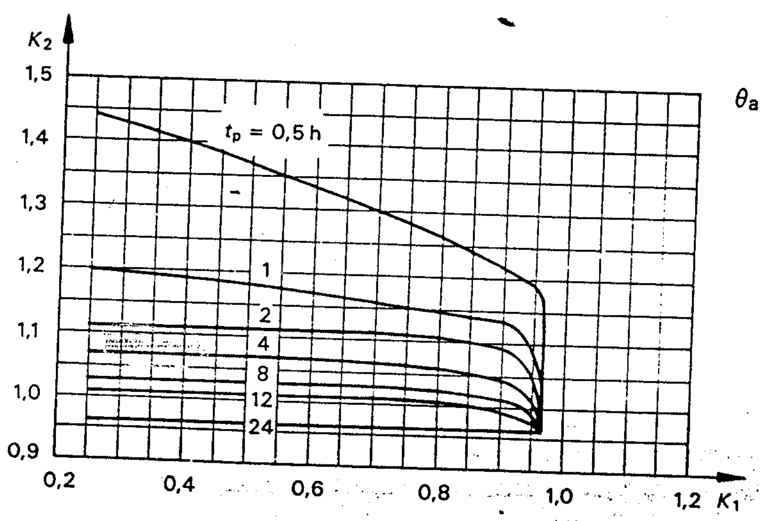
Load curves for insulation system temperature 180 °C, τ = 1.0 h
θ_a = 10, 20 and 30 °C.



θ_a = 10 °C



θ_a = 20 °C



θ_a = 30 °C

FIG. 5(11).

Courbes des charges pour une température de système d'isolation de 220 °C, τ = 0,5 h
θ_a = 10, 20 et 30 °C.

Load curves for insulation system temperature 220 °C, τ = 0.5 h
θ_a = 10, 20 and 30 °C.

Load curves for insulation system