INTERNATIONAL STANDARD

ISO 12130-1

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Plain bearings — Hydrodynamic plain tilting pad thrust bearings under steady-state conditions —

Part 1:
Calculation of tilting pad thrust bearings

Paliers lisses — Butées hydrodynamiques à patins oscillants fonctionnant en régime stationnaire —

Partie 1: Calcul des butées à patins oscillants

Reference number
ISO 12130-1:2001(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 12130 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 12130-1 was prepared by Technical Committee ISO/TC 123, *Plain bearings*, Subcommittee SC 4, *Methods of calculation of plain bearings*.

ISO 12130 consists of the following parts, under the general title *Plain bearings — Hydrodynamic plain tilting pad thrust bearings under steady-state conditions*:

— *Part 1: Calculation of tilting pad thrust bearings*

— *Part 2: Functions for calculation of tilting pad thrust bearings*

— *Part 3: Guide values for the calculation of tilting pad thrust bearings*

Annex A forms a normative part of this part of ISO 12130.

Plain bearings — Hydrodynamic plain tilting pad thrust bearings under steady-state conditions —

Part 1:
Calculation of tilting pad thrust bearings

1 Scope

The aim of ISO 12130 is to achieve designs of plain bearings that are reliable in operation by the application of a calculation method for oil-lubricated hydrodynamic plain bearings with complete separation of the thrust collar and plain bearing surfaces by a film of lubricant.

This part of ISO 12130 applies to plain thrust bearings with tilting-type sliding blocks (tilting pads), where a wedge-shaped lubrication clearance gap is automatically formed during operation. The ratio of width to length of one pad can be varied in the range B/L = 0,5 to 2.

The calculation method described in this part of ISO 12130 can be used for other gap shapes, e.g. parabolic lubrication clearance gaps, as well as for other types of sliding blocks, e.g. circular sliding blocks, when for these types the numerical solutions of Reynolds' differential equation are present. ISO 12130-2 gives only the characteristic values for the plane wedge-shaped gap; the values are therefore not applicable to tilting pads with axial support.

The calculation method serves for designing and optimizing plain thrust bearings e.g. for fans, gear units, pumps, turbines, electric machines, compressors and machine tools. It is limited to steady-state conditions, i.e. load and angular speed of all rotating parts are constant under continuous operating conditions.

This part of ISO 12130 is not applicable to heavily loaded tilting pad thrust bearings.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 12130. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 12130 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3448:1992, *Industrial liquid lubricants — ISO viscosity classification*

ISO 12130-2, *Plain bearings — Hydrodynamic plain tilting pad thrust bearings under steady-state conditions — Part 2: Functions for calculation of tilting pad thrust bearings*

ISO 12130-3, *Plain bearings — Hydrodynamic plain tilting pad thrust bearings under steady-state conditions — Part 3: Guide values for the calculation of tilting pad thrust bearings*

3 Fundamentals, assumptions and premises

The calculation is always carried out with the numerical solutions of Reynolds' differential equations for sliding surfaces with finite width, taking into account the physically correct boundary conditions for the generation of pressure.

$$\frac{\partial}{\partial x}\left(h^3 \frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial z}\left(h^3 \frac{\partial p}{\partial z}\right) = 6 \times \eta \times U \times \frac{\partial h}{\partial x} \tag{1}$$

Reference is made, e.g., to [1] for the derivation of Reynolds' differential equation and to [2] for the numerical solution.

For the solution to equation (1), the following idealizing assumptions and premises are used, the reliability of which has been sufficiently confirmed by experiment and in practice [3]:

a) the lubricant corresponds to a Newtonian fluid;

b) all lubricant flows are laminar;

c) the lubricant adheres completely to the sliding surfaces;

d) the lubricant is incompressible;

e) the lubrication clearance gap is completely filled with lubricant;

f) inertia effects, gravitational and magnetic forces of the lubricant are negligible;

g) the components forming the lubrication clearance gap are rigid or their deformation is negligible; their surfaces are completely even;

h) the lubricant film thickness in the radial direction (z-coordinate) is constant;

i) fluctuations in pressure within the lubricant film normal to the sliding surfaces (y-coordinate) are negligible;

j) there is no motion normal to the sliding surfaces (y-coordinate);

k) the lubricant is isoviscous over the entire lubrication clearance gap;

l) the lubricant is fed in at the widest lubrication clearance gap;

m) the magnitude of the lubricant feed pressure is negligible as compared to the lubricant film pressures themselves;

n) the pad shape of the sliding surfaces is replaced by rectangles.

The boundary conditions for the solution of Reynolds' differential equation are the following:

1) the gauge pressure of the lubricant at the feeding point is $p(x = 0, z) = 0$

2) the feeding of the lubricant is arranged in such a way that it does not interfere with the generation of pressure in the lubrication clearance gap

3) the gauge pressure of the lubricant at the lateral edges of the plain bearing is $p\left(x, z = \pm 0{,}5B\right) = 0$

4) the gauge pressure of the lubricant is $p(x = L, z) = 0$ at the end of the pressure field.

The application of the principle of similarity in hydrodynamic plain bearing theory results in dimensionless parameters of similarity for such characteristics as load carrying capacity, friction behaviour and lubricant flow rate.

The use of parameters of similarity reduces the number of necessary numerical solutions of Reynolds' differential equation which are compiled in ISO 12130-2. In principle, other solutions are also permitted if they satisfy the conditions given in this part of ISO 12130 and have the corresponding numerical accuracy.

ISO 12130-3, contains guide values according to which the calculation result is to be oriented in order to ensure the functioning of the plain bearings.

In special cases, guide values deviating from ISO 12130-3, may be agreed for specific applications.

4 Symbols, terms and units

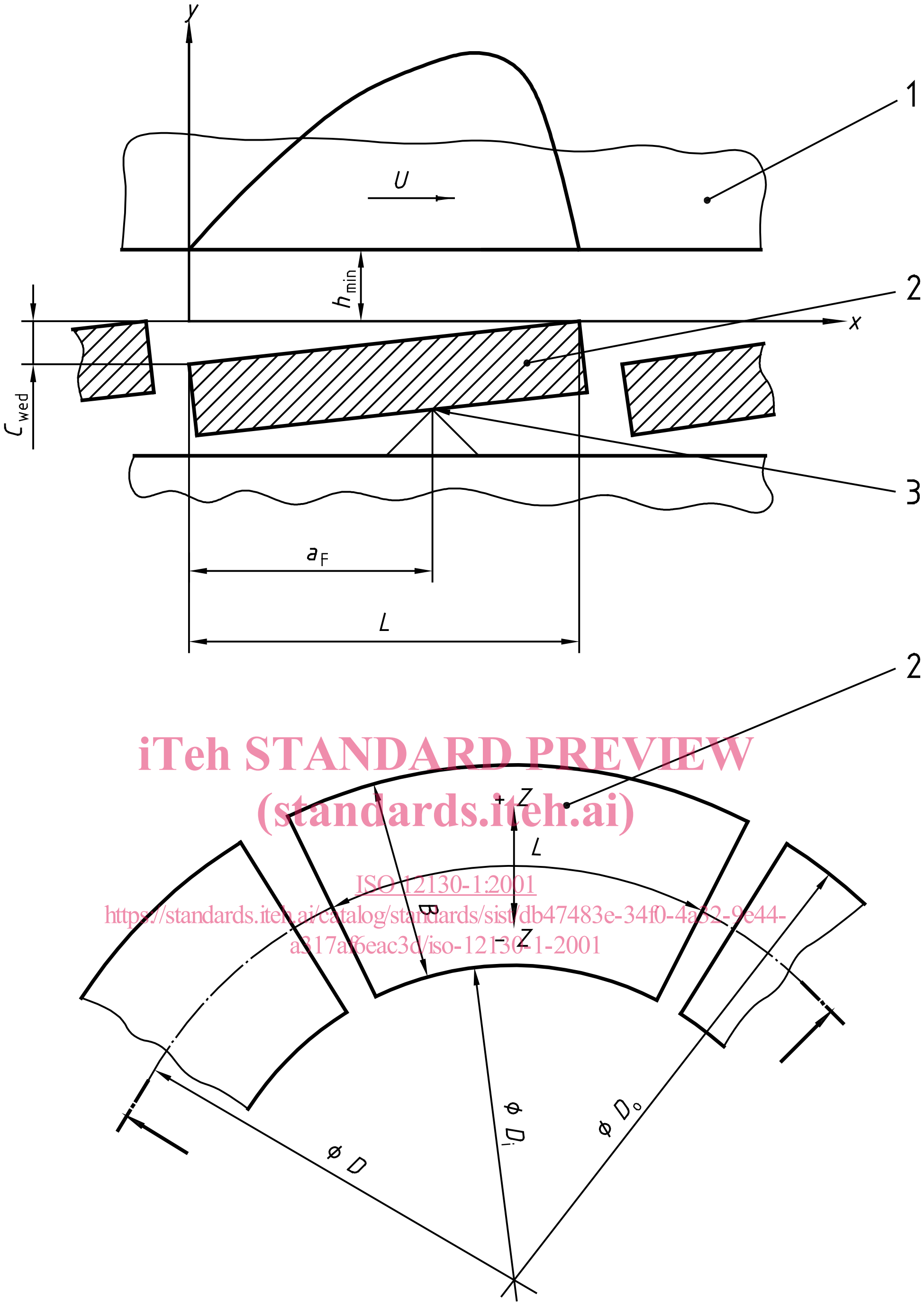
See Table 1 and Figure 1.

Table 1 — Symbols, terms and units

Symbol	Term	Unit
a_F	Distance between supporting point and inlet of the clearance gap in the direction of motion (circumferential direction)	m
a^*_F	Relative distance between supporting point and inlet of the clearance gap in the direction of motion (circumferential direction)	1
A	Heat-emitting surface of the bearing housing	m^2
B	Width of one pad	m
c_p	Specific heat capacity of the lubricant (p = constant)	J/(kg·K)
C_{wed}	Wedge depth	m
D	Mean sliding diameter	m
D_i	Inside diameter over tilting pads	m
D_o	Outside diameter over tilting pads	m
f^*	Characteristic value of friction	1
F	Bearing force (load) at nominal rotational frequency	N
F^*	Characteristic value of load carrying capacity	1
F_{st}	Bearing force (load) at standstill	N
h	Local lubricant film thickness (clearance gap height)	m
h_{lim}	Minimum permissible lubricant film thickness during operation	m
$h_{lim,tr}$	Minimum permissible lubricant film thickness on transition into mixed lubrication	m
h_{min}	Minimum lubricant film thickness (minimum clearance gap height)	m
k	Heat transfer coefficient related to the product $B \times L \times Z$	$W/(m^2 \cdot K)$
k_A	External heat transfer coefficient (reference surface A)	$W/(m^2 \cdot K)$
L	Length of one pad in circumferential direction	m
M	Mixing factor	1
N	Rotational frequency (speed) of thrust collar	s^{-1}
p	Local lubricant film pressure	Pa

Table 1 (*continued*)

Symbol	Term	Unit
$\overline{p}$	Specific bearing load $\overline{p} = F/(B \times L \times Z)$	Pa
$\overline{p}_{lim}$	Maximum permissible specific bearing load	Pa
P_f	Frictional power in the bearing or power generated heat flow rate	W
$P_{th,amb}$	Heat flow rate to the environment	W
$P_{th,L}$	Heat flow rate in the lubricant	W
Q	Lubricant flow rate	m^3/s
Q^*	Characteristic value of lubricant flow rate	1
Q_0	Relative lubricant flow rate $Q_0 = B \times h_{min} \times U \times Z$	m^3/s
Q_1	Lubricant flow rate at the inlet of the clearance gap (circumferential direction)	m^3/s
Q_1^*	Characteristic value of lubricant flow rate at the inlet of the clearance gap	1
Q_2	Lubricant flow rate at the outlet of the clearance gap (circumferential direction)	m^3/s
Q_2^*	Characteristic value of lubricant flow rate $Q_1^* - Q_3^*$ at the outlet of the clearance gap	1
Q_3	Lubricant flow rate at the sides (perpendicular to circumferential direction)	m^3/s
Q_3^*	Characteristic value of lubricant flow rate at the sides	1
Rz	Average peak-to-valley height of thrust collar	µm
Re	Reynolds' number	1
T_{amb}	Ambient temperature	°C
T_B	Bearing temperature	°C
T_{eff}	Effective lubricant film temperature	°C
T_{en}	Lubricant temperature at the inlet of the bearing	°C
T_{ex}	Lubricant temperature at the outlet of the bearing	°C
T_{lim}	Maximum permissible bearing temperature	°C
T_1	Lubricant temperature at the inlet of the clearance gap	°C
T_2	Lubricant temperature at the outlet of the clearance gap	°C
U	Sliding velocity relative to mean diameter of bearing ring	m/s
w_{amb}	Velocity of air surrounding the bearing housing	m/s
x	Coordinate in direction of motion (circumferential direction)	m
y	Coordinate in direction of lubrication clearance gap (axial)	m
z	Coordinate perpendicular to the direction of motion (radial)	m
Z	Number of tilting-pads	1
η	Dynamic viscosity of the lubricant	Pa·s
η_{eff}	Effective dynamic viscosity of the lubricant	Pa·s
ρ	Density of the lubricant	kg/m^3



Key

1 Thrust collar

2 Tilting-pad

3 Centre of pressure (supporting surface)

Figure 1 — Schematic view of a tilting-pad thrust bearing

5 Calculation procedure

5.1 Loading operations

5.1.1 General

Calculation means the mathematical determination of the correct functioning using operational parameters (see Figure 2) which has to be compared with guide values. Thereby, the operational parameters determined under varying operation conditions shall be permissible as compared to the guide values. For this purpose, all continuous operating conditions shall be investigated.

5.1.2 Wear

Safety against wear is assured if complete separation of the mating bearing parts is achieved by the lubricant. Continuous operation in the mixed lubrication range results in early loss of functioning. Short-time operation in the mixed lubrication range, such as starting up and running down machines with plain bearings, is unavoidable and can result in bearing damage after frequent occurence. When subjected to heavy loads, an auxiliary hydrostatic arrangement may be necessary for starting up or running down at low speed. Running-in and adaptive wear to compensate for surface geometry deviations from ideal geometry are permissible as long as these are limited in time and locality and occur without overloading effects. In certain cases, a specific running-in procedure may be beneficial. This can also be influenced by the selection of the material.

5.1.3 Mechanical loading

The limits of mechanical loading are given by the strength of the bearing material. Slight permanent deformations are permissible as long as these do not impair correct functioning of the plain bearing.

5.1.4 Thermal loading

The limits of thermal loading result not only from the thermal stability of the bearing material but also from the viscosity-temperature relationship and the ageing tendency of the lubricant.

5.1.5 Outside influences

Calculation of correct functioning of plain bearings presupposes that the operating conditions are known for all cases of continuous operation. In practice however, additional disturbing influences frequently occur which are unknown at the design stage and cannot always be computed. Therefore, the application of an appropriate safety margin between the operational parameters and the permissible guide values is recommended. Disturbing influences are, e.g.

- spurious forces (out-of-balance, vibrations, etc.);
- deviations from ideal geometry (machining tolerances, deviations during assembly, etc.);
- lubricants contaminated by solid, liquid and gaseous foreign materials;
- corrosion, electric erosion, etc.

Information as to further influence factors is given in 5.9.

The applicability of this part of ISO 12130, for which laminar flow in the lubrication clearance gap is a necessary condition, shall be checked using the Reynolds' number:

$$Re = \frac{\rho \times U \times h_{\text{min}}}{\eta_{\text{eff}}} \leqslant Re_{\text{cr}} \tag{2}$$

For wedge-shaped gaps with h_{min}/C_{wed} = 0,8 a critical Reynolds' number of Re_{cr} = 600 can be assumed as guide value according to [4].

The plain bearing calculation comprises, starting from the known bearing dimensions and operating data:

— the relationship between load-carrying capacity and lubricant film thickness;

— the frictional power;

— the lubricant flow rate;

— the heat balance;

these all being interdependent. The solution is obtained using an iterative method, the sequence of which is summarized in the calculation flow chart in Figure 2.

For optimization of individual parameters, parameter variation can be performed; and modification of the calculation sequence is possible.

5.2 Coordinate of centre of pressure

In the case of tilting pads, the x-coordinate of the centre of pressure a_F corresponds with the x-coordinate of the axis of tilt. The x-coordinate of the centre of pressure $a_F^* = a_F / L$ related to the length of the sliding block is a function of the relative minimum lubricant film thickness h_{min}/C_{wed} and the relative width of sliding block B/L. ISO 12130-2 represents $a_F^* = f\,(h_{min}/C_{wed};\ B/L)$. An approximate function is also given there.

It is essential for the calculation that the relative minimum lubricant film thickness h_{min}/C_{wed} as well as the characteristic values of load-carrying capacity, frictional power and lubricant flow rate are specified by the selection of the supporting point a_F and that these values remain unchanged even under alternating operating conditions.

5.3 Load-carrying capacity

The parameter for the load-carrying capacity is the dimensionless characteristic value of load-carrying capacity F^*:

$$F^* = \frac{F \times h_{min}^2}{U \times \eta_{eff} \times L^2 \times B \times Z} \qquad (3)$$

The function $F^* = f(h_{min}/C_{wed};\ B/L)$ is presented in ISO 12130-2 on the basis of [5]. An approximate function is also given there.

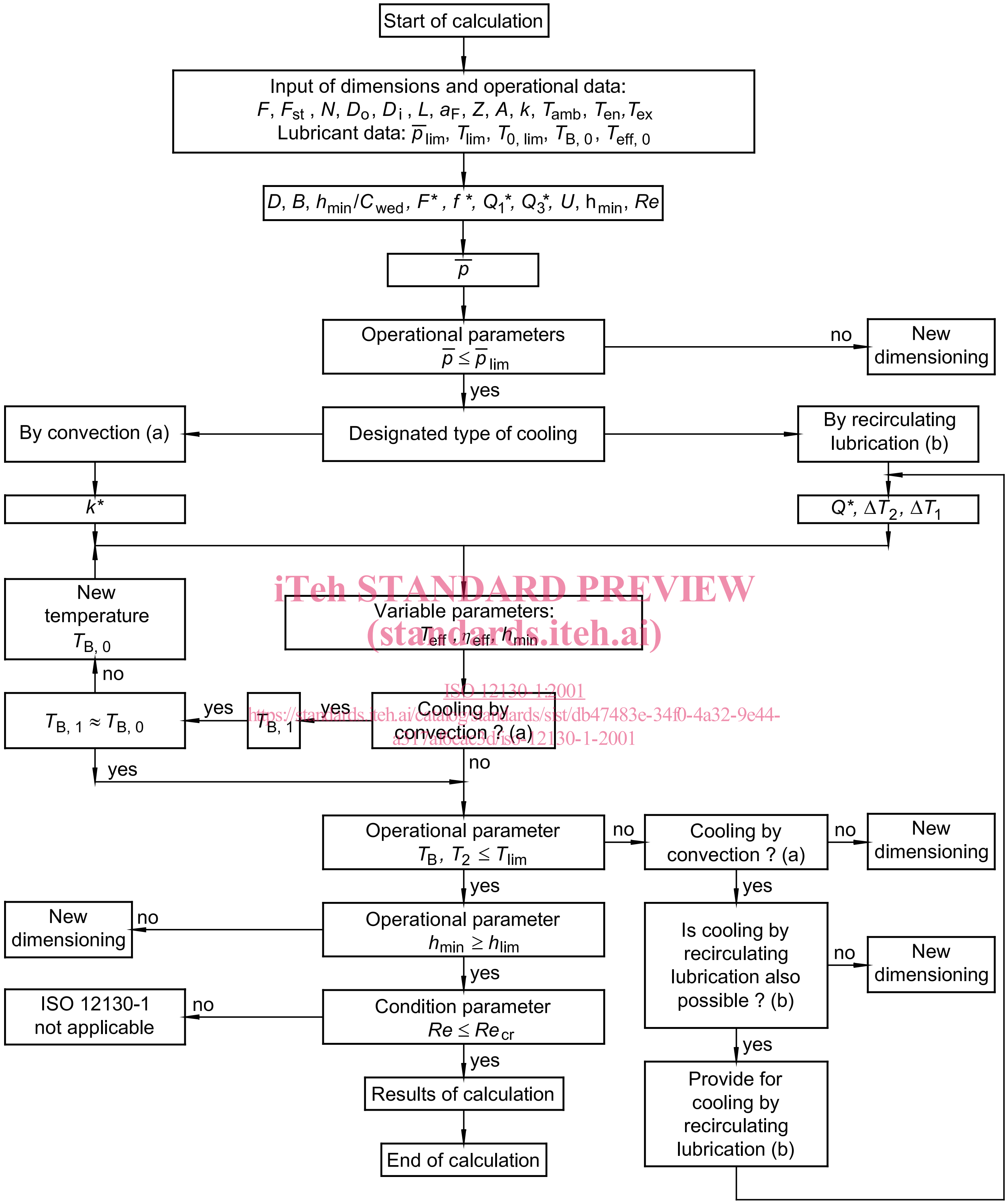


Figure 2 — Scheme of calculation (flow chart)