

CALCULATION METHODS FOR EXTERNALLY PRESSURISED (HYDROSTATIC) JOURNAL BEARINGS WITH CAPILLARY RESTRICTOR CONTROL

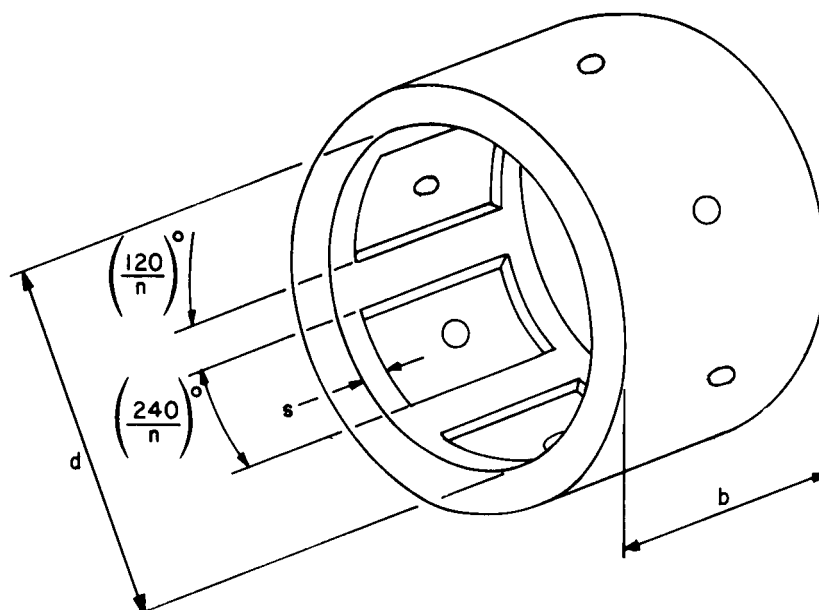
1. NOTATION AND UNITS

The International System of units is given in this Item. Any other coherent system of units may also be used.

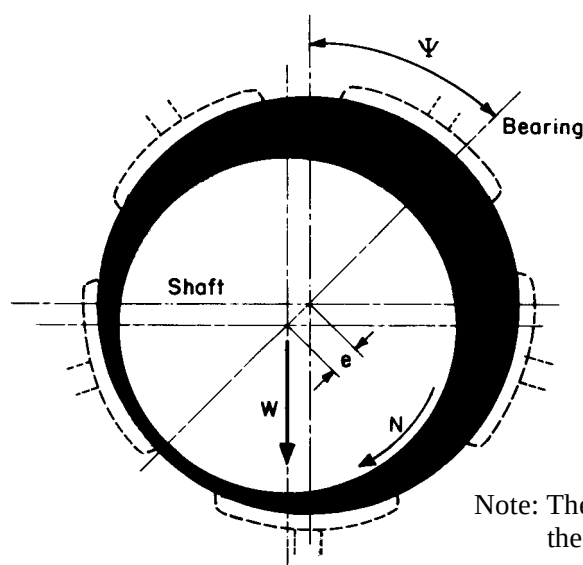
b	bearing width (see Sketch 1.1)	m
C	specific heat capacity of lubricant	J/kg K
c_d	diametral clearance	m
d	bearing diameter (see Sketch 1.1)	m
d_r	capillary restrictor bore diameter	m
e	eccentricity (see Sketch 1.2)	m
e_s	specified permissible journal displacement under load	m
H_f	frictional power loss	W
H_f'	non-dimensional frictional power loss = $\frac{H_f c_d (1 - \epsilon^2)^{1/2}}{\eta_b N^2 b d^3}$	
H_p	pumping power	W
H_t	total power loss	W
K'	non-dimensional stiffness factor = $\frac{W}{p_s b d} \left(\frac{c_d}{e} \right)$	
K_0'	non-dimensional stiffness factor for $N = 0$.	
L	length of a capillary restrictor	m
M	rotor mass associated with one bearing	kg
n	number of recesses	
N	rotational speed	rev/s
N_f	speed factor = $\frac{\eta_b N d^2}{p_s c_d^2}$	
N_{crit}	critical speed	rev/s
p_s	lubricant supply pressure	N/m ²

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Q	lubricant flow rate	m^3/s
Re	bearing Reynolds number = $\frac{\pi d N c_d \rho}{2 \eta_b}$	
Re_r	capillary Reynolds number = $\frac{4 \rho Q}{\pi d_r \eta_s n}$	
s	side-sill width (see Sketch 1.1)	m
T_b	lubricant temperature at bearing	$^{\circ}\text{C}$
T_s	lubricant supply temperature	$^{\circ}\text{C}$
W	applied load	N
z_0	flow resistance from a recess ($\epsilon = 0$)	N s/m^5
z_r	capillary restrictor flow resistance	N s/m^5
ϵ	eccentricity ratio	
η_b	lubricant dynamic viscosity at bearing temperature	N s/m^2
η_s	lubricant dynamic viscosity at supply temperature	N s/m^2
ρ	density of lubricant	kg/m^3
ψ	attitude angle (see Sketch 1.2)	deg
ψ_0	uncorrected attitude angle	deg



Sketch 1.1 Dimensions of bearing



Note: The attitude angle is zero when the bearing is stationary

Sketch 1.2 Eccentricity and attitude angle

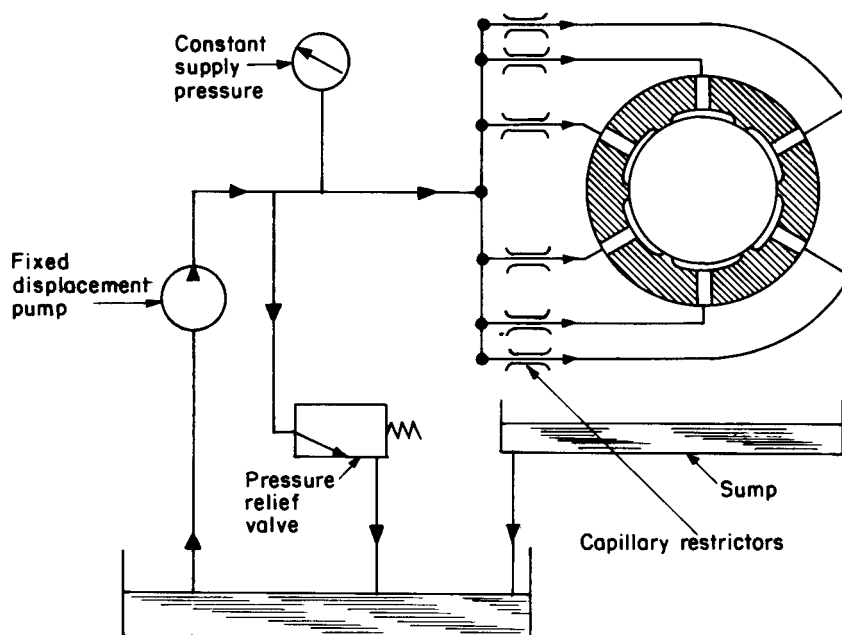
2. INTRODUCTION

This Item provides charts and calculation methods for the design and analysis of externally pressurised (hydrostatic) journal bearings. The charts and calculation methods apply to bearings having five identical equi-spaced rectangular recesses (or pockets) but can be applied without significant error to bearings with more than five recesses. The recesses are fed via identical capillary restrictors from a constant pressure supply. A capillary restrictor is convenient in that the flow resistance of associated restrictors can readily be matched by adjustment of restrictor tube length. This Item does not cover the use of orifices or any other forms of restrictors. The bearings are considered to be steadily loaded, but bearings with slowly varying loads and speeds may also be analysed. For a bearing with five (or more) recesses the variation of performance with load direction is negligible.

This Item is divided into three main sections. In the first of these sections a basic specification for the bearing is drawn-up. Guidance is given on assigning preliminary values to some of the bearing parameters to ensure an adequate, but not necessarily optimal, design. In the second of these sections the performance of the bearing is predicted. Finally, limiting criteria are given to allow the adequacy of the bearing design to be assessed.

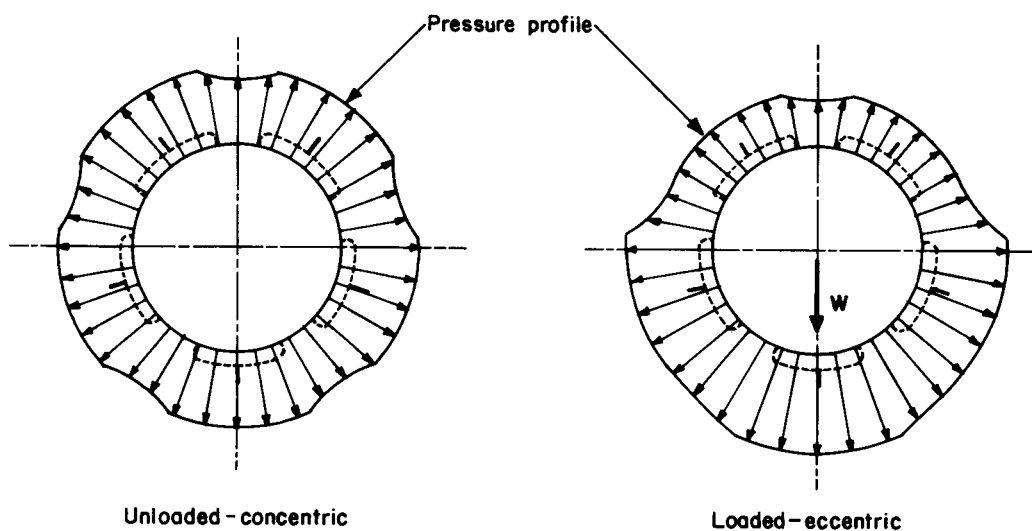
2.1 Description of Bearing

The operation of a hydrostatic bearing depends upon the maintenance of a supply of liquid lubricant to each of the recesses from a common source at suitable pressure. A typical lubricant supply system is shown in Sketch 2.1.



Sketch 2.1 Typical hydraulic circuit

The flow restrictor in the supply line to each recess is essential to enable a hydrostatic bearing to support an external load. Typically, the flow resistance of the restrictors would be chosen so that approximately one half of the total pressure drop from the supply to the drain occurs in the restrictors. An external load applied to the journal causes a displacement of the journal from its concentric position. The reduction in film thickness on the loaded side of the bearing increases the flow resistance for lubricant escaping from the recesses on that side of the bearing. The flow resistance of the capillary restrictors in the supply lines to those recesses, however, remains constant and consequently the pressure in the recesses on the loaded side of the bearing increases (the pressure on the unloaded side decreases). Displacement of the journal thus results in a readjustment of the pressure in the various recesses and a net hydrostatic force to balance the external load as shown in Sketch 2.2.



Sketch 2.2 Lubricant pressure profiles

Unlike hydrodynamic bearings, hydrostatic bearings do not depend upon journal rotation to establish fluid film operation. Herein lies the special merit of hydrostatic bearings in that they provide zero friction support for a non-rotating journal. A further merit is the controlled stiffness available for both rotating and non-rotating journals. The film stiffness is proportional to the supply pressure and for high stiffness it is necessary to use a high pressure pump to supply the lubricant.

Whilst hydrostatic bearings do not depend upon journal rotation for their load carrying capability, rotation does affect the distribution of pressure in the bearing and causes the eccentricity to be at an angle (attitude angle) to the line of the applied load (see Notation).

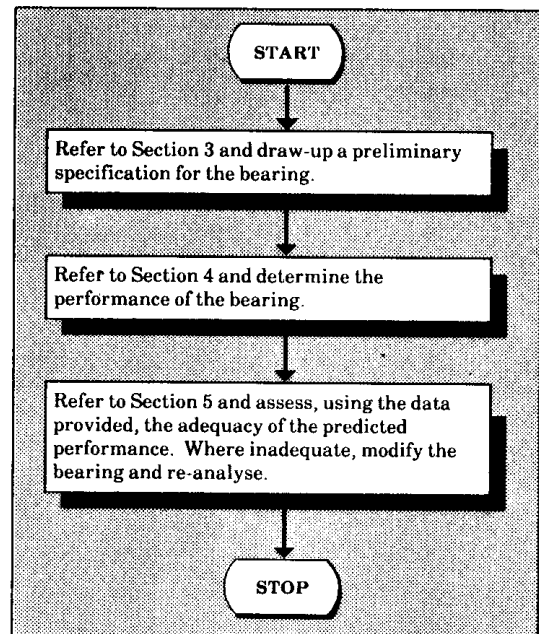
2.2 Guide to the Use of This Item

In order to use this Data Item to design a hydrostatic journal bearing you should have available the following information.

- (i) The intended operating speed and load. The permissible eccentricity under load will also be required.
- (ii) The shaft size, which may be preliminary at this stage.
- (iii) The viscosity/temperature characteristics of the lubricant (where the lubricant has been predetermined) and, if known, the supply temperature.

In order then to assess the adequacy of the design some additional information may be required.

The procedure is illustrated in Sketch 2.3.

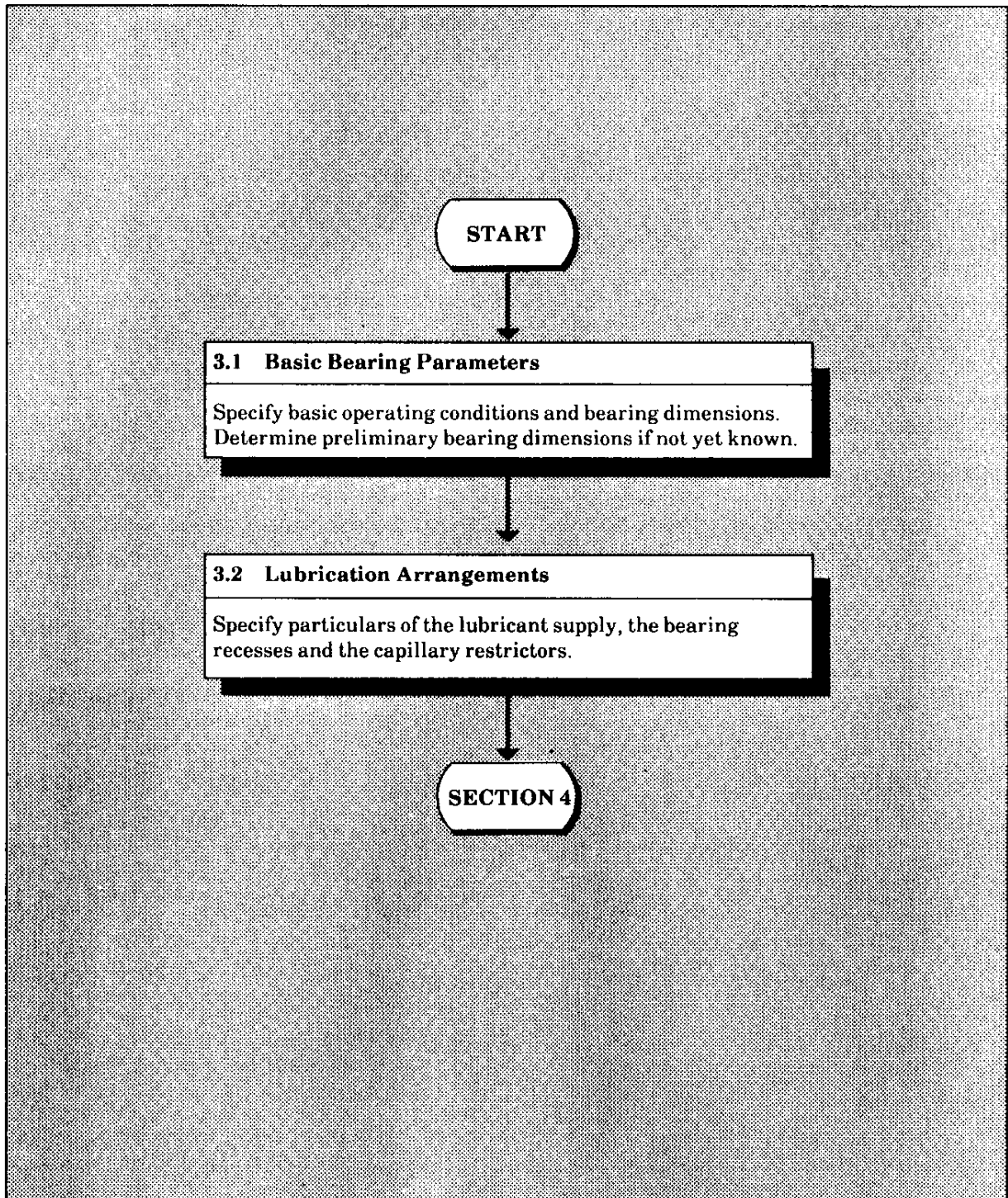


Sketch 2.3 Design process

Worked examples illustrating the use of this Item are in Section 6.

3. SPECIFICATION OF DESIGN REQUIREMENTS

In this section a specification is drawn-up for the bearing to be analysed. Where the bearing has not yet been designed, preliminary values are assigned to the basic bearing parameters which may later be revised. The procedure is summarised in Sketch 3.1.



Sketch 3.1 Design requirements

3.1 Basic Bearing Parameters

A flowchart that summarises the calculation procedure for this part of the design process is given in Sketch 3.2.

- **Load and speed**

The load, W , and the frequency of rotation, N , must be specified assuming steady loading and a constant rotational speed. Usually the bearing will be required to operate over a range of speeds in which case the performance should be investigated at both extremes of the range.

- **Bearing diameter and clearance**

The journal diameter, d , is usually predetermined by considerations of shaft strength or rigidity.

The bearing clearance under running conditions is important for the satisfactory operation of the bearing. Large values of clearance can mean excessive lubricant flow rates and associated large pumping losses. Usually the clearance should be as small as is practicable with regard to manufacturing tolerances. However, high speed bearings may require a more generous clearance to avoid excessive operating temperatures.

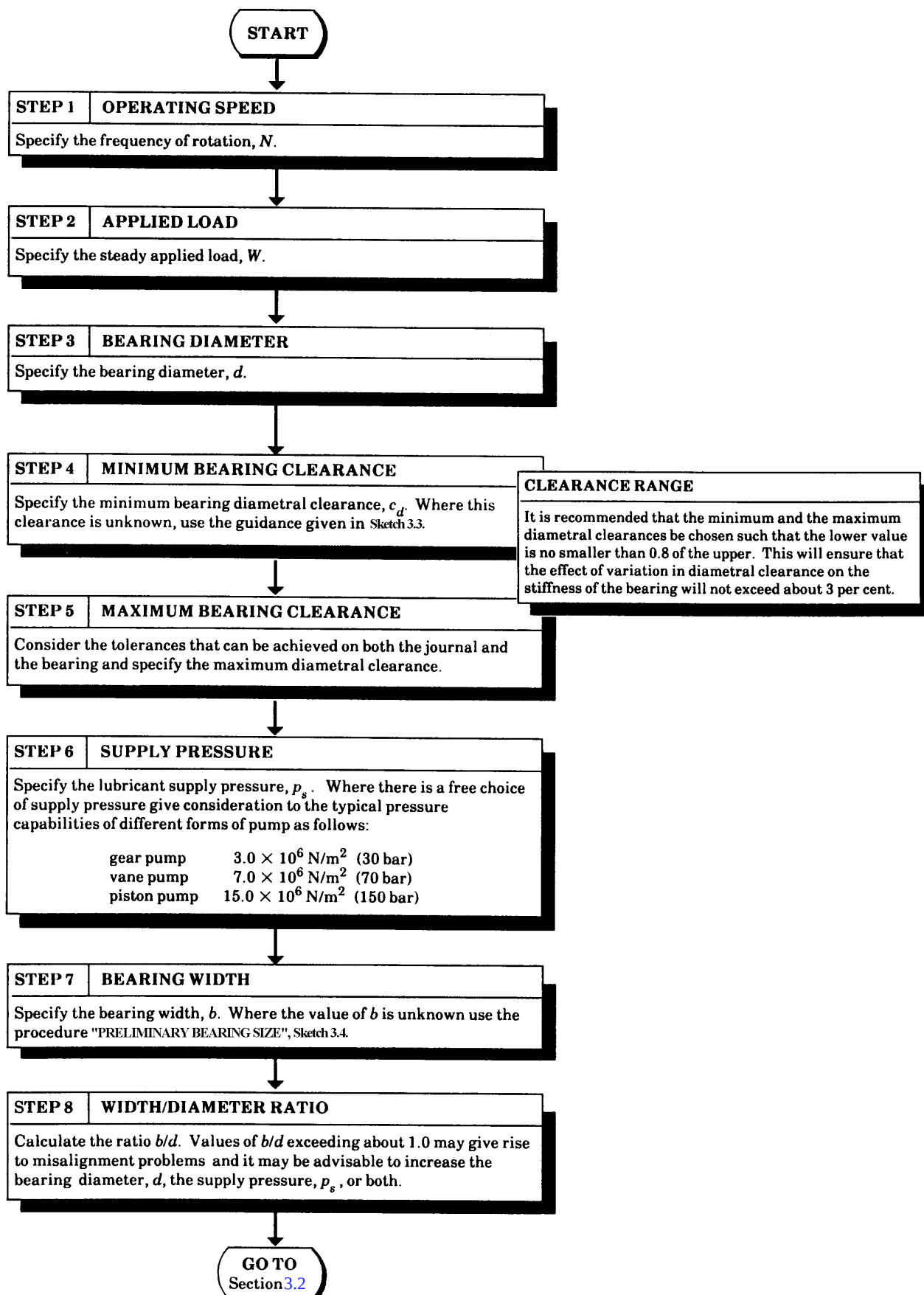
The minimum and maximum running clearances must both be specified. The performance of the bearing must then be analysed for both extremes. Guidance on choosing preliminary values for the minimum and the maximum diametral clearance is given Sketches 3.2 and 3.3.

- **Lubricant supply pressure**

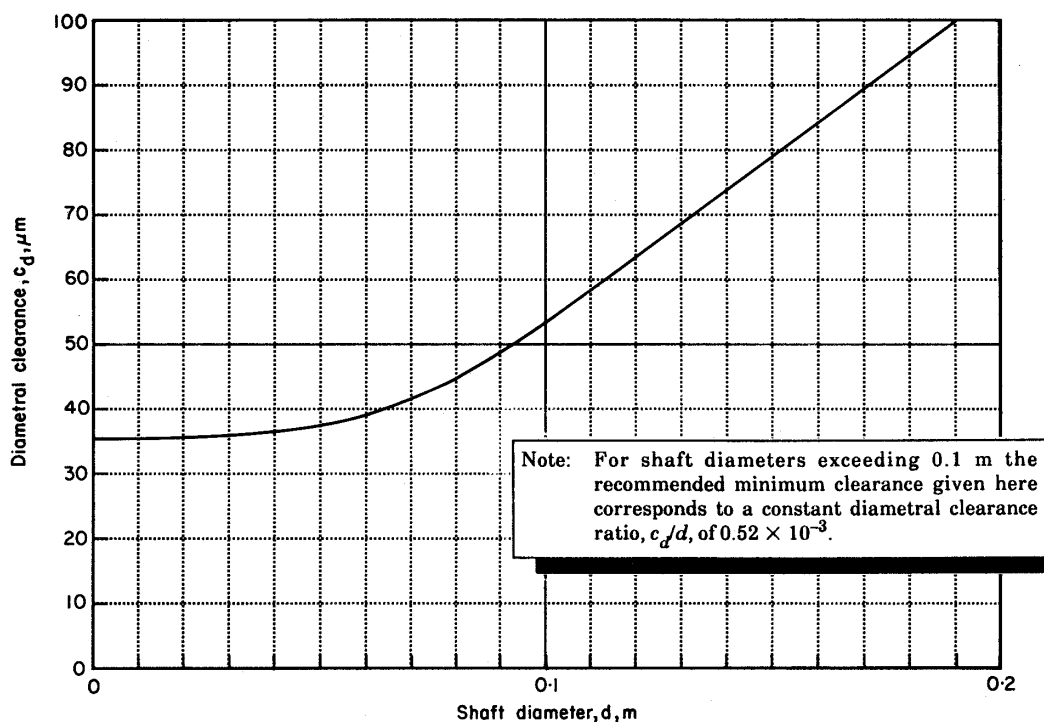
The lubricant supply pressure, p_s , may need to be specified to suit the requirements of other hydrostatic bearings or of hydraulically actuated components. Where there is a free choice of supply pressure, consideration should be given to the higher capital cost of high pressure supply systems.

- **Bearing width**

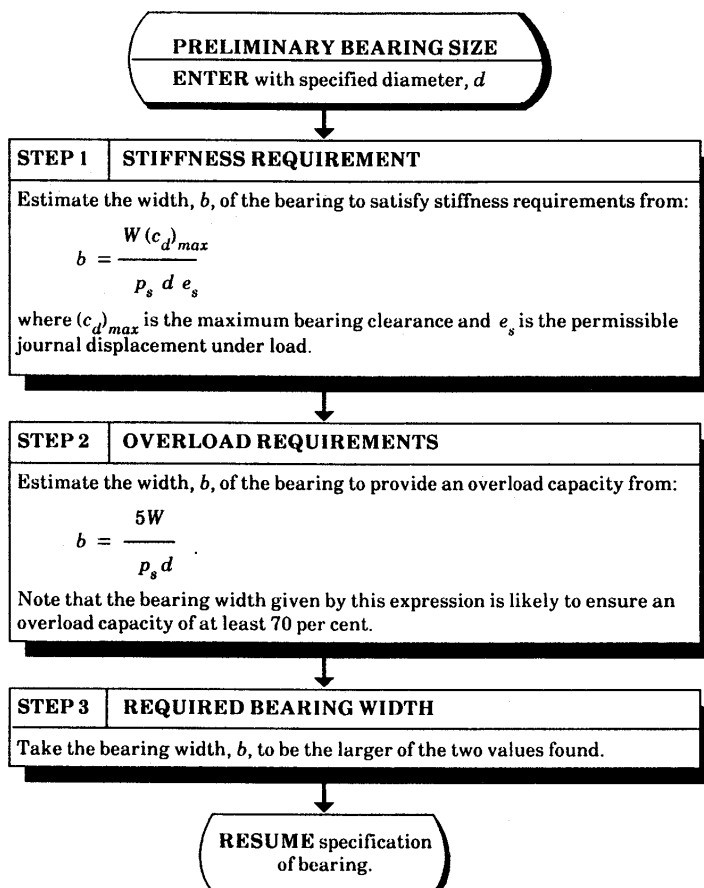
The overall bearing width is determined by the need to provide an overload capacity and to provide adequate stiffness. A procedure for estimating the required bearing width where this is not known is given in Sketch 3.4.



Sketch 3.2 Basic bearing parameters



Sketch 3.3 Recommended minimum diametral clearance on assembly
(At extreme of manufacturing tolerance range)



Sketch 3.4 Preliminary bearing size

3.2 Lubrication Arrangements

Sketch 3.5 provides a flowchart that summarises the lubrication arrangements of the bearing.

- **Lubricant grade**

The lubricant may need to be specified to suit the requirements of another component. Where the designer has a free choice of lubricant, the rotational speed is the primary deciding factor. For a stationary bearing, a high viscosity lubricant will reduce the required flow rate and the associated lubricant pumping power. For a high speed bearing, a low viscosity lubricant will reduce the bearing temperature rise.

- **Supply temperature**

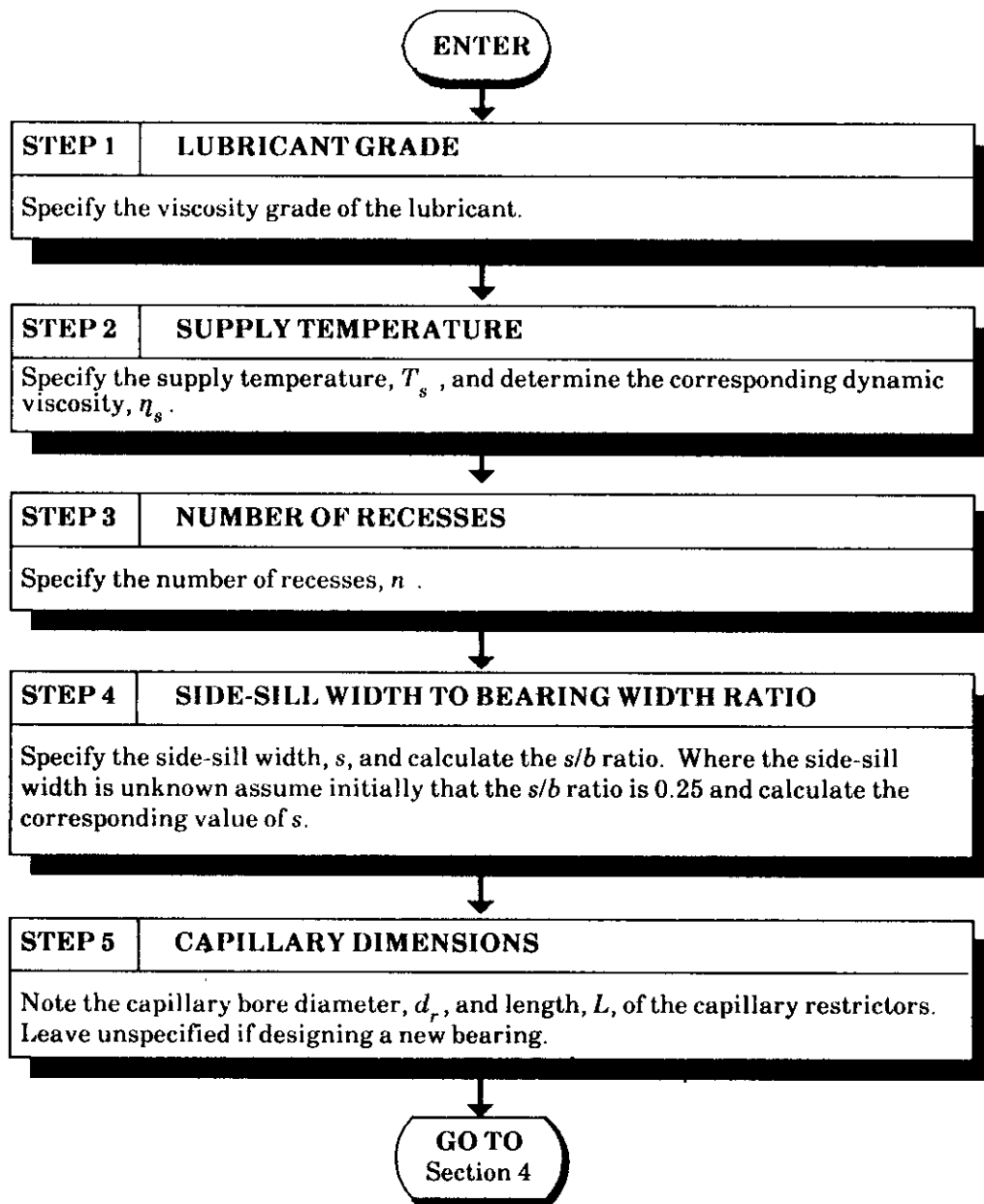
For the purpose of analysing the performance of the bearing it is necessary to assume a value for the temperature of the lubricant supplied to the bearing, T_s , since this is the datum used in calculating temperature rise. Typically, T_s would be about 40 °C.

- **Recess/pocket dimensions**

The data presented in this Item can be applied to bearings having 5 or more pockets that occupy 2/3 of the circumference of the bearing. For example, if the bearing were to have 5 pockets then each pocket would extend 48° circumferentially. It is recommended that the pockets extend $b/2$ axially (giving a side-sill to bearing width ratio, s/b , of 0.25) but narrower side-sills (down to a s/b ratio of 0.15) may be considered for high speed bearings to reduce the bearing temperature by allowing a greater oil flow through the bearing. The depth of the pockets should be about $20c_d$.

- **Capillary restrictor dimensions**

The bore diameter, d_r , and length, L , are usually chosen so that the flow resistance of the restrictors, z_r , is approximately equal to the flow resistance from a recess, z_0 , and the analysis method of this Item requires that the ratio, z_r/z_0 , be within the range 0.5 to 1.5 (see Section 4). Therefore, it may not be possible to analyse certain existing designs in which this criterion has not been met. When designing a new bearing, however, the capillary dimensions are determined after analysing the performance using the method in Section 4.



Sketch 3.5 Lubrication arrangements

4. PERFORMANCE ANALYSIS

This section gives guidance on predicting the performance of the bearing. The performance should be analysed for both the maximum and the minimum diametral clearance cases. The overall strategy to adopt depends on whether the dimensions of the capillary restrictors are known or unknown. When the capillary dimensions are known, the capillary flow resistance, z_r , that is to be used in the analysis can be calculated directly. When designing a new bearing, however, the dimensions of the capillary restrictors are unknown and it is necessary to establish the value of flow resistance that is required for the satisfactory operation of the bearing. It is recommended that this required capillary flow resistance be established for the maximum diametral clearance case. The two strategies are summarised in Table 4.1.

TABLE 4.1 STRATEGIES FOR PERFORMANCE ANALYSIS OF BEARING

CAPILLARY DIMENSIONS KNOWN	CAPILLARY DIMENSIONS UNKNOWN
1. Calculate the capillary restrictor flow resistance from $z_r = \frac{128 \eta_s L}{\pi d_r^4}$	1. Note that the capillary restrictor flow resistance, z_r , is at this stage unknown.
2. Analyse the performance of the bearing for the maximum diametral clearance case using the value of z_r calculated in Step 1.	2. Analyse the performance of the bearing for the maximum diametral clearance case. The value of z_r to assume is indicated at the appropriate point in the procedure.
3. Analyse the performance of the bearing for the minimum diametral clearance case using the value of z_r calculated in Step 1.	3. Analyse the performance of the bearing for the minimum diametral clearance case using the value of z_r established in Step 2.
4. Consider the performance criteria in Section 5.	4. Consider the performance criteria in Section 5 and choose suitable dimensions, d_r and L , for the capillary restrictors.

The data presented in this Item apply strictly to bearing designs in which the total resistance to lubricant flow through the bearing is apportioned equally between the capillary restrictors and the bearing itself. However, the performance analysis procedure can be used without significant error for ratios of z_r/z_0 within the range 0.5 to 1.5 (the point at which this ratio should be monitored is indicated in the procedure).