

DESIGNING WITH ROLLING BEARINGS. PART 2: SELECTION OF SINGLE ROW ANGULAR CONTACT BALL, TAPERED ROLLER AND SPHERICAL ROLLER BEARINGS

1. INTRODUCTION

This Item is the second of three Engineering Sciences Data Items (see References 1 & 2 for Parts 1 and 3) dealing with design considerations in rolling bearing selection. The Item is intended to assist designers in those applications where single row radial ball or single row cylindrical roller bearings are unsuitable (see Part 1, Reference 1).

This Item considers single row angular contact and four point (duplex) ball bearings, single and double row tapered roller bearings and spherical roller bearings (double row). Adjacent pairs of single row angular contact ball bearings and bearing units consisting of a four point (duplex) ball bearing and a cylindrical roller bearing mounted adjacent to each other are also considered. The Item provides a general procedure for selection of the correct type and size of bearings and the most appropriate arrangement of the bearings. The procedure includes flow charts for selection of bearing type and size, and data input tables and calculations sheets for specifying the design requirements and recording the results of the calculations involved.

Further sections of the Item give more detailed information on specific topics of the selection and use of rolling bearings; points at which the user may wish to refer to these sections are indicated. In particular, information is included in the text on the selection of compact bearings, the avoidance of tribological problems and bearing setting and pre-loading. In addition a comprehensive set of charts is presented for selecting suitable bearing dimensions.

Appendices describe examples of typical bearing arrangements and include equations and charts for the calculation of bearing loads and guidance on the choice of contact angle in opposed pair bearing arrangements.

Manufacturers' information, where appropriate, may have to be used to allow the bearing arrangement design to be finalised; points at which the user may have to refer to additional information are indicated.

2. GUIDE TO USE OF THIS ITEM

This Item is intended to be used in conjunction with Part I when it has not been possible to arrive at a satisfactory solution using only the information contained in Part 1.

Experience has shown that traditional methods of selection often lead to unnecessarily complex arrangements. The incorporation of rolling bearings should be considered at an early stage of the machine design process. The first step is to decide what type of bearing arrangement should be adopted. Wherever possible a bearing arrangement consisting of a locating bearing at one end of the shaft and a bearing which allows axial movement at the other end (a locating/non-locating bearing arrangement) should be adopted. The commonly used alternative arrangement consists of an opposed pair of bearings. Table 2.1 lists the main features of the two most commonly used types of arrangement while Appendix A describes in more detail the bearing arrangements used in some typical applications. Further guidance regarding the choice of bearing arrangement is given in Appendix A of Part 1.

Once the bearing arrangement has been chosen, the most appropriate type and size of each bearing in the arrangement has to be selected. The types of rolling bearings considered are described in Section 4 and this Item deals comprehensively with their selection for various applications. **However, only certain parts of this Item will need to be referred to for a particular application.** Selection flow charts (Tables 2.2, 2.4 and 2.6) have been provided which guide the designer to the appropriate sections of the Item. Tables 2.2 and 2.4 are flow charts for the selection of the bearing of a locating/non-locating bearing arrangement while Table 2.6 is a flow chart for the selection of the bearings of an opposed pair arrangement. If a locating/non-locating bearing arrangement has been chosen, the procedure of Table 2.2 should first be followed. If an opposed pair bearing arrangement has been chosen, the procedure of Table 2.6 should be followed.

When following the procedure of any one of the flow charts, the designer is called upon to perform certain calculations. Tables 2.3, 2.5 and 2.7 are calculation sheets which summarize the calculations involved and may be used to record the results of the calculations. The calculation sheets also indicate those sections of the Item where more detailed information on each stage of the calculations may be found.

TABLE 2.1
Main features of the two most commonly used types of bearing arrangement

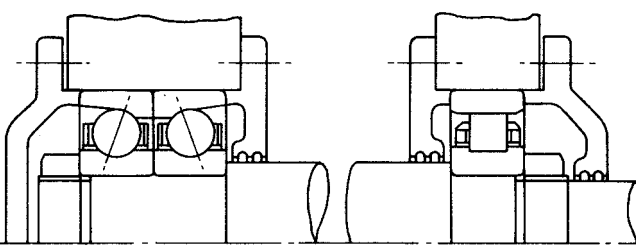
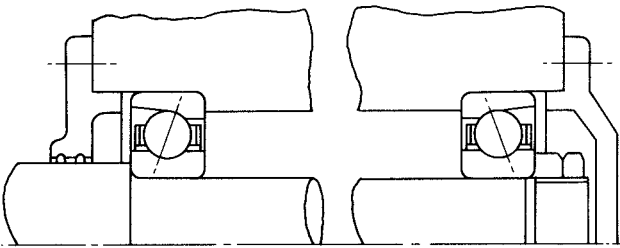
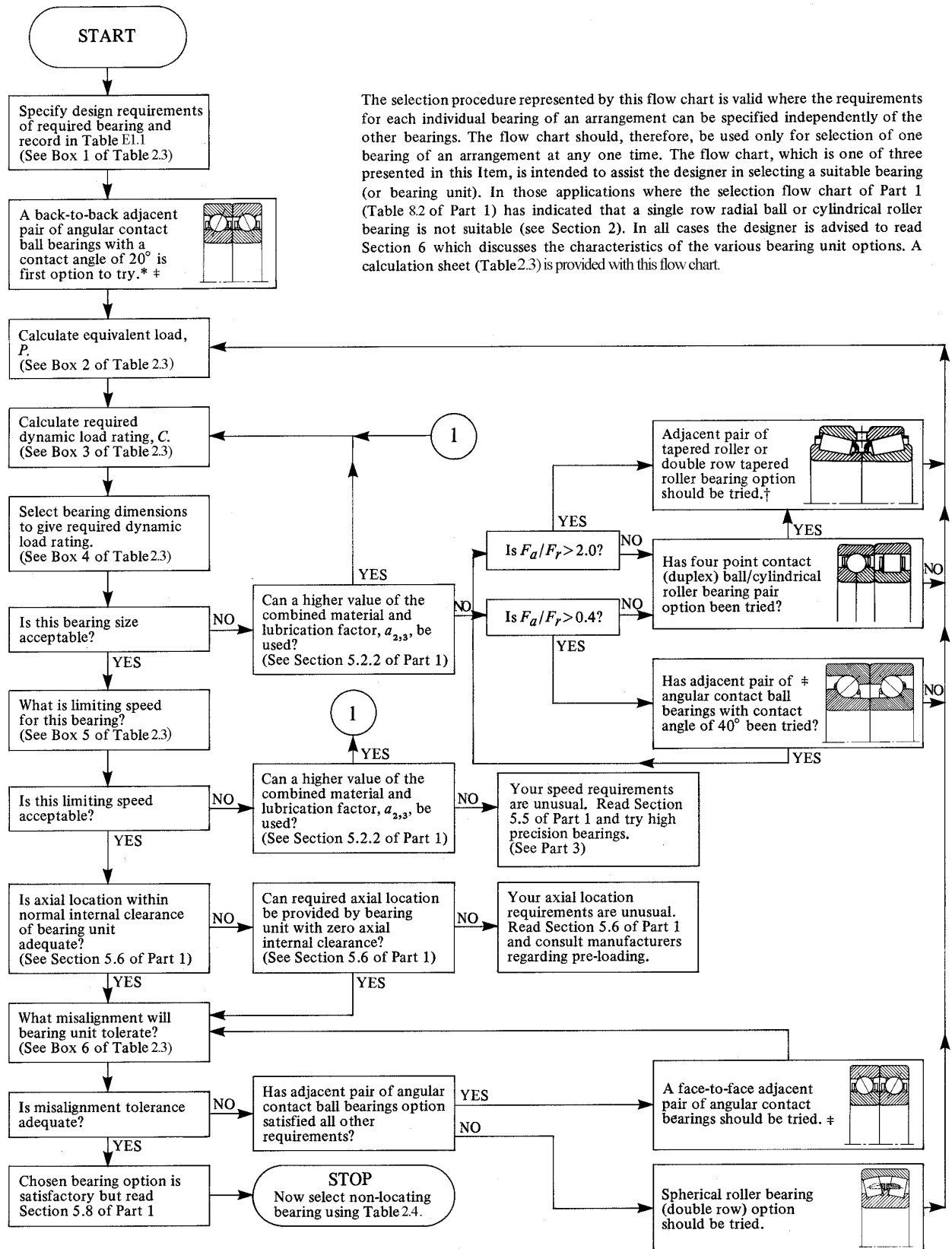
<i>Locating/non-locating arrangement</i>		<i>Opposed pair arrangement</i>	
			
Locating bearing unit locates shaft axially and carries radial and axial loads	Non-locating bearing allows axial movement of shaft and carries radial loads only	One bearing prevents shaft movement and carries axial loads in one direction and carries radial loads	Other bearing prevents shaft movement and carries axial load in other direction and carries radial loads
Calculation of bearing loads usually straightforward Usually no axial adjustment of bearing units required Axial thermal expansion and axial deflection accommodated by non-locating bearing Usually possible to accommodate misalignment by correct choice of bearings Applicable to any shaft length		Calculation of bearing loads complicated by fact that each bearing reacts loads onto opposing bearing Provision of axial adjustment of bearings required Careful consideration must be given to axial thermal expansion and axial deflection Accommodation of misalignment can be a problem Most frequently used on short shafts where misalignment and thermal expansion can be held to a minimum	

TABLE 2.2 Flow Chart for Selection of Locating Bearing Unit



* Back-to-back adjacent pairs provide a higher degree of resistance against tilting moments than face-to-face adjacent pairs and may prove easier to lubricate.

In certain applications, where the axial load is unidirectional, it is possible to use a single row angular contact ball or tapered roller bearing for locating the shaft. However, the designer should ensure that there is absolutely no possibility of the axial load reversing, even momentarily.

† When trying double row tapered roller bearings, select shallow angle bearings ($e \approx 0.35$) when $F_a/F_r < 0.4$. When $F_a/F_r > 0.4$ higher contact angle bearings may provide more compact installations (see Section 6.2).

‡ Double row angular contact ball bearings may be used where a very compact bearing is required (see Part 3).

TABLE 2.3 Calculation Sheet for Selection of Locating Bearing Unit

This table may be used to record the results of the calculations involved in selecting a locating bearing unit using Table 2.2.

1. <i>Calculation of bearing loads:</i> Take specified bearing loads from the First Part of Table E1.1. Where the loads fluctuate or shock and dynamic loads are present take specified bearing loads from the Third Part of Table E1.1. For further guidance refer to Section 5.2.	<table border="1"> <tr> <td>F_r</td> <td>=</td> </tr> <tr> <td>F_a</td> <td>=</td> </tr> </table>	F_r	=	F_a	=						
F_r	=										
F_a	=										
2. <i>Calculation of equivalent dynamic load:</i> $P = XF_r + YF_a$ Values of the factors X and Y are given in Table 2.8 and depend on the type of bearing and the value of F_a/F_r. For further guidance refer to Section 7.1.	<table border="1"> <tr> <td>e</td> <td>=</td> </tr> <tr> <td>F_a/F_r</td> <td>=</td> </tr> <tr> <td>X</td> <td>=</td> </tr> <tr> <td>Y</td> <td>=</td> </tr> <tr> <td>P</td> <td>=</td> </tr> </table>	e	=	F_a/F_r	=	X	=	Y	=	P	=
e	=										
F_a/F_r	=										
X	=										
Y	=										
P	=										
3. <i>Calculation of required dynamic load rating:</i> Take specified value of L_{10} from the First Part of Table E1.1. Where more compact bearings are required take specified value of L_{10} from the Second Part of Table E1.1. $P/C = (L_{10})^{-1/x}$ (or find P/C from Figure 1 of Part 1) $C = P/(P/C)$ $C_{pair} = 1.6 \times C_{single}$ For further guidance refer to Section 7.2.	<table border="1"> <tr> <td>L_{10}</td> <td>=</td> </tr> <tr> <td>P/C</td> <td>=</td> </tr> <tr> <td>C</td> <td>=</td> </tr> </table>	L_{10}	=	P/C	=	C	=				
L_{10}	=										
P/C	=										
C	=										
4. <i>Selection of bearing dimensions:</i> Use bearing manufacturers' catalogues or Figures 1 to 10. For further guidance refer to Section 7.3.	<table border="1"> <tr> <td>d</td> <td>=</td> </tr> <tr> <td>D</td> <td>=</td> </tr> <tr> <td>B</td> <td>=</td> </tr> </table>	d	=	D	=	B	=				
d	=										
D	=										
B	=										
5. <i>Estimation of limiting speed:</i> Take limiting value of $\bar{d}n$ from Table 8.1 of Part 1. $\bar{d} = (d + D)/2$ $n_{limiting} = \bar{d}n/\bar{d}$ For further guidance refer to Section 8	<table border="1"> <tr> <td>$\bar{d}n$</td> <td>=</td> </tr> <tr> <td>$n_{limiting}$</td> <td>=</td> </tr> </table>	$\bar{d}n$	=	$n_{limiting}$	=						
$\bar{d}n$	=										
$n_{limiting}$	=										
6. <i>Estimation of misalignment tolerance:</i> Take maximum misalignment value from Table 8.1 of Part 1. For further guidance refer to Section 10 of this Item and Section 5.7 of Part 1	<table border="1"> <tr> <td>Maximum allowable misalignment</td> <td>=</td> </tr> </table>	Maximum allowable misalignment	=								
Maximum allowable misalignment	=										

TABLE 2.4 Flow Chart for Selection of Non-Locating Bearing

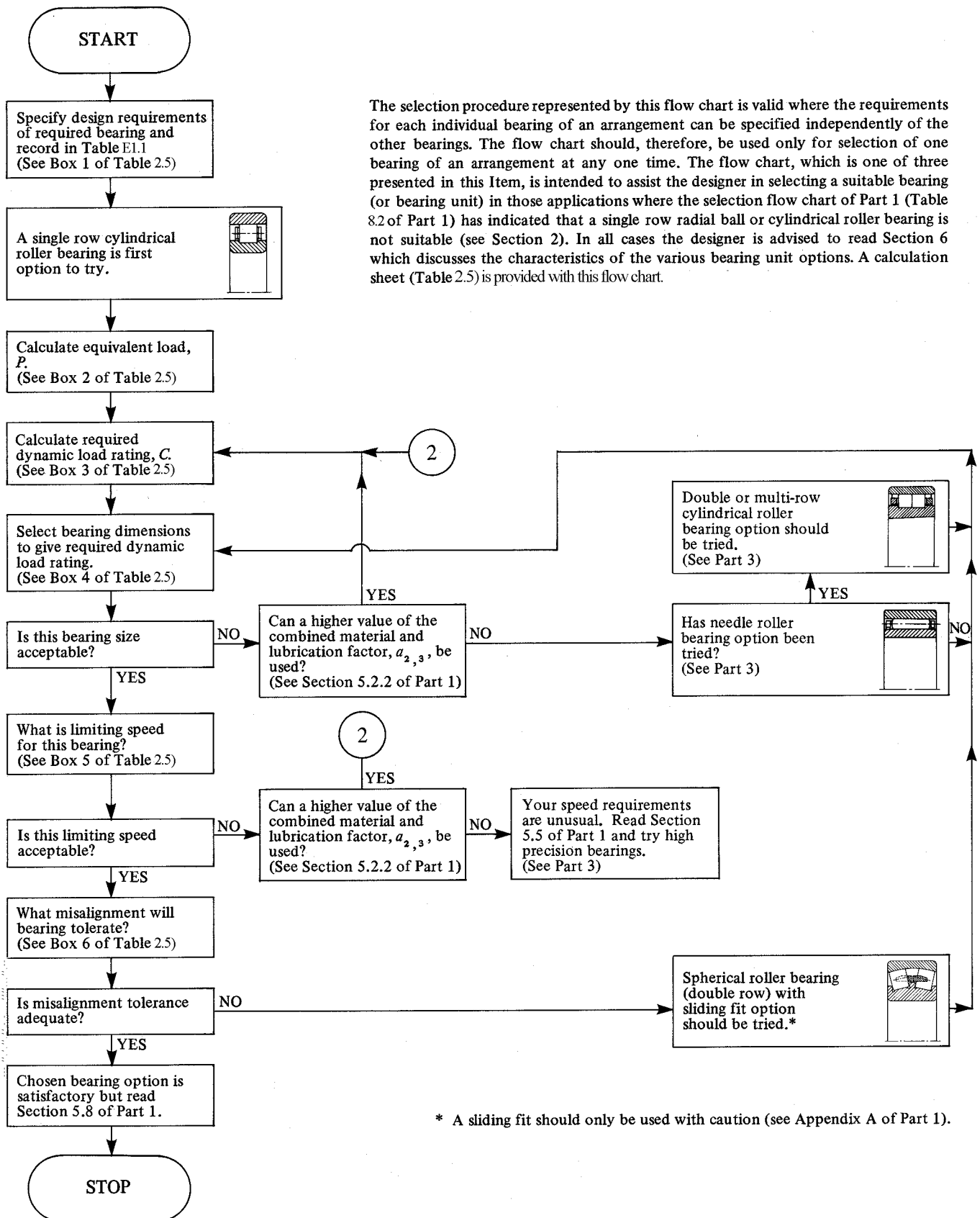


TABLE 2.5 Calculation Sheet for Selection of Non-Locating Bearing

This table may be used to record the results of the calculations involved in selecting a locating bearing unit using Table 2.4.

1. Calculation of bearing loads: Take specified bearing loads from the First Part of Table E1.1. Where the loads fluctuate or shock and dynamic loads are present take specified bearing loads from the Third Part of Table E1.1. (With cylindrical and needle roller bearings assume $F_a = 0$) For further guidance refer to Section 5.2.		$F_r =$ $F_a =$
2. Calculation of equivalent dynamic load: With cylindrical and needle roller bearings: $P = F_r \cdot (F_a = 0)$ With spherical roller bearings (double row) with a sliding fit axial loads may occur due to friction of sliding fit $P = XF_r + YF_a \cdot (F_a \neq 0)$ Values of the factors X and Y are given in Table 2.8. For further guidance refer to Section 7.1.		$e =$ (for spherical roller bearing [double row] only) $F_a/F_r =$ $X =$ $Y =$ $P =$
3. Calculation of required dynamic load rating: Take specified value of L_{10} from the First Part of Table E1.1. Where more compact bearings are required take specified value of L_{10} from the second Part of Table E1.1. $P/C = (L_{10})^{-1/x}$ (or find P/C from Figure 1 of Part 1) $C = P/(P/C)$ For further guidance refer to Section 7.2.		$L_{10} =$ $P/C =$ $C =$
4. Selection of bearing dimensions: Use bearing manufacturers' catalogues or Figures 1 to 10. For further guidance refer to Section 7.3.		$d =$ $D =$ $B =$
5. Estimation of Limiting speed: Take limiting value of $\bar{d}n$ from Table 8.1 of Part 1. $\bar{d} = (d + D)/2$ $n_{limiting} = \bar{d}n/\bar{d}$ For further guidance refer to Section 8.		$\bar{d}n =$ $n_{limiting} =$
6. Estimation of misalignment tolerance: Take maximum misalignment value from Table 8.1 of Part 1. For further guidance refer to Section 10 of this Item and Section 5.7 of Part 1		Maximum allowable misalignment =

TABLE 2.6 Flow Chart for Selection of Bearings of an Opposed Pair Arrangement

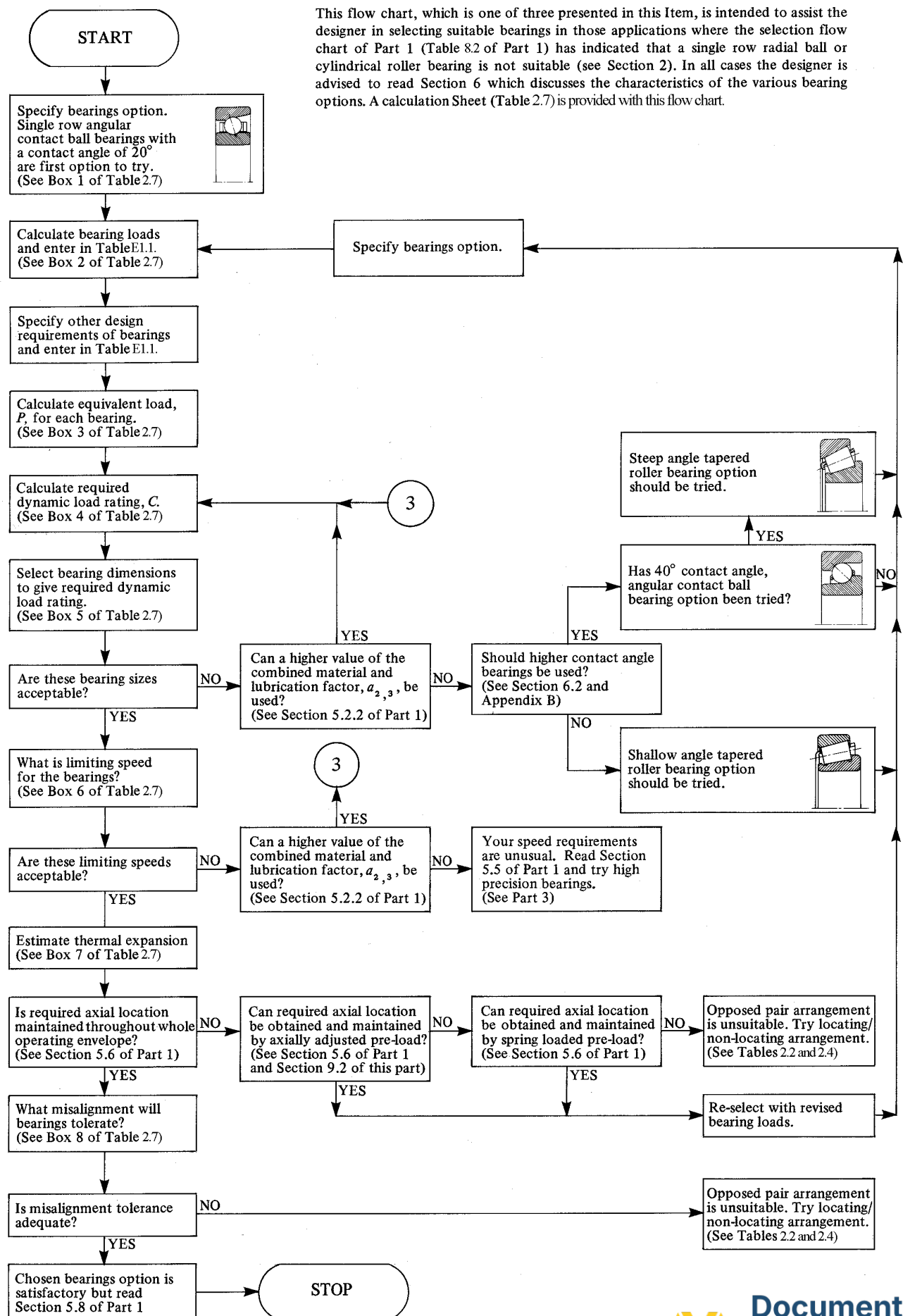


TABLE 2.7 Calculation Sheet for Selection of Bearings of an Opposed Pair Arrangement

This table may be used to record the results of the calculations involved in selecting the bearings of an opposed pair arrangement using Table 2.6.

1. <i>Specification of bearing option:</i> Take value of e for bearing option from bearing manufacturers' catalogues or from Table 2.8. For further guidance regarding choice between back-to-back and face-to-face refer to Appendix A. For further guidance regarding choice of contact angle refer to Appendix B.	<table border="1"> <tr> <td>e =</td> <td></td> </tr> <tr> <td>Face-to-face*</td> <td></td> </tr> <tr> <td>Back-to-back*</td> <td></td> </tr> <tr> <td>*Delete as appropriate</td> <td></td> </tr> </table>	e =		Face-to-face*		Back-to-back*		*Delete as appropriate								
e =																
Face-to-face*																
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*Delete as appropriate																
2. <i>Calculation of bearing load:</i> Calculate bearing radial loads by taking moments about the bearing centres. Find the bearing axial loads using Appendix C. For further guidance refer to Section 5.2.	<table border="1"> <tr> <th>Bearing No.</th> <th>1</th> <th>2</th> </tr> <tr> <td>F_r =</td> <td></td> <td></td> </tr> <tr> <td>F_a =</td> <td></td> <td></td> </tr> </table>	Bearing No.	1	2	F_r =			F_a =								
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Bearing No.	1	2														
$\bar{d}n$ =																
$n_{limiting}$ =																
7. <i>Estimation of thermal expansion:</i> Take specified temperatures from the Fourth part of Table E1.1. For further guidance refer to Section 9.	<table border="1"> <tr> <td>T_a =</td> <td></td> </tr> <tr> <td>T_s =</td> <td></td> </tr> <tr> <td>T_h =</td> <td></td> </tr> <tr> <td>Axial expansion =</td> <td></td> </tr> </table>	T_a =		T_s =		T_h =		Axial expansion =								
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8. <i>Estimation of misalignment tolerance:</i> Take maximum misalignment value from Table 8.1 of Part 1. For further guidance refer to Section 10 of this Item and Section 5.7 of Part 1.	<table border="1"> <tr> <td>Maximum allowable misalignment =</td> <td></td> </tr> </table>	Maximum allowable misalignment =														
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TABLE 2.8 Values of Factors, X and Y

The parameter, e , is a limit value of F_a/F_r , for the applicability of different values of factors X and Y . The values of e and the factors X and Y , given in this table conform where appropriate with ISO 281/1 – 1977 (BS 5512: 1977). Note that for tapered roller bearings only, $e = 1.5 \tan \alpha$.

<i>Single row angular contact ball bearing (mounted singly or in tandem).</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r < e$	
		X	Y	X	Y
20°	0.57	1	0	0.43	1.0
30°	0.80	1	0	0.39	0.76
40°	1.14	1	0	0.35	0.57

<i>Paired angular contact ball bearings (mounted in adjacent pairs, back-to-back or face-to-face)</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r > e$	
		X	Y	X	Y
20°	0.57	1	1.09	0.7	1.63
30°	0.80	1	0.78	0.63	1.24
40°	1.14	1	0.55	0.57	0.93

<i>Single row four point contact (duplex) ball bearing</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r > e$	
		X	Y	X	Y
35°	0.95	1	0.66	0.6	1.07

<i>Single row four point contact (duplex) ball/cylindrical roller bearing unit (see Section 3)</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r > e$	
		X	Y	X	Y
35°	0.67	1 [†]	0.33 [†]	0.21 [†]	1.50 [†]

[†] The value of the factors, X and Y , for a single row four point contact (duplex) ball/cylindrical roller bearing unit depend on the shaft size and the ISO series of the bearings. The values given in this table are intended as only a guide and in all cases the life of the actual bearing combination selected should be calculated (see Appendix D).

TABLE 2.8 Values of Factors, X and Y (Continued)

<i>Single row tapered roller bearings</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r > e$	
		X	Y	X	Y (= 0.6/e)
10.6°	0.28	1	0	0.40	2.14
13.1°	0.35	1	0	0.40	1.71
14.9°	0.40	1	0	0.40	1.50
16.0°	0.43	1	0	0.40	1.40
17.0°	0.46	1	0	0.40	1.30
20.1°	0.55	1	0	0.40	1.09
29.0°	0.83	1	0	0.40	0.72

<i>Double row tapered roller bearings</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r > e$	
		X	Y (= 0.665/e)	X	Y (= 1.005/e)
16.3°	0.44	1	1.51	0.67	2.28
29.0°	0.83	1	0.80	0.67	1.21

<i>Spherical roller bearings (double row)</i>					
Nominal contact angle, α	e	$F_a/F_r \leq e$		$F_a/F_r > e$	
		X	Y (= 0.68/e)	X	Y (= 1.01/e)
5.7°	0.15	1	4.53	0.67	6.73
7.5°	0.20	1	3.40	0.67	5.05
9.4°	0.25	1	2.7	0.67	4.04
11.2°	0.30	1	2.27	0.67	3.37
13.1°	0.35	1	1.94	0.67	2.89
14.8°	0.40	1	1.70	0.67	2.53
16.6°	0.45	1	1.51	0.67	2.24

3. NOTATION AND UNITS

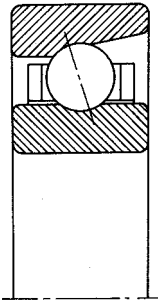
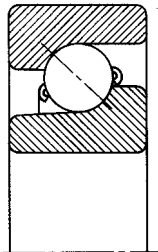
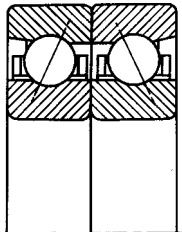
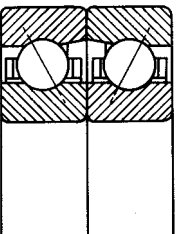
In this notation, units are given for both SI and a familiar British system except for those quantities that, by convention, are expressed in units unique to the rolling bearing industry. The notation used conforms, where appropriate, to British Standards.

		SI	British
a_1	life adjustment factor for reliability		
$a_{2,3}$	combined material and lubrication factor		
a_3	life adjustment factor for operating conditions		
C	dynamic load rating	N	lbf
C_{pair}	dynamic load rating of an adjacent pair of bearings	N	lbf
C_{single}	dynamic load rating of each bearing of an adjacent pair	N	lbf
d	bearing bore diameter	mm	in
$\bar{d}$	bearing mean diameter = $(D + d)/2$	mm	in
D	bearing overall diameter	mm	in
e	factor dependent on contact angle (see Table 2.8)		
f_w	service factor		
F_1, F_2, F_3	limited duration constant loads on bearing	N	lbf
F_a	axial load on bearing	N	lbf
F_r	radial load on bearing	N	lbf
K_a	external axial load on bearing arrangement (necessary where an opposed pair arrangement is considered)	N	lbf
K_r	external radial load on bearing arrangement (necessary where an opposed pair arrangement is considered)	N	lbf
L_{10}	basic rating life in units of 10^6 revolutions		
$L_{10(h)}$	basic rating life in hours		
n	rotational speed of bearing	rev/min	rev/min
n_1, n_2, n_3	limited duration constant rotational speeds	rev/min	rev/min
P	equivalent dynamic load (see Equation (7.1))	N	lbf

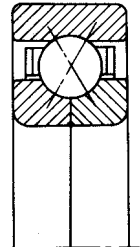
x	exponent of life equation (3 for ball bearings, 10/3 for roller bearings and four point contact (duplex) ball/cylindrical roller bearing units)		
X	factor for calculation of equivalent load		
Y	factor for calculation of equivalent load		
α	contact angle of bearing	degrees	degrees
ψ	extent of load zone	degrees	degrees
<i>Subscript</i>			
a	axial		
r	radial		
1	bearing number 1		
2	bearing number 2		

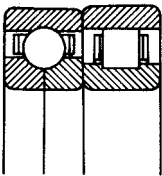
4. TYPES OF ROLLING BEARING UNITS CONSIDERED

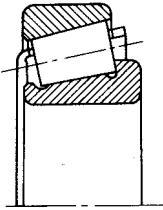
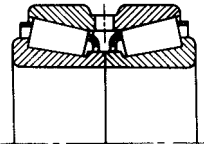
The rolling bearing units considered have been divided into the following broad groups.

BALL BEARING UNITS														
Sketch	Type code [†]	Description												
 	7 XXX (the suffix codes indicated here denote the most widely used contact angles) <table><tr><th>Suffix code</th><th>Contact angle</th></tr><tr><td>C</td><td>15°</td></tr><tr><td>—</td><td>20°</td></tr><tr><td>AC or E</td><td>25°</td></tr><tr><td>A</td><td>30°</td></tr><tr><td>B</td><td>40°</td></tr></table>	Suffix code	Contact angle	C	15°	—	20°	AC or E	25°	A	30°	B	40°	Single row angular contact bearing. A single row of balls runs in inner and outer ring raceway grooves which are off-set to each other so that the lines of action through the points of contact of individual balls are inclined.
Suffix code	Contact angle													
C	15°													
—	20°													
AC or E	25°													
A	30°													
B	40°													
 <i>Back-to-back</i>  <i>Face-to-face</i>	2 off 7 XXXU (the suffix codes indicated here denote the amount of clearance or pre-load) <table><tr><th>Suffix code</th><th>Contact angle</th></tr><tr><td>UA</td><td>Small axial clearance</td></tr><tr><td>UO</td><td>Zero axial clearance</td></tr><tr><td>UL</td><td>Light pre-load</td></tr><tr><td>UM</td><td>Medium pre-load</td></tr></table>	Suffix code	Contact angle	UA	Small axial clearance	UO	Zero axial clearance	UL	Light pre-load	UM	Medium pre-load	Paired single row angular contact bearings. Single row angular contact ball bearings with the ring abutment faces specially faced (universally ground) mounted in adjacent pairs (back-to-back or face-to-face).		
Suffix code	Contact angle													
UA	Small axial clearance													
UO	Zero axial clearance													
UL	Light pre-load													
UM	Medium pre-load													

[†] ISO/DIS 15 is a General Plan for boundary dimensions of radial bearings (excluding tapered roller bearings). ISO 355 is the appropriate standard for tapered roller bearings only. The appropriate bearing type code for the illustrated bearing is given here and 'X' refers to numbers designating the dimensions of the bearings. Explanation of ISO/DIS 15 is given in Part 1. Explanation of ISO 355 is given in the text following the table.

	QJ XXX	Four point contact (duplex) ball bearing. This is a single row angular contact ball bearing with a two-piece inner ring having race-ways arranged to carry a predominance of axial load in either direction. The most widely used contact angle is 35°.
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BALL/ROLLER BEARING UNITS		
	QJ XXX LOC plus N XXX or NU XXX	Four point contact (duplex) ball/cylinder roller bearing unit. A four point contact (duplex) ball bearing with reduced outside diameter mounted adjacent to a cylindrical roller bearing of the same size.

ROLLER BEARING UNITS		
	3 XXXX or J XXXXX	Tapered roller bearing. The rolling elements consist of truncated cones arranged so that the apices of the cones meet a common point on the bearing axis. The inner raceway is usually ribbed to retain the rollers. Paired tapered roller bearing assemblies are available.
	3 XXXX (Various suffix codes are used to denote type of mounting axial clearance and other details).	Double row tapered roller bearing. Two rows of tapered rollers run on separate raceways incorporated in one unit. The rings may incorporate grooves and holes to facilitate lubrication.

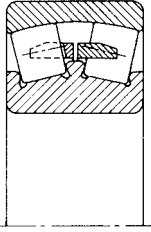
	2 XXXX	Spherical roller bearing (double row). Two rows of “barrel” shaped rollers run on a common spherical outer raceway and on separate raceways in the inner ring.
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Table 8.1 of Part I summarises many characteristics of these bearing types. There exist other specialised bearing types that are not fully covered by Part 1 or Part 2 (see Part 3 and Appendix B of Part 1).

The latest standards for tapered roller bearings (ISO 355-1977 and BS 3134: 1979) differ appreciably from the previous standards. In the new standard the dimension series is designated by a combination of three symbols, for example 2BC.

The first symbol is a numerical character which represents a range of contact angles (angle series).

The second symbol is an alphabetic character, which represents a range of numeric values for the outside diameter to bore relationship (diameter series).

The third symbol is an alphabetic character, which represents a range of numeric values for the width to section height relationship (width series).

The designations for the standardized bearings conform generally with the angle ranges and the numeric values for the relationships given in ISO 355-1977 (BS 3134: 1979). In some cases an exception has been made to avoid the condition that the same designation be used for two different bearing with the same bore diameter.

A complete bearing may be designated by stating its dimension series and bore size, the bore size being given by three digits, for example 2BC 022, 2CD 105.

5. SPECIFICATION OF DESIGN REQUIREMENTS

Once a suitable bearing arrangement has been chosen, the design requirements for each bearing in the arrangement should be specified. Table E1.1 (which is a reproduction of Table E1.1 of Part 1) has been provided to assist the designer in recording this basic information.

5.1 Bearing Life

The method of selecting a suitable bearing size adopted in this Item (and the other Items on designing with rolling bearings) is based on establishing a suitable basic rating life, L_{10} . Guidance on the selection of the required basic rating life, L_{10} , and on the adjustment of rating life, where appropriate, is given in Part I (Sections 5.1 and 5.2).

5.2 Bearing Loads

It is important that bearing loads are known accurately. A 10 per cent underestimate of load, for example, will mean that the bearing life may be up to 30 per cent lower than expected.

The calculation of the bearing loads in a locating/non-locating bearing arrangement usually presents no difficulties (see Section 5.3 of Part 1) except in those circumstances, discussed in Part 1, where the loads fluctuate or shock and dynamic loads are present (see Appendix D of Part 1).

With opposed pair arrangements the calculation of bearing loads is complicated by the fact that each bearing reacts loads axially onto the opposing bearing. Appendix C gives guidance on the calculation of bearing loads in opposed pair arrangements.

6. SUITABILITY OF BEARING UNIT OPTIONS

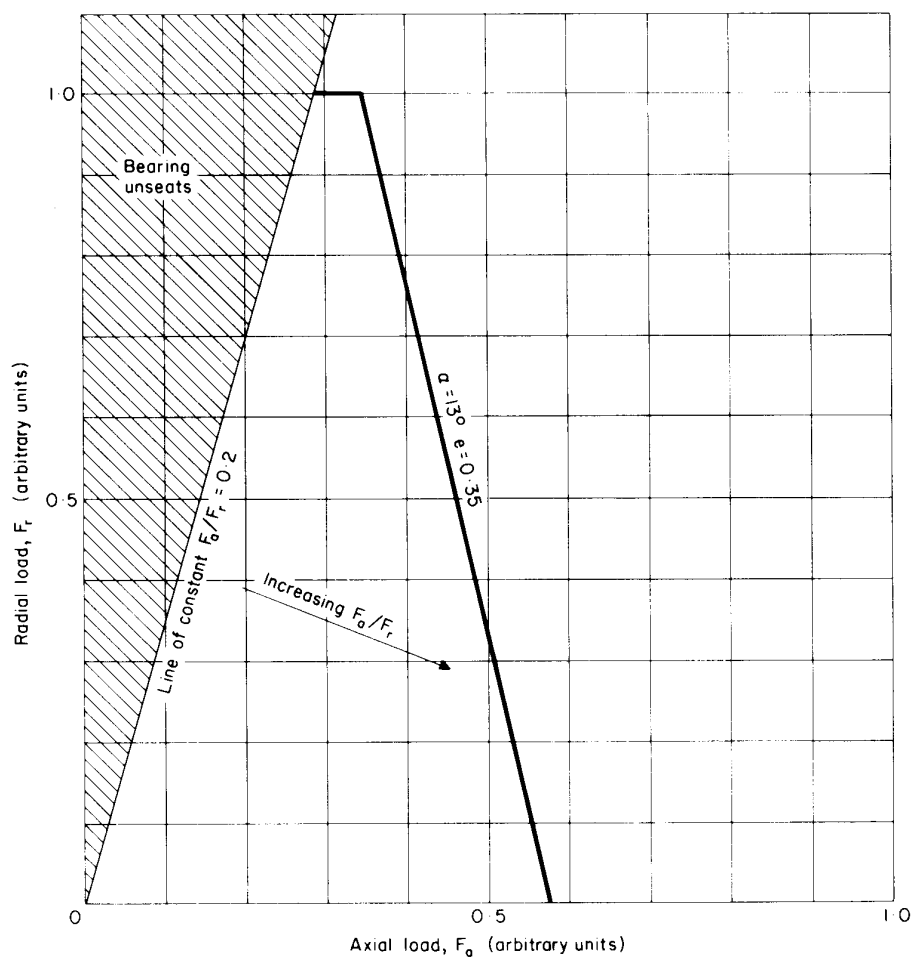
The bearing option chosen should be adequate for the magnitude of the loading and should be suited to the ratio of loading (ratio of axial to radial load).

Adequately sized bearings may be selected by following the method described in this Item (see Section 5.1). However, unless a bearing type which is suited to the ratio of loading is adopted, an unnecessarily large bearing installation may result and tribological problems (difficulties in ensuring adequate lubrication for example) may arise in service.

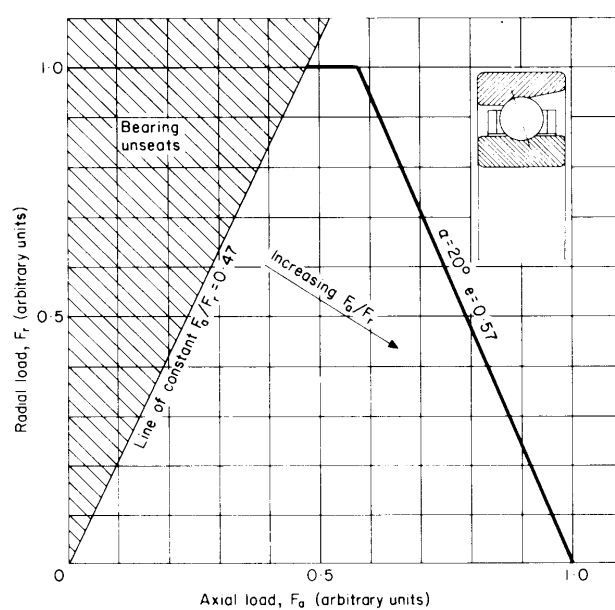
6.1 Avoiding Tribological Problems

A single row angular contact ball or tapered roller bearing can only operate when the ratio of axial load to radial load exceeds a limit which depends on the particular bearing. When this ratio is below this limit the bearing is said to be unseated and no longer properly supports the shaft. Sketches 6.1 and 6.2 show the relative loading characteristics[†] for the particular cases of a tapered roller bearing with a contact angle of approximately 13° and a single row angular contact ball bearing with a contact angle of 20° . As shown on Sketch 6.2, for example, the ratio of axial load to radial load, F_a/F_r , for this particular bearing should exceed 0.47 in order to prevent the bearing unseating.

[†] The relative loading characteristics of a bearing are shown as the relationship between the radial load and the axial load for a constant basic rating life.

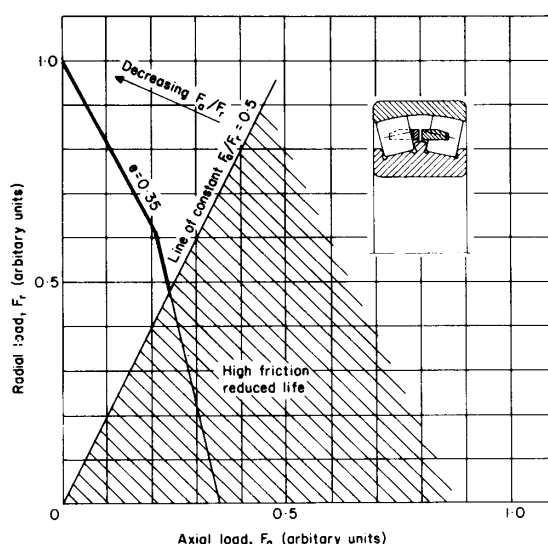


Sketch 6.1 Relative loading characteristics for a single row tapered roller bearing (contact angle, $\alpha = 13^\circ$)



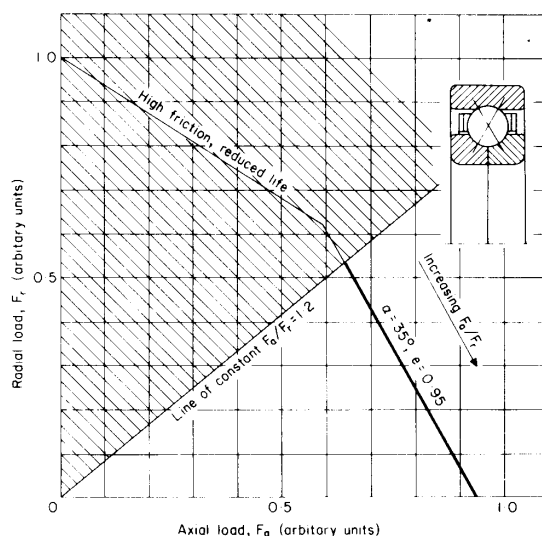
Sketch 6.2 Relative loading characteristics for a single row angular contact ball bearing (contact angle, $\alpha = 20^\circ$)

Back-to-back or face-to-face adjacent pairs of angular contact ball bearings and tapered roller bearings will operate satisfactorily with any ratio of axial to radial load. However, with spherical roller bearings (double row) the axial load should be restricted in order to prevent the life of the bearing from being reduced. The sensitivity of a spherical roller bearing to axial loading depends on the particular bearing internal design but in a typical example (as shown in Sketch 6.3) axial loads exceeding about 0.5 of the radial load may give rise to rolling contact end stresses which reduce raceway life and the temperature rise within the bearing may be increased.



Sketch 6.3 Relative loading characteristics for particular example of a spherical roller bearing (double row)

Considered as a unit, a four point contact (duplex) ball bearing and a cylindrical roller bearing mounted adjacent to each other will operate satisfactorily with any ratio of axial to radial loading. However, where a four point contact (duplex) ball bearing is used on its own the axial load should be sufficient to ensure that the balls contact the raceways across two points only. As shown in Sketch 6.4 an axial load exceeding about 1.2 of the radial load is sufficient to ensure this condition and to prevent an undesirable increase in the friction and the resulting increased heat generation and reduced bearing life.[†]



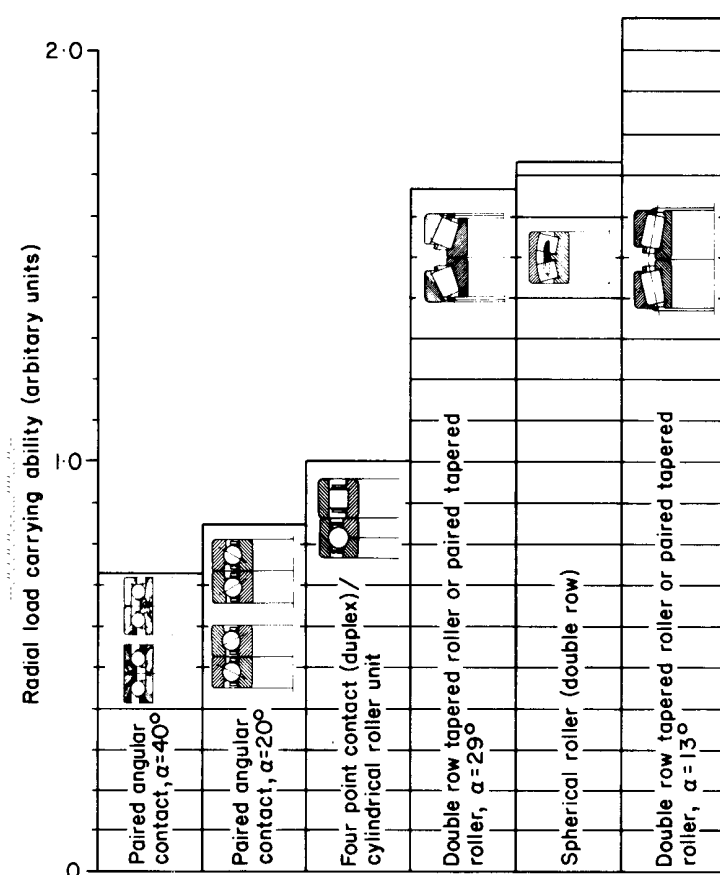
Sketch 6.4 Relative loading characteristics for a four point contact (duplex) ball bearing

[†] See comments in Appendix A regarding the use of this bearing on its own.

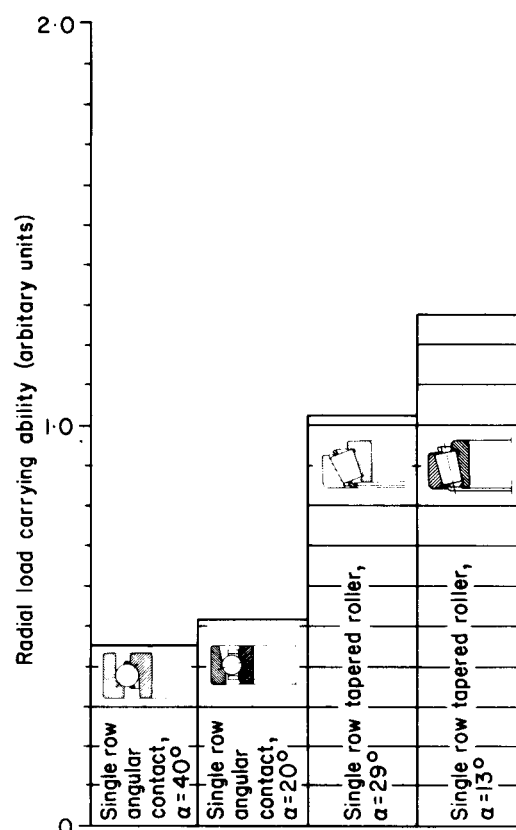
Further tribological problems may occur in service and, in particular, difficulties in lubrication may occur when unnecessarily large bearings are used. Such lubrication difficulties can often be avoided at the design stage by selecting compact bearings as described in Section 6.2.

6.2 Avoiding Unnecessarily Large Bearings

The various types of bearings differ in their ability to carry loads. The values of the load rating (see Section 7.2) listed in the bearing manufacturers' catalogues depend on the type of bearing, the contact angle of the bearing and the size of the bearing. Similarly sized bearings of different type or contact angle will, in general, have different load ratings and will, therefore, be capable of carrying different loads for the same life. Sketch 6.5[†] compares the ability of some similarly sized bearing units to carry purely radial loads. In general, bearing units incorporating small contact angles can carry a greater purely radial load than bearing units of similar type and size incorporating large contact angles. Sketch 6.6 compares the radial load carrying ability of similarly sized single row angular contact and tapered roller bearings operating under pure radial loading[‡]. Again, bearings with a small contact angle have a greater radial load carrying ability than bearings with a large contact angle.



Sketch 6.5 Radial load carrying ability of various bearing unit types

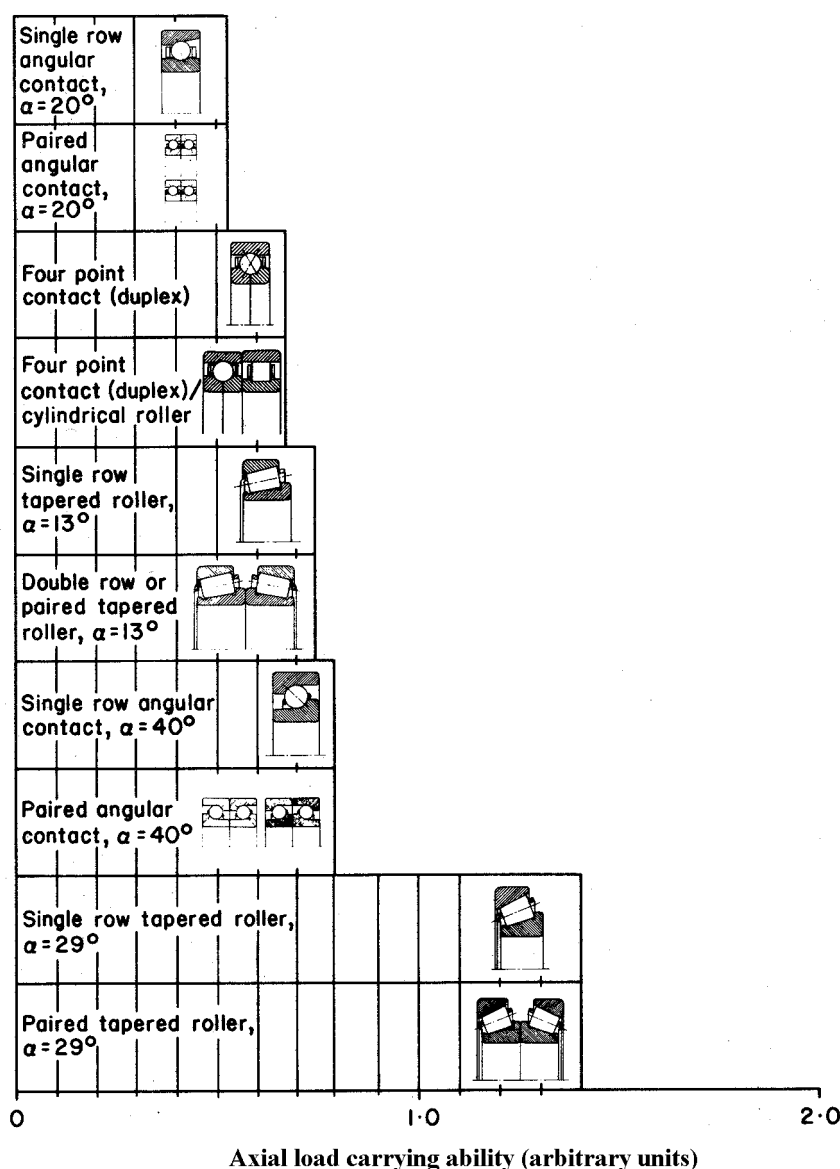


Sketch 6.6 Radial load carrying ability of single row bearings

[†] Sketches 6.5, 6.6 and 6.7 have been prepared for a typical basic rating life L_{10} , of 1000.

[‡] Single row angular contact ball and tapered roller bearings are said to be operating under pure radial loading when just sufficient axial load is applied to exactly counteract the tendency of the bearing to separate (see Appendix C).

Sketch 6.7 compares the ability of the various bearings and bearing units to carry purely axial loading. In this case, bearings with a high contact angle offer the greatest purely axial load carrying ability.



Sketch 6.7 Axial load carrying ability of various bearings

In practice, bearings are usually called upon to carry a combination of radial and axial load and the bearing or bearing unit offering the greatest load carrying ability for a given size of bearing depends on the ratio of axial load to radial load, F_a/F_r . Sketch 6.8 shows the relative magnitudes of the radial and axial loads that would be carried by similarly sized examples of spherical roller bearings (double row), bearing units consisting of back-to-back[†] or face-to-face[†] adjacent pairs of angular contact ball or tapered roller bearings and bearing units consisting of a four point contact (duplex) ball bearing and a cylindrical roller bearing of the same size mounted adjacent to each other.[‡] As the axial load is increased from zero the applied radial load must be reduced, by an amount which depends on the particular bearing, in order that the life of the bearing is not reduced.

[†] 'Indirect' and 'direct' or 'O' and 'X' are alternative terms used for 'back-to-back' and 'face-to-face'.

[‡] The sketches showing the relative magnitudes of the radial and axial loads carried by various bearing types (Sketches 6.8 and 6.9) have been prepared for a typical basic rating life, L_{10} of 1000.