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(* Problem II.4.1 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

"no.208 radial ball"
B10 = 4000; (* hour *)
n = 1200; (* rpm *)

L = B10 * 60 * n; (* rev *)

"Assumption: the life given is for 90% reliability"

LR = 90*10^6;
Print["LR = ",LR, " rev"];

d = 40; (* mm - the bore - from Table.II.4.1 *)
Print["d = ",d, " mm"];

Cap = 9.40 * 10^3; (* N - from Table II.4.2 *)
Print["C = ",Cap, " N"];

Kr = 1; (* from Figure II.4.9 *)
Print["Kr = ",Kr];

"Assumption: the loading is steady"
Ka = 1; (* from Table II.4.3 *)
Print["Ka = ",Ka];

Fr = Cap (LR / L)^(3/10); (* from eq II.4.22 *)
Print["Fr = ",Fr, " N"];

no.208 radial ball

Assumption: the life given is for 90% reliability

LR = 90000000 rev

d = 40 mm

C = 9400. N

Kr = 1

Assumption: the loading is steady

Ka = 1

Fr = 6631.06 N
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(* Problem II.4.3 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

"no.207 angular ball bearing"
Fr = 250; (* lb *)
Fa = 150; (* lb *)
n = 1000; (* rpm *)

"Assumption: 25° angular ball bearing"
r = N[Fa/Fr];
Print["Fa/Fr = ",r];

"for 0 < Fa/Fr < 0.68 => Fe = Fr"
Fe = Fr;
Fe = Fe * 4.448222; (* convert from lb to N *)
Print["Fe = ", Fe, " N"];

"for steady loading Ka = 1 (Table II.4.3)"
Ka = 1;

"Assumption: the life given is for 90% reliability"

LR = 90*10^6;
Print["LR = ",LR, " rev"];

Kr = 1; (* from Figure II.4.9 *)
Print["Kr = ",Kr];

d = 35; (* mm - the bore - from Table.II.4.1 *)
Print["d = ",d, " mm"];

Cap = 8.20*10^3; (* N - from Table II.4.2 *)
Print["C = ",Cap, " N"];

L = Kr LR (Cap / (Ka Fe) )^(10/3);
Print["L = ",L, " rev"];

B10 = L / (60 n);
Print["B10 = ", B10, " hr"];

no.207 angular ball bearing

Assumption: 25° angular ball bearing

Fa/Fr = 0.6

for 0 < Fa/Fr < 0.68 => Fe = Fr

Fe = 1112.06 N

for steady loading Ka = 1 (Table II.4.3)

Assumption: the life given is for 90% reliability

LR = 90000000 rev

```

$$K_r = 1$$

$$d = 35 \text{ mm}$$

$$C = 8200. \text{ N}$$

$$L = 7.02318 \times 10^{10} \text{ rev}$$

$$B_{10} = 1.17053 \times 10^6 \text{ hr}$$

### Problem II.4.5.

From eq.  $L = K_r L_R (\frac{C}{F_r})^{3.33}$ , for identical bearings with the same  $L_R$ ,  $C$ , and  $F_r$  we have:

$$\frac{L}{K_r L_R (\frac{C}{F_r})^{3.33}} \Big|_{90\%} = \frac{L}{K_r L_R (\frac{C}{F_r})^{3.33}} \Big|_{60\%} = \frac{L}{K_r L_R (\frac{C}{F_r})^{3.33}} \Big|_{98\%} \quad (1)$$

or

$$\frac{L}{K_r} \Big|_{90\%} = \frac{L}{K_r} \Big|_{60\%} = \frac{L}{K_r} \Big|_{98\%} \quad (2)$$

From Figure II.4.9 for 90% reliability  $K_r = 1.0$ ; for 60% reliability  $K_r = 6.0$ ; for 98% reliability  $K_r = 0.33$ ;

$$\frac{L_{90\%}}{1.0} = \frac{L_{60\%}}{6.0} = \frac{L_{98\%}}{0.33} \quad (3)$$

For  $L_{90\%} = 12000$  hours,  $L_{60\%} = 6 \times 12000 = 72000$  hours, and  $L_{98\%} = 0.33 \times 12000 = 3960$  hours. A higher reliability requirement (fewer bearing failures) means a shorter life.

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(* Problem II.4.7 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

Fr = 3; (* kN *)
Fa = 2; (* kN *)
n = 1200; (* rpm *)

L = 6000 * 60 * 900;

LR = 90*10^6;
Print["LR = ",LR, " rev"];

Kr = 0.33; (* for 98% reliability from Figure II.4.9 *)
Print["Kr = ",Kr];

r = N[Fa/Fr];
Print["Fa/Fr = ",r];

"a)"
"for 0.35 < Fa/Fr < 10 => Fe = Fr (1+1.115 (Fa/Fr - 0.35)) - for radial ball bearings"
Fe = Fr (1+1.115 (Fa/Fr - 0.35));
Print["Fe = ", Fe, " kN"];

"for light to moderate impacts Ka = 2 (Table II.4.3) - radial ball bearing"
Ka = 2;

Creq = Ka Fe ( L / (Kr LR))^0.3;
Print["Creq = ", Creq, " kN"];

"for 17 kN => d = 70 mm and 200 series - from Table II.4.2"
"from Table II.4.1 => no.214 - for radial ball bearing"

"b)"
"for 0 < Fa/Fr < 0.68 => Fe = Fr - for angular ball bearings"
Fe = Fr;
Print["Fe = ", Fe, " kN"];

"for light to moderate impacts Ka = 2 (Table II.4.3) - angular ball bearing"
Ka = 2;

Creq = Ka Fe ( L / (Kr LR))^0.3;
Print["Creq = ", Creq, " kN"];

"for 13.6 kN => d = 55 mm and 200 series - from Table II.4.2"
"from Table II.4.1 => no.211 - for angular ball bearing"

LR = 90000000 rev

Kr = 0.33

Fa/Fr = 0.666667

a)

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for  $0.35 < F_a/F_r < 10 \Rightarrow F_e = F_r (1 + 1.115 (F_a/F_r - 0.35))$  - for radial ball bearings

$F_e = 4.05925 \text{ kN}$

for light to moderate impacts  $K_a = 2$  (Table II.4.3) - radial ball bearing

$C_{req} = 16.6269 \text{ kN}$

for  $17 \text{ kN} \Rightarrow d = 70 \text{ mm}$  and 200 series - from Table II.4.2

from Table II.4.1  $\Rightarrow$  no.214 - for radial ball bearing

b)

for  $0 < F_a/F_r < 0.68 \Rightarrow F_e = F_r$  - for angular ball bearings

$F_e = 3 \text{ kN}$

for light to moderate impacts  $K_a = 2$  (Table II.4.3) - angular ball bearing

$C_{req} = 12.2882 \text{ kN}$

for  $13.6 \text{ kN} \Rightarrow d = 55 \text{ mm}$  and 200 series - from Table II.4.2

from Table II.4.1  $\Rightarrow$  no.211 - for angular ball bearing

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(* Problem II.4.9 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

"no.207 radial ball bearing"
n = 1500; (* rpm *)
t1 = 0.3;
Fr1 = 5; (* kN *)
t2 = 0.3;
Fr2 = 2; (* kN *)
t3 = 0.4;
Fr3 = 10; (* kN *)
Ka = 1;

LR = 90*10^6;
Print["LR = ",LR, " rev"];

Kr = 1; (* from Figure II.4.9 *)
Print["Kr = ",Kr];

"from Table II.4.1 => d = 35 mm"
"from Table II.4.2 => C = 8.5 kN"
Cap = 8.5; (* kN *)

L1 = Kr LR ( Cap / (Ka Fr1))^(10/3);
L2 = Kr LR ( Cap / (Ka Fr2))^(10/3);
L3 = Kr LR ( Cap / (Ka Fr3))^(10/3);

Print["L1 = ", L1, " rev"];
Print["L2 = ", L2, " rev"];
Print["L3 = ", L3, " rev"];

n1 = t1 * n;
n2 = t2 * n;
n3 = t3 * n;
X = 1 / (n1/L1 + n2/L2 + n3/L3);

Print["B10 = ", X/60, " hr"];
Print["Median life = B10 * 5 = ", X/12, " hr"];

no.207 radial ball bearing

LR = 90000000 rev

Kr = 1

from Table II.4.1 => d = 35 mm

from Table II.4.2 => C = 8.5 kN

L1 = 5.27722×108 rev
L2 = 1.11911×1010 rev
L3 = 5.23567×107 rev

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B10 = 1349.22 hr

Median life = B10 \* 5 = 6746.12 hr

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(* Problem II.4.10 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

n=900; (* rotational speed [rpm] *)
FaA=500; (* [N] *)
FaB=500; (* [N] *)
fr=900; (* [N] *)
FR={0,-fr Sin[N[Pi]/4],fr Cos[N[Pi]/4]}; (* [N] *)
FA={0,FAy,FAz};
FB={0,FBY,FBz};
l=0.3; (* [m] *)

"∑M_A = rAB x FB + rAR x FR = 0 =>"
rAB={1,0,0};
rAR={2 1,0,0};
MA=Cross[rAB,FB]+ Cross[rAR,FR];
sB=Solve[{MA[[2]]==0,MA[[3]]==0},{FBy,FBz}];
By=FBy/.sB[[1]];
Bz=FBz/.sB[[1]];
Print["FBy = ",By," N"];
Print["FBz = ",Bz," N"];
FrB=Sqrt[By^2+Bz^2];
Print["FrB = (FBy^2 + FBz^2)^0.5 = ",FrB," N"];
eB=FaB/FrB;
Print["FaB/FrB = ",eB];
FeB=FrB;
Print["FeB=FrB=",FeB," N"];

"∑F = 0 => FA = -FB -FR "
fA=-{0,By,Bz}-FR;
Ay=fA[[2]];
Az=fA[[3]];
Print["FAy = ",Ay," N"];
Print["FAz = ",Az," N"];
FrA=Sqrt[Ay^2+Az^2];
Print["FrA = (FAy^2 + FAz^2)^0.5 = ",FrA," N"];
eA=FaA/FrA;
Print["FaA/FrA = ",eA];
FeA=FrA (1+1.115(FaA/FrA-0.35));
Print["FeA=FrA(1+1.115(FaA/FrA-0.35))=",FeA," N"];

"design life DL = 30 000 h "
DL=30000; (* h *)
L=n DL 60;
Print["life L = n DL 60 = ",L," rev "];
"application factor Ka = 1 uniform no impact (Table II.4.3)"
Ka = 1;
Kr = 0.33 (* r=98% Figure II.4.9 *);
LR=90 10^6;
"LR = 90 x 10^6; Kr = 0.33 (r=98%)"

"Creq = Ka Fe (L/(Kr LR))^0.3"
CreqA = Ka FeA (L/(Kr LR))^0.3;
CreqB = Ka FeB (L/(Kr LR))^0.3;

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Print["rated capacity at A: CreqA = ",CreqA," N"];
Print["rated capacity at B: CreqB = ",CreqB," N"];

"from Table II.4.2 with CreqA and L00 series => C=4.2 kN and d=35 mm bore"
"from Table II.4.2 with CreqB and 200 series => C=8.5 kN and d=35 mm bore"

"from Table II.4.1 with d=35 mm bore and L00 series => L07 bearing number"
"from Table II.4.1 with d=35 mm bore and 200 series => L207 bearing number"

 $\sum M_A = r_{AB} \times F_B + r_{AR} \times F_R = 0 \Rightarrow$ 

FBy = 1272.79 N

FBz = -1272.79 N

FrB = (FBy^2 + FBz^2)^0.5 = 1800. N

FaB/FrB = 0.277778

FeB=FrB=1800. N

 $\sum F = 0 \Rightarrow F_A = -F_B -F_R$ 

FAy = -636.396 N

FAz = 636.396 N

FrA = (FAy^2 + FAz^2)^0.5 = 900. N

FaA/FrA = 0.555556

FeA=FrA(1+1.115(FaA/FrA-0.35))=1106.28 N

design life DL = 30 000 h

life L = n DL 60 = 1620000000 rev

application factor Ka = 1 uniform no impact (Table II.4.3)

LR = 90 x 10^6; Kr = 0.33 (r=98%)

Creq = Ka Fe (L/(Kr LR))^0.3

rated capacity at A: CreqA = 3671.9 N

rated capacity at B: CreqB = 5974.48 N

from Table II.4.2 with CreqA and L00 series => C=4.2 kN and d=35 mm bore
from Table II.4.2 with CreqB and 200 series => C=8.5 kN and d=35 mm bore
from Table II.4.1 with d=35 mm bore and L00 series => L07 bearing number
from Table II.4.1 with d=35 mm bore and 200 series => L207 bearing number

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(* Problem II.4.11 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

n=1000; (* rotational speed [rpm] *)
FP = {0, -500, 600};
FR = {0, -1000, 0};
FA={0,FAY,FAZ};
FB={0,FBy,FBz};
l=0.2; (* [m] *)
s=0.1; (* [m] *)

" $\sum \mathbf{M}_A = \mathbf{r}_{AP} \times \mathbf{F}_P + \mathbf{r}_{AR} \times \mathbf{F}_R + \mathbf{r}_{AB} \times \mathbf{F}_B = 0 \Rightarrow$ "
rAP={-s,0,0};
rAB={2 l,0,0};
rAR={l,0,0};
MA=Cross[rAP,FP] + Cross[rAR,FR] + Cross[rAB,FB];
sB=Solve[{MA[[2]]==0,MA[[3]]==0},{FBy,FBz}];
By=FBy/.sB[[1]];
Bz=FBz/.sB[[1]];
Print["FBy = ",By," N"];
Print["FBz = ",Bz," N"];
FrB=Sqrt[By^2+Bz^2];
Print["FrB = (FBy^2 + FBz^2)^0.5 = ",FrB," N"];

FeB=FrB;
Print["FeB=FrB=",FeB," N"];

" $\sum \mathbf{F} = 0 \Rightarrow \mathbf{F}_A = -\mathbf{F}_B -\mathbf{F}_R -\mathbf{F}_P$ "
fA=-{0,By,Bz}-FR-FP;
Ay=fA[[2]];
Az=fA[[3]];
Print["FAy = ",Ay," N"];
Print["FAz = ",Az," N"];
FrA=Sqrt[Ay^2+Az^2];
Print["FrA = (FAy^2 + FAz^2)^0.5 = ",FrA," N"];
FeA=FrA;
Print["FeA=FrA=",FeA," N"];

"design life DL = 5 000 h "
DL=5000; (* h *)
L=n DL 60;
Print["life L = n DL 60 = ",L," rev "];
"application factor Ka = 1.5 light to moderate impact (Table II.4.3)"
Ka = 1.5;
Kr = 0.33 (* r=98% Figure II.4.9 *);
LR=90 10^6;
"LR = 90 x 10^6; Kr = 0.33 (r=98%)"

"Creq = Ka Fe (L/(Kr LR))^0.3"
CreqA = Ka FeA (L/(Kr LR))^0.3;
CreqB = Ka FeB (L/(Kr LR))^0.3;
Print["rated capacity at A: CreqA = ",CreqA," N"];
Print["rated capacity at B: CreqB = ",CreqB," N"];

```

"from Table II.4.2 with  $C_{reqA}$  and L00 series => C=4.2 kN and d=35 mm bore"  
"from Table II.4.1 with d=35 mm bore and L00 series => L07 bearing number"

$$\sum M_A = r_{AP} \times F_P + r_{AR} \times F_R + r_{AB} \times F_B = 0 \Rightarrow$$

$$F_{By} = 375. \text{ N}$$

$$F_{Bz} = 150. \text{ N}$$

$$F_{rB} = (F_{By}^2 + F_{Bz}^2)^{0.5} = 403.887 \text{ N}$$

$$F_{eB} = F_{rB} = 403.887 \text{ N}$$

$$\sum F = 0 \Rightarrow F_A = -F_B - F_R - F_P$$

$$F_{Ay} = 1125. \text{ N}$$

$$F_{Az} = -750. \text{ N}$$

$$F_{rA} = (F_{Ay}^2 + F_{Az}^2)^{0.5} = 1352.08 \text{ N}$$

$$F_{eA} = F_{rA} = 1352.08 \text{ N}$$

design life DL = 5 000 h

$$\text{life } L = n \text{ DL } 60 = 300000000 \text{ rev}$$

application factor  $K_a = 1.5$  light to moderate impact (Table II.4.3)

$$L_R = 90 \times 10^6; K_r = 0.33 \text{ (} r=98\%)$$

$$C_{req} = K_a F_e (L / (K_r L_R))^{0.3}$$

$$\text{rated capacity at A: } C_{reqA} = 4058.86 \text{ N}$$

$$\text{rated capacity at B: } C_{reqB} = 1212.44 \text{ N}$$

from Table II.4.2 with  $C_{reqA}$  and L00 series => C=4.2 kN and d=35 mm bore

from Table II.4.1 with d=35 mm bore and L00 series => L07 bearing number

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(* Problem II.4.12 *)
Apply[Clear,Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

n=300; (* rotational speed [rpm] *)
FP = {0, -200, 500};
FR = {0, -600, -1500};
FA={0,FAy,FAz};
FB={0,FBy,FBz};
l=0.025; (* [m] *)
s=0.1; (* [m] *)
OP = 0.15; (* [m] *)
QR = 0.05; (* [m] *)

" $\sum M_A = r_{AP} \times FP + r_{AB} \times FB + r_{AR} \times FR = 0 \Rightarrow$ "

rP = {0,OP,0};
rA = {1,0,0};
rB = {1+s,0,0};
rR = {2*l + s,QR,0};

rAP = rP - rA;
rAB = rB - rA;
rAR = rR - rA;

MA=Cross[rAP,FP] + Cross[rAB,FB] + Cross[rAR,FR];
sB=Solve[{MA[[2]]==0,MA[[3]]==0},{FBy,FBz}];
By=FBy/.sB[[1]];
Bz=FBz/.sB[[1]];
Print["FBy = ",By," N"];
Print["FBz = ",Bz," N"];
FrB=Sqrt[By^2+Bz^2];
Print["FrB = (FBy^2 + FBz^2)^0.5 = ",FrB," N"];

FeB=FrB;
Print["FeB=FrB=",FeB," N"];

" $\sum F = 0 \Rightarrow FA = -FB -FR -FP$ "
fA=-{0,By,Bz}-FR-FP;
Ay=fA[[2]];
Az=fA[[3]];
Print["FAy = ",Ay," N"];
Print["FAz = ",Az," N"];
FrA=Sqrt[Ay^2+Az^2];
Print["FrA = (FAy^2 + FAz^2)^0.5 = ",FrA," N"];
FeA=FrA;
Print["FeA=FrA=",FeA," N"];

"design life DL = 30 000 h from Table II.4.4"
DL=30000; (* h *)
L=n DL 60;
Print["life L = n DL 60 = ",L," rev "];
"Application factor Ka = 1.3 Gearing (Table II.4.3)"
Ka = 1.3;
Kr = 1 (* r=90% Figure II.4.9 *);

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LR=90 10^6;
"LR = 90 x 10^6; Assumption: Kr = 1 (r=90%)"

"Creq = Ka Fe (L/(Kr LR))^0.3"
CreqA = Ka FeA (L/(Kr LR))^0.3;
CreqB = Ka FeB (L/(Kr LR))^0.3;
Print["rated capacity at A: CreqA = ",CreqA," N"];
Print["rated capacity at B: CreqB = ",CreqB," N"];

"from Table II.4.2 with CreqB and L00 series => C=5.8 kN and d=45 mm bore"
"from Table II.4.1 with d=45 mm bore and L00 series => L09 bearing number"

∑M_A = rAP x FP + rAB x FB + rAR x FR = 0 =>

FBY = 700. N
FBZ = 2000. N

FrB = (FBY^2 + FBZ^2)^0.5 = 2118.96 N
FeB=FrB=2118.96 N

∑F = 0 => FA = -FB -FR -FP

FAy = 100. N
FAz = -1000. N

FrA = (FAy^2 + FAz^2)^0.5 = 1004.99 N
FeA=FrA=1004.99 N

design life DL = 30 000 h from Table II.4.4

life L = n DL 60 = 540000000 rev

Application factor Ka = 1.3 Gearing (Table II.4.3)

LR = 90 x 10^6; Assumption: Kr = 1 (r=90%)

Creq = Ka Fe (L/(Kr LR))^0.3

rated capacity at A: CreqA = 2236.4 N
rated capacity at B: CreqB = 4715.33 N

from Table II.4.2 with CreqB and L00 series => C=5.8 kN and d=45 mm bore
from Table II.4.1 with d=45 mm bore and L00 series => L09 bearing number

```