Spindle Assembly Design Review

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Group 1: Knurled but not Broken

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System Level FRs

Parameter	Value	Units	Justification	References
Material to cut	12L14 Steel	-	Staff Requirement	Requirement Sheet
MRR	0.08 (min)	in^3/min	Staff Requirement	Requirement Sheet
Surface Finish	63 (max)	µin	Staff Requirement	Requirement Sheet
Repeatability	50 (max)	µm	Staff Requirement	Requirement Sheet
Drop impulse force	2000	N	Staff Requirement	Drop impulse force 3-5x gravity load
Weight on carriage	600	N	Staff Requirement	Weight on carriage of average sized team member
Sledgehammer force	5000	N	Staff Requirement	Sledgehammer force 1/2mv^2

System Level FRs

Parameter	Value	Units	Justification	References
Maximum workpiece Diameter	15 (min)	mm	Limit of chuck size (internal jaws)	Chuck Datasheet
Machine Life	2000 (min)	hours	Desired machine life for hobbyist or mini shop	1 work year
Maximum runout at end of spindle shaft	50 (max)	µm	Typical values for lathes	*Measure on existing lathe (future work)

Spindle FRs

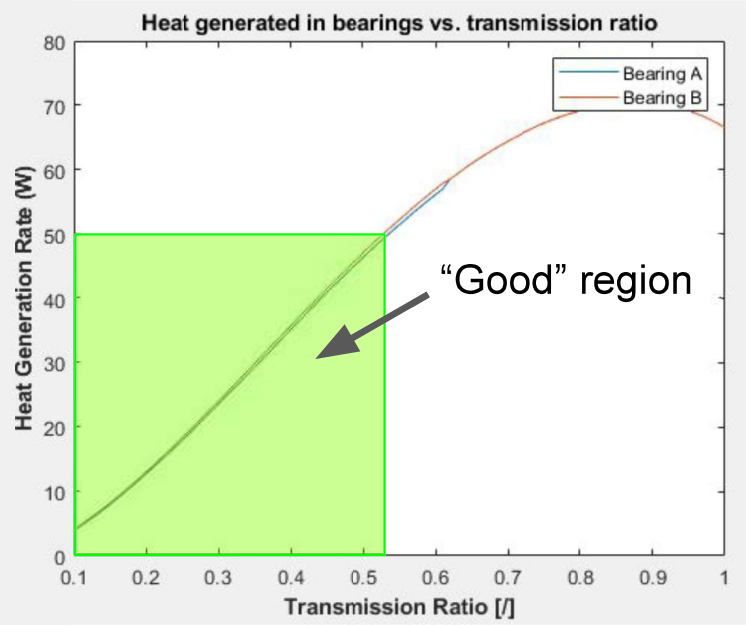
Parameter	Value	Units	Justification	References
Dissipated power	100 (max)	W	u_t = 9 J/mm^3 MRR = 21.85 mm^3/s Cutting power = 200 W Max motor power = 337 W	Machinery's Handbook Kalpakjian Motor spec sheet
Net Axial Stiffness	35 x 10^6 (min)	N/m	Max thrust force = 400 N Allowable deflection = 11.3 µm	
Net Radial Stiffness	17 x 10^6 (min)	N/m	Max cutting force = 200 N Allowable deflection = 11.3 µm	
Machine Life	2000 (min)	Hours	1 work year (8 hrs/day, 5 days/week, 52 weeks/year)	
Temperature of components	40 (max)	Deg C	Thermal imaging experiments using past years' lathes	

Summary of Requirements and Design

Parameter	Value	Units	Design Choices	Measurement to verify
Dissipated power	100 (max)	W	Grease: Timken GR236 Transmission ratio: 1:2 or less	Measure motor operating point (multimeter, current sensor, etc.)
Net Axial Stiffness	35 x 10^6 (min)	N/m	Preload: 400N	Clamp down spindle, Load with known force, measure deflection with dial indicator
Net Radial Stiffness	17 x 10^6 (min)	N/m	Bearing Spacing: 2.6 in Preload: 400 N	Clamp down spindle, Load with known force, measure deflection with dial indicator
Machine Life	2000 (min)	Hours	Bearing Grease: Timken GR236 Preload: 400 N	Run to failure
Temperature of components	40 (max)	Deg C	Grease: Timken GR236	Use thermal imaging

Transmission Ratio

- Primary decision factor: **Heat Generation in Bearings**
- **↑ Transmission Ratio == ↑ Heat Generation**



If transmission ratio is 0.52 or less, heat dissipation FR of 50 W/bearing is met

Transmission ratio =

(pulley diameter on motor) / (pulley diameter on spindle shaft)

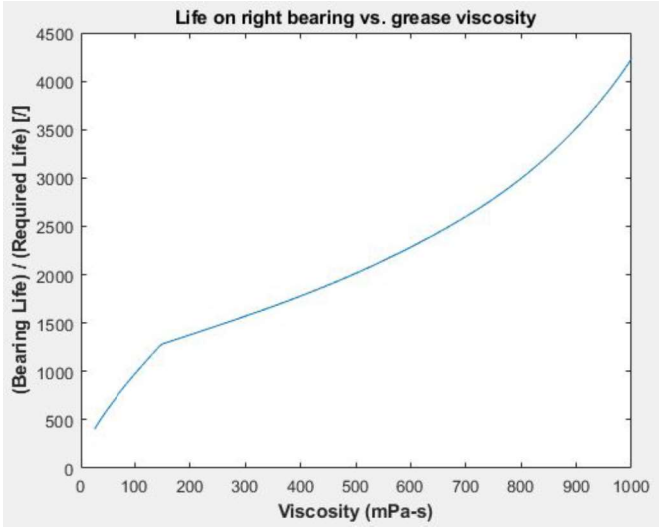
Bearing Grease

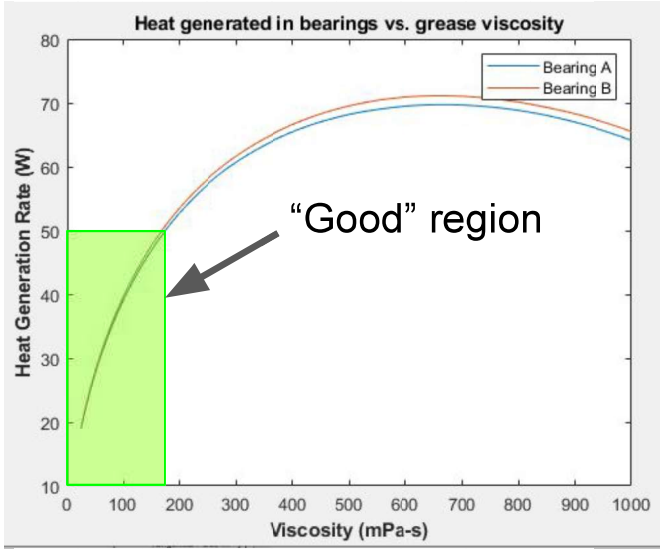
Should pick <u>viscosity</u> so that:

- Heat dissipation < 50 W/bearing
- Acceptable life
- Lowest cost

↓ Grease viscosity

- ↓ Bearing heat
- ↓ Bearing life



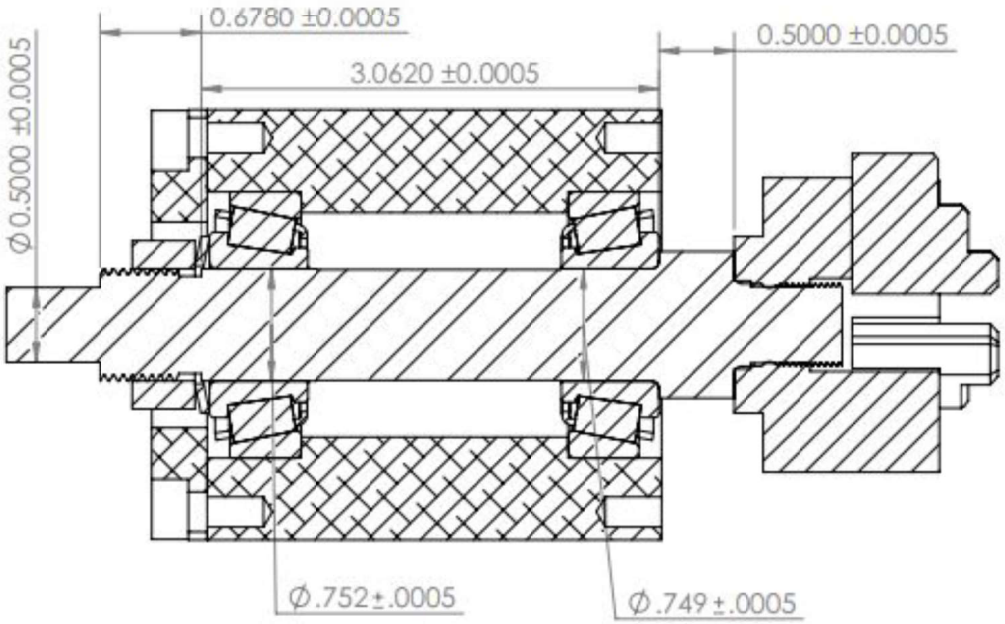


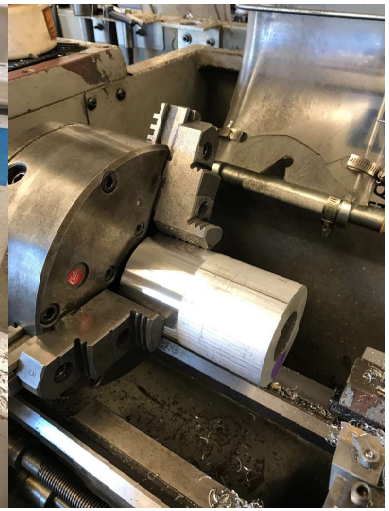
Viscosity of Timken GR236 grease meets heat dissipation requirement with lowest cost

Manufacturer	Product Number	Viscosity (cSt)	Cost ($)
Timken	GR220	120	9.93
Timken	GR217	240	7.20
Timken	GR232	506	22.34
Timken	GR219	490	11.45
Timken	GR231	110	15.90
Timken	GR236/237	145.6	5.50

Spindle Manufacturing

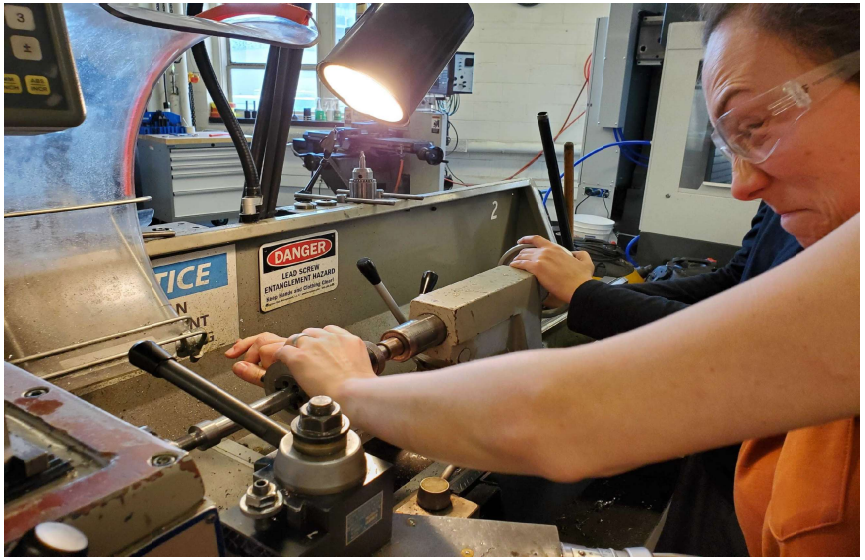
Key Dimensions





All dimensions measured to within spec at the time of manufacturing, but do not have actual measurements on hand

We completed our spindle, but were unable to get data, photos or measurements



Cutting Forces & Power

Assumed Parameter	Value	Units	Justification
Material removal rate (MRR)	0.08	in^3/min	Specified by staff
Material specific cutting energy	9	J/mm^3	High estimate for steel, Kalpakjian + MH
Tool rake angle	0	rad	Worst case; rake angle ↓, cutting forces ↑
Coefficient of friction between tool & part	2	/	Worst case according to Kalpakjian
Part diameter	15	mm	Max diameter for internal jaws, chuck spec sheet

Maximum Cutting Power: 200W

Maximum Cutting Force: 200N

Maximum Thrust Force: 400 N

Cutting Forces: Equations

Equation	Justification	Reference
$V_c = \pi D N / 60$		V = (Radius) * (rot. speed) N in RPM
$F_c = (u_t * MRR) / V_c$		Conservative estimate; all power goes into cutting
$\tan(\beta) = \mu$		Kalpakjian
$F_t = F_c * \tan(\beta - \alpha)$		Kalpakjian
Friction torques from bearings (MA and MB)		Timken manual
$T_m = (F_c*(D/2) + MA + MB)*n$	FBD on spindle shaft	n = transmission ratio from motor shaft to spindle shaft
$N_{new} = \omega_{nl} * (1 - (T_m/T_{stall})) * n$	Torque-speed relation for DC motor	ω_{nl} = no load speed of motor T_{stall} = stall torque of motor Values given in motor spec sheet

Continue to iterate multiple times to allow solution to converge

Bearing Life Calculations

$$L_{na} = a_1 a_2 a_{3d} a_{3k} a_{3l} a_{3m} a_{3p} \left(\frac{C}{P_r} \right)^e (1x10^6) \text{ revolutions}$$

Parameter	Value/calculation	Reference
C = dynamic radial load rating	39100 N	Spec sheet
e	10/3	Pg. 48, for roller bearing
Pr = dynamic equivalent radial load	0.4*Fr + K*Fa	Pg. 43
a1 = reliability life factor	fn(reliability)	Pg. 49
a2 = material life factor	1.0 for Timken steel	Pg. 49
a3d = debris life factor	1.0	Pg. 49, no other info??
a3k = load zone factor	1.0	Pg. 50, no other info??
a3l = lubrication life factor	= Cg*Cl*Cj*Cs*Cv*Cgr	Pg. 50-52
a3m = misalignment life factor	1.0	Pg. 54, no other info??
a3p = low-life factor	1.0 (worst case)	Pg. 54, fn(a3l, C/Pr)

Page numbers refer to Timken manual on Stellar