Manufacturing and Design

Modest Introduction

By: Elliot Bushman 03/13/2021

Value of Manufacturing Knowledge

- Understand what is possible with the tools at our disposal, and what method is best
- Design to ease difficulties of manufacturing process
  - More time for fit and finish
  - Send a lot of our manufacturing out to sponsors who don’t want to deal with that
- Distribute workload across team members more evenly
  - Faster completion of projects
- Valuable skills that many team members have expressed interest in learning

Goals for Team Members

Part 1: Virtual

- Apply manufacturing knowledge to design process
  - Understand manufacturing timelines
  - Design parts to ease manufacturing processes
- Understand in house capabilities and capacities
- Basic mechanical design considerations
  - Standards for hardware, stock, and tools

Part 2: Hands On

- Safely run machines and use tools
- Read technical drawings and extrapolate manufacturing processes
- Take advantage of shop resources to prototype new systems during the design process
- Machine and assemble parts for the car
- Understand basic maintenance and machine care

Goals for the Team

Part 1: Virtual

- Be able to create more realistic manufacturing timelines
- Understand how to create functional, simple, and manufacturable designs

Part 2: Hands On

- Delegate manufacturing workload
- Quickly incorporate new members into hands on positions, and shop practices

Threads Standards

- Below ¼” hardware designated by a number
- Single vs multi pitch
- Thread Profiles
- Shear forces should be applied to dowel section
- Tapped holes must have enough engagement
  - 2x nominal diameter rough min.
  - Thread loads heavily skewed top
- Coarse Threads
  - Less likely to strip, threads are taller and stronger
  - Stronger in tension and and shear (kinda)
  - Better for small engagement length
- Fine Threads
  - Stronger in torsion
  - Better resist self-loosening
  - Provide greater mechanical advantage

Starrett® DECIMAL EQUIVALENTS

INCH/METRIC TAP DRILL SIZES & DECIMAL EQUIVALENTS

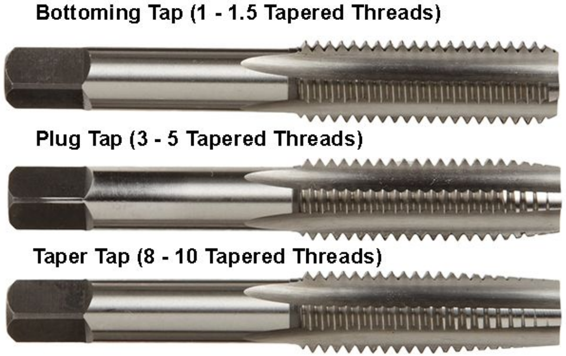
DRILL SIZE	DECIMAL EQUIV.	TAP SIZE
80	.0135	
79	.0145	
1/64	.0156	
78	.0160	
77	.0180	
76	.0200	
75	.0210	
74	.0225	
73	.0240	
72	.0250	
71	.0260	
70	.0280	
69	.0292	
68	.0310	
1/32	.0312	
67	.0320	
66	.0330	
65	.0350	
64	.0360	
63	.0370	
62	.0380	
61	.0390	
60	.0400	
59	.0410	
58	.0420	
57	.0430	
56	.0465	
3/64	.0469	0 - 80
55	.0520	
54	.0550	
53	.0595	1 -64, 72
1/16	.0625	
52	.0635	
51	.0670	
50	.0700	2 -56, 64
49	.0730	
48	.0760	
5/64	.0781	
47	.0785	3 - 48
46	.0810	
45	.0820	3 - 56
44	.0860	
43	.0890	4 - 40
42	.0935	4 - 48
3/32	.0938	
41	.0960	
40	.0980	
39	.0995	
38	.1015	5 - 40

DRILL SIZE	DECIMAL EQUIV.	TAP SIZE
37	.1040	5 - 44
36	.1065	6 - 32
7/64	.1094	
35	.1100	
34	.1110	
33	.1130	6 - 40
32	.1160	
31	.1200	
1/8	.1250	
30	.1285	
29	.1360	8 -32, 36
28	.1405	
9/64	.1406	
27	.1440	
26	.1470	
25	.1495	10 - 24
24	.1520	
23	.1540	
5/32	.1562	
22	.1570	
21	.1590	10 - 32
20	.1610	
19	.1660	
18	.1695	
11/64	.1719	
17	.1730	
16	.1770	12 - 24
15	.1800	
14	.1820	12 - 28
13	.1850	
3/16	.1875	
12	.1890	
11	.1910	
10	.1935	
9	.1960	
8	.1990	
7	.2010	1/4 - 20
13/64	.2031	
6	.2040	
5	.2055	
4	.2090	
3	.2130	1/4 - 28
7/32	.2188	
2	.2210	
1	.2280	
A	.2340	
15/64	.2344	
B	.2380	
C	.2420	

DRILL SIZE	DECIMAL EQUIV.	TAP SIZE
D	.2460	
1/4 E	.2500	
F	.2570	5/16 - 18
G	.2610	
17/64	.2656	
H	.2660	
I	.2720	5/16 - 24
J	.2770	
K	.2810	
9/32	.2812	
L	.2900	
M	.2950	
19/64	.2969	
N	.3020	
5/16	.3125	3/8 - 16
O	.3160	
P	.3230	
21/64	.3281	
Q	.3320	3/8 - 24
R	.3390	
11/32	.3438	
S	.3480	
T	.3580	
23/64	.3594	
U	.3680	7/16 - 14
3/8	.3750	
V	.3770	
W	.3860	
25/64	.3906	7/16 - 20
X	.3970	
Y	.4040	
13/32	.4062	
Z	.4130	
27/64	.4219	1/2 - 13
7/16	.4375	
29/64	.4531	1/2 - 20
15/32	.4688	
31/64	.4844	9/16 - 12
1/2	.5000	
33/64	.5156	9/16 - 18
17/32	.5312	5/8 - 11
35/64	.5469	
9/16	.5625	
37/64	.5781	5/8 - 18

also metric by eww

Threads Cutting and Forming

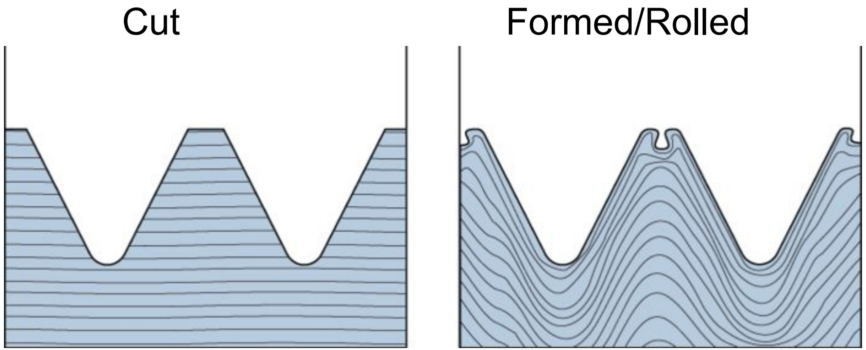


Formed Threads (as in bolts/nuts) are better

- Uninterrupted grain flow is stronger
- Larger shear area
- Better contact area

For in house production threads need to be cut either on the lathe or with a tap/die

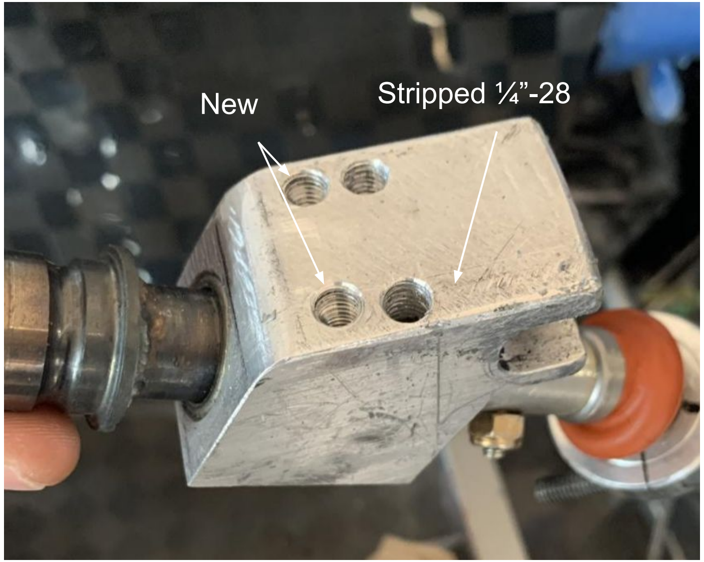
- Cutting threads into a blind hole is more times consuming
- Though adding a step to manufacturing makes assembly easier and reduces items on BOM
- Most stress is concentrated into first couple of threads
    - Diminishing return of added faster length



Threads

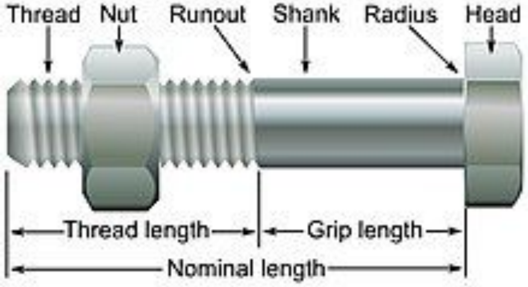
Group Analysis

I learned nothing :(Fail



Hardware Design Considerations

- Bolts from hardware store for example are often much weaker and lower quality
- Locking mechanism
  - Nylock, castle, jet, lockwire, etc.
- Meet ‘critical faster’ rules
- Keep drive type standard
  - We usually use internal/external hex
  - Avoid philip, flat, and other wear prone



Critical Fastener Cut-off

Mechanical Specifications for Externally Threaded Fasteners with Grade Markings

Specification	Material	Size Range (in.)	Min. Proof Strength (psi)	Min. Tensile Strength (psi)	Core Hardness Rockwell		Min. Yield Strength (psi)	Grade Identification Marking
					Min.	Max.		
SAE J429-Grade 1	Low or medium carbon steel	1/4 - 1 1/2	33,000	60,000	B70	B100	36,000	
SAE J429-Grade 2		1/4 - 3/4 7/8 - 1 1/2	55,000 33,000	74,000 60,000	B80 B70	B100 B100	57,000 36,000	
ASTM A307-Grade A	Low or medium carbon steel	1/4 - 4		60,000	B69	B100		307A
ASTM A307-Grade B	Low or medium carbon steel	1/4 - 4		60,000(min) 100,000(max)	B69	B95		307B
SAE J429-Grade 5 ASTM A449-Type1	Medium carbon steel: quenched & tempered	1/4 - 1 1 1/8 - 1 1/2	85,000 74,000	120,000 105,000	C25 C19	C34 C30	92,000 81,000	
ASTM A449-Type 1		1 3/4 - 3	55,000	90,000			58,000	
ASTM A325-Type 1	Medium carbon steel: quenched & tempered	1/2 - 1 1 1/8 - 1 1/2	85,000 74,000	120,000 105,000	C25 C19	C34 C30	92,000 81,000	A325
ASTM A354 Grade BC	Medium carbon alloy steel: quenched & tempered	1/4 - 2 1/2 Over 2 1/2 - 4	105,000 95,000	125,000 115,000	C26 C22	C36 C33	109,000 99,000	B C
ASTM A354 Grade BD	Medium carbon alloy steel: quenched & tempered	1/4 - 2 1/2 Over 2 1/2 - 4	120,000 105,000	150,000 140,000	C33 C31	C39 C39	130,000 115,000	B D See Note 1
SAE J429-Grade 8	Medium carbon alloy steel: quenched & tempered	1/4 - 1 1/2	120,000	150,000	C33	C39	130,000	
SAE J429-Grade 8.2	Low carbon boron steel: quenched & tempered	1/4 - 1	120,000	150,000	C33	C39	130,000	
ASTM A490-Type 1	Medium carbon alloy steel: quenched & tempered	1/2 - 1 1/2	120,000	150,000(min) 173,000(max)	C33	C39	130,000	A 490
ASTM A574 Alloy Steel Socket Head Cap Screw	Medium carbon alloy steel: quenched & tempered	#0 - 1/2 over 1/2 - 2	140,000 135,000	180,000 170,000	C39 C37	C45 C45	153,000	
ASTM F835 Alloy Steel Socket Button & Flat Countersunk Head Cap Screw	Medium carbon alloy steel: quenched & tempered	#0 – 1/2 Over 1/2		145,000 135,000	C39 C37	C44 C44		

Note 1: ASTM A354-Grade BD shall be marked “BD”, and in addition to “BD”, the product may be marked six radial lines 60° apart.

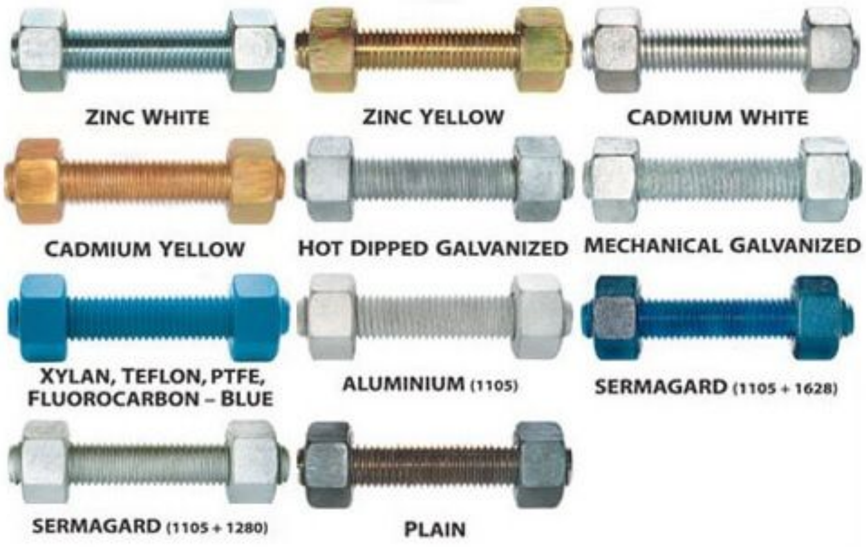
Hardware Material and Coating

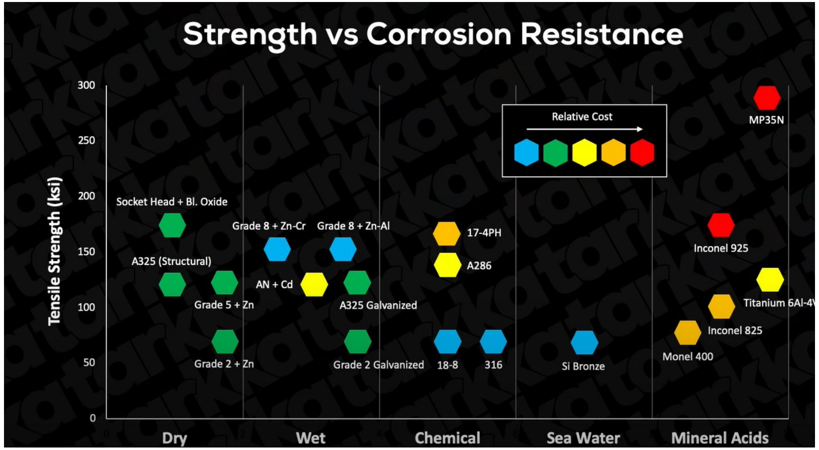
All hardware on car should be corrosion resistant we drive in rain (and rules)

- Cadmium is our coating a choice
- Black oxide may seem sufficient but should be avoided

Rarely is anything besides a medium carbon steel required, but here are some notable exceptions:

- Plastic hardware is electrically insulating
- Stainless steel is exceptionally corrosion resistant
- Aluminum and other soft metals don't hold threads well, particularly fine threads

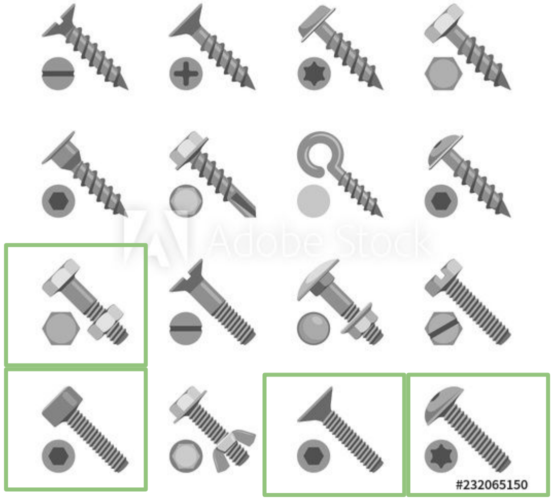




More Hardware

Many varieties of hardware used for:

- Locating part or feature (one dimension or multiple)
  - Pin, key, bearing
- Clamping and locking
  - Shaft collar, clamp,
- Applying force
  - Spring
- And so many more

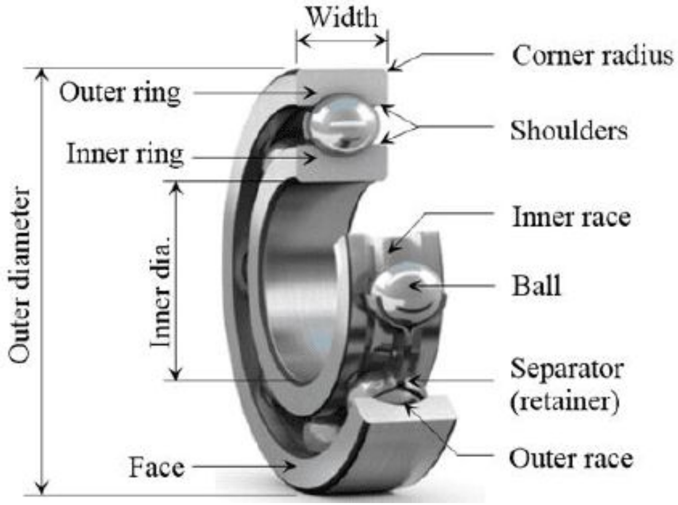


Bearings

Bearings come in many shapes and sizes but which one is right for you?

Bushings tend to be preferred for low speed high force applications
- Self lubricating options such as embedded oil
    - Plastic bushings for light applications
- Larger surface area reduce alignment problems
- Better suited for “shock loads”
- Cheaper and less moving parts, require less maintenance
- Tighter radial packaging, lighter weight
- Easier to install and replace

Bearings are better for high speed applications and are more highly specialised
- Lower rolling friction
- Precise alignment
- Come in large variety for specialty circumstances



Bearings

Roller Bearings

Roller bearings come in a huge variety to fit particular needs, and are often combined to meet all design requirements.

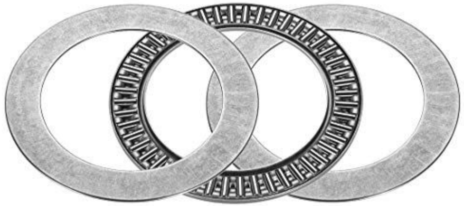
Problems Bearings Can Solve For You:

- High axial, radial, or combined loads
- Axial and radial alignment
- Dynamic misalignment
- High or low speed applications
- Temperature and sealing requirements
- Lubrication limitations (food industry)
- Stiffness
- Packaging

With great power also comes great responsibility. Bearings require precision and care to operate correctly.

Problems Bearings Create For You:

- Housings and shafts must be within tolerance
- Shaft axial displacement
- Combined bearings must be radially aligned
- High temperatures can damage bearings
- Contaminants must be kept out
- Proper lubrication must be applied and maintained
- Installed without damage (unintended loading)
- Proper preload (axial force alignment)
- Packaging



Bearings

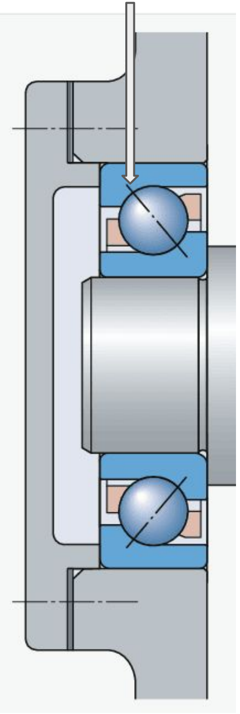
Roller Bearings

Suitability of rolling bearings for industrial applications

Symbols

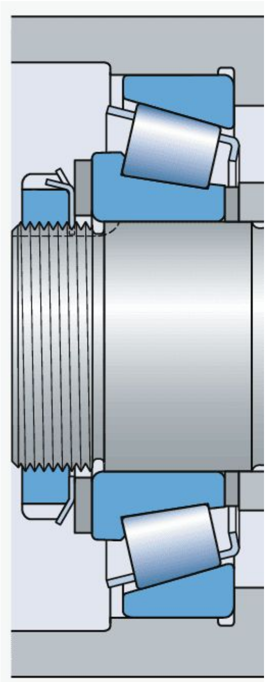
- +++ excellent
- ++ good
- \+ fair
- \- poor
- – – unsuitable
- ↔ double direction
- ← single direction
- □ non-locating displacement on the seat
- ■ non-locating displacement within the bearing
- ✓ yes
- ✗ no

Bearing type		Load carrying capability			Misalignment		Arrangement				Suitable for					Design features			
		Radial load	Axial load	Moment load	Static misalignment	Dynamic misalignment (few tenths of a degree)	Locating	Non-locating	Adjusted	Floating	Long grease life	High speed	Low run-out	High stiffness	Low friction	Integral sealing	Separable ring mounting	Tapered bore	Standard housings and accessories available
Deep groove ball bearings	A, B	+	+ ↔	A –, B +	–	– –	↔	□	✗	✓	A +++ B ++	A +++ B +	A +++ B ++	+	+++	A ✓	✗	✗	✗
Insert bearings	A, B, C	+	+ ↔	– –	++	– –	↔	↔	✗	✗	+++	++	A, B + C ++	+	++	✓	✗	✗	✓
Angular contact ball bearings, single row		+1)	++ ←	– –	–	– –	✗	✗	✓	✗	++	++	+++	++	++	✓	✗	✗	✗
matched single row	A, B, C	A, B ++ C ++1)	A, B ++ ↔ C ++ ←	A ++, B + C – –	A, C – –, B –	– –	A, B ↔ C ←	A, B □ C ✗	✗	✗	++	++	+++	++	++	✗	✗	✗	✗
double row	A, B	++	++ ↔	++	– –	– –	↔	□	✗	✗	++	++	++	++	++	A ✓	B ✓	✗	✗
four-point contact		+1)	++ ↔	– –	– –	– –	↔1)	– –	– –	– –	+	+++	++	++	++	✗	✓	✗	✗
Self-aligning ball bearings		+	–	– –	+++	+2)	↔	□	✗	✓	+++	++	++	+	+++	✓	✗	✓	✓
Cylindrical roller bearings, with cage	A, B	++	– –	– –	–	– –	✗	■	✗	✗	++	+++	+++	++	+++	✗	✓	✗	✗
	A, B, C, D	++	A, B + ← C, D + ↔	– –	–	– –	A, B ← C, D ↔	A, B ■ ← C, D ✗	✗	A ✓ B, C, D ✗	++3)	+++	++	++	+++	✗	✓	✗	✗
full complement, single row	A, B	+++	+ ←	– –	–	– –	←	A, B ←	✗	✓	–	+	+	+++	–	✗	A ✗ B ✓	✗	✗
full complement, double row	A, B, C, D	+++	A – –, B + ← C + ↔	– –	–	– –	B ← C, D ↔	A ■ ↔ B ■ ←	✗	✗	–	+	+	+++	–	D ✓	✗	✗	✗
Needle roller bearings, with steel rings	A, B, C	++	– –	– –	A, B – C ++	– –	✗	■ ↔	✗	✗	++	++	+	++	+	A ✓	✓	✗	✗
assemblies / drawn cups	A, B, C	++	A, B – – C –	– –	–	– –	A, B ✗ C ←	A, B ■ C ■ ←	✗	✗	++	++	+	++	+	B, C ✓	✓	✗	✗
combined bearings	A, B, C	++	A –, B + C ++	– –	– –	– –	←	✗	✓	✗	+	+	+	++	+	✗	✓	✗	✗
Tapered roller bearings, single row		+++1)	++ ←	– –	–	– –	←	✗	✓	✗	+	++	+++	++	+	✗	✓	✗	✗
matched single row	A, B, C	A, B +++ C +++1)	A, B ++ ↔ C ++ ←	A +, B ++ C – –	A – B, C – –	– –	A, B ↔ C ←	A, B □ C ✗	A, B ✗ C ✓	✗	+	+	++	+++	+	✗	✓	✗	✗
double row	A, B	+++	++ ↔	A + B ++	A –, B – –	– –	↔	□	✗	✗	+	+	++	+++	+	✓	✓	B ✓	✗
Spherical roller bearings		+++	+ ↔	– –	+++	+2)	↔	□	✗	✓	+	++	+++	++	+	✓	✗	✓	✓
CARB toroidal roller bearings, with cage		+++	– –	–	++	–	✗	■	✗	✗	+	++	+++	++	+	✗	✗	✓	✓
full complement		+++	– –	–	++	–	✗	■	✗	✗	–	+	+++	++	–	✓	✗	✓	✓
Thrust ball bearings	A, B	– –	A + ← B + ↔	– –	– –	– –	A ← B ↔	✗	✗	✗	+	–	++	+	+	✗	✓	✗	✗
with sphered housing washer	A, B	– –	A + ← B + ↔	– –	++	– –	A ← B ↔	✗	✗	✗	+	–	+	+	+	✗	✓	✗	✗
Cylindrical roller thrust bearings		– –	++ ←	– –	– –	– –	←	✗	✗	✗	–	–	+	+++	+	✗	✓	✗	✗
Needle roller thrust beairngs		– –	++ ←	– –	– –	– –	←	✗	✗	✗	–	–	+	+++	+	✗	✓	✗	✗
Spherical roller thrust bearings		+1)	+++ ←	– –	+++	+2)	←	✗	✓	✗	–	+	+	+++	+	✗	✓	✗	✗



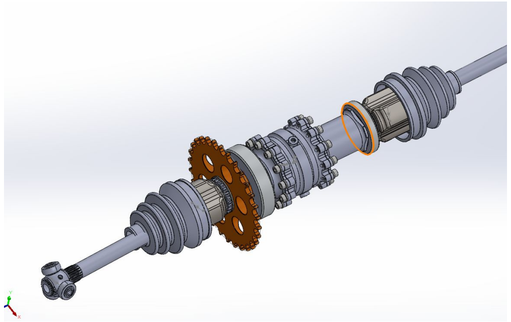
Angular contact bearing

Tapered roller bearing



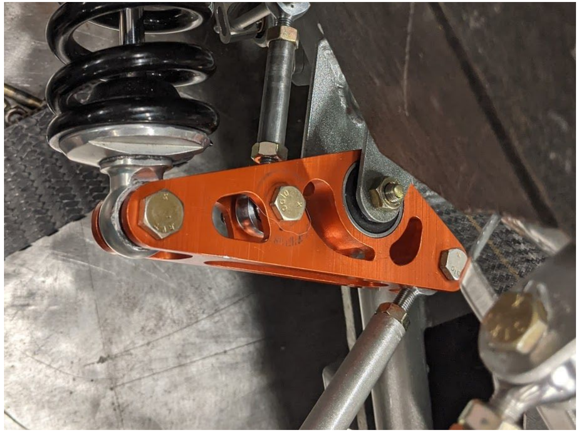
Bearings

Our Car Examples

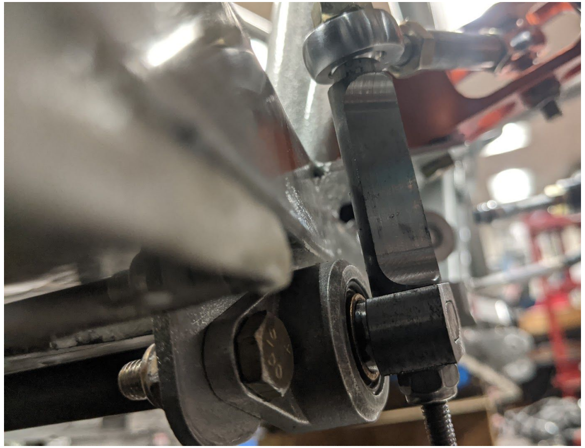


Differential Mounting

Deep groove ball bearing rocker pivot



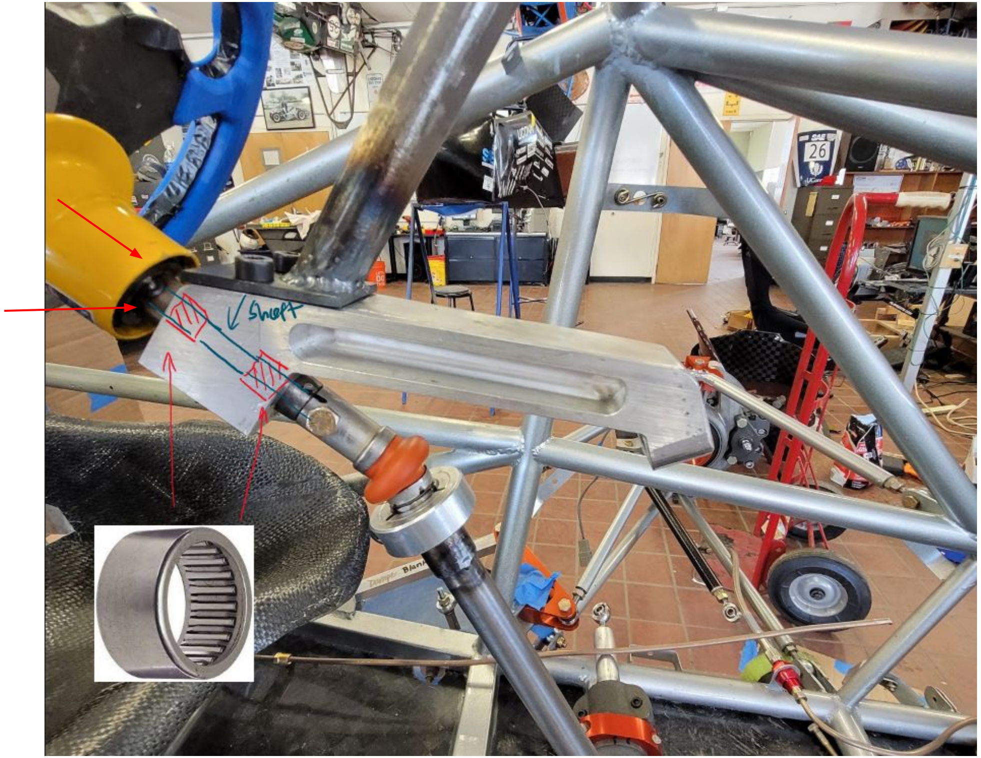
Mounted sintered bushing for ARB



Bearings

Group Analysis

This is wrong!

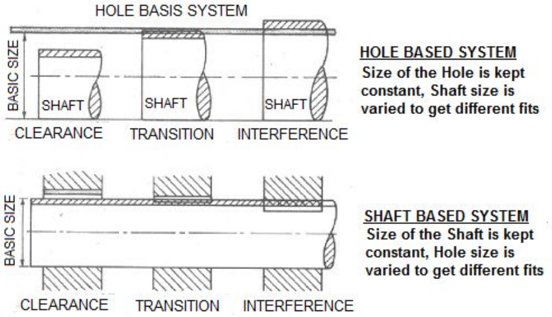


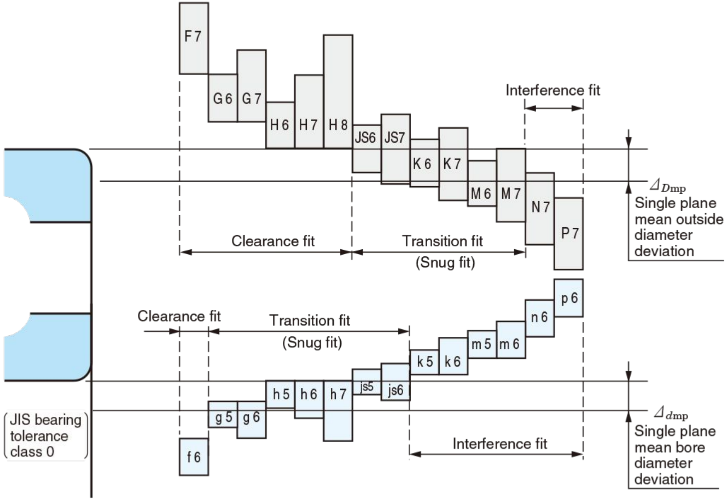
- What possible force types are being applied (radial, axial, both)?
- Advantages and disadvantages of this bearing combination?
- Is this design suitable, if not what changes should be made?

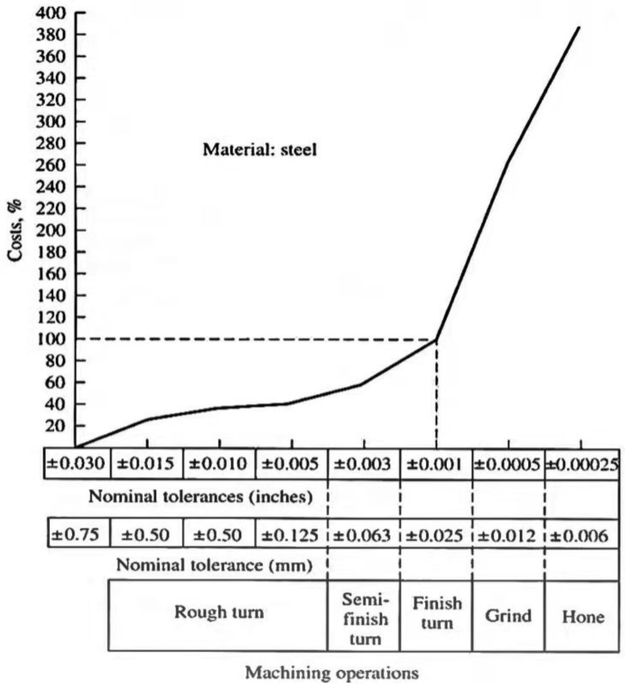
Fits and Tolerances

High tolerances are more expensive and require more skill. Higher tolerances rarely increase system quality in car unless dealing with bearings, high rpm, high forces, or wear.

- Important for moving or sliding parts
- Permanent or temporary assembly

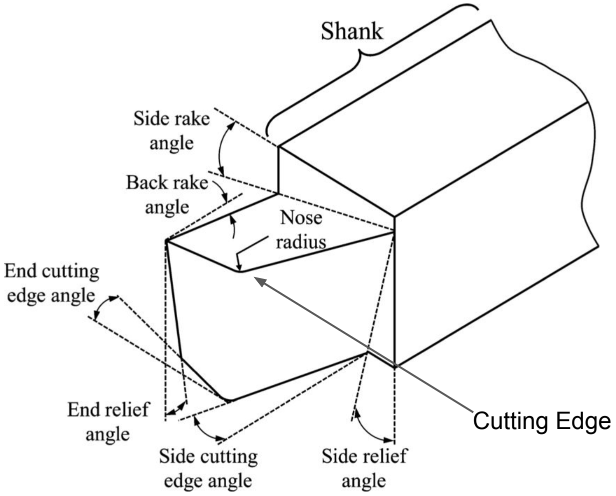


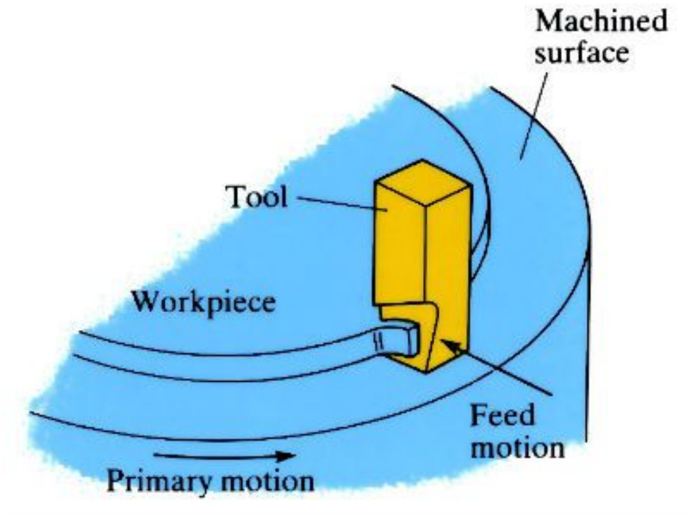




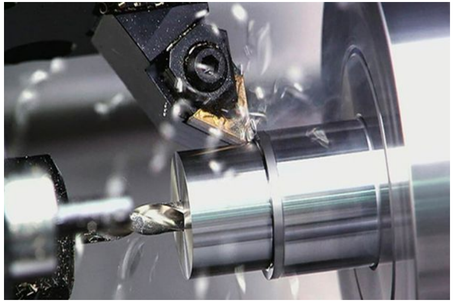
Machining How Do You Cut Metal?

We can cut metal with tools of equal or greater hardness. Typically in our machine shop that means high speed steel or tungsten carbide. Tool geometry is what lets you cut materials of equal hardness and increase cutting efficiency.





Machining Turning

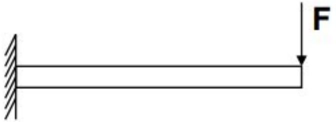


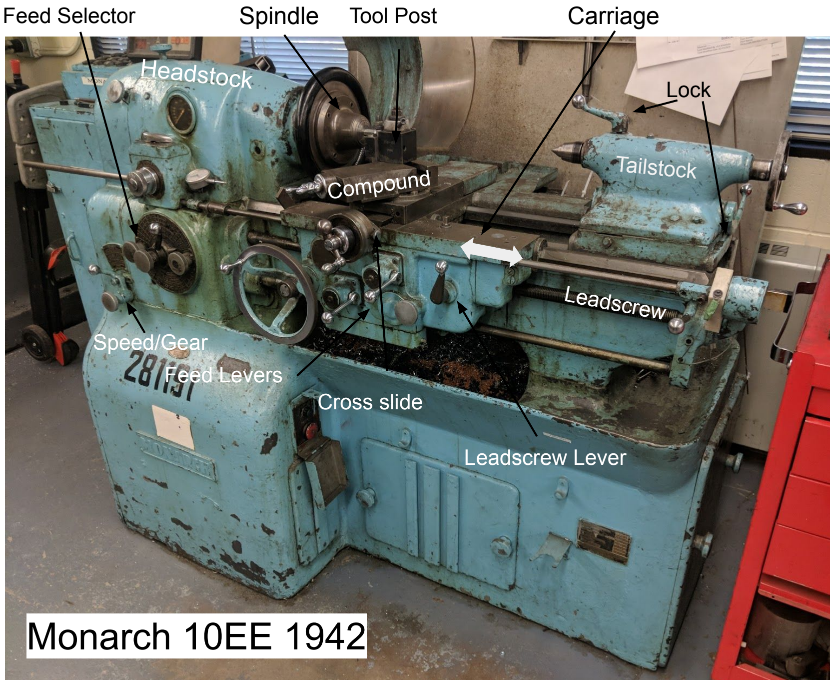
For making concentric and generally circle-y shapes. X/Y bed of machine locates single part cutter relative to the work.

- Cut threads
- Precise outer and inner diameters
- Shoulders
- Rounded shapes
- Tapers

Workholding matters and parts that require multiple lathe setups may sacrifice concentricity. Though this can be mitigated with a 4-jaw or collet chuck, or time.

- Reduce number of setups
- Reduce length to diameter ratio when cutting
- Deeps holes and threads will require chip clearing increasing time





Machining Milling

Considerations
- Machinability of material
- If CNC would be better
- Tolerances and tolerance stack
- Common mill tooling size
- Common stock size

When designing for manual mill things to avoid
- Large number of setups
- Setups that involve locating a hole or angle
- Outside radii and large interior radii
- Non standard fillets or chamfers
- Curves, arcs, and drafts
- Deep small features (that would require large length diameter ratio cutter)

Measuring and Precision

It is important to verify the accuracy of your parts and tools. As times is spent machining knowing what tools to use when will start to become clear. This is something I wish to elaborate on in future hands on examples.

For the most parts on the car high accuracy is not needed but the ability to check parts is a useful troubleshooting technique.

Group Design Example

Steering System

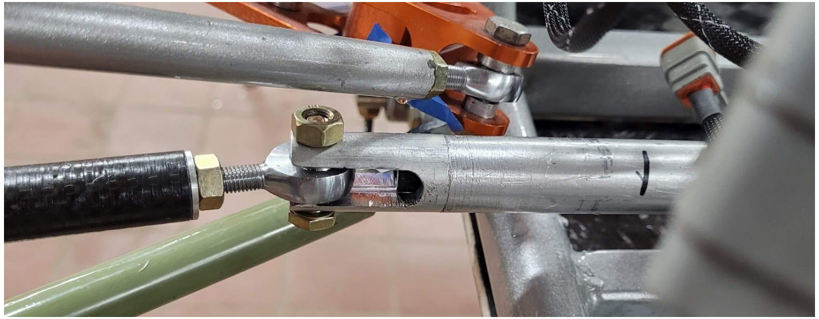
Parts / assemblies and hardware to:

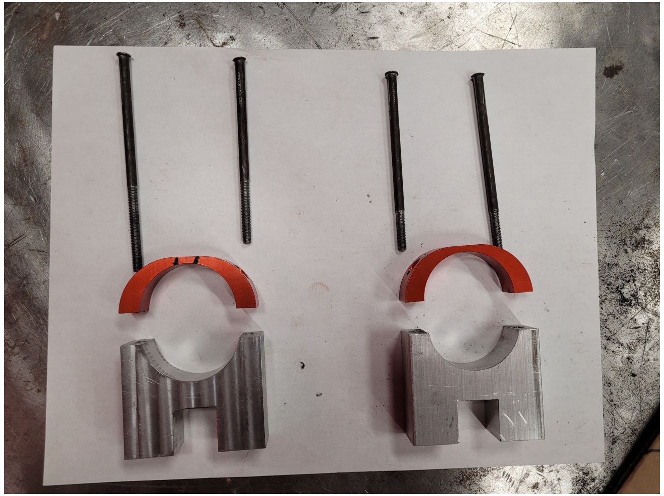
- Mount bearings from prior example
  - Tolerance requirements for housings?
    - +- x inches
  - Hardware to mount to chassis?
    - ¼ 20
- Bearing shaft requirements?
    -
- Column Connections
  - Axially locate shaft
  - Resists high torsional load
  - Low play and wear
- Mount rack to chassis
  - What hardware would be good fit?
    - 10-32
  - What process could be used to make brackets?

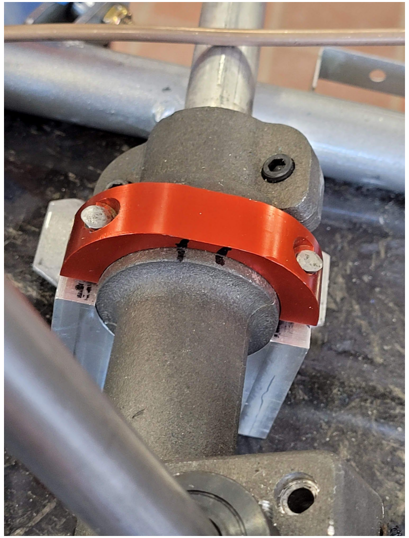
What manufacturing process are required and how precise for each part?

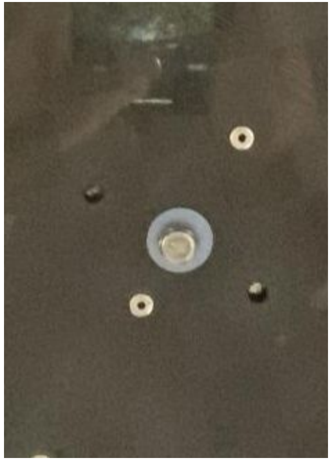
Group Design Example

Steering System









More resources

Nothing can replace experience but here is some entertaining videos that got me started

Dan Gelbart's Prototyping Series Design for manufacturing
https://www.youtube.com/user/dgelbart/videos

This Old Tony Machining Basics   Funny
https://www.youtube.com/playlist?list=PLNp7TZf13Bq7_U_n03ynKQOKGuk4H1VGF

Blondihacks Mill and Lathe Skills Introduction
https://www.youtube.com/playlist?list=PLY67-4BrEae9m8v20LNARIRl9Pd9bdFRZ
https://www.youtube.com/watch?v=H6Dnmd3lDzA&list=PLY67-4BrEae9Ad91LPRIhcLJM9fO-HJyN

Applied Science
https://www.youtube.com/channel/UCivA7_KLKWo43tFcCkFvydw/featured

Group Discussion

Comments, would people be interested in another virtual session? More of this less of that?

Composites manufacturing
Designing for manufacturing

Would people be interested in hands on portion? What do we want that to look like?
Project based

- Aero Projects
  - Bungs (Lathe project) (ez ~1hr)
  - Angle Plate (mill project) (ez ~2hr)
- Collet Block (mill and lathe) (hard ~5 hr)
- Hot Wire tensioner (lathe maybe mill?)
-

Open Discussion & Questions

Thank you!