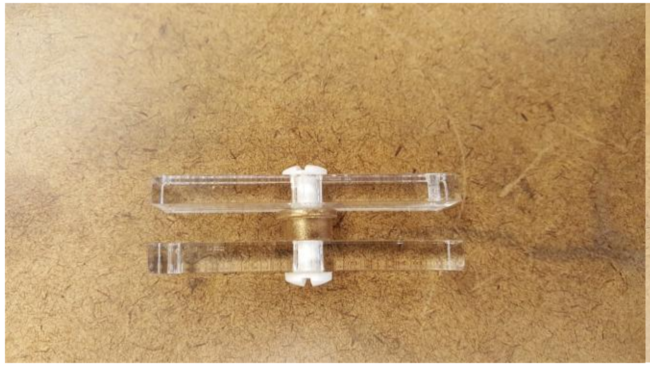
Examples of purchasable parts

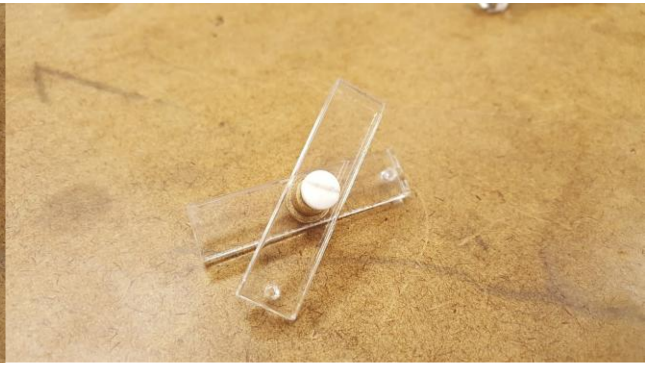
- The Innovation Studio has lots of common solutions available for these projects from previous semesters. Part numbers and prices available online; search parts for CAD files in incorporate into your design.
- Examples: Push nut, flanged bearing, sleeve bearing, shaft collar, binding post, 1/4" D-shaft (not shown).

(https://docs.google.com/spreadsheets/d/19iFsIeNSVlpb3mRsQ6xO_TIcKsF_Z2XOxtY5RyyS6aY/edit?gid=1904274958#gid=1904274958)

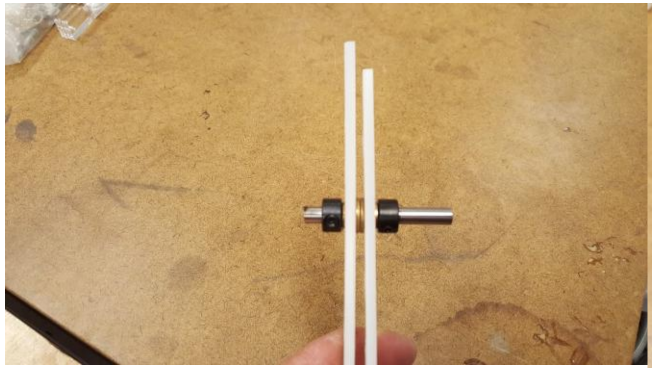
Construction examples using Studio components

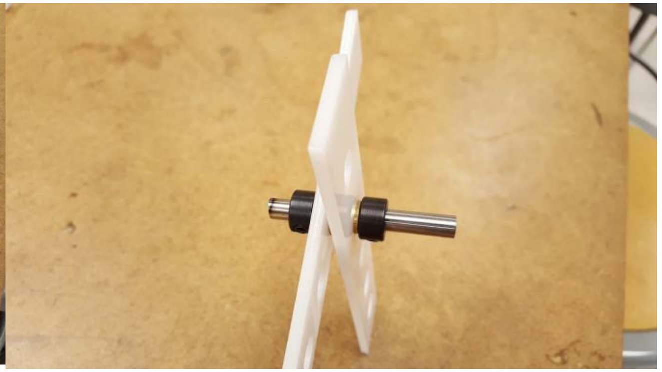
(Acrylic linkage with binding post shaft and flanged bearing separator)



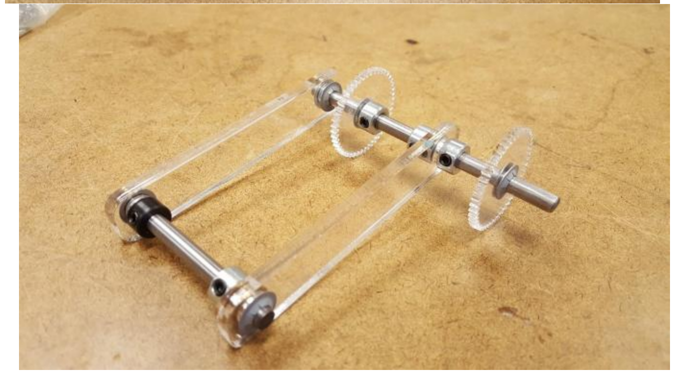


(Delrin linkage with round steel shaft using shaft collars and flanged bearings.)





(Part of Transmission Mechanism using laser cut acrylic gears, shaft collars, shaft, flanged bearing, push nuts, D-shaft for gears)



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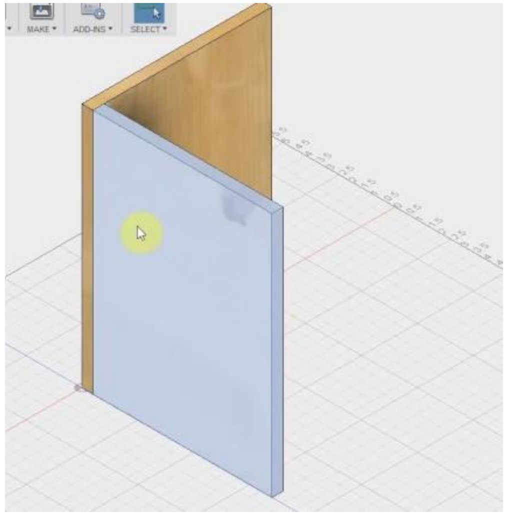
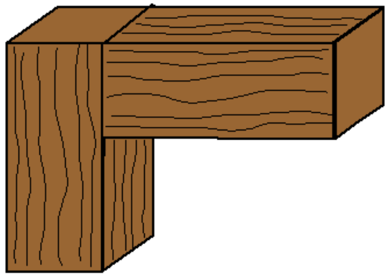
Terminology pointers

- Delrin = Dupont tradename for acetal plastic (engineering thermoplastic with high stiffness, low friction, excellent dimensional stability). Cost at Innovation Studio: 24” x 12” x ¼” = $20.
- Acrylic sheet = often called plexiglass, outstanding strength, stiffness, and optical clarity. **Acrylic sheet** is easy to fabricate, bonds well with adhesives and solvents, and is easy to thermoform. It has superior weathering properties compared to many other transparent plastics. Cost at Innovation Studio: 24” x 12” x ¼” = $20

Mechanism Manufacture: Practical considerations

- 3D Printers vs. Laser Cutters
  - Materials
  - Precision
  - Time
- Attaching frame & components
  - Adhesives
    - Do not use as only source of bonding parts! Use screws for durability.
    - Poor bonding, irreversible, can be contaminated
  - Brackets & shafts
    - Poor precision, wobbly, expensive
    - Do not use brackets, which are structural, for mechanical components.





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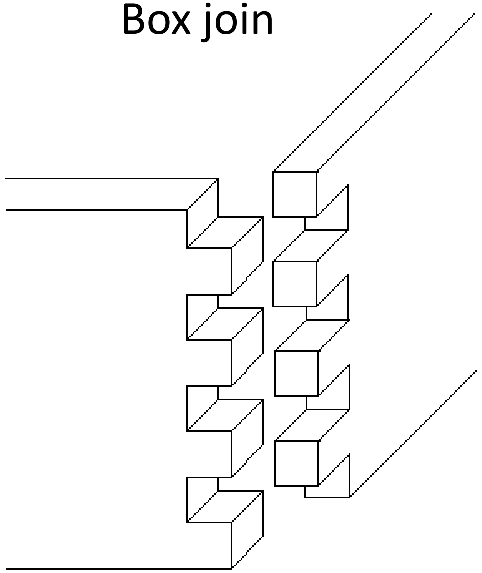
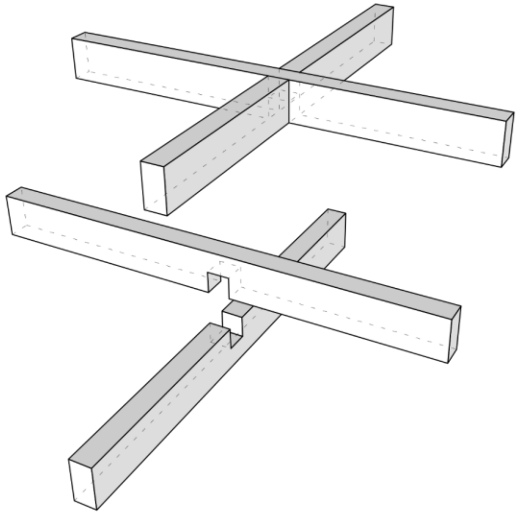
Joinery- borrowed from woodworking

- Design holes, slots & grooves into your CAD components
- Highly conducive to laser cutting
- Self aligns components
- Adds mechanical rigidity
- Allows alignment of shaft holes
- Can use screws to hold components together
- Remember to add pilot holes for screws!

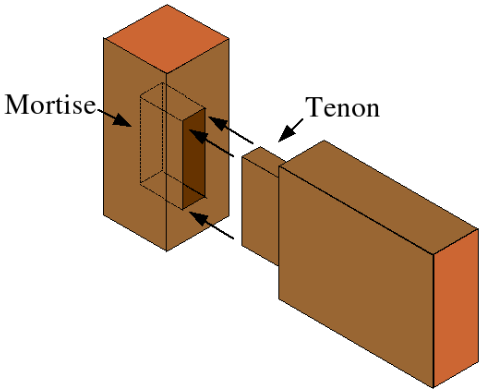
Box join



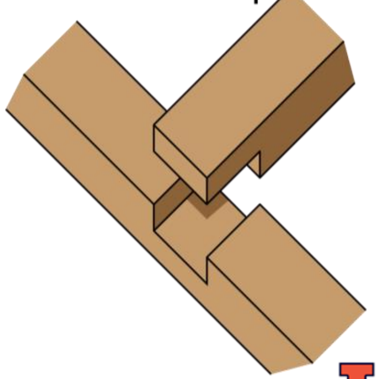
Lap join



Mortise & Tenon



Cross Lap



How to choose the drill bit size (reference)

Imperial Tap Drill Chart

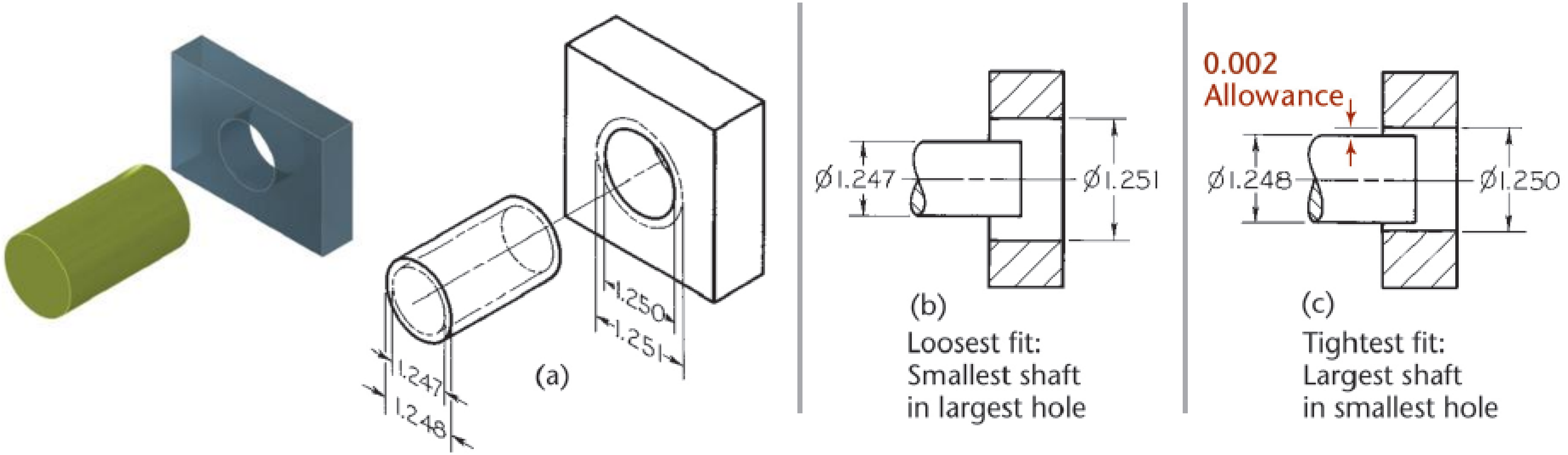
Machine Screw Size: No. or Dia.	Machine Screw Size: Major Dia.	Number of Threads Per Inch	Minor Dia.	Tap Drills – Aluminum, Brass & Plastics, 75% Thread: Drill Size	Tap Drills – Aluminum, Brass & Plastics, 75% Thread: Decimal Equiv.	Tap Drills – Stainless Steel, Steels & Iron, 50% Thread: Drill Size	Tap Drills – Stainless Steel, Steels & Iron, 50% Thread: Decimal Equiv.	Clearance Hole Drills – All Materials, Close Fit: Drill Size	Clearance Hole Drills – All Materials, Close Fit: Decimal Equiv.	Clearance Hole Drills – All Materials, Free Fit: Drill Size	Clearance Hole Drills – All Materials, Free Fit: Decimal Equiv.
0	.0600	80	.0447	3/64	.0469	55	.0520	52	.0635	50	.0700
1	.0730	64	.0538	53	.0595	1/16	.0625	48	.0760	46	.0810
		72	.0560	53	.0595	52	.0635				
2	.0860	56	.0641	50	.0700	49	.0730	43	.0890	41	.0960
		64	.0668	50	.0700	48	.0760				
3	.0990	48	.0734	47	.0785	44	.0860	37	.1040	35	.1100
		56	.0771	45	.0820	43	.0890				
4	.1120	40	.0813	43	.0890	41	.0960	32	.1160	30	.1285
		48	.0864	42	.0935	40	.0980				
5	.1250	40	.0943	38	.1015	7/64	.1094	30	.1285	29	.1360
		44	.0971	37	.1040	35	.1100				
6	.1380	32	.0997	36	.1065	32	.1160	27	.1440	25	.1495
		40	.1073	33	.1130	31	.1200				
8	.1640	32	.1257	29	.1360	27	.1440	18	.1695	16	.1770
		36	.1299	29	.1360	26	.1470				
10	.1900	24	.1389	25	.1495	20	.1610	9	.1960	7	.2010
		32	.1517	21	.1590	18	.1695				
12	.2160	24	.1649	16	.1770	12	.1890	2	.2210	1	.2280
		28	.1722	14	.1820	10	.1935				
		32	.1777	13	.1850	9	.1960				
1/4	.2500	20	.1887	7	.2010	7/32	.2188	F	.2570	H	.2660
		28	.2062	3	.2130	1	.2280				
		32	.2117	7/32	.2188	1	.2280				
5/16	.3125	18	.2443	F	.2570	J	.2770	P	.3230	Q	.3320
		24	.2614	I	.2720	9/32	.2812				
		32	.2742	9/32	.2812	L	.2900				
3/8	.3750	16	.2983	5/16	.3125	Q	.3320	W	.3860	X	.3970
		24	.3239	Q	.3320	S	.3480				

Metric Tap & Clearance Drill Sizes

Screw Size (mm)	Thread Pitch (mm)	Tap Drill – 75% Thread for Aluminum, Brass, & Plastics: Drill Size (mm)	Tap Drill – 75% Thread: Closest American Drill	Tap Drill – 50% Thread for Steel, Stainless, & Iron: Drill Size (mm)	Tap Drill – 50% Thread: Closest American Drill	Clearance Drill – Close Fit: Drill Size (mm)	Clearance Drill – Close Fit: Closest American Drill	Clearance Drill – Standard Fit: Drill Size (mm)	Clearance Drill – Standard Fit: Closest American Drill
M1.5	0.35	1.15	56	1.25	55	1.60	1/16	1.65	52
M1.6	0.35	1.25	55	1.35	54	1.70	51	1.75	50
M 1.8	0.35	1.45	53	1.55	1/16	1.90	49	2.00	5/64
M 2	0.45	1.55	1/16	1.70	51	2.10	45	2.20	44
	0.40	1.60	52	1.75	50				
M 2.2	0.45	1.75	50	1.90	48	2.30	3/32	2.40	41
M 2.5	0.45	2.05	46	2.20	44	2.65	37	2.75	7/64
M 3	0.60	2.40	41	2.60	37	3.15	1/8	3.30	30
	0.50	2.50	39	2.70	36				
M 3.5	0.60	2.90	32	3.10	31	3.70	27	3.85	24
M 4	0.75	3.25	30	3.50	28	4.20	19	4.40	17
	0.70	3.30	30	3.50	28				
M 4.5	0.75	3.75	25	4.00	22	4.75	13	5.00	9
M 5	1.00	4.00	21	4.40	11/64	5.25	5	5.50	7/32
	0.90	4.10	20	4.40	17				
	0.80	4.20	19	4.50	16				
M 5.5	0.90	4.60	14	4.90	10	5.80	1	6.10	B
M 6	1.00	5.00	8	5.40	4	6.30	E	6.60	G
	0.75	5.25	4	5.50	7/32				
M 7	1.00	6.00	B	6.40	E	7.40	L	7.70	N
	0.75	6.25	D	6.50	F				
M 8	1.25	6.80	H	7.20	J	8.40	Q	8.80	S
	1.00	7.00	J	7.40	L				
M 9	1.25	7.80	N	8.20	P	9.50	3/8	9.90	25/64
	1.00	8.00	O	8.40	21/64				
M 10	1.50	8.50	R	9.00	T	10.50	Z	11.00	7/16
	1.25	8.80	11/32	9.20	23/64				
	1.00	9.00	T	9.40	U				
M 11	1.50	9.50	3/8	10.00	X	11.60	29/64	12.10	15/32
M 12	1.75	10.30	13/32	10.90	27/64	12.60	1/2	13.20	33/64
	1.50	10.50	Z	11.00	7/16				
	1.25	10.80	27/64	11.20	7/16				
M 14	2.00	12.10	15/32	12.70	1/2	14.75	37/64	15.50	39/64
	1.50	12.50	1/2	13.00	33/64				
	1.25	12.80	1/2	13.20	33/64				
M 15	1.50	13.50	17/32	14.00	35/64	15.75	5/8	16.50	21/32
M 16	2.00	14.00	35/64	14.75	37/64	16.75	21/32	17.50	11/16
	1.50	14.50	37/64	15.00	19/32				
M 17	1.50	15.50	39/64	16.00	5/8	18.00	45/64	18.50	47/64
M 18	2.50	15.50	39/64	16.50	41/64	19.00	3/4	20.00	25/32
	2.00	16.00	5/8	16.75	21/32				
	1.50	16.50	21/32	17.00	43/64				
M 19	2.50	16.50	21/32	17.50	11/16	20.00	25/32	21.00	53/64
M 20	2.50	17.50	11/16	18.50	23/32	21.00	53/64	22.00	55/64
	2.00	18.00	45/64	18.50	47/64				
	1.50	18.50	47/64	19.00	3/4				

Fits between mating parts

- When a shaft/pin is inserted into a hole, the fit between them is determined by their limit dimensions.



Shaft tolerance = 1.248 – 1.247 = 0.001

Hole tolerance = 1.251 – 1.250 = 0.001

Allowance = 1.250 – 1.248 = 0.002

Max clearance = 1.251 – 1.247 = 0.004

IT Standards

- "International Tolerance"
- Need for standardization

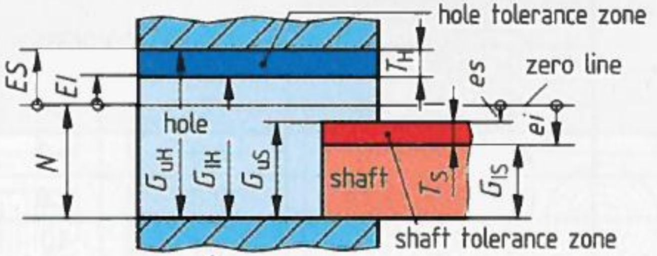
Example:
http://mdmetric.com/Ch6.8wGO.pdf

ISO system of limits and fits

Terms cf. DIN ISO 286-1 (1990-11)

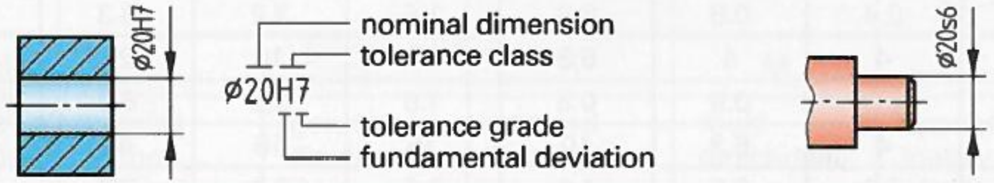
Hole

N	nominal size
G_{uH}	hole max. dimension
G_{lH}	hole min. dimension
ES	hole upper deviation
EI	hole lower deviation
T_H	hole tolerance



shaft

N	nominal dimension
G_{uS}	shaft max. dimension
G_{lS}	shaft min. dimension
es	shaft upper deviation
ei	shaft lower deviation
T_S	shaft tolerance



Designation	Explanation	Designation	Explanation
Zero line	It represents the nominal dimension that is referenced by the deviations and tolerances.	**Fundament. tolerance grade**	A group of tolerances assigned to same level of precision, e.g IT7.
Fundamental deviation	The fund. deviation determin. the position of the tolerance zone with resp. to the zero line.	**Tolerance grade**	Number of the fundamental tol. grade, e.g. 7 for the fundamental tolerance grade IT7.
Tolerance	Difference between the max. and the min. dimension or between the upper and lower deviation.	**Tolerance class**	Name for a combination of a fundamental deviation and a tolerance grade, e.g. H7.
Fundamental tolerance	A tolerance assigned to a fundamental tolerance grade, e.g. IT7 and a nominal dimension range, e.g. 30 to 50 mm.	**Fit**	Planned joining condition between hole and shaft.

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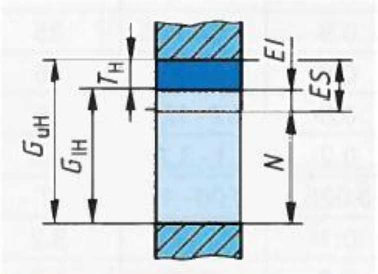
General fit types and subtypes

Limits, deviations and tolerances

cf. DIN ISO 286-1 (1990-11)

Hole



$$G_{uH} = N + ES$$

$$G_{lH} = N + EI$$

$$T_H = ES - EI$$

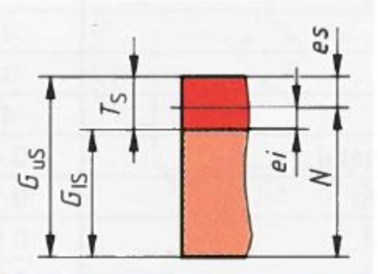
$$T_H = G_{uH} - G_{lH}$$

Example: Hole ∅50 + 0.3/+ 0.1; G_{uH} = ?; T_H = ?

$G_{uH} = N + ES = 50\ \text{mm} + 0.3\ \text{mm} = 50.30\ \text{mm}$

$T_H = ES - EI = 0.3\ \text{mm} - 0.1\ \text{mm} = 0.2\ \text{mm}$

Shaft



$$G_{uS} = N + es$$

$$G_{lS} = N + ei$$

$$T_S = es - ei$$

$$T_S = G_{uS} - G_{lS}$$

Example: Shaft ∅20e8; G_{lS} = ?; T_S = ?

For values for *ei* and *es* see page 107.

$ei = -73\ \mu m = -0.073\ \text{mm};\quad es = -40\ \mu m = -0.040\ \text{mm}$

$G_{lS} = N + ei = 20\ \text{mm} + (-0.073\ \text{mm}) = 19.927\ \text{mm}$

$T_S = es - ei = -40\ \mu m - (-73\ \mu m) = 33\ \mu m$

Hole

N	nominal size
G_{uH}	hole max. dimension
G_{lH}	hole min. dimension
ES	hole upper deviation
EI	hole lower deviation
T_H	hole tolerance

shaft

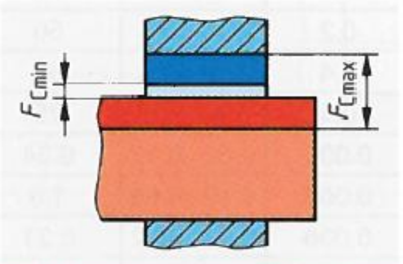
N	nominal dimension
G_{uS}	shaft max. dimension
G_{lS}	shaft min. dimension
es	shaft upper deviation
ei	shaft lower deviation
T_S	shaft tolerance

Fits

cf. DIN ISO 286-1 (1990-11)

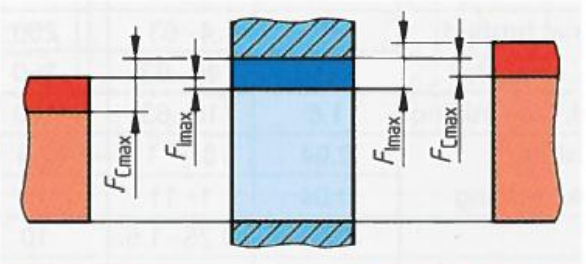
Clearance fit

F_{Cmax} max. clearance
F_{Cmin} min. clearance



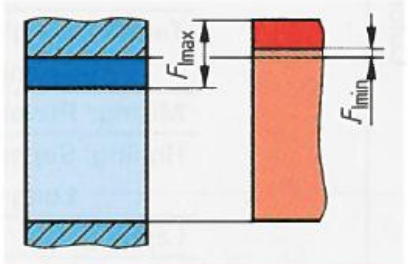
Transition fit

F_{Cmax} max. clearance
F_{Imax} max. interference



Interference fit

F_{Imax} max. interference
F_{Imin} min. interference



$$F_{Cmin} = G_{lH} - G_{uS}$$

$$F_{Cmax} = G_{uH} - G_{lS}$$

$$F_{Imax} = G_{lH} - G_{uS}$$

$$F_{Imin} = G_{uH} - G_{lS}$$

Example: Fit ∅30 H8/f7; F_{Cmax} = ?; F_{Cmin} = ?

For values for *ES, EI, es, ei* see page 107.

$G_{uH} = N + ES = 30\ \text{mm} + 0.033\ \text{mm} = 30.033\ \text{mm}$

$G_{lH} = N + EI = 30\ \text{mm} + 0\ \text{mm} = 30.000\ \text{mm}$

$G_{uS} = N + es = 30\ \text{mm} + (-0.020\ \text{mm}) = 29.980\ \text{mm}$

$G_{lS} = N + ei = 30\ \text{mm} + (-0.041\ \text{mm}) = 29.959\ \text{mm}$

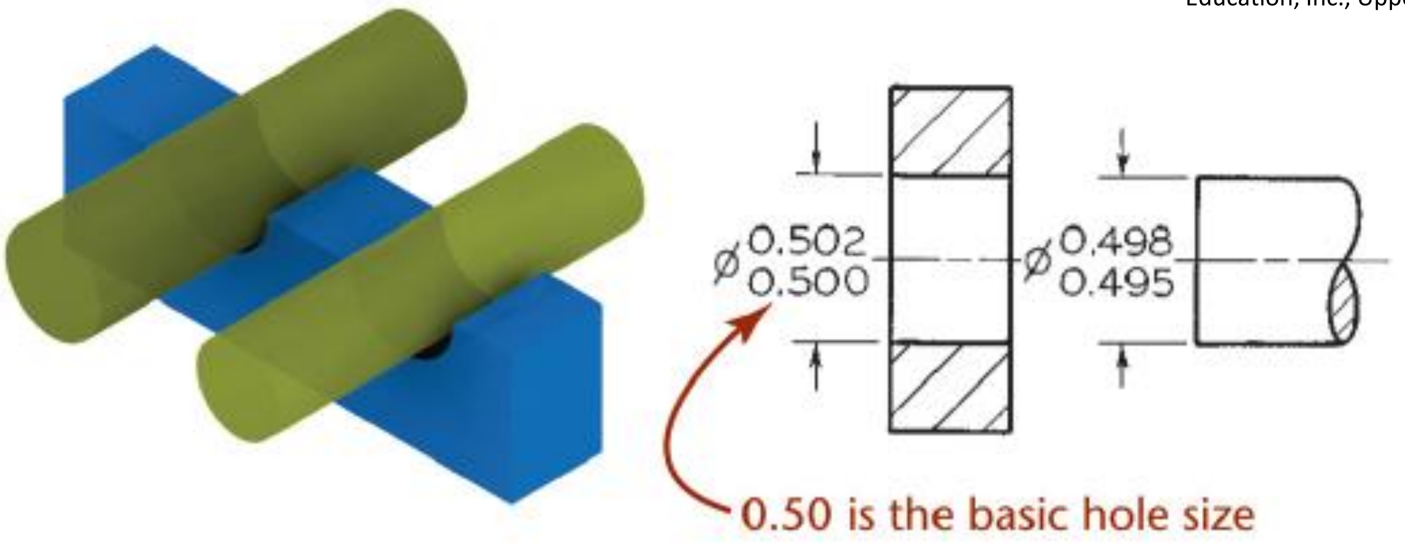
$F_{Cmax} = G_{uH} - G_{lS} = 30.033\ \text{mm} - 29.959\ \text{mm} = 0.074\ \text{mm}$

$F_{Cmin} = G_{lH} - G_{uS} = 30.000\ \text{mm} - 29.980\ \text{mm} = 0.02\ \text{mm}$

The Hole Base system (H-hole)

- Minimum hole size is the nominal dimension
- Hole Base is preferred because of use of drill bits and reamers

(Lockhart, Shawna D.; Johnson, Cindy M., *Engineering Design Communication: Conveying Design Through Graphics, 1st, © 2000. Printed and* electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.)



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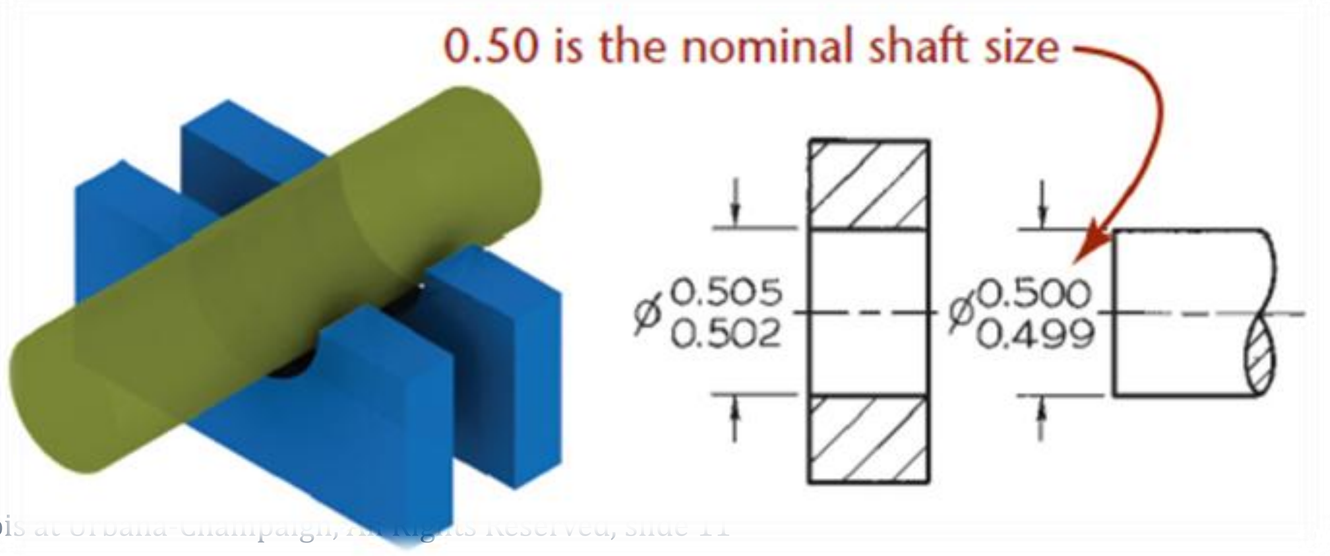
The Shaft Base system (h-shaft)

- Maximum shaft diameter is nominal dimension
- Used when purchasing standard shafts or pin
- Need to measure shaft or pin before specifying hole size
- Hole is tailored to size using lathe or laser



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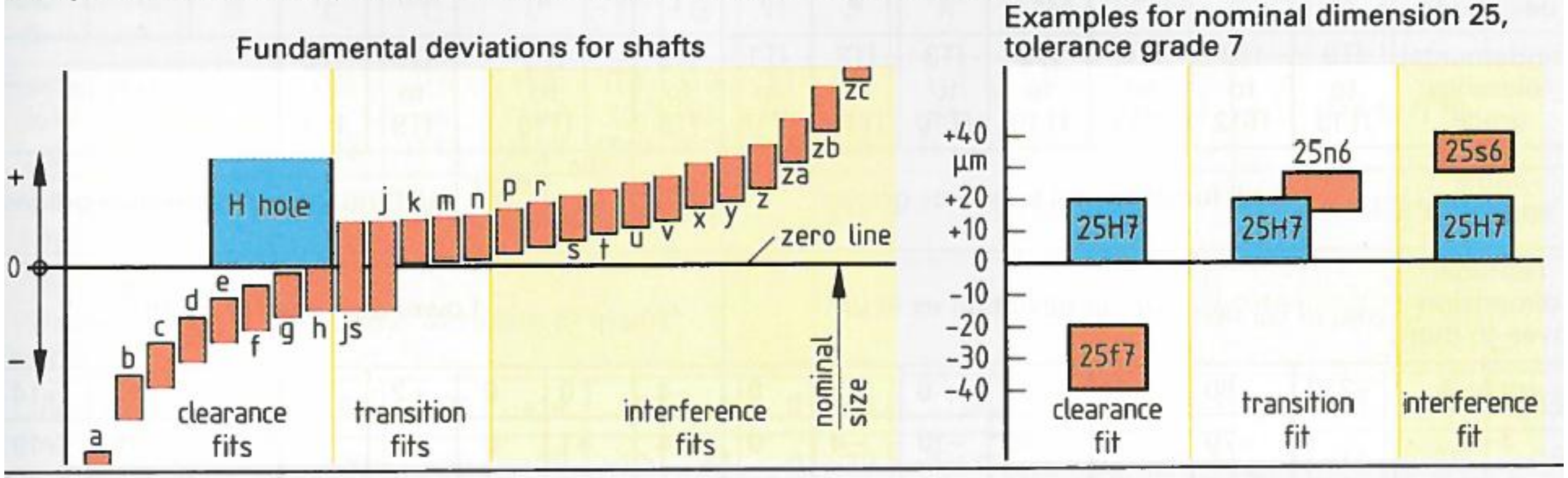
ISO system of limits and fits

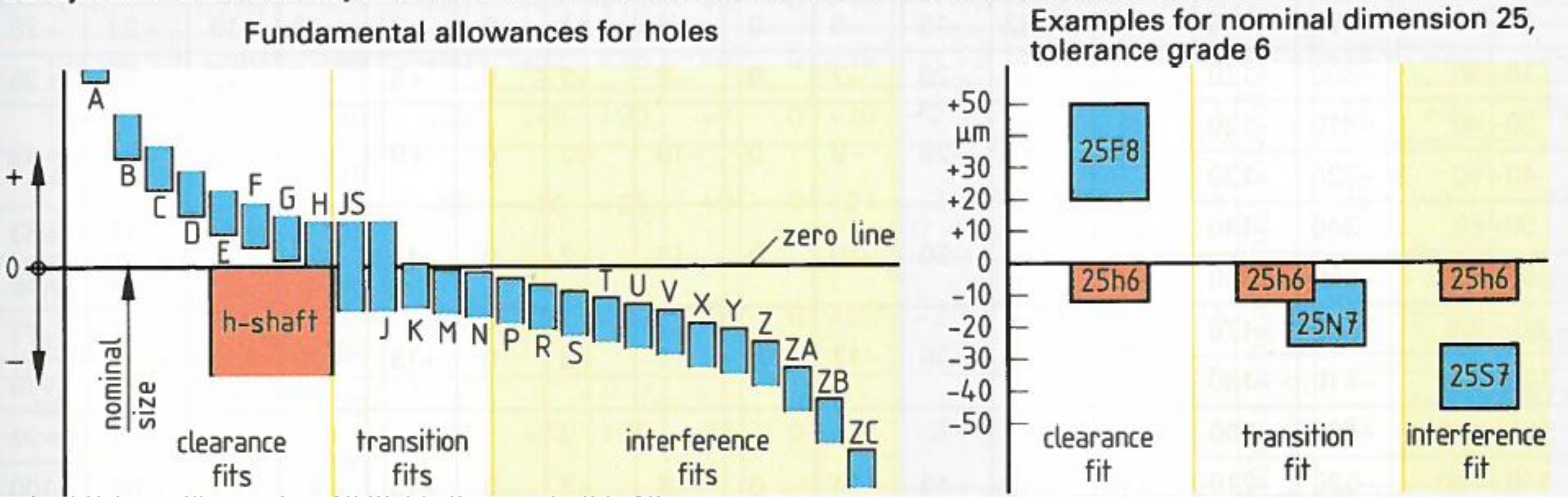
Fit systems

cf. DIN ISO 286-1 (1990-11)

Fit system: basic hole system (all hole dimensions have the fundamental deviation H)



Fit system: basic shaft system (all shaft dimensions have the fundamental deviation h)



Recommendations (good reference)

Fit recommendations, possible fits

Fit recommendations[1] — cf. DIN 7157 (1966-01)

From row 1	C11/h9, D10/h9, E9/h9, F8/h9, H8/f7, F8/h6, H7/f7, H8/h9, H7/h6, H7/n6, H7/r6, H8/x8 or u8
From row 2	C11/h11, D10/h11, H8/d9, H8/e8, H7/g6, G7/h6, H11/h9, H7/j6, H7/k6, H7/s6

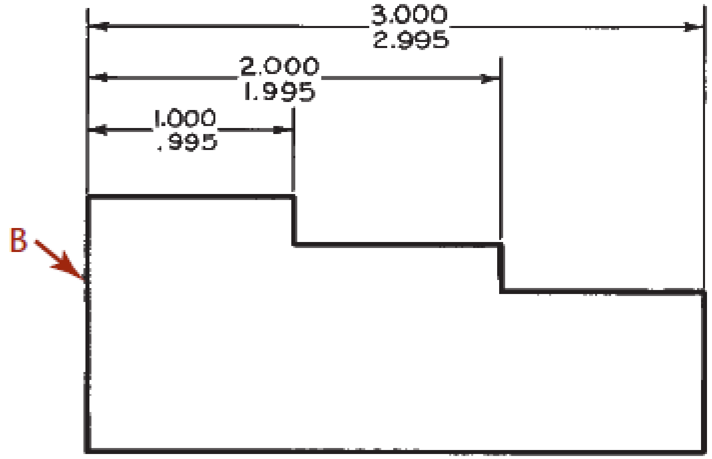
Possible fits (examples) — cf. DIN 7157 (1966-01)

Basic hole[2]	Characteristic/application examples	Basic shaft[2]
	Clearance fits	
H8/d9	**Loose running fit** Clearance allows for loose fit of mating parts. (i.e. spacer sleeves on shafts)	**D10/h9**
H8/e8	**Free running fit (Medium running fit):** Sufficient clearance is allowed for ease of assembly. (i.e. collar on shaft)	**E9/h9**
H8/f7	**Close running fit:** Clearance allows for parts to be easily assembled by hand while maintaining location accuracy. (i.e. plain bearing of shaft)	**F8/h9**
H7/f7	**Sliding fit – free:** Clearance allows accurate location and free movement, including turning. (i.e. piston valves in cylinders)	**F8/h6**
H7/g6	**Sliding fit – constrained:** Clearance allows better locational accuracy while still allowing sliding or turning movement. (i.e. transmission gear on shaft)	G7/h6
H8/h9	**Minimal clearance fit:** Allows locational accuracy and hand force assembly without being a snug fit. (i.e. spacer sleeves)	**H8/h9**
H7/h6	**Locational clearance fit:** Allows snug fit of stationary parts that may be assembled by hand force. (i.e. punch in punch holder)	**H7/h6**
	Transition fits	
H7/j6	**Locational transition fit – clearance:** For accurate location allowing more clearance than interference. (i.e. gears on shafts)	not specified
H7/n6	**Locational transition fit – interference:** For accurate location where interference is permissible. (i.e. drill bushing in jigs)	not specified
	Interference fits	
H7/r6	**Locational interference fit:** For rigidity and alignment/accurate location without special bore requirements. (i.e. bushings in housings)	not specified
H7/s6	**Medium drive fit:** For ordinary steel parts or shrink fits of light sections. Tightest fit possible for cast iron. (i.e. plain bearing bushings)	not specified
H8/u8	**Force fit:** For parts fitting that can withstand high mechanical pressing force or shrink fitting. (i.e. wheel on axle)	not specified
H8/x8	**Extreme force fit:** For parts that can only be assembled by stretching or shrinking. (i.e. turbine blade on shaft)	not specified

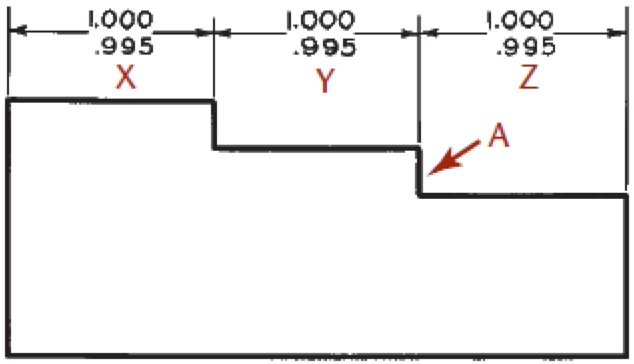
[1] Deviations from these fit recommendations should only be made in exceptional cases, e.g. installation of roller bearings.
[2] The fits in **bold** print are tolerance combinations according to row 1. Their use is preferred.

Tolerance stacking

- A ***Chained dimension*** uses the end of one dimension as the beginning of the next.
- ***Tolerance stacking*** refers to the way the tolerance for one dimension is added to the next dimension in the chain and so on from one feature to the next, resulting in a large variation in the location of the last feature in the chain.



(b) Baseline dimensioning



(a) Chained or continued dimensioning

(Preferred practice) Baseline dimensioning locates a series of features from a common base feature. Tolerances do not stack up because dimensions are not based on other tolerance dimensions.

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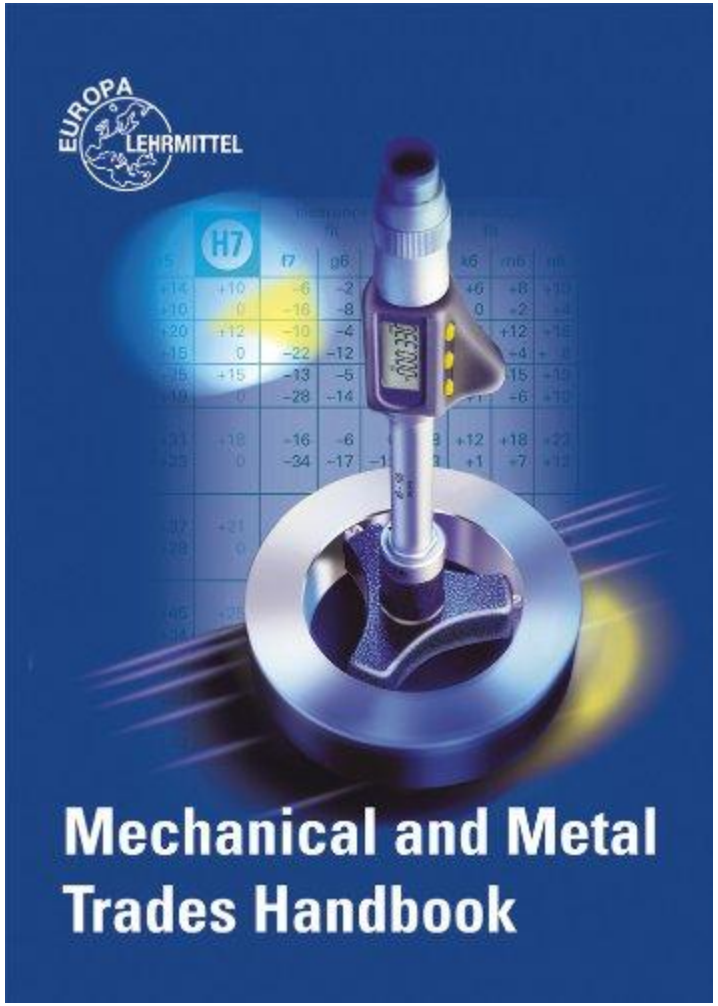
Reference text available in Innovation Studio



http://www.amazon.com/Mechanical-Trades-Handbook-Ulrich-Fischer/dp/3808519134#

Additional reference (but not in Studio):
Technical Drawing with Engineering Graphics 14^{th} Ed. (Giesecke et al.)
Chapter 11 – Tolerancing
http://www.amazon.com/Technical-Drawing-Engineering-Graphics-14th/dp/0135090490/ref=sr_1_1?s=books&ie=UTF8&qid=1411745308&sr=1-1&keywords=technical+drawing+with+engineering+graphics+14th+edition

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