2.810 – Homework # 1

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1.1: Understanding Engineering Drawings/Process Plans

a) Please explain the "feature control frames" in the engineering drawing for the connecting link, Fig. 1.1 (attached at back).

b) Sketch (hand sketch is OK) an isometric view of this part.

c) What machining processes (beyond turning and milling) might be needed to meet the requirements given in the feature frames?

d) What does the notation "MATERIAL:Drill Rod:RC 48-52" mean? How will this affect the process?

e) Write a process plan to make a peanut butter and jelly sandwich. How would it change if you had to make peanut butter and jelly sandwiches in high volumes?

Refer to *Part Drawing of Connecting Link* at the end of this handout and *Geometric Tolerancing Explanations* as a pdf with lecture #1 on the class website.

1.2: Relating Process Behavior to Engineering Fundamentals

a) **Solids**

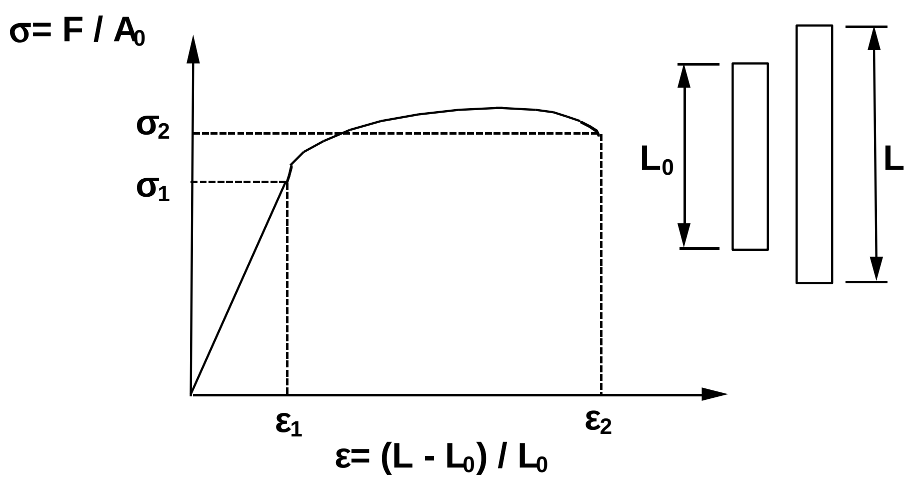

Fig. 1.2 Engineering Stress – Strain Diagram

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Consider the tension test of a specimen with original dimensions L_0 and A_0 shown in Fig. 1.2. Please identify the following items;

1. stiffness,
2. yield strength,
3. ultimate strength,
4. permanent extension just before failure.

Please answer the following questions;

5. How would the diagram change if we used $\sigma = F / A$, where A is the current area of the sample rather than the original area? Please redraw the figure using $\sigma = F / A$.
6. Now consider a tension test for an aluminum alloy connecting rod as shown in Fig. 1.3.

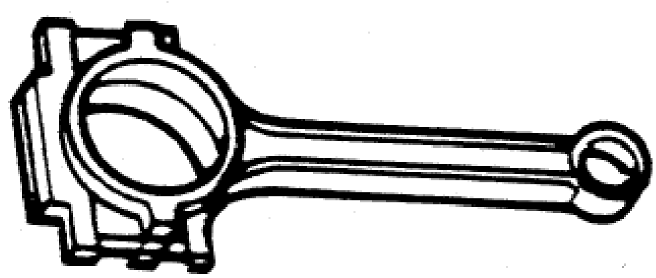

Fig. 1.3 Connecting Rod

Assuming failure is in the central section, similar to the tension specimen; how would the stress strain diagram change if one sample was machined and another was cast? Or if one sample was machined and the other was forged?

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b) **Fluids**

Consider the constant shearing of a viscous fluid in a gap of dimension "h" as shown in Fig. 1.4.

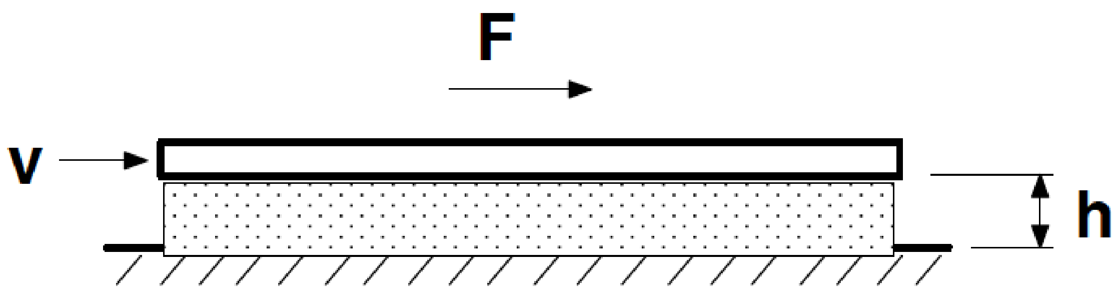

Fig. 1.4 Viscous liquid in gap "h"

Here a top plate of area A is pushed with a Force F to maintain a velocity v. (This situation could be produced by the rotation of one cylinder inside another with a liquid in the gap, assuming the gap to diameter ratio is small.)

1. Please define the Newtonian viscosity μ.
2. How does this value change if the temperature is increased ?
3. Would μ change a) linearly with temperature,
b) more than linearly or
c) less than linearly ?
4. Now consider pushing this fluid with viscosity μ through a tube at constant rate v. How would the pressure drop Δp along the tube vary as a function of tube diameter ?

c) **Heat**

Consider the adiabatic heating of a fixed mass "M" of a metal in an inert atmosphere as shown in Fig. 1.5

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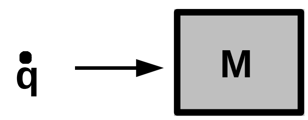

Fig 1.5 Heating of mass "M" at a constant rate, dq/dt = constant

1) If heat is supplied at a constant rate (dq/dt = constant), please describe how the temperature would change by plotting the temperature vs. the heat input q.
2) Please also sketch how the total volume of the fixed mass would change as the part is heated from room temperature to the molten state (assuming the liquid metal is contained).

d) **Process Classification**

Using the classification system discussed in class (see Paper by Dave Hardt), please classify the following processes:

(1) extrusion,
(2) sintering,
(3) stereo lithography,
(4) swaging,
(5) arc welding,
(6) die casting,
(7) forging,
(8) thermoforming,
(9) injection molding,
(10) reaming

e) **Energy Calculation**

Make <u>order of magnitude</u> estimates of (1) the minimum required energy per unit volume (J/mm^3) and (2) the minimum energy cost per unit weight ($/lb) when removing material by:

(1) plastic deformation (e.g., turning, but ignoring friction),
(2) melting,
(3) vaporization.

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Consider two materials: mild steel ($0.36/lb) and aluminum ($2.27/lb). Assume that the cost of energy is $0.10/kW-hr. Other physical data that might be of use are given in Table 1. How do the energy costs for the processes listed above compare to the material costs ?

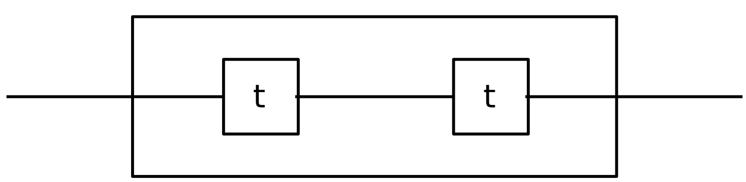
Table 1. Selected Material Properties

	Y (MPa)	ρ (kg/m^3)	c kJ/kg·K	T_m (K)	T_v (K)	ΔH_m (kJ/kg)	ΔH_v (kJ/kg)
Steel	2000	8000	0.5	1773	~3134	270	6259
Aluminum	330	2700	0.9	933	~2773	400	10,900

1.3: Basic Understanding of Time, Rate, Cost, Quality, and Flexibility.

a) The two systems shown in the Figure 1.6 represent serial and parallel arrangements of unit processes, each with processing times of t. Each of the unit processes handles only one part at a time and there is no waiting, transport, or inspection time. Please give L, W and λ for each system (refer to Little's Law in handout)..

a) Serial Processes



b) Parallel Processes

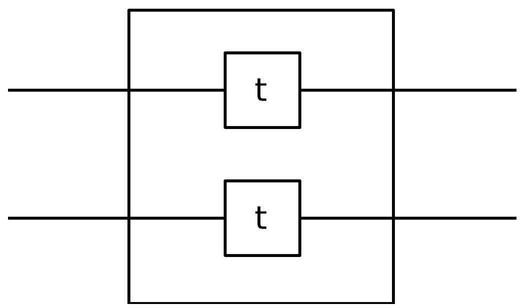


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Fig. 1.6 Unit processes in series and parallel

b) If the cycle time to make one injection molded part is t, please explain the advantage of a multi-cavity die using Little's Law.
c) For a given factory with in-process inventory L_f and lead time W_f, what does Little's Law suggest for increasing the production rate λ_f?
d) If 5,000 parts are required in 3 months what is the Takt time?
e) Can you give a physical analogy to Little's Law.
f) When a system is not in steady state

$$\lambda_{in} - \lambda_{out} = \frac{\Delta L}{\Delta t}$$

What does this mean for a factory?

g) Consider the cost data given below for the processing of automobile fenders.

Stamped Steel	Molded Composite
Tooling: $1.0M	Tooling: $0.5M
Cycle Time: 10 sec.	Cycle Time: 1 min.
Number of Operators: 2	Number of Operators: 1
Labor Rate: $25/hr.	Labor Rate: $25/hr.
Mat'l Wt. 7 lbs.	Mat'l Wt. 6 lbs.
Mat'l Cost: $0.35/lb.	Mat'l Cost: $1.00/lb.

You have an order to make 50,000 fenders. If these are the only costs, which method should you choose? What if the order is increased to 300,000?

h) Using a statistical table please verify that $C_p = 0.50$ corresponds 13.4% out of spec. and that $C_p = 0.90$ corresponds to 0.7% out of spec.

i) Consider the case shown graphically below, where USL corresponds to $\mu + 3\sigma$.

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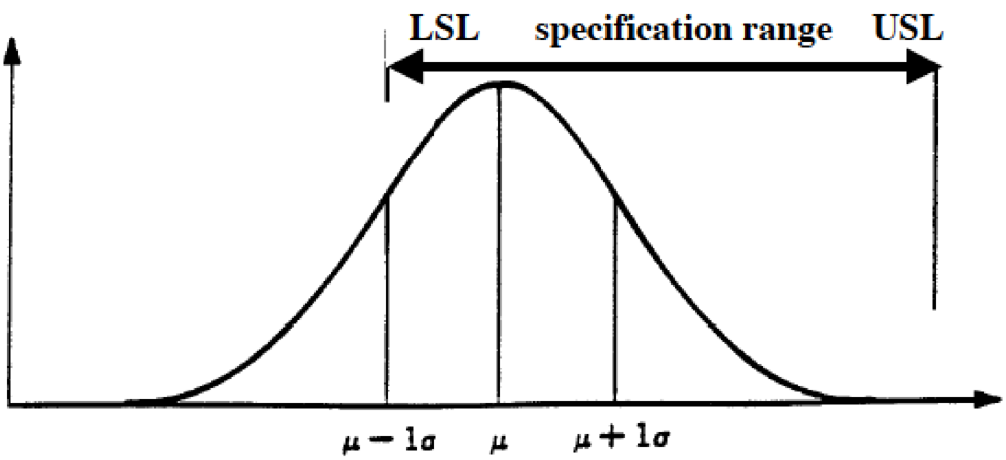

mean = μ
(standard deviation = s).

Does C_p make sense in this case? What percentage of parts are out of specification?

j) The set-up cost for a machine is C_{su}, the processing cost per unit is V, hence the total processing cost is

$$C = C_{su} + N \cdot V$$

Assume that these N parts go to a store where they are sold over a period of time T. There is a cost to keep these parts in the store, it is I per part, per unit time. Hence if the parts are sold evenly during the period T the Inventory cost is $\frac{NTI}{2}$.

Now consider the alternative where we instead supply the store with N/2 parts at T/2 intervals, hence we will set-up twice to do this.

1) Please write down the total costs (set-up, processing and inventory) for the two cases.

2) When generalized, this is is the "economic order quantity" problem, or EOQ. The idea is to find the right batch size to trade off set-up costs with inventory costs. If we generalize the batch size as B = N/n (rather than N/2), can you find the optimum batch size to minimize cost?

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1.4: Process Control.

a) In his article, Dave Hardt outlined three different control regimes. What are they?

b) Please classify the following control events according to these regimes:
   1) inspection of incoming material,
   2) monitoring for tool breakage,
   3) controlling the ambient temperature in the machine shop,
   4) warranty repair,
   5) poke-yoke inspection,
   6) SPC,
   7) process simulation, and
   8) design of experiments parameter optimization.

Refer to *Manufacturing Processes and Process Control* by David Hardt.

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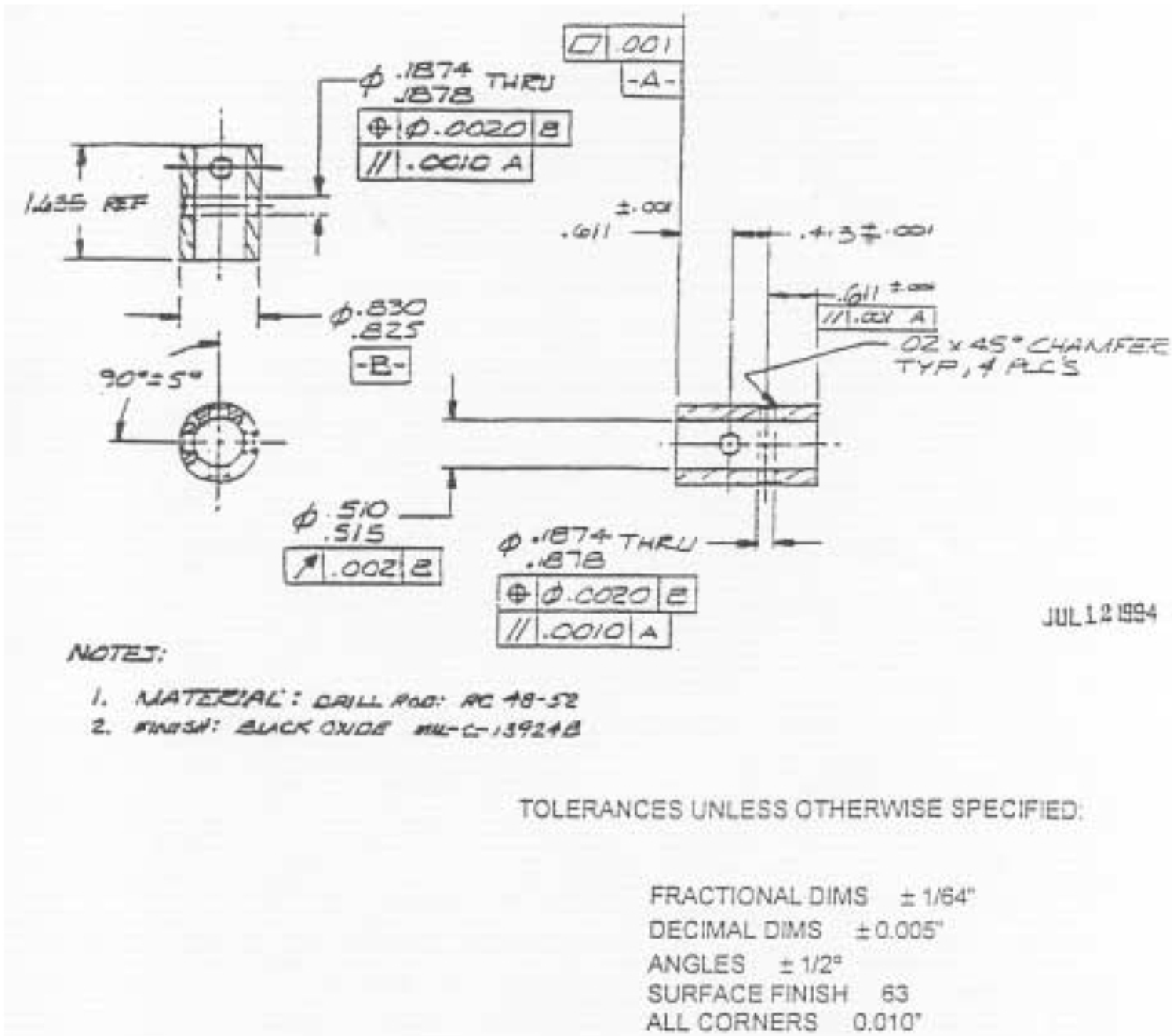

Fig 1.1 Part Drawing of Connecting Link

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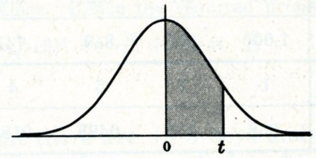
STANDARD NORMAL CURVE AREAS

This table gives areas under the standard normal distribution ϕ between 0 and $t \geq 0$ in steps of 0.01.



t	0	1	2	3	4	5	6	7	8	9
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0754
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2258	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	.2612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2996	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990
3.1	.4990	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
3.2	.4993	.4993	.4994	.4994	.4994	.4994	.4994	.4995	.4995	.4995
3.3	.4995	.4995	.4995	.4996	.4996	.4996	.4996	.4996	.4996	.4997
3.4	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4998
3.5	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998
3.6	.4998	.4998	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
3.7	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
3.8	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
3.9	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000

Table 6.2