Engineering Design ...

… is a creative process,
i.e.
the art of applying engineering knowledge and experience ...

… to create a new products and processes which satisfy human needs ...

There are three schools of design.

Click to Review an Example

- The **traditional** school:
  believes that design requires **experience** and cannot be taught (still dominates).
- The **optimization** based school:
  deals with a subset of design, using computer-based tools such as genetic algorithms, fuzzy logic, and the like.
- The **axiomatic** school of thought:
  believes that there are basic principles that govern good design decisions.

A good designer needs to use all three methodologies

- **Experience**
- **Optimization techniques**
- **Axiomatic principles**

What is engineering design?

- Analysis versus Design
- Syntheses versus Design
- Selection versus Design

Design is none of the above,
but includes all of the above

General design methods:

- Brainstorming
- Inversion method
- Adaptation/Analogy method
- Involvement/Empathy method
- Synectic method (using non-similar approach)
- Morphological/Orderly-creative method
- Matrix/Combinatorial method
- Theory of Inventive problem solving (Russian)
- Literature and patent surveys

An inventive design approach

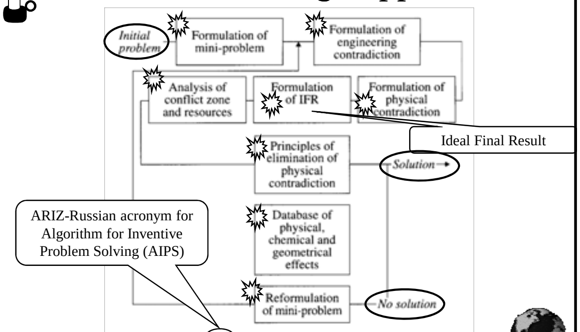
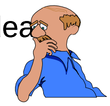


Figure 1-26 A typical ARIZ structure (Fey et al., 1994, p. 108. Printed by permission).

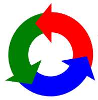
Design proceeds ...

- from abstract and qualitative ideas



- to quantitative descriptions/specifications.

It is an <u>iterative process</u> by nature ...



... new information is generated with each step, and

... it is necessary to <u>continuously (re)evaluate these information/results</u> in terms of the preceding step, etc.

Thus,

design involves a continuous interplay between:

- the <u>requirements</u> the designer wants to achieve, <u>**the GOALS**</u>, and
- <u>how the designer wants to achieve</u> these requirements, <u>**the KNOW-HOWS!**</u>.

Designers often find that ...

... a clear description of the design requirements is a difficult task.

- Therefore, some designers <u>deliberately</u> leave them <u>implicit rather than explicit</u>.
- Then, they spend a great deal of time trying to <u>**improve and iterate**</u> the design.

To be efficient and ...

... to generate the design that meets the perceived needs,

- the designer <u>must specifically state the (users') requirements</u>, before the synthesis of solution concepts can begin.

Solution alternatives are important and ...

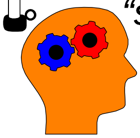
... must be generated after the requirements are established.

- Many problems in mechanical engineering can be solved by applying <u>practical knowledge</u> of engineering, manufacturing, and economics.
- Other problems require <u>far more imaginative</u> ideas and inventions for their solution.

The word "creativity" has been used ...

- to describe the human activity that results in **ingenious**, unpredictable or unforeseen results
  (e.g., new products, processes, and systems).
- In this context, creative solutions are discovered or derived by **inspiration**,
  (without ever defining specifically what one sets out to create).

This creative and intuitive "spark" may occur ...



… since our brain is a huge information storage and processing device, that can digest data and synthesize solutions through the use of associative memory, pattern recognition, and permutations of diverse facts and of events, on conscious and subconscious levels.

Design will always benefit ...

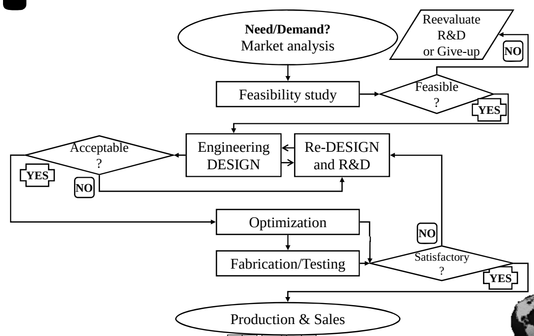
… when "***inspiration***" and/or "***imagination***" or "***creativity***," plays a role,

- but this process must be enhanced
  - **by extending human ability systematically, through fundamental understanding of cognitive behavior, and**
  - **by the development of scientific foundations for design methods.**

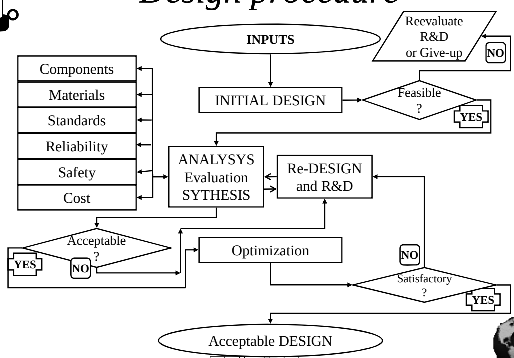
Design Basics ...

- ✓ Determine the "customers' needs"
- ✓ Define the problem(s)
  (to be solved to satisfy the needs)
- ✓ Conceptualize the solution (synthesis, etc...)
  (satisfy several different functional requirements using a set of inputs of product design parameters within given constraints)
- ✓ Analyze the proposed solution
  (to establish its optimum conditions and parameter)
- Check the resulting design solution
  (check if it meets the original customer needs)

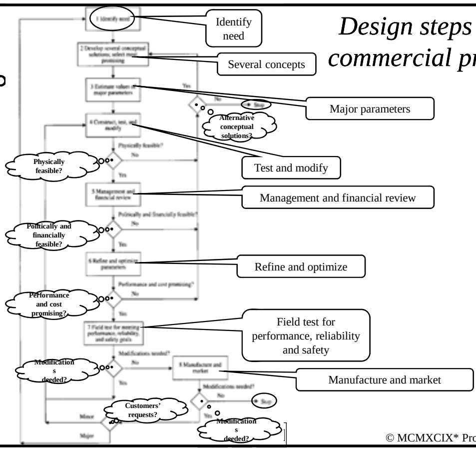
Design: Creative and iterative process



Design procedure



Design steps for a commercial product



A Choice Example: Forced Convection Cooling

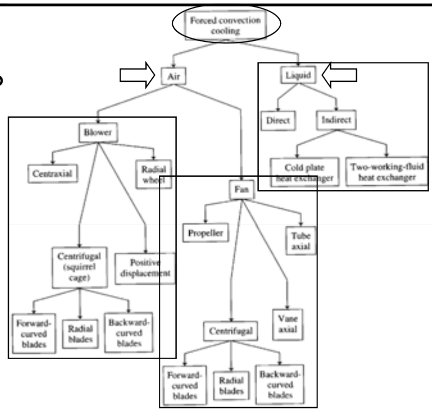
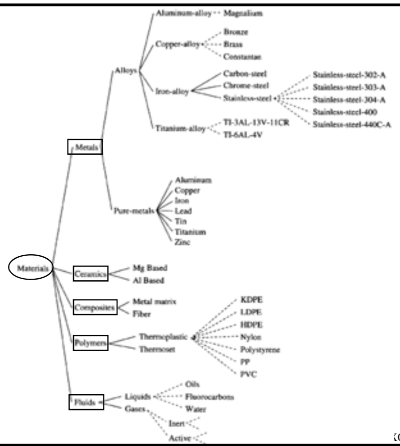


FIGURE 2.7
Various arrangements and processes for the forced convective cooling of an electronic

Materials-Design Choice Example



Appendix:

Compressed Air Piping Example

Let's Review
One Specific Design Example
...

Engineering Design Example

Compressed-Air System for a Manufacturing Plant

[From L.C. Burmeister, *Elements of Thermal-Fluid System Design*, Prentice Hall, 1998]

A C/A system is to be designed and installed to operate C/A tools:

Tool	Location	Number	Free air/tool @ 90 psig, cfm	Total free air, cfm	Load factor
Blowgun, chuck, vise	Machine shop	10	10	100	0.5
Grinder	Cleaning room	10	50	500	
Chipper	Cleaning room	10	40	400	
Hoist	Cleaning room	2	30	60	
				960	0.5
Screwdriver	Assembly room	20	10	200	
Nutsetter	Assembly room	2	20	40	
				240	0.5
Woodborer	Shipping room	1	40	40	
Screwdriver	Shipping room	1	10	10	
Hoist	Shipping room	1	30	30	
				80	0.5
			Peak load	1,380	

Compressor and piping layout

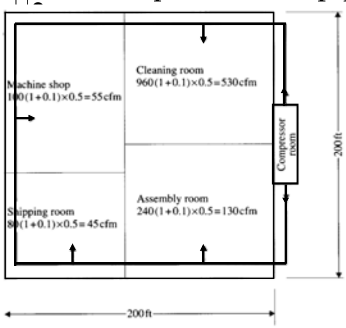


Figure 1-4 Plant configuration and piping layout.

Air supply circumferentially from two sides (reliability), based on locations and tools.

Possible design steps:

- Estimate the load [cfm] based on current and future demand.
- Size the compressor(s).
- Size the pipes so that $\Delta p<10$ psi.
- Size air receiver/reservoir to "damp" peak-demands and dynamics of the system on compressor .

System “load”: Compressed air rate

- Peak load is 1380 cfm, from the table.
- Average load (factor 0.5) is 50% of the peak load.
- Allowance for leakage 10% and 5% per year increase for 5 years is 25%, totaling 1380*1.35=1900 cfm.
- Centrifugal or reciprocating compressor may be chosen (later). From handbooks:

$$W = \dot{m} c_p (T_2 - T_1) = \rho \dot{V} c_p T_1 \left(\left(P_2 / P_1 \right)^{(k-1)/k} - 1 \right) =$$

$$= \left(0.075 \frac{lb_m}{ft^3}\right)\left(1900 \frac{ft^3}{\min}\right)\left(0.24 \frac{Btu}{lb_m}\right)(530\,R)\left(\left(\frac{114\,psi}{14\,psi}\right)^{(1.4-1)/1.4} - 1\right)\left(60 \frac{\min}{h}\right)\left(3413 \frac{Btu}{kWh}\right) = 260\,kW$$

Tools 90 psi + 10 psi friction + 14 psi atmospheric

For typical compressor efficiency $\eta = 0.7$:

$$W_{actual} = W/\eta = 260\,kW / 0.7 = 374\,kW = 500\,HP$$

Compressor power

Dynamics of air consumption in time

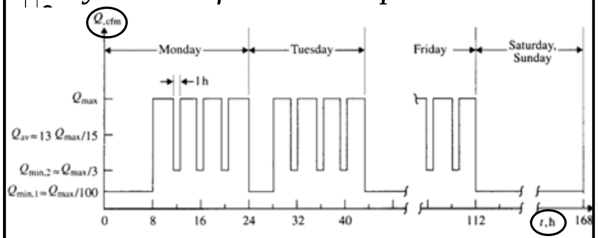


Figure 1-3 Estimated free-air consumption versus time.

The above load dynamics and load factors (0.5) suggest that the determined 500 HP compressor power is overestimated

System “load” and Compressor resizing

- Take into account 50% load factor.
- Allowance for 25% plant expansion for 5 years may be replaced with addition of second compressor if and when needed, so:

$$W_{actual,NEW} = \frac{0.5 \times 1.1}{1.1 + 0.25} W_{actual} = \frac{0.5 \times 1.1}{1.1 + 0.25} 374\,kW = 150\,kW = 201\,HP$$

New power

Also,

Prorated by

$$\dot{V}_{NEW} = \frac{0.5 \times 1.1}{1.1 + 0.25} \dot{V} = \frac{0.5 \times 1.1}{1.1 + 0.25} 1900\,cfm = 770\,cfm$$

New load

Piping sizing

- Pipe diameter (D) is determined to handle clinging room (530 cfm) and machine shop (55 cfm) pipe run with half allowable pressure drop (10 psi), i.e.:

$$\Delta p = f \frac{L}{D} \frac{\rho V}{2 g_c} = \frac{8}{\pi^2} f \frac{L}{D^5} \rho \frac{Q^2}{g_c}$$

$$\frac{10}{2} \frac{lb_f}{in^2} = \frac{8}{\pi^2} 0.025 \frac{100\,ft}{D^5} \left(0.075 \frac{lb_m}{ft^3}\right) \frac{\left(530 \frac{ft^3}{\min} + 55 \frac{ft^3}{\min}\right)^2}{\left(32.2 \frac{lb_m\,ft}{lb_f\,s^2}\right)} \left(12 \frac{in}{ft}\right)\left(60 \frac{s}{\min}\right)$$

$D = 4.13\,in \approx 4\,in$ satisfy the above equasion.

Piping Layout

- Similarly, for piping run from cleaning room to machine shop (55 cfm) and Δp/2=5 psi, D=1.6≈2 in.

Piping sizing (continue)

- Remaining two piping runs’ diameters are 2 and 2.5 in.
- However, to allow for future expansions, simplify installation and maintenance processes, we may select the 4 in pipe diameter for all pipe runs.
- Or we may stick with the calculated sizes …

Piping Layout

Air receiver sizing

Conservatiom of mass:

$$\frac{dm}{dt} = -\rho_0 (Q_{in} - Q_{out}), \text{ also: } \rho = \frac{p}{RT} \text{ and } m = \rho \forall = \forall p / RT$$

$$\frac{d\left(\forall p / RT\right)}{dt} = \left(p_0 / RT\right)(Q_{in} - Q_{out}) \Rightarrow \frac{dp}{dt} = \frac{-p_0}{\forall}(Q_{in} - Q_{out}) = constant$$

$$\forall = \frac{t\, p_0 (Q_{in} - Q_{out})}{(p_1 - p_2)}$$

Total volume

Assume that for $t = 2\ min$: $(Q_{out} - Q_{in}) = 76\,cfm$ (10% of $Q_{nominal}$) and $(p_1 - p_2) = 10\,psi$

Then, $\forall = (2\,\text{min})(14\,psi)(76\,cfm)/(10\,psi) = 213\ ft^3$,

NOTE: $(Q_{out} - Q_{in}) = Q_{out}$ if $Q_{in} = 0$ (compressor not working)

The volume $\forall_{pipe}$ of the piping is:

$$\forall_{pipe} = L\left(\pi/4\right)\left(D^2\right) = (400\ ft)\left(\pi/4\right)\left(4^2 + 2^2\right)in^2\left(\frac{ft^2}{144\,in^2}\right) = 44\ ft^2$$

Piping Layout

Thus, the volume of the receiver tank(s) is(are):

$$\forall_{tank} = \forall - \forall_{pipe} = 213\ ft^3 - 44\ ft^3 = 169\ ft^3$$

Tank volume

Tank design choices:

- Should the above volume be provided by <u>one or two</u> receiver tanks, and <u>where to place them</u>?
- Tank close to compressor will benefit it and also help in removal of the condensate
- Tank close to the shop will benefit load fluctuations there
- Two smaller tanks <u>may or may not</u> be less expensive than a big one?

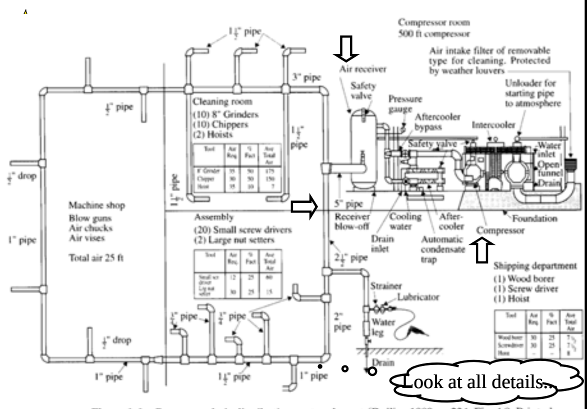


Figure 1-6 Compressed-air distribution system layout (Rollins 1989, p. 234, Fig. 4.8. Printed by permission).

Final comments...

- The major parameters (compressor, piping, receiver tank) have been sized.
- Many other details remained to be resolved, see the previous slide Figure.
- Installation and operational cost, as well as maintenance, safety, reliability, etc., may be determining factors in designing or selecting different components ...

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