MECH 3200 – 10S
Notes: Pahl & Beitz Chap.6

Conceptual Design

Prerequisite: Engineering Requirements (ER's)

- Result of Product Planning Process, or Quality Function Deployment

Process Steps:

1. Reduction of ER's to essential problem statement (simplification)
2. Adaption of preliminary concept
3. Functional Decomposition, Functional Structure
4. Working principles for lowest functional level
5. Concept combination
6. Concept assessment and selection

Result: Principal Solution

1. Ready for Embodiment Design

Example: Means for stopping a long board in a narrow space

1. Product Planning
    a. Users
        i. Downtown finance worker
        ii. AU student

    b. Needs
        i. Stop for emergency (traffic in front)
        ii. Stop in constrained area (traffic around)
        iii. Stop for fear (steeper than thought)
        iv. Cost less than 25% of board price
        v. Doesn't upset rider while stopping
        vi. Easy to install
        vii. As robust as board

    c. Existing Alternatives
        i. Drag foot
        ii. Jump off
        iii. Existing products

    d. Engineering Requirements
        i. Stopping surge force greater than 85 lbs.
        ii. Stopping surge force less than 65 lbs.
        iii. Stopping yaw moment - 150 in·lbs.
        iv. Weight – 8 oz.
        v. Drag - 10% of wheel rolling resistance
        vi. Cost (this one might need to be a trade-off – see below)

vii. Installation time 20 min. with ‘household’ (define) tools and misleading instructions

2. Reduction to essential problem statement
   - Stop board in a mild emergency while maintaining rider control using an easy-to-live-with add-on device

3. Functional Decomposition
   a. Apply retarding force
      i. Generate controlling force
      ii. Transfer controlling force
      iii. Apply controlling force

   b. Hold retarding force
      i. Generate force
      ii. React force to board
      iii. Regulate force

   c. Release retarding force
      i. Return to free-wheeling
      ii. Reset stopping system

4. Working principles (each of these needs a sketch!)
   a. Generate controlling force
      i. Arm
      ii. Foot
      iii. Hydraulic
      iv. Electrical

   b. Transfer controlling force
      i. Mechanical linkage
      ii. Hydraulic
      iii. Electrical

   c. Apply controlling force
      i. Hydraulic piston
      ii. Lever
      iii. Direct action

   d. Generate force
      i. Friction pair – board to ground
      ii. Friction pair – board to rotating parts

   e. React force to board
      i. To board
      ii. To undercarriage

f. Regulate force
    i. Control force regulation
    ii. Lock and ablation

g. Return to free-wheeling
    i. Spring return
        1. Mechanical spring
        2. Hydraulic spring
    ii. Magnetic
    iii. Manual disengage

h. Reset stopping system

5. Optional step – selecting working structures (rank and rate working principles)

6. Combining Working Principles
    a. Foot, mechanical, direct, board-to-ground, board, regulation, manual
    b. Arm, hydraulic, piston, board-to-rotating, board, regulation, hydraulic spring

7. Necessary Step – firming up the design. This is the big layout and calculate step, proving that the concept can meet the ER's (be sure to use lean calculation!). Might do some concurrent engineering here.

Tangent: Axiomatic Design

i. Independence Axiom – the best designs result from concepts where each Functional Requirement (FR) is met independently by one (set of) Design Features (DF's). That way, the any FR can be adjusted by adjusting one DF, without affecting any other FR

ii. Information Axiom – the best designs are those with the lowest information content (more broadly known as KISS)

Tangent: Incorporation of Analogies – Case 1108B: "there really hasn't ever been anything remotely like this!"

- Refer to AU Vet School, Large Animal Clinic, Male Bovine Manure Removal Unit (LAC – MBMRU)

8. Assessment
    a. Decision matrix, v. needs, with +,0,- scale (or just +,-)
        i. Absolute scale
        ii. v. datum
    b. Decision matrix, v. needs, weighted, with 0-10 scale (confidence adjusted)
    c. Decision matrix, v. objective tree, weighted, with 0-10 scale (confidence adjusted)
    d. Trade-off – development of optimality function

Another example: Problem – improve productivity and smoothness of drywall taping. Intuitive concept/premise – device to spread joint compound and tape in one pass. [reference: Magrab, E.B., *Integrated Product and Process Design and Development*, CRC Press, 1997]

1. Product planning
    a. Users
        i. Worker
        ii. Contractor
        iii. Homeowner
        iv. Distributor
        v. Tool rental center
        vi. Manufacturer
    b. Needs (functional requirements – FR's)
        i. FR_1 Load joint compound
        ii. FR_2 Load tape
        iii. FR_3 Dispense tape and joint compound uniformly and smoothly to wall
            (1) FR_{31} Dispense tape simultaneously with joint compound
            (2) FR_{32} Provide joint compound to dispenser
            (3) FR_{33} Dispense joint compound uniformly
            (4) FR_{34} Apply tape and joint compound smoothly to wall
            (5) FR_{35} Separate tape from roll
        iv. FR_4 Unload tape
        v. FR_5 Unload joint compound
    c. Axiomatic design features (DF's) or design parameters (DP's)
        i. DP_1 Joint compound loading system
        ii. DP_2 Tape holding device
        iii. DP_3 Tape and joint compound dispensing device
            (1) DP_{31} Tape dispensing device
            (2) DP_{32} Means to move joint compound through system
            (3) DP_{33} Joint compound dispenser
            (4) DP_{34} Tape and joint compound wall application device
            (5) DP_{35} Tape severing device
        iv. DP_4 Tape unloading device
        v. DP_5 Joint compound removal system
    d. Alternative solutions
        i. Manual, multi-step process
        ii. Inexpensive tool (150 $), results worse than a careful manual job
        iii. Expensive tool (1650 $), results meet functional needs
    e. Engineering requirements (a bit extensive – more like a "Product Design Specification")
        i. Quantity
            (1) 20,000 units per year
        ii. Cost
            (1) Retail price: 500 $
            (2) Manufacturer's price (direct and indirect manufacturing cost): 200 $

(a) No new manufacturing facilities required (this is an organization-specific requirement, of the type Pahl & Beitz often focus on)
(b) Minimize number of manufacturing operations; time and cost of each manufacturing operation
(c) Familiar materials

iii. Performance
(1) Tape inside corners
(2) Tape joints in any orientation
(3) Tape joints without leaking joint compound
(4) Taped joints will require no additional smoothing
(5) Tape will not break prematurely
(6) Compound will flow evenly across tape/wall
(7) Will work with both paper and fiberglass tape, with tape widths varying between 1.5 and 2.5 in, tape thicknesses varying between 0.005 and 0.007 in
(8) Work with thick or thin viscosity compounds
(9) Dispense tape at 6 in/s

Why 6 in/s?

- Average room 16 × 12 × 8 ft, drywall sheets 8 × 4 ft, ⇒ 20 sheets per room
- Tape 1 short edge & 1 long edge ⇒ 240 ft per room
- 8 rooms per house ⇒ 1920 ft per house
- 1 house per hour ⇒ 1920 ft/h = 0.533 ft/s = 6.4 in/s
- Above not precise enough to support more than 1 significant figure accuracy

(10) Dispense joint compound at 2 in^3/s

Why 2 in^3/s?

- 2.5 in tape, ⅛ in thick layer of joint compound, 6.4 in/s ⇒ 2 in^3/s joint compound volumetric flow rate

iv. Time scale
(1) In market by (pick date)

v. Size
(1) Total device easily transported by one person
(2) Hand-held part of device smaller than 29 × 16 × 12 in

vi. Shipping
(1) Shock resistant
(a) 8 ft drop test
(2) Vibration resistant
(a) 4 to 33 Hz at 0.06 in amplitude
(3) Weather resistant
(a) Temperature and humidity
(4) Cardboard box packaging, stackable to 8 ft high, no special handling

vii. Disposal and Recycling
(1) No environmentally hazardous materials

(2) Easily disassembled for component recovery

viii. Political, Social, Legal
   (1) OSHA standards (see www.osha.gov)
   (2) Inoffensive product names (race, creed, gender)
   (3) No patent infringement (see http://patft.uspto.gov, search for Wall Board, Wallboard, Joint Compound, Drywall)

ix. Product environment
   (1) Temperature from 40˚F to 120˚F
   (2) Pressure from sea level to 7000 ft
   (3) Dust particles to 500 μm

x. Safety
   (1) No sharps (except smoothing component)
   (2) Shield electrical, hot, moving

xi. Documentation
   (1) User's guide
   (2) Maintenance manual
   (3) Test reports
   (4) Customer questionnaire (success in meeting needs)

xii. Life
   (1) 5 yr
   (2) 10,000 tape separations
   (3) Modular to allow component upgrade

xiii. Materials
   (1) Non-corrosive

xiv. Ergonomics
   (1) Single operator, two hands
   (2) Good balance
   (3) Extended use (full shift)

xv. Aesthetics
   (1) Product will convey ruggedness
   (2) Durable finish
   (3) Company colors

xvi. Weight
   (1) 5 lb max (empty)
   (2) 20 lb max (loaded with tape and joint compound)

xvii. Maintenance
   (1) Standard fasteners
   (2) Wear surfaces replaceable with standard tools
   (3) Modular design for repair and cleaning
   (4) No or very few lubrication points
   (5) Facilitate removal of joint compound after day's use

2. Reduction to essential problem statement
   - Simple, light, rugged, reliable commercial tool for continuous and simultaneous application of joint compound and drywall tape to drywall seams

3. Going straight to Working Principles for the DP's (only a subset of the complete morphological chart!):

Design parameter	Concept						
Means to dispense tape [$(DP)_{31}$]	11 Tape	12 Tape	13 Tape	14 Tape			
Means to move joint compound [$(DP)_{32}$]	21 Gear	22 Screw	23 Bellows	24 Friction	25 Piston	26 Air pressure	
Means to dispense joint compound [$(DP)_{33}$]	31 Spray	32 Bead	33 Slot orifice	34 Viscous shear			
Means to apply tape and joint compound to wall [$(DP)_{34}$]	41 Plate	42 Brush	43 Roller	44 Blade			
Means to sever tape from roll [$(DP)_{35}$]	51 Rotating saw	52 Rotating blade	53 Translating blade	54 Tear	55 Hot wire	56 Chemical	57 Laser

Lagniappe:
Several means for converting rotational motion into linear motion