Session 6
Embodiment Design

Session Speaker:
Dr. Govind R. Kadambi
Session Objectives

To understand:

• Progression of Abstract Concept to Developed Design
• Concept of Embodiment design
• Overall, Specific and General Guidelines for Embodiment Design
Session Topics

- Abstract Concept to Developed Design
- Overall Guidelines for Embodiment Design
- Specific Guidelines for Embodiment Design
- General Guidelines for Embodiment Design
Abstract Concept to Developed Design

• Prototype is built and put through rigorous test program, which is a costly and time consuming exercise

• Tactically it is well worthwhile when mass-production is contemplated, but the tendency towards shorter and shorter development times may make it economically unacceptable

• New products are now often introduced right on the production line by employing an incremental approach

• Involves systematically introducing new technology or redesigned components on existing products to test and prove them in practice, rather than taking the more risky approach to introducing everything at once in a completely new product
Overall Guidelines for Embodiment Design

- During embodiment design, the aim is to resolve overall geometrical, dynamic, and safety issues, and to develop more complete layouts of the concept by consideration of each assembly, sub-assembly, and component in turn.
- Questions need to be answered such as
- Will it work?
- Is it safe?
- What function does it serve?
- Will it be made from scratch, bought in, or made from semi-finished material?
- How does it fit in with the rest of the design?
- What development will be required?
- How long will it last?
- How might it fail in practice?
Clarity

• It should be clear:
  What purpose each component or sub-assembly serves
  How it is to be manufactured
  How it fits together with all the other parts
Simplicity

- Simpler the arrangement and the shapes used are:
  - Lower the cost of manufacture
  - Better the overall design is likely to be

- Aim is to use the minimum number of components with the simplest possible shapes
Safety

• Commercial pressures often demand that products are used to the limits of their designed capability

• Yet if there is a failure the design engineer becomes liable for damage

• It is over matter of safety and product liability that the advantage of having used a systematic and well-documented approach to design becomes obvious

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Safety

• Safety hierarchy is aimed specifically at minimizing the harmful effects of component, system, or operational failures as follows
• First priority – Eliminate the hazard and / or risk ( direct approach )
• Second priority – Apply protective systems ( indirect approach )
• Third priority – Provide warnings
• Fourth priority – Provide for training and instruction
• Fifth priority – Prescribe personal protection
• Safety are used here, means more than human safety
• Includes situations where the failure of one component may adversely affect the performance of another and lead to operational or reliability problems, whether or not human safety is involved
Direct Approaches to Safety and Reliability in Design
Safe-Life Design

- Likelihood of failure is reduced by
  - Clearly specifying all operating conditions
  - Careful attention to detail design, including application of safety factors
  - Provision of overload capacity
  - Regular maintenance and inspection during operation
Fail-Safe Design

• After a failure, some capacity to perform critical functions should remain

• Failure should be signaled so that the system can be shut down safely

• During design work:
  Possible failures must be foreseen
  Steps taken to ensure that the consequences are acceptable or can be made safe
Redundant Design

- Additional elements or systems are provided to take over the function in the event of a failure

- Possibility of a first failure causing a catastrophic failure by also damaging the redundant system must be avoided, such as an explosion that damages a stand-by system

- Redundancy can be
  - Parallel – active or passive
  - Series – active or passive

- Parallel active – aircraft with more than one engine
- Parallel passive – stand-by generator
- Series active – double in-line filters
- Series passive – anti-lock braking unit
Indirect Approaches to Safety and Reliability in Design

• Indirect approach involves providing protective systems, Electrical fuses; Overspeed devices; Safety valves; Alarm systems; Machine guards; Sprinkler systems

• Protective system should, if possible, be self-monitoring, with the capability to detect and act on faults by itself
Warnings

• Approach involves providing warnings of potential danger by means of notices, signals, or barriers

• Third level of safety measure should be used only as backup

• Direct or indirect safety measures should be incorporated whenever possible and in preference to warnings
Training and Instruction

• Many products rely on training of the operator as an integral part of design for safety, and thought must be given to this during embodiment design.

• Driver of a car, for example, must be trained in vehicle handling as well as in learning how to behave and cope with typical driving situations on the road.

• For simpler products, instruction manuals are sufficient.

• Great care must go into their design to ensure that the product is used correctly and that warnings are produced to cover foreseeable misuse.
Personal Protection

- Situations, such as use of sandblasting equipment, where it is essential for operators to wear protective clothing and devices to ensure safe working conditions

- Becomes part of the design of the system, and the design engineer must treat it as such

- May require the services of safety experts to advise on how best to meet the applicable regulations and standards
Special Guidelines for Embodiment Design
Flowlines of Force

• Function of many components is to transmit forces (and moments) from one point to another
• External loads applied to a structure are balanced at every section by internal forces and moments
• At critical sections the stresses can be calculated and compared with the material strength

• Guidelines for uniform strength
  – Avoid abrupt changes of cross-section
  – Avoid sharp changes in direction
  – Avoid changes in flowline density
Division of Tasks

- Component may be designed to serve just one specific task, such as a dowel, or a component may be designed to perform several tasks, such as an engine drive pulley.
- Several identical components may be required for high-load situations, such as multiple Vee-belts.

**Guidelines for Combining Tasks**

- Assign several tasks to a component for economy in space, weight, number of parts or cost, but note might
  - Compromise the performance of individual functions
  - Require design and analysis of more complicated shapes
  - Be more expensive to replace if there is a fault
Division of Tasks

• Guidelines for division of tasks

  – Assign specific component to a specific task for optimization or if the task is critical
  – Use several identical components to cope with loads or size too great for one, but note
  – Increased space and weight involved
  – More parts and connections used;
  – There is difficulty in getting identical parts each to carry the same load
Self-help

• Idea of self help is to improve the performance of a function by the way in which components interact with each other

• Can provide a greater effect, a reduced effect, or greater safety (in overload conditions), depending on the circumstances and what is required

\[ \text{Overall effect} = \text{Initial effect} + \text{Supplementary effect} \]
Self-Reinforcing

• Required effect increases with increasing need for the effect, such as better sealing of O-rings as pressure increases.

• Leading shoe drum breaks are reinforcing, in that the braking force increases rapidly with increasing pedal effect, but through a different mechanism.

• Breaking force increases as the break disk expands with heat.
Self Damaging or Self Balancing

• In this case the supplementary effect reduces the initial effect

• For example, with a trailing shoe drum break an increased force is required to maintain braking effect as the break heats up

• Can be used to exercise control over the grabbing tendencies of a leading shoe break and a stable system results when a leading shoe is combined with a trailing shoe design
Self-Protecting

- Self protecting means that components should be designed to survive in the event of an overload unless intentionally used as weak links.

- By providing an additional force transmission path it is possible to alter the flowlines of force after, for example, a given elastic deformation, so that the load is still carried without component damage.

- This is termed a self-protecting solution, and an example would be the bump stop car suspension spring.
Summary

• Guidelines for self-help include

  – For self-reinforcing solutions use primary or associated forces acting in the same sense as other main forces

  – For self-balancing solutions use associated forces acting in the opposite sense to primary forces

  – For self-protecting solutions change the force depending on elastic deformation and note that self-damaging effects can easily be produced which are usually, but not always, detrimental
Stability

• Stability of a design can be considered on a number of different levels
• Important thing is whether the designed system should, and if so will, recover appropriately from a disturbance
• Guidelines for stability
  – Consider the effects of abnormal disturbances and ensure that these effects will be reduced or cancelled out
  – Sometimes planned instability is useful, such as the over-center toggle action of an electric switch to ensure that the switched is either on or off and cannot stay in the middle neutral position
• Guidelines for use of planned instability are
  – Introduce self-reinforcing effects when a selected physical quality reaches a limiting value
General Guidelines for Embodiment Design
Use of Calculations

• Approximate calculations should be used throughout the embodiment design phase to determine effects and consequences (gain insight)

• More accurate calculations (and repeat of first order calculations) should be carried out as the layout and form design is firmed up

• Calculations should be completed on standard format sheets, which include the date, project nature, title of calculation, assumption made, and symbols used. Origin of equations, etc. should be referred in a right-hand margin

• Calculations should be indexed, checked (by another person), and retained with the project file
Materials Selection

• Improved materials can lead to better products, easier manufacturer, longer service life, and lower cost

• Used to be that a larger number of brochures, handbooks, catalogs, directories, and materials specialists had to be consulted to ensure that the most appropriate material was found

• Becoming possible to design a material to suit a specific application as well as to select a material most appropriate to a particular design

• Developments should help to overcome
  – A tendency to avoid use of new or alternative materials
  – Inappropriate use of materials
  – Waste of material resources
Guidelines for Selecting Materials

- Determine basic form of component
- Determine form, availability, and cost of several candidate materials
- Use computer based selection procedure or Internet product information search, as appropriate
- Match form and manufacturing process of available material against form design of component
- Select the most appropriate materials and check physical properties against basic functional requirements
- Iterate if necessary
- Refer to database or data sheets for material details and make final selection
Design Standards and Codes

• Design standard encapsulate what has become accepted best practice for the design of particular types of product

• Provide at least a baseline set of criteria for the evaluation of designs produced

• In the event of a safety or performance problem with a product, the very first questions are likely to be:
  – What standards were applicable to the product?
  – Does the product comply with current standards?
  – If not, why not?

• Basic idea of a Code is to keep designers on the right track by giving them guidance through encapsulated experience
Guidelines to Use Standards and Codes

- Use them whenever appropriate to save money, time, and arguments
- Check which standards and codes apply to the product or system being designed. There may be several and they may conflict
- Obtain the latest edition of any standard or code to be followed
- Meet the requirements as closely as possible (even if they are not mandatory)
- Safety standards take priority over rationalization procedures and economics
Purchased Components

• Generally, it makes economic and practical sense to buy ready-made assemblies and components whenever possible

• Main thing to ensure is that the item bought meets the specification stated

• **Guidelines for the Use of Purchased Components**
  
  − Use them whenever possible
  − Obtain price and delivery quotations
  − Specify functional and quality requirements in agreement with the supplier
  − Inspect components on arrival
  − Insist the components meet agreed specification
Layouts and Models

• Layouts and models are important tools for communication, negotiation, understanding, and development throughout the design process
• Helps the design engineer to visualize the complete design clearly
• Guidelines concerning layouts, drawings, and computer printouts:
  – Use standard sheet sizes, or computer-generated format, for all work
  – Label and date all layouts and printouts
  – Use a standard title block (or devise one) for all drawings, including name, date, and tolerancing
  – Number all layouts and drawings according to a rational system (e.g. by system and sheet size). Allow for addition of new drawings and revisions
  – Choose scales that will assist in building up and checking assembly drawings
Layouts and Models

- For mechanical assemblies use a different sheet (and number) for every component
- Use the smallest convenient size sheets for each drawing
- Comply with the current national standards
- Retain original copies in file with revisions shown
Prototypes and Testing

- Question of whether or not a prototype is built as part of the design process depends on what is being designed.
- In case of some high-volume products, it is now possible to have sufficient confidence in the design to allow manufacture of the first units directly on the production line.
- In case of others, specially built prototypes are needed for extensive field-testing before final design.
- In the case of on-off (or low volume) products, manufacture of the final product often proceeds directly from design.
- Systematic testing and commissioning procedure is generally required before acceptance by the customer.
Guidelines Concerning Prototypes and Testing

- Prove new technologies separately
- If major tooling is required, prove the design first
- Test the developed hardware
- Anticipate having to do modifications
- Expect and allow for integration problems
Summary
Summary - Overall Product

- Test functional performance – must meet or exceed customer expectations
- Check for economic feasibility – cost must be acceptable to the customer
- Check safety performance – must meet applicable safety standards
- Test ergonomic performance – user expectations must be satisfied
Summary - Overall Design

- Insist on clarity, simplicity, and safety in the design
- Ensure the force transmission paths will be satisfactory
- Ensure satisfactory allocation of functional tasks to components
- Ensure that self-help has been appropriately incorporated
- Ensure that the design will perform in a stable manner
- If planned instability is used, ensure required effect will be achieved
Summary - General

• Ensure that:
  - Calculations are appropriate, adequate and correct
  - Calculations have been recorded in a professional manner
  - Most appropriate materials have been selected or designed
  - Requirements of applicable standards and codes are met
  - Purchased components have been incorporated efficiently
  - Models, layouts, printouts, and drawings have been used to best advantage