Design Methodology in the Development of Mechatronic Products
- Part 2

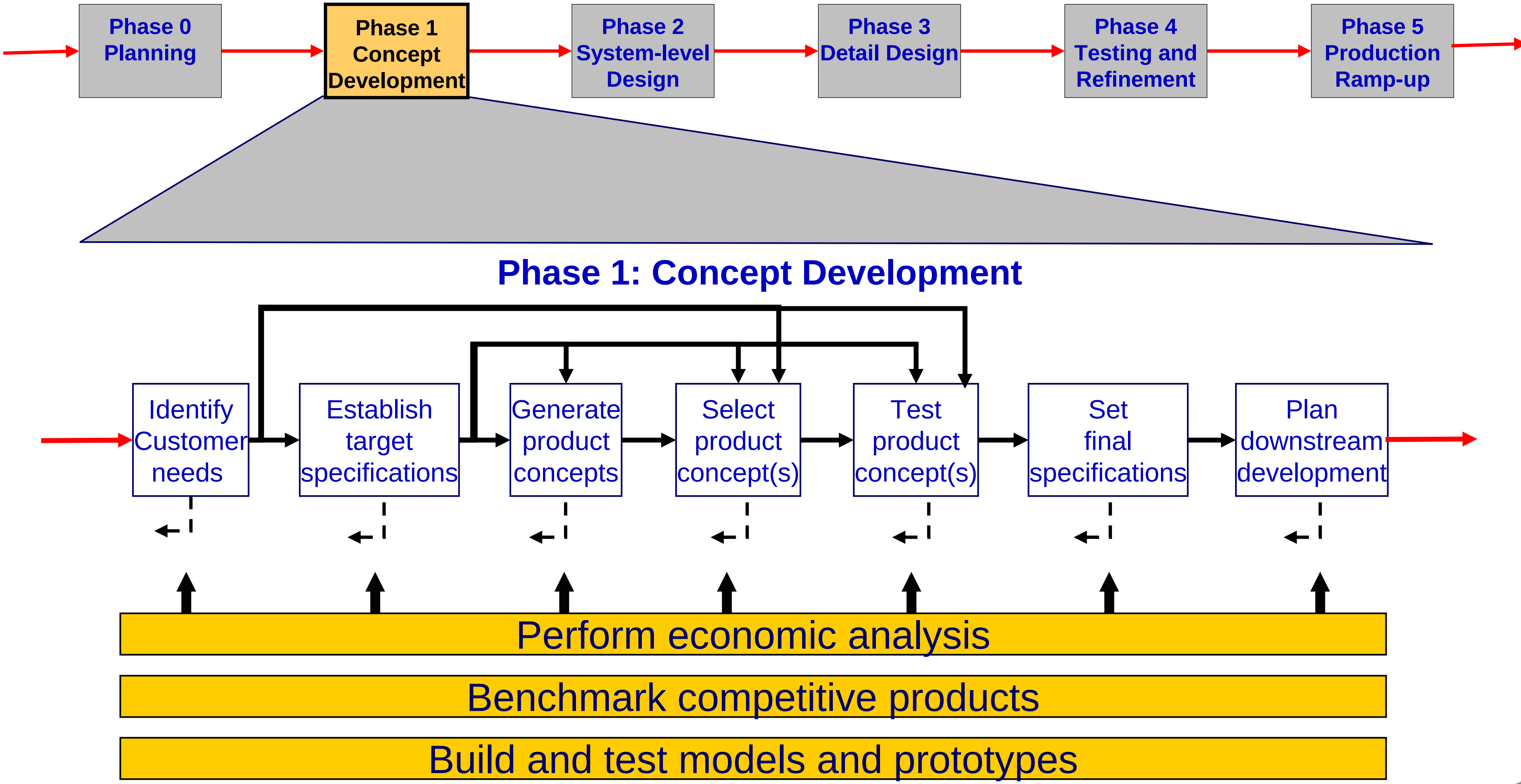
Robert Bjärnemo

Division of Machine Design at the Department of Design Sciences

Agenda

- *Concept Development – the front end process*
- *Identify Customer Needs*
- *Establish Product Specifications*
- *Generate Product Concepts*
- *Task*

Concept Development – the front end process



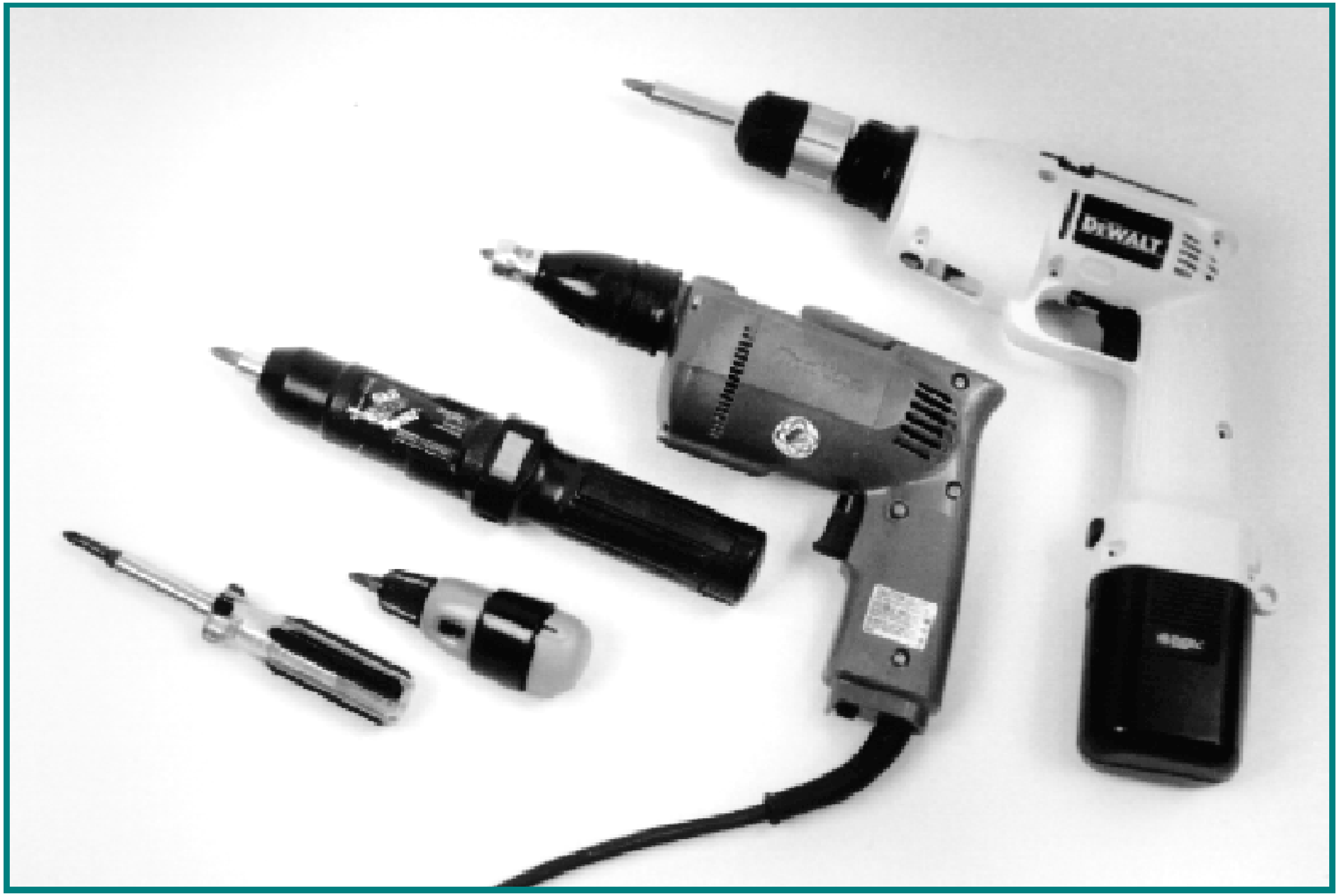
The Starting Point – The Mission Statement

Mission Statement: Screwdriver Project	
Product Description	• A hand-held, power-assisted device for installing threaded fasteners
Key Business Goals	• Product introduced in fourth quarter of 2006 • 50% gross margin • 10% share of cordless screwdriver market by 2008
Primary Market	• Do-it-yourself consumer
Secondary Markets	• Casual consumer • Light-duty professional
Assumptions	• Hand-held • Power-assisted • Nickel-metal-hydride rechargeable battery technology
Stakeholders	• User • Retailer • Sales force • Service center • Production • Legal department

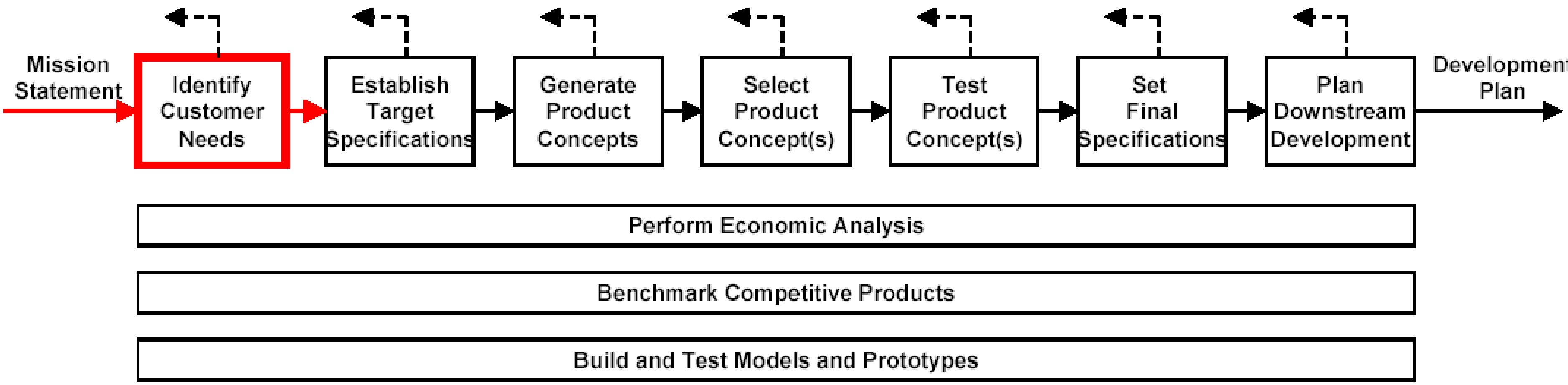
The ***mission statement*** for the ***Screwdriver project.***

Alternative terminology: ***charter*** or ***design brief.***

Identify Customer Needs



Identify Customer Needs



The Goals of Identify Customer Needs

- Ensure that the product is focused on customer needs
- Identify latent or hidden needs as well as explicit needs.
- Provide a fact base for justifying the product specifications.
- Create an archival record of the needs activity of the development process.
- Ensure that no critical customer need is missed or forgotten.
- Develop a common understanding of customer needs among members of the development team.

The Five Step Process of Identifying Customer Needs

Step 1: Interpret the raw data in terms of customer needs

Step 2: Organize the needs into a hierarchy of primary, secondary, and (if necessary) tertiary needs

Step 3: Establish the relative importance of the needs

Step 4: Ensure that the product is focused on customer needs

Step 5: Reflect on the results and the process

Step 1: Gather Raw Data from the Customers *p 56*

Frequently used methods for gathering raw data from the customer / user are:

- ***Interviews***
- ***Focus groups***
- ***Observing the product in use***

Step 2: Interpret Raw Data in Terms of Customer Needs

Customer:	Bill Esposito	**Interviewer(s):**	Jonathan and Lisa
Address:	100 Memorial Drive Cambridge, MA 02139	**Date:**	19 December 2002
Telephone:	617-864-1274	**Currently uses:**	Craftsman Model A3
Willing to do follow-up?	Yes	**Type of user:**	Building maintenance

Question/Prompt	Customer Statement	Interpreted Need
Typical uses	I need to drive screws fast, faster than by hand.	The SD drives screws faster than by hand.
	I sometimes do duct work; use sheet metal screws.	The SD drives sheet metal screws into metal duct work.
	A lot of electrical; switch covers, outlets, fans, kitchen appliances.	The SD can be used for screws on electrical devices.
Likes—current tool	I like the pistol grip; it feels the best.	The SD is comfortable to grip.
	I like the magnetized tip.	The SD tip retains the screw before it is driven.
Dislikes—current tool	I don't like it when the tip slips off the screw.	The SD tip remains aligned with the screw head without slipping.
	I would like to be able to lock it so I can use it with a dead battery.	The user can apply torque manually to the SD to drive a screw. (!)
	Can't drive screws into hard wood.	The SD can drive screws into hard wood.
	Sometimes I strip tough screws.	The SD does not strip screw heads.
Suggested improvements	An attachment to allow me to reach down skinny holes.	The SD can access screws at the end of deep, narrow holes.
	A point so I can scrape paint off of screws.	The SD allows the user to work with screws that have been painted over.
	Would be nice if it could punch a pilot hole.	The SD can be used to create a pilot hole. (!)

Step 4: Establish the Relative Importance of the Needs

Cordless Screwdriver Survey

For each of the following cordless screwdriver features, please indicate on a scale of 1 to 5 how important the feature is to you. Please use the following scale:

1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it.
3. Feature would be nice to have, but is not necessary.
4. Feature is highly desirable, but I would consider a product without it.
5. Feature is critical. I would not consider a product without this feature.

Also indicate by checking the box to the right if you feel that the feature is unique, exciting, and/or unexpected.

Importance of feature on scale of 1 to 5		Check box if feature is unique, exciting, and/or unexpected.
______	The screwdriver maintains power for several hours of heavy use.	❑
______	The screwdriver can drive screws into hardwood.	❑
______	The screwdriver speed can be controlled by the user while turning a screw.	❑
______	The screwdriver has a pleasant sound when in use.	❑

And so forth.

Product Specifications

What are Product Specifications?

Customer needs are generally expressed in the ”language of the customer.”

In order to provide specific guidance about how to design and engineer a product, development teams establish a ***set of product specifications***, which spell out in precise, measurable detail ***what*** the product has to do in order to be commercially successful.

What are Product Specifications?

A ***product specification*** (singular) consist of a ***metric*** and a ***value.***

For example *"average time to assemble"* is a ***metric,*** while *"less than 75 seconds"* is a ***value.***

Note that the value might take on several forms, including a particular number, a range or an inequality. Values are always labeled with the appropriate ***unit.***

Establish Product Specifications

Alternative terms to ***product specifications*** are ***product requirements*** or ***engineering characteristics***.

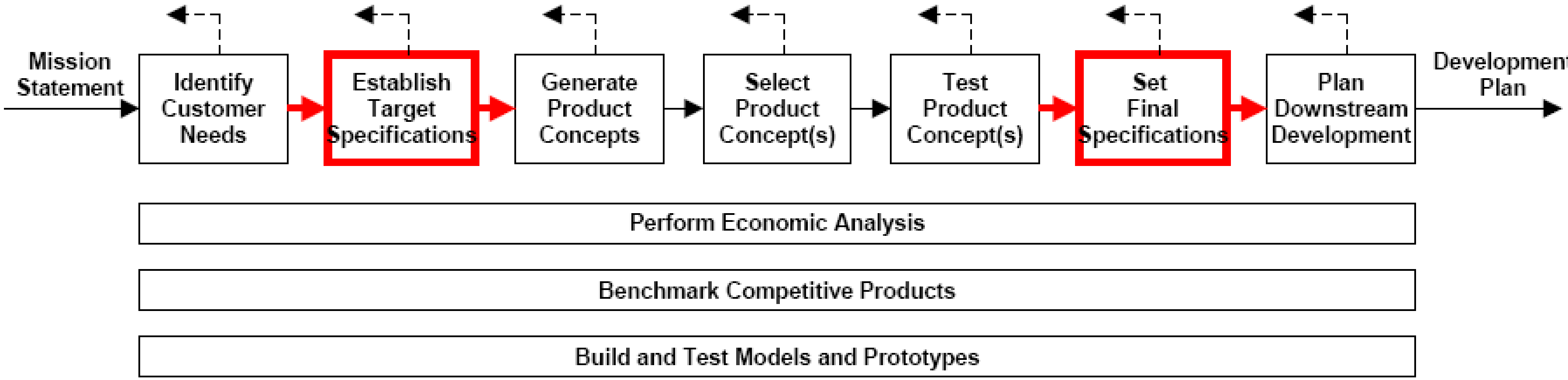
In Swedish: ***"produktspecifikation"*** (avseende listningen av ***alla*** egenskaper produkten förväntas ha. Även ***"kravspecifikation"*** är vanligt förekommande – trots att alla egenskaper inte nödvändigtvis har rangen av att vara krav.)

Establishing Target Specifications

#	NEED		Imp
1	The suspension	reduces vibration to the hands.	3
2	The suspension	allows easy traversal of slow, difficult terrain.	2
3	The suspension	enables high speed descents on bumpy trails.	5
4	The suspension	allows sensitivity adjustment.	3
5	The suspension	preserves the steering characteristics of the bike.	4
6	The suspension	remains rigid during hard cornering.	4
7	The suspension	is lightweight.	4
8	The suspension	provides stiff mounting points for the brakes.	2
9	The suspension	fits a wide variety of bikes, wheels, and tires.	5
10	The suspension	is easy to install.	1

Start with the Customer Needs

Establish Product Specifications



Target Specs

Based on customer needs and benchmarking

Final Specs

Based on selected concept, feasibility, models, testing, and trade-offs

Establishing Target Specifications

The process of establishing target specifications contains four steps:

Step 1: Prepare a list of metrics

Step 2: Collect competitive benchmarking information.

Step 3: Set ideal and marginally acceptable target values.

Step 4: Reflect on the result and the process.

Step 1: Prepare the List of Metrics

Establish Metrics and Units

Metric #	Need #s	Metric	Imp	Units
1	1,3	Attenuation from dropout to handlebar at 10hz	3	dB
2	2,6	Spring pre-load	3	N
3	1,3	Maximum value from the Monster	5	g
4	1,3	Minimum descent time on test track	5	s
5	4	Damping coefficient adjustment range	3	N-s/m
6	5	Maximum travel (26in wheel)	3	mm
7	5	Rake offset	3	mm
8	6	Lateral stiffness at the tip	3	kN/m
9	7	Total mass	4	kg
10	8	Lateral stiffness at brake pivots	2	kN/m

Step 1: Prepare the List of Metrics

Link Metrics to Needs

	Need \ Metric	1 Attenuation from dropout to handlebar at 10 Hz	2 Spring preload	3 Maximum value from the Monster	4 Minimum descent time on test track	5 Damping coefficient adjustment range	6 Maximum travel (26-in. wheel)	7 Rake offset	8 Lateral stiffness at the tip	9 Total mass	10 Lateral stiffness at brake pivots
1	Reduces vibration to the hands	●		●	●						
2	Allows easy traversal of slow, difficult terrain		●								
3	Enables high-speed descents on bumpy trails	●		●	●						
4	Allows sensitivity adjustment					●					
5	Preserves the steering characteristics of the bike						●	●			
6	Remains rigid during hard cornering		●						●		
7	Is lightweight									●	
8	Provides stiff mounting points for the brakes										●
9	Fits a wide variety of bikes, wheels, and tires										
10	Is easy to install										

Step 2: Collect the Competitive Benchmarking Information

Competitive benchmarking based on *Metrics*

Metric No.	Need Nos.	Metric	Imp.	Units	ST Tritrack	Maniray 2	Rox Tahx Quadra	Rox Tahx Ti 21	Tonka Pro	Gunhill Head Shox
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB	8	15	10	15	9	13
2	2, 6	Spring preload	3	N	550	760	500	710	480	680
3	1, 3	Maximum value from the Monster	5	g	3.6	3.2	3.7	3.3	3.7	3.4
4	1, 3	Minimum descent time on test track	5	s	13	11.3	12.6	11.2	13.2	11
5	4	Damping coefficient adjustment range	3	N-s/m	0	0	0	200	0	0
6	5	Maximum travel (26-in. wheel)	3	mm	28	48	43	46	33	38
7	5	Rake offset	3	mm	41.5	39	38	38	43.2	39
8	6	Lateral stiffness at the tip	3	kN/m	59	110	85	85	65	130
9	7	Total mass	4	kg	1.409	1.385	1.409	1.364	1.222	1.100
10	8	Lateral stiffness at brake pivots	2	kN/m	295	550	425	425	325	650

Step 3: Set Ideal and Marginally Acceptable Target Values for Each Metric

There are five ways to express the values of the metrics:

- At least X – higher is better
- At most X – lower is better
- Between X and Y
- Exactly X
- A set of discrete values X, Y, Z

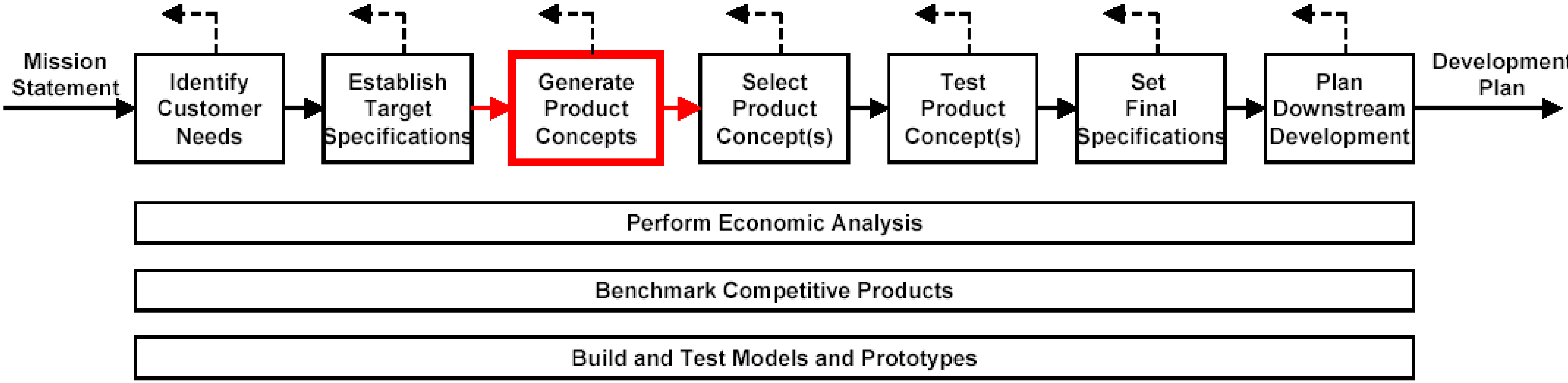
Step 3: Set Ideal and Marginally Acceptable Target Values for Each Metric

The target specifications

Metric No.	Need Nos.	Metric	Imp.	Units	Marginal Value	Ideal Value
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB	>10	>15
2	2, 6	Spring preload	3	N	480–800	650–700
3	1, 3	Maximum value from the Monster	5	g	<3.5	<3.2
4	1, 3	Minimum descent time on test track	5	s	<13.0	<11.0
5	4	Damping coefficient adjustment range	3	N-s/m	0	>200
6	5	Maximum travel (26-in. wheel)	3	mm	33–50	45
7	5	Rake offset	3	mm	37–45	38
8	6	Lateral stiffness at the tip	3	kN/m	>65	>130
9	7	Total mass	4	kg	<1.4	<1.1
10	8	Lateral stiffness at brake pivots	2	kN/m	>325	>650
11	9	Headset sizes	5	in.	1.000 1.125	1.000 1.125 1.250

Concept Generation – example Cordless Electric Roofing Nailer

Concept Generation



What is a Product Concept?

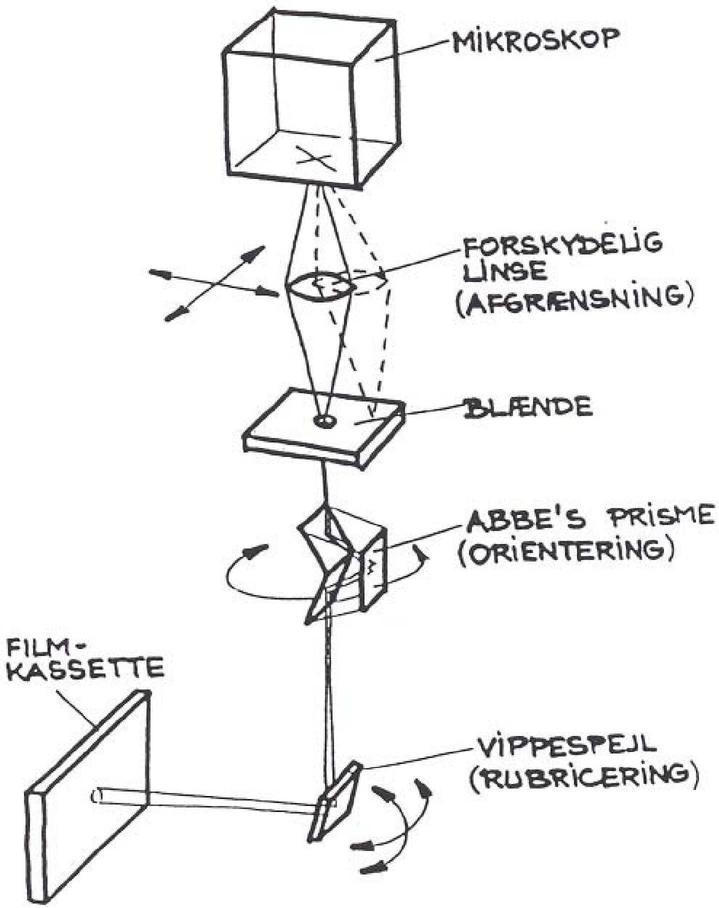
A ***product concept*** is an ***approximate*** description of the technology, ***working principle(s)***, and ***form*** of the product.

A ***working principle*** is the ***technical realization based on one or a combination of the laws of nature.***

A concept is a ***concise description*** of how the product will satisfy the customer needs.

A concept is usually expressed as a ***sketch or as a rough three-dimensional model and is often accompanied by a brief textual description.***

Working Principles – an Example



Working principle for a microscope - specialized for studies of chromosomes

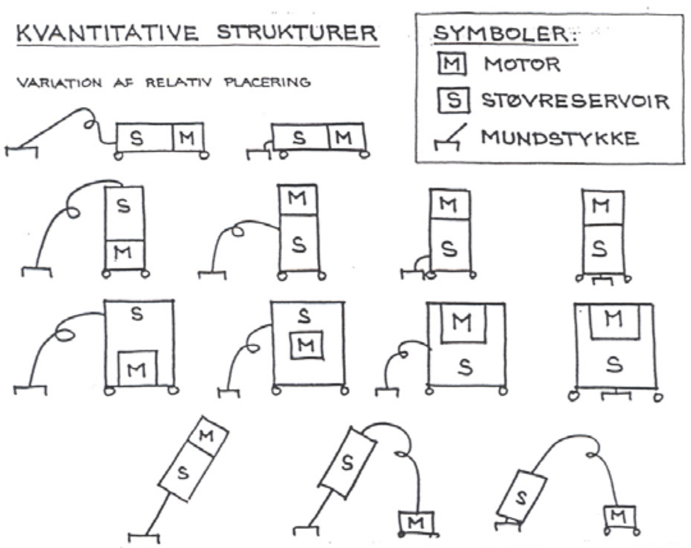
Source: E. Tjalve "Systematisk utformning af industriprodukter", 1976

Product Architecture ➡ Embodiment

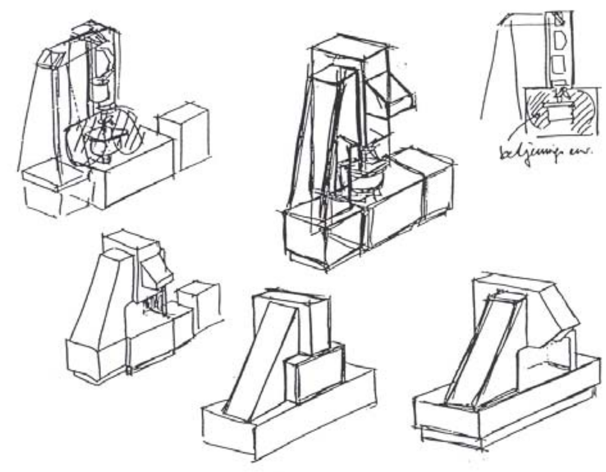
Having established the ***Working principle*** of the concept, the next step is to create its ***Architecture*** (localization of its constitutive subsystems). Based on this the ***Embodiment*** (form and shape) will finalize the generation of the concept.

Note that the ***Architecture*** and ***Embodiment*** of the concept is most frequently of a ***preliminary nature***, while the establishment of the ***Working Principle*** is final!

Concept - Architecture



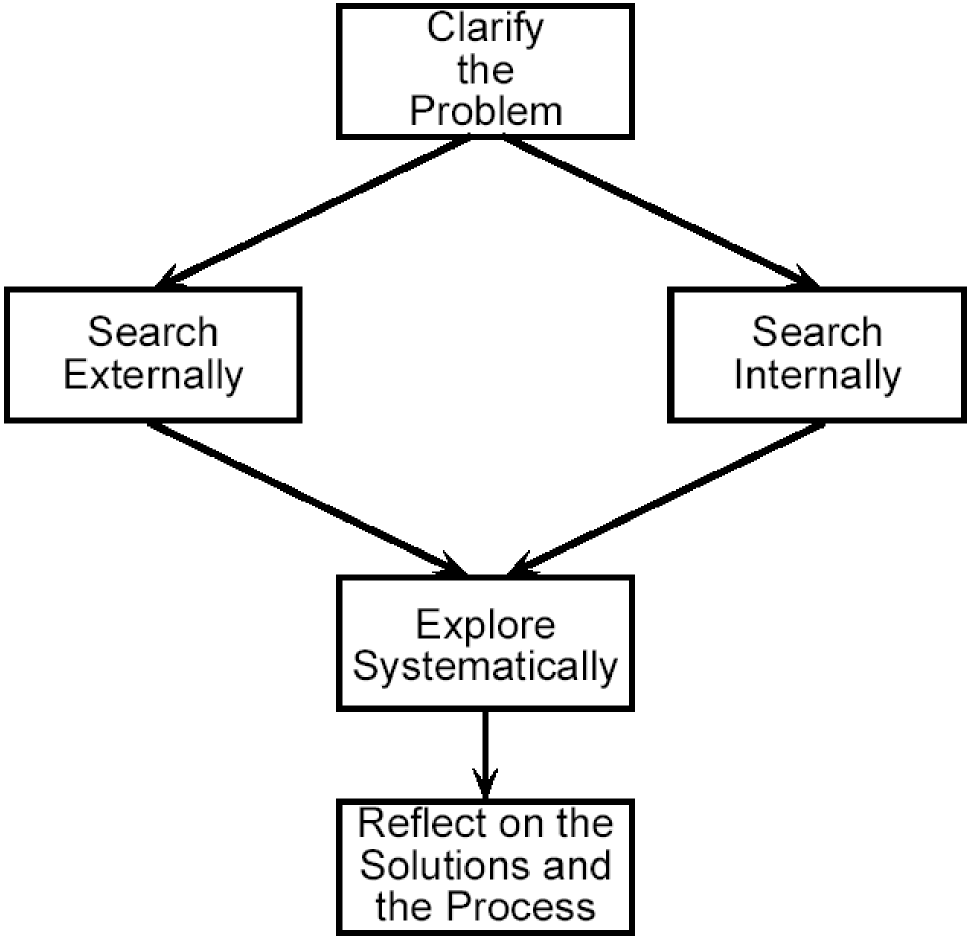
Concept – Embodiment



Source: E. Tjalve "Systematisk utformning af industriprodukter", 1976

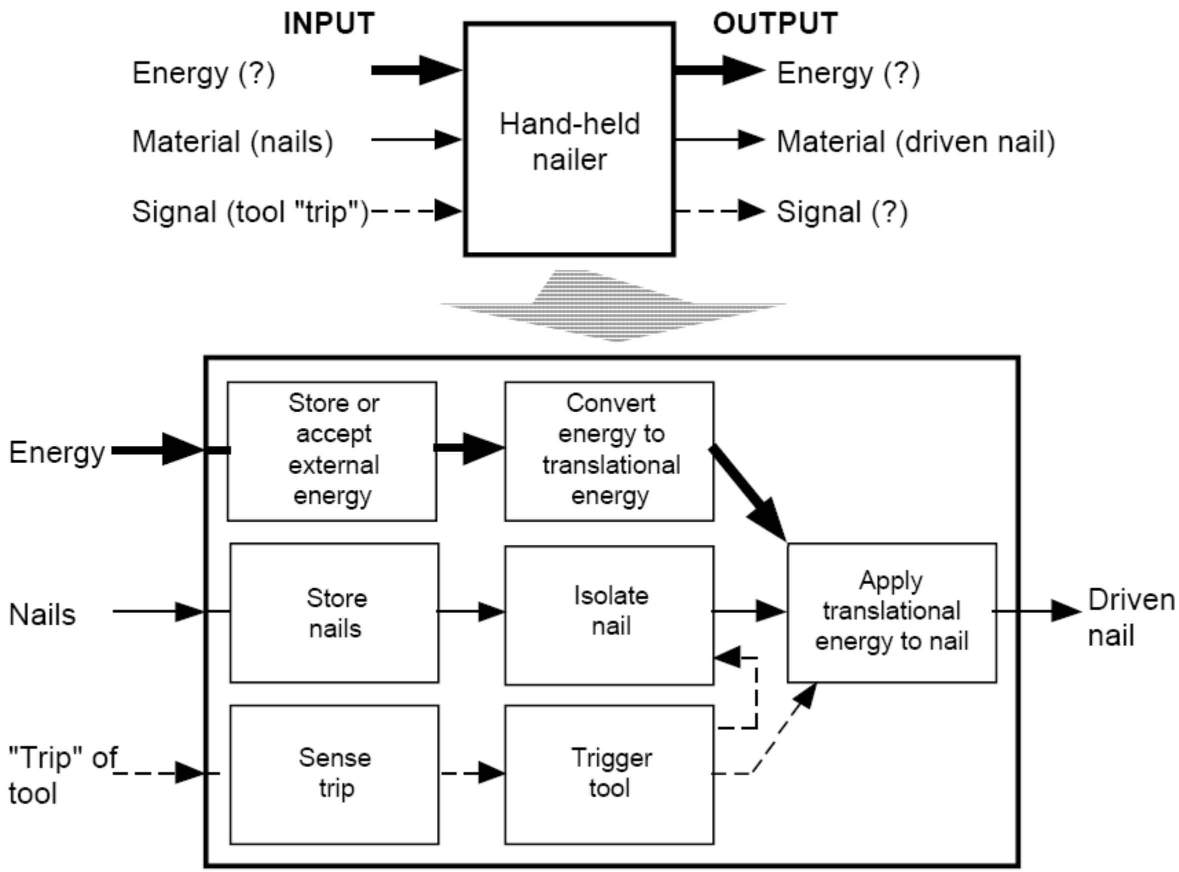
A Five-Step Method Concept Generation Method

- Clarify the Problem
  - Problem Decomposition
- External Search
  - Lead Users
  - Experts
  - Patents
  - Literature
  - Benchmarking
- Internal Search
  - Individual Methods
  - Group Methods
- Systematic Exploration
  - Classification Tree
  - Combination Table
- Reflect on the Process
  - Continuous Improvement



Step 1: Clarify the Problem

Decomposition of a Complex problem into Simpler Subproblems



Step 2: Search Externally

There are at least five good ways to gather information from external sources. These are:

- ***Interview lead users***
- ***Consult experts***
- ***Search patents***
- ***Search published literature***
- ***Benchmark related products***

Step 3: Search Internally

Guidelines **useful for** *improving both individual and group internal search:*

- *Suspend judgment*
- *Generate a lot of ideas*
- *Infeasible ideas are welcome*
- *Use graphical and physical media*

Step 4: Explore Systematically

Solutions to Subproblem of Storing or Accepting Energy

- Self-regulating chemical reaction emitting high-pressure gas
- Carbide (as for lanterns)
- Combusting sawdust from job site
- Gun powder
- Sodium azide (air bag explosive)
- Fuel-air combustion (butane, propane, acetylene, etc.)
- Compressed air (in tank or from compressor)
- Carbon dioxide in tank
- Electric wall outlet and cord
- High-pressure oil line (hydraulics)
- Flywheel with charging (spin-up)
- Battery pack or tool, belt, or floor
- Fuel cell
- Human power: arms or legs
- Methane from decomposing organic

Solutions to Subproblem of Applying Translational Energy to Nail

Single Impact

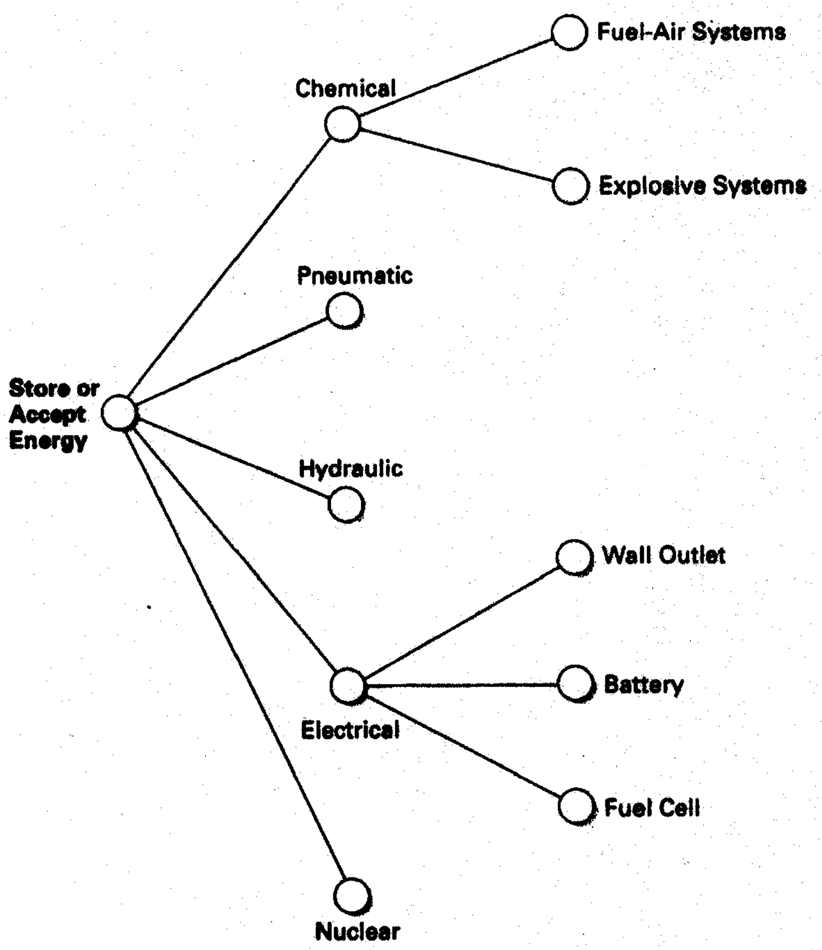
Multiple Impacts (tens or hundreds)

Multiple Impacts (hundreds or thousands)

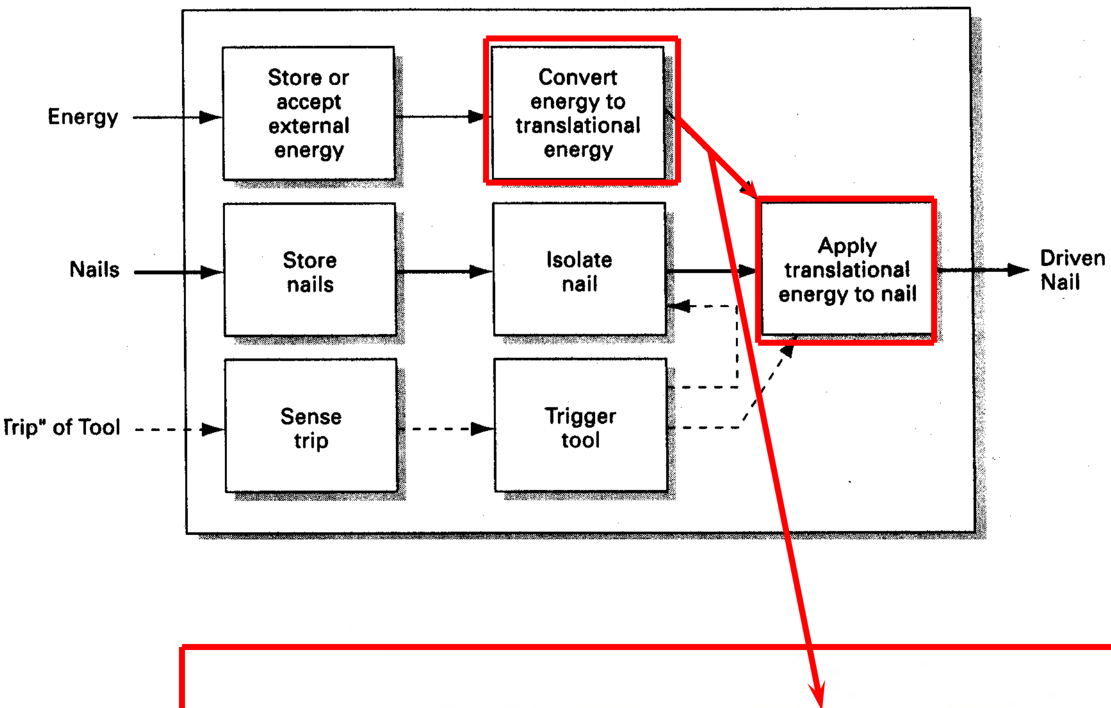
Step 4: Explore Systematically

Classification Tree – benefits:

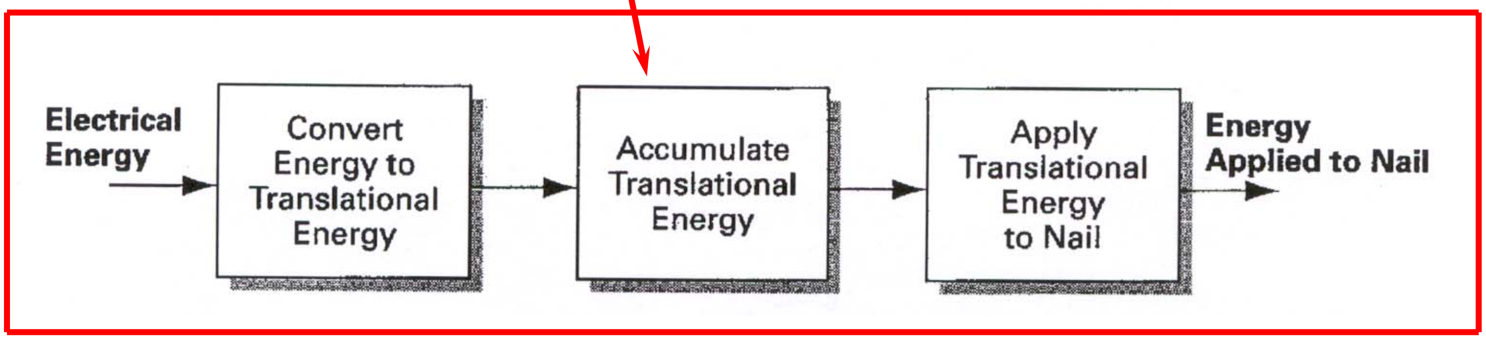
- Pruning of less promising branches
- Identification of independent approaches to the problem
- Exposure of inappropriate emphasis on certain branches
- Refinement of the problem decomposition for a particular branch



Step 4: Explore Systematically

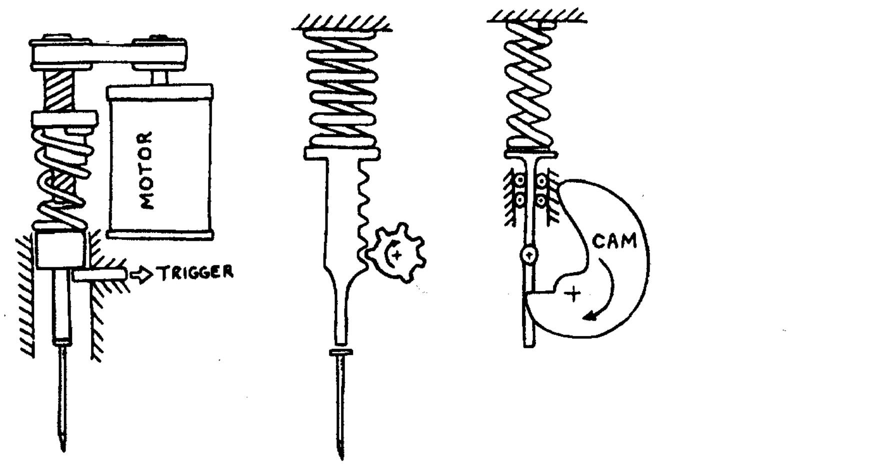


A new problem decomposition



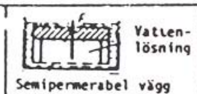
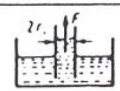
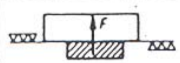
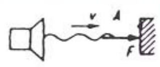
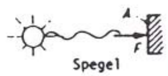
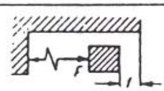
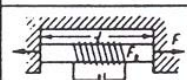
Step 4: Explore Systematically

Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		



Concept Combination Table

Step 4: Explore Systematically – an Alternative Approach Using Design Catalogues

KATALOGENS LÖSNINGSFÖRSLAG			Nr	URVALSKRITERIER 5 Erhållna kraftens storlek	7 Konstruktions-parameter	4 Arbets-förmåga? Storlek?	2 Nödvändiga intensitets- eller fält-storheter	Vald förs
Osmos	$F = A \cdot \frac{\cdots}{V} RT$		21	Medel	A,v,r	Ja	Koncentra-tions-gradient	
Kapilläreffekt	$F = 2\pi r \sigma_0$		22	Liten	Typ av vätska,r	Ja liten	Molekylärt fält	
Adhesion	$F = f(\text{Material}, R_t)$		23		Material R_t			
Ljudtryck	$F = \rho \cdot v \cdot c \cdot A$		24	Mycket liten	Mellan-liggande medium,A		Strålning	
Elektromagnetiskt strålningstryck	$F = 2 \frac{\bar{S}}{c} \cdot A$		25					
Fjäderdeformation	$F = c \cdot l$		26	Stor	c	Ja	Deformation	
Elektrostriktion	$F = c \cdot [l(E) - l(E_0)]$		27	Liten	Material,l	Ja liten	Elektrisk fältstyrka	
Magnetostriktion	$F = c[l(B) - l(B_0)]$		28				Magnetisk fältstyrka	

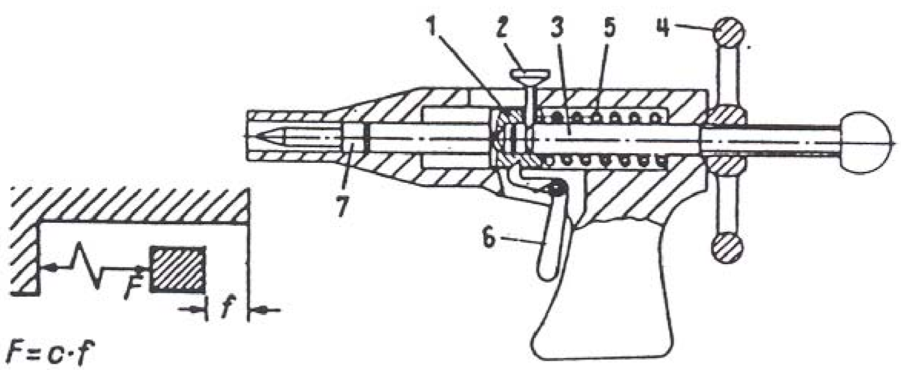
Design Catalogue based on a listing of the existing laws of physics for the elementary sub-problem "Generating Force"

Source: Lic. Eng. Thesis by R. Bjärnemo 1983

Step 4: Explore Systematically – an Alternative Approach Using Design Catalogues

Concept (candidate) solutions

Fjäderdeformation



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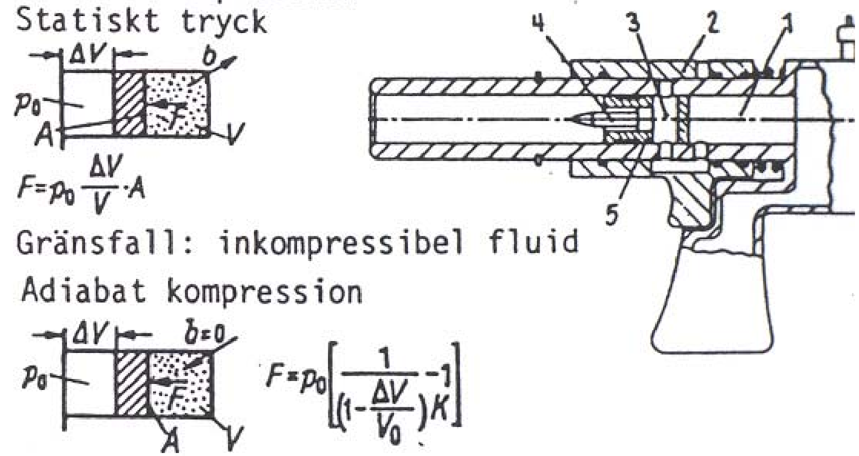

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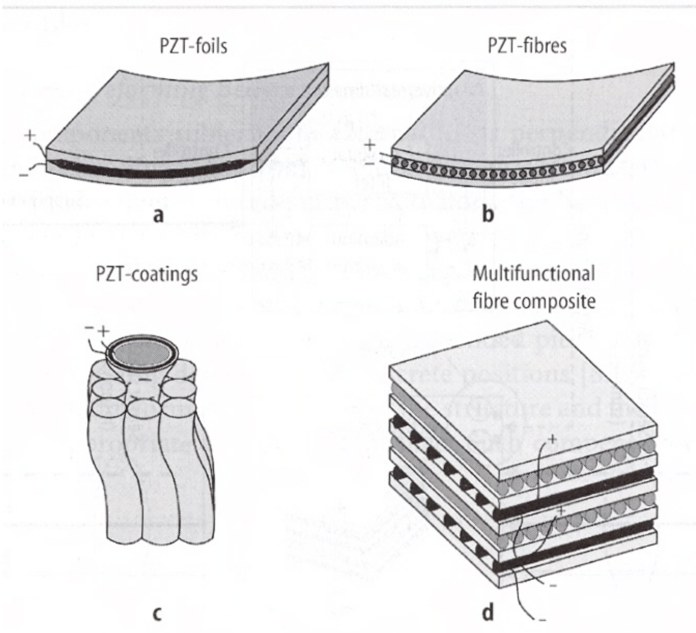
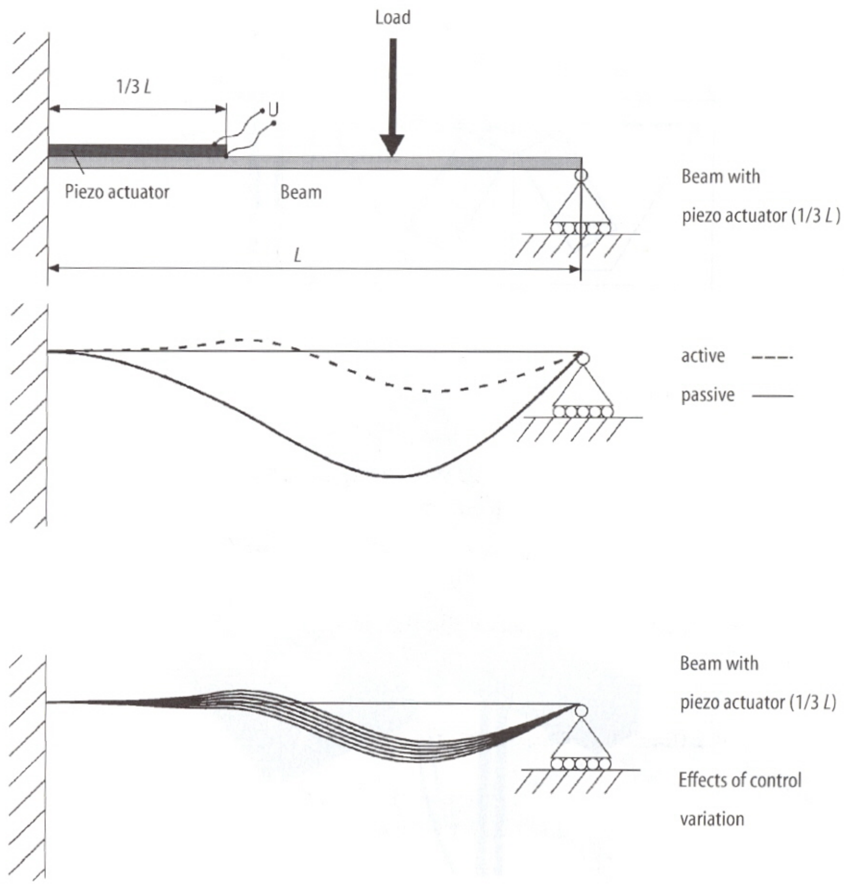
Source: Lic. Eng. Thesis by R. Bjärnemo 1983

Mechatronic products - examples

Adaptronic products

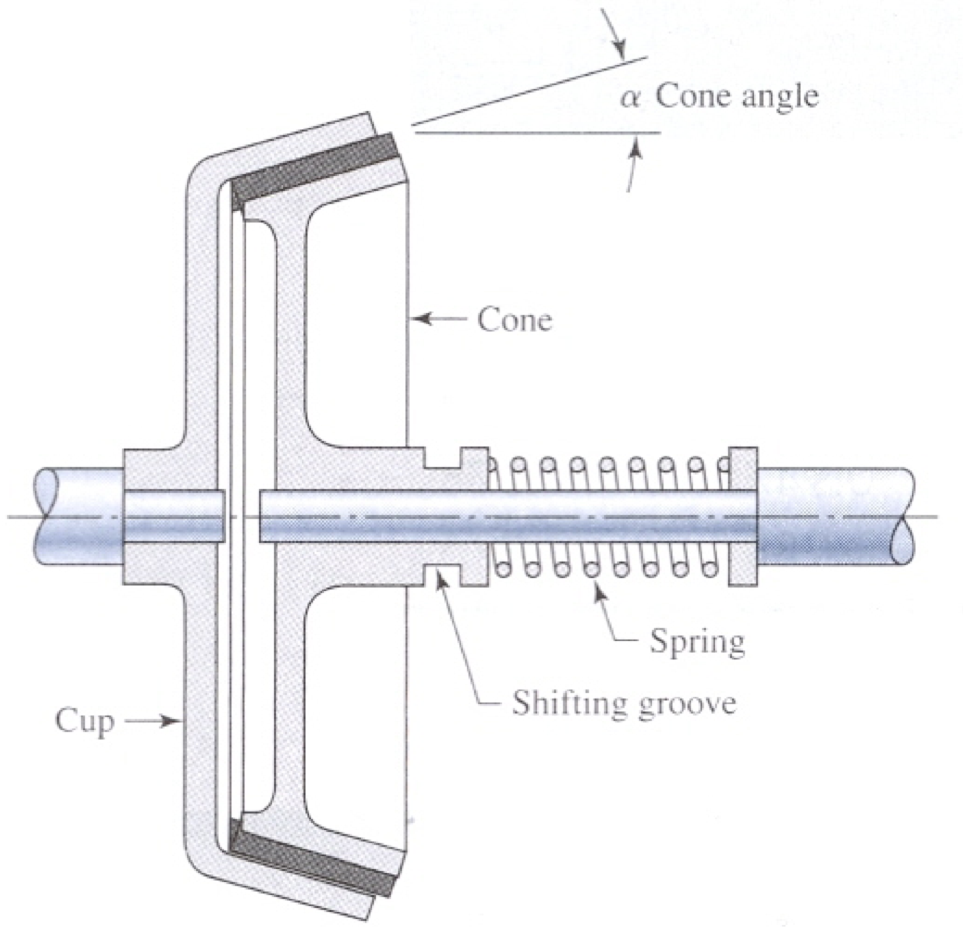




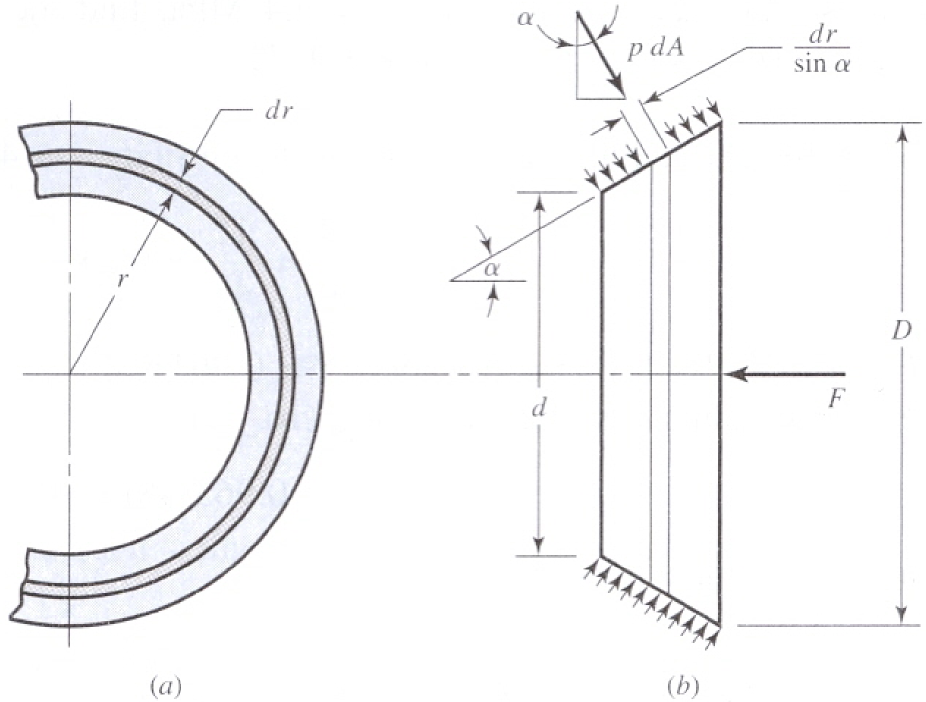
An example of a mechanical clutch - the Cone Clutch

In the drawing ot the ***cone clutch*** in the figure shows that it consists of a ***cup*** keyed or splined to the left shaft, a ***cone*** that must slide axially on splines or keys on the mating shaft (right), and a ***helical spring*** to hold the clutch in engagement.

The clutch is disengaged by means of a ***fork*** that fits into the ***shifting grow*** on the friction cone. The ***cone angle α*** and the ***diameter*** and ***face width of the cone*** are the important geometric ***design parameters***.



An example of a mechanical clutch - the Cone Clutch



Based on the assumption of ***uniform wear*** and ***uniform pressure*** the force ***F*** and the ***torque transmitted***.

These relations forms the ***underlying phenomena*** upon which the ***working principle*** of the cone clutch is based.

The DESIGN TASK

1. Design a clutch based on a ***mechanical working principle!***
2. Design a clutch based on an ***electrical working principle!***
3. Design a clutch which is based on a ***combination of mechanical and electrical working principles!*** Note that in order to design such a clutch ***at least one of the working principles is utilized for a subfunction of the overall function*** of the clutch. An example of such a subfunction with reference to the cone clutch might be the mechanism by which the clutch is disengaged!

The DESIGN TASK

The results should be ***documented in a report!***

In the report the ***results of each of the tasks*** should contain:

- A ***sketch of the clutch*** and a ***verbal description of how it works!***
- A ***discussion*** of the ***constitutive phenomena of the working principle(s).***
- ***If possible*** present the ***torque transmitted as a function of some of the important design parameters!***
- The report should be sent to robert.bjarnemo@mkon.lth.se ***latest Tuesday 2nd of February.***
- File format ***Word and Pdf!***
- The ***results of the report will be discussed individually with each of the participants*** in the course! ***Date, time and location for these discussions will be on Friday 5th February distributed by Henriette Weibull!***