14MEPR0	ASSEMBLY ENGINEERING	Category	L	T	P	Credit
		PE	3	0	0	3

Preamble

The increasing need for finishing goods in large quantities has led engineers to search for and to develop new methods for manufacturing. As a result of developments in the various manufacturing processes, it is now possible to mass-produce high quality durable goods at low cost. One of the manufacturing processes is assembly process that is required when two or more components are to be secured together. The history of assembly process development is closely related to the history of the development of mass-production methods. The assembly process is concerned with prediction of time taken to accomplish the various tasks such as grasp, orient, insert and fasten. This process can be carried out manually and/or automatically based on its cost estimation.Besides, Design for Assembly (DFA) provides systematic procedure and guidelines for evaluating and improving the product design for both manufacture and assembly economically.

Prerequisite

- 14ME330 – Metal Joining Processes and Manufacturing Practices
- 14ME450 – Production Drawing
- 14ME530 – Manufacturing Systems and Automation

Course Outcomes

On the successful completion of the course, students will be able to

CO1 :	Implement dimensional and geometrical tolerances for the given assembly/part to meet its specified functional requirement.	Apply
CO2:	Determine feasible assembly sequences for the given set of parts using Liaison Sequence diagram and precedence constraints.	Apply
CO3:	Determine the time and number of workers required for the given assembly requirement.	Apply
CO4:	Estimate the cost involved in indexing and free-transfer machines in an assembly.	Apply
CO5:	Implement design modifications on the given component using DFA guidelines.	Apply

Mapping with Programme Outcomes

COs	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1.	S	M	L			L					M	
CO2.	S	M	L			L					M	L
CO3.	S	M	L			L					M	
CO4.	S	M	L			L					M	M
CO5.	S	L				L					M	

S- Strong; M-Medium; L-Low

Assessment Pattern

Bloom's Category	Continuous Assessment Tests			Terminal Examination
	1	2	3	
Remember	20	20	20	0
Understand	20	20	20	30
Apply	60	60	60	70
Analyse	-	-	-	-
Evaluate	-	-	-	-
Create	-	-	-	-

Course Level Assessment Questions

Course Outcome 1 (CO1):

1. A 30mm diameter hole is made on a turret lathe to the limits, 30.035 and 30.00. The followingtwo grades of shafts are used to fit in the hole:(*a*) ϕ29.955mm and 29.925mm, and (*b*) ϕ 30.055mm and 30.050mm.Calculate the maximum tolerance, clearance and indicate the type of fit in each case by a sketch.
2. Interpret and write the specification of all the feature control frames in the drawing as shown in figure 1 and draw their respective tolerance zones.

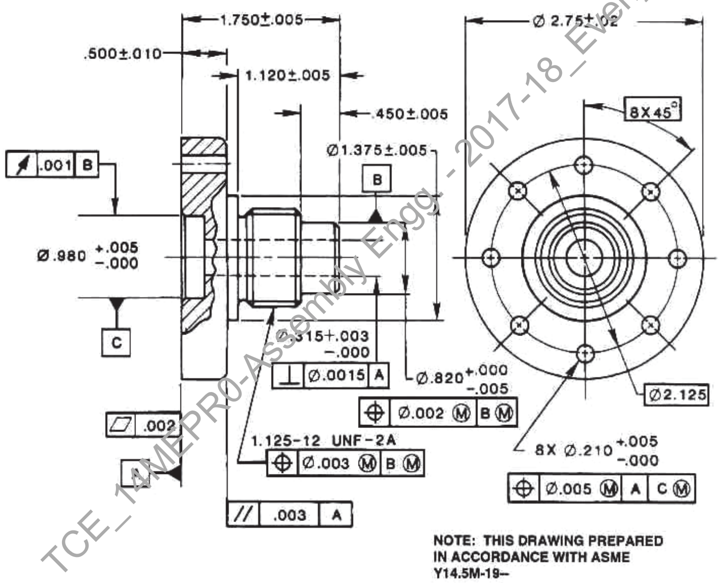


Figure 1

3. The following two components as shown in Figure 2 are to be assembled with a tolerance of fit +0.002±0.002 mm. Design a selective assembly structure and justify the same. Is there any change in selective assembly structure, if the tolerance of fit is set to be +0.004±0.002 mm ? Justify the same.

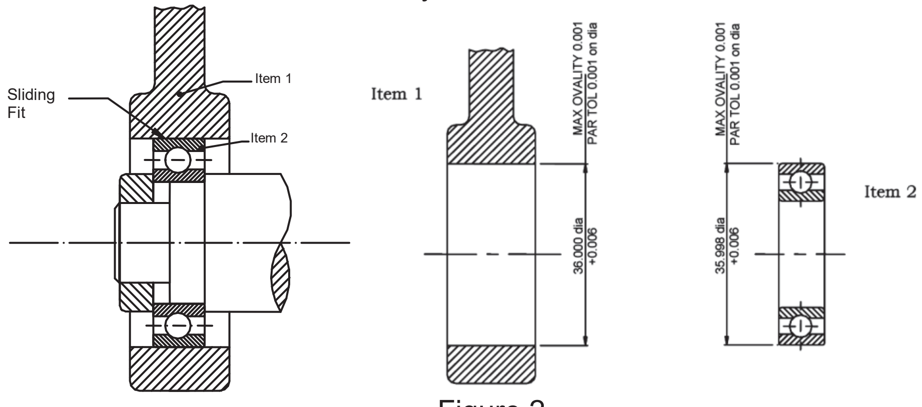


Figure 2

Course Outcome 2 (CO2):

1. Prepare an assembly sequence for the following exploded view of assembly as given in figure 3.

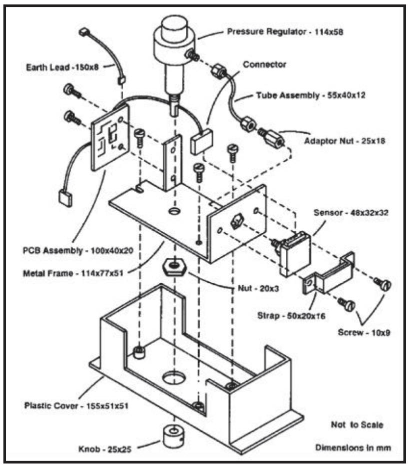
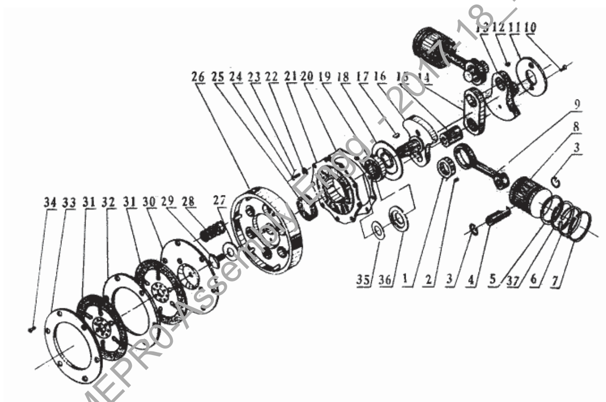


Figure 3

2. The exploded view of a crank shaft and clutch assembly shown in Figure 4. Suggest assembly plan for this assembly with its precedence diagram of its assembly sequence where its part numbers are on the node. Justify the assumptions made if any.



Part #	CJ 750 Parts name	Qty	Part #	CJ 750 Parts name	Qty	Part #	CJ 750 Parts name	Qty
1	Retainer	2	9	Link rod copper insert SV	1	31	Friction wafer	4
2	CJ750 Rollers	24		Link rod copper insert OHV	1	32	Drive wafer	4
3	Piston pin circlip or clasp SV	4	10	Screw	1	33	Supporting plate	1
	Piston pin circlip OHV		11	Front oil slinger	1	34	Screw	1
4	Piston pin SV	2	12	Crank shaft front part key	1	35	Washer	1
	Piston pin OHV		13	Crank shaft front part	1	36	Rear oil proof disc	1
5	OHV oil seal piston ring +0.00	2	14	Crank cheek	9	37	SV Oil seal piston ring +0.00	1
	SV Oil seal piston ring +0.00	2	15	Crank pin	1		OHV oil seal piston ring +0.00	1
	SV oil seal piston ring +0.25	2	16	Crank shaft rear part	9		SV oil seal piston ring +0.25	
	SV Oil seal piston ring +0.50	2	17	Crank shaft rear part key	1		SV oil seal piston ring +0.50	1
	SV Oil seal piston ring +0.75		18	Rear oil slinger	1		SV oil seal piston ring +0.75	
	SV Oil seal piston ring +1.00	2	19	Bearing	1		SV oil seal piston ring +1.0	
	SV Oil seal piston ring +1.25		20	Washer	6		SV oil seal piston ring +1.25	1
6	OHV air seal pistin ring +0.00		21	Rear bearing fitting body	1	3-8	Piston, pins, rings and clips	
	SV Air seal piston ring +0.00	2	22	Washer	1	37	combination	
	SV Air seal piston ring +0.25	1	23	Fuse		1-2		
	SV Air seal piston ring +0.50	1	24	Screw		9	Crank shaft combination	
	SV Air seal piston ring +0.75	1	25	Sealing leather cup and spring		13-16		
	SV Air seal piston ring +1.0	1	26	Flywheel combination		1-2		
	SV Air seal piston ring +1.25	2	27	Lock wafer		18	Crank shaft combination w/oil	
7	OHV air seal piston ring +0.00		28	Clutch spring		9-11	proof key	
	SV Air seal piston ring +0.00		29	Crank shaft rear screw		13-16		
	SV Air seal piston ring +0.25		30	Platen				
	SV Air seal piston ring +0.50							
	SV Air seal piston ring +0.75							
	SV Air seal piston ring +1.00							
	SV Air seal piston ring +1.25							
8	Pistons							
	SV high speed pistons and rings							
	SV oversize pistons & rings +0.25							

Figure 4

3. Suggest a suitable assembly processes and appropriate tools for the gear box assembly as shown in figure 5. Identify the expected bottleneck operation in this assembly and predict the estimated time for the same.

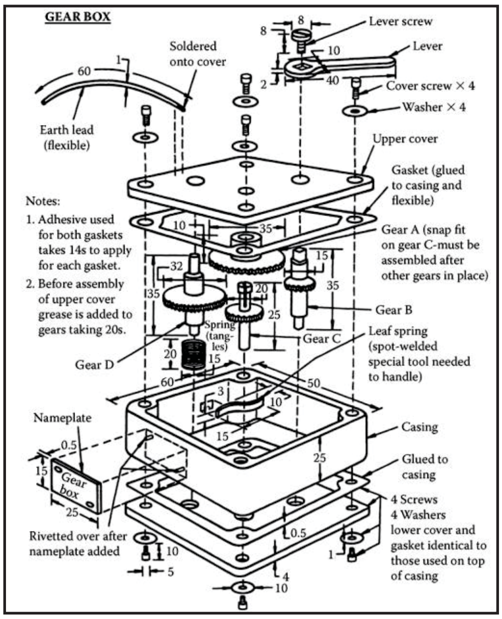


Figure 5

Course Outcome 3 (CO3):

1. The following data have been obtained for a vehicle assembly.

   Customer demand for Vehicle: 2500 / day
   No of Shifts working : 2
   Working time : 8.5 hrs/ shift
   Lunch Break : 30 min/ shift
   Tea time : 2 times/shift at 10 min/tea break

Calculate the TAKT time and the number of workers required to meet the demand.

2. The hourly production rate and work content time for two models to be produced on a mixed model assembly line are given in the table below.

Model *j*	Production Rate R_{pj}	Time T_{wcj}(min)
A	4	27.0
B	6	25.0

Also, given is that line efficiency E=0.96 and manning level M=1. Determine the theoretical minimum number of workers required on the assembly line.

3. A small electrical appliance is to be produced on a single model assembly line. The work content of assembling the product has been reduced to the work elements listed in Table 1. The table also lists the standard times that have been established for each element as well as the precedence order in which they must be performed. The line is to be balanced for an annual demand of 100,000 units/yr. The line will operate 50 weeks/year, 5 shifts/week and 7.5 hours/shift. Manning level will be one worker per station. Previous experience suggests that the uptime efficiency for the line will be 96%, and repositioning time lost per cycle will be 0.08 min. Determine:
   (i) total work content time T_{wc},
   (ii) required hourly production rate R_p to achieve the annual demand,
   (iii) cycle time T_c
   (iv) theoretical minimum number of workers required on the line, and
   (v) service time T_s, to which the line must be balanced.

Table 1 Work elements

No.	Work element description	Time, T_{ek} (min)	Must be preceded by
1.	Place frame in work-holder and clamp	0.2	-
2.	Assemble plug, grommet to power cord	0.4	-
3.	Assemble brackets to frame	0.7	1
4.	Wire power cord to motor	0.1	1,2
5.	Wire power cord to switch	0.3	2
6.	Assemble mechanism plate to bracket	0.11	3
7.	Assemble blade to bracket	0.32	3
8.	Assemble motor to brackets	0.6	3,4
9.	Align blade and attach to motor	0.27	6,7,8
10.	Assemble switch to motor bracket	0.38	5,8
11.	Attach cover, inspect, and test	0.5	9,10
12.	Place in tote pan for packing	0.12	11

Course Outcome 4 (CO4):

1. Differentiate indexing and free-tranfser machine.
2. Discuss the effect of part quality on downtime of indexing machines.
3. A 20--station transfer line is being proposed to machine a certain component currently produced by conventional methods. The proposal received from the machine tool builder states that the line will operate at a production rate of 50 pc/hr at 100% efficiency. From similar transfer lines, it is estimated that breakdowns of all types will occur with a frequency *F* = 0.10 breakdown per cycle and that the average downtime per line stop will be 8.0 min. The starting casting that is machined on the line costs Rs.3.00 per part. The line operates at a cost of Rs.*75.00/hr.* The 20 cutting tools (one tool per station) last for 50 parts each, and the average cost per tool = Rs.2.00 per cutting edge Based on this data, compute the following: (a) production rate, (b) line efficiency, and *(c)* cost per unit piece produced on the line.

Course Outcome 5 (CO5):

1. The controller assembly as in figure 6 has been assembled manually. If the company is interested to assemble this equipment through an automated assembly system in order to avoid errors in manual assembly and availability of skilled labours, suggest suitable modification in design of this assembly for the improvement of its assembly efficiency.

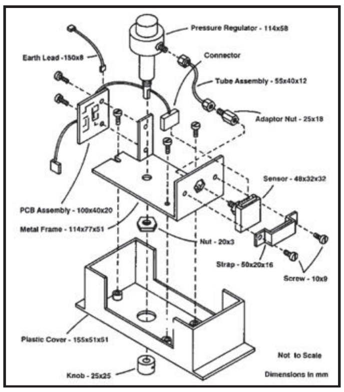


Figure 6

2. Suggest and justify the suitable modifications on the design of the following components as shown in figure 7to ensure proper assemblywith minimum effort.

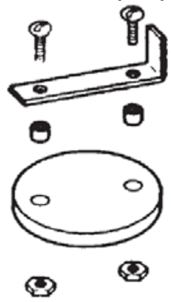


Figure 7

3. Recommend necessary modifications in part design of the following alternator assembly as shown in figure 8 and its assembly sequences in order to improve the efficiency of its manual assembly.

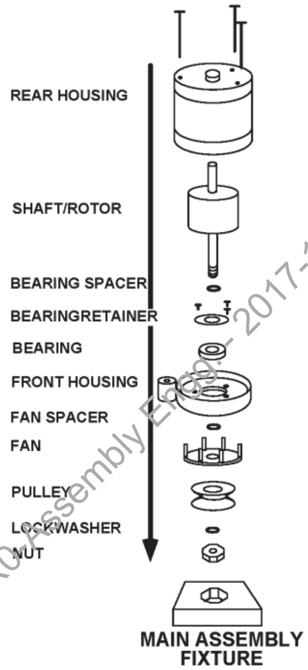
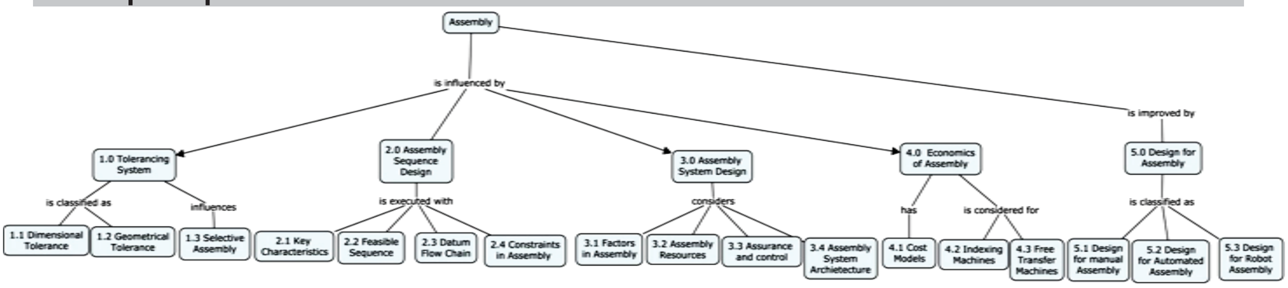


Figure 8

Concept Map



Syllabus

Tolerancing System: Importance- Dimensional and geometric tolerances - Process capability - surface finish– Fit of an assembly - Cumulative effect of tolerances. Datum systems: Degrees of freedom. True position theory: Virtual size concept - Projected tolerance zone - Selective Assembly:Interchangeable part manufacture and selective assembly - Deciding the number of groups - Group tolerances of mating parts equal - Total and group tolerances of shaft equal.

Assembly Sequence Design: Key Characteristics (KC) – Flow down of KC –Ideal KC process – KC Conflicts. Assembly Sequence Design Process: Methods for finding feasible sequences - Liaison diagram – Governing Rule – Generating the feasible sequences- Cutset method. Datum Flow Chain: Nominal Design – Variation Design – Assumptions – Role of assembly features. Constraints in Assembly: Completely constrained assemblies – Partially constrained assemblies - Assembly precedence constraints. Design Procedure for assemblies.

Assembly System Design: Factors in system design – capacity planning, available time & required number of units per year, assembly resources choice, assignment of operations of resources, floor layout, workstation design, material handling and work transport, parts feeding and presentation and quality. Assembly Resources: Characteristics of manual, fixed and flexible automation. Parts feeding and presentation: Automatic feeding and orienting - feed tracks – escapements – part placement mechanism and robots.Assurance and control: Elements of testing strategy – Effect of assembly faults on assembly cost and assembly system capacity. Assembly System Architectures: Single serial line, team assembly, fishbone serial line with sub-assembly feeder, loop architecture, U-shaped cell and cellular assembly line.

Economics of Assembly System: Kinds of cost – Cost models of assembling – Unit cost models of manual, fixed and flexible automation. Indexing machines: Effect of parts quality on downtime, production time and cost of assembly. Free-transfer machines: performance – average production time – Number of personnel for fault correction. Economic comparisons of automation equipment – effect of production volume.

Design for Assembly (DFA): Need and applications - Role of Design for Manufacture and Assembly in concurrent engineering - General guidelines of Design for Assembly - Design for manual assembly: guidelines for part handling, insertion and fastening - Effect of symmetry, part thickness and size and weight on handling time and on grasping and manipulation - Effect of chamfer design on insertion operations. Design for automated assembly: effect of feed rate on cost – high speed automatic insertion - Design for feeding and orienting - Design for Robot assembly: types of robot assembly system - design rules – Case studies.

Text Book

1. Daniel E Whitney, “Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development”, Oxford University Press, 2009.

Reference Books/Learning Resources

1. Alex Krulikowski, “Fundamentals of Geometric Dimensioning and Tolerancing”, Third Edition, Cengage Learning, 2012.
2. Geoffrey Boothroyd, “Assembly Automation and Product Design”, Second Edition, Manufacturing Engineering and Materials Processing Series, CRC Press, Taylor & Francis, 2005.
3. Geoffrey Boothroyd, Peter Dewhurst, Winston A Knight, “Product Design for Manufacture and Assembly”, Third Edition, CRC Press, 2010.
4. David M. Anderson, “Design for Manufacturability & Concurrent Engineering; How to Design for Low Cost, Design in High Quality, Design for Lean Manufacture, and Design Quickly for Fast Production”, CIM Press, 2010.
5. E-Learning source on Mechanical Assembly and Its Role in Product Development - https://ocw.mit.edu/courses/mechanical-engineering/2-875-mechanical-assembly-and-its-role-in-product-development-fall-2004/
6. Web source on DFMA Case Studies: Boothroyd Dewhurst, Inc.2016: https://www.dfma.com/resources/studies.htm

Course Contents and Lecture Schedule

Module No.	Topic	No. of Lectures
1.	**Tolerancing System:**	
1.1	Tolerancing System: Importance - Dimensional and geometric tolerances	1
1.1.1	Process capability - surface finish – Fit of an assembly	1
1.1.2	Cumulative effect of tolerances	1
1.2	Datum systems: Degrees of freedom	1
1.3	True position theory: Virtual size concept - Projected tolerance zone	2
1.3	Selective Assembly:Interchangeable part manufacture and selective assembly	1
1.3.1	Deciding the number of groups - Group tolerances.	1
2.	**Assembly Sequence Design:**	
2.1	Key Characteristics (KC) – Flow down of KC – Ideal KC process – KC Conflicts.	1
2.2	Assembly Sequence Design Process: Methods for finding feasible sequences	1
2.2.1	Liaison diagram – Governing Rule	1
2.2.2	Generating the feasible sequences- Cutset method	1
2.3	Datum Flow Chain: Nominal Design – Variation Design – Assumptions – Role of assembly features.	1
2.4	Constraints in Assembly: Completely constrained assemblies – Partially constrained assemblies	1
2.4.1	Assembly precedence constraints	1
2.4.2	Design Procedure for assemblies	1
3.	**Assembly System Design**	
3.1	Factors in system design: capacity planning, available time & required number of units per year, assembly resources choice, assignment of operations of resources, floor layout, workstation design, material handling and work transport, parts feeding and presentation and quality.	1
3.2	Assembly Resources: Characteristics of manual, fixed and flexible automation.	1
3.2.1	Parts feeding and presentation: Automatic feeding and orienting	1
3.2.2	Feed tracks – escapements – part placement mechanism and robots	1
3.3	Assurance and control: Elements of testing strategy	1
3.3.1	Effect of assembly faults on assembly cost and assembly system capacity.	1
3.4	Assembly System Architectures: Single serial line, team assembly	1
3.4.1	Fishbone serial line with sub-assembly feeder, loop architecture, U-shaped cell and cellular assembly line	1
4.	**Economics of Assembly System**	
4.1	Cost models of assembling – Kinds of cost	1
4.1.1	Unit cost models of manual automation.	1
4.1.2	Unit cost models of fixed automation.	1
4.1.3	Unit cost models of flexible automation.	1
4.2	Indexing machines: Effect of parts quality on downtime, production time and cost of assembly	1
4.3	Free-transfer machines: performance – average production time – Number of personnel for fault correction.	1

Module No.	Topic	No. of Lectures
4.3.1	Economic comparisons of automation equipment – effect of production volume.	1
5.	**Design for Assembly (DFA)**	
5.1	Concurrent Engineering: Need and applications - Role of Design for Manufacture and Assembly in concurrent engineering	1
5.1.1	General guidelines of Design for Assembly	1
5.2	Design for manual assembly: guidelines for part handling, insertion and fastening	1
5.2.1	Effect of symmetry, part thickness and size and weight on handling time and on grasping and manipulation	1
5.2.2	Effect of chamfer design on insertion operations.	
5.3	Design for automated assembly: effect of feed rate on cost – high speed automatic insertion	1
5.3.1	Design for feeding and orienting	1
5.4	Design for Robot assembly: types of robot assembly system - design rules Case studies.	1
	Total	**38**

Course Designers:

1. Dr.S.SaravanaPerumaal sspmech@tce.edu
2. Mr.K. Ravi, TVSM, Hosur k.ravi@tvsmotor.co.in
3. Mr.D. Dhamodharan, TVSM, Hosur d.dhamodharan@tvsmotor.co.in

Thiagarajar College of Engineering, Madurai-625015.
Department of Mechanical Engineering
Pre-Test (15.06.2017)

Course:14MEPR0 – Assembly Engineering
Class : VII B.E. (Mechanical Engineering) Faculty: Dr. S.Saravana Perumaal

1. Define assembly.

2. List any two human-made assembled and non-assembled products.

3. State the significance of assembly sequence.

4. Name the components used in an assembly workstation.

5. Define Tolerance.

6. List out any two reasons for assigning tolerance in product specification.

7. Name any two situations of personal experience in which you find difficult to handle any of parts.

8. Do you aware of concurrent engineering/approach in product design? Specify its significance.

9. Specify your motivations to undergo this course.

10. Your expectations from the course 14MEPR0 – Assembly Engineering.

Thiagarajar College of Engineering, Madurai – 625015

Department of Mechanical Engineering

14MEPR0 - Assembly Engineering

Details of Learning Materials - 2017-18 (Odd Semester)

Faculty In-Charge: Dr. S.Saravana Perumaal

Module No.	Module	Reference Book	Chapter	Page No.s
I	Tolerancing System	1	4	71-110
			8	209-248
			Appendix B	370-371
			Appendix D	373
II	Assembly Sequence Design	2	7	180-208
III	Assembly System Design	2	16	420-439
IV	Economics of Assembly System	2	18	489-499
		3	6	187-206
V	Design for Assembly	2	15	379-417
		3	7 (Manual)	219-256
			8 (Automated)	257-286
		4	3 (Manual)	85-146
			5 (Automated)	191-218

Reference Books:

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4. Geoffrey Boothroyd, Peter Dewhurst, Winston A Knight, “Product Design for Manufacture and Assembly”, Third Edition, CRC Press, 2010.

MODULE I -TOLERANCING SYSTEM

DIMENSIONAL AND GEOMETRICAL TOLERACING

14MEPR0 – ASSEMBLY ENGINEERING

Dr. S.Saravana Perumaal
Assistant Professor
Department of Mechanical Engineering
Thiagarajar College of Engineering
Madurai – 625015
sspmech@tce.edu

COURSE OUTCOME

- CO1 : Implement dimensional and geometrical tolerances for the given assembly/part to meet its specified functional requirement (Apply)

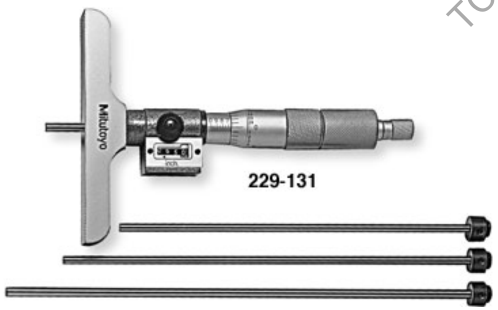
TOOLS FOR MEASURING DIMENSIONS

Dial Indicator

Surface Plate

Micrometer

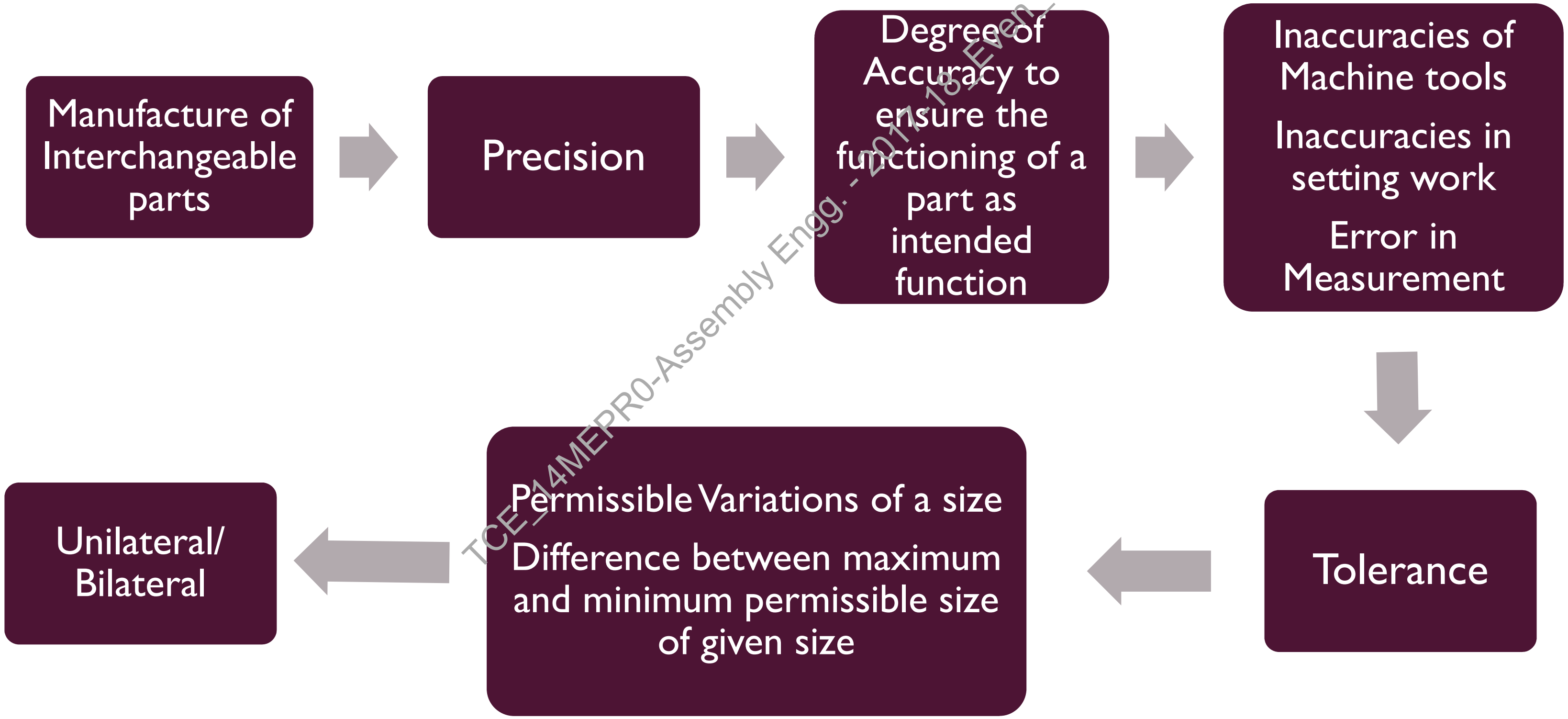
Caliper



Depth Gauge

Comparator

TOLERANCE


Manufacture of Interchangeable parts
Precision
Degree of Accuracy to ensure the functioning of a part as intended function
Inaccuracies of Machine tools
Inaccuracies in setting work
Error in Measurement
Tolerance
Permissible Variations of a size
Difference between maximum and minimum permissible size of given size
Unilateral/ Bilateral

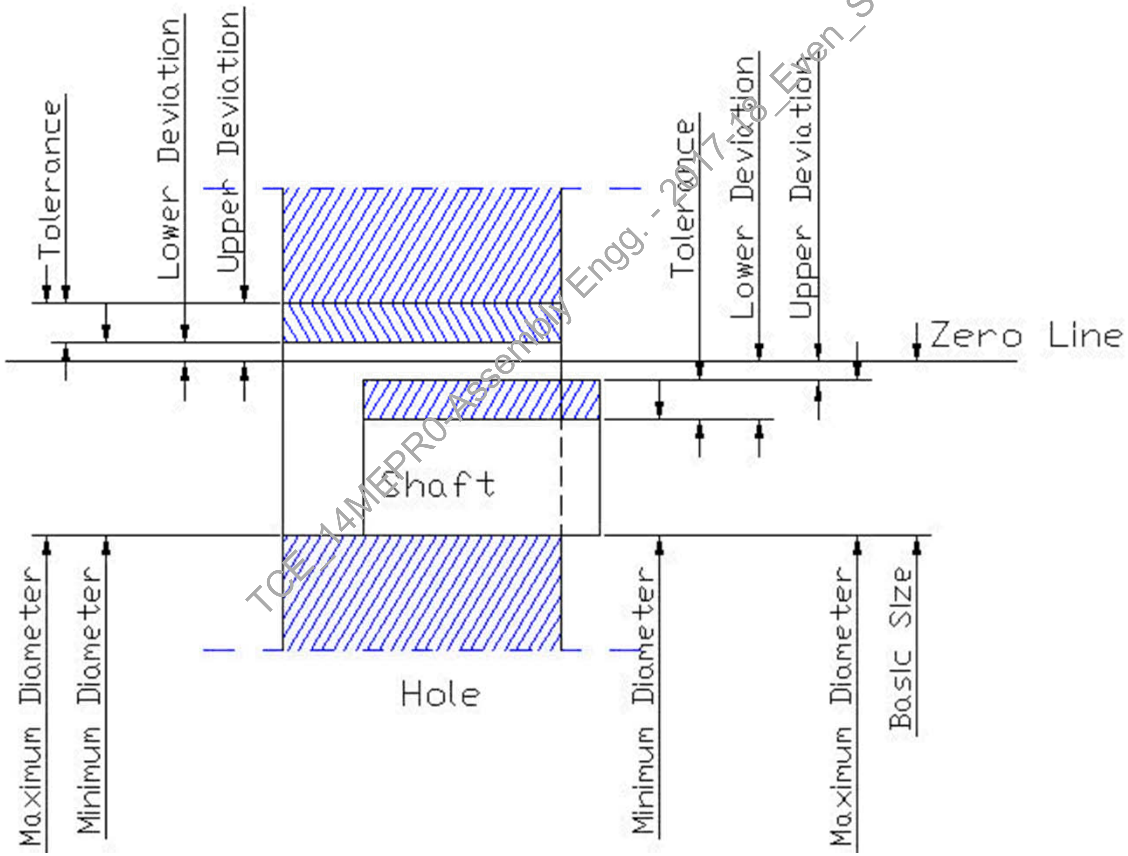
TOLERANCING - INTRODUCTION

- Tolerances define the **manufacturing limits for dimensions**.
- All dimensions have tolerances
  - either written directly on the drawing as part of the dimension or implied by a predefined set of standard tolerances
- Basic Size : Result of design calculations
- Design Size: Derived from the application of tolerances
- Actual Size: Size obtained after manufacturing

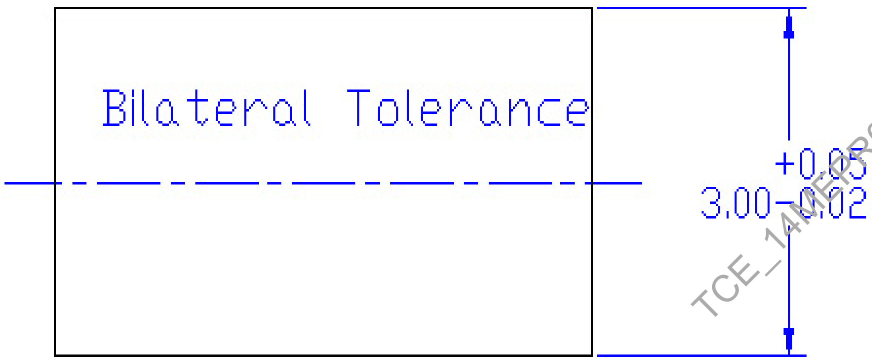
TOLERANCING

- Limits : Two Extreme permissible sizes between which actual size is contained
- Maximum Size – Upper limit; Minimum Size: Lower limit
- Deviation: Algebraic difference between a size and corresponding basic size
- Upper deviation = Maximum limit – Basic size
- Lower deviation = Basic size – Minimum Limit
- Allowance: Dimensional difference between the maximum material limits/conditions of mating parts
- Fit: Relation between two mating parts

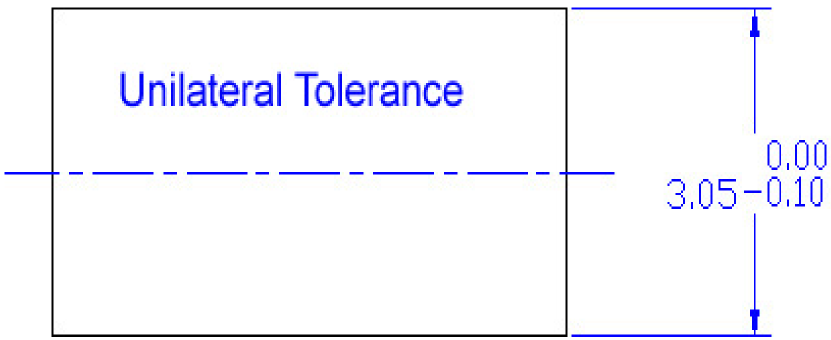
TOLERANCING



TOLERANCING - TYPES (Cont)

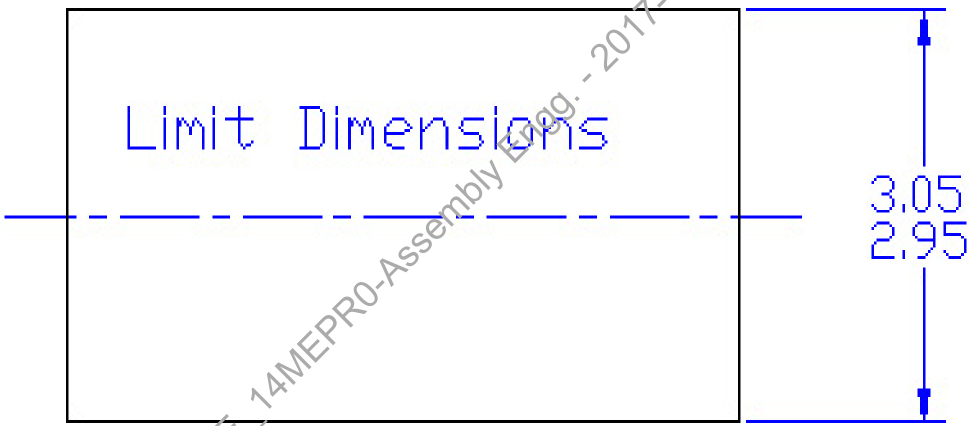


BILATERAL TOLERANCE



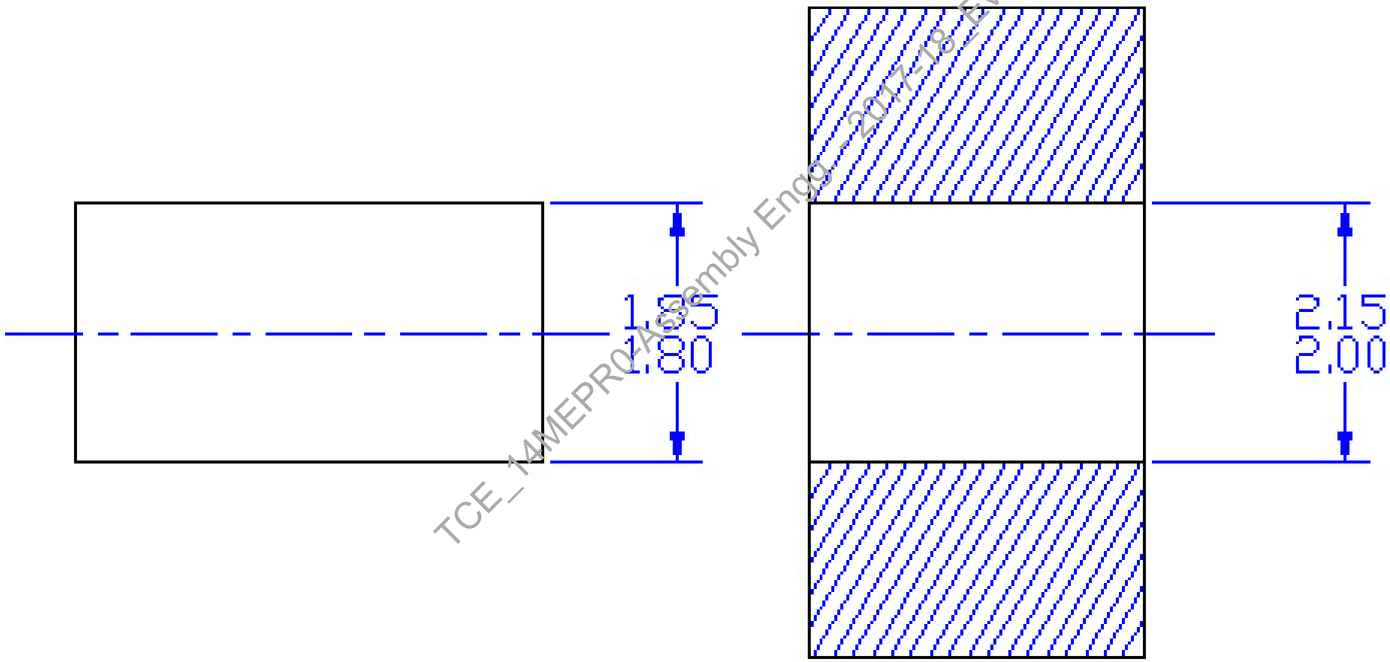
UNILATERAL TOLERANCE

TOLERANCING - TYPES (Cont)



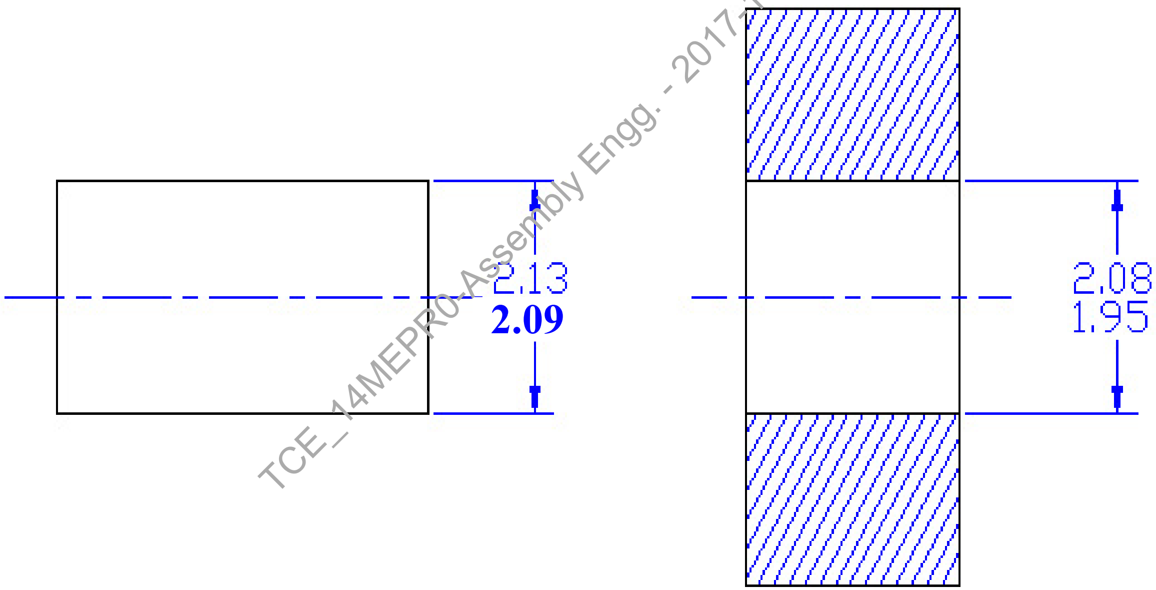
Limit Dimensions

TOLERANCING - FITS



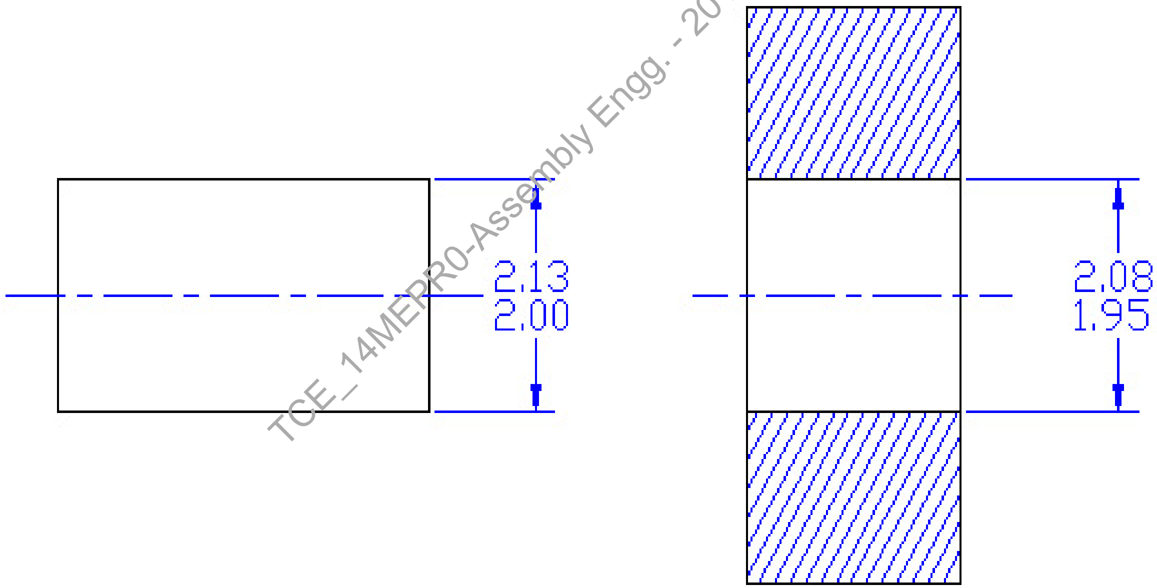
Clearance Fit

TOLERANCING - FITS



Interference Fit

TOLERANCING - FITS

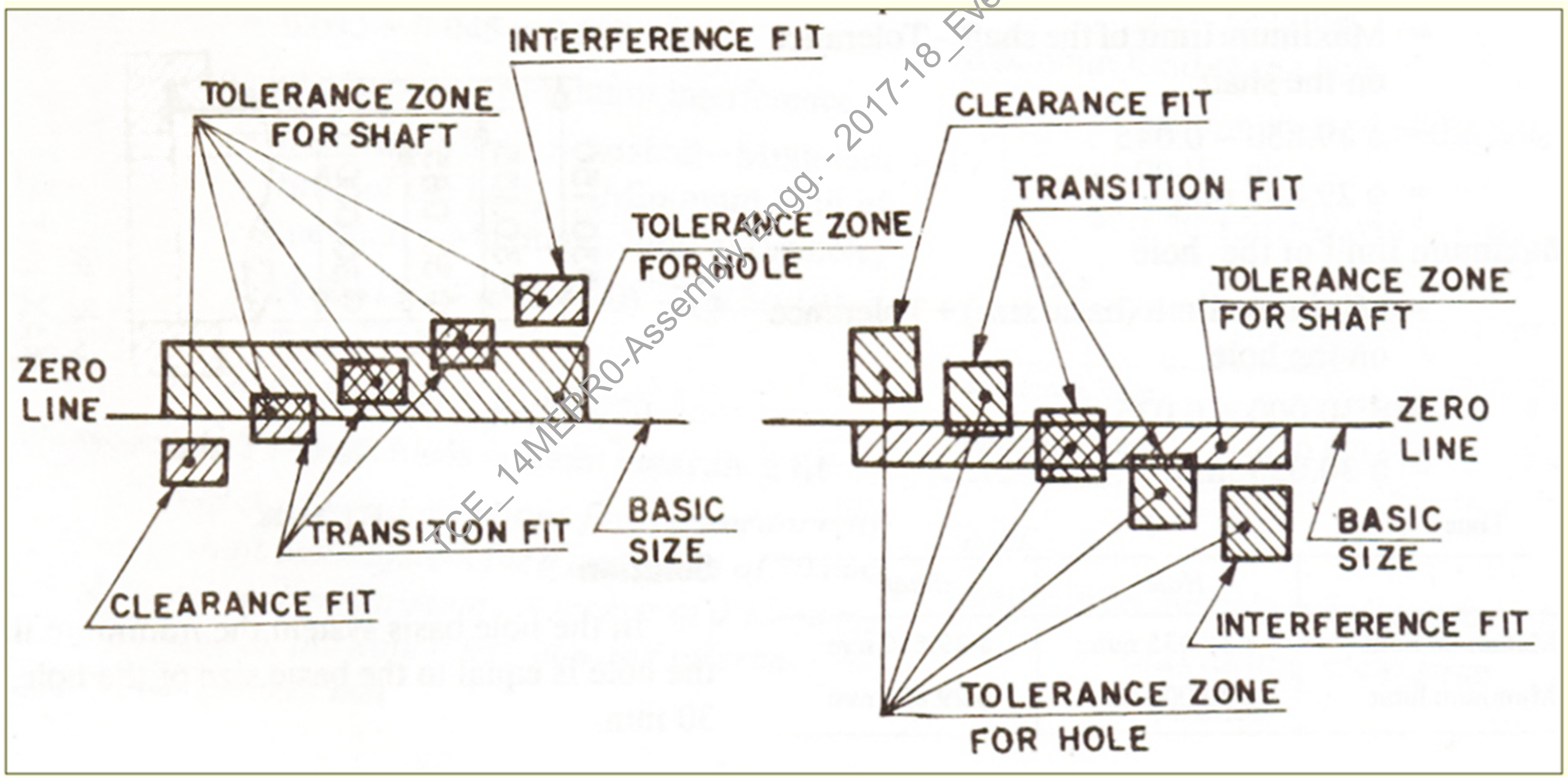


Transition Fit

TOLERANCING - FITS

1. Hole tolerance: $T_H = H_{max} – H_{min}$
2. Shaft tolerance: $T_S = S_{max} – S_{min}$
3. Maximum clearance: $C_{max} = H_{max} – S_{min}$ (+)
4. Minimum clearance: $C_{min} = H_{min} – S_{max}$ (+)
5. Maximum interference: $I_{max} = H_{min} – S_{max}$ (-)
6. Minimum interference: $I_{min} = H_{max} – S_{min}$ (-)
7. Fit tolerance: $T_F = T_H + T_S$

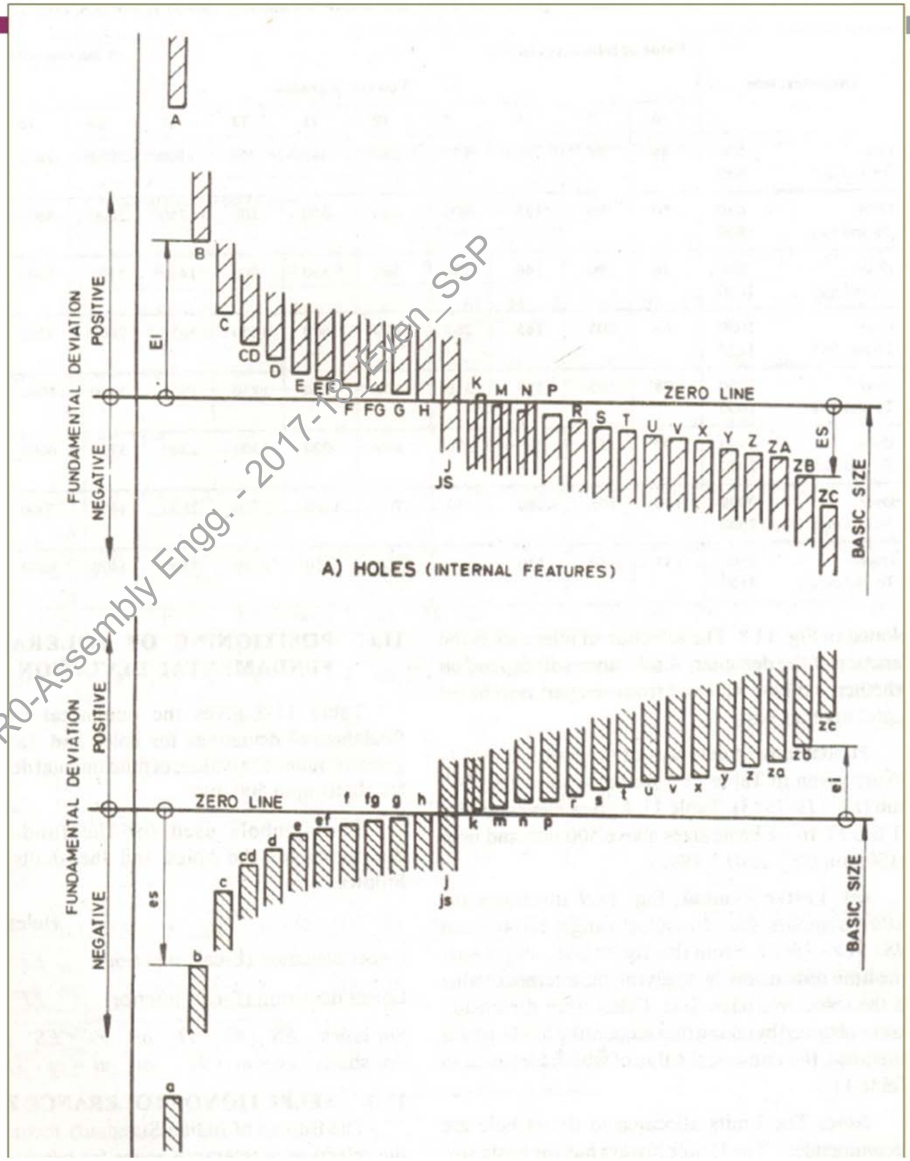
HOLE/SHAFT BASIS SYSTEMS



IS:919-1963 (revised): Recommendations for Limits and Fits for Engineering

- Eighteen **standard grades of tolerances** with designations IT01, IT0, IT01-----IT16.
- Twenty seven **fundamental deviations** indicated by letters. Capital letters are used for hole and small letter are used for shaft.
- The values of these tolerance grades or fundamental deviations depend on the basic size of the assembly.
- One example of fit may be **60mm H_8/f_7** Shaft basis.

Fundamental deviations



TRY….

1. Find T_H, T_s, T_f, C_{max}, C_{min}, and what kind of fit it is ?

Hole F 50 upper deviation +0.041, lower deviation 0.0

Shaft F 50 upper deviation -0.014, lower deviation -0.040

2. Find T_H, T_s, T_f, C_{max}, I_{max}, and what kind of fit it is ?

Hole F 25 upper deviation +0.021, lower deviation 0.0

Shaft F 25 upper deviation +0.028, lower deviation +0.015

GEOMETRIC TOLERANCES

ADAPTED FROM J. M. MCCARTHY, FALL 2003

- OVERVIEW OF GEOMETRIC TOLERANCES
- FORM TOLERANCES
- ORIENTATION TOLERANCES
- LOCATION TOLERANCES
- SUMMARY

OVERVIEW OF GEOMETRIC TOLERANCES

- Geometric tolerances define the shape of a feature as opposed to its size.

Three basic types of dimensional tolerances:

1. **Form tolerances**: straightness, circularity, flatness, cylindricity
2. **Orientation tolerances**; perpendicularity, parallelism, angularity; and
3. **Position tolerances**: position, symmetry, concentricity.

GEOMETRIC TOLERANCE SYMBOLS

Pertainsto	Type of Tolerance	Geometric Characteristics	Symbol
Individual Feature Only	Form	STRAIGHTNESS	⏤
		FLATNESS	⏥
		CIRCULARITY	○
		CYLINDRICITY	⌭
Individual Feature or Related Features	Profile	PROFILE OF A LINE	⌒
		PROFILE OF A SURFACE	⌓
Related Features	Orientation	ANGULARITY	∠
		PERPENDICULARITY	⊥
		PARALLELISM	//
	Location	POSITION	⌖
		CONCENTRICITY	◎
		SYMMETRY	⌯
	Runout	CIRCULAR RUNOUT	↗
		TOTAL RUNOUT	⌰

SYMBOLS FOR GEOMETRIC TOLERANCES

DIMENSIONING SYMBOLS

CURRENT PRACTICE	ABBREVIATION IN NOTES	PARAMETER
⌀	DIA	Diameter
S⌀	SPHER DIA	Spherical Diameter
R	R	Radius
CR	CR	Controlled Radius
SR	SR	Spherical Radius
⌴	CBORE	Counterbore
⌴	SF or SFACE	Spotface
⌵	CSK	Countersink
↧	DP	Deep
⌱	—	Dimension Origin
□	SQ	Square
( )	REF	Reference
X	PL	Places, Times
⌒	—	Arc Length
⌳	—	Slope
⌲	—	Conical Taper
[2.38]	—	Basic Dimension
⟨ST⟩	—	Statistical
↔	—	Between
▲	—	Datum Feature Triangle

DIMENSIONING SYMBOLS

CURRENT PRACTICE	ABBREVIATION IN NOTES	PARAMETER
□	—	Datum Feature Symbol
⊖	—	Datum Target Symbol
Ⓢ	RFS	Regardless Of Feature Size
Ⓜ	MMC	Maximum Material Condition
Ⓛ	LMC	Least Material Condition
Ⓟ	—	Projected Tolerance Zone
—	—	Straightness
⏥	—	Flatness
○	—	Circularity
⌭	—	Cylindricity
⊥	—	Perpendicularity
//	—	Parallelism
∠	—	Angularity
⌖	—	Position
⌯	—	Symmetry
◎	—	Concentricity
↗	—	Circular Runout
⌰	—	Total Runout
⌒	—	Line Profile
⌓	—	Surface Profile

FEATURE CONTROL FRAME

A geometric tolerance is prescribed using a feature control frame.
It has three components:

1. the tolerance symbol,
2. the tolerance value,
3. the datum labels for the reference frame.

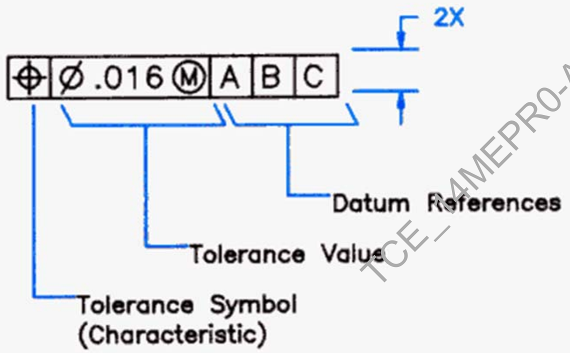


Figure 2-18. Feature control frames are always read from left to right.

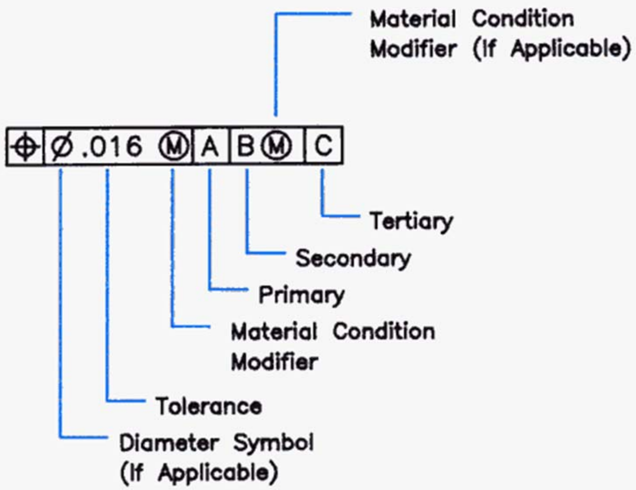


Figure 2-19. Whether a diameter symbol and material condition modifier are used, or omitted, depends on the desired tolerance specification and the type of feature being controlled.

REFERENCE FRAME

- A reference frame is defined by three perpendicular datum planes.
- The left-to-right sequence of datum planes defines their order of precedence.

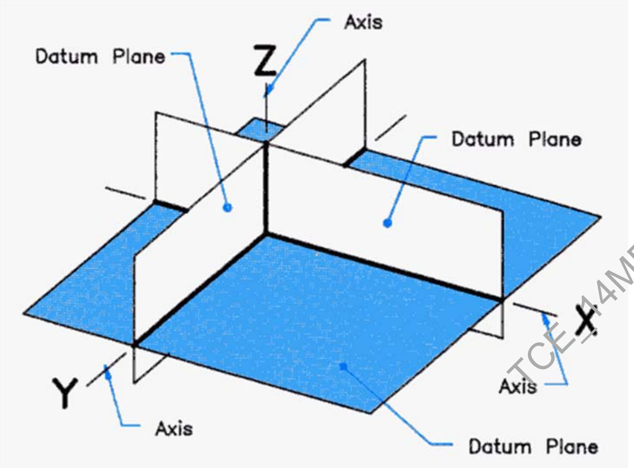


Figure 6-3. A datum reference frame is theoretically perfect and is made of three mutually perpendicular planes.

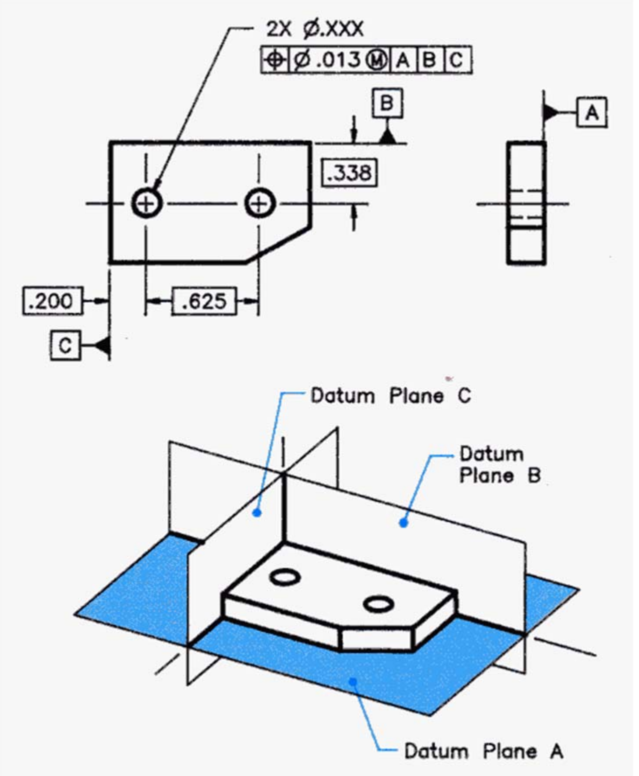


Figure 6-4. Datum references made in a feature control frame determine how a part is located in the datum reference frame.

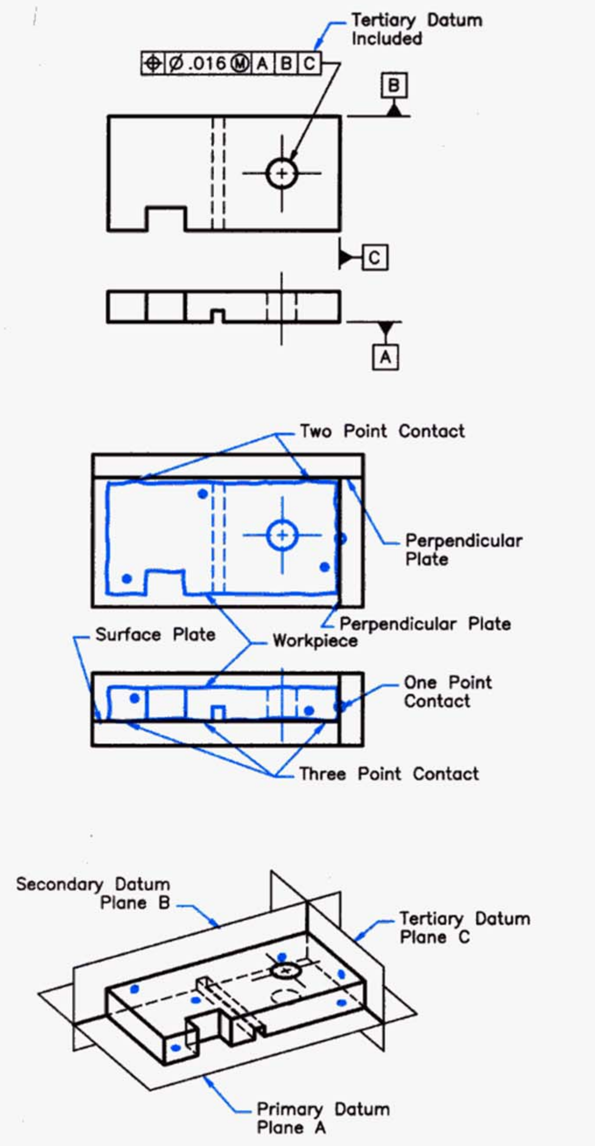


Figure 6-17. The tertiary datum plane is perpendicular to the primary and secondary planes, and is located by the tertiary datum feature on the part.

ORDER OF PRECEDENCE

The part is aligned with the datum planes of a reference frame using **3-2-1** contact alignment.

- **3** points of contact align the part to the primary datum plane;
- **2** points of contact align the part to the secondary datum plane;
- **1** point of contact aligns the part with the tertiary datum plane

USING A FEATURE AS A DATUM

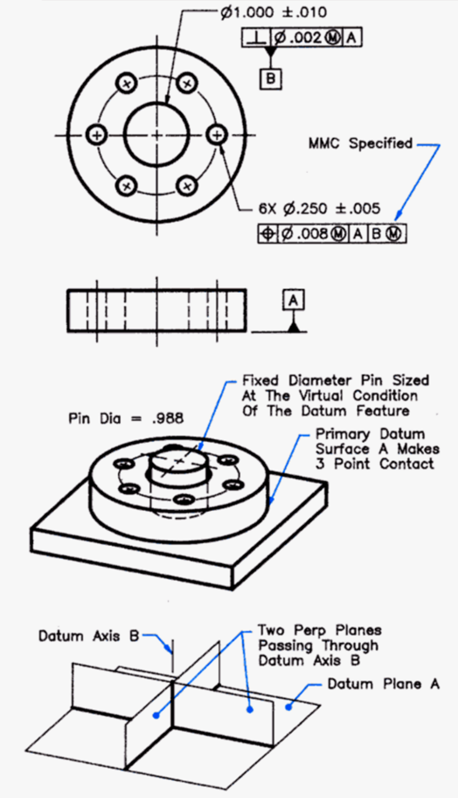


Figure 6-31. A secondary or tertiary datum reference showing an MMC modifier requires the datum to be simulated by a tool that has a size equal to the virtual condition of the datum feature.

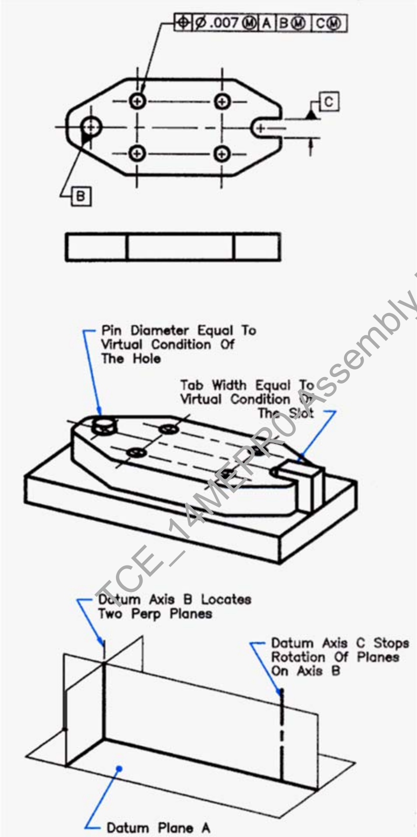


Figure 6-32. A primary datum surface and secondary datum feature of size can be used to establish the datum reference frame with a tertiary datum feature of size used to set the orientation of the datum reference frame.

A feature such as a hole, shaft, or slot can be used as a datum.

The “circle M” denotes the datum : Maximum Material Condition (MMC) given by the tolerance.

MATERIAL CONDITIONS

- Maximum Material Condition (MMC): The condition in which a feature contains the maximum amount of material within the stated limits. e.g. minimum hole diameter, maximum shaft diameter.
- Least Material Condition (LMC): The condition in which a feature contains the least amount of material within the stated limits. e.g. maximum hole diameter, minimum shaft diameter
- Regardless of Feature Size (RFS): This is the default condition for all geometric tolerances. No bonus tolerances are allowed and functional gauges may not be used.

ANSI Y14.5M RULE #1:
A dimensioned feature must have perfect form at its maximum material condition.
This means:

- A hole is a perfect cylinder when it is at its smallest permissible diameter,
- A shaft is a perfect cylinder when at its largest diameter.
- Planes are perfectly parallel when at their maximum distance.

ANSI Y14.5M RULE #2:
If no material condition is specified, then the it is "regardless of feature size."

STRAIGHTNESS OF A SHAFT

- A shaft has a size tolerance defined for its fit into a hole. A shaft meets this tolerance if at every point along its length a diameter measurement fall within the specified values.
- This allows the shaft to be bent into any shape. A straightness tolerance on the shaft axis specifies the amount of bend allowed.

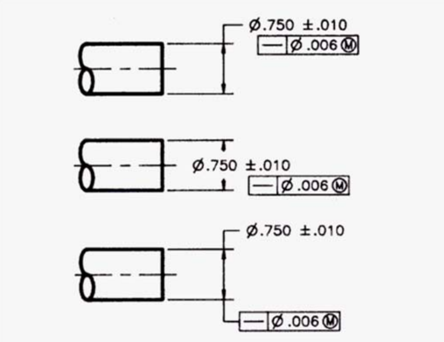


Figure 5-16. The axis of a feature can be controlled by placing a form tolerance adjacent to the size dimension or on the dimension line.

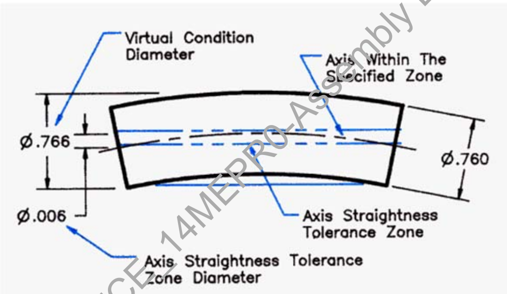


Figure 5-17. A straightness tolerance applied to control axis straightness permits the part to have an axis straightness error when the part is at MMC.

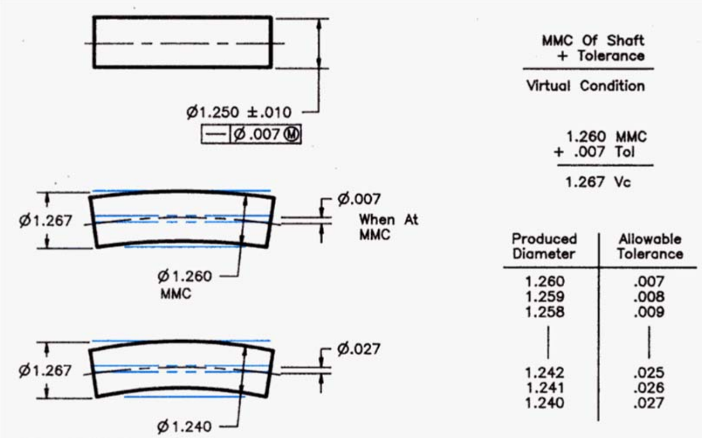


Figure 5-18. The permitted axis error applied to a cylinder has an effect on the apparent diameter of the cylinder. The combined effect of the MMC size and the permitted axis error is known as the virtual condition.

- Add the straightness tolerance to the maximum shaft size (MMC) to obtain a "virtual condition" VC, or virtual hole, that the shaft must fit to be acceptable.

STRAIGHTNESS OF A HOLE

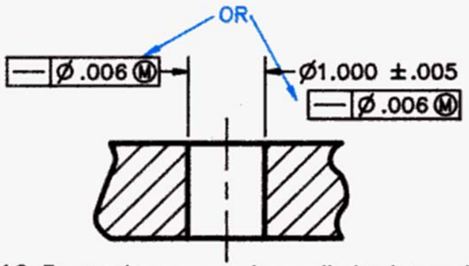


Figure 5-19. Form tolerance can be applied to internal features such as holes.

- The size tolerance for a hole defines the range of sizes of its diameter at each point along the centerline. This does not eliminate a curve to the hole.
- The straightness tolerance specifies the allowable curve to the hole.
- Subtract the straightness tolerance from the smallest hole size (MMC) to define the virtual condition Vc, or virtual shaft, that must fit the hole for it to be acceptable.

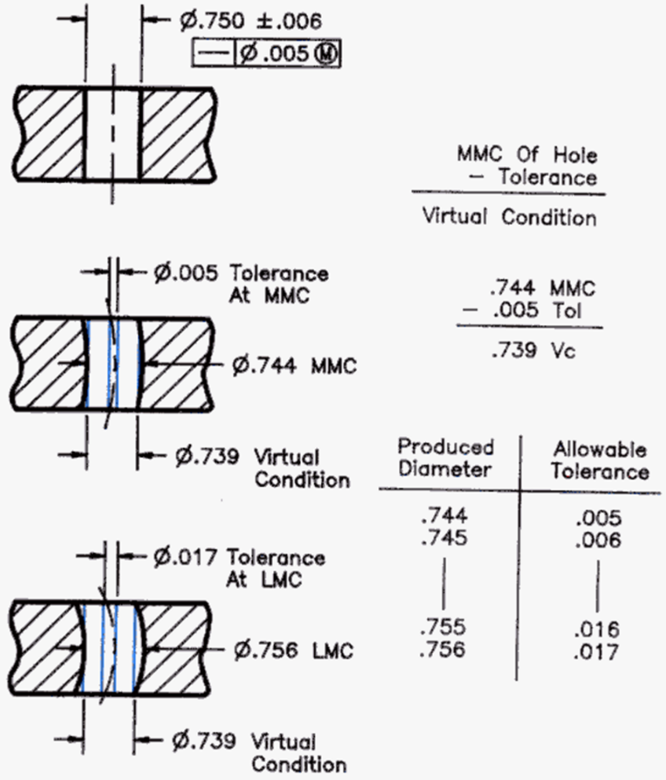


Figure 5-20. The virtual condition of a hole has a diameter smaller than the MMC diameter permitted by the size dimension.

STRAIGHTNESS OF A CENTER PLANE

- The size dimension of a rectangular part defines the range of sizes at any cross-section.
- The straightness tolerance specifies the allowable curve to the entire side.
- Add the straightness tolerance to the maximum size (MMC) to define a virtual condition Vc that the part must fit into in order to meet the tolerance.

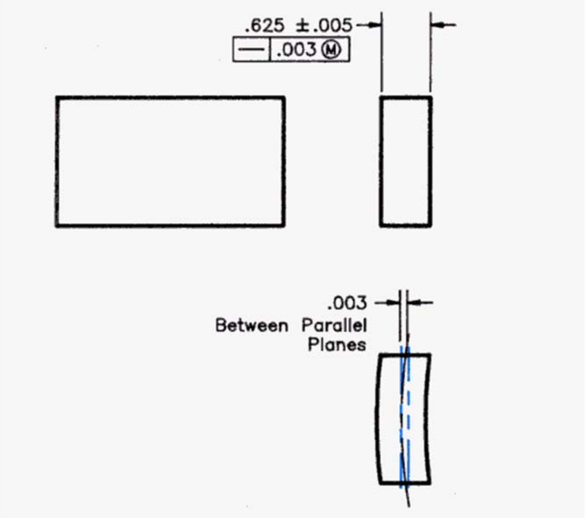


Figure 5-28. Center plane flatness is toleranced by placing the feature control frame, showing a straightness tolerance, adjacent to the dimension value.

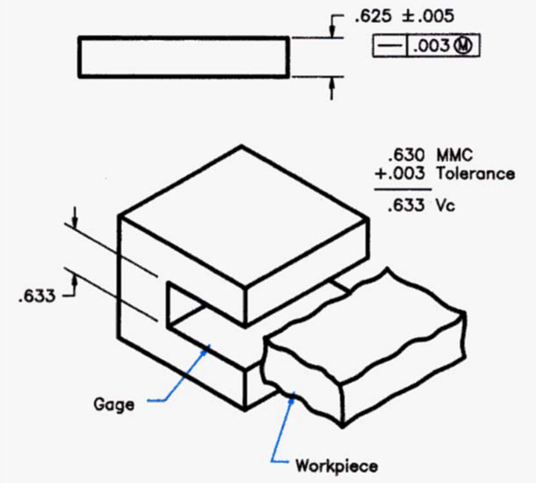


Figure 5-29. Flatness applied to control the center plane at MMC can be verified with a functional gage.

FLATNESS, CIRCULARITY AND CYLINDRICITY

Flatness

Cylindricity

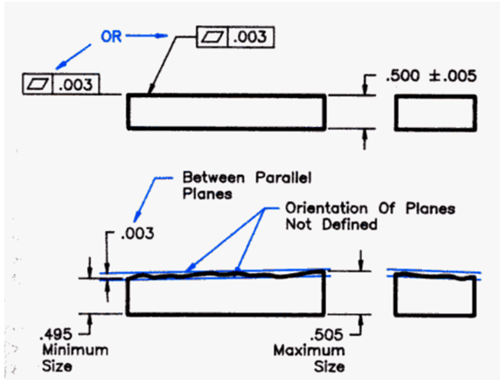


Figure 5-25. Flatness tolerances create a tolerance zone bounded by two parallel planes.

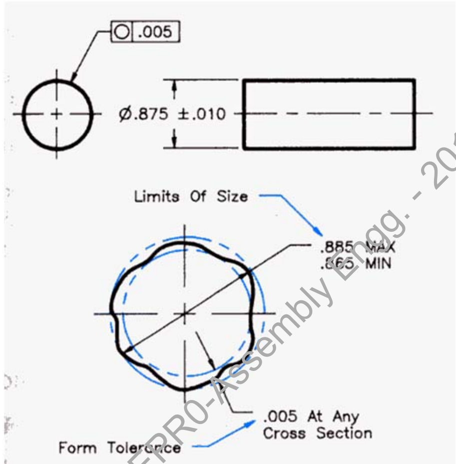


Figure 5-30. Circularity tolerances control circular cross sections.

Circularity

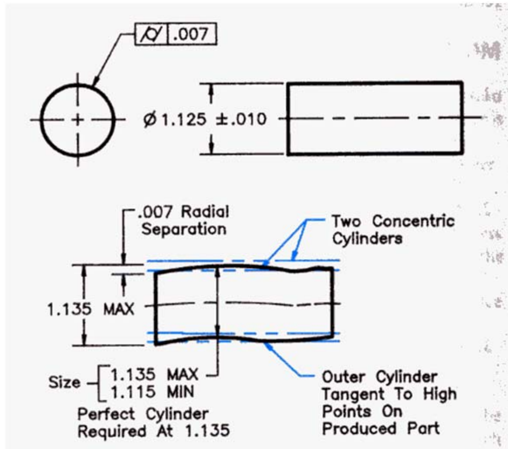


Figure 5-31. Cylindricity tolerances result in a tolerance zone bounded by two concentric cylinders.

- The **flatness** tolerance defines a distance between parallel planes that must contain the highest and lowest points on a face.
- The **circularity** tolerance defines a pair of concentric circles that must contain the maximum and minimum radius points of a circle.
- The **cylindricity** tolerance defines a pair of concentric cylinders that much contain the maximum and minimum radius points along a cylinder.

PARALLELISM TOLERANCE

A parallelism tolerance is measured relative to a datum specified in the control frame.
If there is no material condition (ie. regardless of feature size), then the tolerance defines parallel planes that must contain the maximum and minimum points on the face.

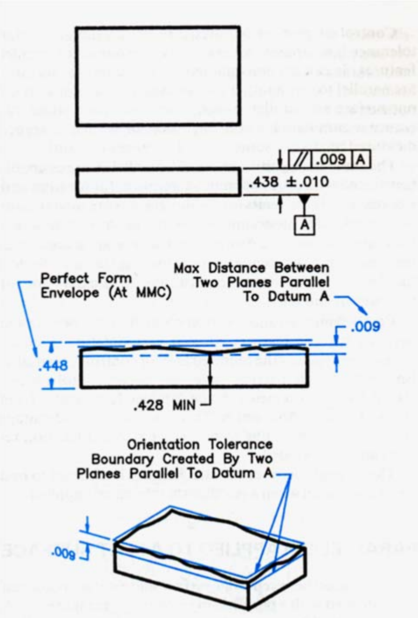


Figure 7-6. Two planes form the boundary for a parallelism tolerance.

If MMC is specified for the tolerance value:

- If it is an external feature, then the tolerance is *added* to the maximum dimension to define a virtual condition that the part must fit;
- If it is an internal feature, then the tolerance is *subtracted* to define the maximum dimension that must fit into the part.

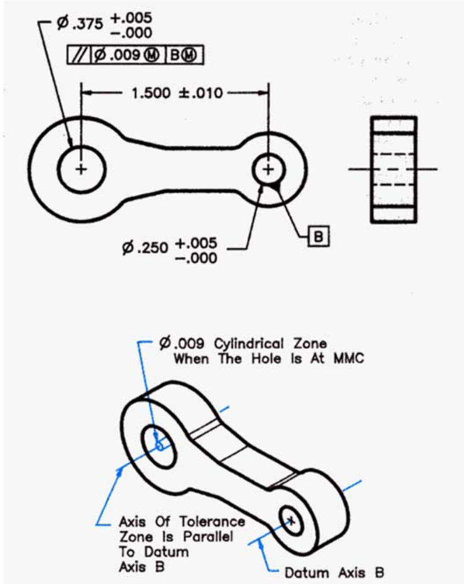


Figure 7-8. Parallelism can be used to control the orientation of one axis to another.

PERPENDICULARITY

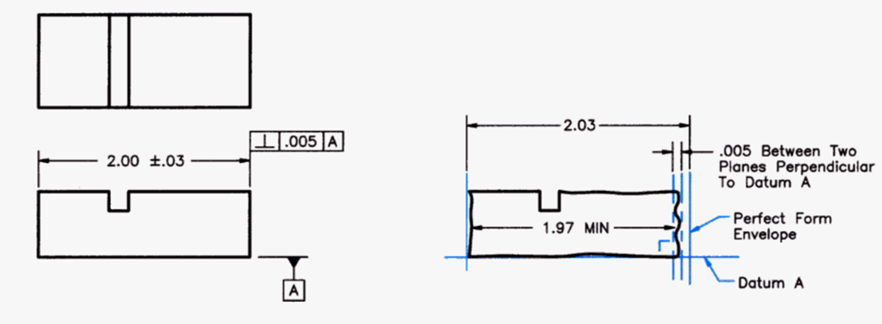


Figure 7-12. The tolerance zone for a perpendicularity tolerance on a flat surface is bounded by two planes.

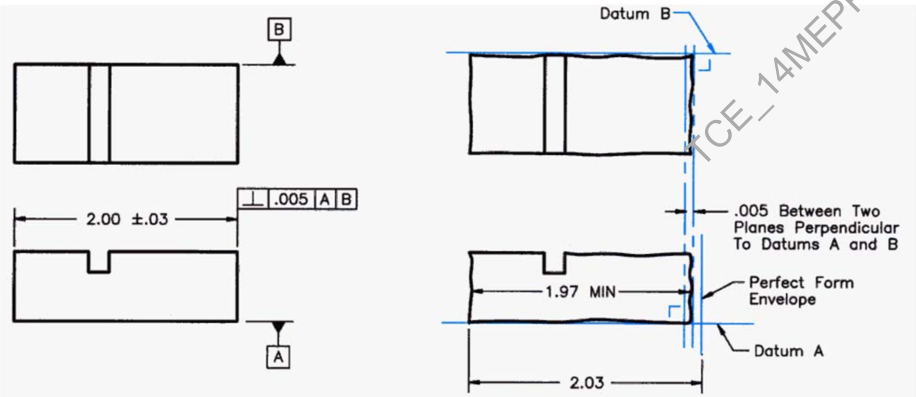


Figure 7-14. A perpendicularity tolerance can be referenced to two datums.

- A perpendicular tolerance is measured relative to a datum plane.
- it defines two planes that must contain all the points of the face.
- A second datum can be used to locate where the measurements are taken.

PERPENDICULAR SHAFT, HOLE, AND CENTER PLANE

Shaft

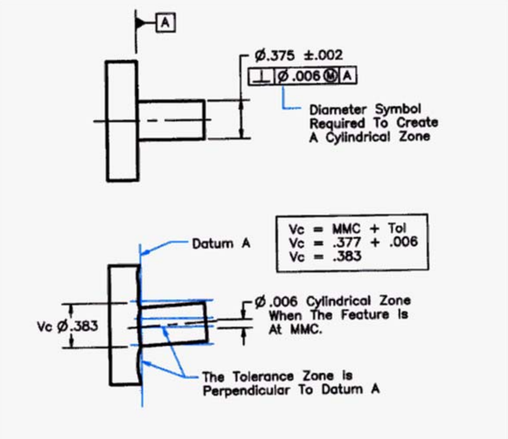


Figure 7-19. The virtual condition for an external feature of size is larger than the MMC of the feature.

Hole

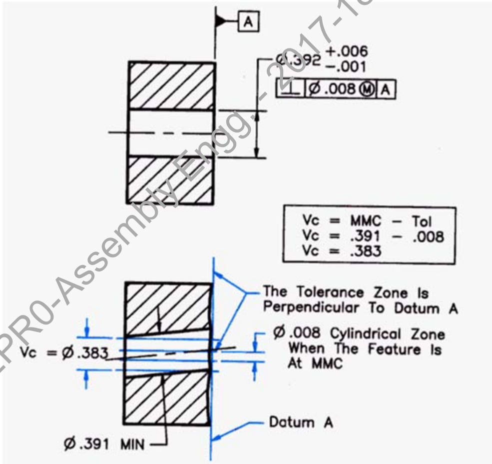


Figure 7-21. The virtual condition for an internal feature of size is smaller than the MMC of the feature.

Center Plane

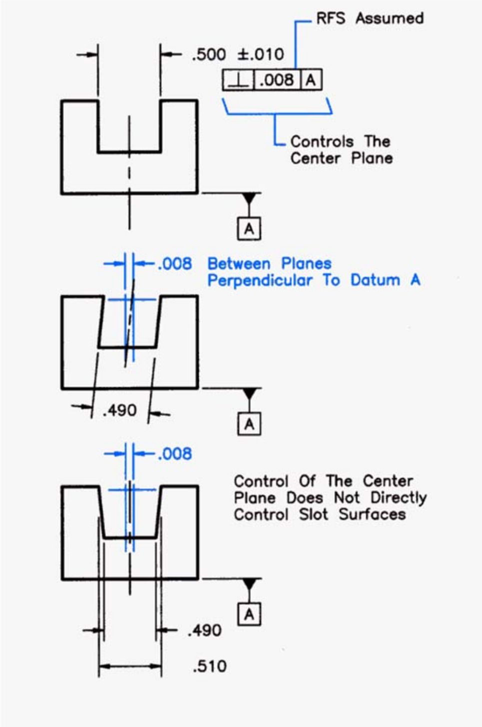


Figure 7-24. An orientation tolerance applied to a rectangular feature of size controls the orientation of the center plane of the feature.

- Shaft: The maximum shaft size plus the tolerance defines the virtual hole.
- Hole: The minimum hole size minus the tolerance defines the virtual shaft.
- Plane: The tolerance defines the variation of the location of the center plane.

ANGULARITY

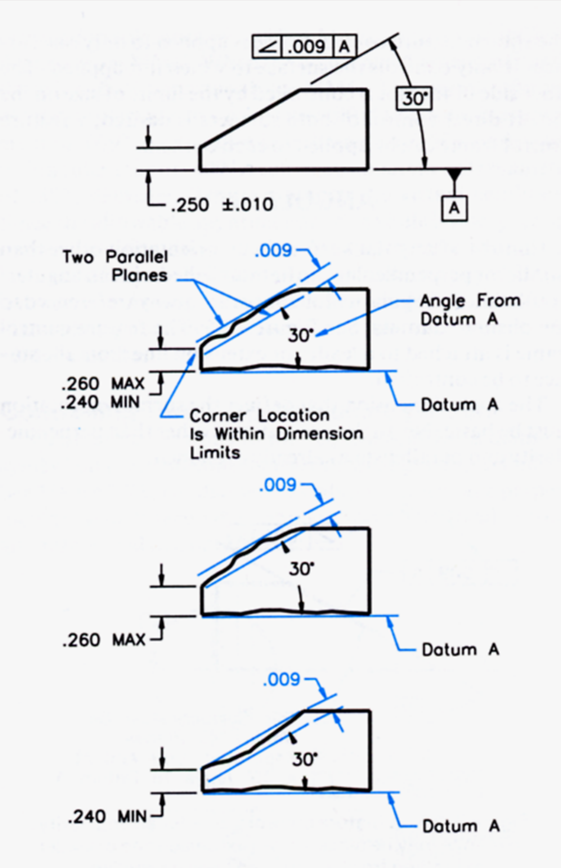


Figure 7-27. The angle dimension defining the surface orientation must be basic when an angularity tolerance is

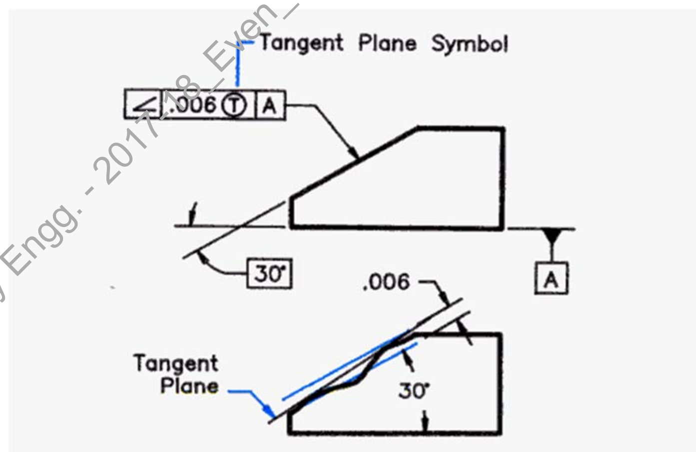


Figure 7-30. Angularity may be specified to control the plane that is tangent to surface high points.

An angularity tolerance is measured relative to a datum plane. It defines a pair planes that must

1. contain all the points on the angled face of the part, or
2. if specified, the plane tangent to the high points of the face.

POSITION TOLERANCE FOR A HOLE

- The position tolerance for a hole defines a zone that has a defined shape, size, location and orientation.
- It has the diameter specified by the tolerance and extends the length of the hole.
- Basic dimensions locate the theoretically exact center of the hole and the center of the tolerance zone.
- Basic dimensions are measured from the datum reference frame.

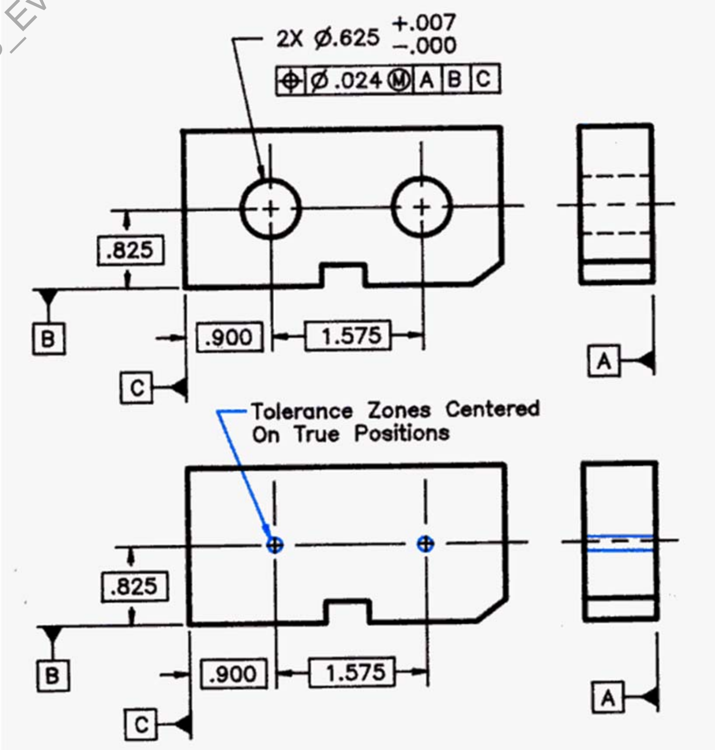


Figure 8-6. Tolerance zones for holes are centered on the theoretically true positions for the holes.

MATERIAL CONDITION MODIFIERS

RFS

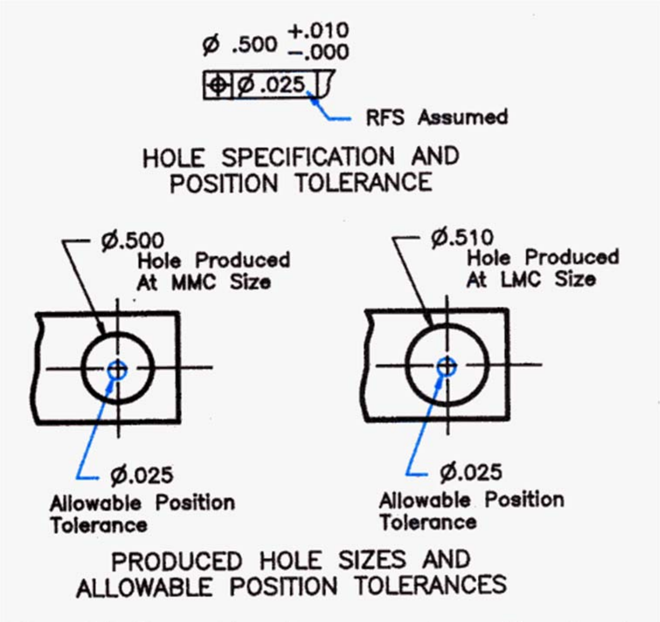


Figure 8-8. The position tolerance zone is not affected by the produced feature size when the RFS modifier is applicable to the tolerance specification.

If the tolerance zone is prescribed for the maximum material condition (smallest hole). Then the zone expands by the same amount that the hole is larger in size.
Use MMC for holes used in clearance fits.

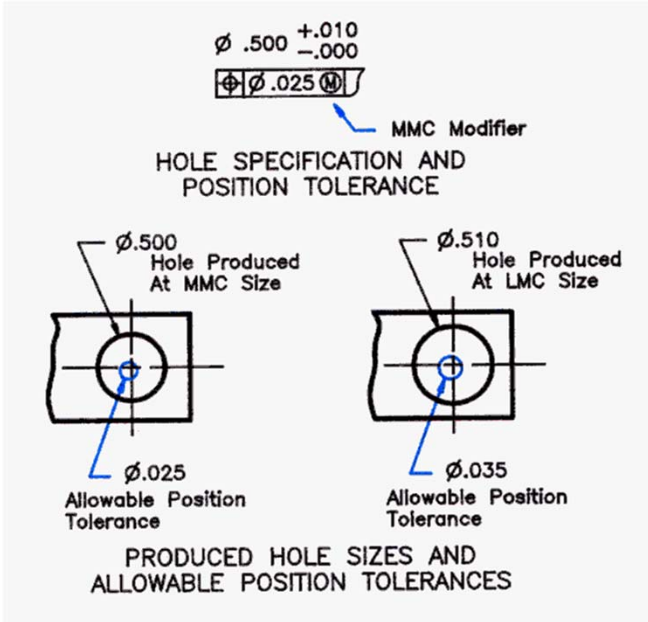


Figure 8-9. The position tolerance zone increases in size when the produced feature size departs from MMC and the MMC

No material condition modifier means the tolerance is "regardless of feature size."
Use RFS for holes used in interference or press fits.

POSITION TOLERANCE ON A HOLE PATTERN

A composite control frame signals a tolerance for a pattern of features, such as holes.

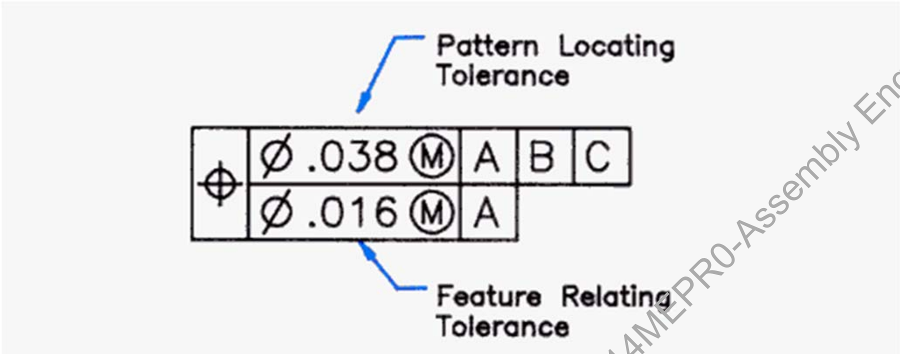
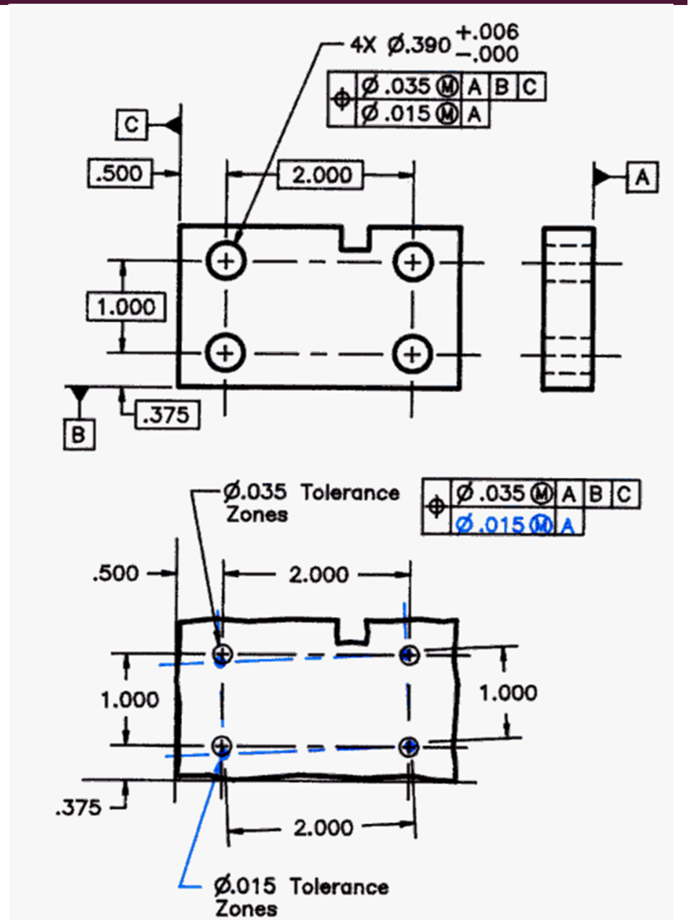


Figure 9-1. The feature control frame for a composite position tolerance includes a pattern locating tolerance and a feature relating tolerance.

- The first line defines the position tolerance zone for the holes.
- The second line defines the tolerance zone for the pattern, which is generally smaller.



DATUM REFERENCE IN A COMPOSITE TOLERANCE

A datum specification for the pattern only specifies the orientation of the pattern tolerance zones.

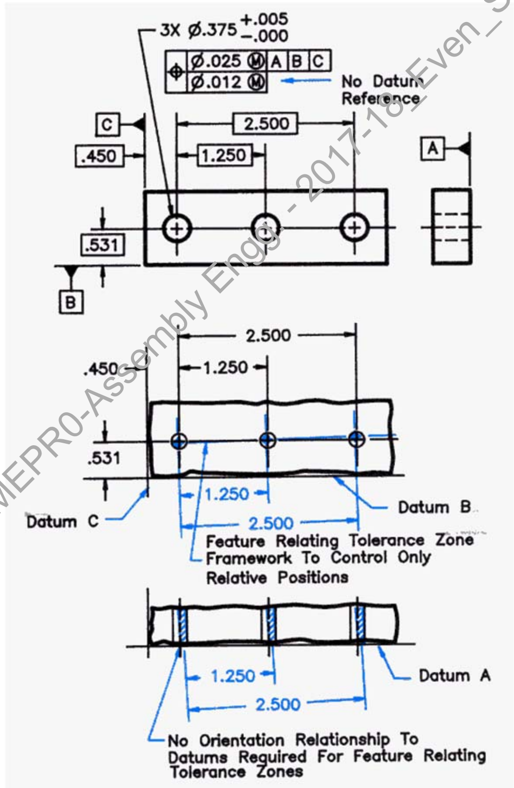


Figure 9-5. Omitting all datum references from the second line releases all orientation requirements from the feature relating tolerance. The second line of the composite tolerance only controls feature-to-feature locations.

No datum for the pattern

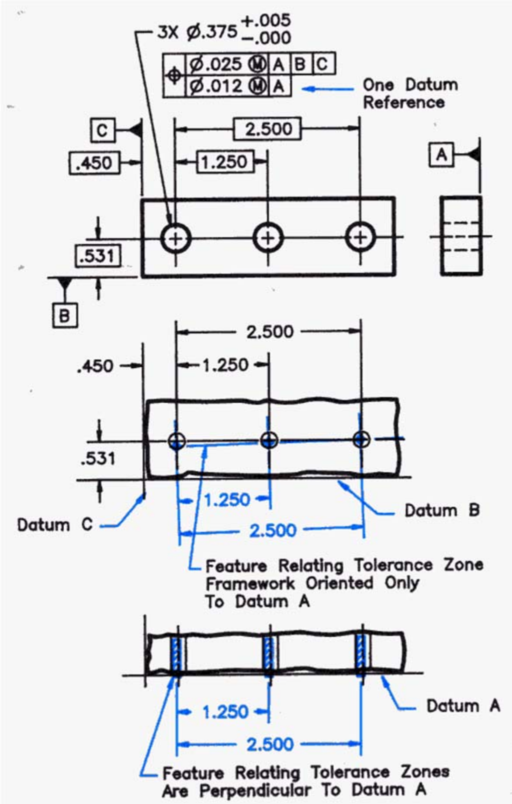


Figure 9-6. The primary datum reference requires the feature relating tolerance zones to be properly oriented to the primary datum.

Primary datum specified.

SUMMARY

Geometric tolerances are different from the tolerances allowed for the size of feature, they specify the allowable variation of the shape of a feature.

There are three basic types of geometric tolerances: Form, Orientation and Position tolerances.

Geometric tolerances are specified using a control frame consisting of a tolerance symbol, a tolerance value and optional datum planes.

Material condition modifiers define the condition at which the tolerance is to be applied. If the maximum material condition is specified, then there is a "bonus tolerance" associated with a decrease in material.

1. The form of a feature is assumed to be perfect at its maximum material condition.
2. If no material condition is specified, then it is regard less of feature size.

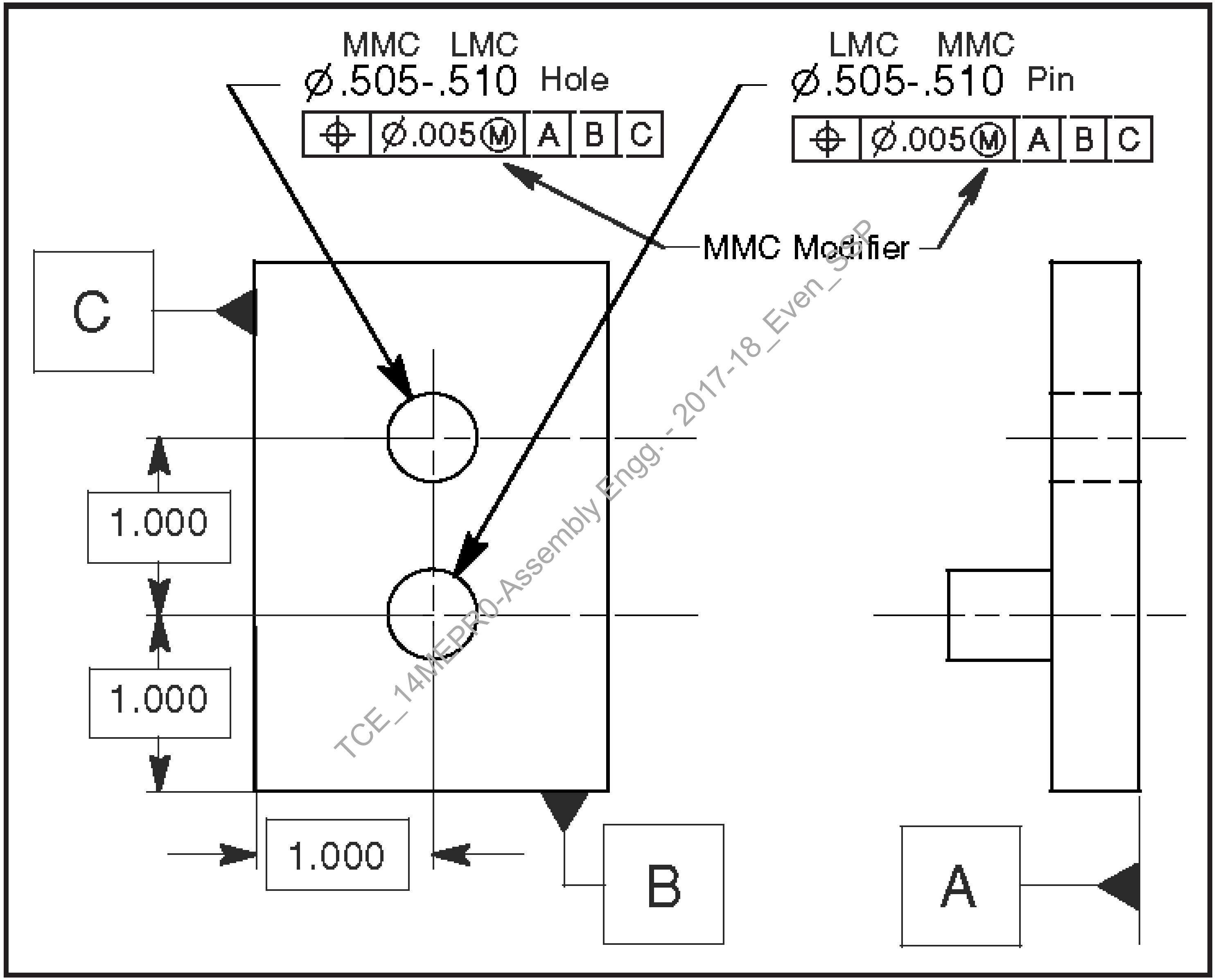
Tutorial 1 - Tolerancing

14MEPR0 - Assembly Engineering

B.E. Mechanical Engineering

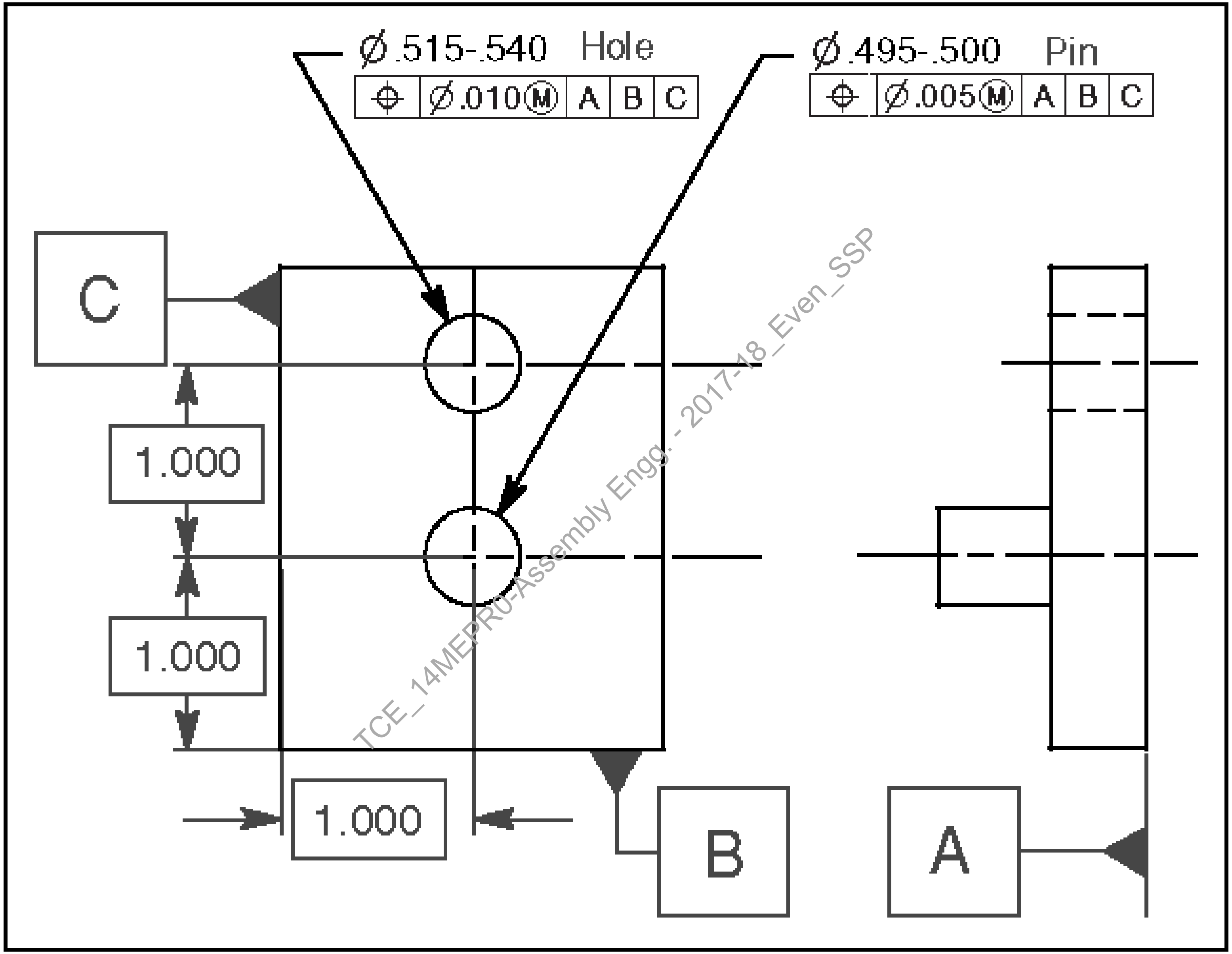
- Feature: A feature is a physical portion of a part, such as a flat surface,pin, hole, tab, or slot.
- Feature of size:Features of size are features that have a size dimension.
- There are 14 geometric characteristic symbols. They are divided into five categories: form, profile, orientation, runout, and location.
- The datum feature symbol consists of a capital letter enclosed in a square box. It is connected to a leader directed to the datum ending in a triangle.
- The datum feature symbol is used to identify physical features of a part. It must not be attached to centerlines, center planes, or axes.
- Datum feature symbols placed in line with a dimension line or on a feature control frame associated with a size feature identify the size feature as the datum.
- The feature control frame is the sentence of the GD&T language.
- Feature control frames may be attached to features with extension lines, dimension lines, and leaders.

- The composite feature control frame consists of one geometric characteristic symbol followed by two, tolerance and datum sections.
- If no material condition symbol is specified for the tolerance or datum reference of a size feature in a feature control frame, RFS automatically applies.
- An RFS tolerance is only the tolerance specified in the feature control frame; no bonus tolerance is added.
- Where the MMC symbol is specified, the tolerance applies at the MMC, and applicable bonus tolerances are added to the geometric tolerance.
- MMC is the most common of the material conditions and is often used when parts are to be joined in a static assembly.
- Where the LMC symbol is specified, the tolerance applies at the LMC, and applicable bonus tolerances are added to the geometric tolerance.
- LMC is used to maintain a minimum distance between features.


MMC LMC
Ø.505-.510 Hole
⌖ Ø.005Ⓜ A B C
LMC MMC
Ø.505-.510 Pin
⌖ Ø.005Ⓜ A B C
MMC Modifier
C
1.000
1.000
1.000
B
A

	Hole	Pin
What is the MMC?		
What is the LMC?		
What is the geometric tolerance?		
What material condition modifier is specified?		
What datum(s) control(s) perpendicularity?		
What datum(s) control(s) location?		

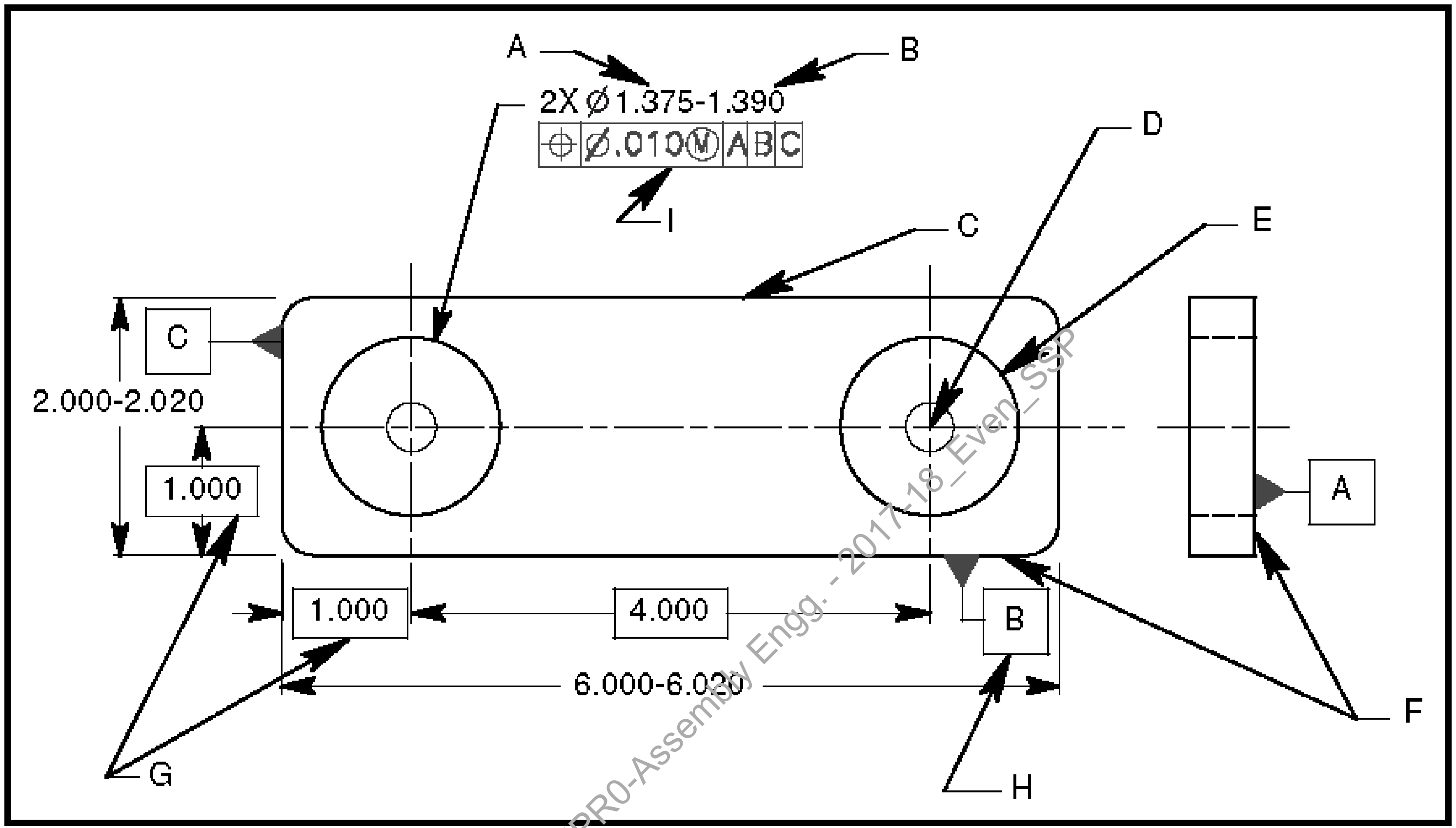
Actual feature size	MMC	Bonus	Geometric tolerance	Total positional tolerance
Internal Feature (Hole)				
MMC .505	.505	.000	.005	.005
.506	.505	.001	.005	.006
.507	.505	.002	.005	.007
.508	.505	.003	.005	.008
.509	.505	.004	.005	.009
LMC .510	.505	.005	.005	.010
External Feature (Pin)				
MMC .510	.510	.000	.005	.005
.509	.510	.001	.005	.006
.508	.510	.002	.005	.007
.507	.510	.003	.005	.008
.506	.510	.004	.005	.009
LMC .505	.510	.005	.005	.010



Ø.515-.540 Hole
⌖ | Ø.010Ⓜ | A | B | C
Ø.495-.500 Pin
⌖ | Ø.005Ⓜ | A | B | C
C
1.000
1.000
1.000
B
A

Actual feature size	Internal feature (Hole)			Total positional tolerance
	MMC	Bonus	Geometric tolerance	
MMC 0.515				
0.520				
0.525				
0.530				
0.535				
LMC 0.540				

Actual feature size	External feature (Pin)			Total positional tolerance
	MMC	Bonus	Geometric tolerance	
MMC 0.500				
0.499				
0.498				
0.497				
0.496				
LMC 0.495				



Place the letters of the items on the drawing in Fig. next to the terms below. Make a dash next to the terms not shown.

________ Datum ________ Basic Dimension ________ Feature control frame

________ MMC ________ Feature ________ True Position

________ LMC ________ Feature of Size ________ Datum feature symbol

SELECTIVE ASSEMBLY

Dr.S.Saravana Perumaal

Assistant Professor

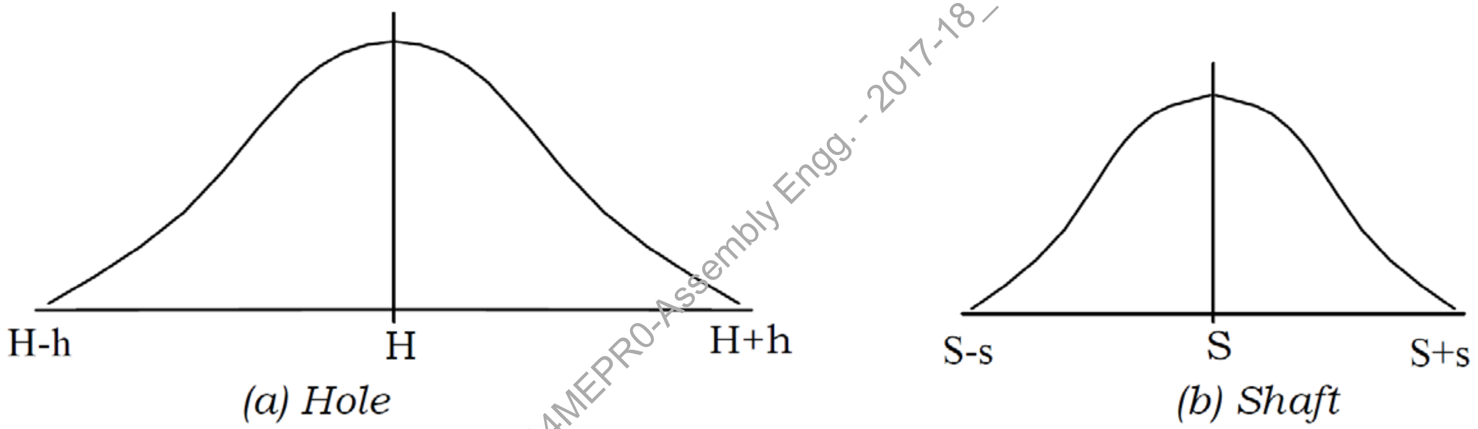
Department of Mechanical Engineering

Thiagarajar College of Engineering, Madurai – 625015

sspmech@tce.edu

INTRODUCTION

Interchangeability



- Interchangeability or random assembly is an assembly technique in which all the components assemble with any other mating components.
- For example, M12 bolts of any manufacturer mate with all M12 nuts

INTRODUCTION

- Selective Assembly

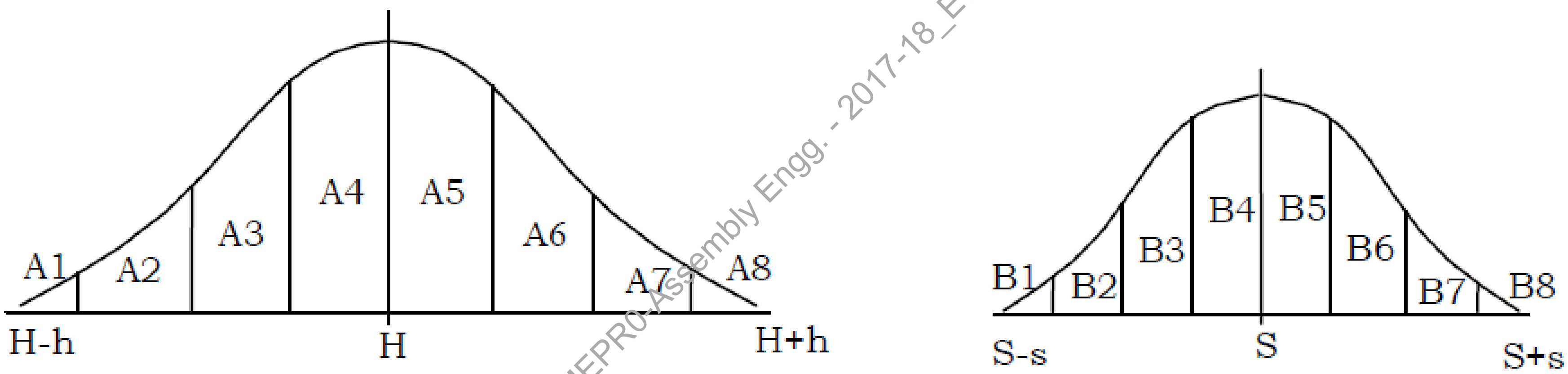


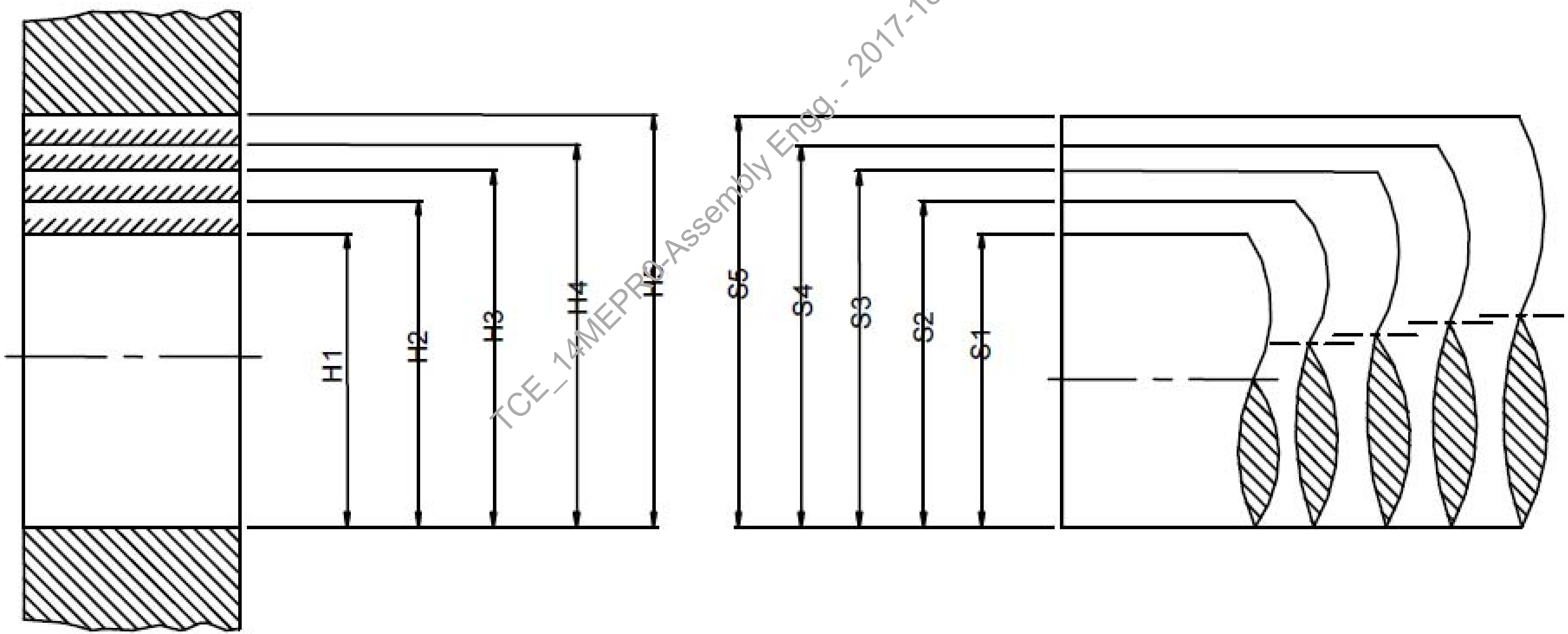
Fig.2 Grouping of components in normal distribution for selective assembly

- If the tolerance limit of a mating part is very high, in the case of fully interchangeability, the demanded accuracy of assembly may not be obtained.

- Selective assembly technique, where all the parts are measured, graded and grouped according to the size, and finally corresponding groups are assembled together

INTRODUCTION

- Selective Assembly



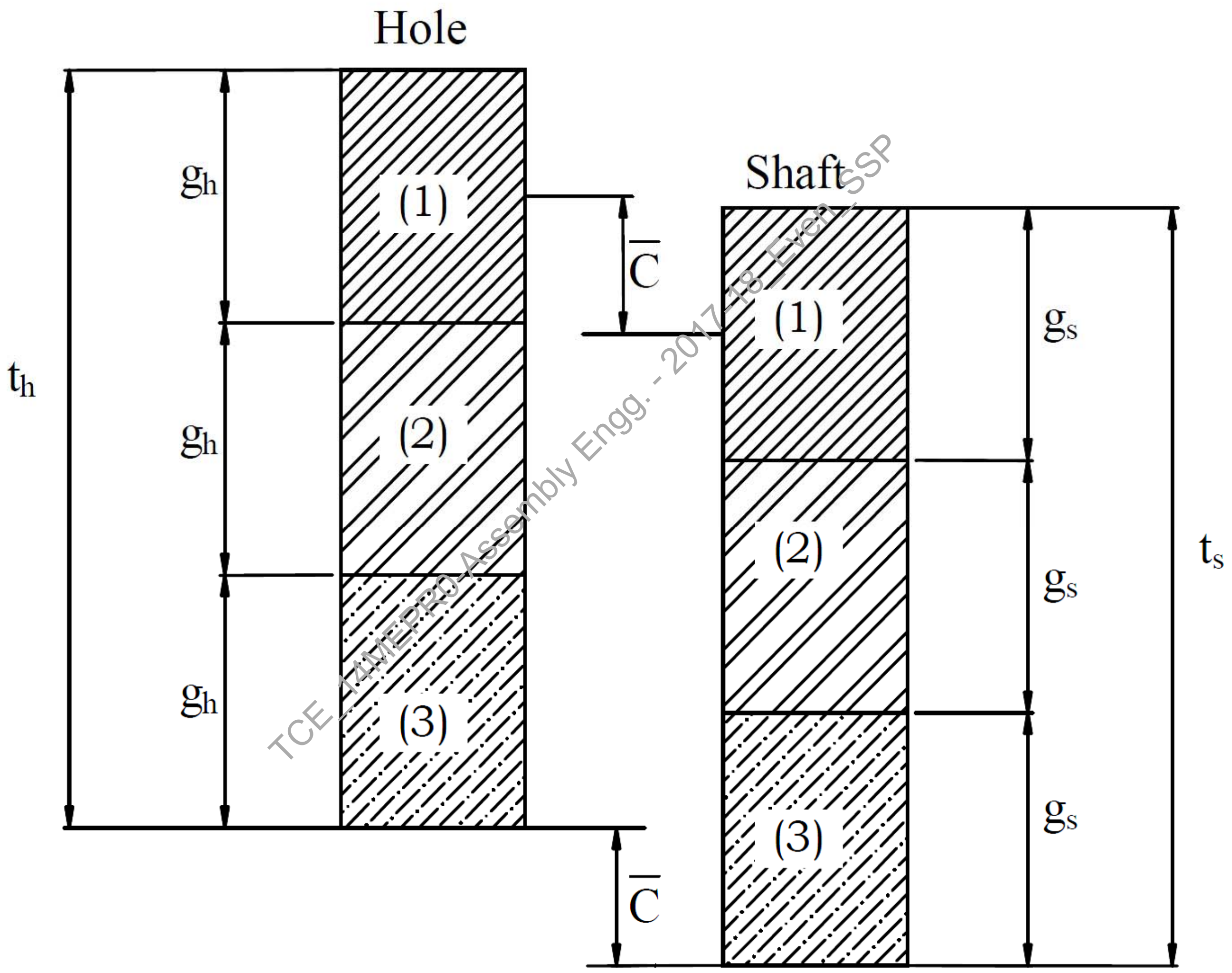
Limits of sizes of groups of a hole and a shaft

INTRODUCTION

- Selective Assembly

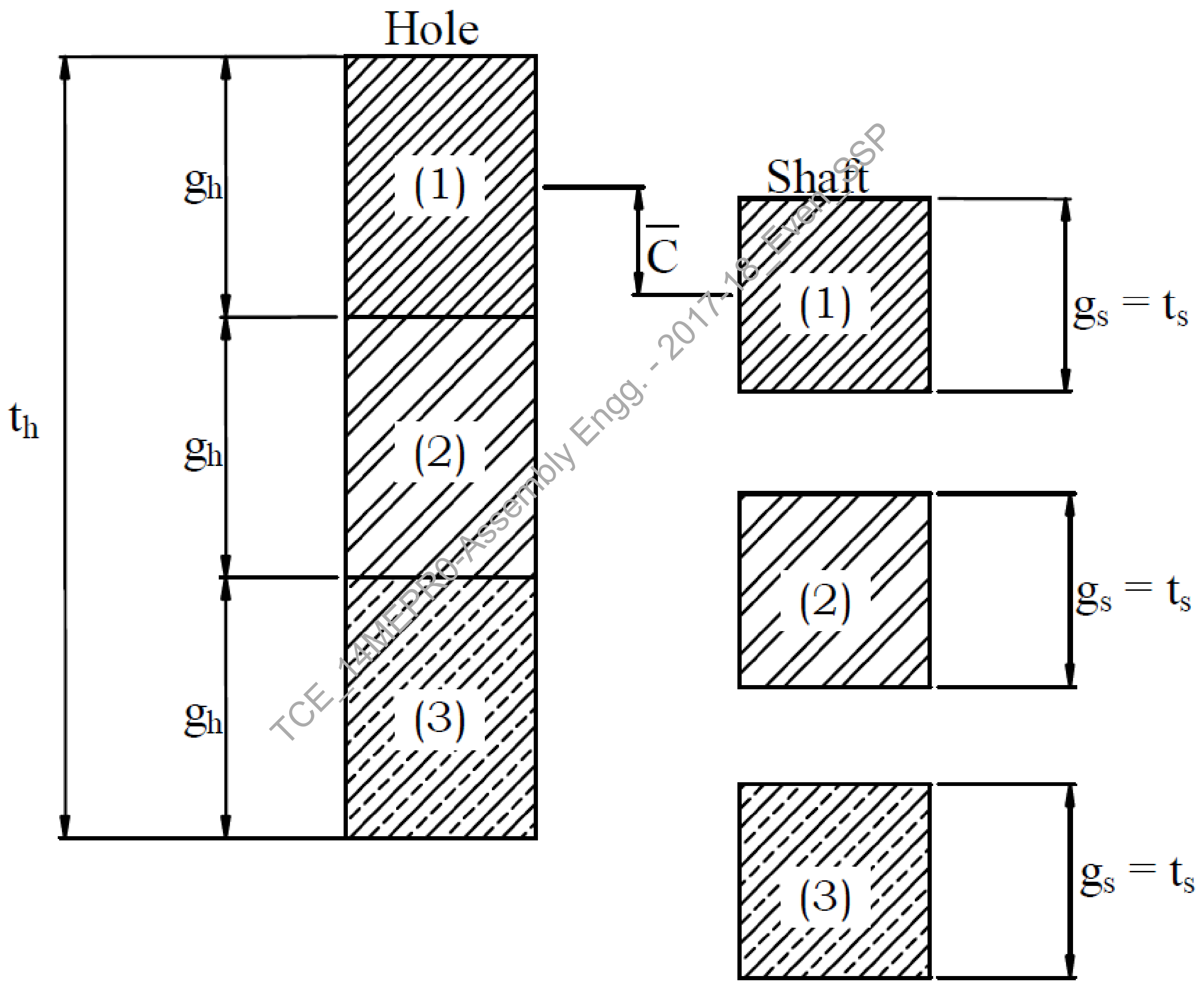
t_h - Total tolerance for hole
t_s - Total tolerance for shaft
g_h - Group tolerance for hole
g_s - Group tolerance for shaft
$\overline{C}$ - Mean fit
c - Maximum permissible variation from mean fit
$C = \overline{C} \pm c$, is the fit
B - Basic fit

Selective Assembly



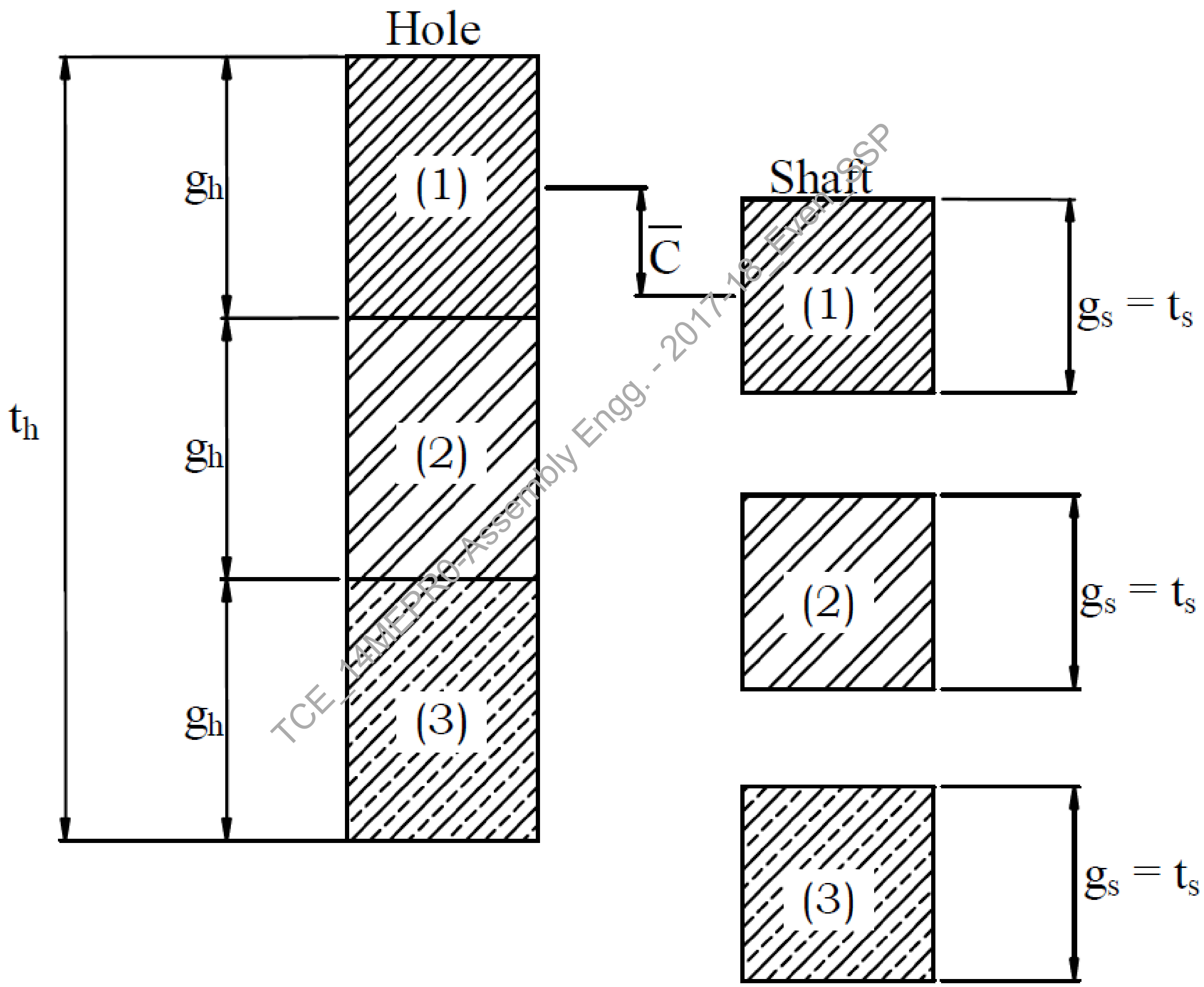
Model I ($t_h = t_s$)

Selective Assembly



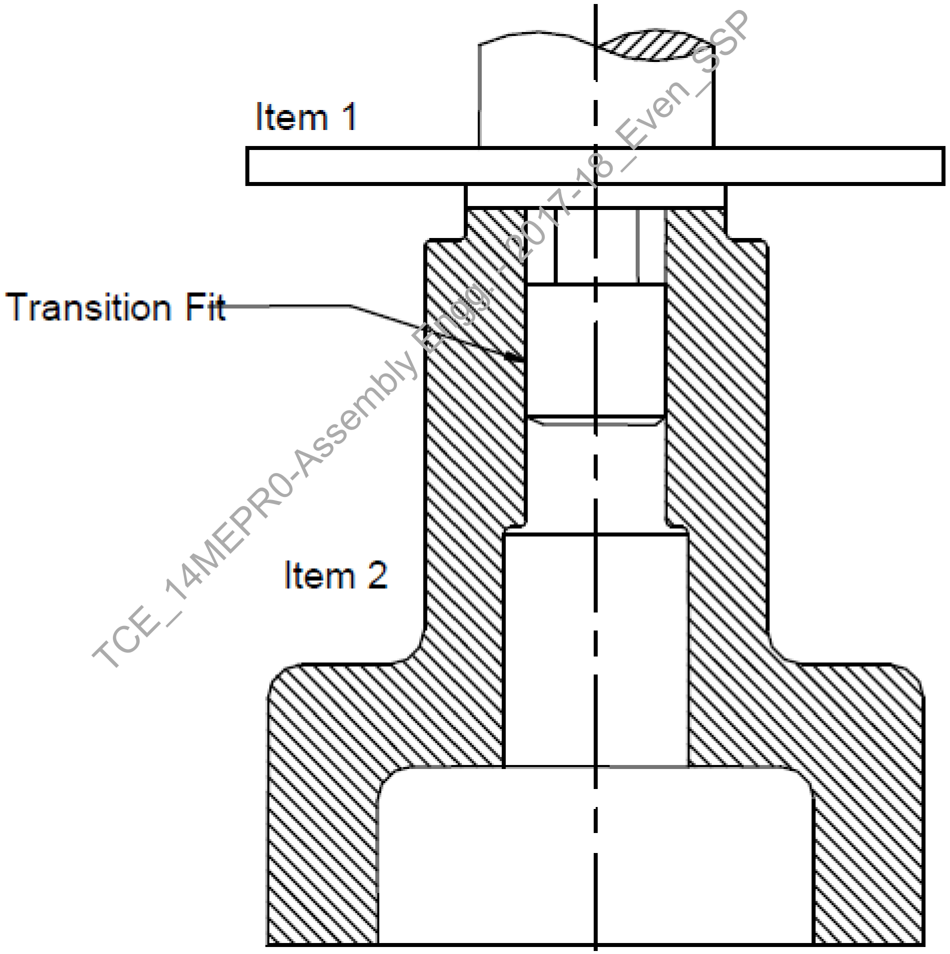
Model II ($g_s = t_s$)

Selective Assembly



Model II (g_s = t_s)

Selective Assembly



Selective Assembly

Following the section 2.1.1, we have, C= +0.005 ± 0.007 mm

Take B= 8.89 mm

H_1 = 8.89

H_2 = 8.89 + 0.007 = 8.898

H_3 = 8.89 + 0.015 = 8.905

So t_h = 0.015 and g_h = 0.007

Similarly,

S_1 = 8.89 - 0.005 = 8.885

S_2 = 8.885 + 0.007 = 8.893

S_3 = 8.885 + 0.015 = 8.900

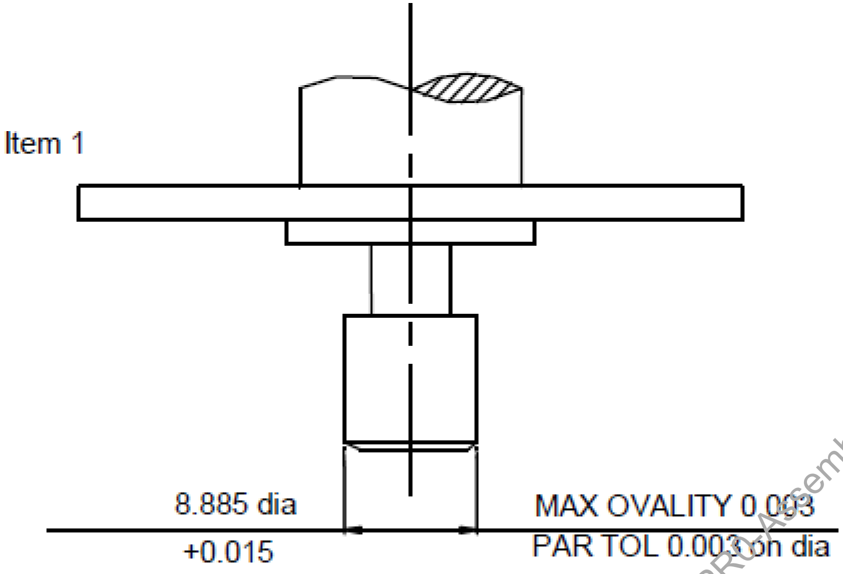
So t_s =0.015 and g_s = 0.007

Here,

t_h = 0.015 corresponds to IT 7 (High quality reaming)

t_s = 0.015 corresponds to IT 7 (High quality grinding)

Selective Assembly

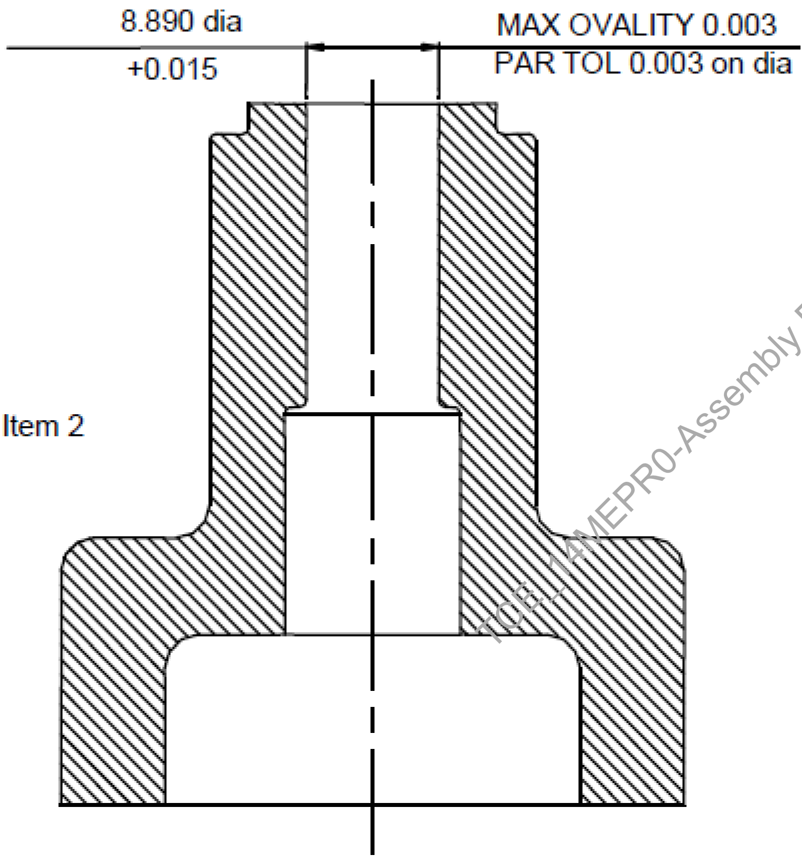


Sort into following groups, and assemble with corresponding groups of item2

Group 1 --- 8.885 to 8.893

Group 2 --- 8.893 to 8.900

Selective Assembly



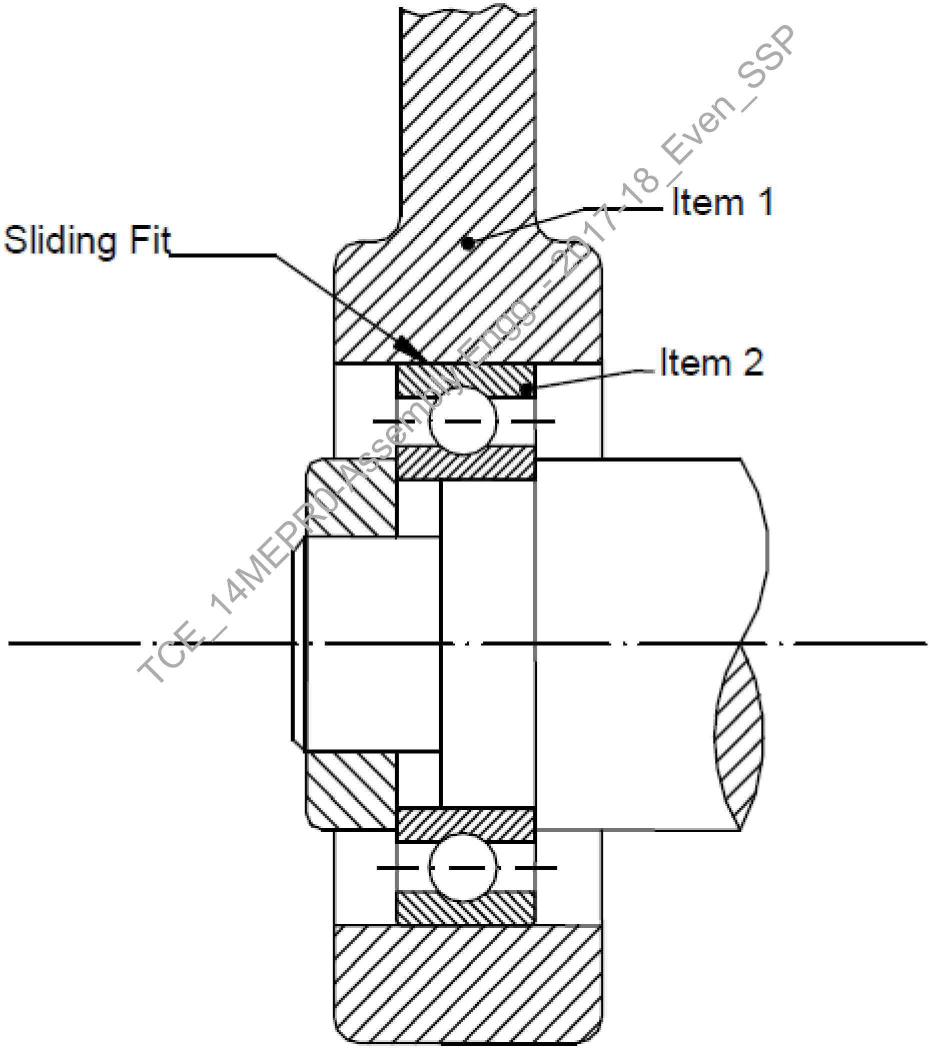
Sort into following groups, and assemble with corresponding groups of item 1

Group 1 --- 8.890 to 8.898

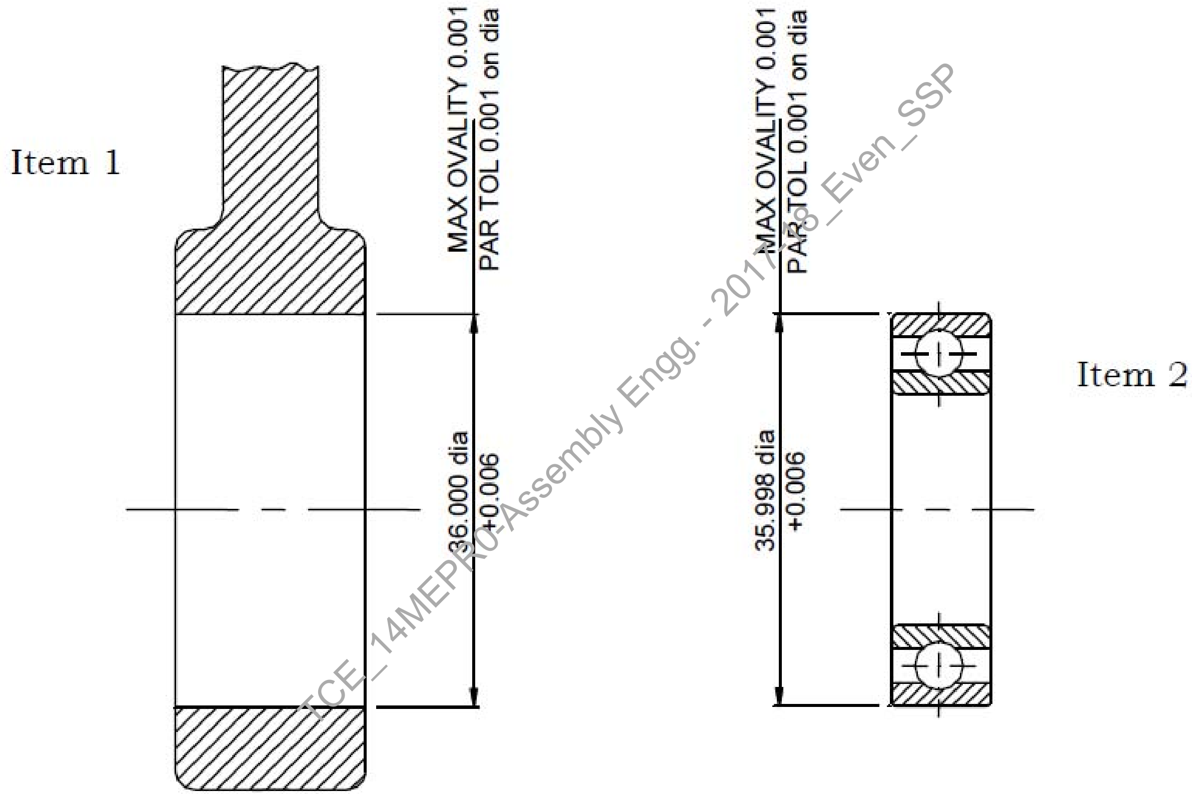
Group 2 --- 8.898 to 8.905

Fig E2

Selective Assembly



Selective Assembly



Sort into following groups, and assemble with the corresponding groups of item 2

Group 1 --- 36.000 to 36.002

Group 2 --- 36.002 to 36.004

Group 3 --- 36.004 to 36.006

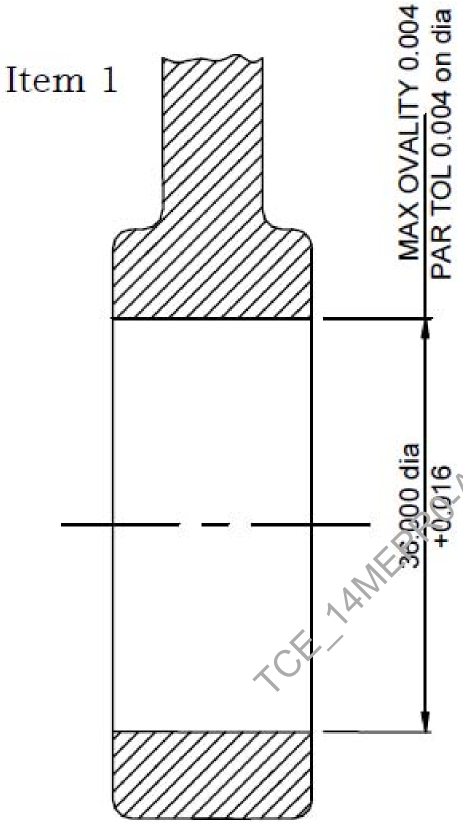
Sort into following groups, and assemble with the corresponding groups of item 1

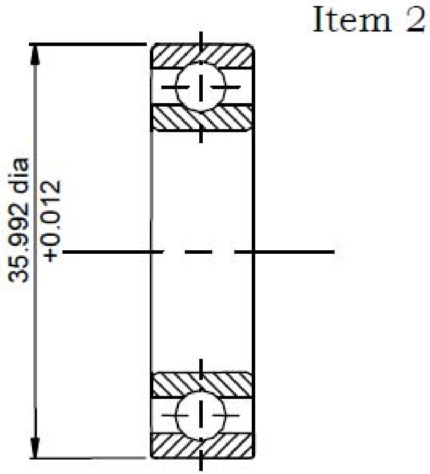
Group 1 --- 35.998 to 36.000

Group 2 --- 36.000 to 36.002

Group 3 --- 36.002 to 36.004

Selective Assembly





Sort into following groups, and assemble with the corresponding groups of item 2
Group 1 --- 36.000 to 36.008
Group 2 --- 36.008 to 36.016

Sort into following groups, and assemble with the corresponding groups of item 1
Group 1 --- 35.992 to 35.996
Group 2 --- 36.000 to 36.004

TABLE 2.2 Shape Generation Capabilities of Processes

	Depress		UniWall	UniSect	AxisRot	RegXSec	CaptCav	Enclosed	NoDraft	PConsol	Alignmt	IntFast	
Sand casting	Y	Y	Y	Y	Y	Y	Y	N	N	4	3	1	Solidification processes
Investment casting	Y	Y	Y	Y	Y	Y	Y	N	N	5	5	2	
Die casting	Y	Y[a]	Y	Y	Y	Y	N	N	N	4	5	3	
Injection molding	Y	Y[a]	Y	Y	Y	Y	N[b]	N	N	5	5	5	
Structural foam	Y	Y[a]	Y	Y	Y	Y	N	N	N	4	4	3	
Blow molding (extr)	Y	Y[a]	M	N	Y	Y	M	Y	N	3	4	3	
Blow molding (inj)	Y	Y[a]	M	N	Y	Y	M	N	N	3	4	3	
Rotational molding	Y	Y[a]	M	N	Y	Y	N	M	N	2	2	1	
Impact extrusion	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	Bulk deformation processes
Cold heading	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	
Closed die forging	Y	Y[a]	Y	Y	Y	Y	N	N	N	3	2	1	
Power metal parts	Y	N	Y	Y	Y	Y	N	N	Y	3	3	1	
Hot extrusion	Y[d]	N	Y	M	Y	Y	N	N	Y	2	2	3	
Rotary swaging	N[c]	N	N	N	M	N[c]	N	N	N	1	1	1	
Machining (from stock)	Y	Y	Y	Y	Y	Y	Y	N	Y	2	3	2	Material removal processes
ECM	Y	Y[c]	Y	Y	Y	Y	N	N	N	3	4	1	
EDM	Y	Y[c]	Y	Y	Y	Y	N	N	N	3	4	1	
Wire-EDM	Y[d]	N	Y	Y	Y	Y	N	N	Y	2	2	3	Profile generating processes
Sheetmetal stamp/bend	Y	Y	M	Y	Y	Y	N	N	N	4	3	4	Sheet forming processes
Thermoforming	Y	Y[a]	M	N	Y	Y	N	N	N	3	3	3	
Metal spinning	N	N	M	N	M	N	Y	N	N	1	1	1	

[a] Possible at higher cost.
[b] Shallow undercuts are possible without significant cost penalty.
[c] Possible with more specialized machine and tooling.
[d] Only continuous, open-ended possible.
Y, Process is capable of producing parts with this characteristic, N, Process is not capable of producing parts with this characteristic. M, Parts produced with this process must have this characteristic. An underlined entry indicates that parts using this process are easier to form with this characteristic.
The last three columns refer to DFA guidelines and are rates on a scale of 1 to 5, with 5 assigned to processes most capable of incorporating the respective guideline.

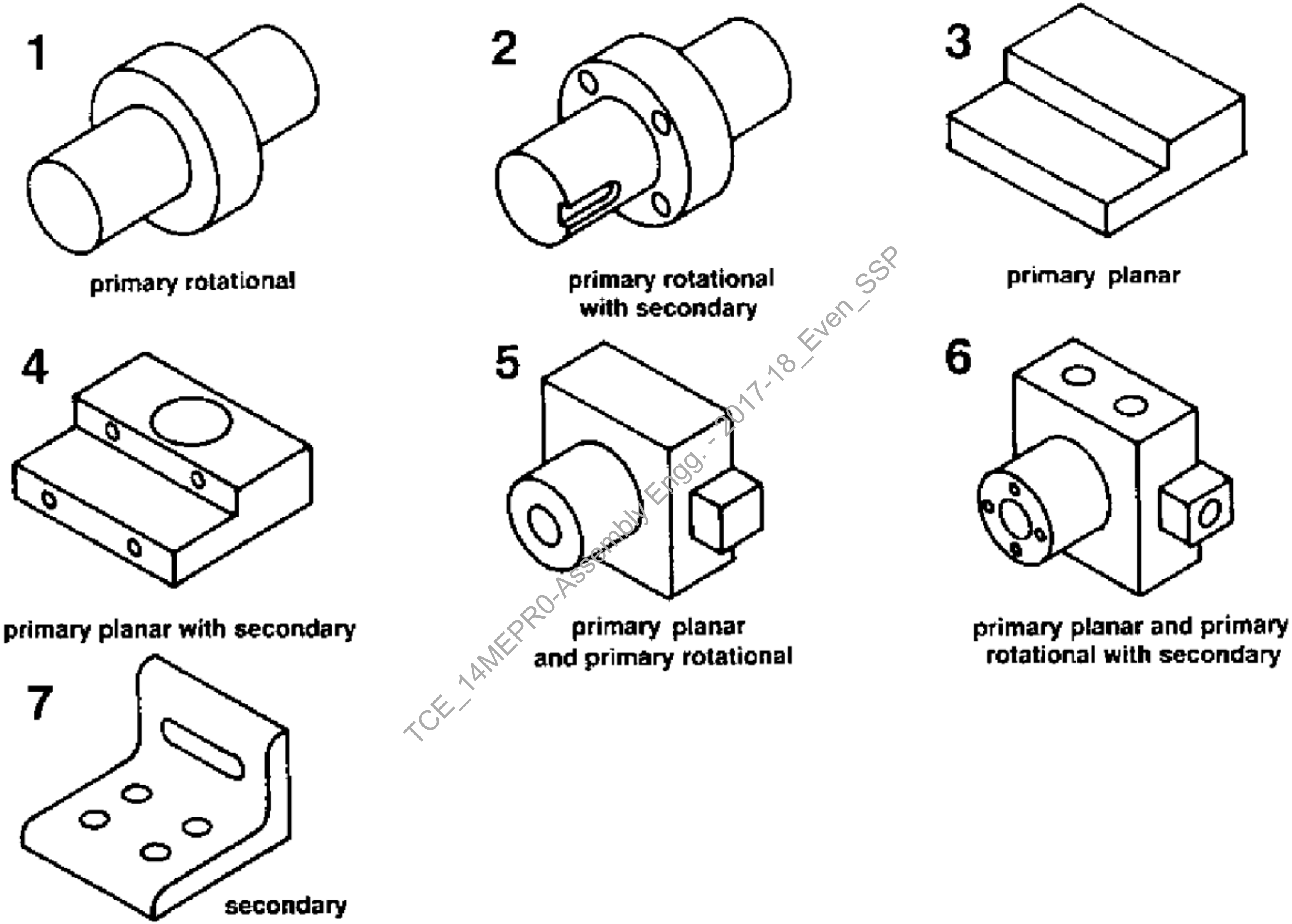
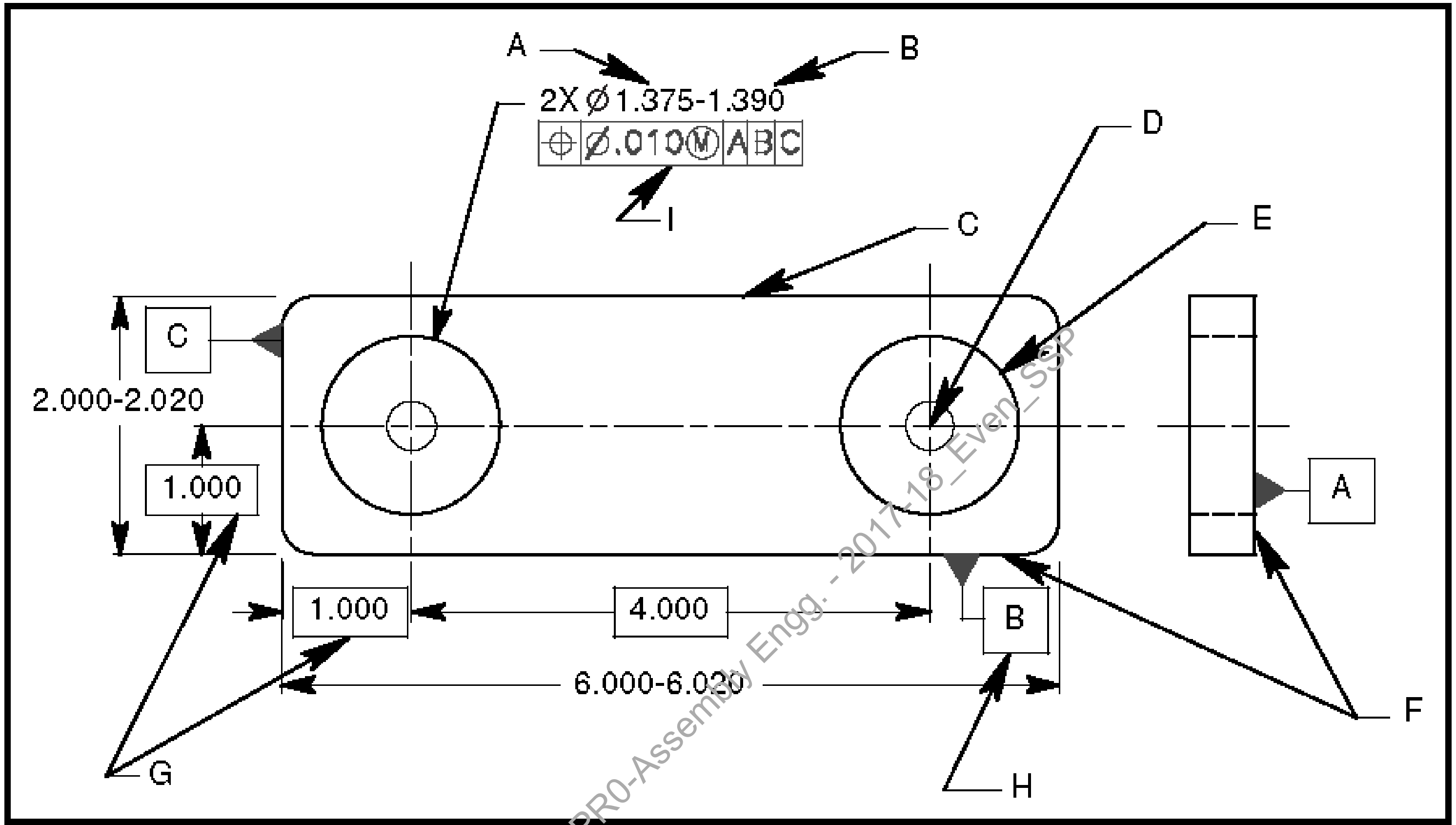


FIG. 2.17 Seven basic categories of machines component parts. (From Ref. 26.)

Tutorial 2 – Selective Assembly

14MEPR0 - Assembly Engineering

B.E. Mechanical Engineering



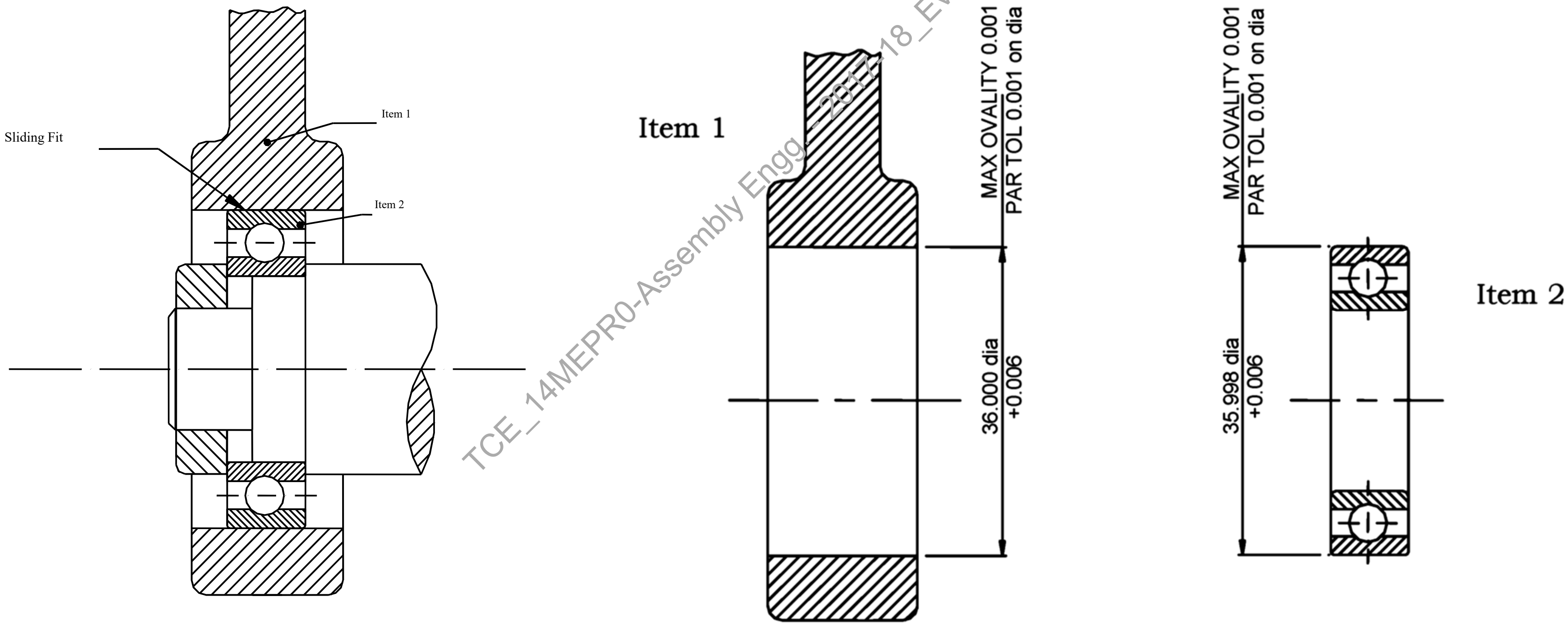
Place the letters of the items on the drawing in Fig. next to the terms below. Make a dash next to the terms not shown.

________ Datum ________ Basic Dimension ________ Feature control frame

________ MMC ________ Feature ________ True Position

________ LMC ________ Feature of Size ________ Datum feature symbol

The following two components as shown in Figure 1 are to be assembled with a tolerance of fit +0.002±0.002 mm. Design a selective assembly structure and justify the same. Is there any change in selective assembly structure, if the tolerance of fit is set to be +0.004±0.002 mm ? Justify the same.



Interpret and write the specification of all the feature control frames in the drawing as shown in figure and draw their respective tolerance zones.

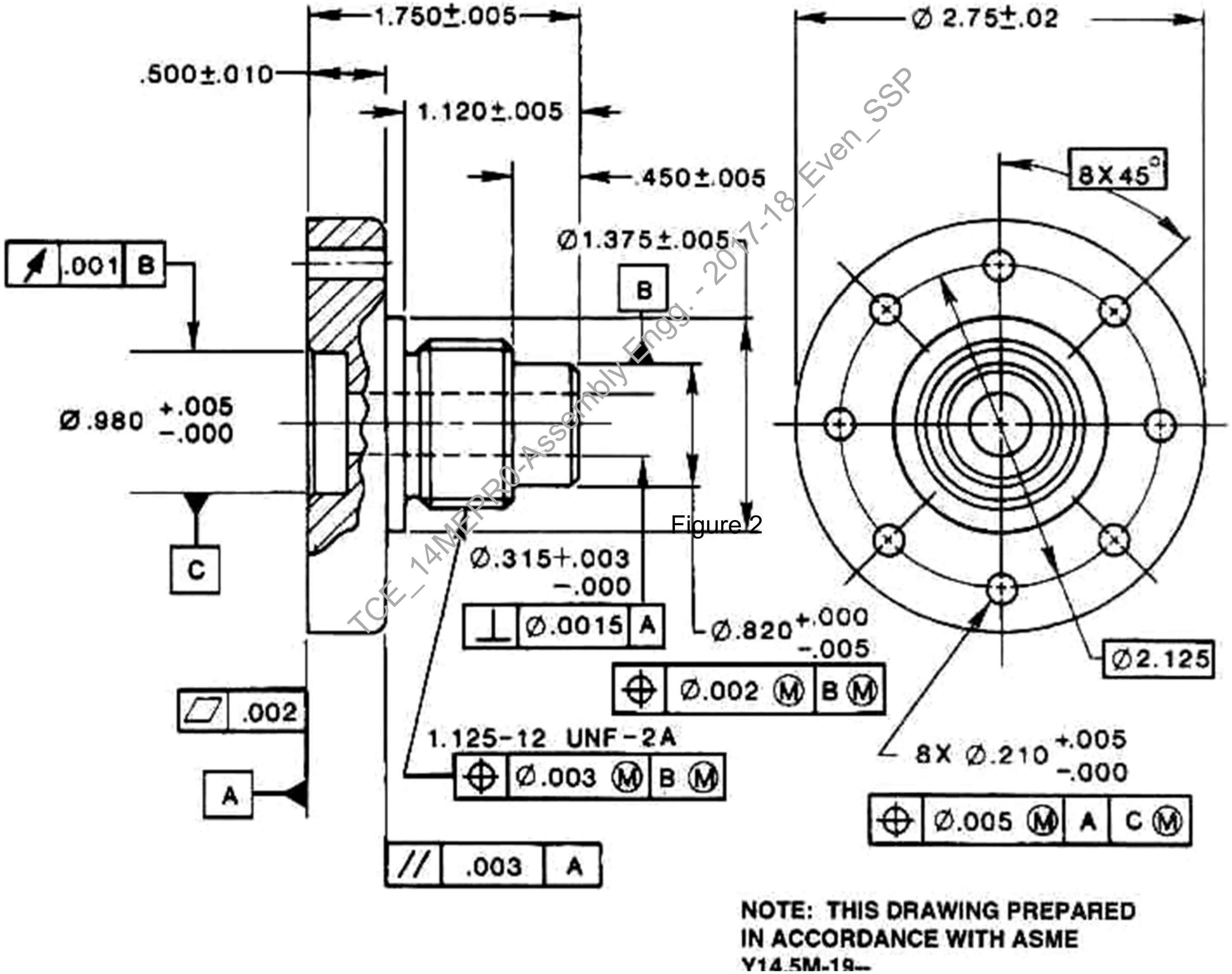


Figure 2

Module 2 – Assembly Sequence Analysis

ASSEMBLY ENGINEERING

Introduction

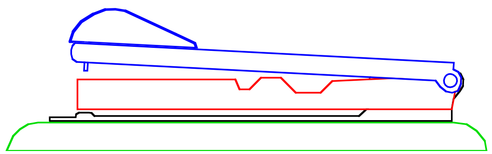
Example : Stapler

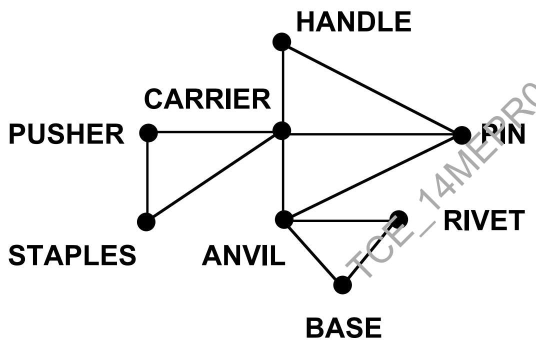
1. What makes the stapler work?
2. What could cause it not to work?

BoM of Stapler

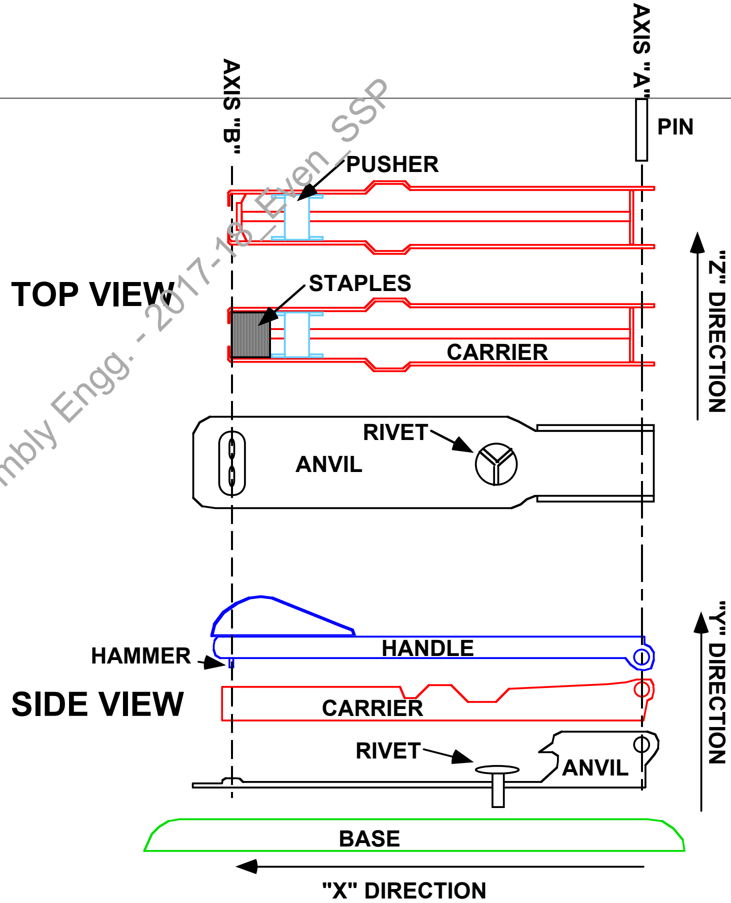
1. Base
2. Anvil
3. Hammer
4. Handle
5. Carrier
6. Pusher
7. Staples

Office Stapler





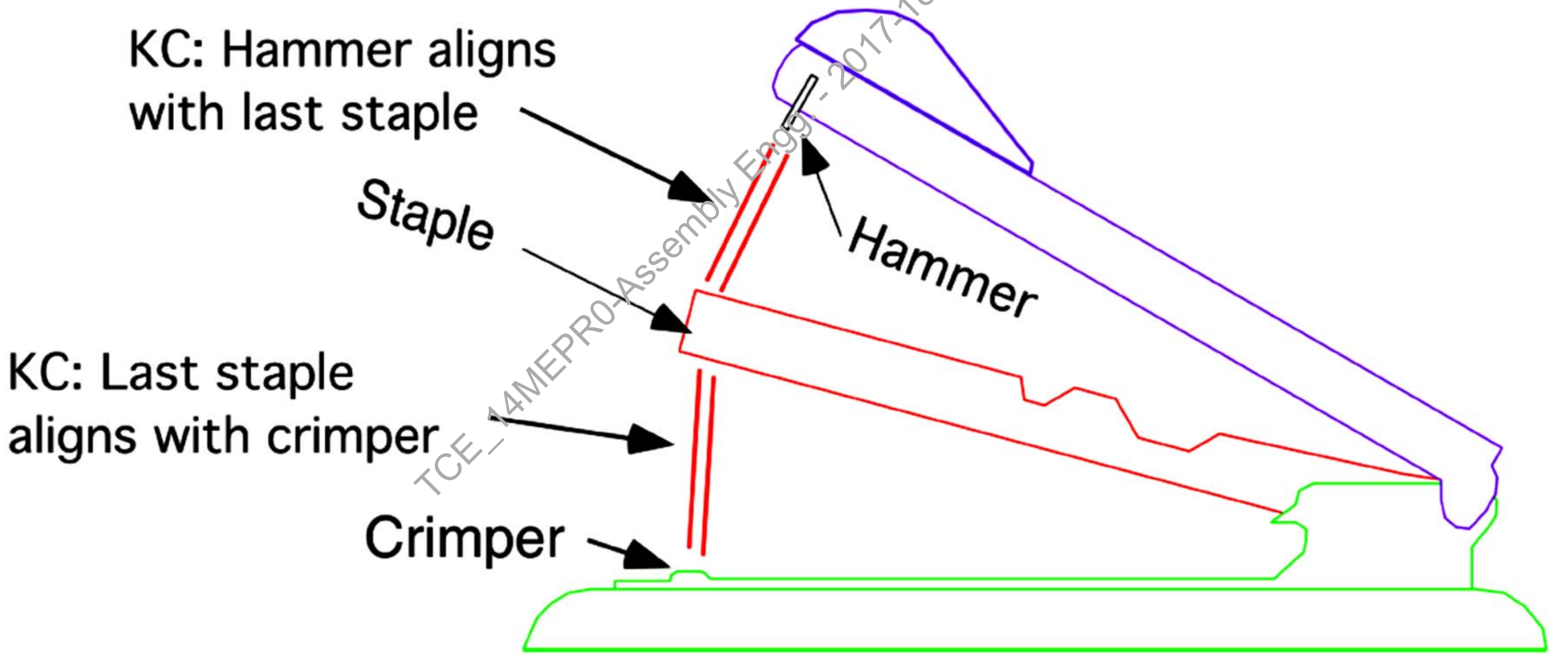
Liaison Diagram



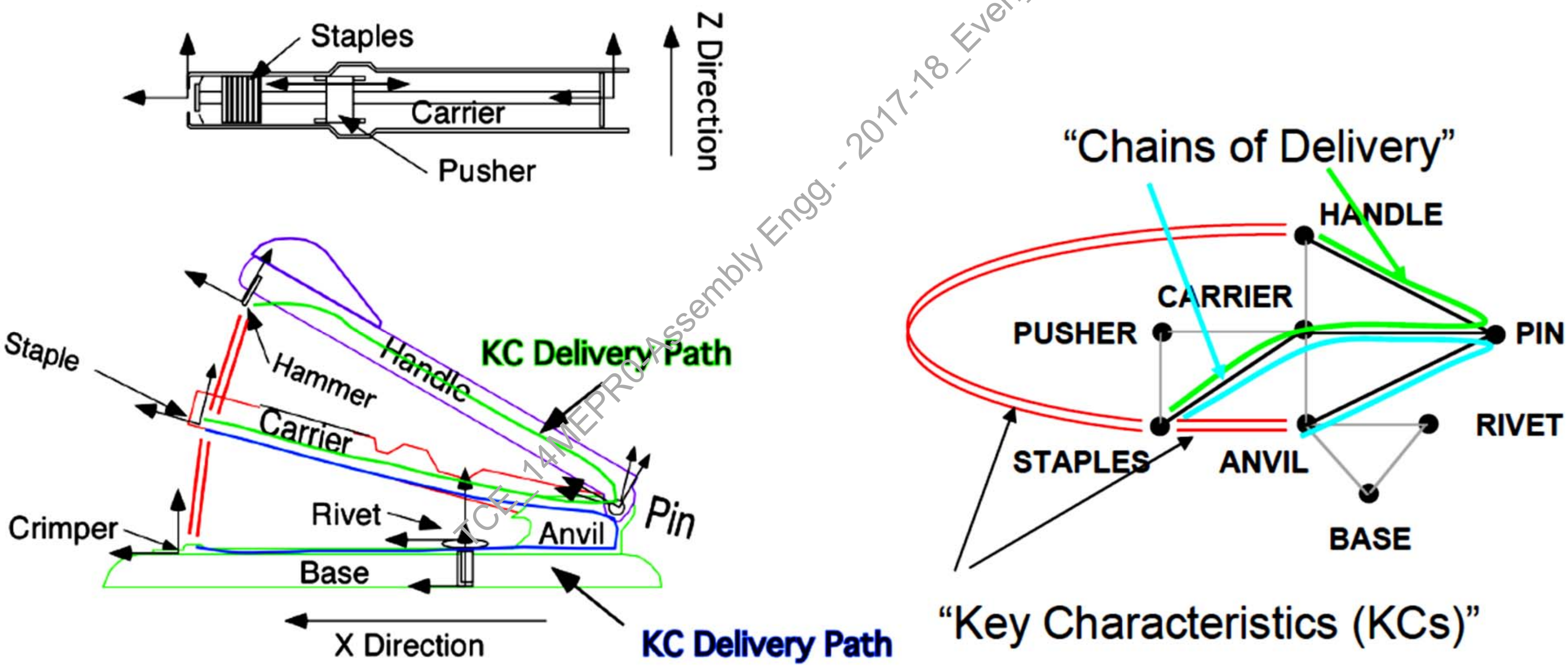
Key Characteristics

Key Characteristics are the *product, sub-assembly, part and process features* whose variation from nominal significantly impact the final cost, performance [including consumer's perception of quality], or safety of a product. Special control should be applied to those KCs is the cost of variation justifies the cost of control (Thornton 1999).

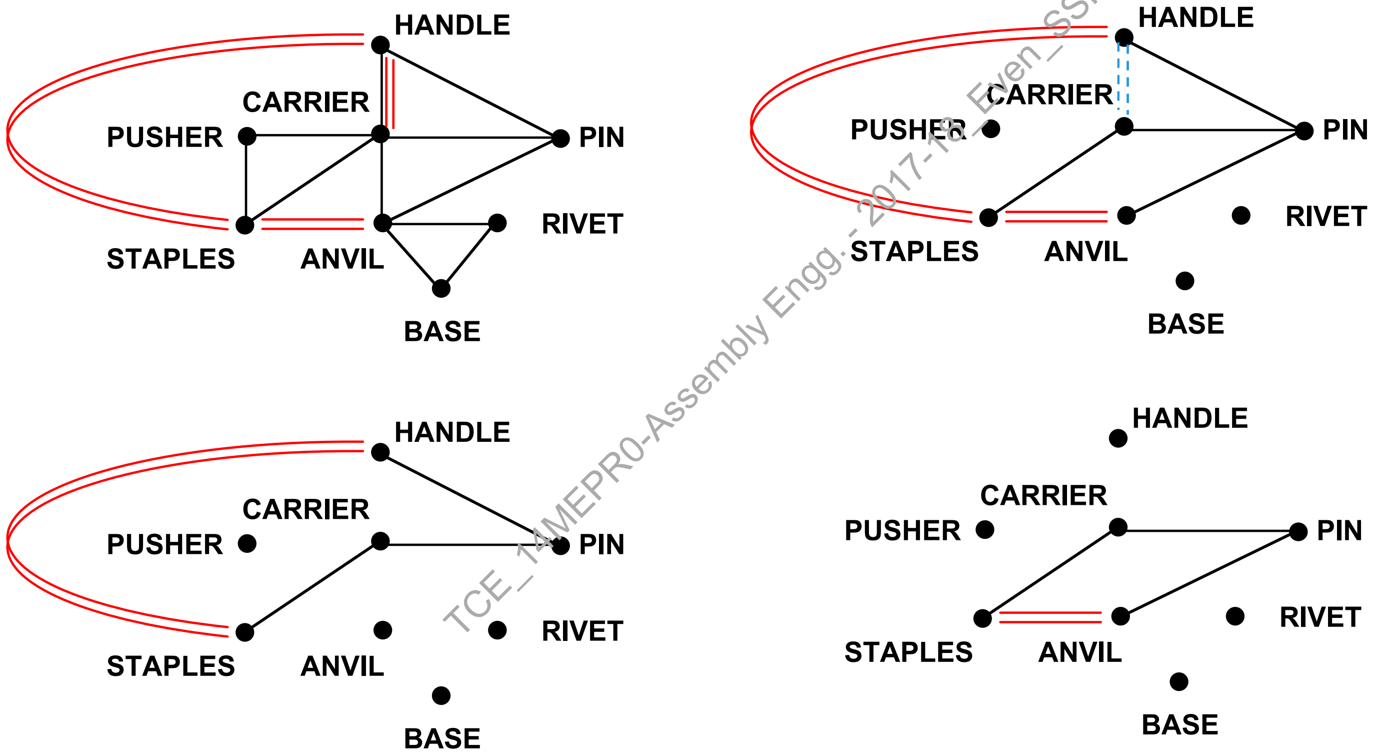
Key Characteristics



KC Delivery

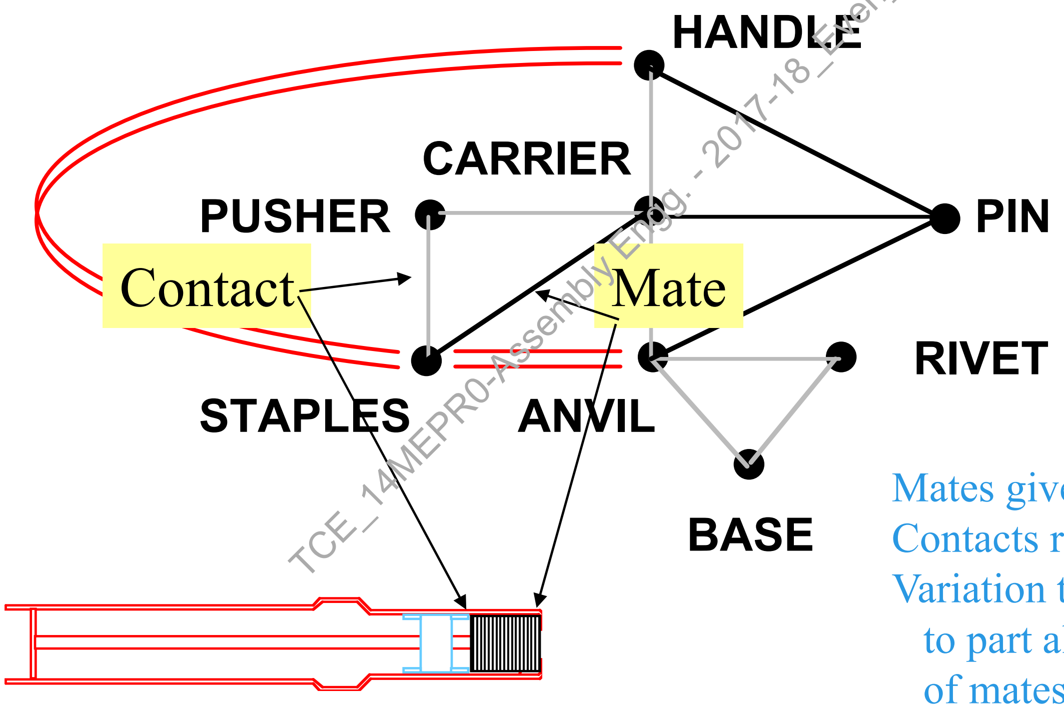

Staples
Carrier
Pusher
Z Direction
Staple
Hammer
Handle
KC Delivery Path
Carrier
Rivet
Anvil
Pin
Crimper
Base
X Direction
KC Delivery Path
"Chains of Delivery"
HANDLE
CARRIER
PUSHER
PIN
RIVET
STAPLES
ANVIL
BASE
"Key Characteristics (KCs)"

Datum Flow Chains in the Stapler



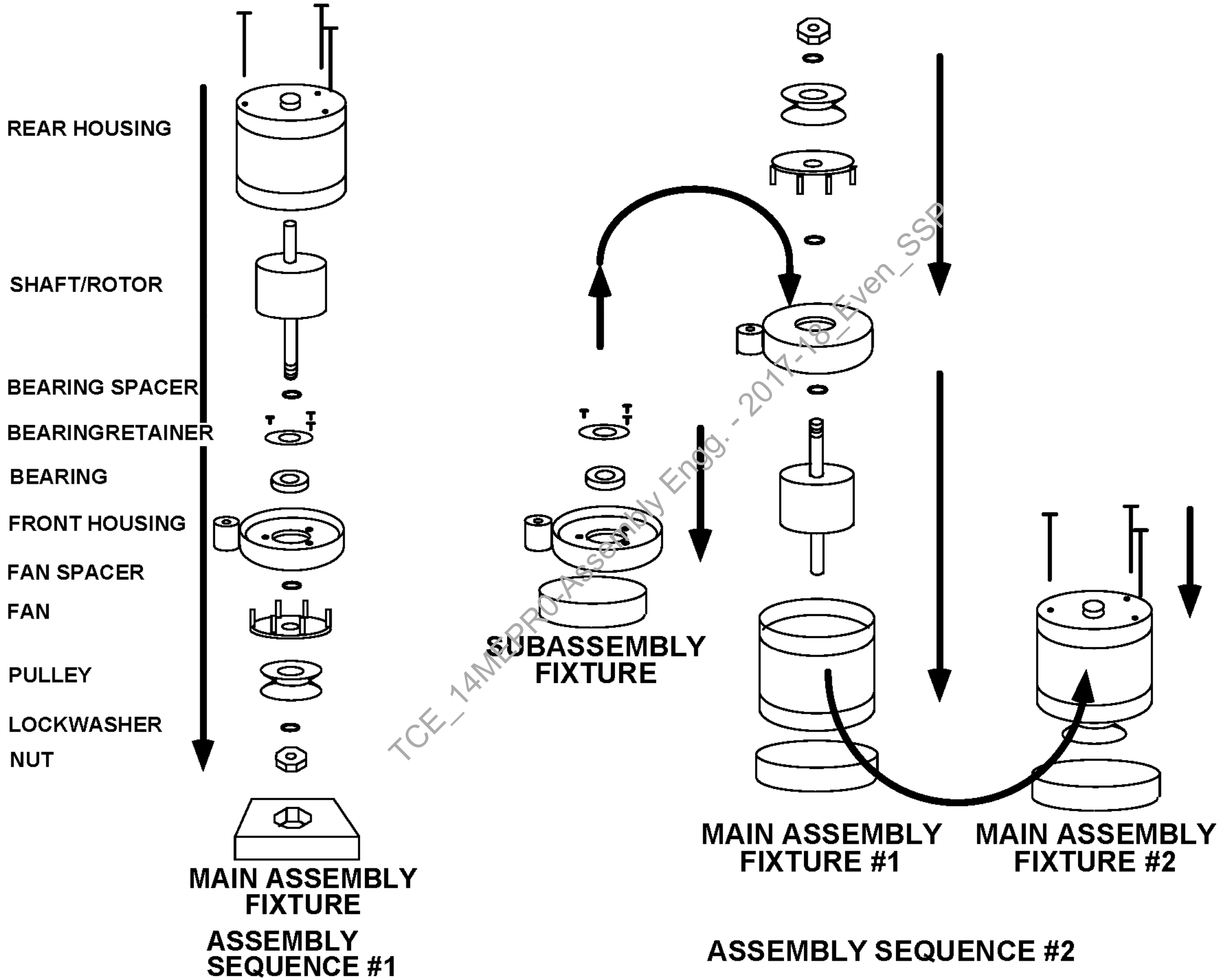
The datum flow chain is a chain of constraining mates from one end of the KC to the other.

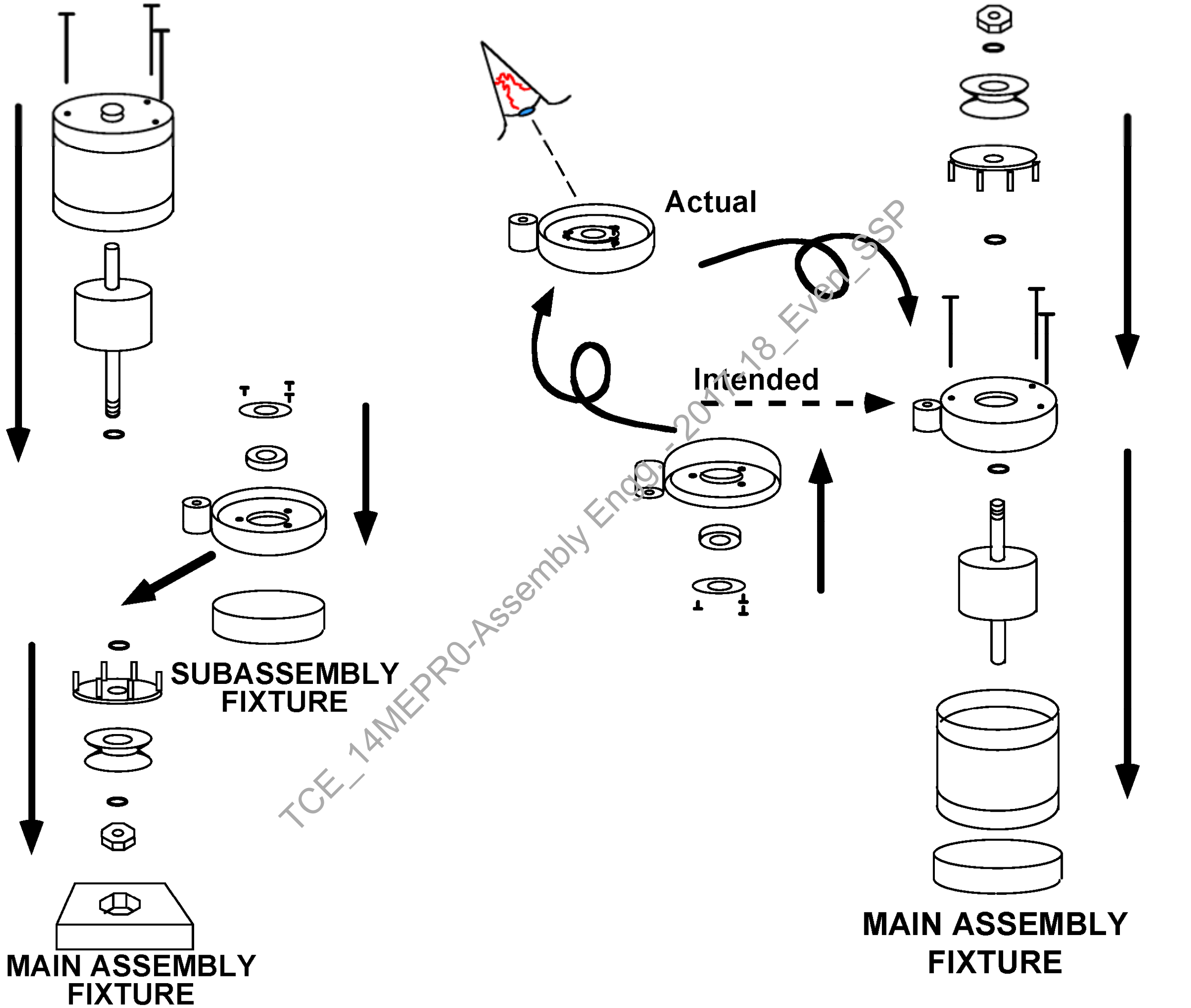
Mates, Contacts, and KC Delivery



Mates give location.
Contacts reinforce location.
Variation travels from part to part along the chain of mates.

Two Alternator Sequences



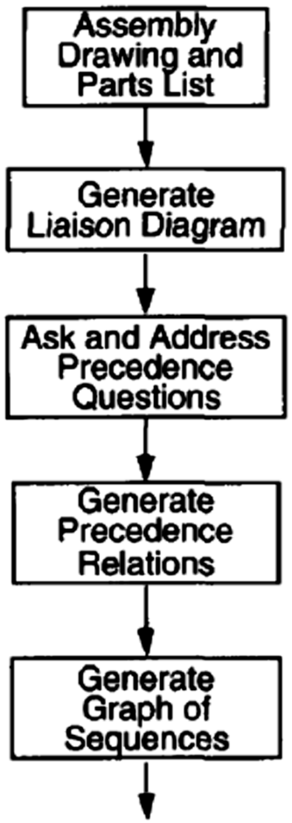


ASSEMBLY
SEQUENCE #3

ASSEMBLY SEQUENCE #4

Generating Feasible Sequences

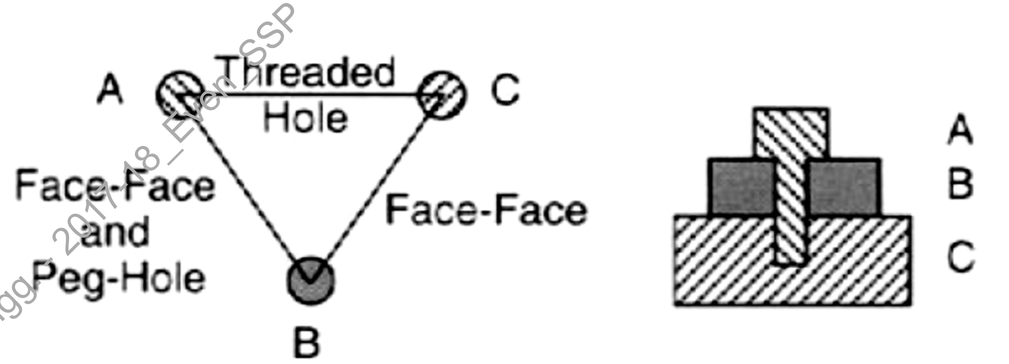
- Make drawing and parts list
- Generate liaison diagram
- Answer precedence questions
  - local constraints on movement
  - global constraints
- Generate precedence relations
- Generate graph of sequences

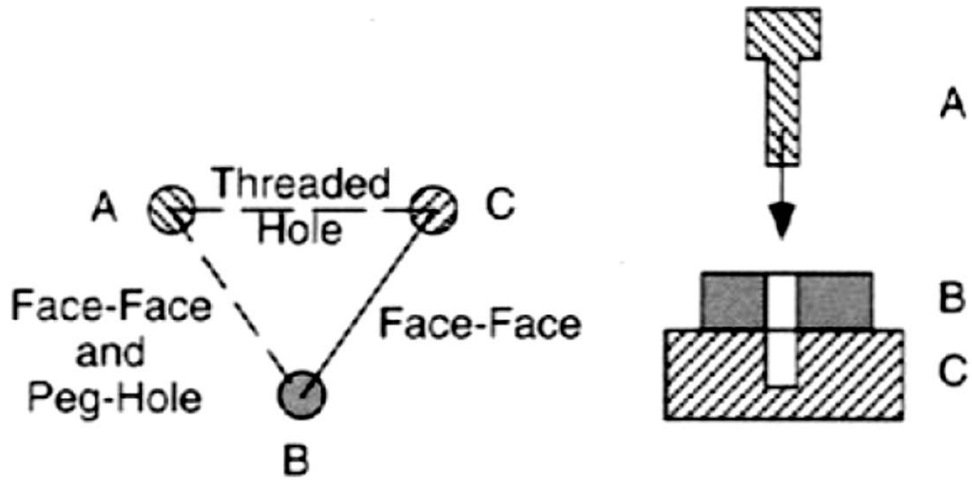


Generating Feasible Sequences

Liaison Diagram
- Each part is a node
- Each link is a liaison

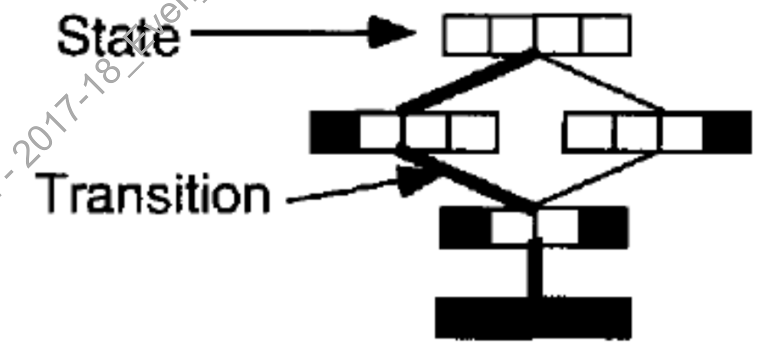
Loop closure rule:
- Any loop in a liaison diagram and reads as follows:
  - If at some point in an assembly process, a loop of *n* liaisons stands with *n — 2* liaisons already made, then the next step applied to that loop will close *both* of the remaining open liaisons.
  - It is impossible for a partial assembly to exist in which there is a loop with only one undone liaison.





Generating Feasible Sequences

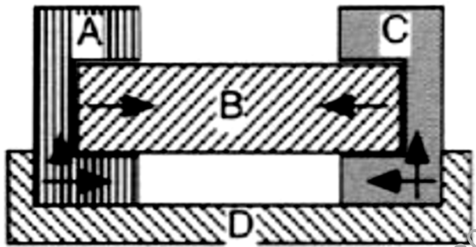
- Each row contains one or more state elements containing empty or filled-in cells.
- Each state corresponds to a feasible subassembly or as many as two feasible subassemblies.
- Each cell in a state corresponds to a liaison.
- Empty cells indicate liaisons that have not been done, while filled-in cells indicate completed liaisons.
- Each line between states is a transition, during which one or more liaisons are done.
- A path from the top state (no liaisons done) to the bottom state (all liaisons done) is a feasible liaison sequence.
- Diagram expresses two feasible sequences.

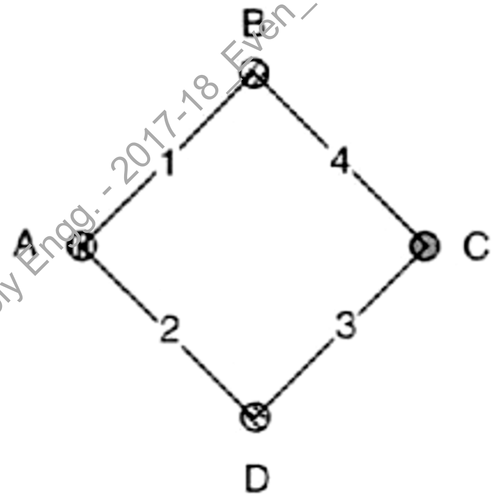


Feasible Sequences

	Liaisons for Sequence 1	Liaisons for Sequence 2
Step 1	1	4
Step 2	4	1
Step 3	2 and 3 at once	2 and 3 at once

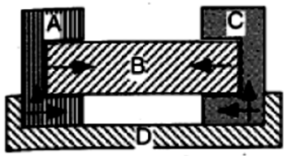
Generating Feasible Sequences



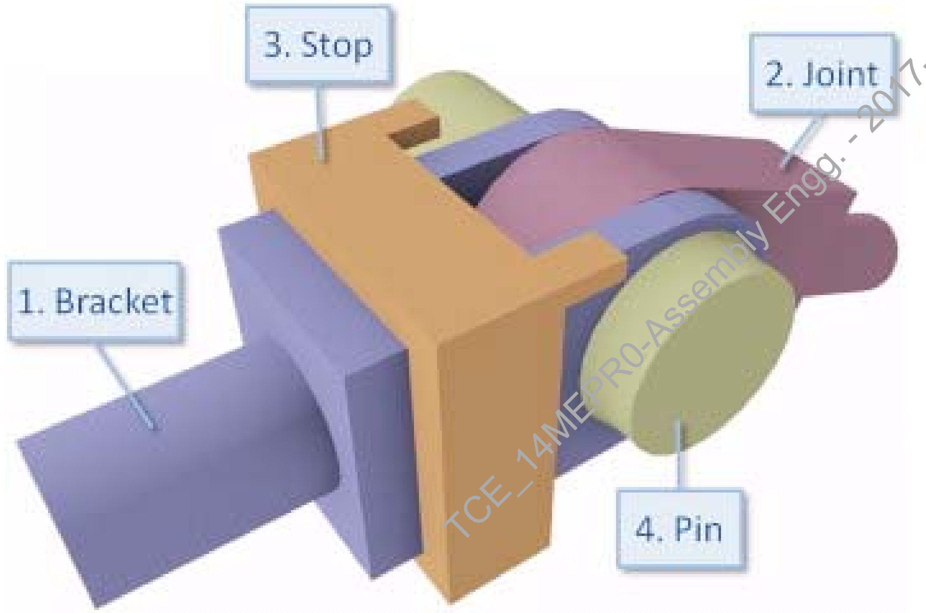


Arrows on the assembly drawing indicate escape directions for part B relative to parts A and C, and for parts A and C relative to part D.

Generating Feasible Sequences

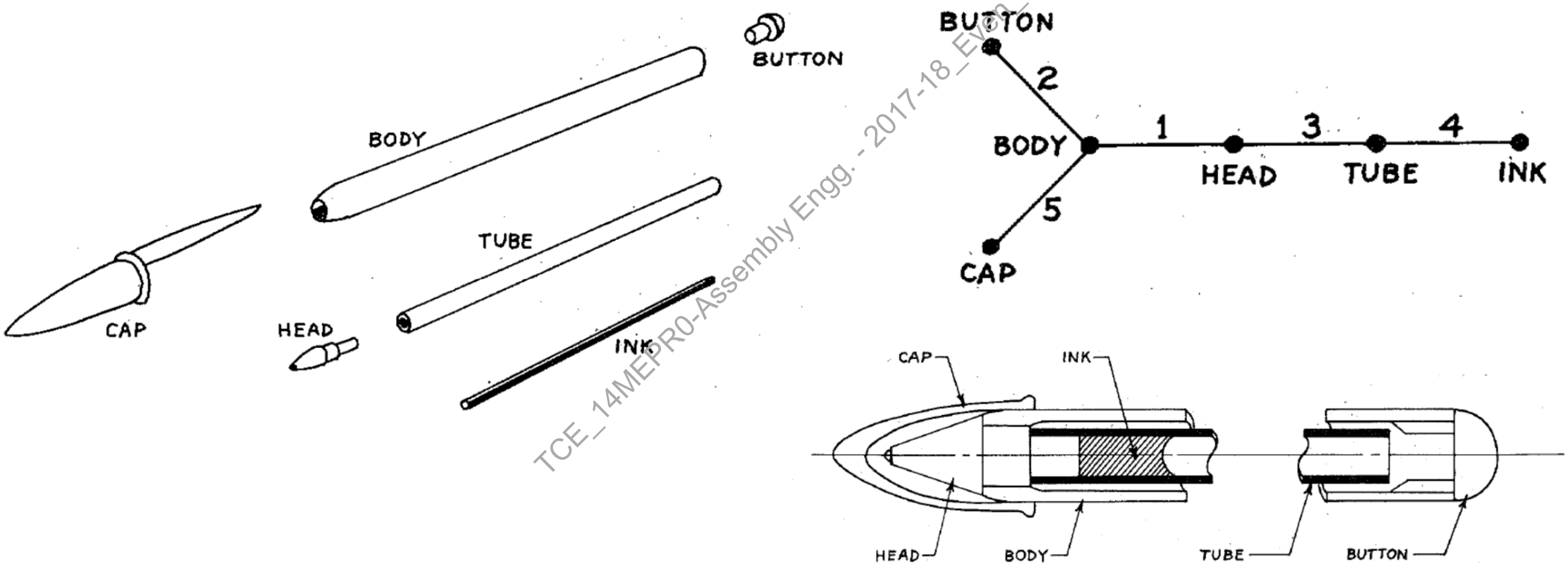


Tutorial



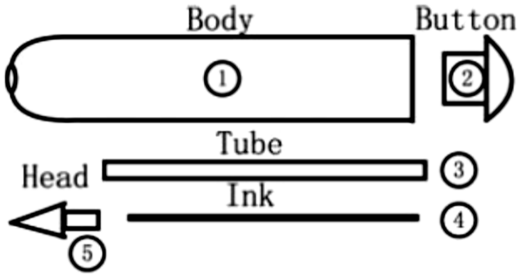
Coupling Assembly

Tutorial



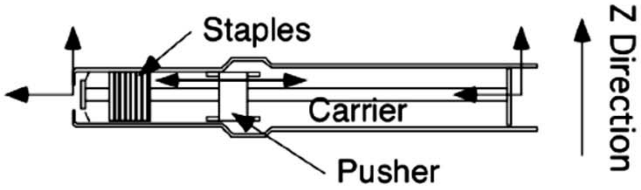
Ballpoint Pen Assembly

Tutorial

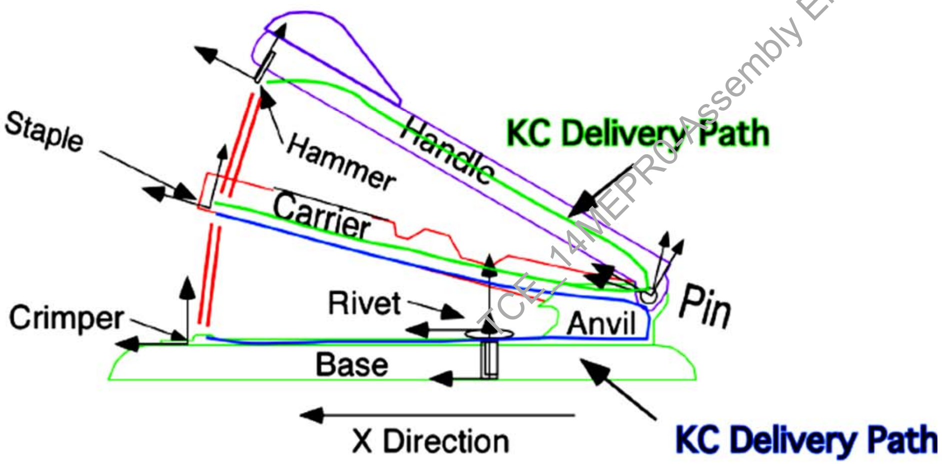


Ballpoint Pen Case

Tutorial

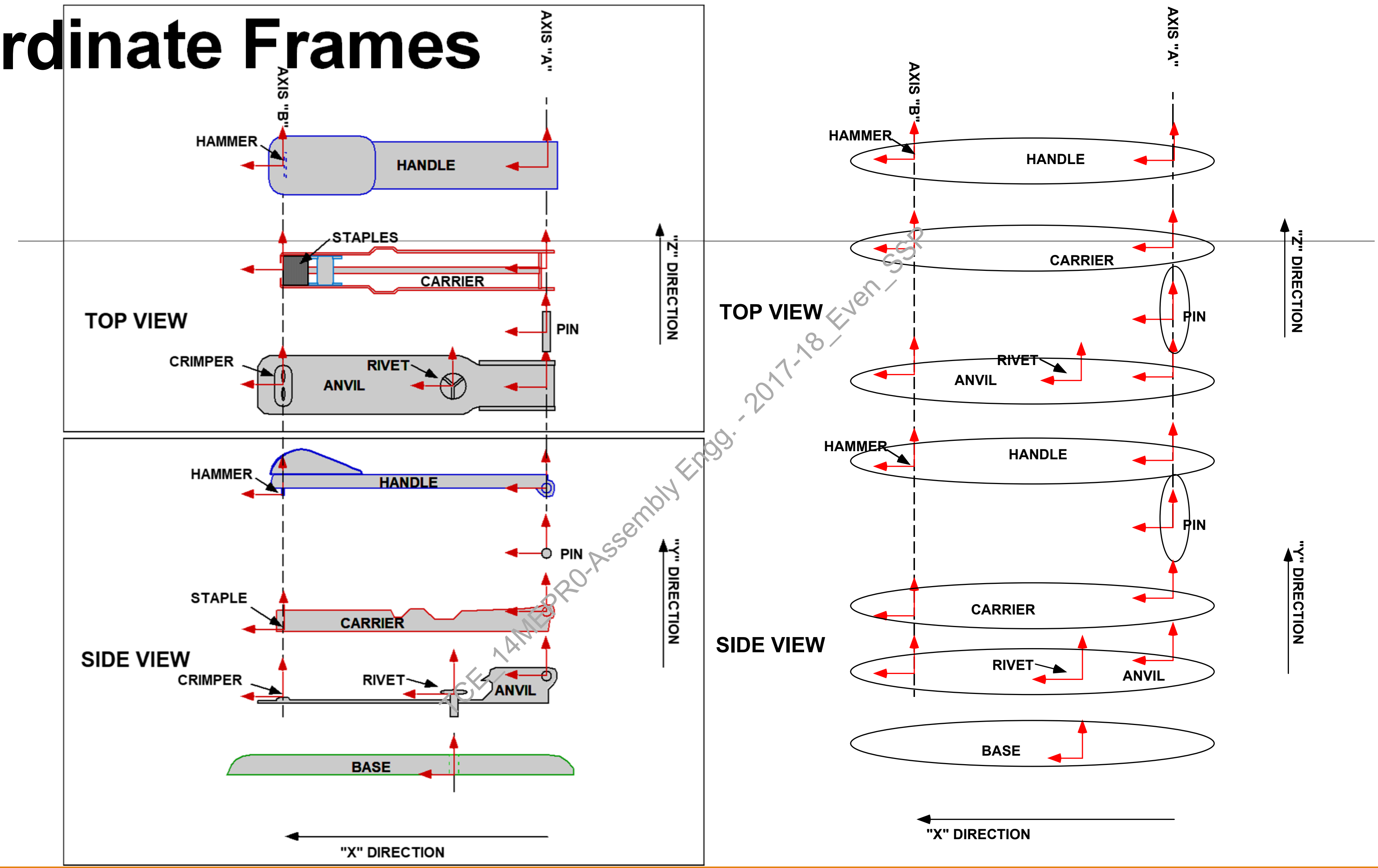


Staples
Carrier
Pusher
Z Direction

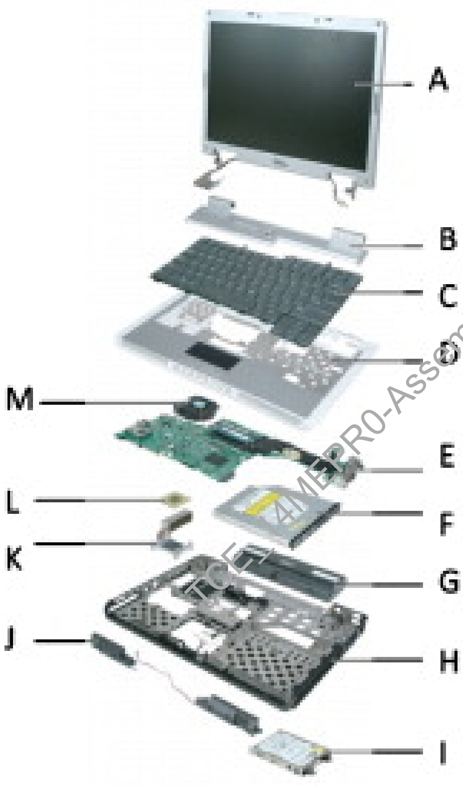


Staple
Hammer
Handle
KC Delivery Path
Carrier
Rivet
Crimper
Anvil
Pin
Base
X Direction
KC Delivery Path

Coordinate Frames



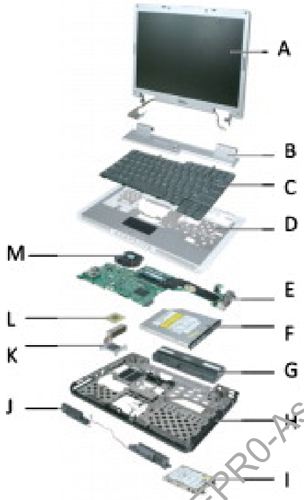
Tutorial



Parts List	
A	display assembly
B	hinge cover
C	keyboard
D	palm rest (w ith touch pad)
E	system board
F	optical drive
G	main battery
H	computer base
I	hard drive
J	speakers
K	microprocessor thermal-cooling assembly
L	microprocessor
M	fan

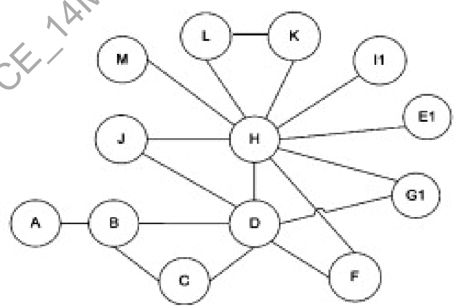
Source: www.support.dell.com

Tutorial



Parts List	
A	display assembly
B	hinge cover
C	keyboard
D	palm rest (with touch pad)
E	system board
F	optical drive
G	main battery
H	computer base
I	hard drive
J	speakers
K	microprocessor thermal-cooling assembly
L	microprocessor
M	fan

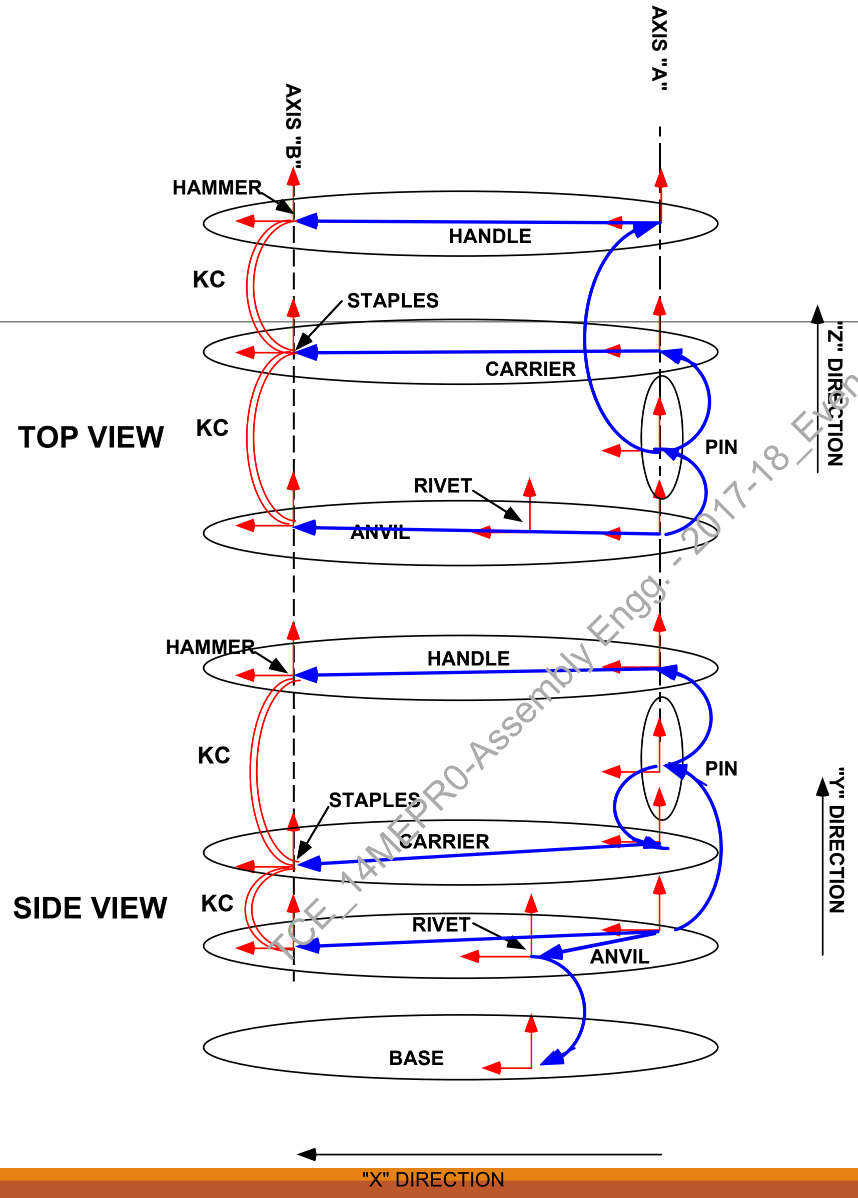
Source: www.support.dell.com



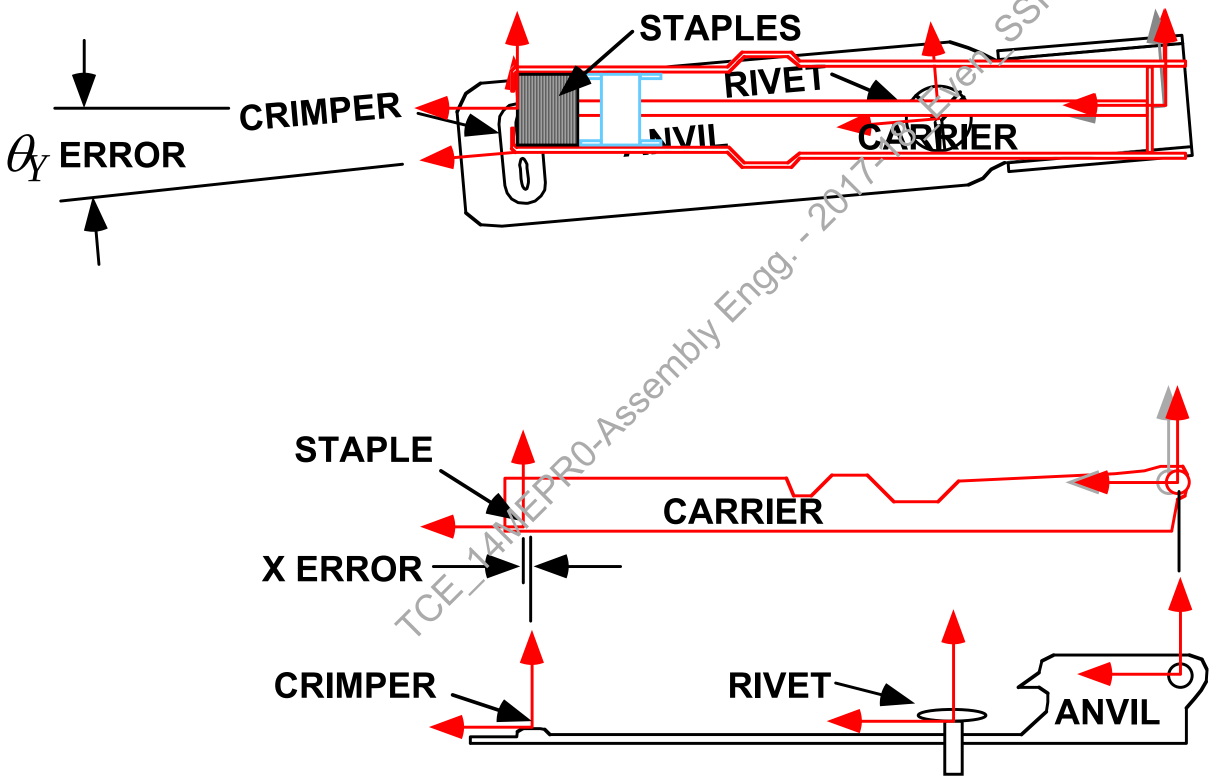
Datum Flow Chain

- A DFC is an assembly-level statement of design intent that documents the chain that delivers the KC
  - identifies the parts that make up the chain
  - provides a skeleton for the strategy by which the parts will be located in space as links in the chain
- Each step in the assembly process adds links to the chain and each subassembly is kinematically constrained

Chains of Frames = Assembly



Stapler Variations



THIAGARAJAR COLLEGE OF ENGINEERING, MADURAI 625 015.

Department of Mechanical Engineering

Continuous Assessment Test – I

Course Code	14MEPR0	Course Name	Assembly Engineering		
Degree	B.E.	Programme	Mechanical Engineering	Semester	VII
Date	10.08.2017	Duration	90 minutes	Max. Marks	50
Faculty-in-Charge		Dr. S.Saravana Perumaal			

Assessment Pattern

Remember	Understand	Apply	Analyze	Evaluate	Create	Total
10	10	30	-	-	-	50

Answer All Questions

Part A (Remember) 5 x 2 = 10

A1. Define assembly.

A2. Define bonus tolerance.

A3. State the advantages of selective assembly.

A4. Mention the significance of diagram.

A5. Define key characteristics.

Part B (Understand) 2 x 5 = 10

B1. Differentiate the geometrical and dimensional tolerances with an illustration. (05)

B2. Explain the steps involved in performing assembly sequence analysis. (05)

Part C (Apply) 2 x 15 = 30

C1. Interpret and write the specification of all the feature control frames in the drawing as shown in figure 1.

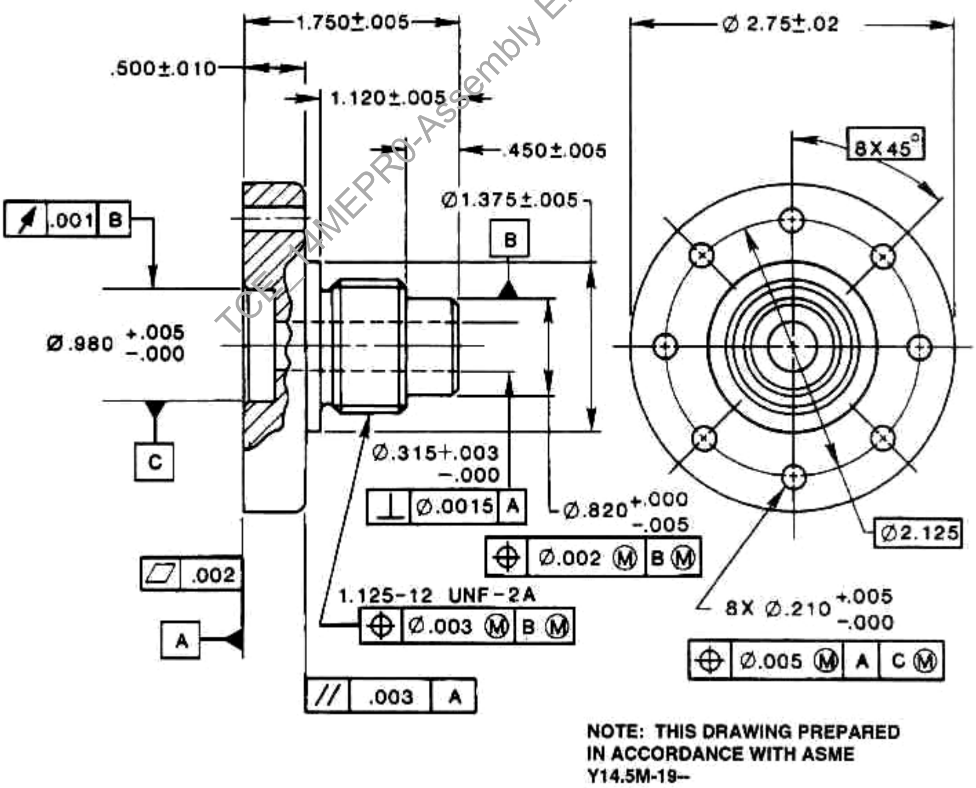


Figure 1 (15)

(OR)

C2. a) Compute the limit dimensions for a clearance fit on the hole basis system for a basic size of 40 mm diameter, with a minimum clearance of 0.05 mm, tolerance on the hole 0.021 mm and tolerance of the shaft 0.15 mm.

(05)

b) Determine the type of fit and calculate the clearance and or interference for the schematic tolerance zones shown in figure 2.

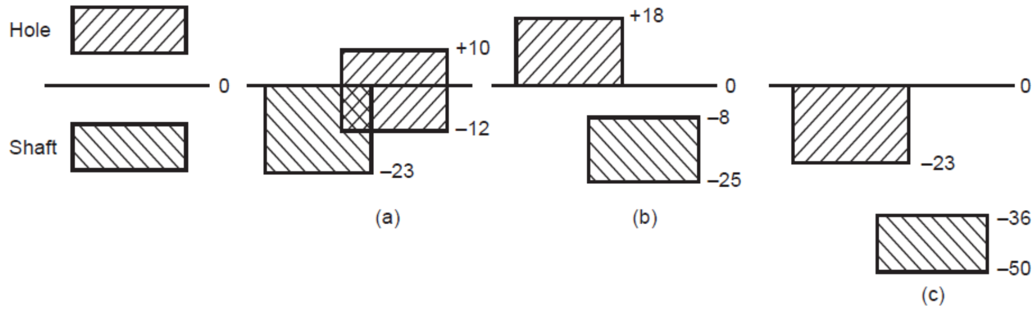
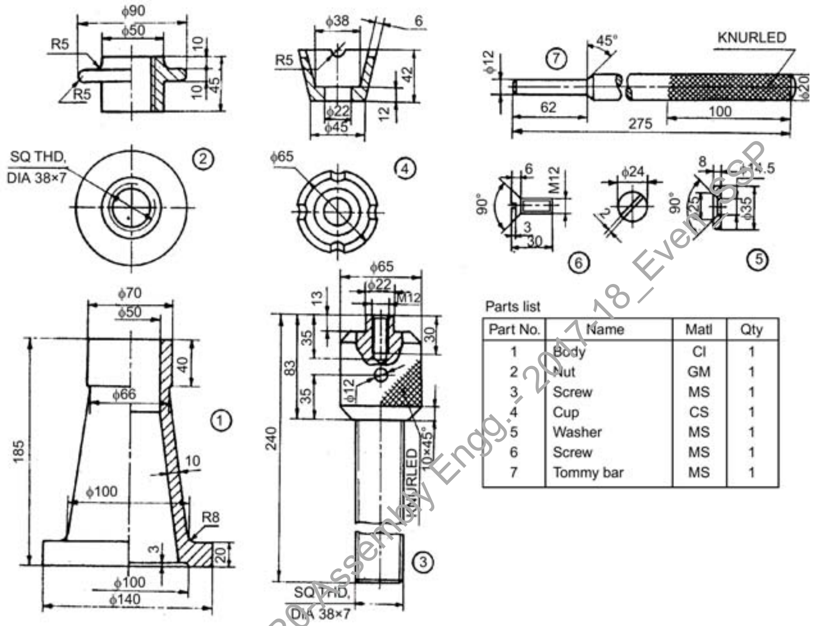


Figure 2 (10)

C3. Draw the liaison diagram of the screw jack assembly as shown in figure 3. Determine the key characteristics of the assembly and specify the mates and contacts involved in its assembly.



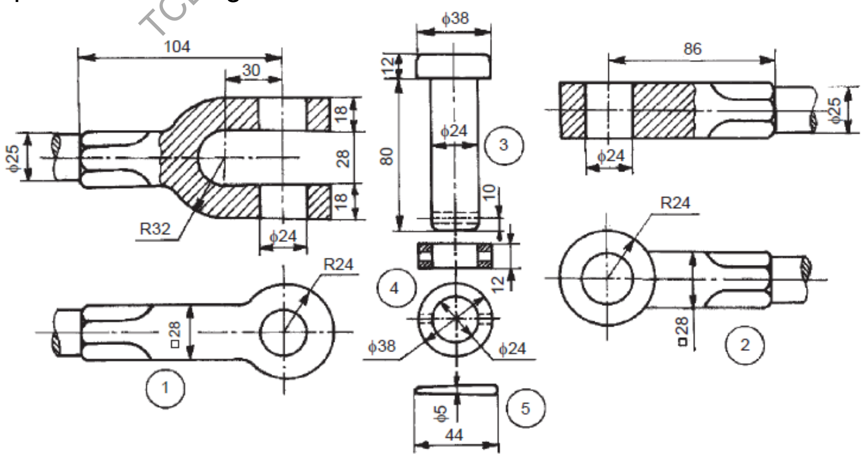
Parts list

Part No.	Name	Matl	Qty
1	Body	CI	1
2	Nut	GM	1
3	Screw	MS	1
4	Cup	CS	1
5	Washer	MS	1
6	Screw	MS	1
7	Tommy bar	MS	1

Figure 3 Components of Screw Jack (15)

(OR)

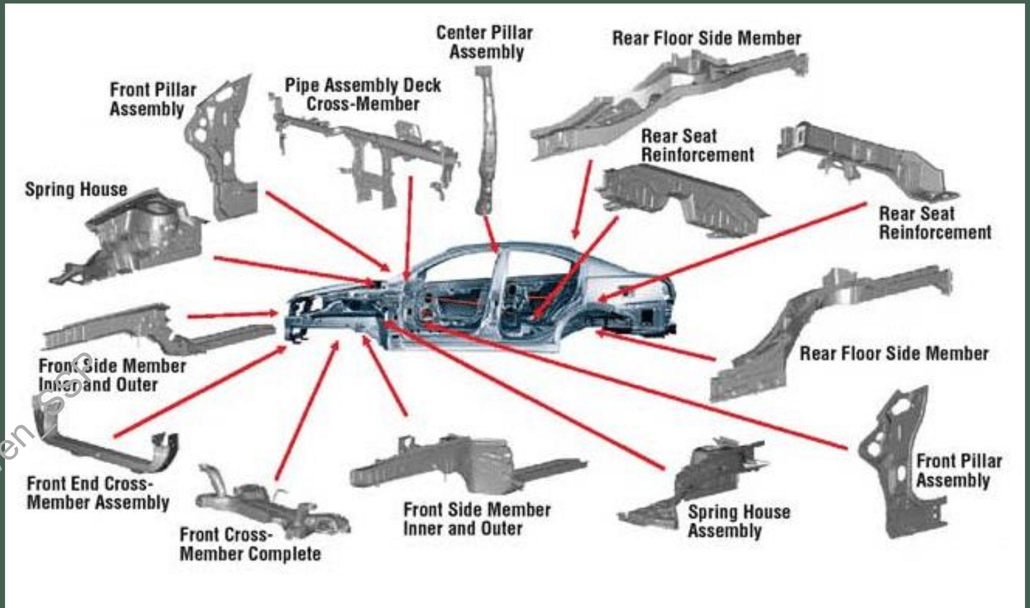
C4. Determine the feasible sequence of the knuckle joint as shown in figure 4 using its appropriate liaison diagram.



Parts list

Sl. No.	Name	Matl.	Qty.
1	Fork end	Forged steel	1
2	Eye end	Forged steel	1
3	Pin	Mild steel	1
4	Collar	Mild steel	1
5	Taper pin	Mild steel	1

Figure 4 Components of Knuckle Joint (15)



Module 3 – Assembly System Design

Dr. S.Saravana Perumaal
Assistant Professor
Department of Mechanical Engineering
Thiagarajar College of Engineering
Madurai – 625015
sspmech@tce.edu
Mobile: 99444 61010

Module Outcome

On the successful completion of the course, students will be able to

- CO3: Determine the time and number of workers required for the given assembly requirement (Apply)

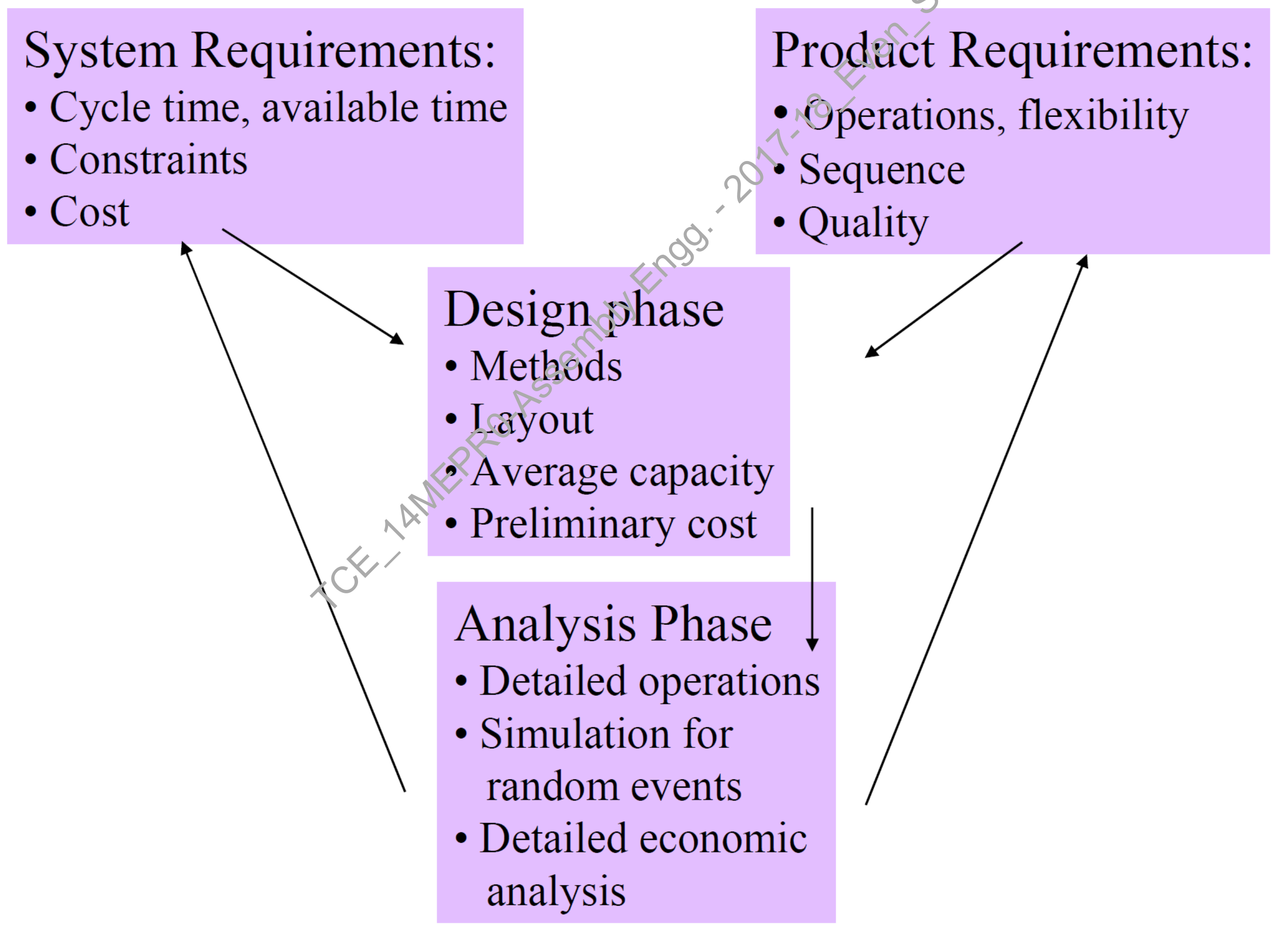
Assembly

- Putting the parts together to perform a function
- Assemblies are product of a complex design process.
- This process involves defining the functions that the item must perform and then defining physical objects (parts and sub-assemblies) that will work together to deliver those functions.

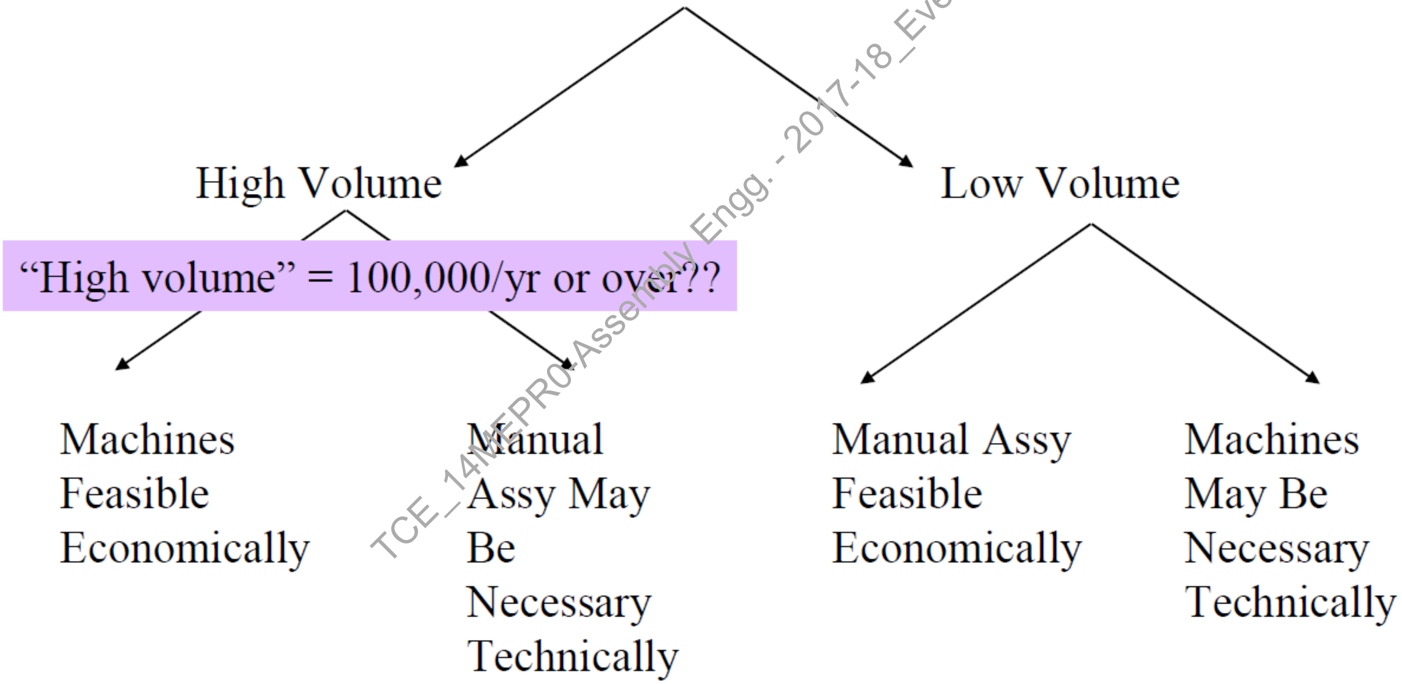
Basic Factors in System Design

- Capacity planning -required number of units/year
- Resource choice -assembly methods
- Task assignment
- Floor layout
- Workstation design
- Material handling and work transport
- Part feeding and presentation
- Quality
- Economic analysis
- Personnel training and participation

Basic Decision Process



Basic Trade-offs



Note: Machines are good when variety is low; People are needed when variety is high. Variety tends to increase as the process runs from part fabrication to subassembly to final assembly.

Manual Assembly

The process of manual assembly can be divided into two separate areas:

- Handling (acquiring, orienting and moving the parts) and
- Insertion and Fastening (mating a part to another part or group of parts).

Characteristics of Manual Assembly

- Technical
  - dexterous, able to learn and improve, flexible
  - can overlap operations -move+flip+inspect
  - may be too innovative, or may be unable to repeat exactly the operation or the cycle time
- Economic
  - top speed dictates need for more people to get more output (called variable cost)

Characteristics of Fixed Automation

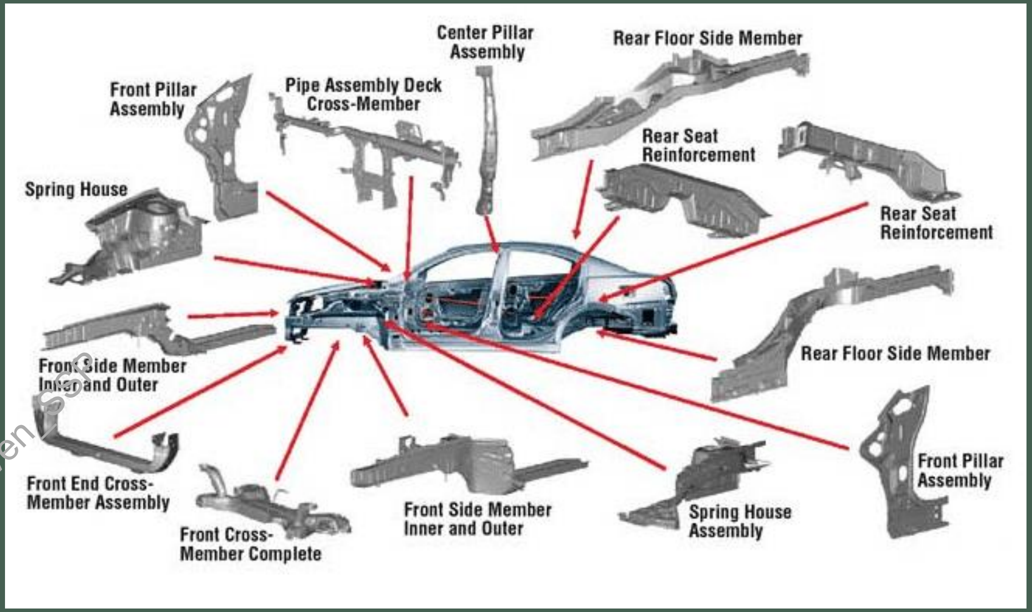
- Technical
  - simple operations with few DoF and simple alternatives
  - each station is dedicated to one operation (place/fasten/confirm) built from standard modules strung together
  - small parts, relatively high speed
  - basic architectures include in-line and rotary
- Economic
  - the investment is in fixed increments regardless of required capacity (fixed cost)
  - the payoff is in keeping uptime high (many stories)

Characteristics of Flexible Automation

- Technical
  - multiple motion axes
  - motion (gross and fine) modulated by sensing and decisions
  - multiple tasks with or without tool change
- Economic
  - multiple tasks (within a cycle or next year)
  - investment scalable to demand (variable cost)
  - tools and parts presentation costly (fixed cost)

Summary

- Assemblies are product of a complex design process
- Involves defining functions that the item must perform and then defining physical objects (parts and subassemblies) that work together to deliver those functions.
- The structure of the item must be defined including all the interrelationships between the parts
- Each of the parts must be defined and given materials, dimensions, tolerances, surface finishes and so on.
- Systematic approach is required to understand the assemblies



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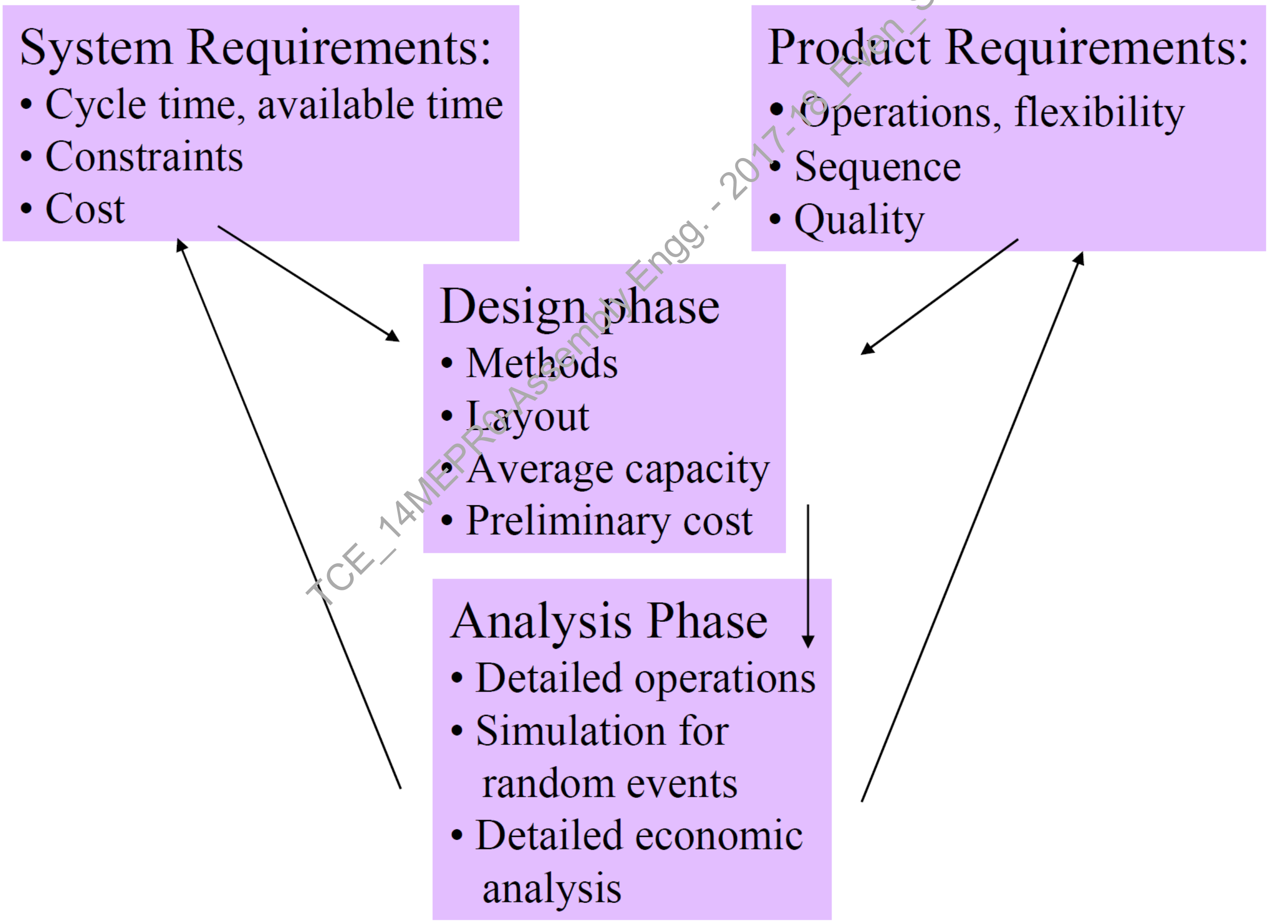

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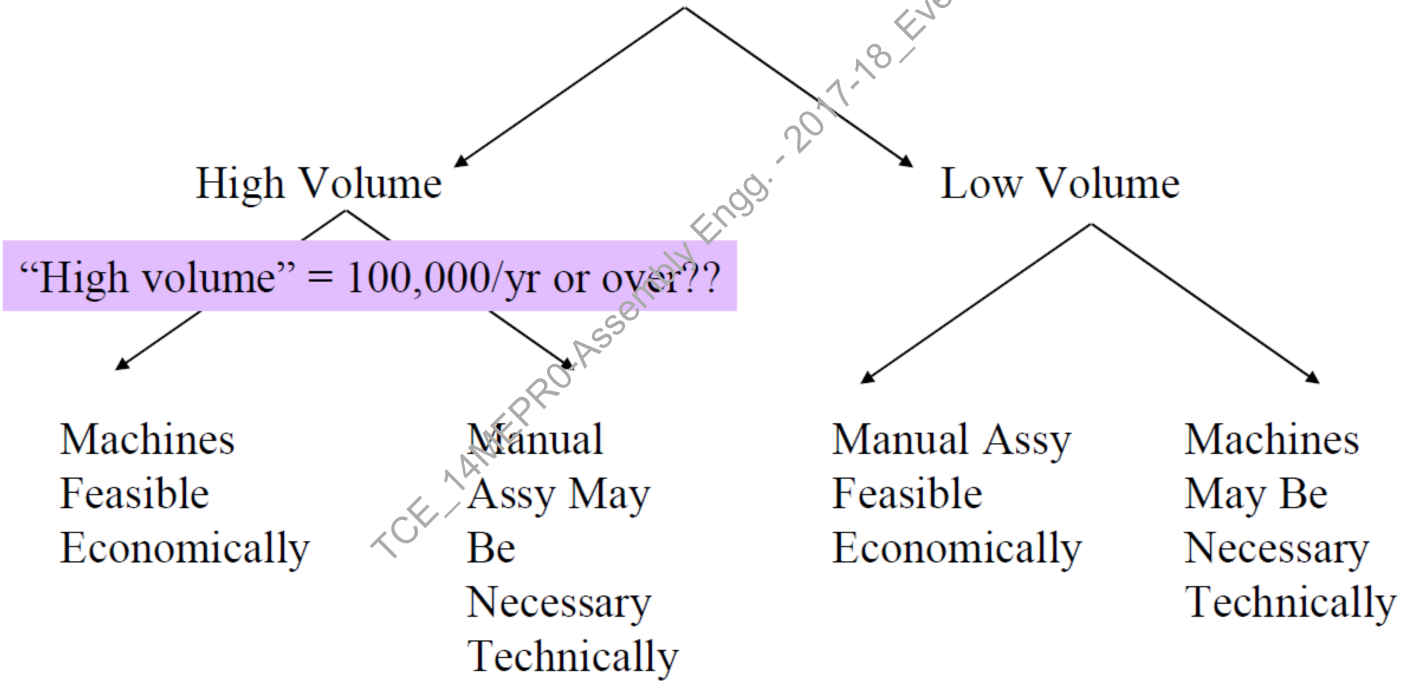

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Takt Time:

The rate at which customers demand a product

Pace of manufacturing the products to meet customer demand

Takt time calculation:

$$\textbf{TAKT TIME} = \frac{\textbf{Available time for Production}}{\textbf{Customer Demand}}$$

Example

Consider the following data

Customer demand	: 2000 / day
No of Shifts working	: 2
Working time	: 8.5 hrs/ shift
Lunch Break	: 30 min/ shift
Tea time	: 2 times/shift @7min/tea break

What is our Takt time ?

Solution to Exercise

Available time = Total time – Lunch time – Tea time

Total time	= 8.5 hrs / shift X 2 shifts	= 17 hr (1020 min)
Lunch time	= 0.5 hrs / shift X 2 shifts	= 01 hr (60min)
Tea time	= 7 X 2 min / shift X 2 shift	= 28min

Available time = 1020 – 60 – 28 = 932 min

Customer demand = 2000

Takt time = Available time / Customer demand
= 932 / 2000 (min)
= 0.466 min
= 28 secs

Analysis of Single Model Lines

- Aim is to convert production rate, R_p, to cycle time, T_c.
- One should take into account that some production time will be lost due to
  - equipment failures
  - power outages,
  - material unavailability,
  - quality problems,
  - labor problems.
- **Line efficiency** (uptime proportion): only a certain proportion of the shift time will be available.

$$T_c = \frac{60E}{R_p}$$

Cycle time

$$R_c = \frac{60}{T_c}$$

Ideal cycle time

where production rate, R_p, is converted to a cycle time, T_c, accounting for line efficiency, *E.*

R_c = Ideal cycle rate for the line (cycle/hr)

Analysis of Single Model Lines

$R_c < R_p$ [Ideal cycle rate must be less than required production rate]

Line efficiency, $$E_c = \frac{R_p}{R_c} = \frac{T_c}{T_p}$$

T_p = average production cycle time

$= T_p = 60/ R_p$

No of worker, $$w = \frac{WL}{AT}$$

WL = workload in a given time period

AT = available time in the period

Workload to be accomplished $$WL = R_p T_{wc}$$

R_p = *production rate*

T_{wc} = *work content time*

Available time $$AT = 60E$$

**60 minute*

Work content time (T_{wc}): The total time of all work elements that must be performed to produce one unit of the work unit.

Analysis of Single Model Lines

- The theoretical minimum number of stations that will be required to on the line to produce one unit of the work unit, w^*:

$$w^* = \text{Minimum Integer} \geq \frac{T_{wc}}{T_c}$$

where
T_{wc} = work content time, min;
T_c = cycle time, min/station

If we assume one worker per station then this gives the minimum number of workers

Line Balancing Problem

Given:

- The total work content consists of many distinct work elements
- The sequence in which the elements can be performed is restricted
- The line must operate at a specified cycle time (=service time + repositioning time)

The Problem:

- To assign the individual work elements to workstations so that all workers have an equal amount of work to perform

Assumptions About Work Element Times

1. Element times are constant values
   - But in fact they are variable

2. Work element times are additive
   - The time to perform two/more work elements in sequence is the sum of the individual element times
   - Additivity assumption can be violated (due to motion economies)

Work Element Times

- Total work content time T_{wc}

$$T_{wc} = \sum_{k=1}^{n_e} T_{ek}$$

where T_{ek} = work element time for element k

- Work elements are assigned to station i that add up to the service time for that station

$$T_{si} = \sum_{k \in i} T_{ek}$$

- The station service times must add up to the total work content time

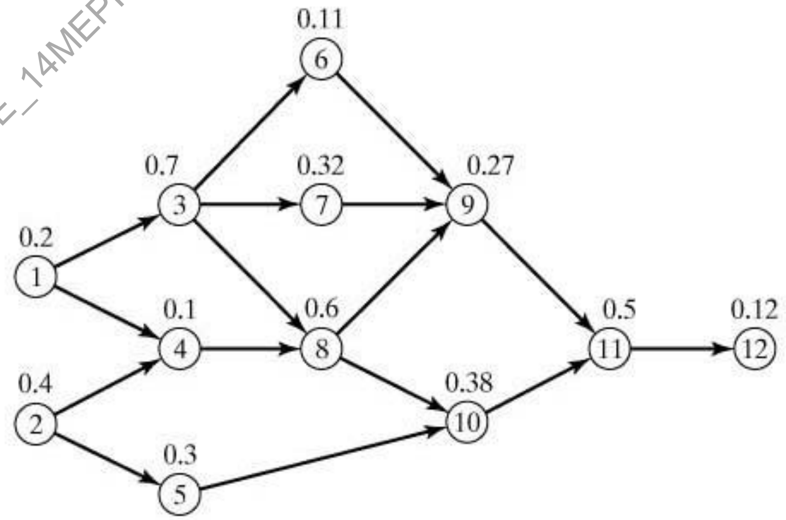
$$T_{wc} = \sum_{i=1}^{n} T_{si}$$

Constraints of Line Balancing Problem

- Different work elements require different times.
- When elements are grouped into logical tasks and assigned to workers, the station service times, T_{si}, are likely not to be equal.
- Simply because of the variation among work element times, some workers will be assigned more work.
- Thus, variations among work elements make it difficult to obtain equal service times for all stations.

Precedence Constraints

- Some elements must be done before the others.
- Restrictions on the order in which work elements can be performed
- Can be represented graphically (precedence diagram)



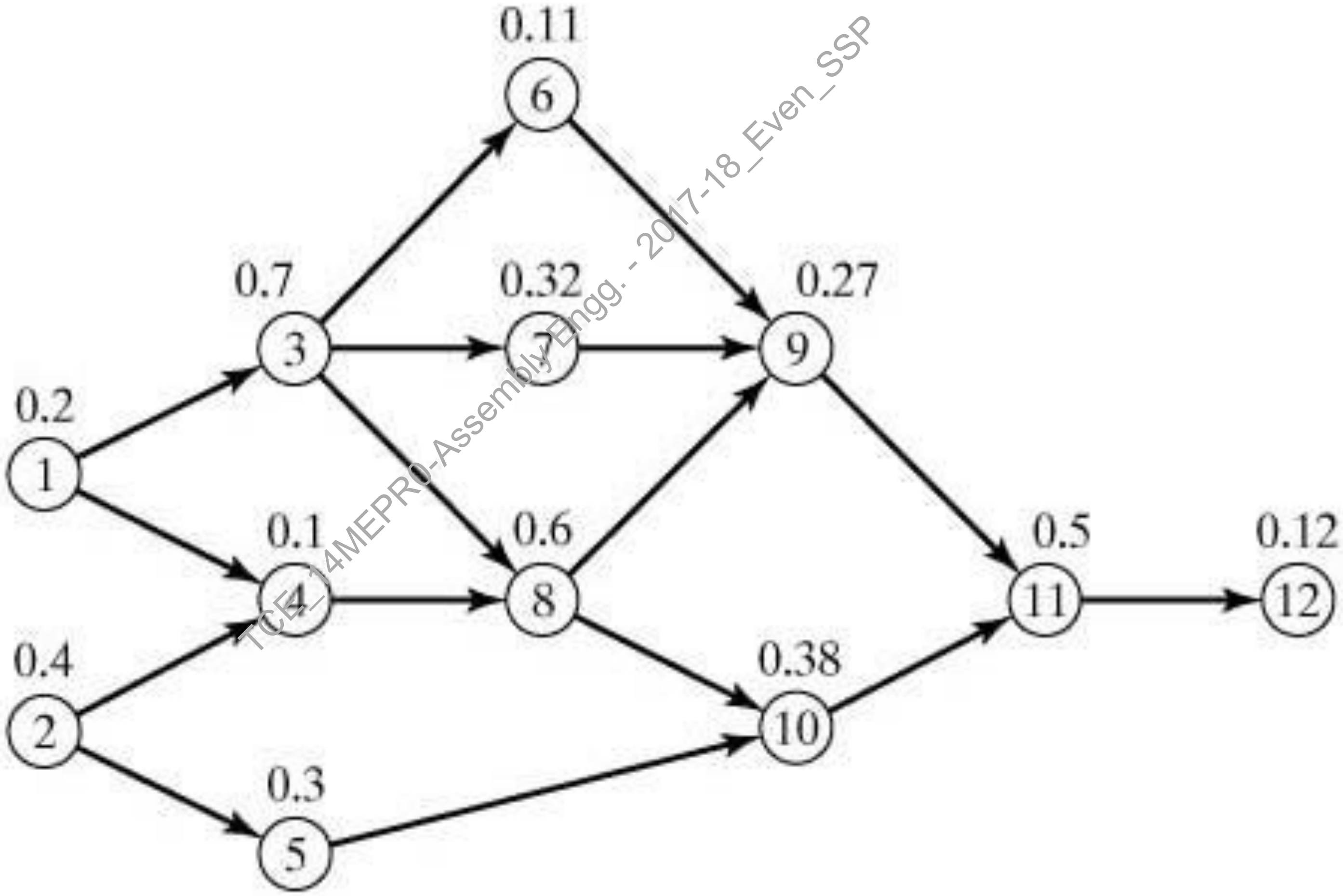
Example:

TABLE 4.3 Work Elements for Example 4.1

No.	Work Element Description	T_{ek} (min)	Must Be Preceded by
1	Place frame in workholder and clamp	0.2	—
2	Assemble plug, grommet to power cord	0.4	—
3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1,2
5	Wire power cord to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to brackets	0.6	3,4
9	Align blade and attach to motor	0.27	6,7,8
0	Assemble switch to motor bracket	0.38	5,8
1	Attach cover, inspect, and test	0.5	9,10
2	Place in tote pan for packing	0.12	11

Grommet : sealant like ring

Example:



Example: A problem for line balancing

- **Given:** The previous precedence diagram and the standard times. Annual demand=100,000 units/year. The line will operate 50 wk/yr, 5 shifts/wk, 7.5 hr/shift. Uptime efficiency=96%. Repositioning time lost=0.08 min.

- **Determine**

  (a) total work content time,

  (b) required hourly production rate to achieve the annual demand,

  (c) cycle time,

  (d) theoretical minimum number of workers required on the line,

  (e) service time to which the line must be balanced.

Example: Solution

(a) The total work content time is the sum of the work element times given in the table

T_{wc}=4.0 min

$$T_{wc} = \sum_{k=1}^{n_e} T_{ek}$$

(b) The hourly production rate

$$R_p = \frac{100{,}000}{50(5)(7.5)} = 53.33 \text{ units/hr}$$

$$R_p = \frac{D_a}{50 S_w H_{sh}}$$

(c) The corresponding cycle time with an uptime efficiency of 96%

$$T_c = \frac{60(0.96)}{53.33} = 1.08 \text{ min}$$

$$T_c = \frac{60E}{R_p}$$

(d) The minimum number of workers:

w^* = (Minimum Integer ≥ 4.0 /1.08=3.7)=4 workers

$$w^* = \frac{T_{wc}}{T_c}$$

(e) The available service time

T_s=1.08-0.08=1.00 min

$$T_s = T_c - T_r$$

Measures of Balance Efficiency

- It is almost imposible to obtain a perfect line balance
- **Line balance efficiency**, E_b:

$$E_b = \frac{T_{wc}}{wT_s}$$

Perfect line: $E_b = 1$

- **Balance delay**, d:

$$d = \frac{wT_s - T_{wc}}{wT_s}$$

Perfect line: $d = 0$

- Note that $E_b + d = 1$ (they are complement of each other)

Overall Efficiency

- Factors that reduce the productivity of a manual line

  - **Line efficiency** (Availability), *E*,
  - **Repositioning efficiency** (repositioning), E_r,
  - **Balance efficiency** (balancing), E_b,

$$T_c = \frac{60E}{R_p} \qquad E_b = \frac{T_{wc}}{wT_s} \qquad E_r = \frac{T_s}{T_c} = \frac{T_c - T_r}{T_c}$$

- **Overall Labor efficiency** on the assembly line = $E \cdot E_r \cdot E_b$

Cycle time:

- Inherent time to complete a piece in each process step
- Maximum time spent at any one workstation
- How often a product is completed

Elements in the cycle time

Auto Cycle Time: The time required by the machine to finish the operation independently without manual interventions

Online Routine: The time required for all manual activities which are repeated in every cycle. Also, the machine needs to be stopped to carry out these activities
E.g- Loading and unloading of workpiece in machines

Elements in the cycle time

Online Occasional: The time required for manual activities that are not repeated in every cycle. Also, the machine needs to be stopped to carry out these activities.

E.g- Tool change time. The tool change time is apportioned for every workpiece. If the Tool change time is 5min (300 sec) at a frequency of once in 300 nos. Then the Tool change time / piece is 1 sec (300 sec/ 300 nos)

Offline Occasional: The time required for manual activities that are not repeated in every cycle. Also, the machine need NOT be stopped to carry out these activities.

E.g- Inspection time. The Inspection time is apportioned for every workpiece. If the Inspection time is 3 min (180 sec) at a frequency of once in 60 nos. Then the Tool change time / piece is 3 sec (180 sec/ 60 nos)

Walking time : The time required to walk from one operation to the next operation is called the walking time

Takt time and Cycle time relationship (to meet customer demand)

1. Any Cycle time in the system = < Takt time
2. Any Operator Cycle Time = < Takt time

Calculation of Number of operators/ stages (to meet customer demand)

$$\text{Estimated number of operators} = \frac{\text{Total manual activity time in the system}}{\text{Takt time}}$$

Note: Final Number of operators should be decided based on cell / line layout design

Takt time calculation:

$$\text{TAKT TIME} = \frac{\text{Available time for Production}}{\text{Customer Demand}}$$

Calculation of Number of operators/ stages (to meet customer demand)

Example: Pre line assembly

- Total manual activity time = 12 min per vehicle
- Takt time = 0.466 min

$$\text{Estimated number of operators} = \frac{12}{0.466}$$

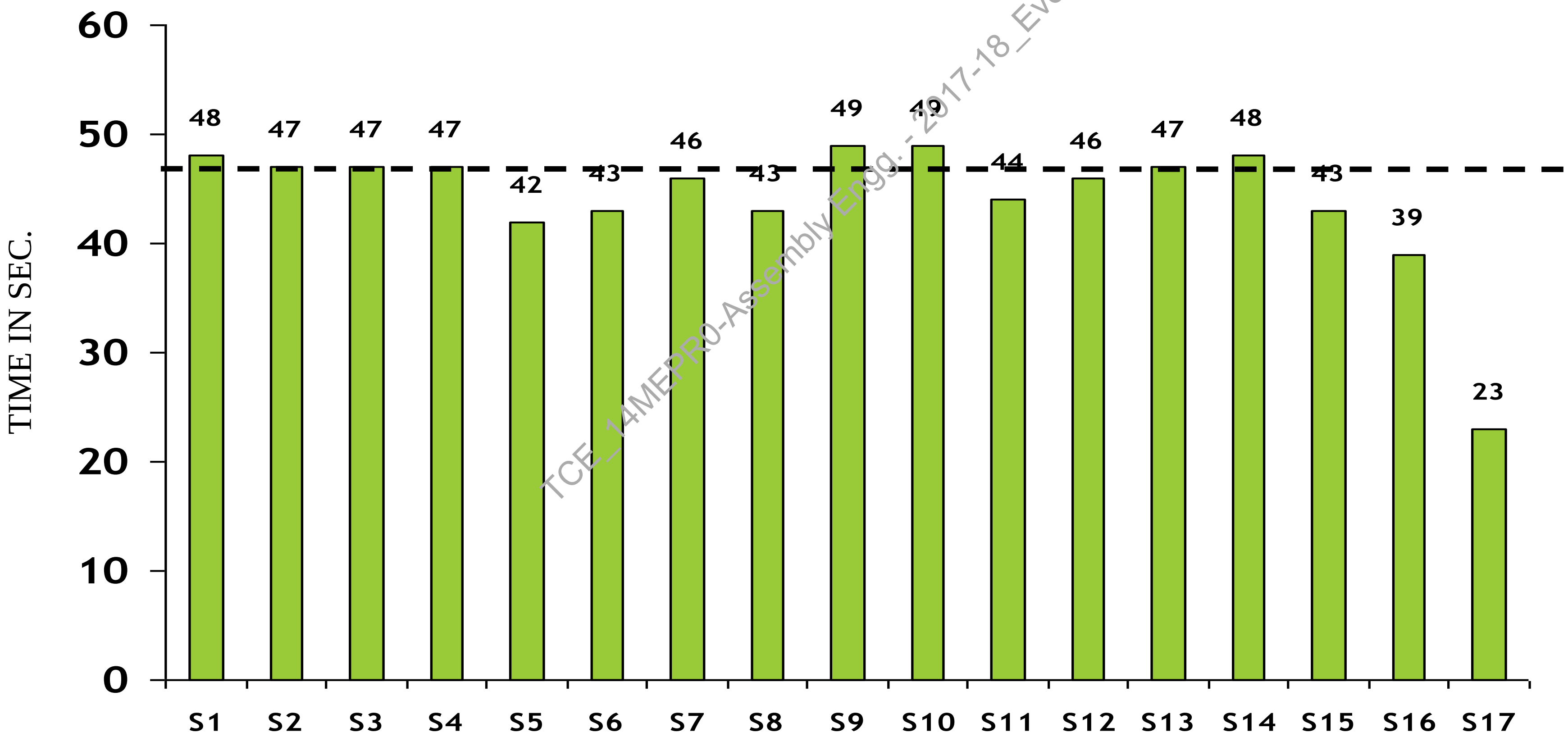
$$= 25.75$$

$$= 26 \text{ operators}$$

LINE BALANCING

Assembly line balancing is a technique to group tasks among workstations so that each work-station has, ideally, the same amount of work.

ENGINE ASSY – MAIN LINE - - VOLUME = 600 / SHIFT - - TAKT TIME = 46.6 SEC



Inputs for Assembly line balancing

1. A set of tasks to be performed and the time required to perform each task
2. The precedence relations among the tasks- that is, the sequence in which tasks must be performed, and
3. The desired output rate or forecast of demand for the assembly line.

The first two requirements can be obtained from the product design documents

The third one is specified by the management.

BALANCING EFFICIENCY

$$\text{Balancing Efficiency}(\%) = \frac{\text{TOTAL CYCLE TIME}}{\text{CYCLE TIME x NO. OF STAGES}} \text{ X100}$$

Balance delay =1- Efficiency

Example

Cycle Time = 48 Secs

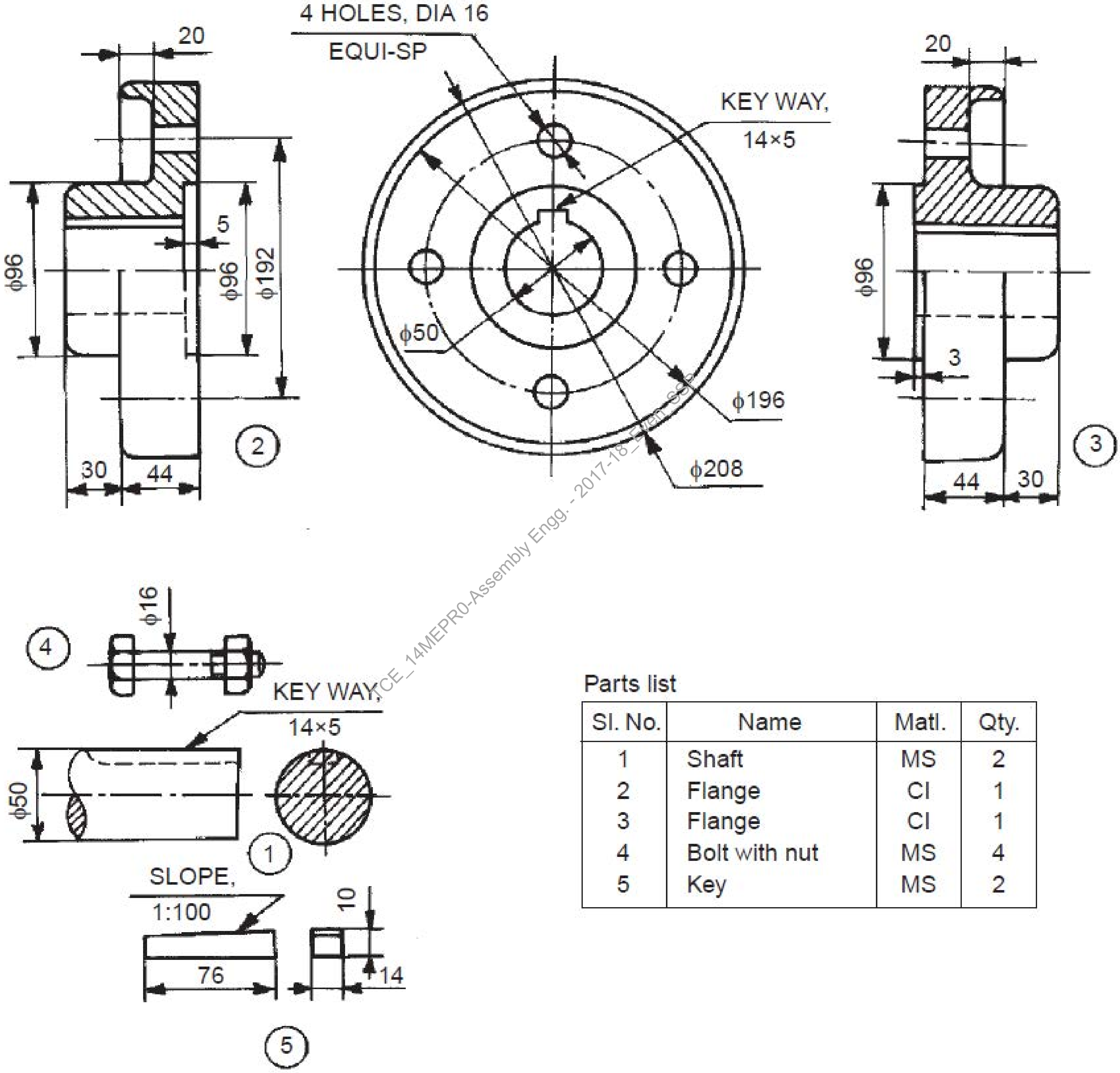
Total Cycle Time = 12.52 mins. = 751 sec.

Number of stages = 17

$$\text{Balancing Efficiency} = \frac{751}{48 \times 17} \text{ X 100}$$

$$= 92\ \%$$

Balance delay / Imbalance = 8 %



Parts list

Sl. No.	Name	Matl.	Qty.
1	Shaft	MS	2
2	Flange	CI	1
3	Flange	CI	1
4	Bolt with nut	MS	4
5	Key	MS	2

Economics of Assembly Systems

Symbol		Description
n	:	Number of automatic workheads
t	:	Machine cycle time (sec)
x	:	A ratio of defective parts to acceptable parts
m	:	A proportion of the defective parts will cause machine stoppages
T	:	Average time for an operator to locate the failure, remove the defective part, and restart the machine
N	:	Number of Assemblies to be produced
d	:	Downtime
D	:	Proportion of Downtime
t_{pr}	:	The average production time of acceptable assemblies
M_t	:	Total cost of operating the machine per unit time
M	:	Cost of operating the machine per unit time
B	:	A measure of the cost due to quality level
C_t	:	Total cost of each acceptable assembly
A_i	:	Basic cost of the parts
P_u	:	The number of unacceptable assemblies produced per unit time
x_{opt}	:	Optimum value of quality level of the minimum cost of assembly
b	:	Buffer Storage capacity
K	:	A factor that depends on the values of *T/t* and *b*
N_{tech}	:	Minimum number of technicians required to correct faults
$n_{s\max}$	:	Maximum number of stations that one technician can attend
n_s	:	Economical number of stations per technician
Q_e	:	Economical cost of the equipment for one-shift working
S_n	:	Number of shifts
W_a	:	Rate for one assembly worker
W_t	:	Total rate for the machine personnel
C_e	:	Total capital cost for all equipment, including engineering setup and debugging cost
t_a	:	Average manual assembly time per part
C_d	:	Dimensionless assembly cost per part
W_r	:	Ratio of the cost of all personnel compared with the cost of one manual assembly worker, expressed per part in the assembly
t_q	:	Required average production time
V_s	:	Required annual production volume per shift
P_e	:	Plant efficiency
C_T	:	cost of transfer device per workstation for an indexing machine stoppages
C_B	:	cost of transfer device per space (workstation or buffer space) for a free-transfer machine
C_C	:	cost of work carrier
C_F	:	cost of automatic feeding device and delivery track
C_W	:	Cost of workhead
W_{tech}	:	Rate for one technician engaged in correcting faults on the machine
Q_e	:	Equivalent cost of one assembly worker in terms of capital investment

Indexing machines:

Effect of parts quality on downtime

The proportion of downtime	$D = \dfrac{downtime}{assemblytime + downtime}$
	$D = \dfrac{mxnNT}{Nt + mxnNT}$

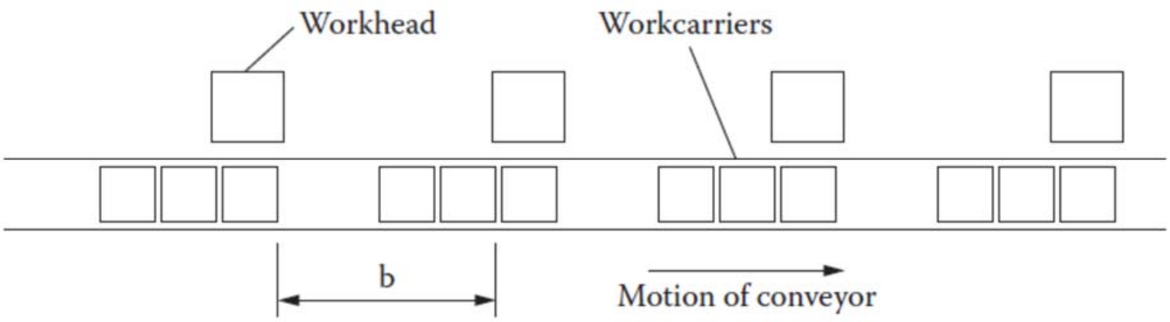
Effect of parts quality on production time

The average production time	$t_{pr} = \dfrac{Machinetime + downtime}{acceptable \quad assemblies}$
	$t_{pr} = \dfrac{Nt + mxnNT}{N - (1-m)xnNT} = \dfrac{t + mxnT}{1-(1-m)xnT}$
When m=1	$t_{pr} = t + xnT$

Effect of parts quality on cost of assembly

Total cost of each acceptable assembly	$C_t = \dfrac{M(t + mxnT) + (1-m)xnt_c W_a}{1-(1-m)xn} + \sum_{i=1}^{n} A_i + \dfrac{nB}{x}$			
When m=1	$C_t = Mt$	$+ \quad MxnT$	$+ \quad \dfrac{nB}{x}$	$+ \quad \sum_{i=1}^{n} A_i$
	Cost of Assembly operations	Cost of down time	Cost of part quality	Basic cost of parts
Optimum quality level of the parts for minimum cost of assembly	$x_{opt} = \left(\dfrac{B}{MT}\right)^{1/2}$			
Minimum Cost of assembly	$C_t(\min) = Mt + 2n(MBT)^{1/2} + \sum_{i=1}^{n} A_i$			

Free-transfer machines:



Performance

Downtime	$\frac{d}{Nx} = T + [2T - bt] + [2T - 2bt] + [2T - 3bt] + \ldots$
The proportion of downtime	$D = \frac{downtime}{assemblytime + downtime}$
	$D = \frac{d}{Nt + d}$

Average production time

The average production time	$t_{pr} = \frac{Machinetime + downtime}{acceptable\ assemblies}$
	$t_{pr} = t + 2xT$

Number of personnel for fault correction

Minimum Number of technicians required to correct the faults	$N_{tech} = \frac{total\ correction\ time}{total\ production\ time}$
	$t_{pr} = t + 2xT$ $N_{tech} = \frac{NxnT}{N(2xT + t)} = \frac{xn}{2x + t/T}$
Maximum number of stations that one technician can tend	$n_{s\max} = \frac{n}{N_{tech}} = 2 + \frac{t}{xT}$

Comparison of Indexing and Free-Transfer Machines

Indexing Machines	**Free-Transfer Machines**
Total Equipment Cost	
$C_e = n(C_T + C_W + C_F + C_C)$	$C_e = n\left[C_W + C_F + (b+1)\square\left(C_B + \frac{C_C}{2}\right)\right]$
Total rate for the personnel (Assumption: 2 Workers to load and unload assemblies)	
$W_t = 2W_a + W_{\text{tech}}$	$W_t = 2W_a + \left(\frac{nW_{\text{tech}}}{2 + (2t/3xT)}\right)$
Dimensionless cost of assembly per part	
$C_d = \frac{(t + xnT)\square\left[2 + \frac{W_{\text{tech}}}{W_a} + \frac{n(C_T + C_W + C_F + C_C)}{S_n Q_e}\right]}{nt_a}$	$C_d = (t + 2xT)$ $\left\{2 + \left(\frac{nW_{\text{tech}}}{2 + (2t/3xT)}\right)\left(\frac{1}{W_a}\right) + n\frac{C_W + C_F + (1 + T/t)\ (C_B + C_C/2)}{S_n Q_e}\right\} / nt_a$

The obtainable annual production volume per shift $V_s = 0.072P_e/t_{\text{pr}}$

THIAGARAJAR COLLEGE OF ENGINEERING, MADURAI – 625015

DEPARTMENT OF MECHANICAL ENGINEERING

14MEPR0 – ASSEMBLY ENGINEERING

Module 4 - Tutorial Problems on Economics of Assembly Systems

1. The details of an assembly system with an indexing machine are given as: Cycle time=5 sec; Time for a worker to locate, repair and restart the machine = 25 sec; Value of the part quality=0.01; Number of work-heads = 20; Number of assemblies produced = 1000; Cost of operating the machine per unit time = Rs. 200; Assume the cost of the parts are equal and is =Rs.10; Measure of cost due to quality level = Rs. 1;
   Rate of one assembly worker = Rs.10/sec;
   Case1: Assume all the defective parts will produce a stoppage of the machine.
   Case 2: Assume no defective part will stop the machine.
   Determine the following for both cases:
   i. Proportion of the downtime
   ii. Average production time
   iii. Total cost of each acceptable assembly
   iv. Optimal part quality
2. If the assembly system is equipped with a free-transfer machine and operated with a Buffer capacity = 6, determine the following:
   i. Proportion of the downtime
   ii. Average production time
   iii. Number of personnel required
   iv. Maximum number of stations per technician
   v. Economical number of stations per technician
3. The cost information for an indexing machine of an assembly line is given below:
   Cost of transfer device per workstation for machine stoppages C_T = Rs. 100000;
   Cost of work carrier C_C = Rs. 10000; Cost of automatic feeding device and delivery track C_F = Rs.70000; Cost of workhead C_W = Rs.100000;
   Rate for one technician engaged in correcting faults on the machine W_{tech} =Rs.120;
   Rate for one assembly worker W_a = Rs.80; Number of working shifts S_n = 2;
   Equivalent cost of one assembly worker in terms of capital investment Q_e = Rs. 900000;
   Machine cycle time, t = 6 sec; Time to troubleshooting T = 30sec;
   Average manual assembly time per part t_a = 8 sec
   Determine the dimensionless cost of assembly per part.
4. If a free-transfer machine has been planned for the above assembly line, cost involved for transfer device per space (workstation or buffer space) is Rs. 50000. Determine the dimensionless cost of assembly per part and observe the change cost involved in it.

Design for Assembly

Dr. S. Saravana Perumaal

Assistant Professor

Department of Mechanical Engineering

Thiagarajar College of Engineering

Madurai – 625015.

sspmech@tce.edu

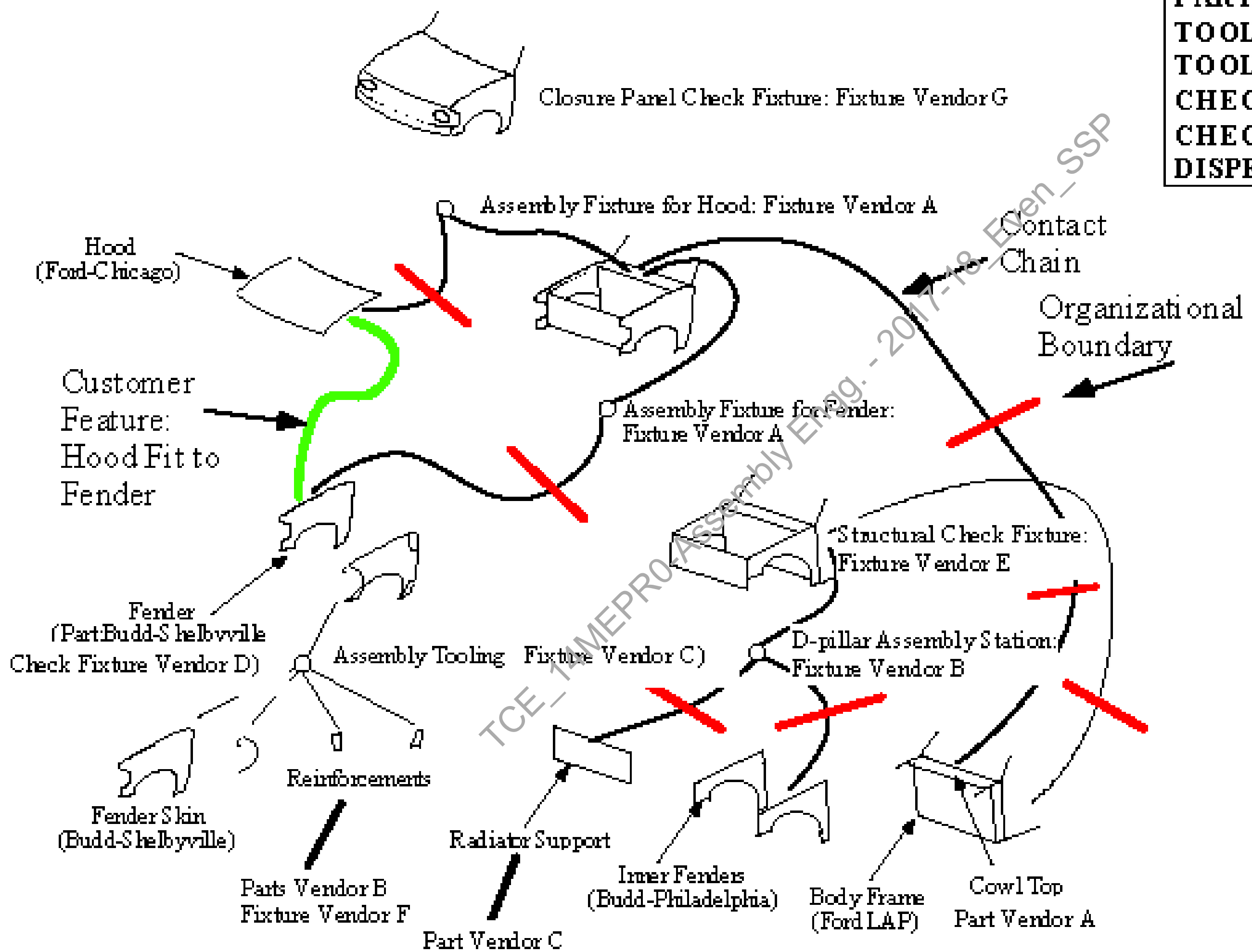
Course Outcome

On the successful completion of the course, students will be able to

- CO5: Implement design modifications on the given component using DFA guidelines (Apply)

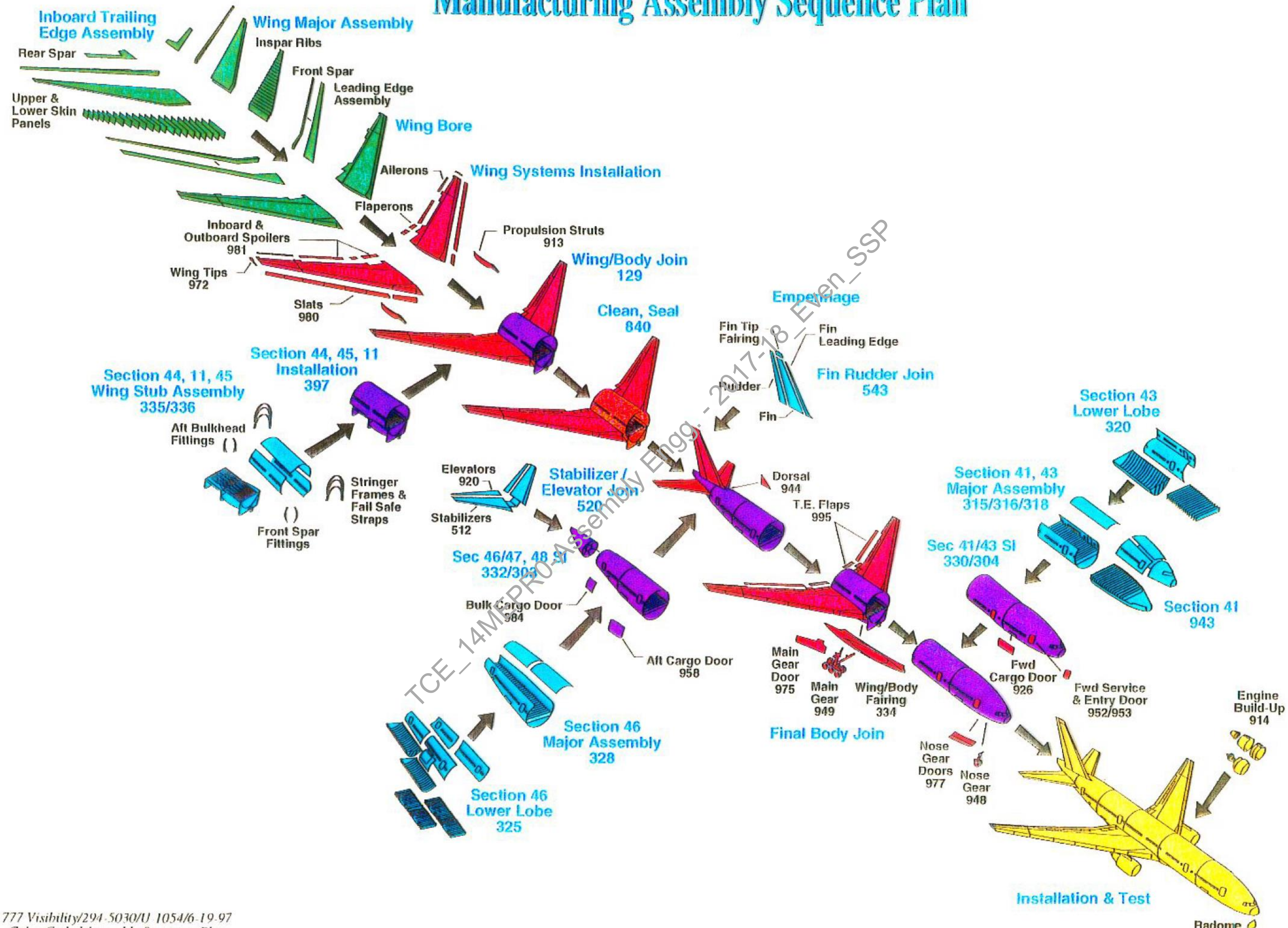
"Chain of Delivery" of Quality

PART COUNT: 9
PART SOURCES: 7
TOOL COUNT: 5
TOOL SOURCES: 4
CHECK FIXTURE COUNT: 2
CHECK FIXTURE SOURCES: 2
DISPERSAL INDEX: 81%



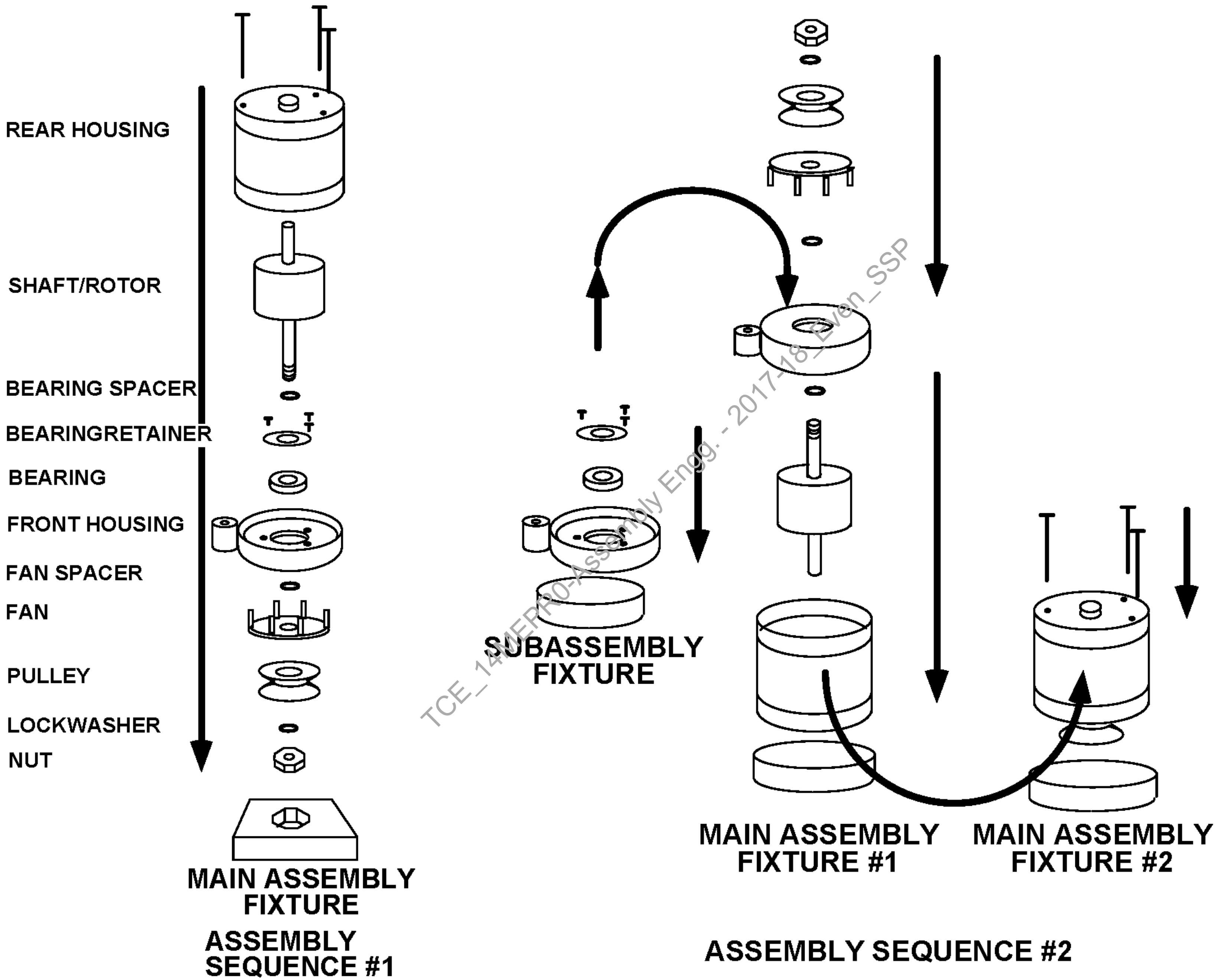
N. Soman, M. Chang

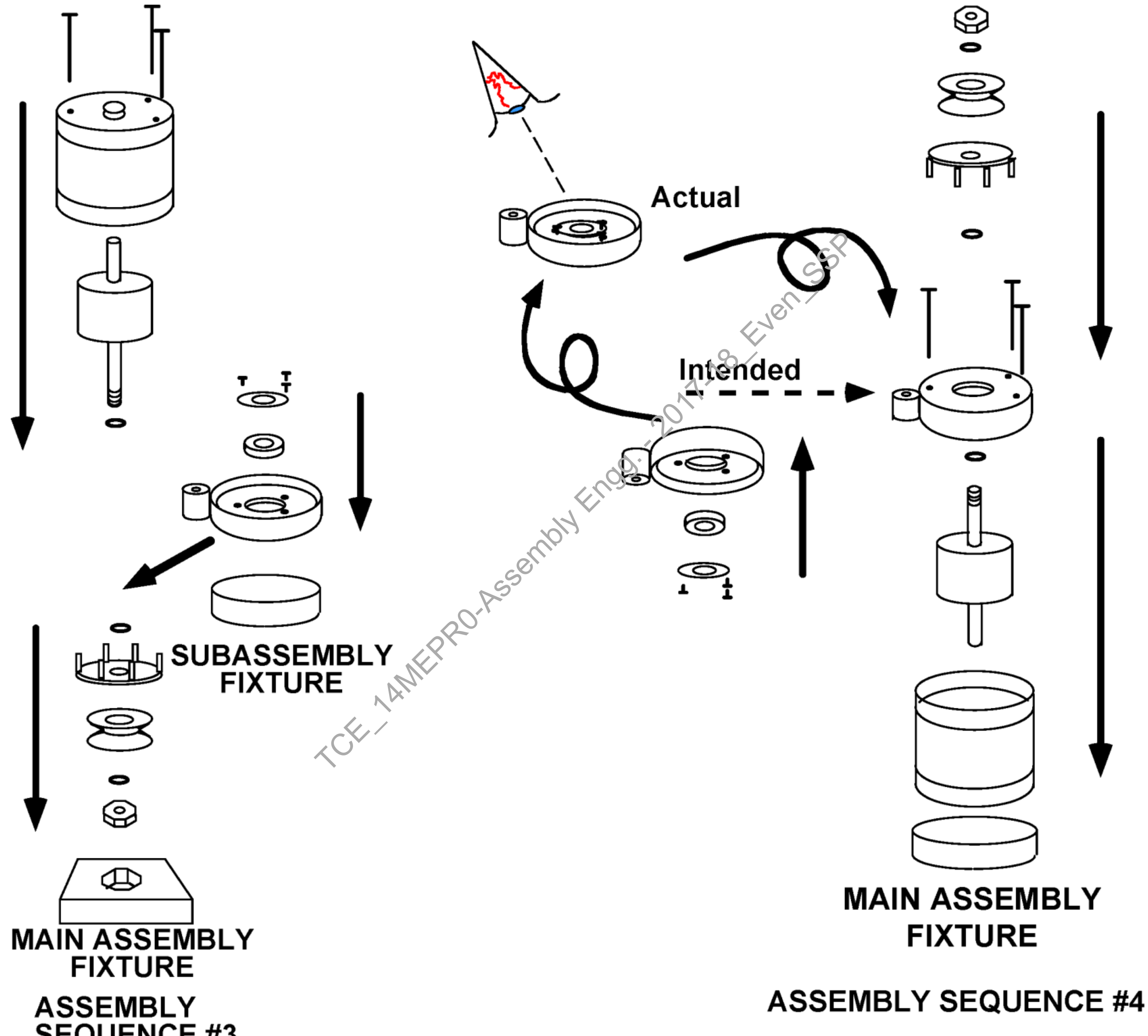
Model 777-200
Manufacturing Assembly Sequence Plan

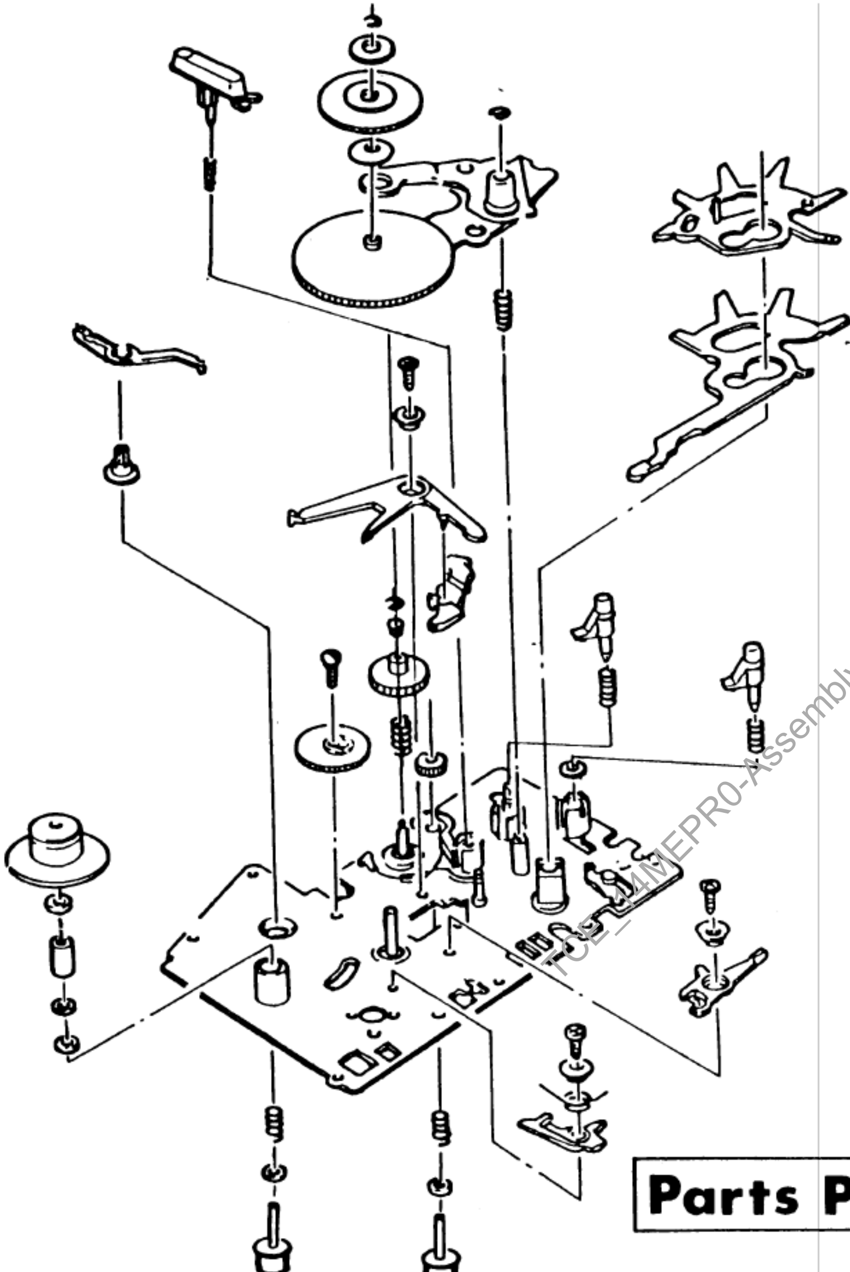


777 Visibility/294-5030/U 1054/6-19-97
Color Coded Assembly Sequence Plan

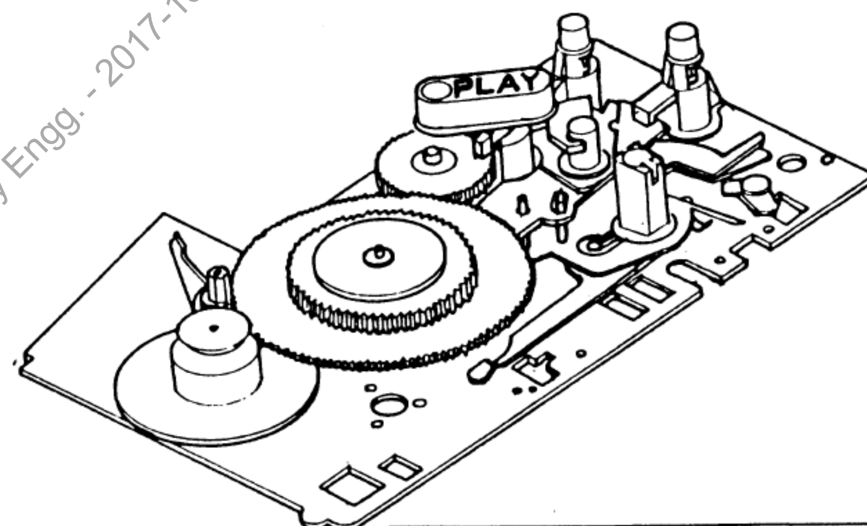
Two Alternator Sequences




Actual
Intended
SUBASSEMBLY FIXTURE
MAIN ASSEMBLY FIXTURE
ASSEMBLY SEQUENCE #3
MAIN ASSEMBLY FIXTURE
ASSEMBLY SEQUENCE #4



Number of Parts 48



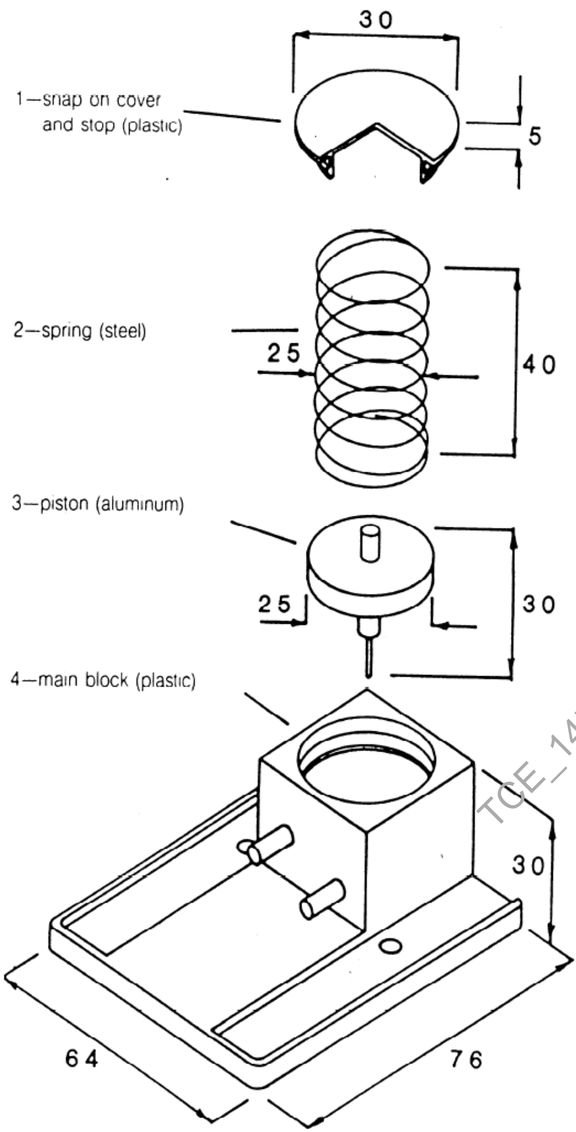
Finished Product

Parts Placement

B&D Pump Redesign

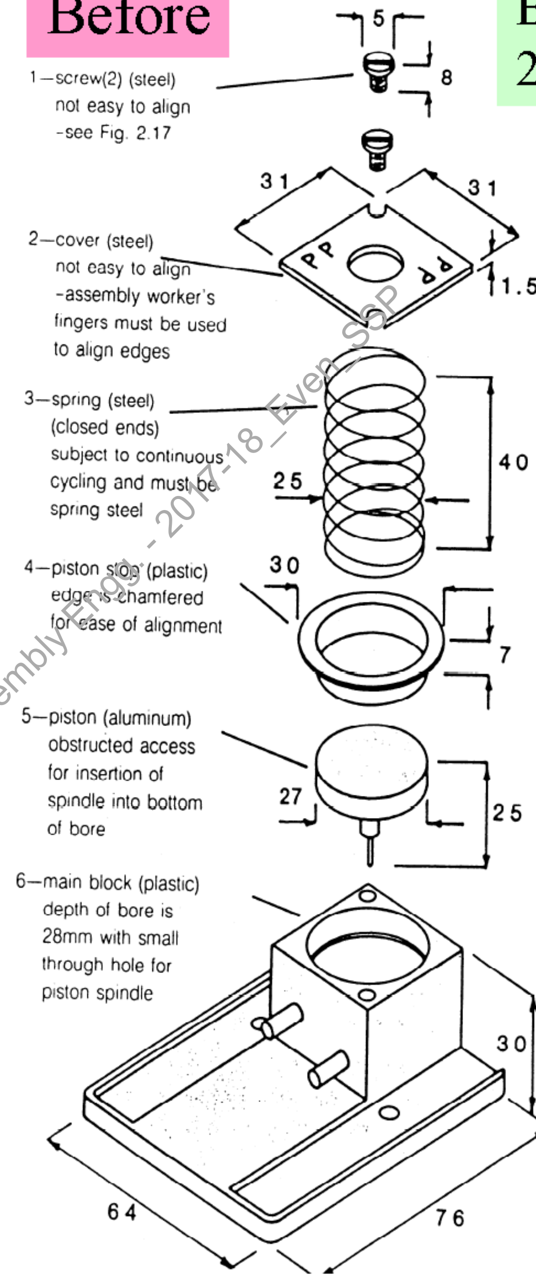
Bore * stroke = 25*17

After

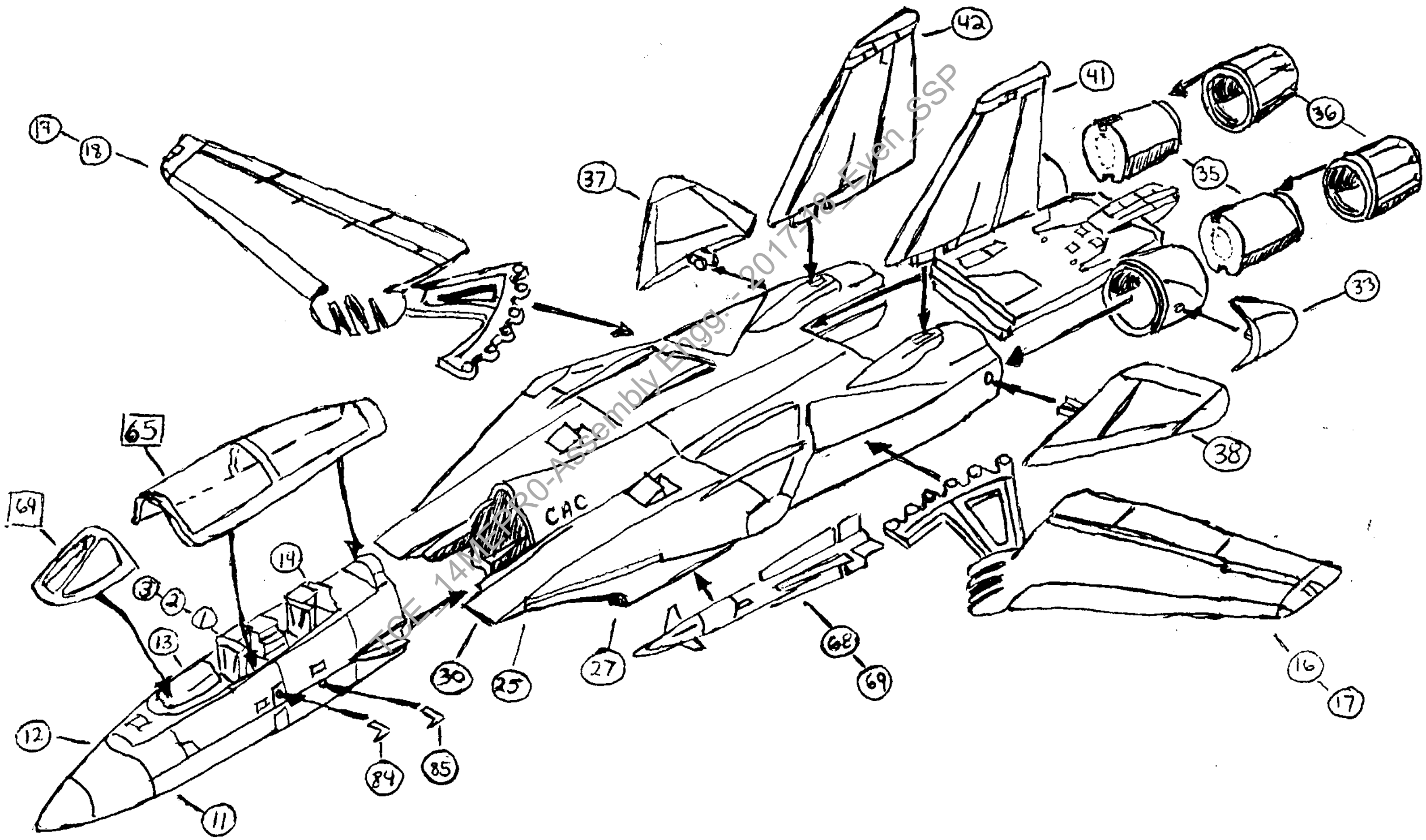


Before

Bore * stroke = 27*20



Product Assembly Drawing



Design for Manual Assembly

- The design team conceptualizes alternative solutions
  - serious consideration to the ease of assembly of the product or subassembly.
  - Need of a DFA tool to effectively analyze the ease of assembly of the products or subassemblies it designs.
  - Ensure consistency and completeness in its evaluation of product assemblability.
  - Eliminate subjective judgment from design assessment,
  - allow free association of ideas
  - enable easy comparison of alternative designs
  - ensure that solutions are evaluated logically, identify assembly problem areas, and
  - suggest alternative approaches for simplifying the product structure
- thereby reducing manufacturing and assembly costs.

DFA – A systematic procedure

- A tool for the designer or design team which assures that considerations of product complexity and assembly take place at the earliest design stage.
  - Eliminates the danger of focusing exclusively during early design on product function with inadequate regard for product cost and competitiveness.
  - Guides the designer or design team to simplify the product so that savings in both assembly costs and piece parts can be realized.
- Gathering information normally possessed by the experienced design engineer and arranging it conveniently for use by less-experienced designers.
- Establishing a database that consists of assembly times and cost factors for various design situations and production conditions.

GENERAL DESIGN GUIDELINES FOR MANUAL ASSEMBLY

The process of manual assembly can be divided into two separate areas:

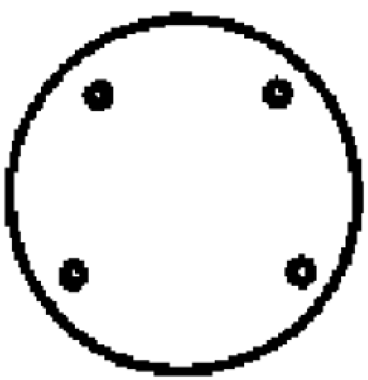
- Handling (acquiring, orienting and moving the parts) and
- Insertion and Fastening (mating a part to another part or group of parts).

Design Guidelines for Part Handling

- Design parts that have end-to-end symmetry and rotational symmetry about the axis of insertion.
- If this cannot be achieved, try to design parts having the maximum possible symmetry

Design Guidelines for Part Handling

- Design parts that, in those instances where the part cannot be made symmetric, are obviously asymmetric



slightly asymmetrical

pronounced asymmetrical

Design Guidelines for Part Handling

- Provide features that will prevent jamming of parts that tend to nest or stack when stored in bulk

will jam

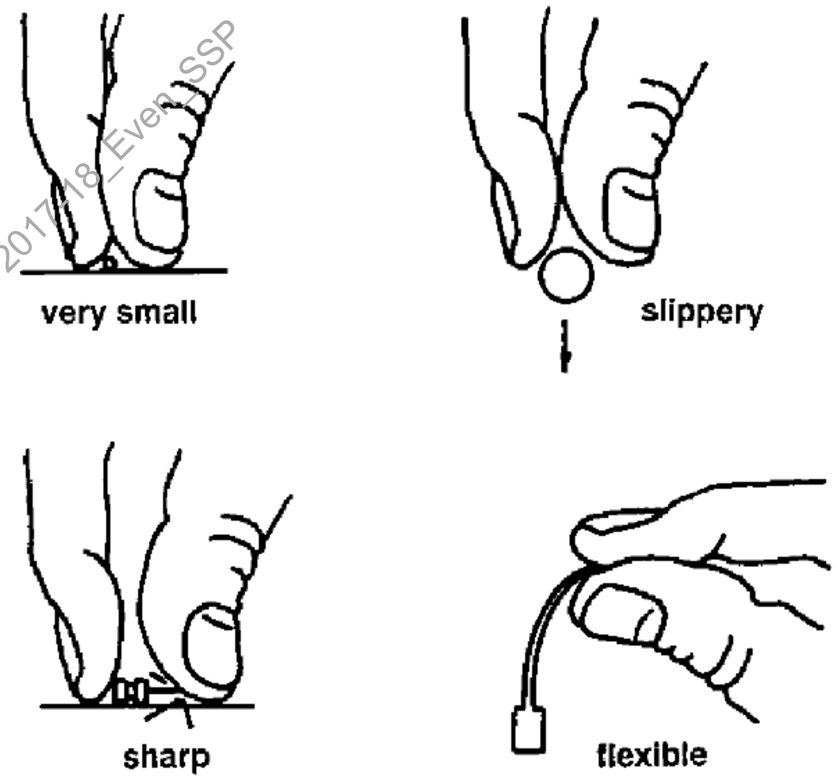
cannot jam

Design Guidelines for Part Handling

- Avoid features that will allow tangling of parts when stored in bulk

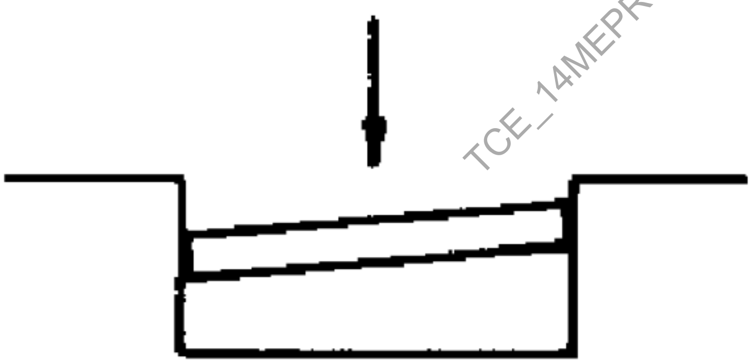
Design Guidelines for Part Handling

- Avoid parts that stick together or are slippery, delicate, flexible, very small, or very large or that are hazardous to the handler (i.e., parts that are sharp, splinter easily, etc.)

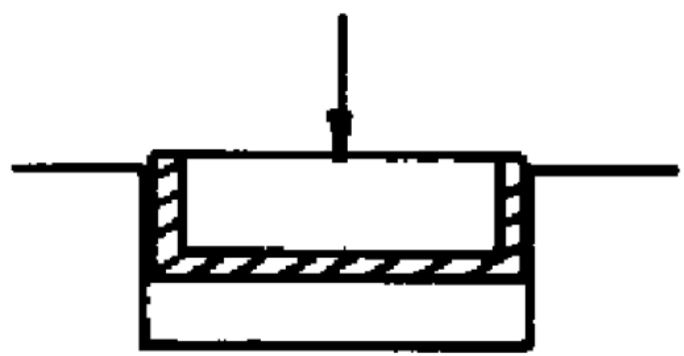


Design Guidelines for Insertion and Fastening

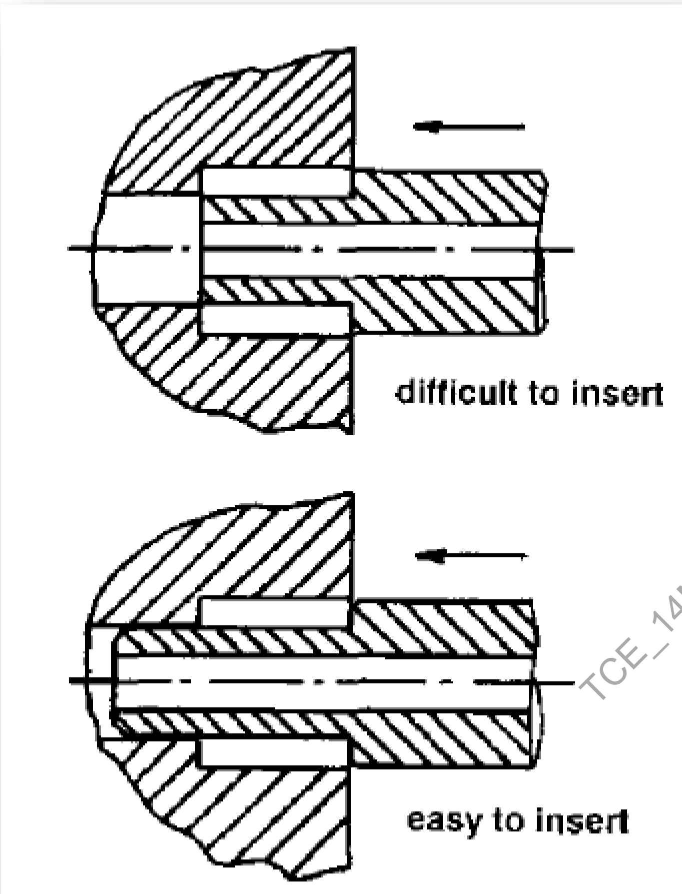
- Design so that there is little or no resistance to insertion and provide chamfers to guide insertion of two mating parts.
- Generous clearance should be provided, but care must be taken to avoid clearances that will result in a tendency for parts to jam or hang-up during insertion

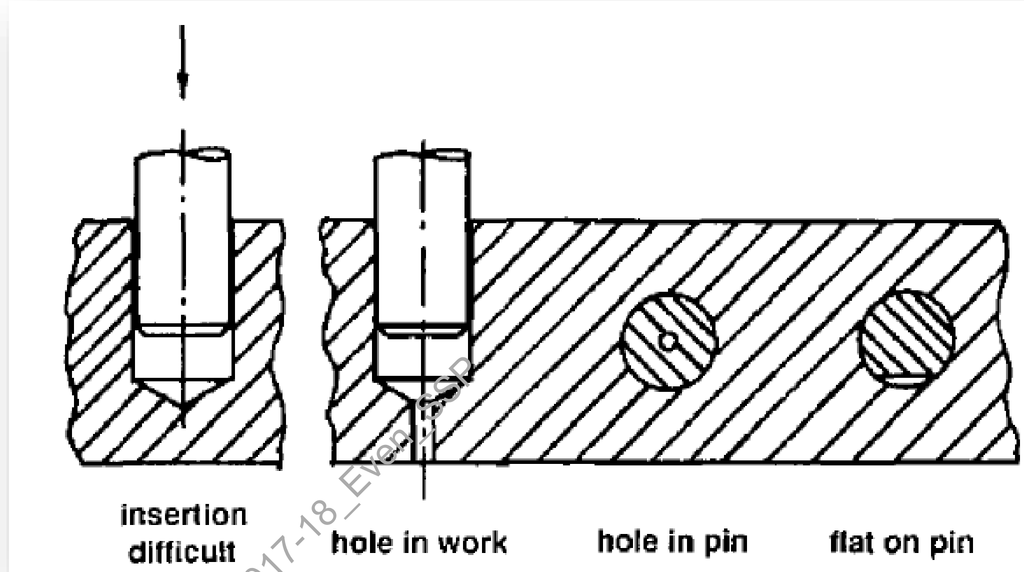


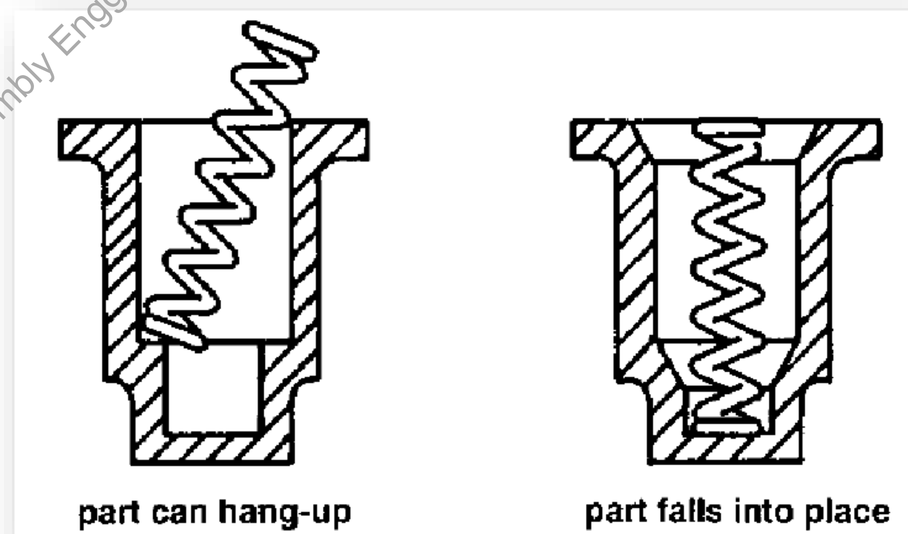
part jams across corners



part cannot jam

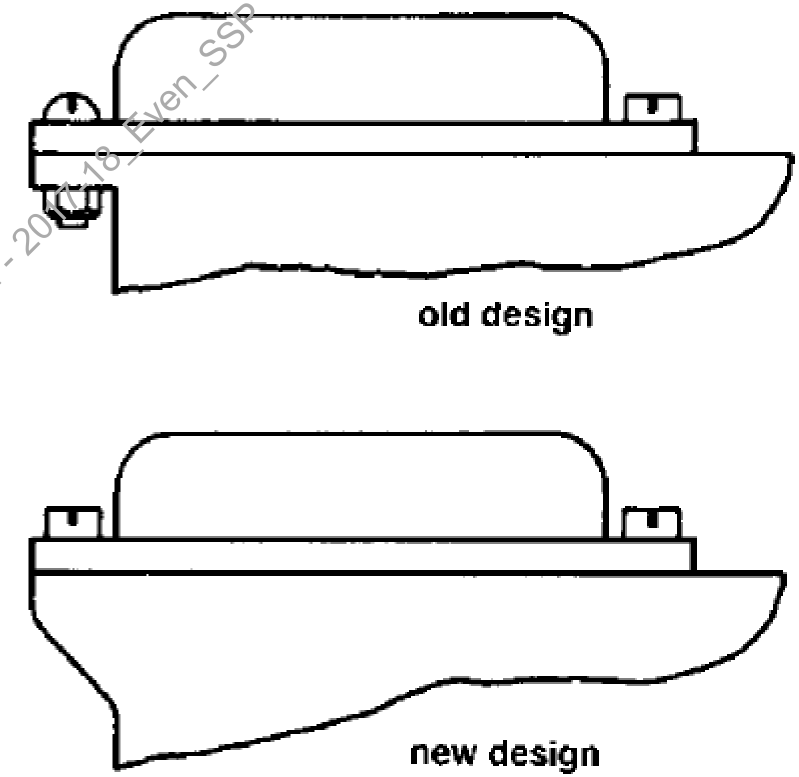

difficult to insert
easy to insert


insertion difficult
hole in work
hole in pin
flat on pin


part can hang-up
part falls into place

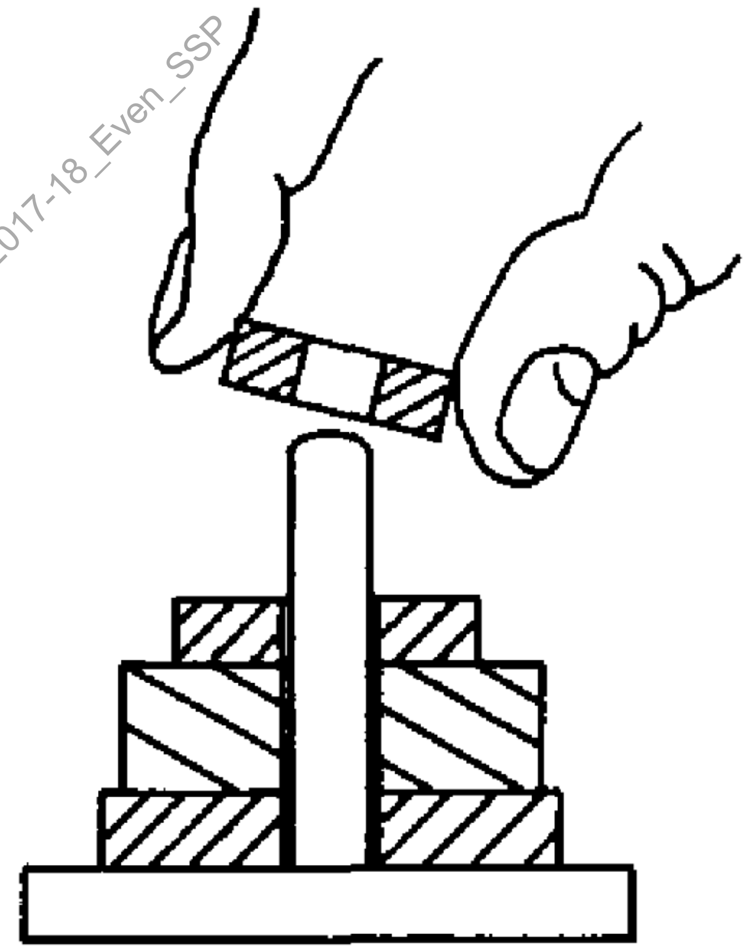
Design Guidelines for Insertion and Fastening

- Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost



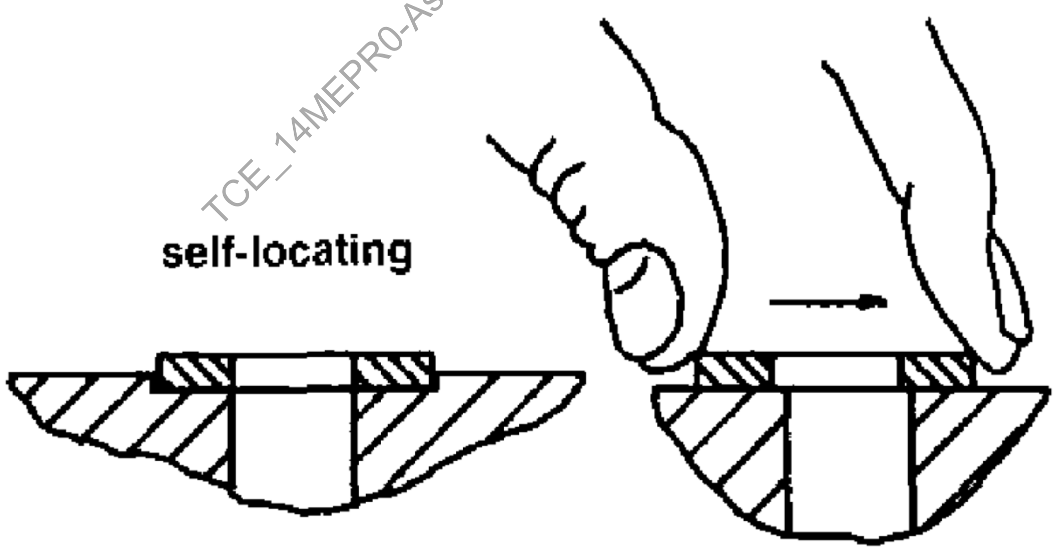
Design Guidelines for Insertion and Fastening

- Use pyramid assembly—provide for progressive assembly about one axis of reference. In general, it is best to assemble from above



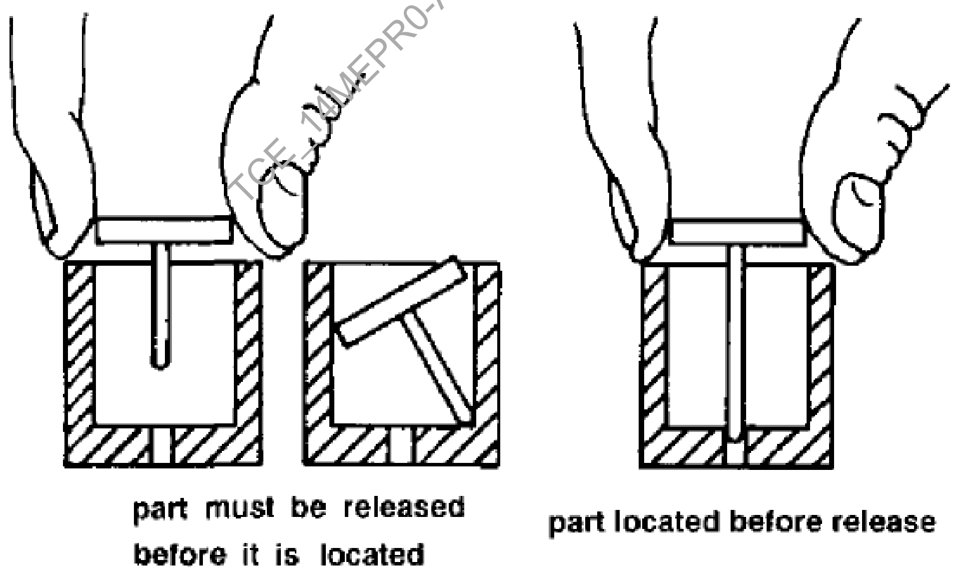
Design Guidelines for Insertion and Fastening

- Avoid, where possible, the necessity for holding parts down to maintain their orientation during manipulation of the subassembly or during the placement of another part. If holding down is required, then try to design so that the part is secured as soon as possible after it has been inserted.



Design Guidelines for Insertion and Fastening

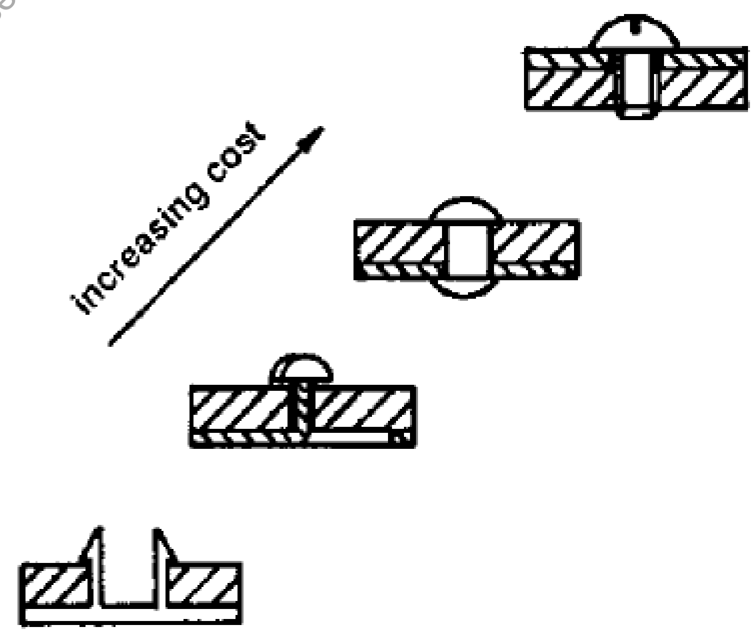
- Design so that a part is located before it is released. A potential source of problems arises from a part being placed where, due to design constraints, it must be released before it is positively located in the assembly. Under these circumstances, reliance is placed on the trajectory of the part being sufficiently repeatable to locate it consistently



Design Guidelines for Insertion and Fastening

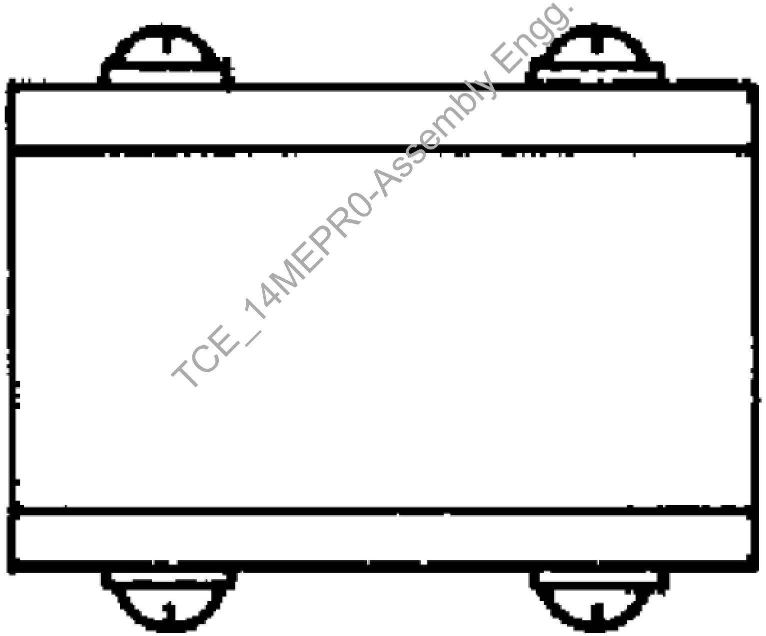
- When common mechanical fasteners are used the following sequence indicates the relative cost of different fastening processes, listed in order of increasing manual assembly cost

a. Snap fitting
b. Plastic bending
c. Riveting
d. Screw fastening



Design Guidelines for Insertion and Fastening

- Avoid the need to reposition the partially completed assembly in the fixture



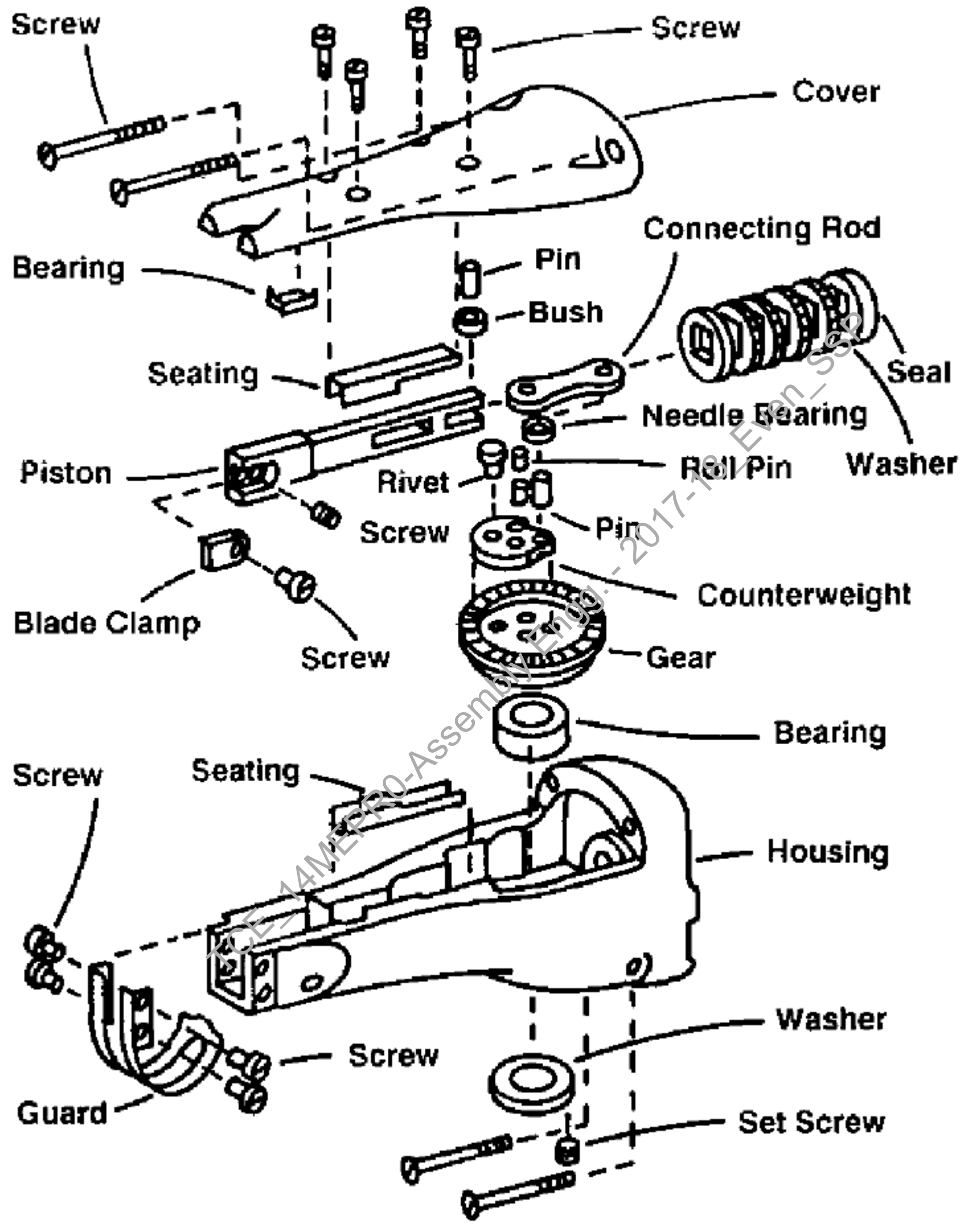


FIG. 3.13 Power saw (initial design—41 parts, 6.37 min assembly time).

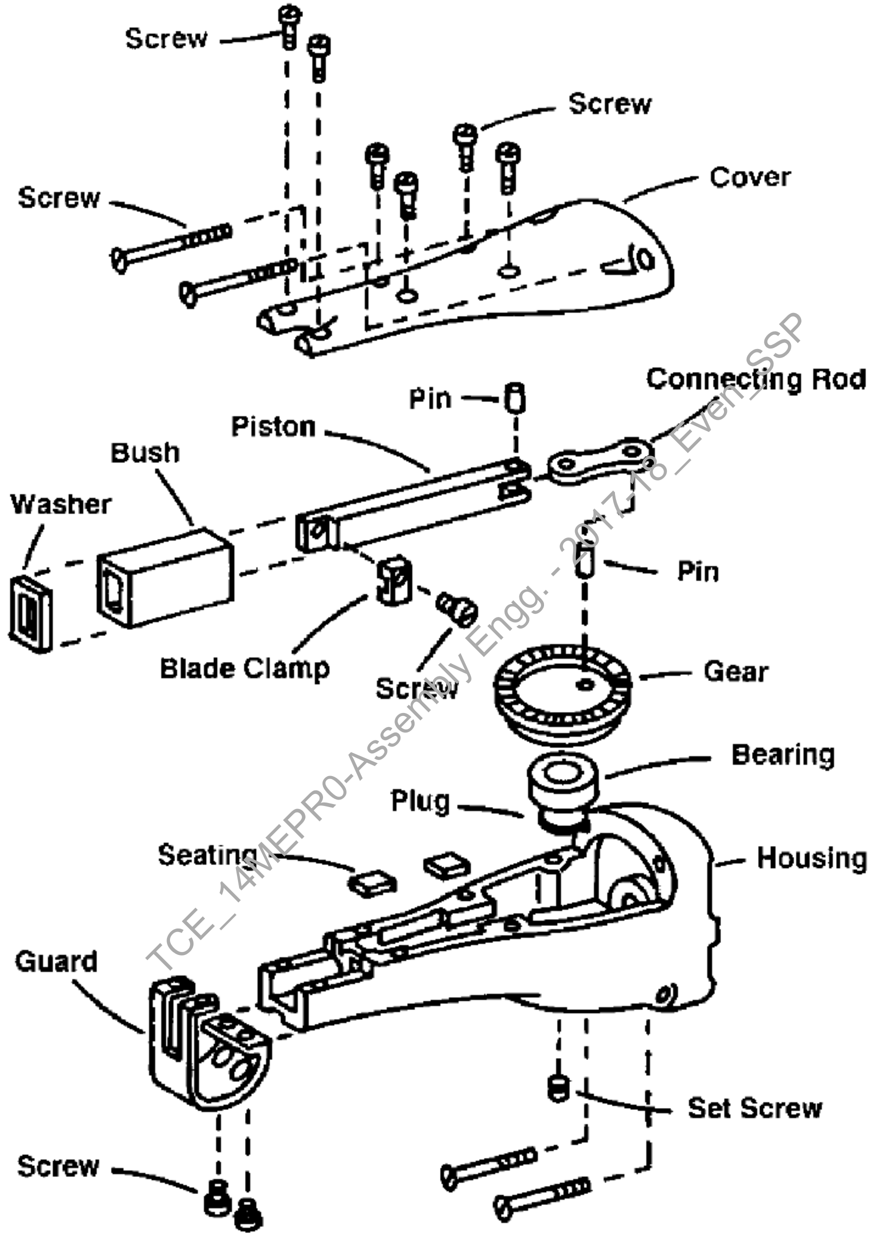
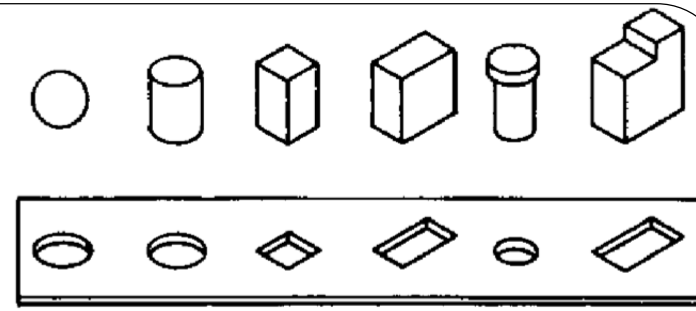


FIG. 3.14 Power saw (new design—29 parts, 2.58 min assembly time).

Classification Systems for assembly processes

- A systematic arrangement of part features that affect acquisition, movement, orientation, insertion, and fastening of the part together with some operations that are not associated with specific parts such as turning the assembly over.

Definitions

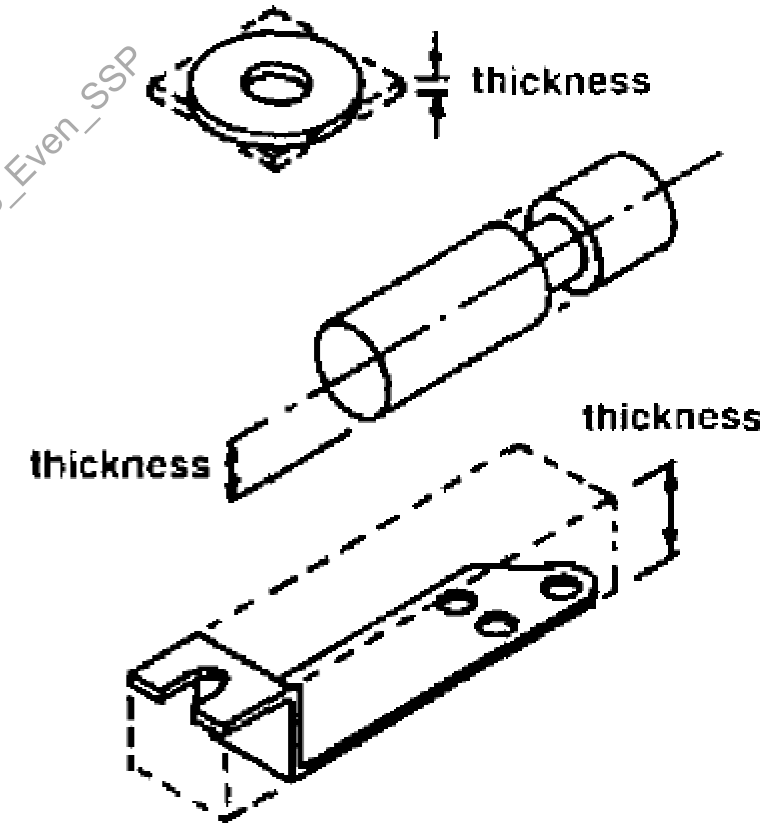


α	0	180	180	90	360	360
β	0	0	90	180	0	360

- *Alpha is the rotational symmetry of a part about an axis perpendicular to its axis of* insertion.
  - For parts with one axis of insertion, end-to-end orientation is necessary when alpha equals 360 degrees, otherwise alpha equals 180 degrees.
- *Beta is the rotational symmetry of a part about its axis of insertion.*
  - *The magnitude of* rotational symmetry is the smallest angle through which the part can be rotated and repeat its orientation.
  - For a cylinder inserted into a circular hole, beta equals *zero.*

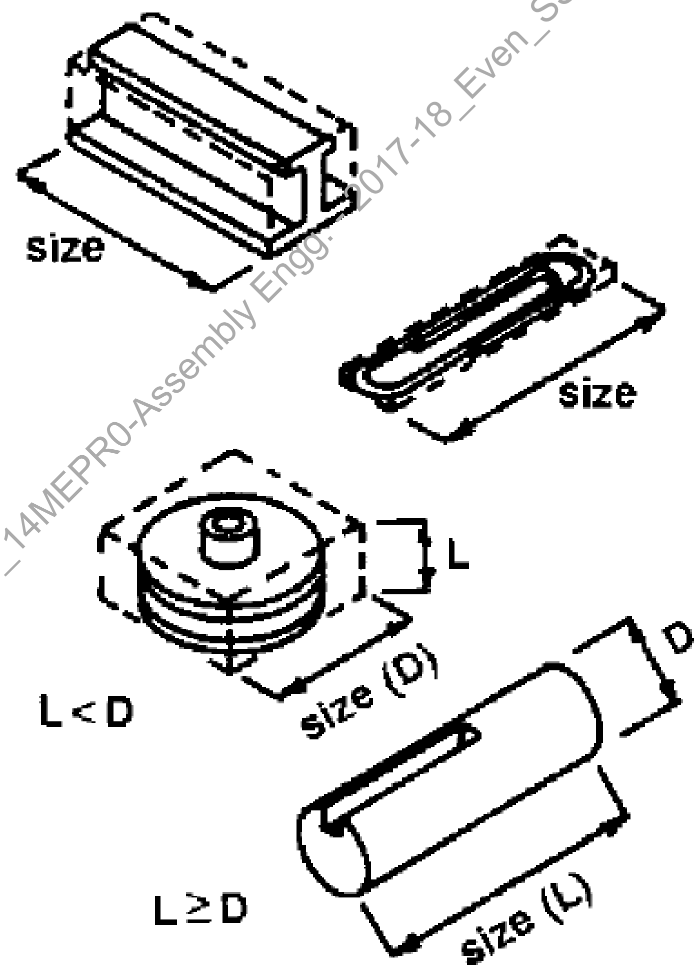
Definitions

- **Thickness** - *length of the shortest side of the smallest rectangular prism that* encloses the part.
- if the part is cylindrical, or has a regular polygonal cross-section with five or more sides, and the diameter is less than the length, then thickness is defined as the radius of the smallest cylinder which can enclose the part.



Definitions

- **Size** - *length of the longest side of the smallest rectangular prism that can enclose*the part.



Definitions

- **Holding -** *the part will require gripping, realignment, or holding* down before it is finally secured.
  - Easy to *align and position means that insertion is facilitated by well designed chamfers* or similar features.
- **Obstructed access -** *the space available for the assembly operation causes a* significant increase in the assembly time.
- **Restricted vision -** *the operator has to rely mainly on tactile sensing during the* assembly process.

for parts that can be grasped and manipulated with one hand without the aid of grasping tools

sym (deg) = (alpha+ beta)		no handling difficulties: thickness > 2mm, size > 15mm	no handling difficulties: thickness > 2mm, 6mm < size < 15mm	no handling difficulties: < 2mm, size > 6mm	part nests or tangles: thickness > 2mm, size > 15mm	part nests or tangles: thickness > 2mm, 6mm < size < 15mm	part nests or tangles: < 2mm, size > 6mm
		0	1	2	3	4	5
sym < 360	0	1.13	1.43	1.69	1.84	2.17	2.45
360 <= sym < 540	1	1.5	1.8	2.06	2.25	2.57	3.0
540 <= sym < 720	2	1.8	2.1	2.36	2.57	2.9	3.18
sym = 720	3	1.95	2.25	2.51	2.73	3.06	3.34

for parts that can be lifted with one hand but require two hands because they severely nest or tangle, are flexible or require forming etc.

	alpha <= 180: size > 15mm	alpha <= 180: 6mm < size <15mm	alpha = 360: size > 6mm
	0	1	2
4	4.1	4.5	5.6

FIG. 3.15 Selected manual handling time standards, seconds (parts are within easy reach, are no smaller than 6 mm, do not stick together, and are not fragile or sharp). (Copyright 1999 Boothroyd Dewhurst, Inc.)

part inserted but not secured immediately or secured by snap fit

		secured by separate operation or part				secured on insertion by snap fit	
		no holding down required		holding down required			
		easy to align	not easy to align	easy to align	not easy to align	easy to align	not easy to align
		0	1	2	3	4	5
no access or vision difficulties	0	1.5	3.0	2.6	5.2	1.8	3.3
obstructed access or restricted vision	1	3.7	5.2	4.8	7.4	4.0	5.5
obstructed access and restricted vision	2	5.9	7.4	7.0	9.6	7.7	7.7

part inserted and secured immediately by screw fastening with power tool

(times are for 5 revs or less and do not include a tool acquisition time of 2.9s)

		easy to align	not easy to align
		0	1
no access or vision difficulties	3	3.6	5.3
restricted vision only	4	6.3	8.0
obstructed access only	5	9.0	10.7

FIG. 3.16 Selected manual insertion time standards, seconds (parts are small and there is no resistance to insertion). (Copyright 1999 Boothroyd Dewhurst, Inc.)

	screw tighten with power tool	manipulation, reorientation or adjustment	addition of non solids
	0	1	2
6	5.2	4.5	7

FIG. 3.17 Selected separate operation times, seconds (solid parts already in place). (Copyright 1999 Boothroyd Dewhurst, Inc.)

Effect of Part Symmetry on Handling Time

- Orientation involves the proper alignment of the part to be inserted relative to the corresponding receptacle

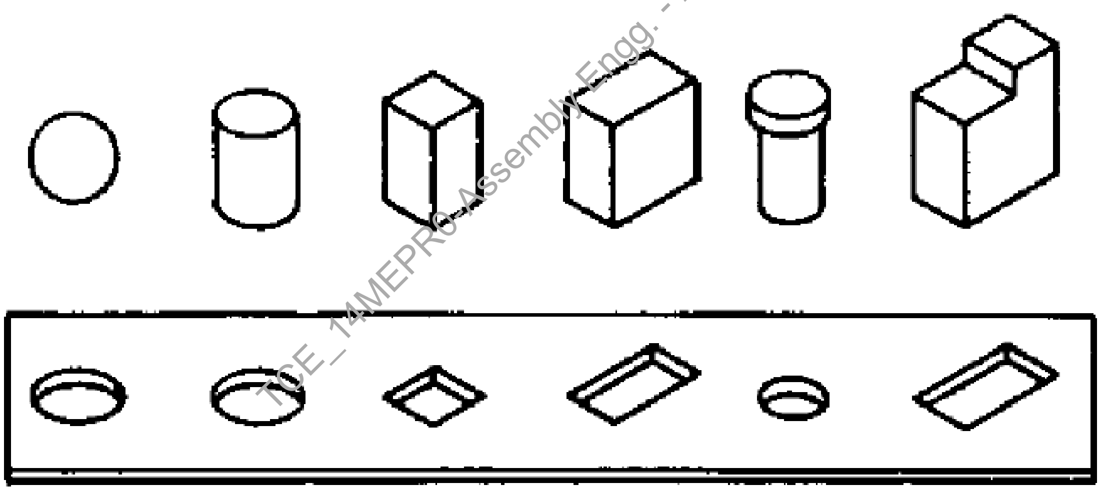
Two distinct operations:

- alignment of the axis of the part that corresponds to the axis of insertion, and
- rotation of the part about this axis.

Effect of Part Symmetry on Handling Time

Alpha symmetry: depends on the angle through which a part must be rotated about an axis perpendicular to the axis of insertion to repeat its orientation.

Beta symmetry: depends on the angle through which a part must be rotated about the axis of insertion to repeat its orientation.



α	0	180	180	90	360	360
β	0	0	90	180	0	360

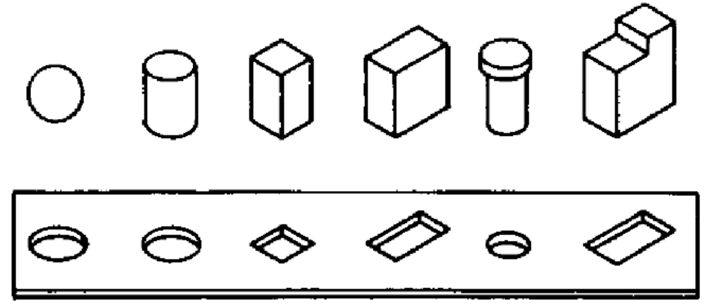
FIG. 3.18 Alpha and beta rotational symmetries for various parts.

Example

- **A plain square prism that is to be inserted into a square hole**

1. have to be rotated about an axis perpendicular to the insertion axis.
   - Since, with such a rotation, the prism will repeat its orientation every 180°, it can be termed 180° alpha symmetry.
2. have to be rotated about the axis of insertion
   - since the orientation of the prism about this axis would repeat every 90°, this implies a 90° beta symmetry.

- if the square prism were to be inserted in a circular hole, it would have 180° alpha symmetry and 0° beta symmetry.



α	0	180	180	90	360	360
β	0	0	90	180	0	360

FIG. 3.18 Alpha and beta rotational symmetries for various parts.

Effect of Part Symmetry on Handling Time

- Total angle of symmetry = alpha + beta

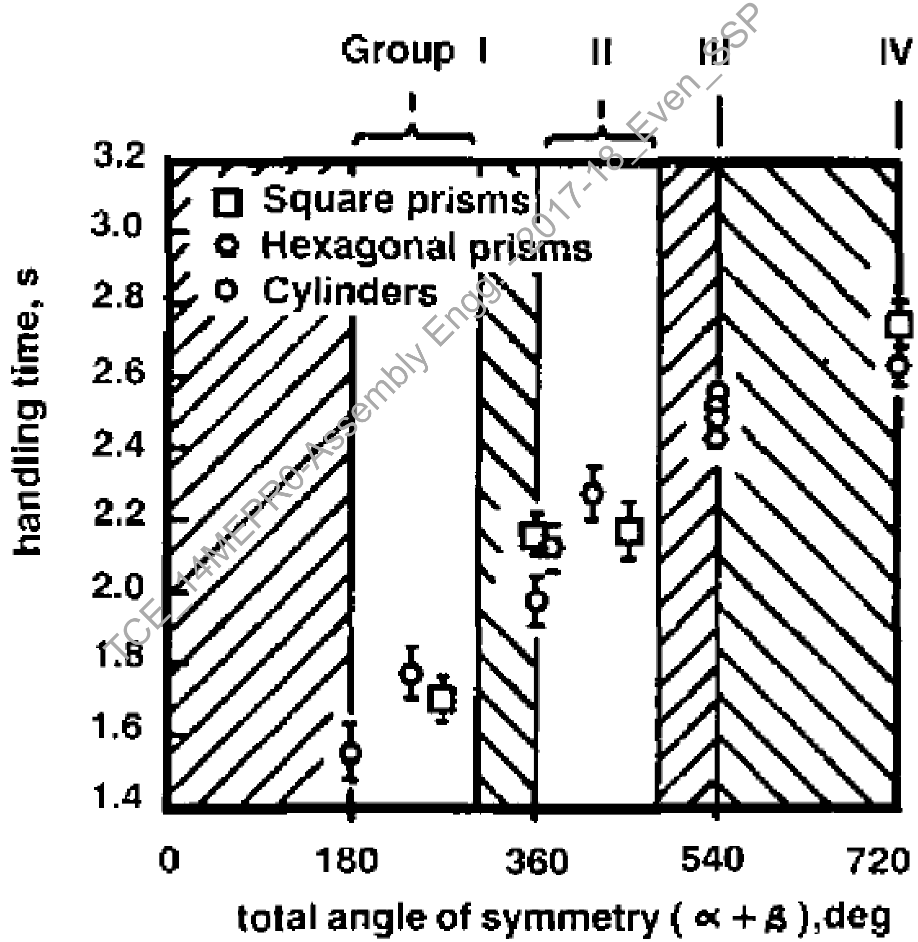


FIG. 3.19 Effect of symmetry on the time required for part handling.

Effect of Part Thickness on Handling Time

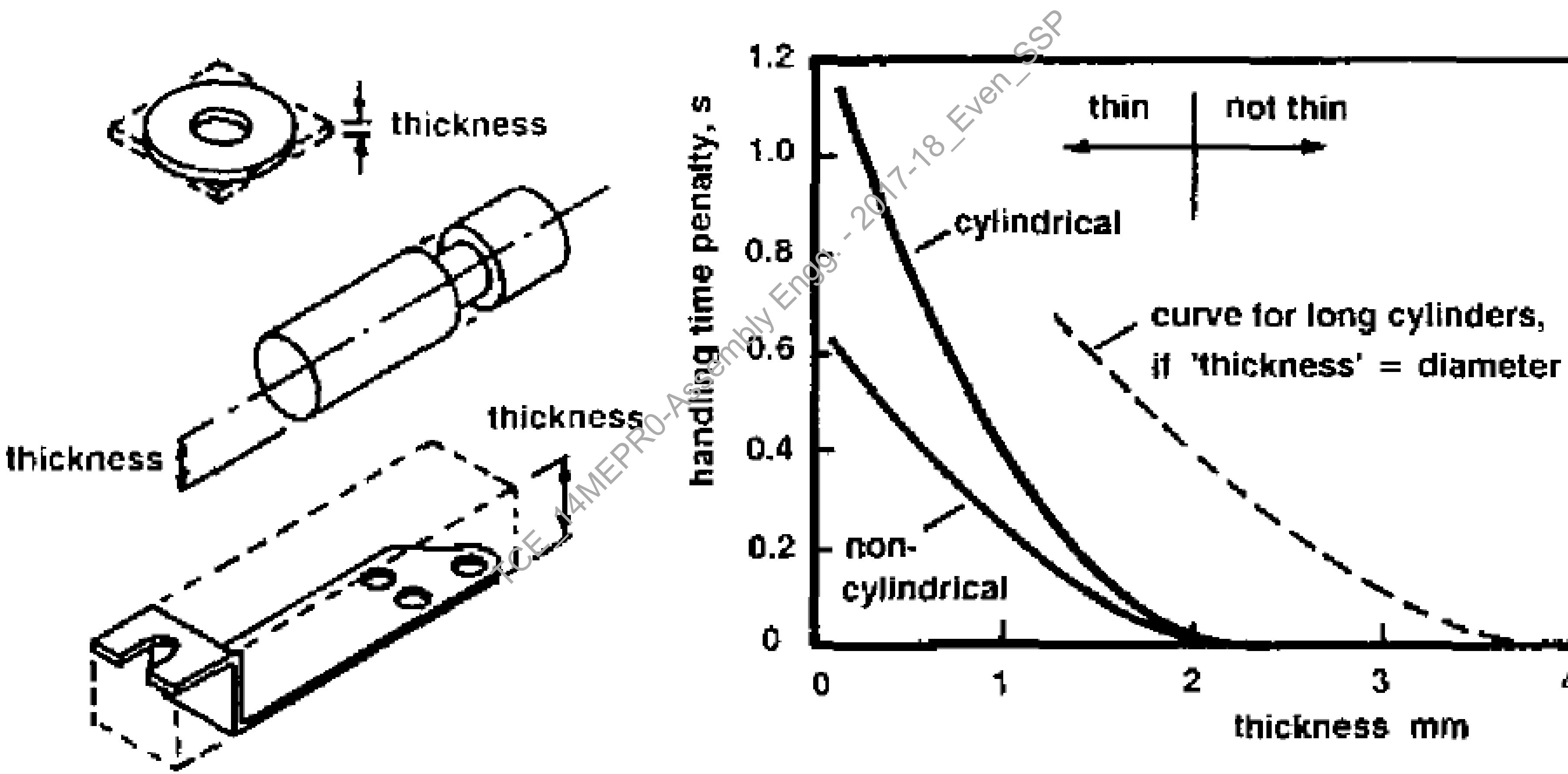


FIG. 3.20 Effect of part thickness on handling time.

Effect of Part Size on Handling Time

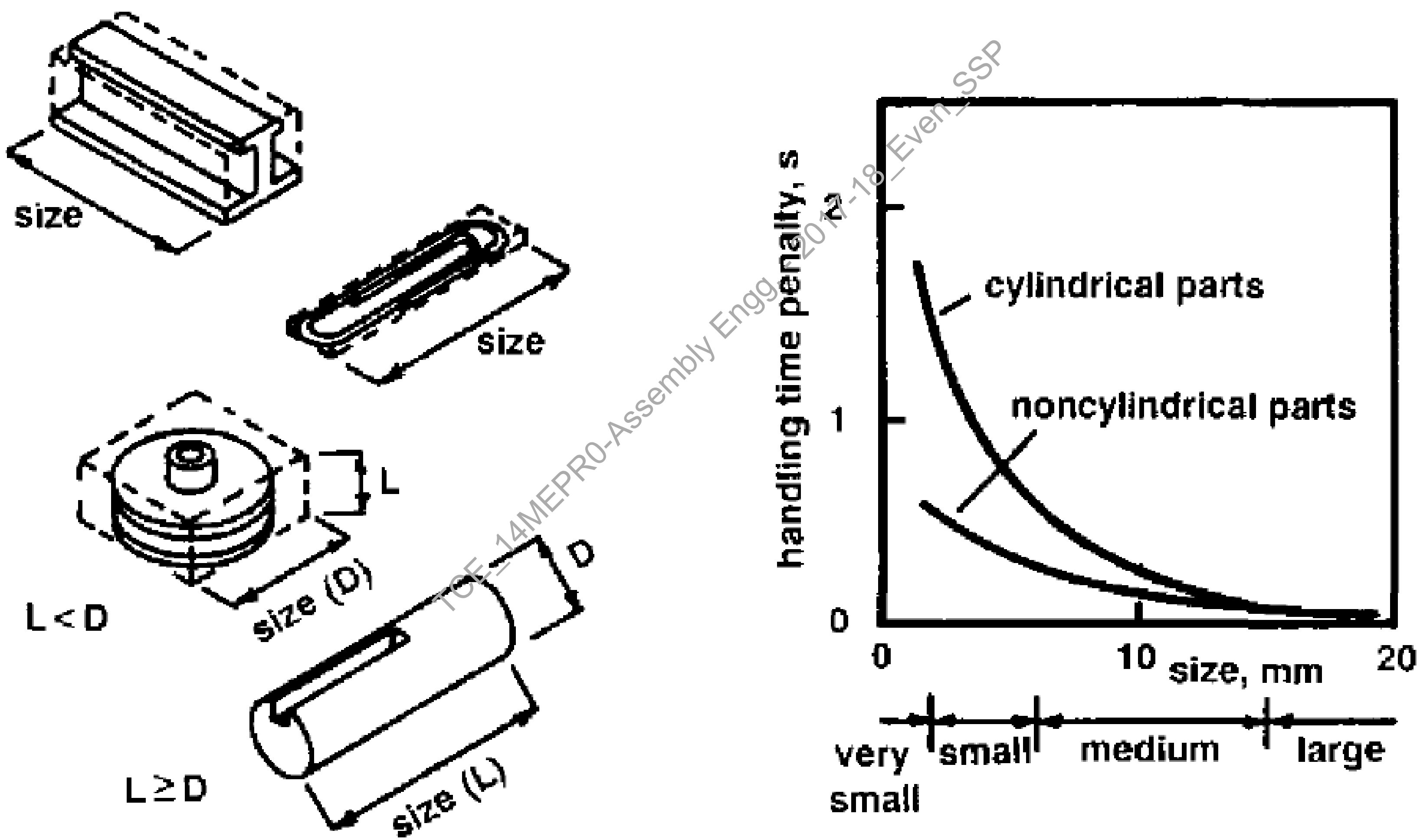


FIG. 3.21 Effect of part size on handling time.

Effect of Weight on Handling Time

- the effects of weight on the grasping, controlling, and moving of parts
- The effect of increasing weight on grasping and controlling is found to be an additive time penalty and the effect on moving is found to be a proportional increase of the basic time

Effect of Weight on Handling Time

- For the effect of weight on a part handled using one hand, the total adjustment t_{pw} *to handling time can be*

$$t_{pw} = 0.0125W + 0.011Wt_h$$

  - W – Weight (lb)
  - t_h (s) is the basic time for handling a "light" part when no orientation is needed and when it is to be moved a short distance
  - (Average: 1.13 - the total time penalty due to weight would be approximately 0.025 W)

Effect of Chamfer Design on Insertion Operations

Two common assembly operations are

- The insertion of a peg (or shaft) into a hole
- The placement of a part with a hole onto a peg.

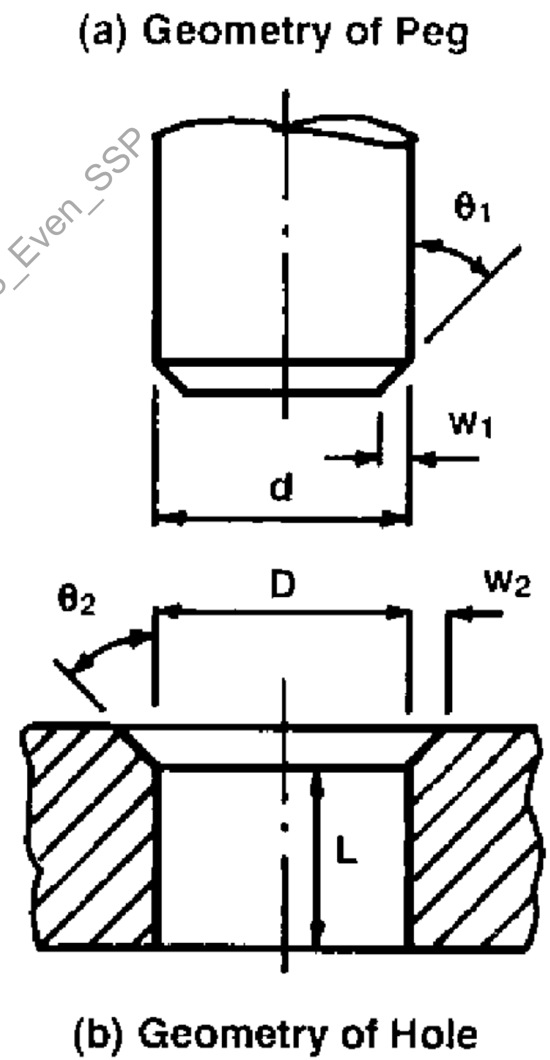


FIG. 3.24 Geometries of peg and hole.

Effect of Chamfer Design on Insertion Operations

<u>Chamfered peg</u>

- *d is the diameter of the peg,*
- *w_1 is the width of the* chamfer, and
- θ_1 is the semi-conical angle of the chamfer.

<u>Chamfered hole,</u>

- *D is the diameter of the hole,*
- w_2 *is the* width of the chamfer, and
- θ_2 *is the semi-conical angle of the chamfer.*

- *The* dimensionless diametrical clearance *c between the peg and the hole is defined by*

$$c = (D - d)/D$$

Effect of Chamfer Design on Insertion Operations

The following conclusions have been drawn:

- For a given clearance, the **difference in the insertion time for two different chamfer designs is always a constant**.
- **A chamfer on the peg is more effective** in reducing insertion time than the same chamfer on the hole.
- The **maximum width of the chamfer** that is effective in reducing the insertion time for both the peg and the hole is approximately **0.1D**.
- For conical chamfers, the most effective design provides chamfers on both the peg and the hole, with $w_1 = w_2 = 0.1D$ **and** $\theta_1 = \theta_2 < 45$.
- The manual insertion time is not sensitive to variations in the **angle of the chamfer for the range** $10 < \theta < 50$.
- A radiused or curved chamfer can have advantages over a conical chamfer for small clearances.

Effect of Chamfer Design on Insertion Operations

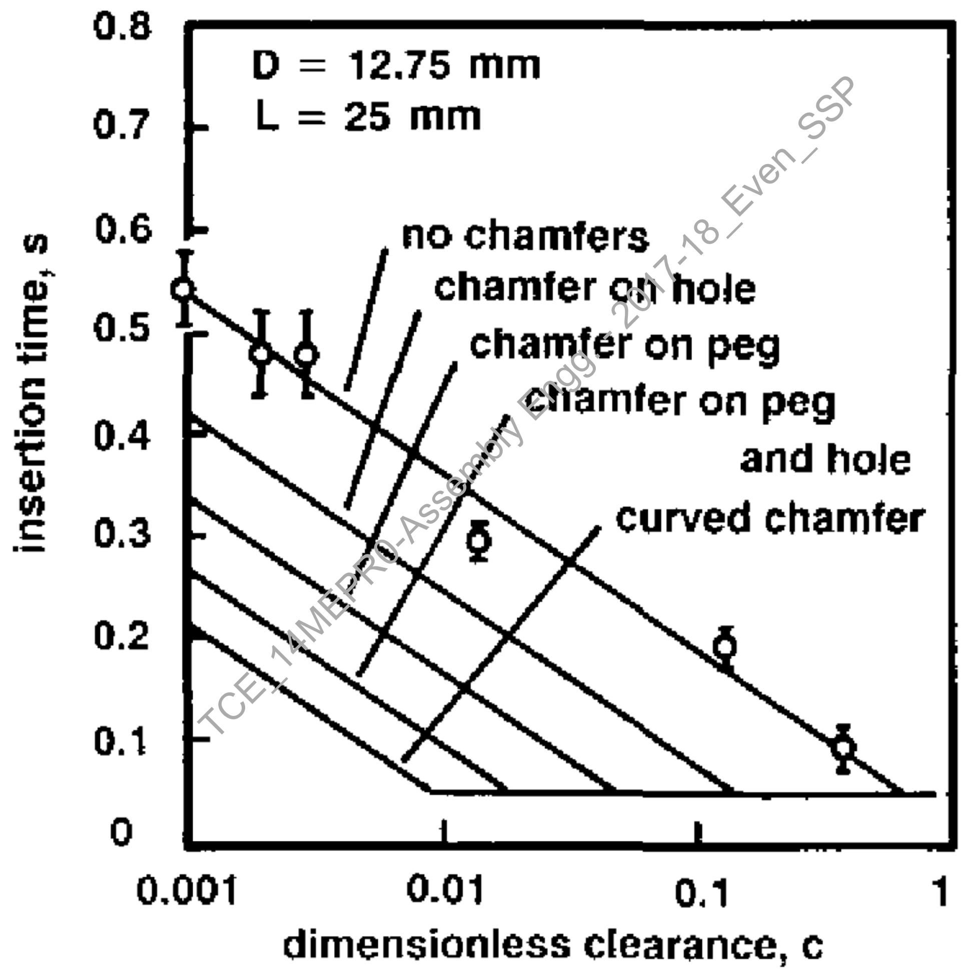


FIG. 3.25 Effect of clearance on insertion time. (

Effect of Chamfer Design on Insertion Operations

Two possible situations that will cause difficulties.

- the two points of contact arising on the same circular cross section of the peg give rise to forces resisting the insertion.
- the peg has become jammed at the entrance of the hole.

Effect of Chamfer Design on Insertion Operations

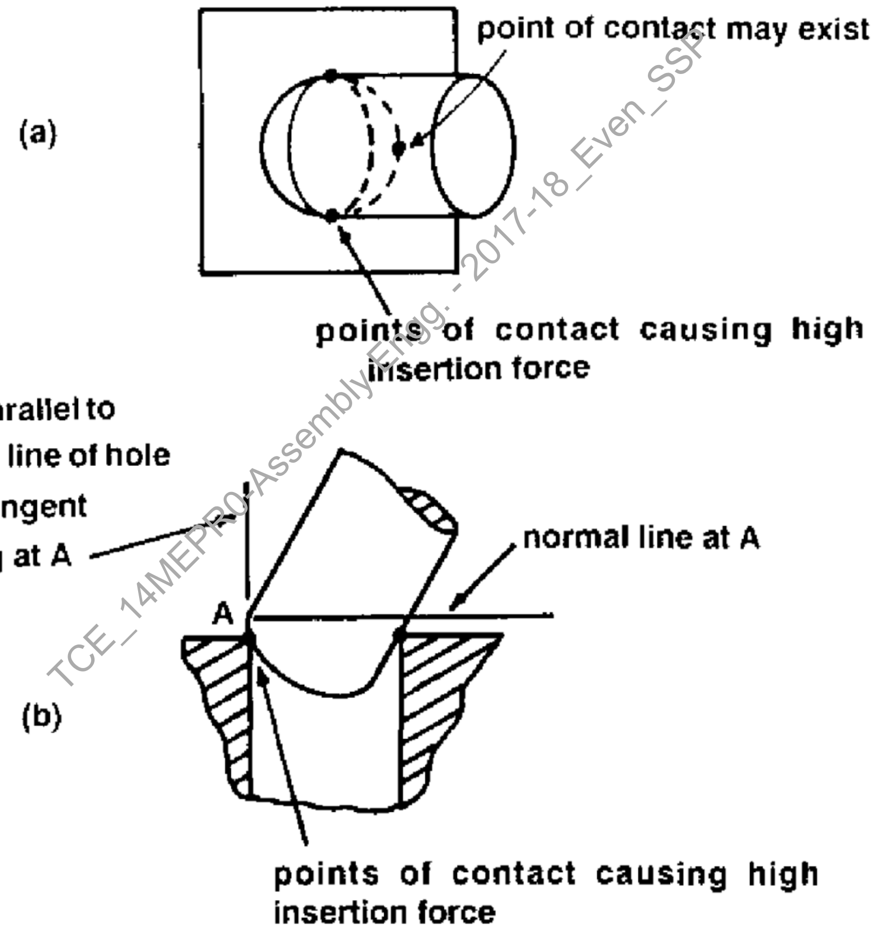


FIG. 3.26 Points of contact on chamfer and hole.

Effect of Chamfer Design on Insertion Operations

- The insertion time is independent of the dimensionless clearance *c in the range* $c > 0.001$.
- *the curved chamfer is the optimum design for peg-in-hole* insertion operations
- Since the manufacturing costs for curved chamfers would normally be greater than for conical chamfers
  - the modified chamfer would only be worthy of consideration for very small values of clearance when the significant reductions in insertion time might compensate for the higher cost.
- An interesting example of a curved chamfer is the geometry of a bullet. Its design not only has aerodynamic advantages but is also ideal for ease of insertion.

DESIGN FOR AUTOMATED ASSEMBLY: EFFECT OF FEED RATE ON COST

- The cost of feeding and orienting parts will depend on the *cost of the equipment required and on the time interval between delivery of successive parts*.
- The time between delivery of parts is the reciprocal of the delivery rate
- nominally equal to the cycle time of the machine or system.

DESIGN FOR AUTOMATED ASSEMBLY: EFFECT OF FEED RATE ON COST

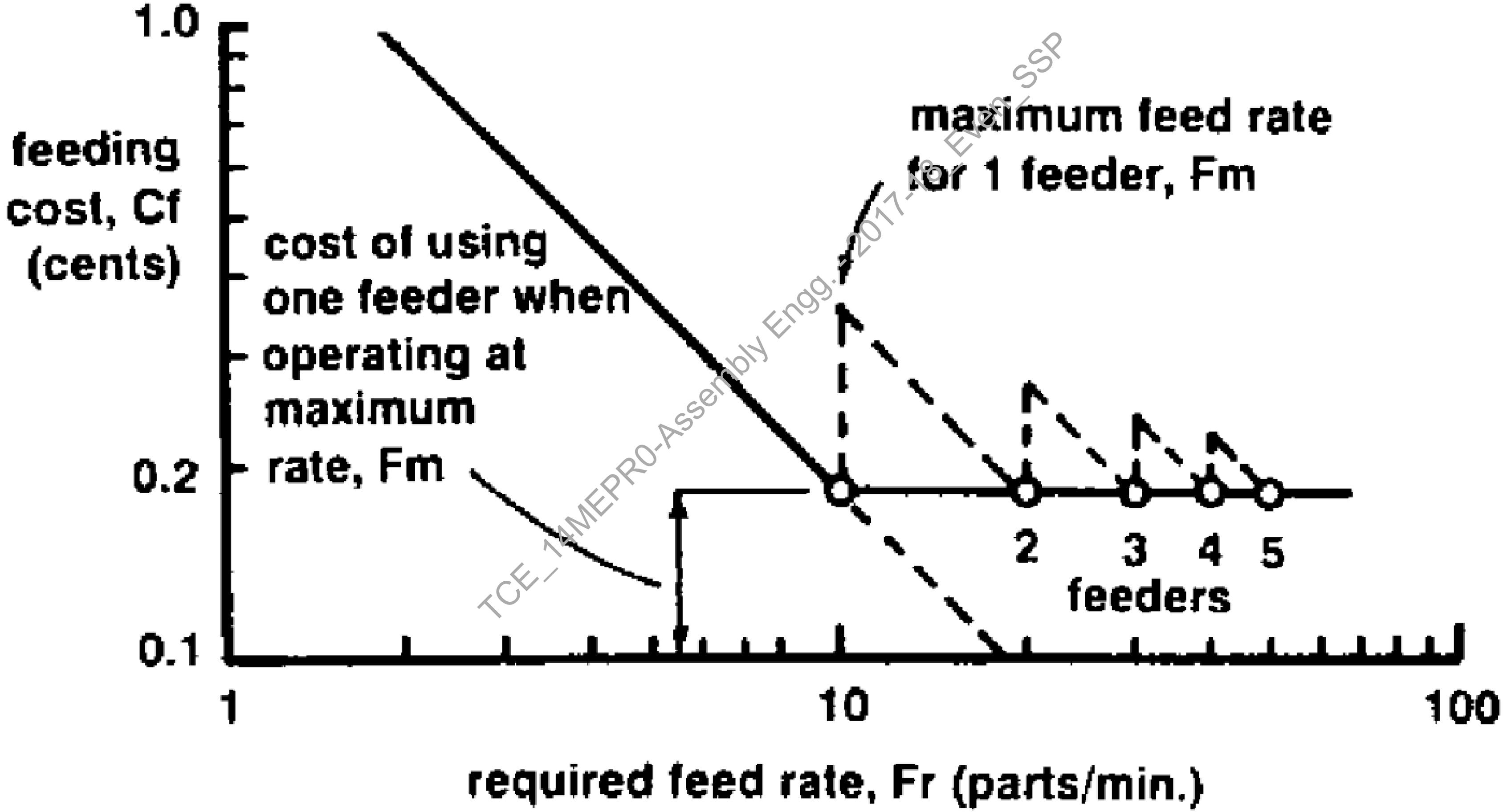


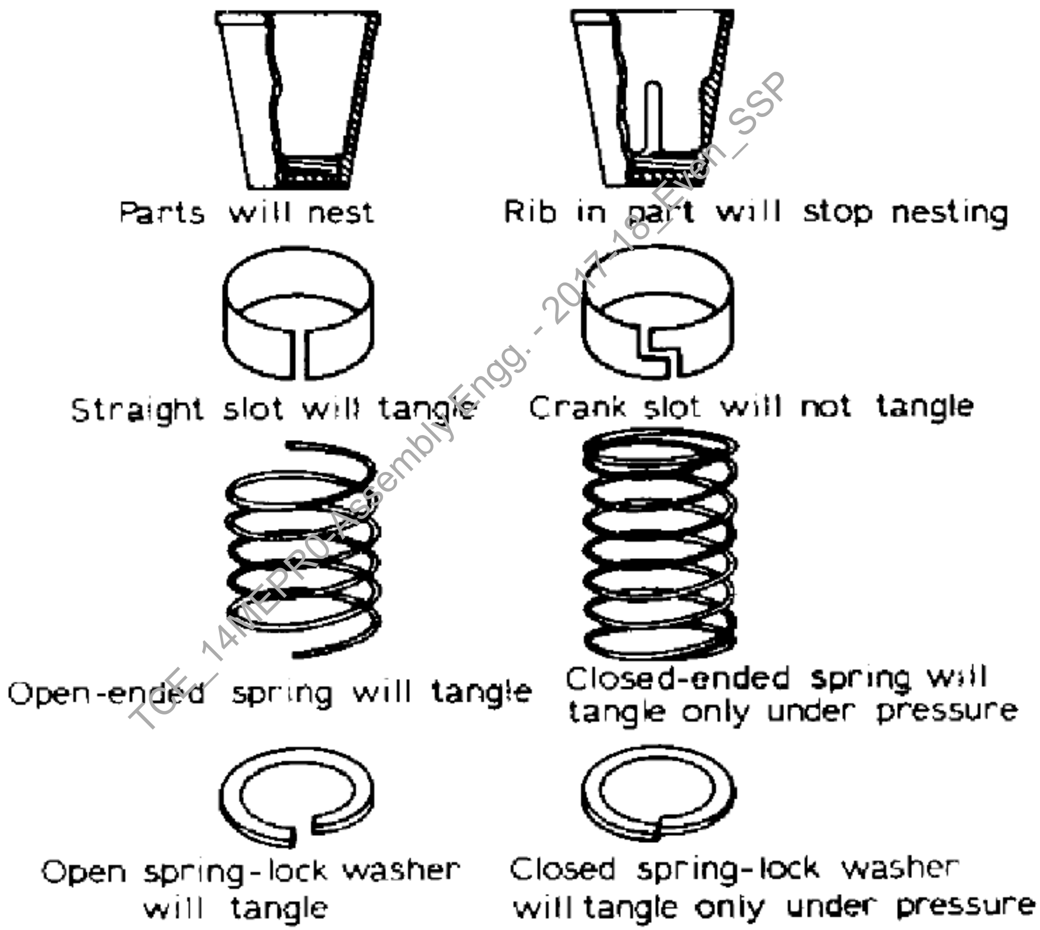
FIG. 5.2 Effect of required feed rate on feeding cost.

DESIGN OF PARTS FOR FEEDING AND ORIENTING

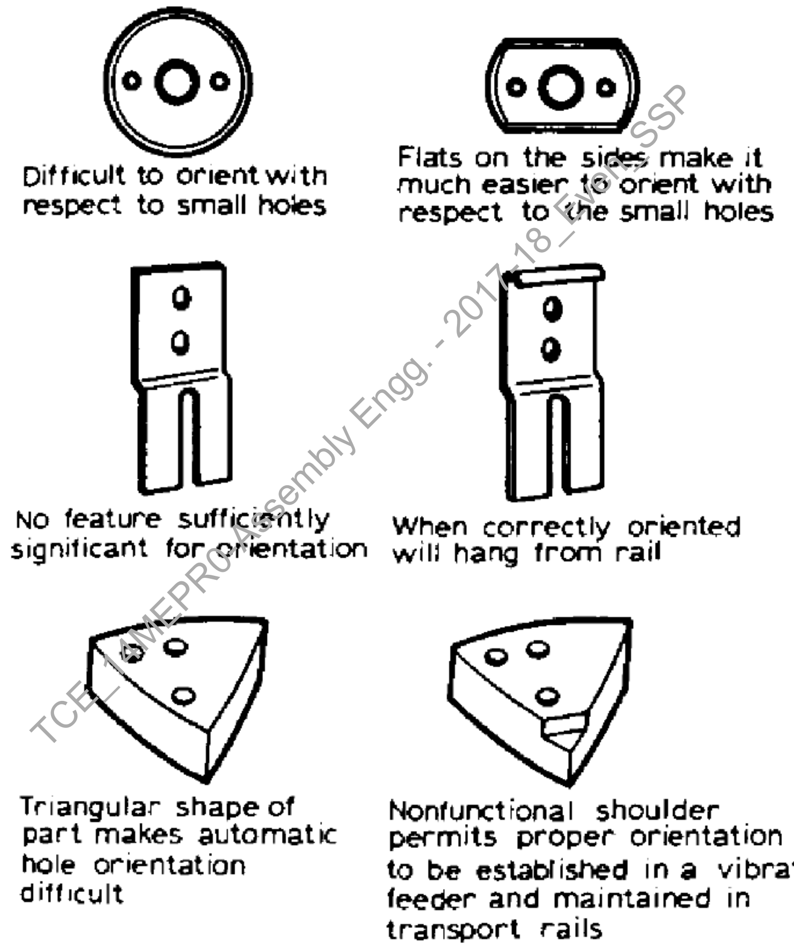
Three basic design principles :

- Avoid designing parts that will tangle, nest, or shingle.
- Make the parts symmetrical.
- If parts cannot be made symmetrical, avoid slight asymmetry or asymmetry resulting from small or non-geometrical features.

DESIGN OF PARTS FOR FEEDING AND ORIENTING



DESIGN OF PARTS FOR FEEDING AND ORIENTING



Provision of asymmetrical features to assist in orientation.

DESIGN RULES FOR HIGH-SPEED AUTOMATIC ASSEMBLY

Rules for Product Design

- Minimize the number of parts.
- Ensure that the product has a suitable base part on which to build the assembly.
- Ensure that the base part has features that enable it to be readily located in a stable position in the horizontal plane.
- If possible, design the product so that it can be built up in layers, each part being assembled from above and positively located so that there is no tendency for it to move under the action of horizontal forces during the machine index period.
- Try to facilitate assembly by providing chamfers or tapers that help to guide and position the parts in the correct position.
- Avoid expensive and time-consuming fastening operations, such as screw fastening, soldering, and so on.

DESIGN RULES FOR HIGH-SPEED AUTOMATIC ASSEMBLY

Rules for the Design of Parts

- Avoid projections, holes, or slots that cause tangling with identical parts when placed in bulk in the feeder.
- Attempt to make the parts symmetrical to avoid the need for extra orienting devices and the corresponding loss in feeder efficiency.
- If symmetry cannot be achieved, exaggerate asymmetrical features to facilitate orienting or, alternatively, provide corresponding asymmetrical features that can be used to orient the parts.

ROBOT ASSEMBLY SYSTEMS

- Single-station with one robot arm
- Single-station with two robot arms
- Multistation with robots, special-purpose workheads, and manual assembly stations as appropriate.

DESIGN RULES FOR ROBOT ASSEMBLY

- *Reduce part count*—a major strategy for reducing assembly, manufacture, and overhead costs irrespective of the assembly system to be used.
- Include features such as leads, lips, chamfers, etc., to *make parts self-aligning* in assembly.
  - Because of the relatively poor repeatability of many robot manipulators—when compared to dedicated work-head mechanisms—
  - important measure to ensure consistent fault-free part insertions.

DESIGN RULES FOR ROBOT ASSEMBLY

- Ensure that parts which are not secured immediately on insertion are self-locating in the assembly.
  - For multistation robot assembly systems, or one arm single-station systems, this is an essential design rule.
  - Holding down of unsecured parts cannot be carried out by a single robot arm, and so *special fixturing* is required which must be activated by the robot controller. This adds significantly to special-purpose tooling and, hence, assembly costs.
- With a two-arm single-station system, one arm can, in principle, hold down an unsecured part while the other continues the assembly and fastening processes.
  - In practice, this requires one arm to change end-of-arm tooling to a hold-down device; the system then proceeds with 50% efficiency while one arm remains immobile.

DESIGN RULES FOR ROBOT ASSEMBLY

- Design parts so that they can all be gripped and inserted using the same robot gripper.
  - One major cause of inefficiency in robot assembly systems - need for gripper or tool changes.
  - Even with rapid gripper or tool change systems, each change to a special gripper and then back to the standard gripper is approximately equal to two assembly operations.
  - Note that the use of screw fasteners always results in the need for tool changes since robot wrists can seldom rotate more than one revolution.
- Design products so that they can be assembled in layer fashion from directly above (z-axis assembly).
  - This ensures that the simplest, least costly, and most reliable 4 degree-of-freedom robot arms can accomplish the assembly tasks. It also simplifies the design of the special-purpose work-fixture.

DESIGN RULES FOR ROBOT ASSEMBLY

- *Avoid the need for reorienting* the partial assembly or for manipulating previously assembled parts.
  - These operations increase the robot assembly cycle time without adding value to the assembly.
  - if the partial assembly has to be turned to a different resting aspect during the assembly process, then this will usually result in increased work-fixture cost and the need to use a more expensive 6 degree-of-freedom robot arm.

DESIGN RULES FOR ROBOT ASSEMBLY

- Design parts that can be easily handled from bulk. To achieve this goal avoid parts that
  - Nest or tangle in bulk
  - flexible
  - Have thin or tapered edges that can overlap or "shingle" as they move along a conveyor or feed track
  - Are so delicate or fragile that recirculation in a feeder would cause damage
  - Are sticky or magnetic so that a force comparable to the weight of the part is required for separation
  - Are abrasive and will wear the surfaces of automatic handling systems
  - Are light so that air resistance will create conveying problems (less than $1.5N/m^3$)

DESIGN RULES FOR ROBOT ASSEMBLY

- If parts are to be presented using automatic feeders, then ensure that they can be oriented using simple tooling.
  - feeding and orienting at high speed is seldom necessary in robot assembly
  - the main concern is that the features that define part orientation can be easily detected.

DESIGN RULES FOR ROBOT ASSEMBLY

- If parts are to be presented using automatic feeders, then ensure that they can be delivered in an orientation from which they can be gripped and inserted without any manipulation.
  - For example, avoid the situation where a part can only be fed in one orientation from which it must be turned over for insertion. This will require a 6 degree-of-freedom robot and special gripper, or a special 180° turn delivery track—both solutions leading to unnecessary cost increases.

DESIGN RULES FOR ROBOT ASSEMBLY

- If parts are to be presented in *magazines or part trays*, then ensure that they have a stable resting aspect from which they can be gripped and inserted without any manipulation by the robot.
  - If the production conditions are appropriate, the use of robots holds advantages over the use of special purpose work-heads and some design rules can be relaxed.
  - For example, a robot can be programmed to acquire parts presented in an array—such as in a pallet or part fray which has been loaded manually, thus avoiding many of the problems arising with automatic feeding from bulk. However, when making economic comparisons, the cost of manual loading of the magazines must be taken into account.

THIAGARAJAR COLLEGE OF ENGINEERING, MADURAI 625 015.

Department of Mechanical Engineering

Continuous Assessment Test – II

Course Code	14MEPR0	Course Name	Assembly Engineering		
Degree	B.E.	Programme	Mechanical Engineering	Semester	VII
Date	09.10.2017	Duration	90 minutes	Max. Marks	50
Faculty-in-Charge		Dr. S.Saravana Perumaal			

Assessment Pattern

Remember	Understand	Apply	Analyze	Evaluate	Create	Total
10	10	30	-	-	-	50

Answer All Questions

Part A (Remember) 5 x 2 = 10

A1. Name any four components in an assembly system.

A2. Define cycle time.

A3. List advantages of synchronous material handling system.

A4. State any two design guidelines of robotic assembly.

A5. Mention the advantages of chamfer in an assembly.

Part B (Understand) 2 x 5 = 10

B1. Discuss the effect of floor layout in designing an automated assembly system. (05)

B2. Describe any two design guidelines for ease of manual assembly. (05)

Part C (Apply) 3 x 10 = 30

C1. Determine the line balancing efficiency and balance delay for the following data that have been observed from an assembly unit.

Workstations	1	2	3	4	5	Total
Time (min)	2	3	6	2	3	16

Also, suggest the possibilities of increasing the line balancing efficiency. (10)

(OR)

C2. The manager of a computer assembly line plans to produce 100 assembled computers per 10-hour work day. Work Element data for the assembly is shown in the table below.

Work Element	Time (min)	Immediate Predecessors
A	2	-
B	3	A
C	1	B
D	5	B
E	5	C,D
F	4	E
G	1	D,E
H	2	F
I	6	G
J	4	H
K	2	I,J
L	6	K

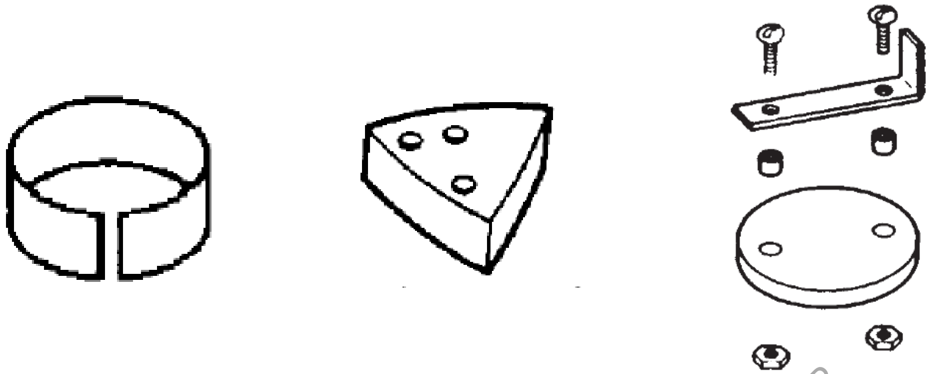
Determine the cycle time and theoretical minimum number of workers per station. (10)

C3. Determine the proportion of the downtime for indexing machine with following data: Machine cycle time=6 sec; Average time to clear a fault = 30 sec; Average value of the part quality=0.01; Number of workheads = 10; Number of assemblies produced = 100; Assume all the defective parts will produce a stoppage of the machine. (10)

(OR)

C4. In a free-transfer machine, Machine cycle time= 10 sec; Average time for clearing a fault = 50 sec; Average value of the part quality=0.01; Buffer capacity = 25; Number of workheads = 10; Number of assemblies produced = 100; Determine the average production time and optimum number of personnel required for this free-transfer machine. (10)

C5. Suggest and justify the suitable modifications on the design of the following components as shown in figure 3 to ensure proper assembly with minimum effort. (10)

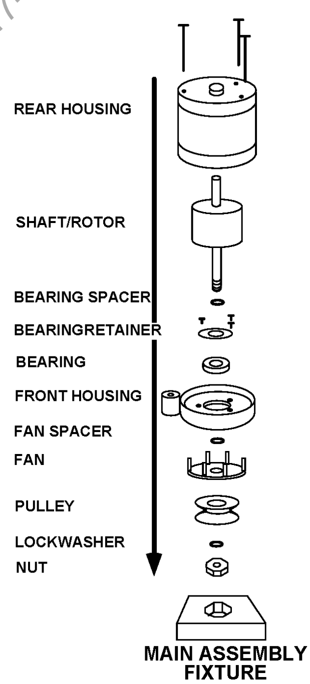


(a) (b) (c)

Figure 3

(OR)

C6. Recommend necessary modifications in part design of the following alternator assembly as shown in figure 4 and its assembly sequences in order to improve the efficiency of its manual assembly.



(10)

Figure 4

THIAGARAJAR COLLEGE OF ENGINEERING, MADURAI 625 015.

Department of Mechanical Engineering

Continuous Assessment Test – III

Course Code	14MEPR0	Course Name	Assembly Engineering		
Degree	B.E.	Programme	Mechanical Engineering	Semester	VII
Date	16.10.2017	Duration	90 minutes	Max. Marks	50
Faculty-in-Charge		Dr. S.Saravana Perumaal			

Assessment Pattern

Remember	Understand	Apply	Analyze	Evaluate	Create	Total
-	15	35	-	-	-	50

Answer All Questions

Part A (Understand) 5 x 3 = 15

A1. State any three consequences of tight tolerance in manufacturing.

A2. Define key characteristics and draw a simple sketch of product with its key characteristics.

A3. Name any four factors influencing assembly system design.

A4. State the characteristics of fixed automation.

A5. Write any three design guidelines for ease of automated assembly.

Part B (Apply) 1x 7 + 2 x 6 + 2 x 8 = 35

B1. A 32 mm diameter hole in a mass produced component is made within the limits 32.035 mm and 32.000 mm. The two grades of shafts as shown in table are used to fit in the hole.Calculate the maximum tolerances, clearances and indicate the type of fit in each case. (07)

Grade I	Grade II
31.955 mm	32.055 mm
31.925 mm	32.050 mm

(OR)

B2. Interpret the meaning of geometrical tolerances of the parts as shown in figure 1 (a,b&c). (07)

B3. Draw the liaison diagram for the assembly shown in figure 2. (08)

(OR)

B4. Determine the feasible sequence for the coupling assembly as shown in figure 3 using liaison diagram. (08)

B5. The precedence diagram for an assembly is given in figure 4. Assume Annual demand=100,000 units/year. The line will operate 50 wk/yr, 5 shifts/wk, 7.5 hr/shift. Uptime efficiency=96%. Determine total work content time and required hourly production rate to achieve the annual demand. (06)

(OR)

B6. Consider an two automobile assembly unit has following data: Customer demand = 1000 / day; No of Shifts working = 2; Working time = 8 hrs/ shift; Lunch Break = 30 min/ shift; Tea time = 2 times/shift @8 min/tea break. Determine TAKT time. (06)

B7. Determine the proportion of the downtime for indexing machine with following data: Machine cycle time=5 sec; Average time for troubleshooting = 25 sec; Average value of the part quality=0.01; Number of workheads = 10; Number of assemblies produced = 100; Assume all the defective parts will produce a stoppage of the machine. (06)

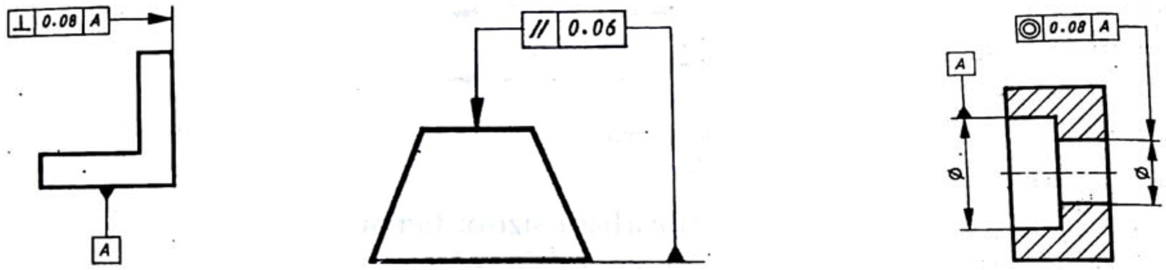
(OR)

B8. In a free-transfer machine, Machine cycle time= 6 sec; Average time for clearing a fault = 30 sec; Average value of the part quality=0.01; Buffer capacity = 4; Number of workheads = 10; Number of assemblies produced = 100; Determine the average production time for this free-transfer machine. (06)

B9. Suggest a suitable modification for the following components shown in figure 5(a,b &c) for ease of manual assembly. (08)

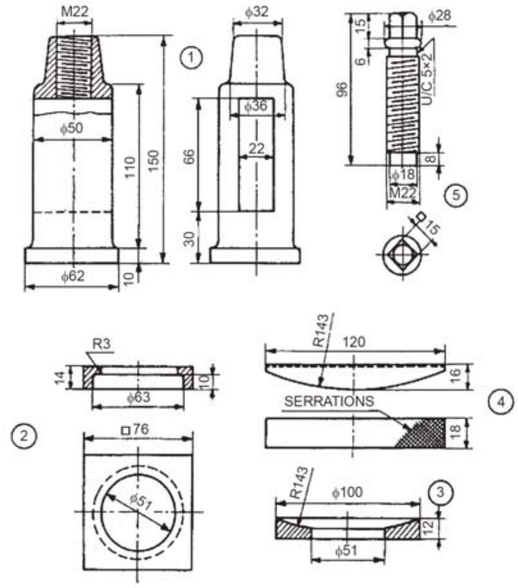
(OR)

B10. Recommend suitable modifications in the design for assembly of component shown in figure 6. (08)



(a) (b) (c)

Figure 1



Parts list

No.	Name	Matl	Qty
1	Piller	MCS	1
2	Block	MCS	1
3	Ring	MS	1
4	Wedge	MCS	1
5	Screw	TS	1

Figure 2

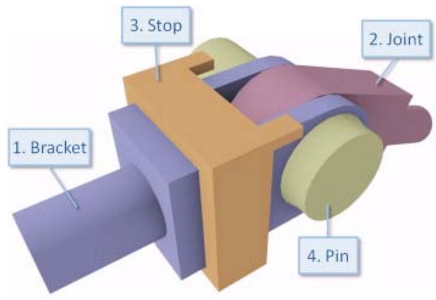


Figure 3

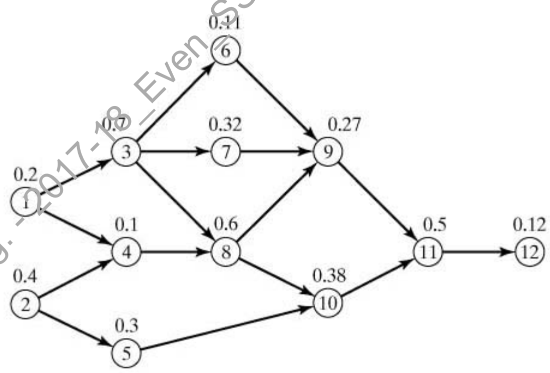
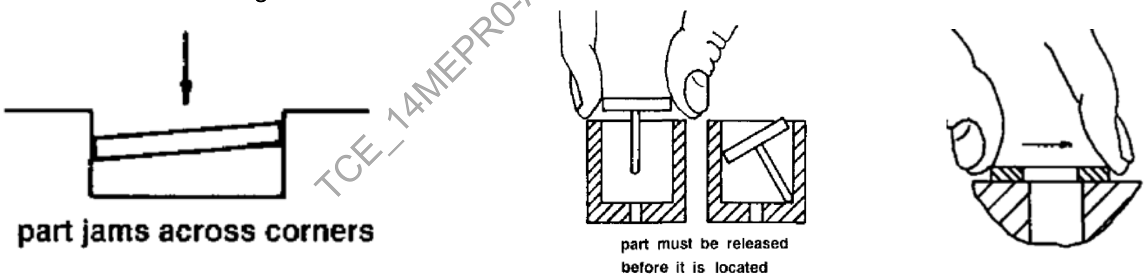


Figure 4



(a) (b) (c)

Figure 5

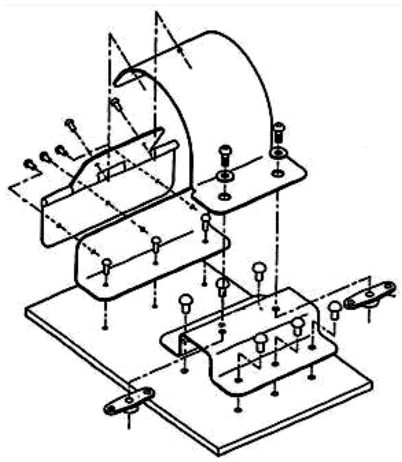


Figure 6