

*MAE 2250*

*CONTROLLING SPATIAL VARIABILITY in MECHANICAL DESIGN*

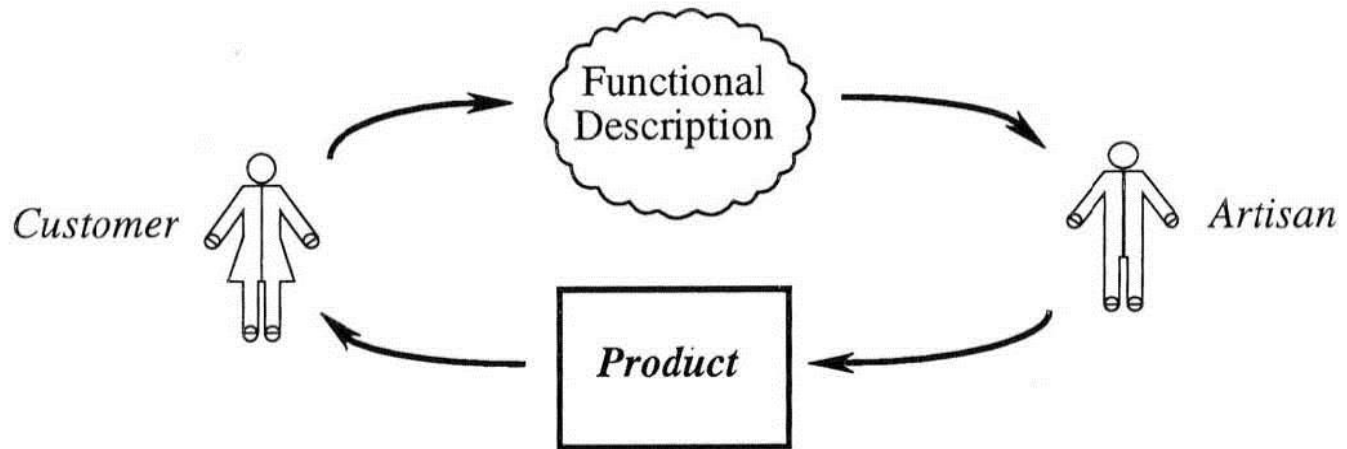
*( CONTROLLING SIZE, SHAPE, & POSITIONAL VARIABILITY ... )*

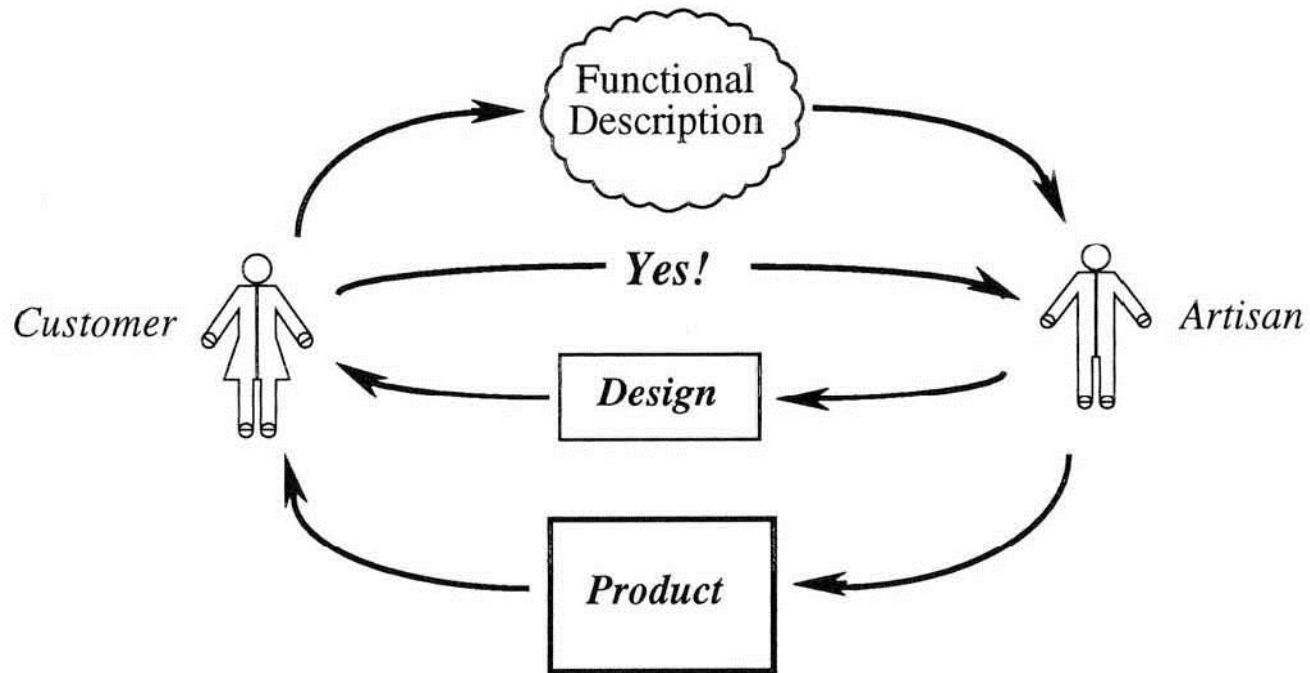
*by*

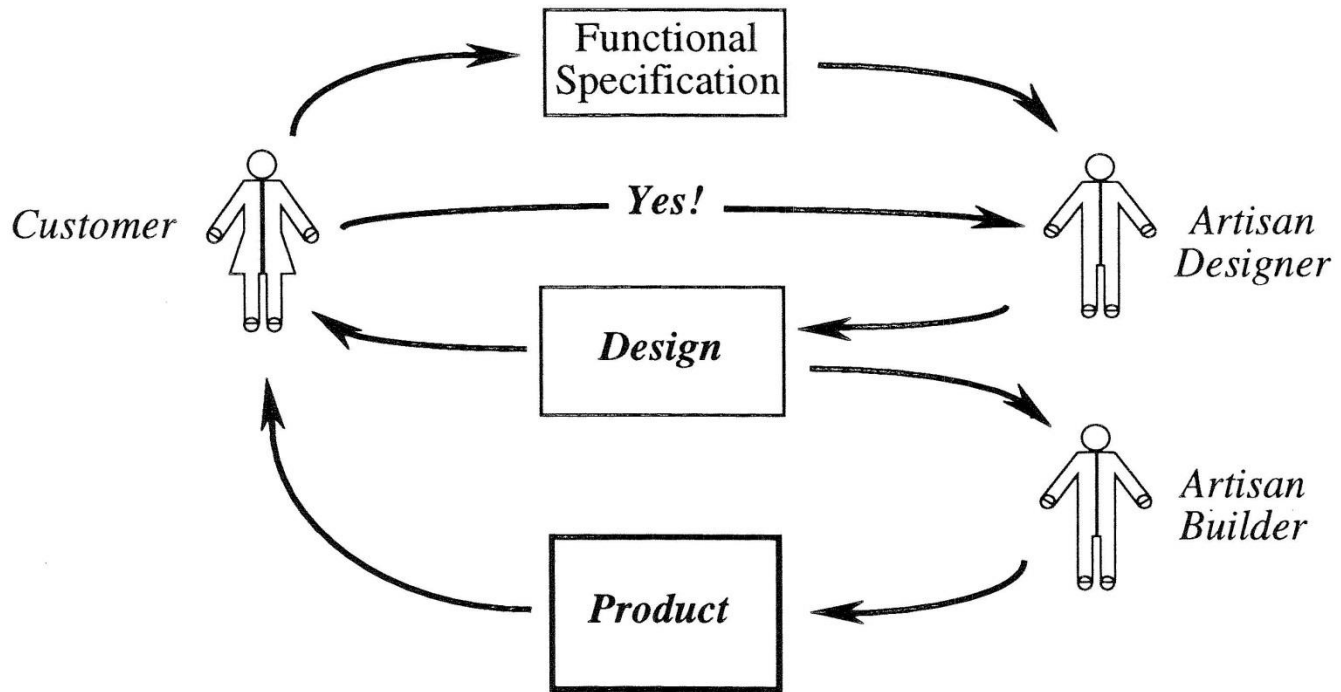
*PROF. H. B. VOELCKER*

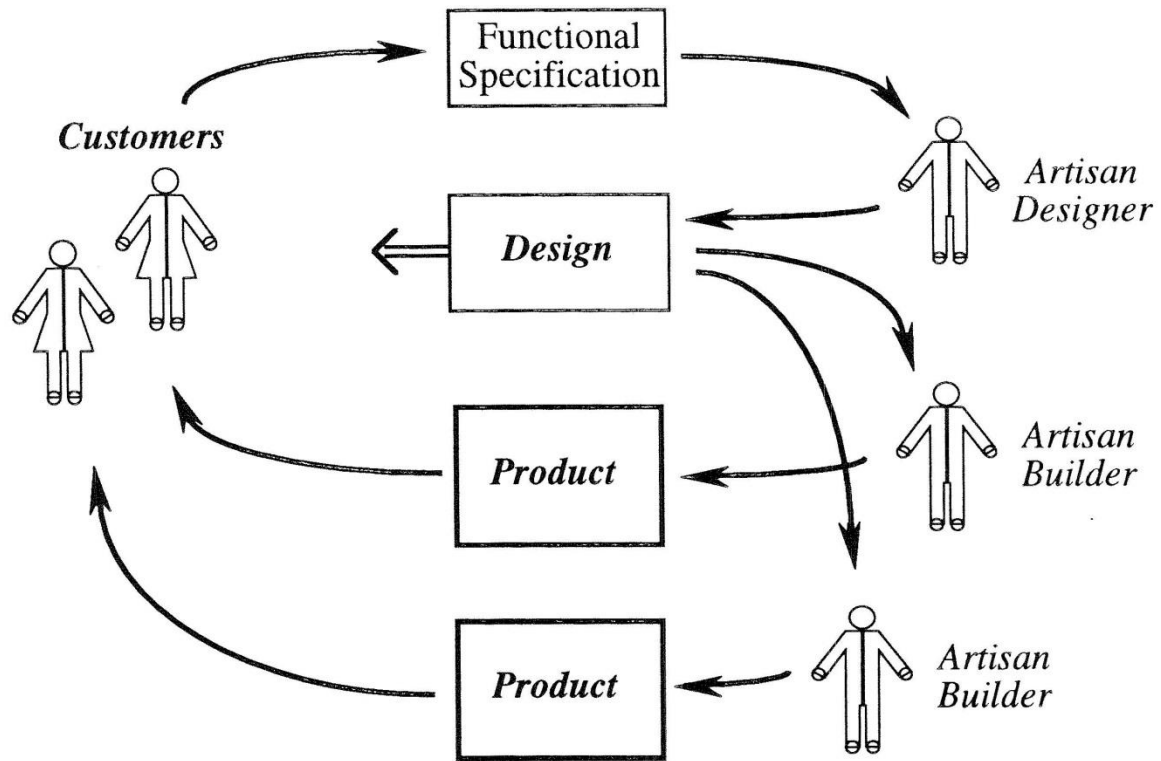
1 – TRADITIONAL (PARAMETRIC) TOLERANCES

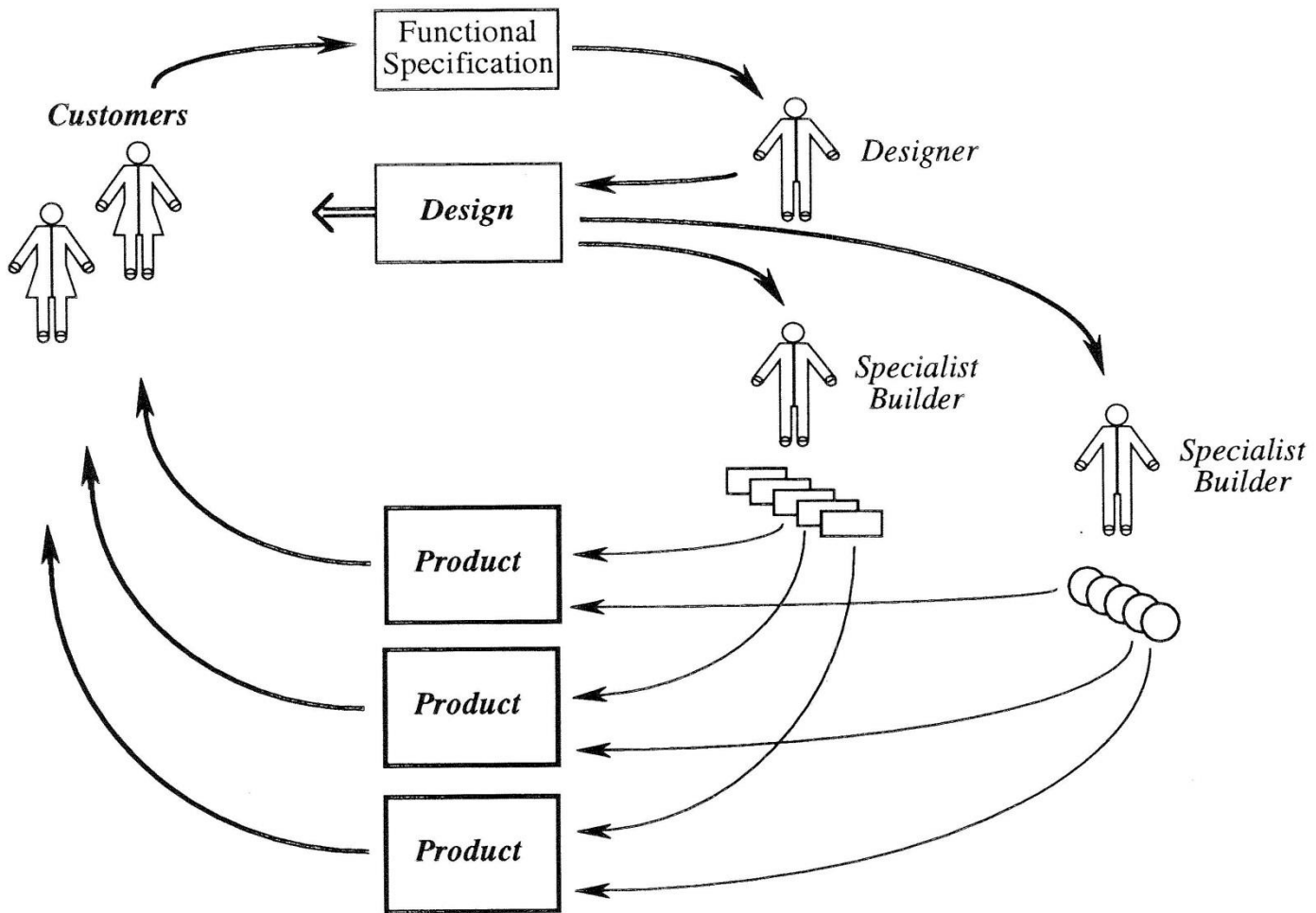
2 – ASSEMBLIES & GEOMETRIC TOLERANCES











- Mechanical *parts* VARY in  $\left\{ \begin{array}{l} \text{'form' (size, shape, surface)} \\ \text{material properties} \end{array} \right.$
- Mechanical *assemblies*  $\left\{ \begin{array}{l} \text{inherit } \textit{part} \text{ variations} \\ \text{introduce new } \textit{relational} \text{ variations} \end{array} \right.$
- Does variability matter ?  
*Yes, almost ALWAYS ... ..* *functional* *requirements*  
*assembly* *requirements*
- Strategies for managing variability

## THE ARTISAN'S STRATEGY – "*COMPLIANT OVER-DESIGN*"

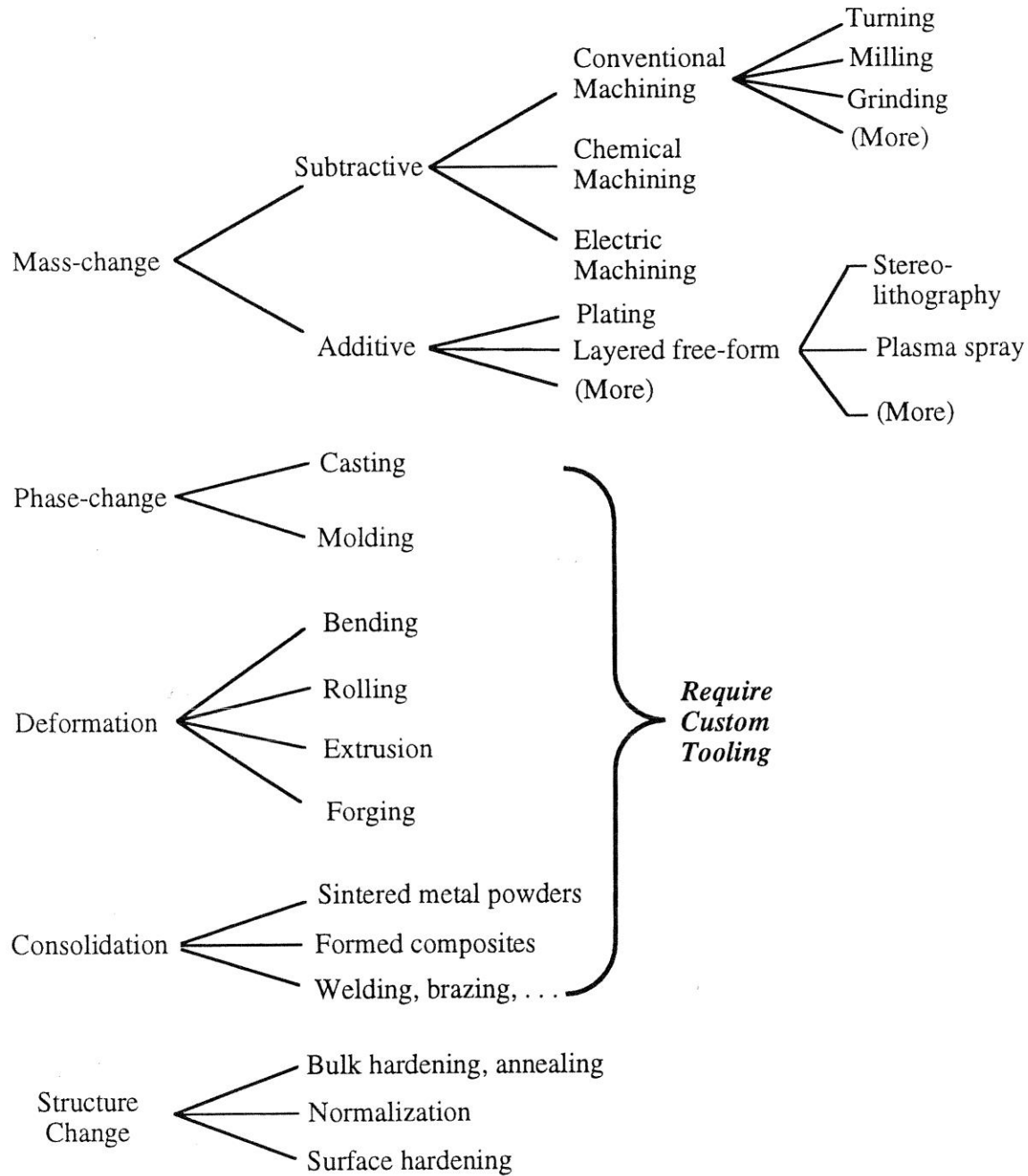
- *Make parts overly strong*
- *Custom-fit the parts ("file-to-fit")*



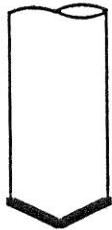
## MODERN INDUSTRIAL PRACTICE –

### *"DESIGN FOR FUNCTION and INTERCHANGEABLE ASSEMBLY"*

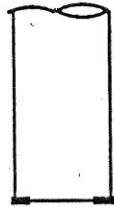
- Specify variability limits for each part using *dimensional tolerances* that are
  - wholly self-referential (cannot refer to other parts)
  - process independent.
- Select and control mfg. processes to meet the tolerances
- Assemble the parts per the assembly plan



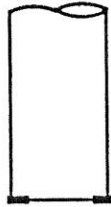
<u><i>PROCESS</i></u>	<u><i>FORM</i></u>
DRILLING	Straight cylindrical hole
BORING	Straight cylindrical hole
REAMING	Straight cylindrical hole
FACE MILLING	Plane surface
PROFILE MILLING	Ruled surface normal to a plane
END MILLING	Ruled surface normal to a plane (Approximations to general curved surfaces)
SHAPING, PLANING	Plane surface
TURNING	Rotationally symmetric surface
• • •	• • •



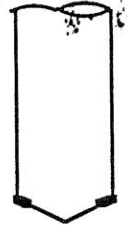
Drill



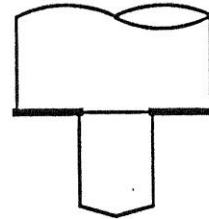
Reamer



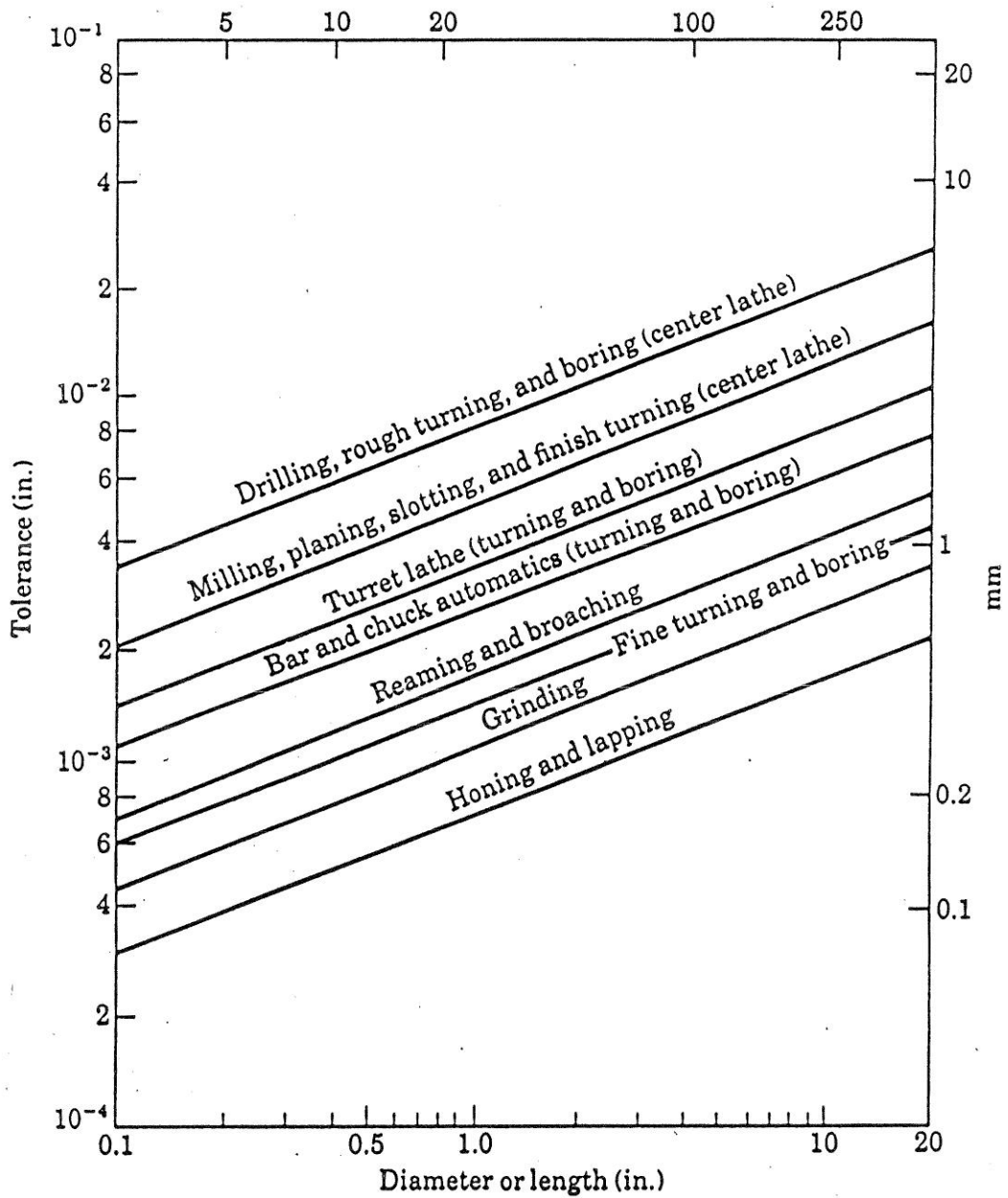
Boring  
tool



Tap



Counter-bore



## Machinery's Handbook (27th Edition) & Guide to Machinery's Handbook



By: Oberg, Erik; Jones, Franklin D.; Horton, Holbrook L.; Ryffel, Henry H. © 2004 Industrial Press

**Description:** This handbook and accompanying Guide provide mechanical and manufacturing engineers, designers, draftsmen, machine toolmakers, machinists and students with a broad range of basic and advanced material. 137 graphs in this title have been made interactive. The PDF files in this book have been encrypted to protect the content from unauthorized use.

### Title Details | Citation

Filter:  Graphs/Tables with Graph Digitizer

#### Table of Contents

Data (Records)

Text

#### • *Machinery's Handbook (27th Edition)*

• Front Matter

 Text


• Preface

 Text

• Table of Contents

 Text

• Interactive Graphs

 **Table** (137)

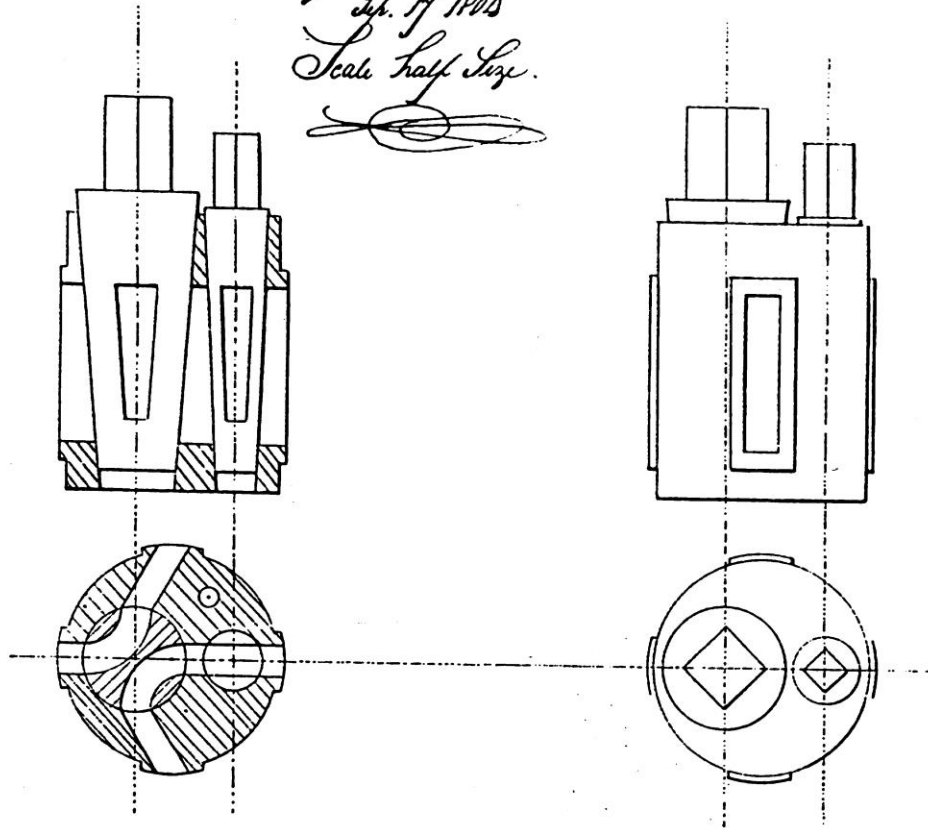
Mathematics

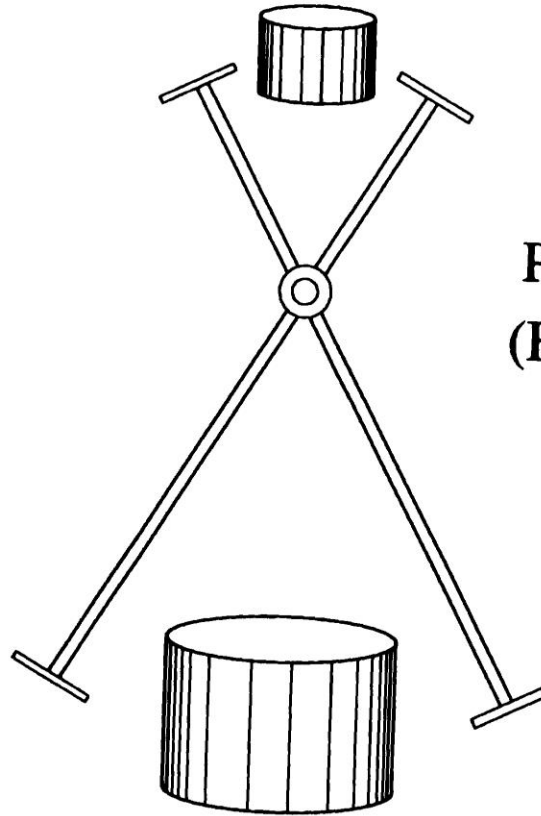
 Text

Mechanics and Strength of Materials

 Text

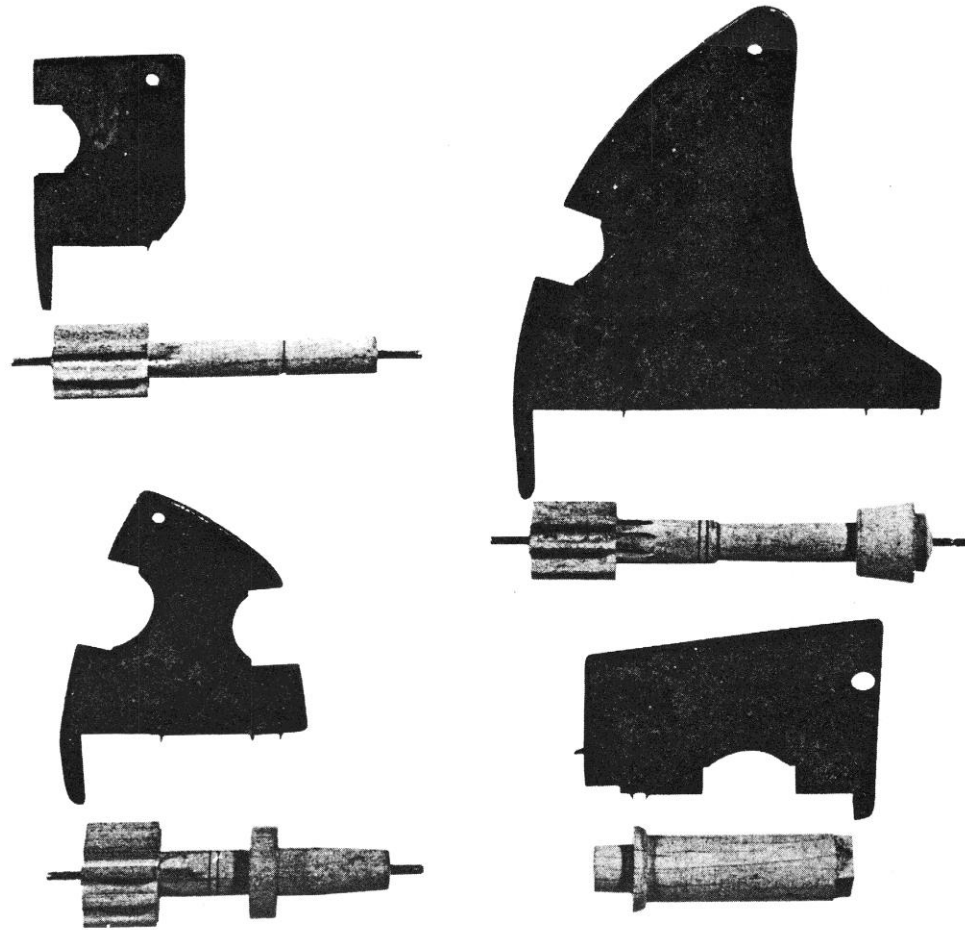
*Regulating & Throttle Valve  
for Engines N° 8  
Sep. 17 1903  
Scale half size.*



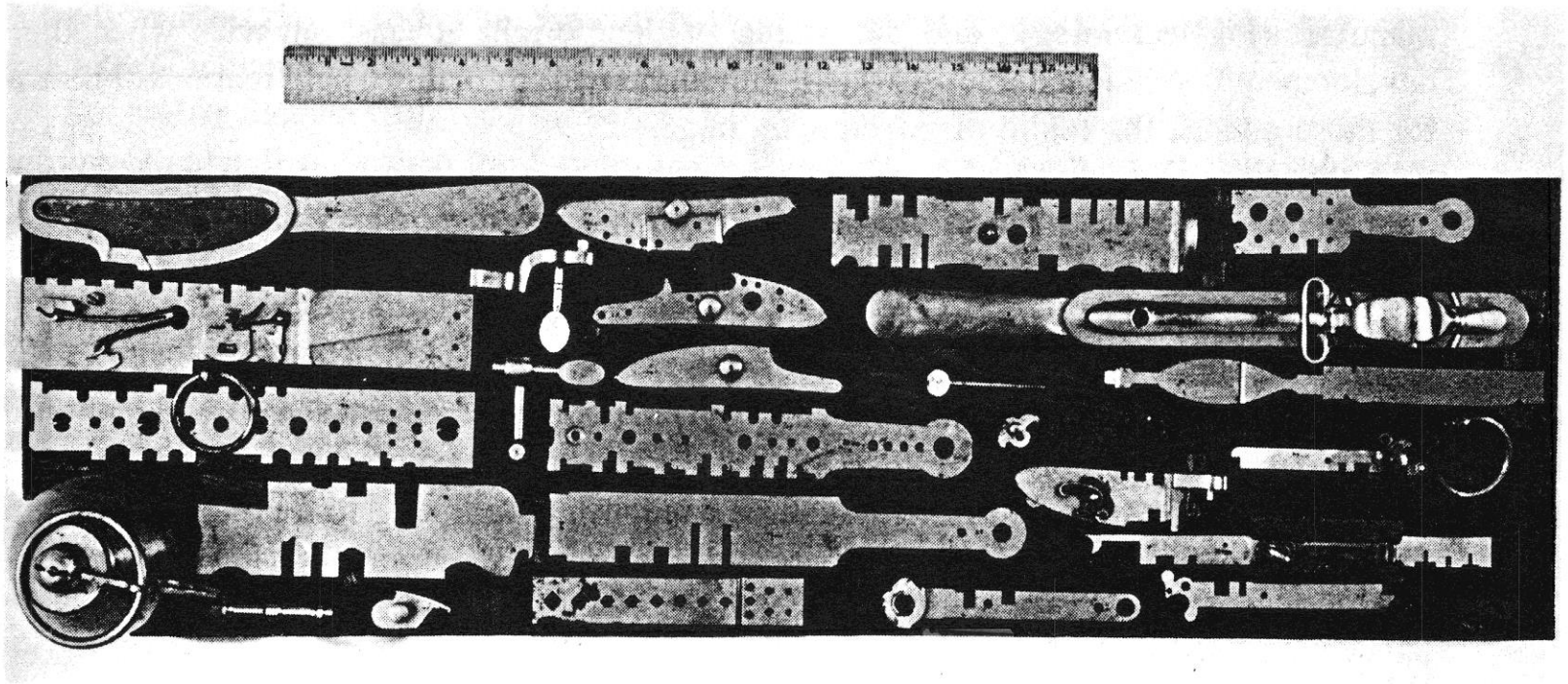


**Proportional  
(Fixed-Ratio)  
Dividers**



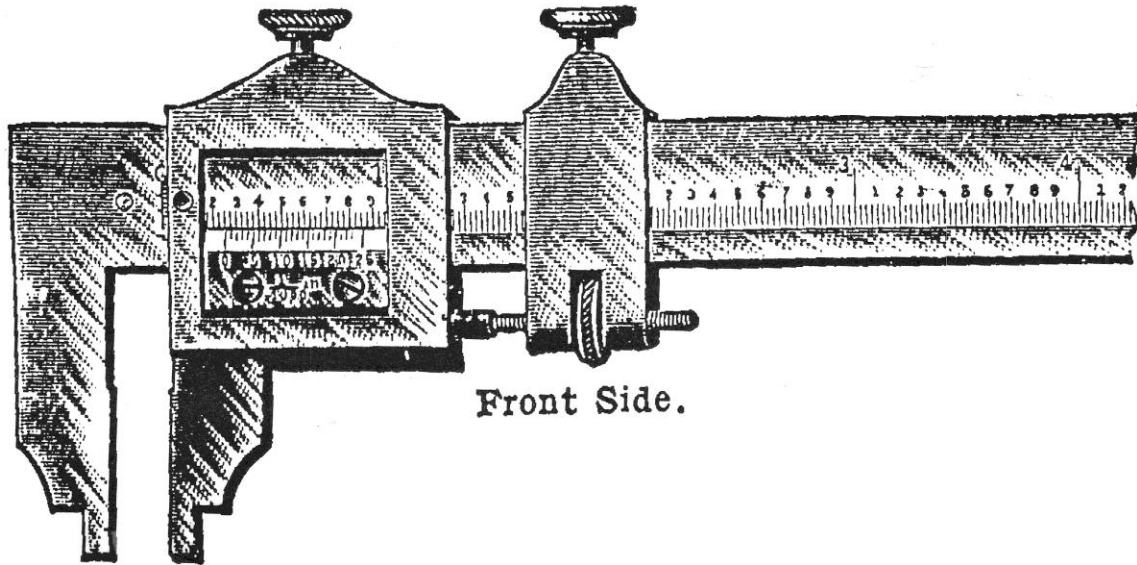


*Inspection & Marking Gages for Seth Thomas Wooden Clocks*



*Inspection Gages for the U. S. Model 1841 Rifle*

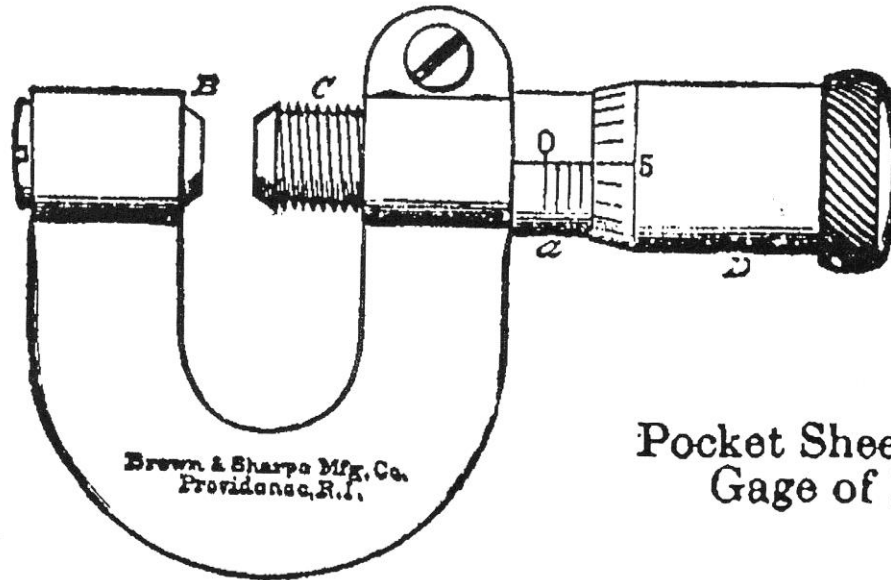
# VERNIER CALIPERS



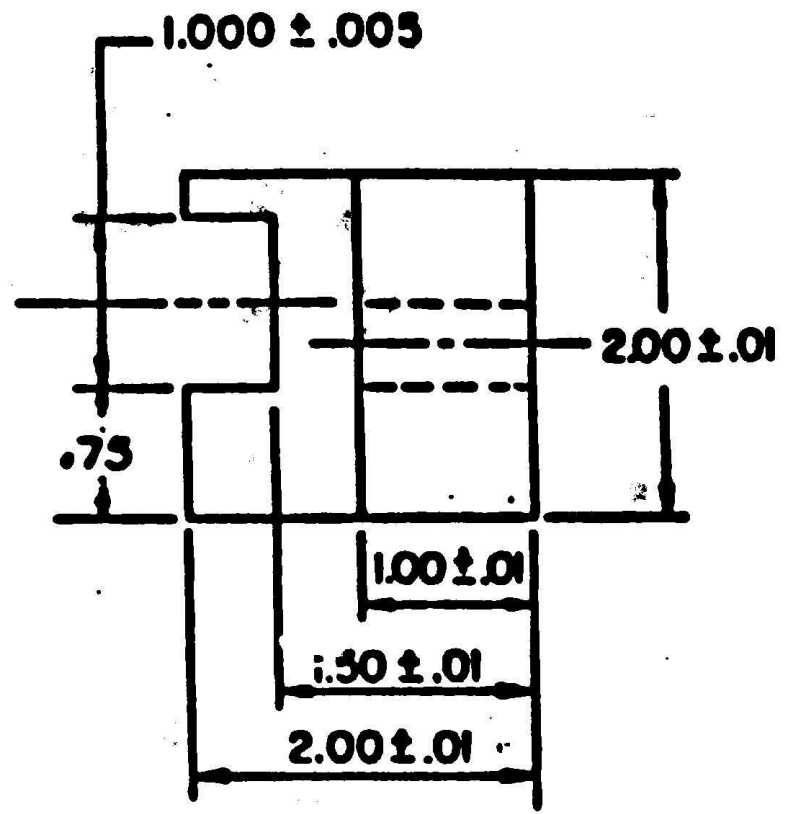
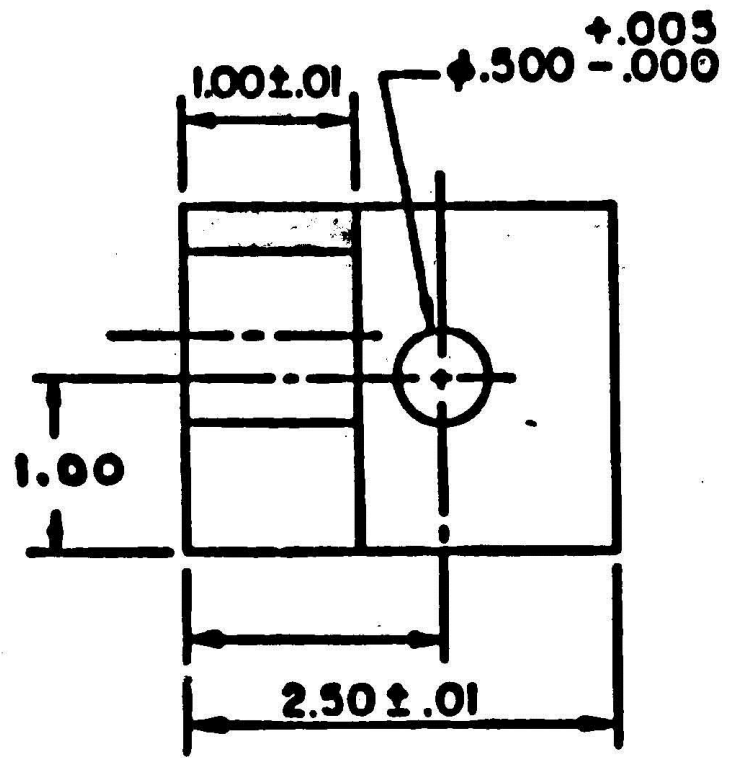
Front Side.

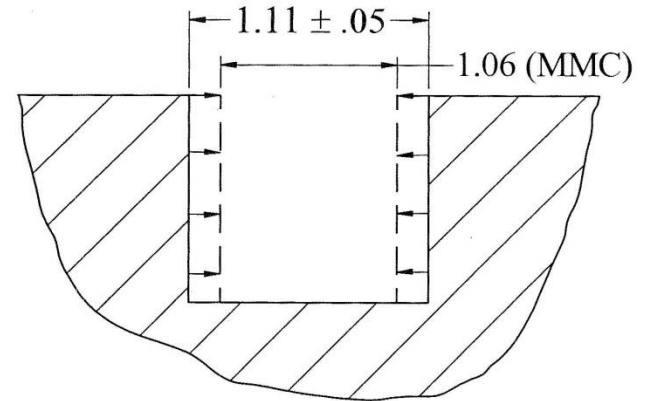
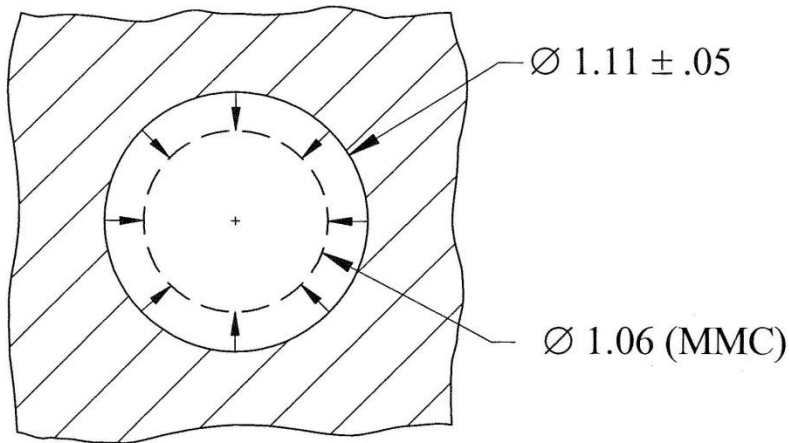
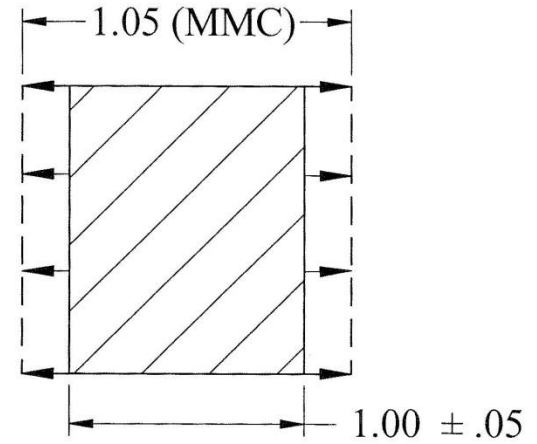
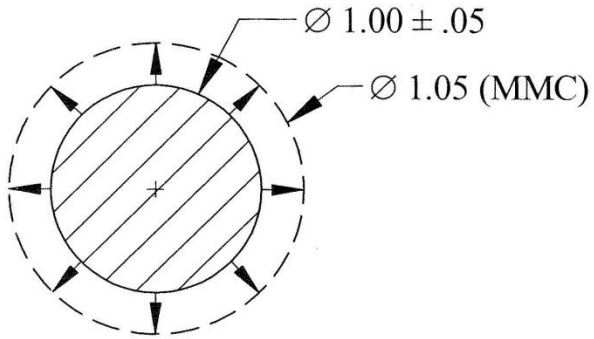
# MICROMETER CALIPER No. 1.

Price, \$4 00. In Morocco Case, \$4 50.



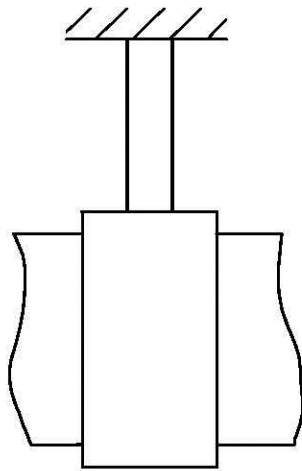
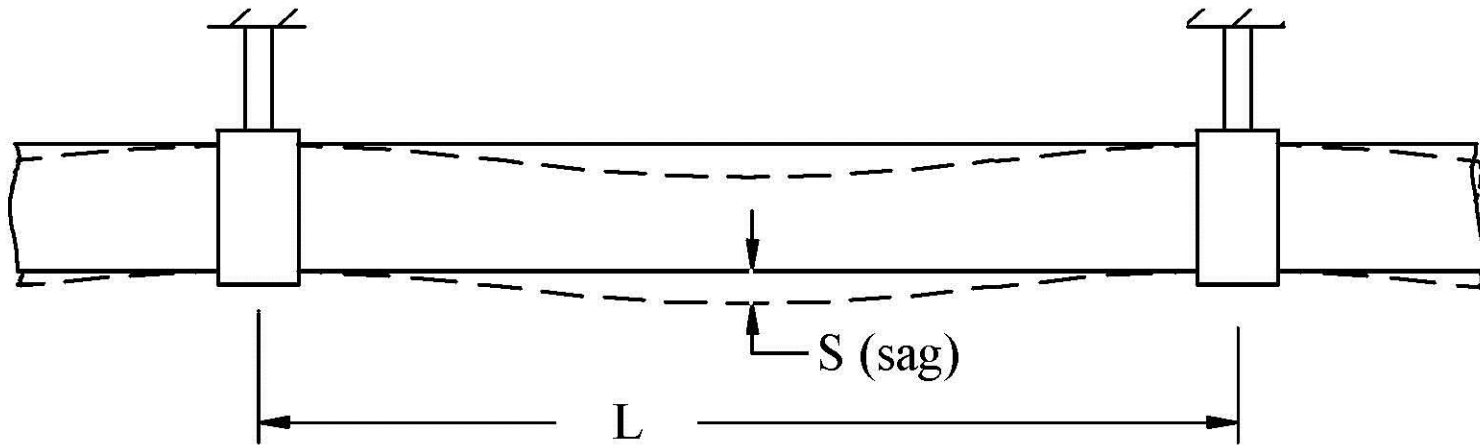
Pocket Sheet Metal  
Gage of 1867



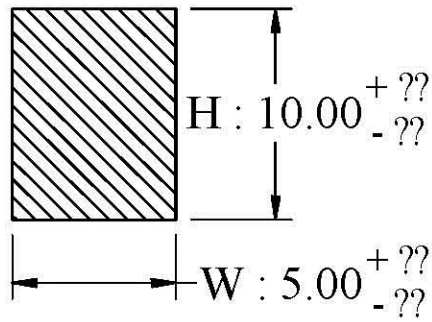


$$A = MMC(\text{Receiver}) - MMC(\text{Insert})$$

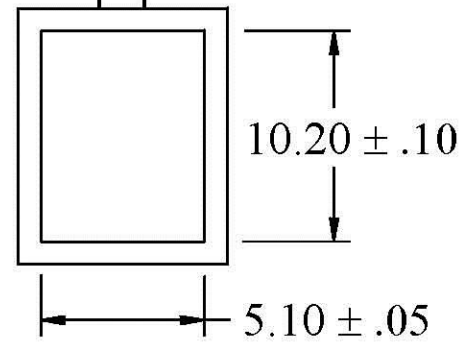
Assembly is guaranteed *iff*  $A > 0$

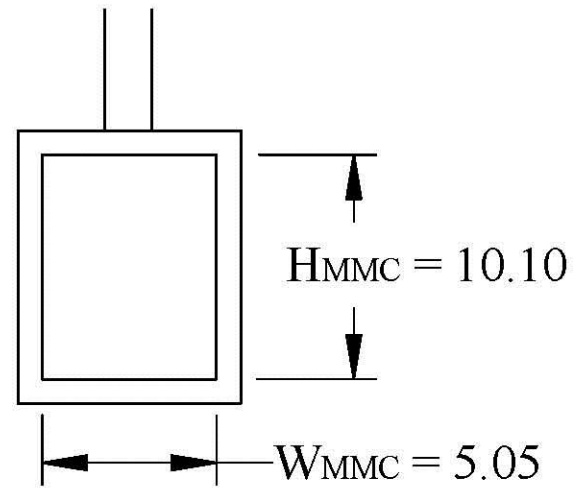
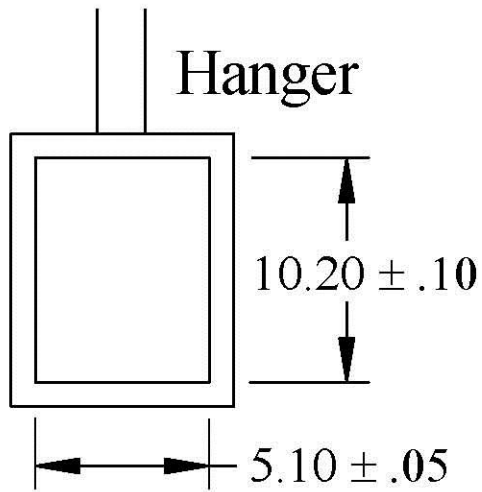


Busbar

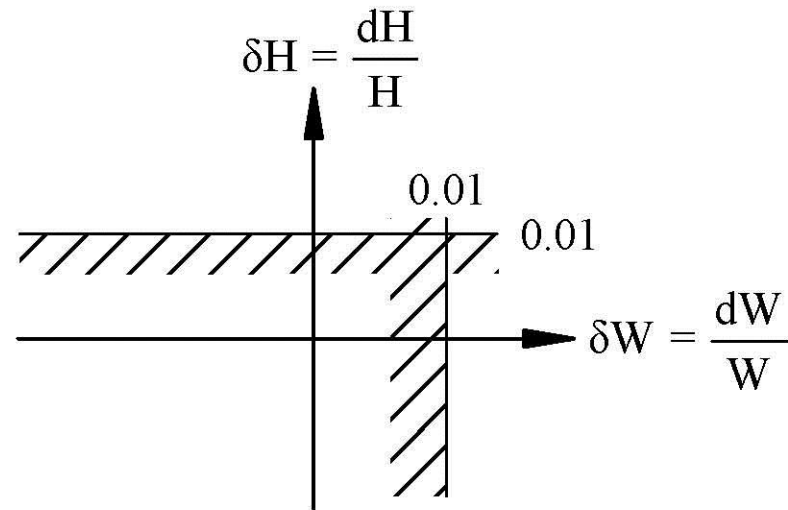
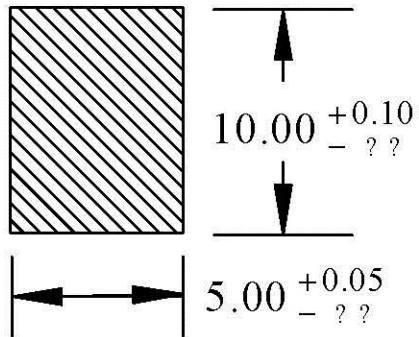


Hanger





Busbar





$$G = gHW$$

= *conductance per unit length*

$$\delta G = \frac{dG}{G} \text{ (fractional change)}$$

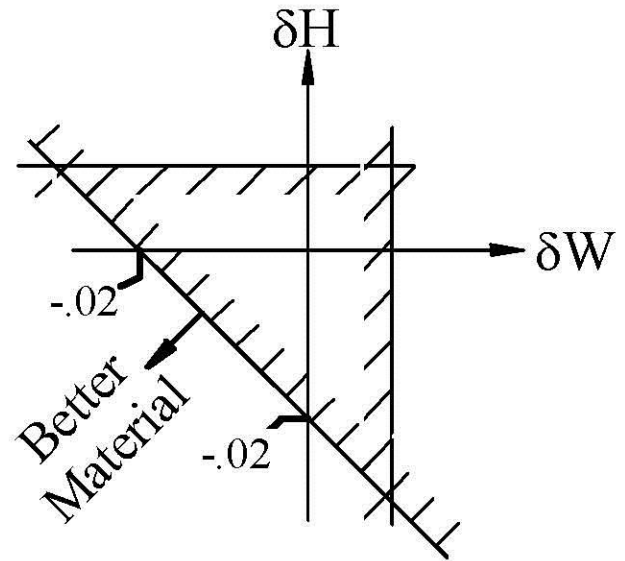
$$= \frac{dGHW + g dHW + gH dW}{gHW}$$

$$= \delta g + \delta H + \delta W$$

If  $\delta G \geq -.02$  (a 2% decrease)

then

$$\delta W + \delta H \geq -(0.02 + \delta g)$$



$$S = K' L^4 H^{-2}$$

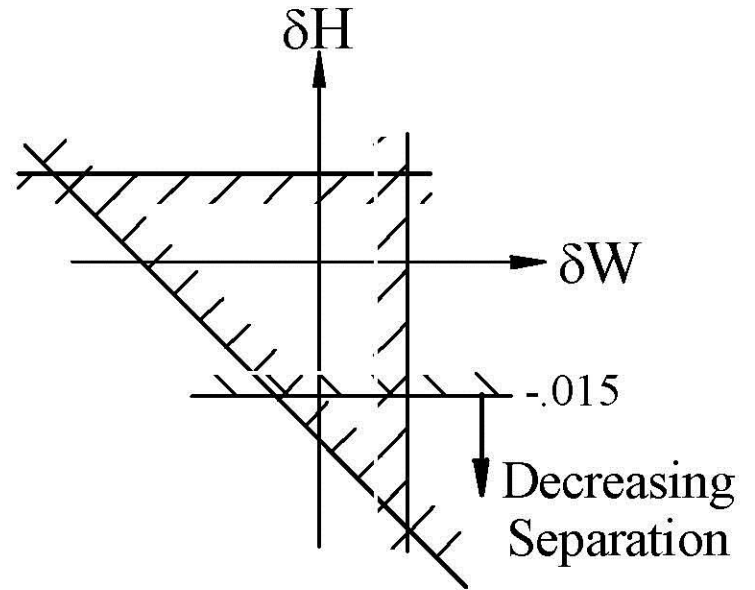
= Sag, for separation  
L between hangers

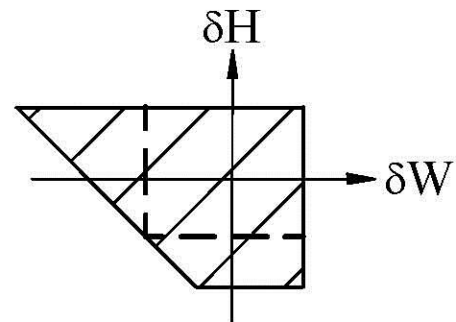
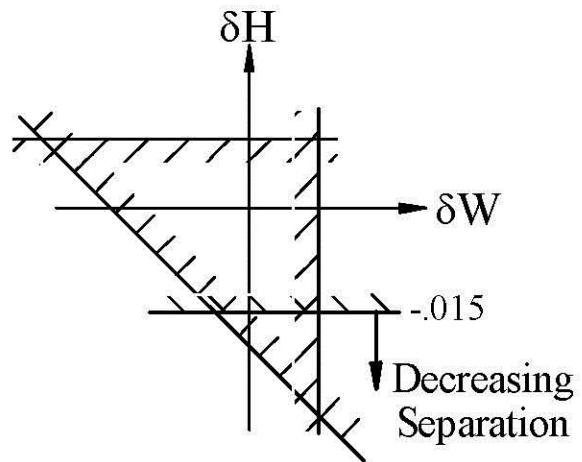
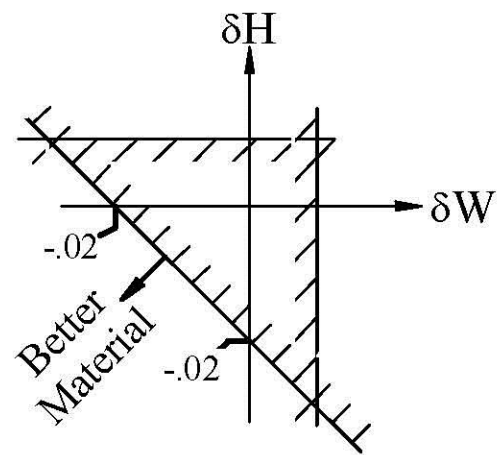
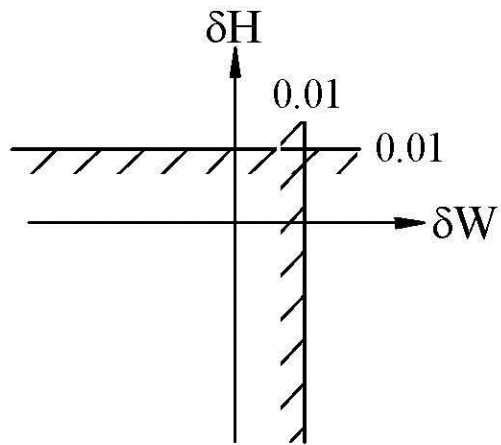
$$\delta S = \frac{dS}{S} \text{ (fractional change)}$$

$$= \frac{K'(4L^3 H^{-2} dL - 2L^4 H^{-3} dH)}{K' L^4 H^{-2}}$$

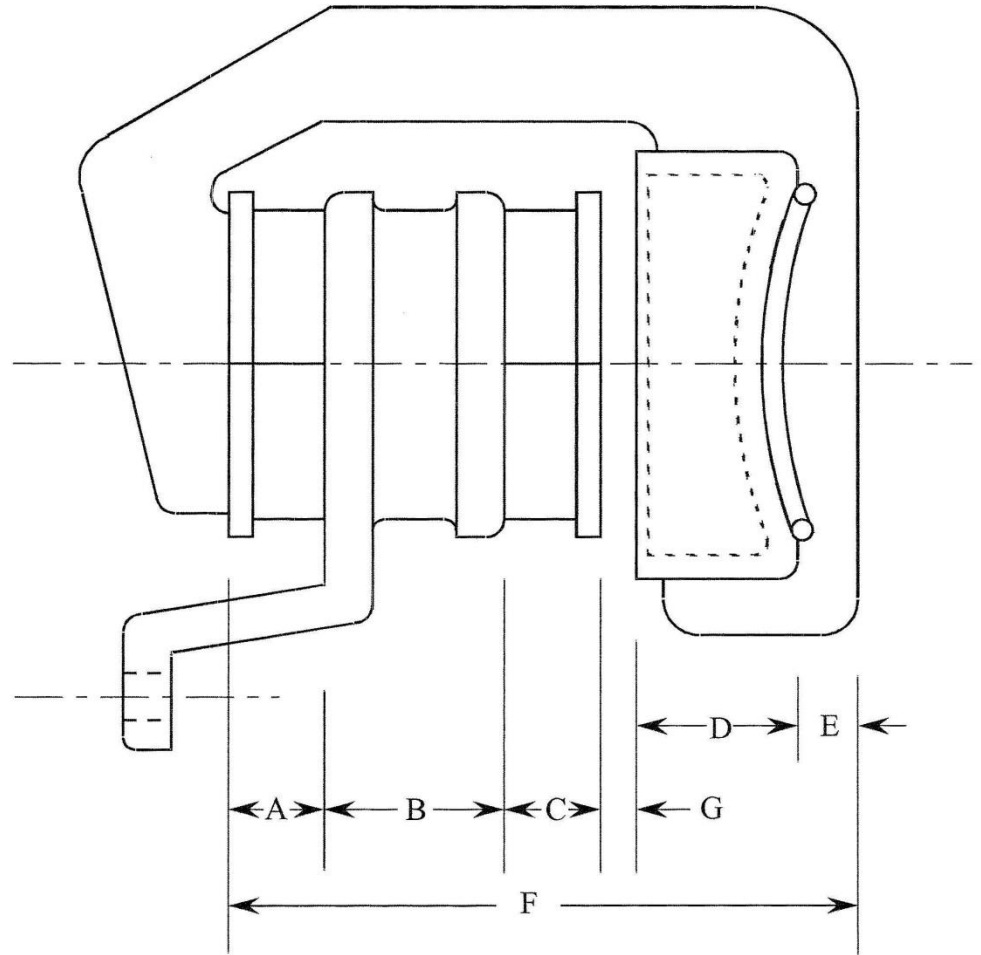
$$= 4\delta L - 2\delta H$$

If  $\delta S \leq 0.03$  (a 3% increase)  
then  
 $4\delta L - 2\delta H \leq 0.03$

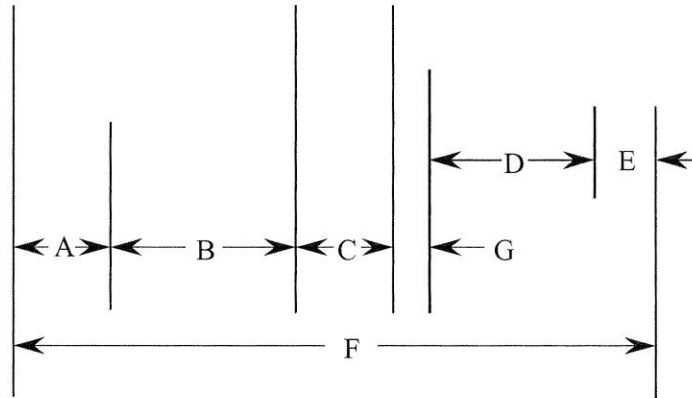




<i>Dimension Name</i>	<i>Nominal Value</i>	<i>Limit Tolerances</i>
A	15.0	$\pm 0.2$
B	30.0	$\pm 0.3$
C	15.0	$\pm 0.2$
D	50.0	$\pm 0.1$
E	11.0	$\pm 0.1$
F	122.0	$\pm 0.1$
G		



<i>Dimension Name</i>	<i>Nominal Value</i>	<i>Limit Tolerances</i>
A	15.0	± 0.2
B	30.0	± 0.3
C	15.0	± 0.2
D	50.0	± 0.1
E	11.0	± 0.1
F	122.0	±0.1
G		



$$F = A + B + C + G + D + E$$

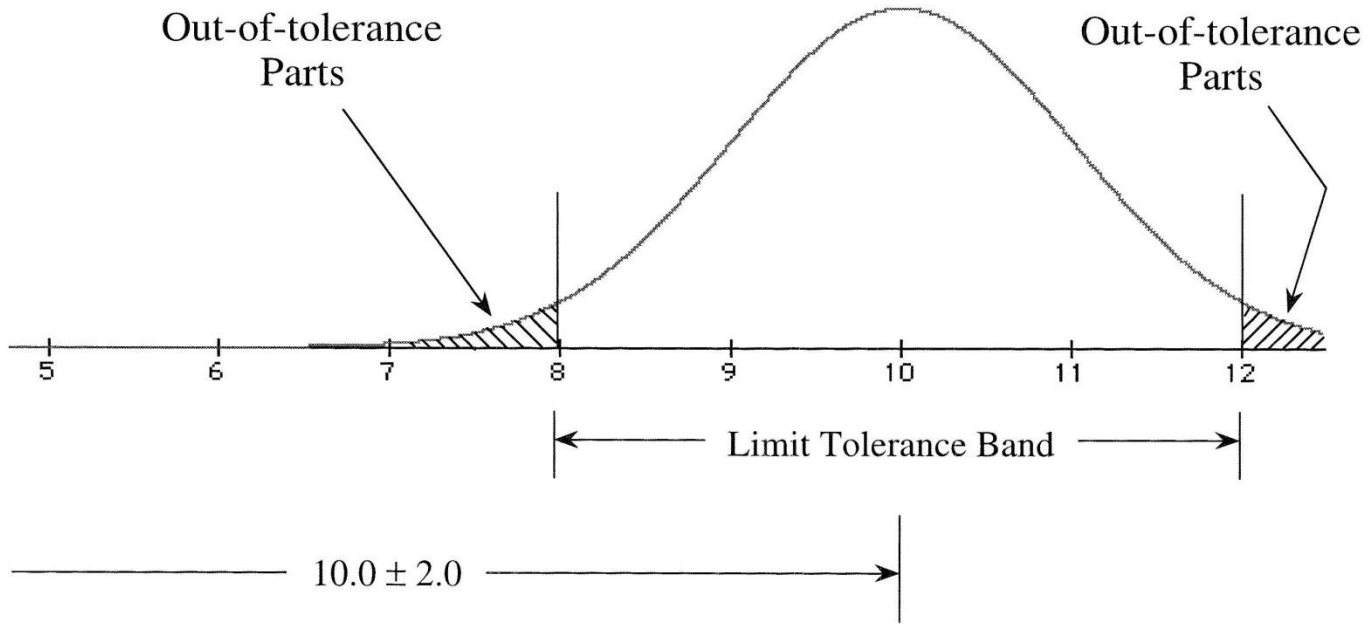
$$\text{so } G = F - (A + B + C + D + E)$$

<p><b><i>Tolerance "Stackup"</i></b>  <b><i>Equations</i></b>  <b><i>for</i></b>  <b><i>1-D Dimension Chains</i></b></p>	$\text{Max } G = \sum_{(+)} \text{Max } x_i - \sum_{(-)} \text{Min } x_i$ $\text{Min } G = \sum_{(+)} \text{Min } x_i - \sum_{(-)} \text{Max } x_i$
--	---

$$\begin{aligned} \text{Max } G &= 122.1 - (14.8 + 29.7 + 14.8 + 49.9 + 10.9) \\ &= 2.0 \end{aligned}$$

$$\begin{aligned} \text{Min } G &= 121.9 - (15.2 + 30.3 + 15.2 + 50.1 + 11.1) \\ &= 0.0 \end{aligned}$$

Normal (Gaussian) *pdf* (Probability Density Function)



Dim. Name	Nominal Value	Limit Tolerances	Std Deviation
A	15.0	$\pm 0.2$	.150
B	30.0	$\pm 0.3$	.225
C	15.0	$\pm 0.2$	.150
D	50.0	$\pm 0.1$	.075
E	11.0	$\pm 0.1$	.075
F	122.0	$\pm 0.1$	.075
G			

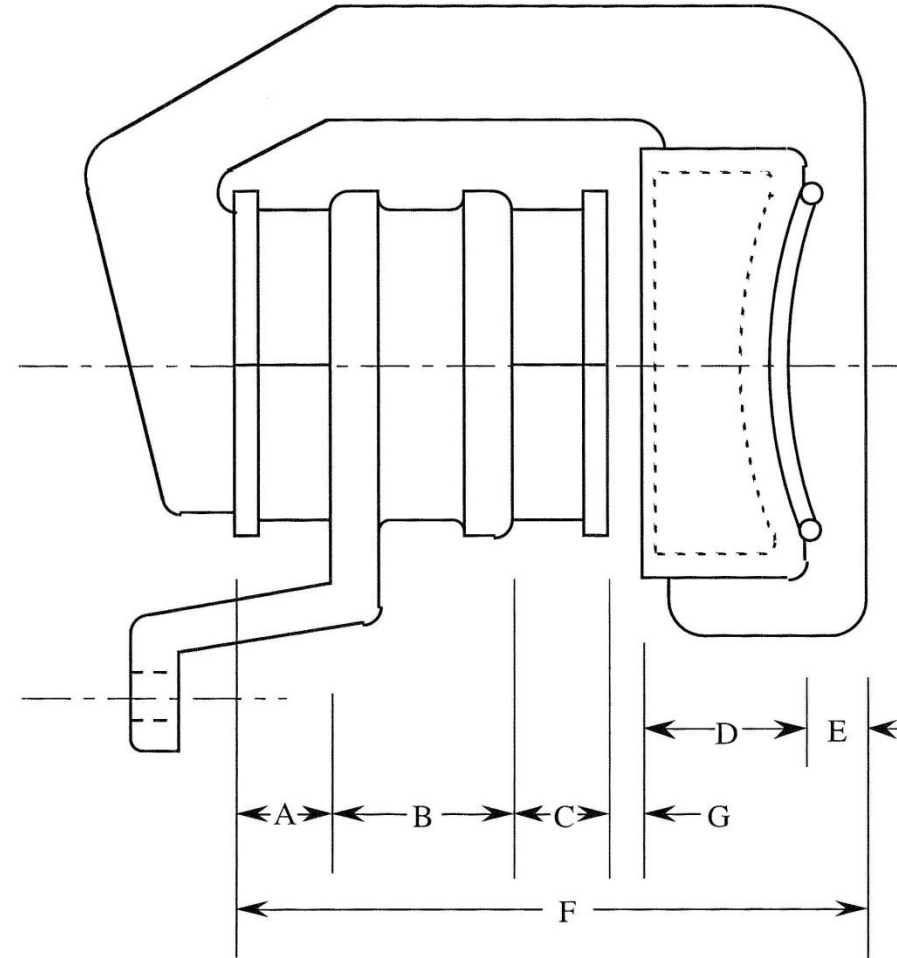
GOAL: Gap  $G \geq 0$  for all disk-brake assemblies.

#### WORST-CASE DESIGN

The goal will be met if all limit tolerances are met.

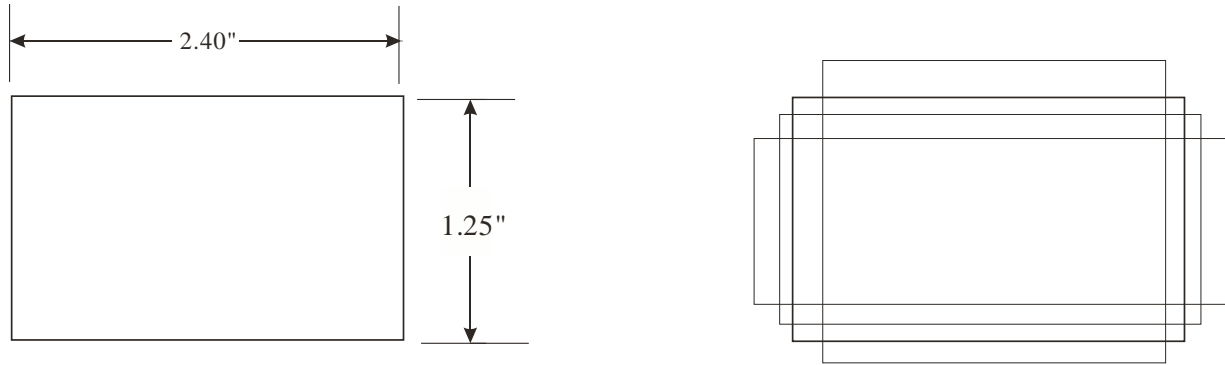
#### STATISTICAL DESIGN

- About 18% of each part type will fall outside of the worst-case limits for the given standard deviations, and yet
- Only .14% of the brake assemblies will fail the gap test (*if* the underlying assumptions are valid).



# LIMITATIONS OF PARAMETRIC TOLERANCES

## WEAK MODEL OF VARIABILITY

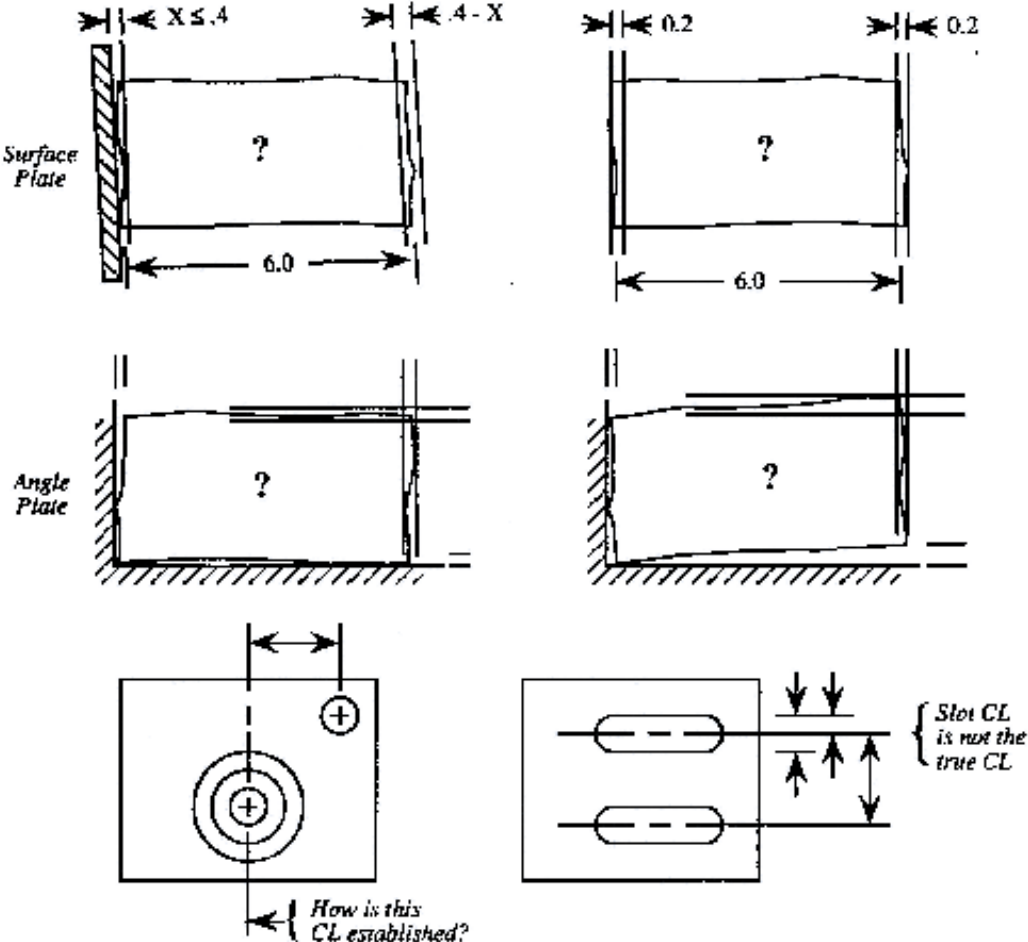


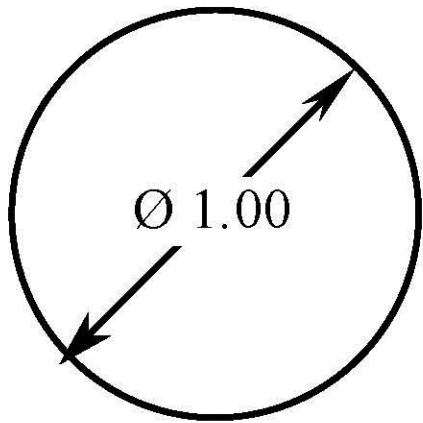
## TWO OF THE UNCONTROLLABLE VARIATIONS



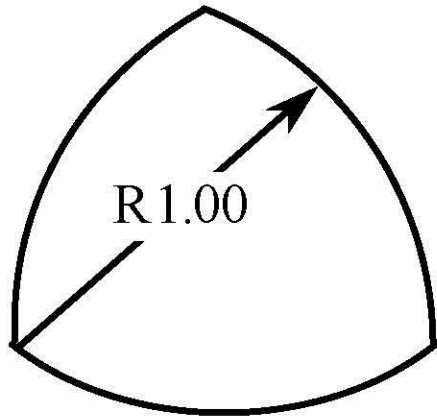


# MORE LIMITATIONS – LACK OF DEFINED PROCEDURES

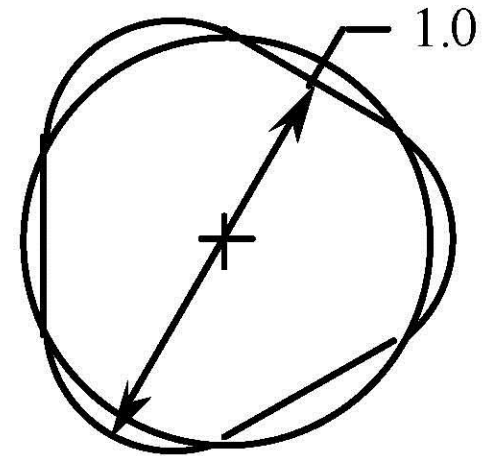




Circular Section



Reuleaux Section



Fourier Section

