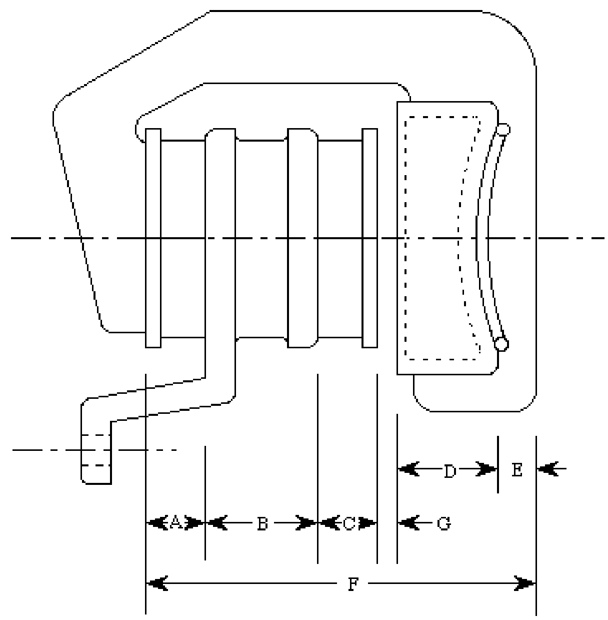
# *MAE 1170 – Introduction to Mechanical Engineering*

## *Problem HV-1*

September 2009

The dimensions shown in the illustration control the assembly and operation of a disk brake. Each dimension has –

| Actual Value | Nominal Value | Limit Tolerances | Exemplary Values | |
|---|---|---|---|---|
| | | | Nominal | Tolerances |
| $\underline{A}$ | A | $+a_1$<br>$-a_2$ | 15.0 | $\pm 0.2$ |
| $\underline{B}$ | B | $+b_1$<br>$-b_2$ | 30.0 | $+0.2$<br>$-0.3$ |
| $\underline{C}$ | C | $+c_1$<br>$-c_2$ | 15.0 | $\pm 0.2$ |
| $\underline{D}$ | D | $+d_1$<br>$-d_2$ | 50.0 | $\pm 0.1$ |
| $\underline{E}$ | E | $+e_1$<br>$-e_2$ | 11.0 | $\pm 0.1$ |
| $\underline{F}$ | F | $+f_1$<br>$-f_2$ | 122.0 | $+0.1$<br>$-0.2$ |
| $\underline{G}$ | G | | | |




- An *actual* ("real", measured) value denoted by $\underline{A}$, $\underline{B}$, … .
- A *nominal* (ideal, design-target) value denoted A, B, … .
- High and low tolerance limits denoted $a_1$, $a_2$, $b_1$, … whose values are always $\geq 0$.
- The nominal value and tolerance limits define an allowable range for an actual value; specifically, a real dimension $\underline{A}$ is "in-spec" if and only if $A - a_2 \leq \underline{A} \leq A + a_1$ .

Note in the diagram that if values are assigned independently to A, B, … F, Gap G cannot be assigned an independent value; it is determined by the other values, and it "inherits" variability limits from the other dimensions. This inheritance process is called tolerance accumulation or "stack-up".

1) Find symbolic expressions for $G_{max}$ and $G_{min}$ , the maximum and minimum of G, in terms of the nominal values A, B, … and tolerance limits $a_1$, $a_2$, $b_1$, … .

   How? Start at the left side of the gap G and traverse the chain of dimensions until you get to the right side, recording the path as a sequence of signed distances.

   $$G = -C - B - A + F - E - D \ , \quad \text{or} \quad G = F - (A + B + C + D + E) \ .$$

   Now calculate the maximum and minimum of G. If you don't see how to do this, study a simpler case for insight. For example: if $X = Y - Z$ , then $X_{max} = Y_{max}$ - ($Z_{max}$ or $Z_{min}$??), where $X_{max} = X + x_1$ , and so forth.

2) What practical considerations govern the acceptable ranges of values for $G_{max}$ and $G_{min}$ ?

3) Use the results of 1. to evaluate the gap limits for the numerical values in the table. Can the brake *always* be assembled, and is it likely to work acceptably *always*, with these values?

*Discussion*

When limit tolerances are used to control the dimensional variability of parts in assemblies, the parts' assemblability and performance can be *guaranteed* if the tolerances are assigned correctly and if *every* controlled dimension is checked to insure that it conforms to its limits. This guarantee comes with a relatively high price tag, because relatively accurate manufacturing processes must be used and every dimension must be checked.

When some assembly or performance failures can be tolerated, manufacturing and inspection costs can be reduced substantially by using *statistical* tolerancing. The basic idea is that 'high' variations in some parts will be cancelled by 'low' variations in other parts 'most of the time'. This approach is widely used for some kinds of products -- mainly those that pose no safety or environmental hazards and that are made in large enough quantities to allow the "law of averages" to work.

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