Precision Machine Design: Constant preload

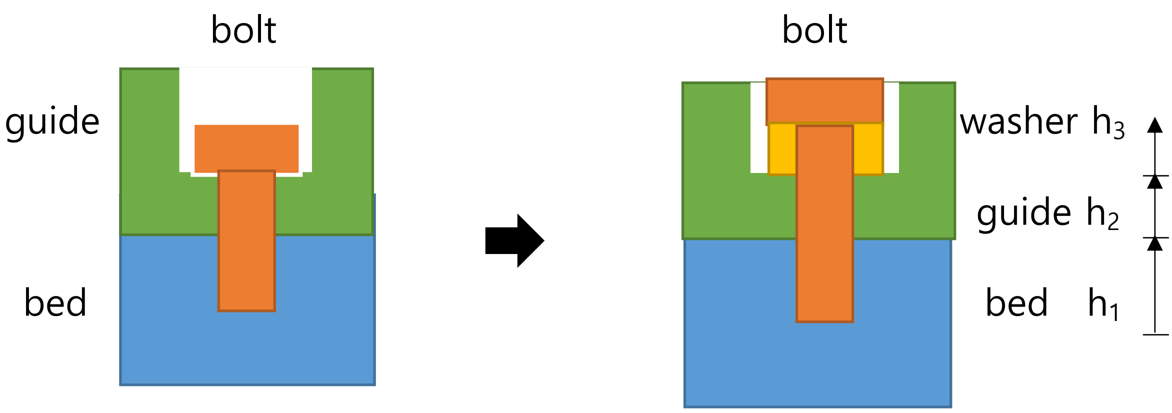
Design for Constant Preload

:Design strategy for keeping constant preload under the thermal deformation.

Temperature change gives not only thermal elongation of structures, but change in preloading between elements due to thermal strain induced. The loosening in preloading significantly deteriorates the stiffness, vibration/noise, inaccurate functioning of machine, etc.

The bolted structure of machine guideway is a typical example. (source from Slocum)

Bolted guideway



Configurations: Bolt slot for avoiding interference, materials of different expansion coefficients for bed(cast iron), guide(steel), and bolt(alloy-steel), where α_{bed}=10ppm/˚C, α_{guide}=12ppm/˚C, α_{bolt}=10ppm/˚C. Temperature decrease (-T) gives less shortening in the bolt length than the corresponding bed and guide length, thus the bolting force (or preload) is loosened. This situation can be avoided by adding an epoxy washer (α_w=5ppm/˚C) to compensate the thermal deformation.

$\Delta bed=\int_0^{h1}\alpha_{bed}(-T)dx=-\alpha_{bed}h_1T$;

$\Delta guide=\int_0^{h2}\alpha_{guide}(-T)dx= -\alpha_{guide}h_2T$

$\Delta washer=\int_0^{h3}\alpha_w(-T)dx=-\alpha_w h_3T$; and

$\Delta bolt=\int_0^{h1+h2+h3}\alpha_{bolt}(-T)dx= -\alpha_{bolt}(h_1+h_2+h_3)T$

Thermal deformation should be the same, which is to maintain the constant preload.

$\Delta bolt=\Delta bed+\Delta guide+\Delta washer$,

$\therefore \alpha_{bolt}(h_1+h_2+h_3)= \alpha_{bed}h_1+ \alpha_{guide}h_2+ \alpha_{washer}h_3$

$h_1=10$, $h_2=10$ (given)

Thus, $h_3=[(\alpha_{bed}-\alpha_{bolt})h_1+(\alpha_{guide}-\alpha_{bolt})h_2]/[\alpha_{bolt}-\alpha_{washer}]=4$ [mm]

And bolt length$=h_1+h_2+h_3=24$[mm]

Washer has another effect of avoiding stress concentration on the bolted structure.

Therefore, for 1˚C decrease, T=-1

<u>With washer</u>

Δbed=10(0.01)(-1)=-0.1[um], Δwasher=5(0.004)(-1)=-0.02[um]

Δguide=12(0.01)(-1)=-0.12[um],

Δbolt=10(0.024)(-1)=-0.240[um]

$\therefore\Delta$bolt=Δbed+Δguide+Δwasher

<u>$\therefore$Bolting stress is maintained under the temperature change</u>

<u>Without washer</u>

h_1=10, h_2=10;

Δbed=10(0.01)(-1)=-0.1;

Δguide=12(0.01)(-1)=-0.12

Δbolt=10(0.02)(-1)=-0.2; $\therefore$ Δbolt-(Δbed+Δguide)=0.02[um];

<u>$\therefore$Bolting stress is changed, and loosening in bolting, which is undesirable</u>

Air temperature control techniques

:To stabilize temperature and temperature gradient for minimum thermal error

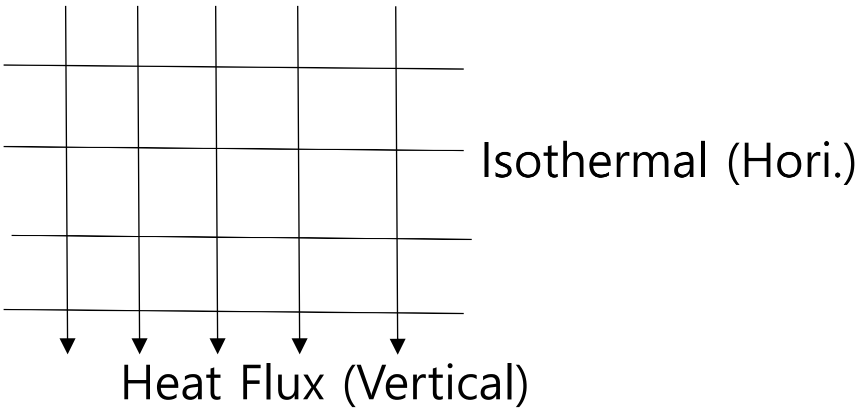
Vertical Laminar Air Flow

:To provide horizontal isothermal lines,

much similar to the conduction

:To give minimum interference for air flows

:Less than 0.125 m/s for comfort



The followings are typical examples for air temperature control

(source: Hans J. Hansen, techniques for precision air temperature control)

1) Thermal enclosure

Plastic curtain enclosure with top air blowers

Control scheme in heating with controller

To keep temperature higher than the environment

To provide net positive pressures and laminar flows downward

To limit the entry of operator with minimum requirements of arms and hands

Compact, efficient configuration

±0.3˚F (±0.16˚C) observed

while outside environment within ±2.0˚F (±1.1˚C)

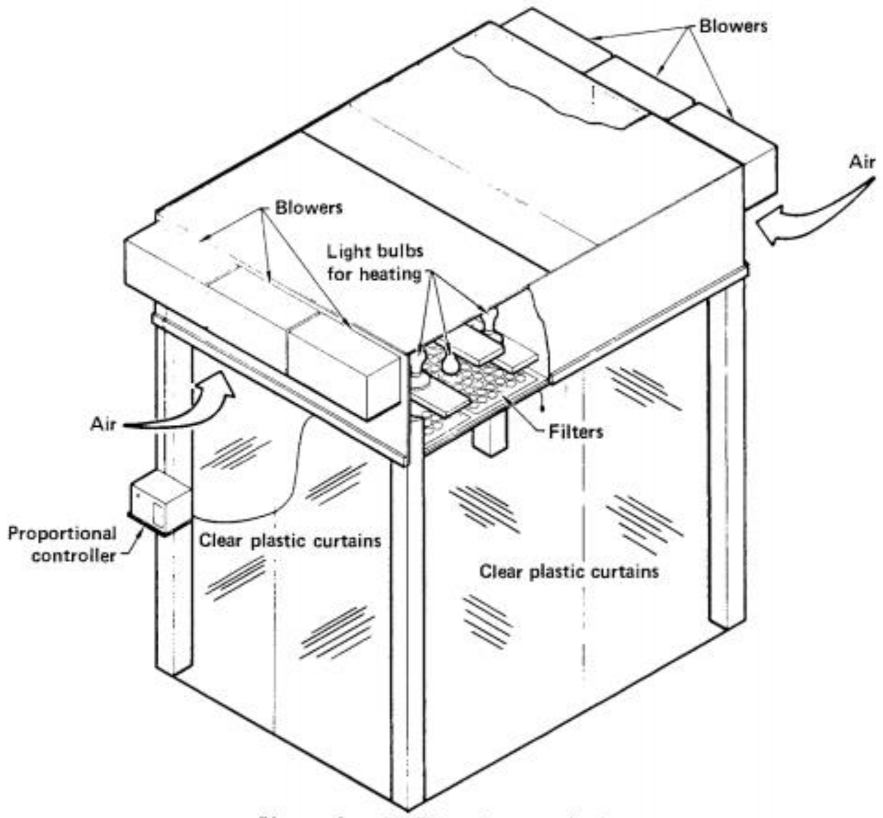


Figure 1. BODTM enclosure design

2) Air distribution for precision clean room

:To reduce heat sources from conduction or radiation from the walls

:To provide high velocity (100-150 ft/min) of air flows near surrounding walls, it is for wall isolation, and for boosting the vertical laminar flows thru the boundary layer near the wall

:To provide medium velocity (30-40 ft/min) of airflows from plenums

:To use return air duct on the bottom for boosting the vertical laminar flows

:68˚F±0.05˚F or (20˚C±0.027˚C) observed

for 6 months

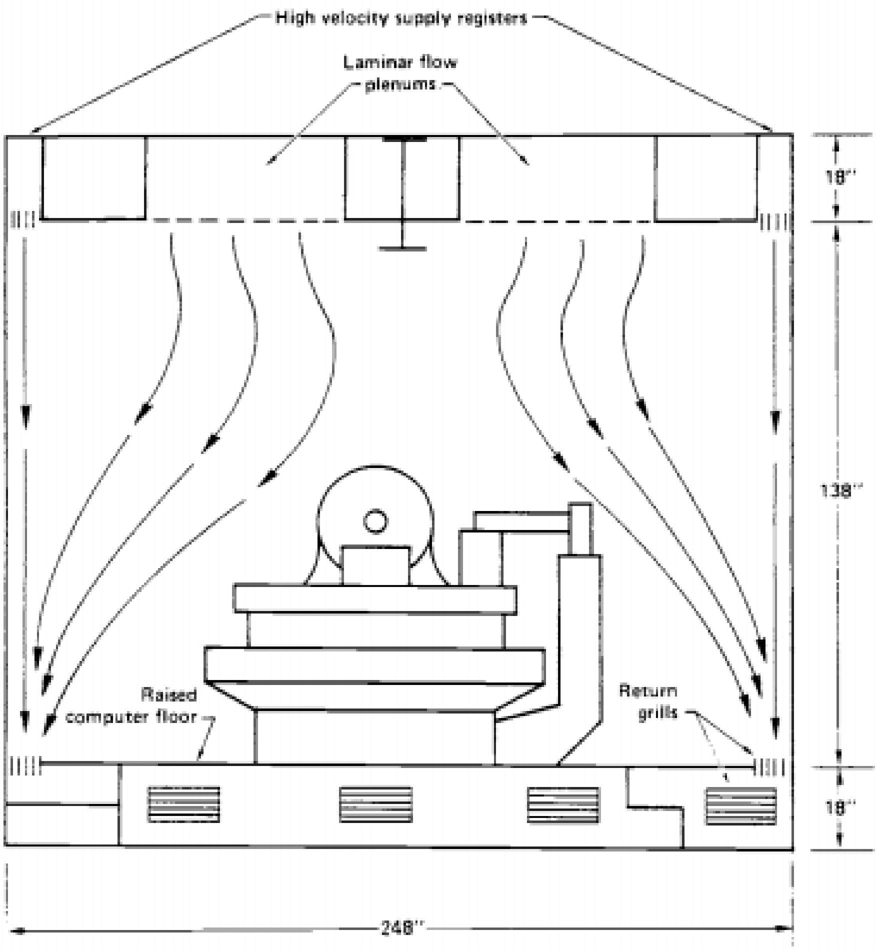


Figure 6. CBN room air distribution scheme

Summary and Guidelines for Thermal Design

1. Material selection for minimum thermal deformation of structures

   -Low thermal expansion

   -Shorter/Longer time constant, $\tau=\rho CV/hA$, for Faster/Slower equilibrium

   -Shorter critical distance, $X_c=\sqrt{PD/\pi}$, for minimizing dynamic thermal response

   -Avoid bimetallic structure or use materials having small difference in expansion coefficients

2. Symmetric design w.r.t the heat source, and avoid asymmetric C frame
3. Design for constant preload in bolted joint
4. Minimize the Abbe offset for potential thermal bending
5. Minimize temperature change, and temperature gradient

6. Use thermal enclosure or temperature control techniques for thermal stability
7. Use the downward laminar flow for the stabilized horizontal isothermal lines
8. Others;

   -Isolate leadscrews from heat source

   -Use linear scale rather than rotary encoder

   -Thermal error compensation by software