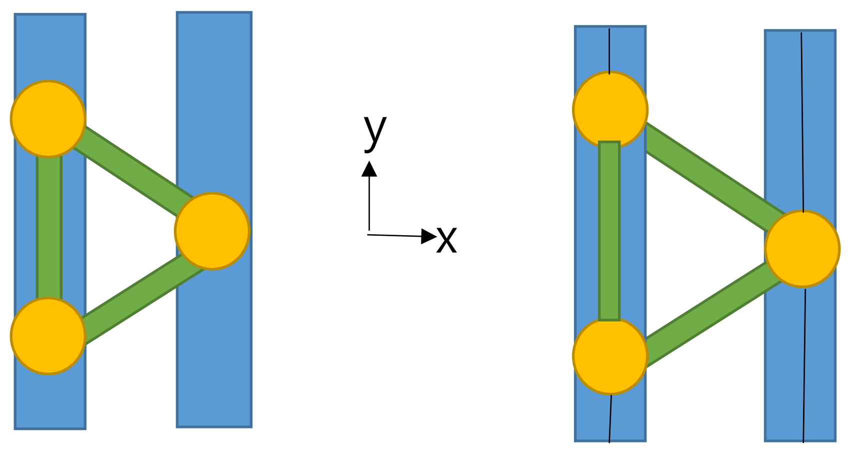
Precision Machine Design-Elastic Design

Elastic Design:

High stiffness design that can give higher load capacity with over-constraints and elastic averaging, while the kinematic design of minimum constraints gives medium or small load capacity is based on rigidity of structures

Kinematic Design vs Over-constrained Design



Kinematic Over-Constrained

Kinematic design: C=5, D=1; C+D=6

Over-constrained design: C=6, D=1; C+D=7>6

Stiffness in X direction increase:

$K_x|_{\text{kinematic}} < K_x|_{\text{over-constrained}}$ $\therefore$ About 50% increase in Kx

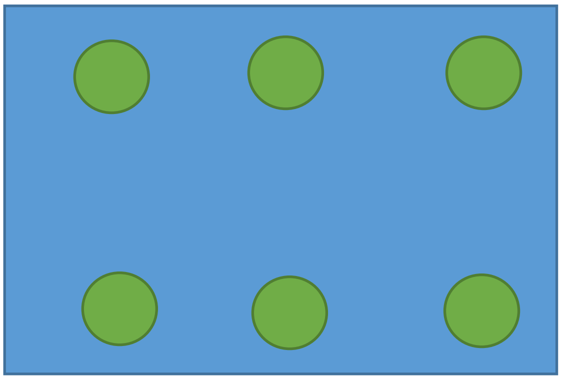
Thus over-constrained design has higher loading capacity in X direction, although it needs the parallelism tolerance of the V guides.

The three balls together with the two V guides are elastically deforming, and the relevant forces are balancing each other in the average sense, thus provides the Y slide mechanism stiffened in X direction. Therefore, the over-constrained design is also called as ‘Elastic Design’ or ‘Elastic averaging design’.

Beam with more than two supports, Machine foundation with more than 3 legs, two V-V Pads slide are typical examples of the elastic averaging design, performing higher load capability

Multi-supported Beam

Multi-Legged Foundation



V-V Pads Slides

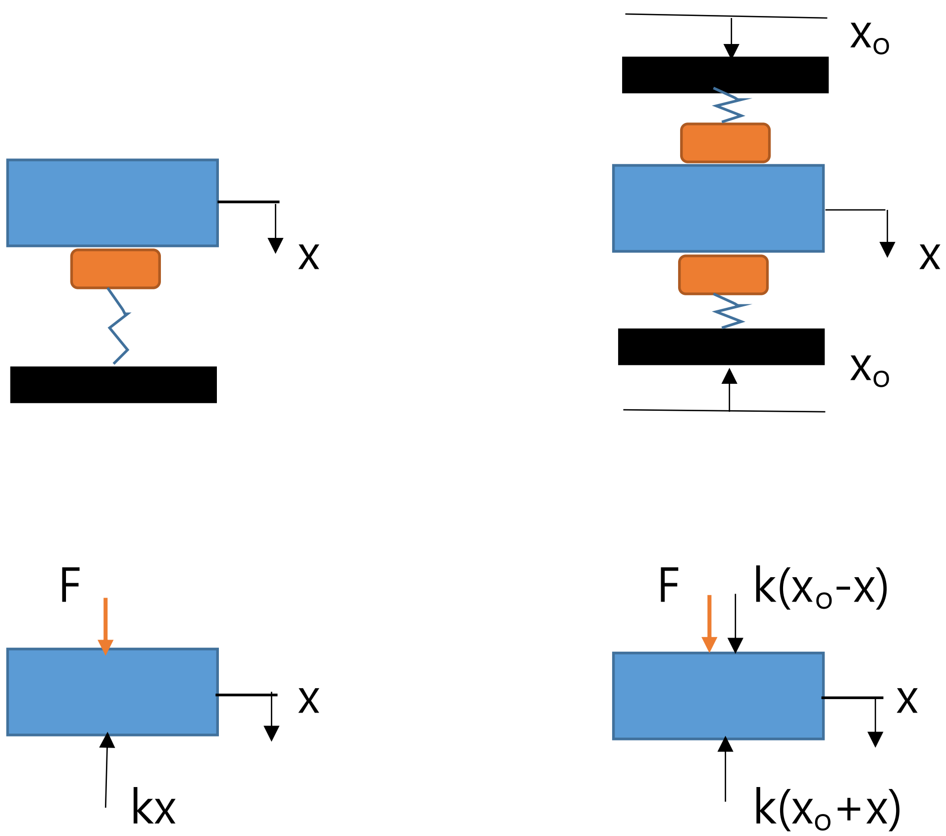
Elastic Preloading:

: Elastic preloading can give higher stiffness or more accurate functioning; the preloading can make all bearing components are in contact with the mating surfaces, thus giving the elastic averaging effect of all bearing components engaged.

1) Preloaded Rolling guides

Let x_o be preloaded displacement, and K is the vertical spring constant of needle bearing, F is the loading force applied.

Not-preloaded Preloaded



$F-kx=0$

$\therefore$ Stiffness$=F/x=k$

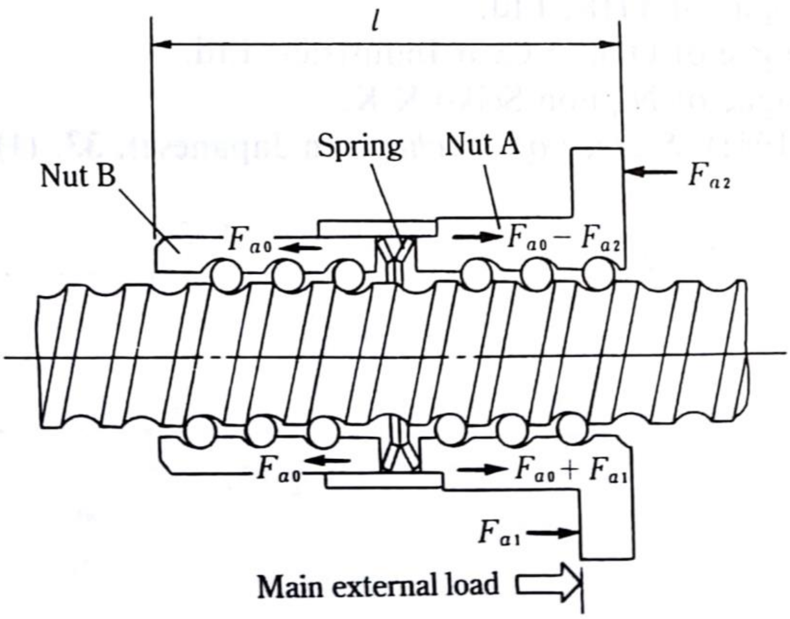
$F+k(x_o-x)-k(x_o+x)=0$

$\therefore$ Stiffness$=F/x=2k$

∴ The preloaded guides give doubled stiffness, and making all bearing components in contact, thus reducing the load for each bearing components and extending the bearing's life

2) Preloaded ball screw

Lead screw's backlash (play) can be avoided or minimized, by using spring preloaded nuts with ball recirculating mechanism

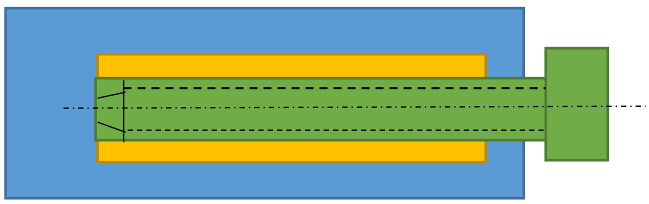


Constant Pressure Preloaded Double Nut (Nippon Seiko K.K.)

(source: Nakazawa's Principles of Precision Engineering, Oxford Science Publications)

3)Preloaded beam

The beam bending stiffness can be strengthened by the axial internal preloading; the internal preloading is adjusted by the internal bolt tightening. Compressive load by bolt is compensated by tensile load on the thin wall member outside. This is similar to the enhanced bending stiffness of Guitar strings. Other methods of expanding core would be accepted such as Aluminum beam with AsarcoLo-158 Alloy.



(source: Rivin's Handbook on Stiffness and Damping)

The tensile load P will act as stiffening of bending stiffness by Euler equation,

$K_b=[1+P/P_{cr}]K_o$

k_o=bending stiffness unpreloaded

P=Applied Tensile Load

P_{cr}=Buckling Load=$\pi^2 EI/n^2L^2$,

n=1 (both pinned),n=0.5(both ends fixed),n=0.707(one end fixed and other end pinned), n=2.0 (one end fixed and other end free)

4) Various Preloadable Slides

There are couples of preloadable slide designs; T slide design, and Dovetail slide design for precision machine slides are shown as examples. In order to adjust the preload, a straight gib is commonly used with linear sliding contact bearings, and it is to control the clearance between the saddle and rail. The area of gib is the area of bearing pad, and the thickness of gib is chosen such that the deflection is 1/2 of desired repeatability. That is,

$t_{gib}=[2\alpha\eta ab^3P_{max}/\delta E]^{1/3}$

where δ is the desired repeatability of the system

(by Slocum)

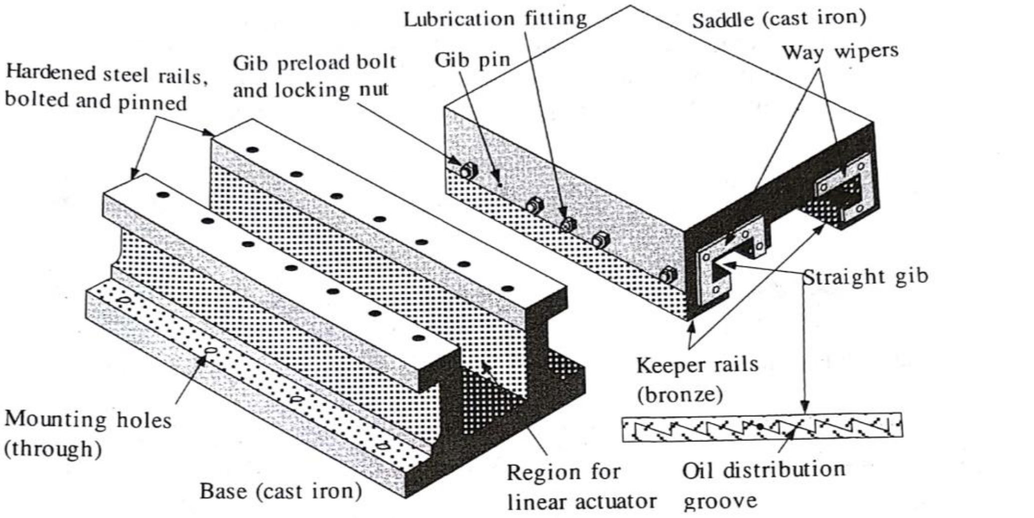


Figure 8.2.5 Components of a tee-shaped slide. Note the straight gib and way wipers. (Courtesy of Setco Industries Inc.)

(source: Slocum's Precision Machine Design, SME)

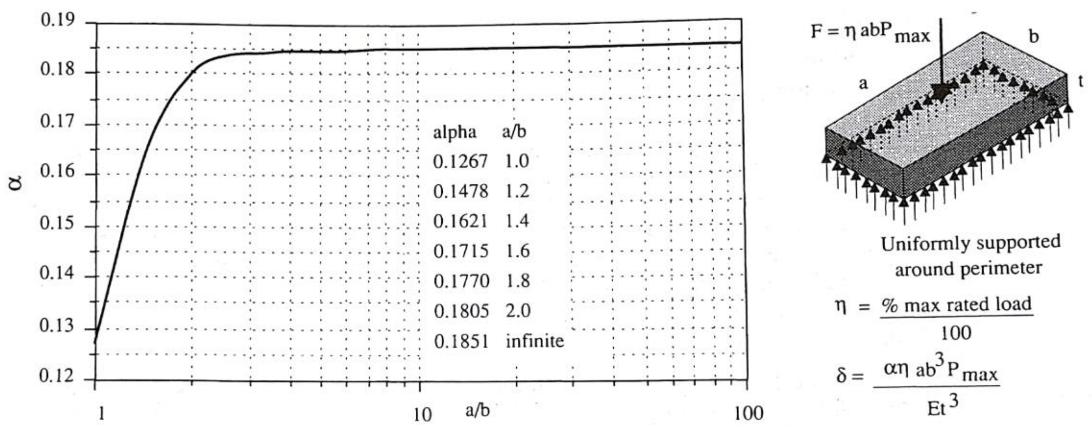


Figure 8.2.6 Model for calculating straight gib thicknesses.

(source: Slocum's Precision Machine Design, SME)

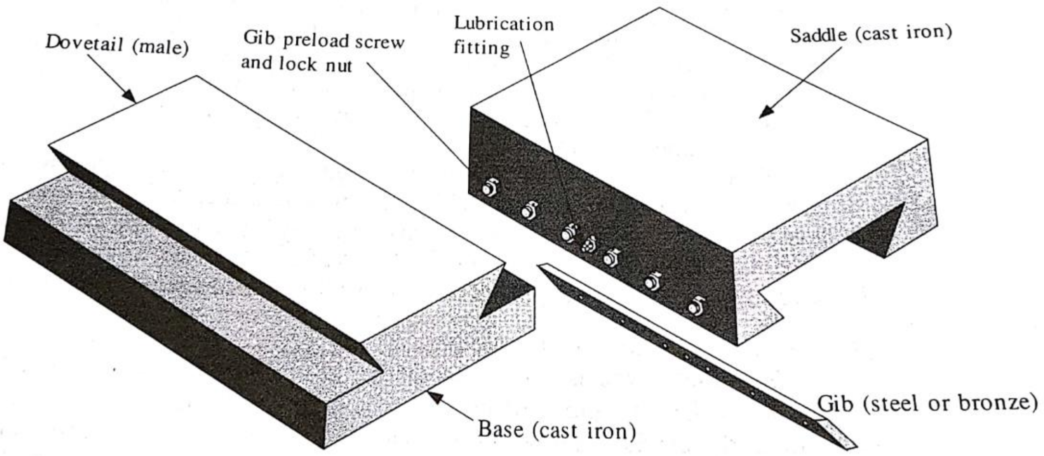


Figure 8.2.13 Construction of a modular dovetail slide assembly. (Courtesy of Russell T. Gilman, Inc.)

(source: Slocum's Precision Machine Design, SME)

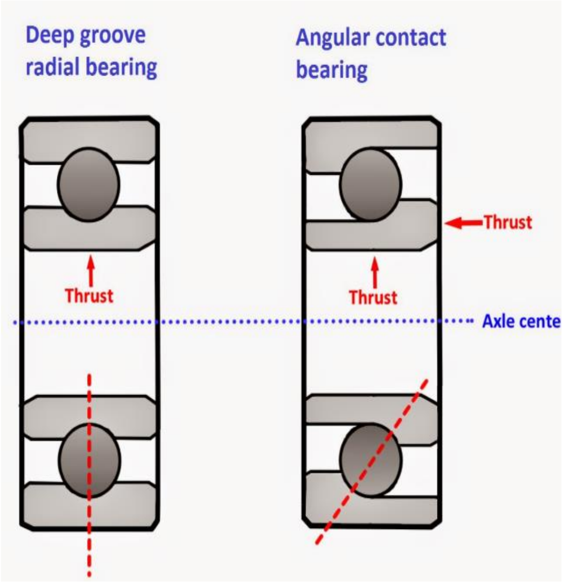
5) Preloading of Bearing components

Radial contact bearing is preloaded by the use of oversized balls from factory

Angular contact bearing is preloaded by clamping the races.

Straight roller bearings, or needle bearings are preloaded by oversized rolling elements.

Many other bearings are preloaded with the preload screws



(source:www.bikeforums.net)

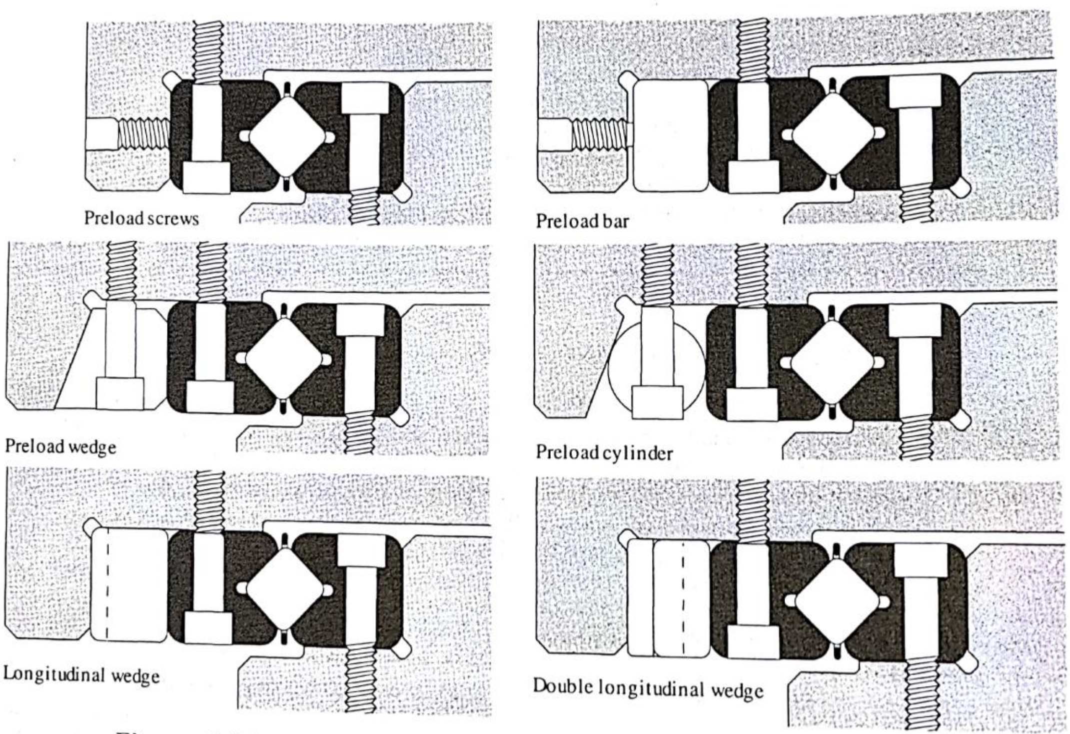


Figure 8.5.14 Methods for preloading crossed roller bearings. (Courtesy of Schneeberger Inc.)

(source: Slocum's Precision Machine Design, SME)

Force Loop and Measurement Loop

There are two closed loops from the work to the tool through the machine frame structures:

force loop and measurement loop

Force loop:

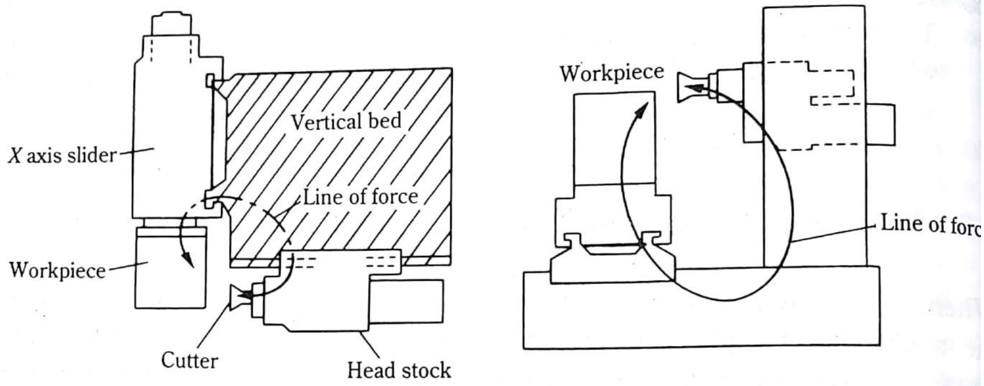
Continuous path to transmit the force from the workpiece to the tool.

(Tool->Ram->Frame->Carriage->Work)

Any force loop is stressed and strained, i.e. all components in the force loop are strained.

Force loop should be small in size (or length) to keep high stiffness, and thus to keep dimensional stability during operation.

96 *The principle of compliance*



Machining centre by Tsugami Corp. (top view)   Conventional horizontal machining centre (front vi

Fig. 8.6 Machining centre with shortened line of force.

(source: Nakazawa's Principles of Precision Engineering, Oxford Science Publications)

<u>Measurement Loop:</u>

Continuous path to link the measurand (Specimen) and datum

<u>(Stylus->Sensor->Frame->Carriage->Specimen)</u>

:Any change that occurs to components in the measurement loop will result in change in measured results that are not distinguishable from the measurement.

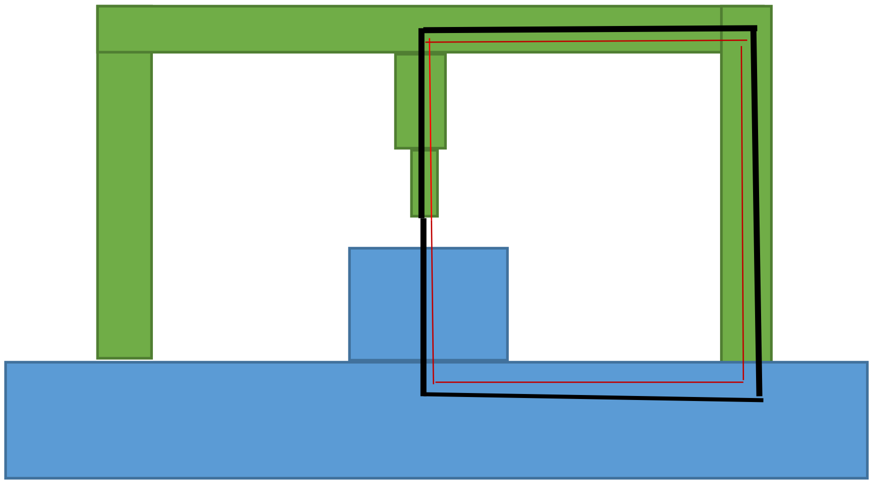
Any measurement loop is better to be avoided from any stress and strain, or other environmental change such as temperature, humidity, pressure, etc.

Components in the measurement loop should have good dimensional stability during any environmental change.

Metrology Frame:

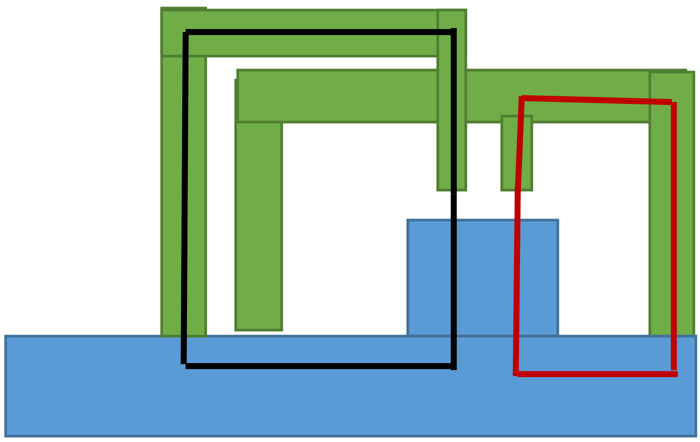
The two loops are better to be separated or isolated with each other, or not in common; This is to isolate the measurement loop from the stress and strain under operation -> This concept of isolated measurement loop is further implemented practically into the metrology frame that isolated from the force loop.

Metrology Loop: Force Loop:



Two Loops Identical (Traditional Machine)

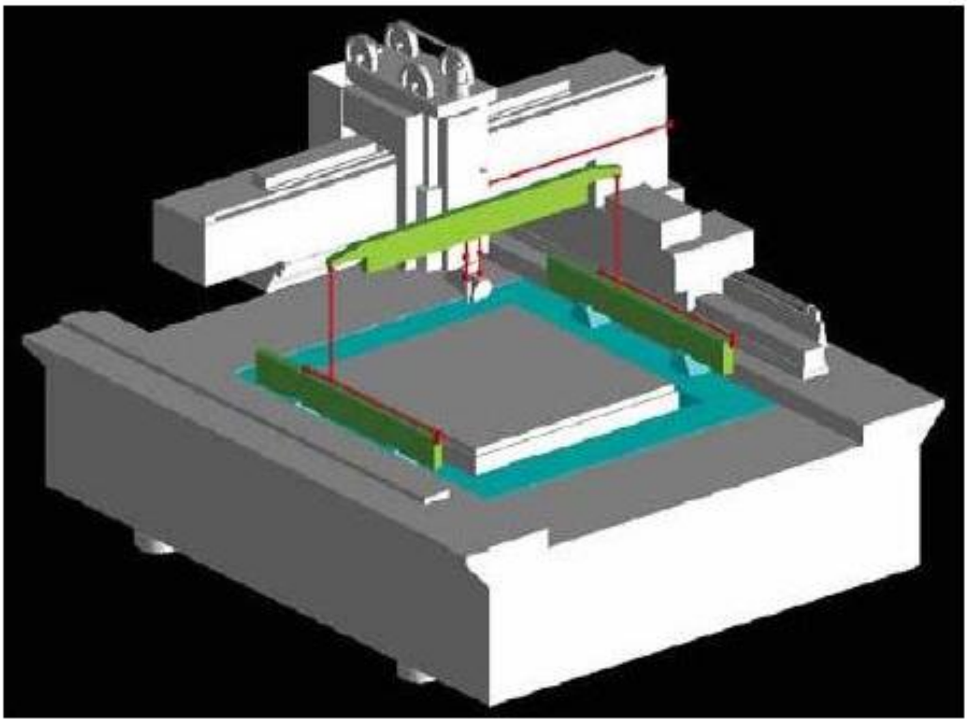
without Metrology Frame



Two Loops Separated (New Concept)

with Metrology Frame

The metrology loop is formed within the metrology frame separated designed.



Principle Components of the Laser Metrology Frame

(source:www.cranfieldprecision.com)

The following example shows a typical metrology frame that isolated from the force loop such that any cutting related-force or stress is not transmitted through the metrology frame. The Abbe principle is well implemented, too.

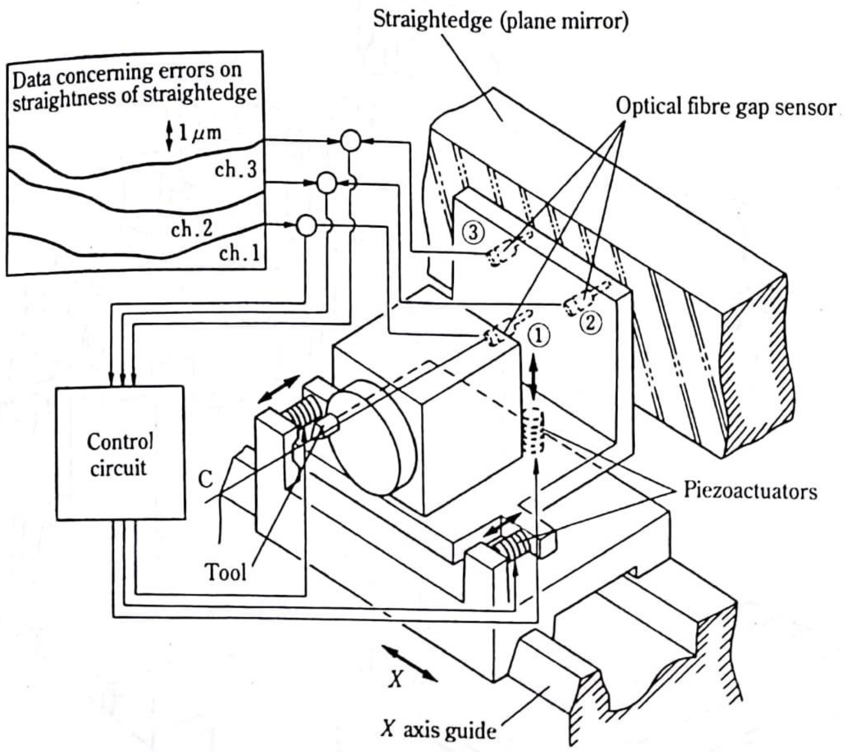


Fig. 7.7 Diamond fly-cutting device for machining asymmetric aspheric mirrors developed by Hitachi.[2]

(source: Nakazawa's Principles of Precision Engineering, Oxford Science Publications)