CMM's Main Functions

- Generating data points on the work piece surface using a measuring probe.
- Using the points to compute substitute geometric elements defined by parameters such as size, form, location, and orientation.
- Compare parameters to those specified in the drawing, i.e. the design intent.

Main Machine Components

- Machine with three motion axes and displacement measurement transducers.
- Probe or probes of different types to locate part surfaces.
- Machine control unit and remote control (usually).
- Computer with peripherals and extensive control and analysis software.

Measurement Steps -1-

- Calibration of the probe WRT the machine reference usually using a sphere.
- Location of workpiece coordinate system in the CMM coordinate system.
- Measurement of surface points on the workpiece by moving the CMM and (usually) contacting the part surface.

Measurement Steps -2-

- Grouping the surface points into geometric elements and analyzing these elements to create parameterized substitute geometries.
- All results can be represented in the part coordinate system, usually in the system specified in the drawing.

CMM Benefits

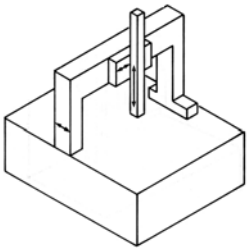
- Alignment of the part to the machine is usually eliminated.
- Many part reorientation steps can be eliminated. Only one setup is usually required.
- Software replaces hardware for alignment.

The most common CMM configurations

- Moving Bridge
- Fixed Bridge
- Cantilever
- Horizontal Arm
- Gantry
- Column CMM
- Above account for the vast majority of machines shipped.

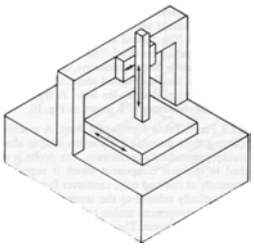
Moving Bridge CMM

- Ram moves vertically on a cross slide that moves side to side on a moving bridge.
- Very common design.
- Our XCel and Starrett machines.
- Hard to center drive on bridge.



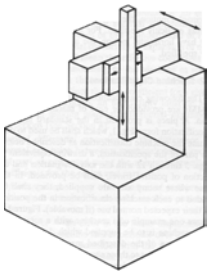
Fixed Bridge CMM

- Ram moves vertically on cross slide on bridge.
- Table moves on base under bridge.
- Main problem is table bending.
- Our Leitz Machine, M48s and the M60.



Cantilever CMM

- Ram moves vertically on a carriage that moves in and out on a cantilever beam.
- Cantilever moves horizontally, left to right over table.
- Easy part access.



Horizontal Arm CMM - 1

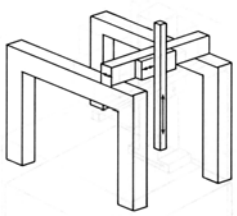
- Several varieties with and without moving tables.
- Also used in Duplex mode (2 facing each other).
- Common in automotive.

Horizontal Arm CMM - 2

- "High-accuracy" machines also available with this configuration.

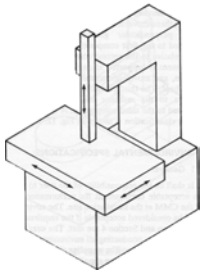
Gantry CMM

- Ram moves vertically on cross slide which moves side to side on third carriage. The third carriage moves on two large fixed beams on either side of the part.
- Common for large parts



Column CMM

- Ram with probe moves vertically WRT a fixed column.
- Part is on table which moves in X and Y.
- Common for vision machines (our Werth and View) as well as the Moore #3



CMM Hardware Components

- All machines consist of bases supporting moving carriages that position a measurement probe with respect the part to be measured.
- The positions of the carriages must be controlled rapidly and their positions accurately measured.

Common CMM materials

- Bases: Granite and Cast Iron
- Carriages: Range from Granite to Aluminum reflecting different designers opinions.
- Dimensional Stability is often considered the main requirement for a machine base therefore the choices above.

Desired Material Attributes

- Temporal Stability.
- High Stiffness.
- Low Density.
- High Damping.
- Low Thermal Expansion Coefficient?
- High Thermal Conductivity.

Common Bearing Systems Guide ways

- Ground steel on steel (Moore #3)
- Caged roller (needle) bearings or ball bearings. (Werth - roller, View - ball?)
- Polymeric bearing pads - Moglice, Teflon, etc.
- Aerostatic (air) bearings, either orifice or porous graphite or sintered bronze.

Bearing Maintenance

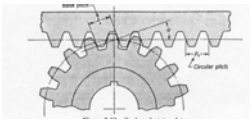
- Roller and ball bearings must be lubricated.
- Air bearings require a controlled pressure air supply with **clean** air. Air must be filtered for oil, water, and particulates.
- In high accuracy applications the supply air may need to be temperature controlled. A local tank can help.
- All machines/bearing surfaces should be kept clean.

Common Machine Drives

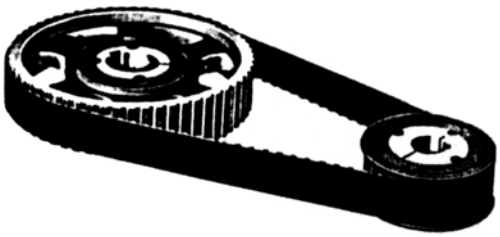
- Rack and Pinion
- Timing belts (belts with gear like teeth)
- Capstan drives (friction drives with rollers)
- Ball screws
- Rohlix drives - friction drives using canted ball bearings pressing on a rotating shaft.
- Lead Screws (old Moore and SIP machines)

Rack and Pinion

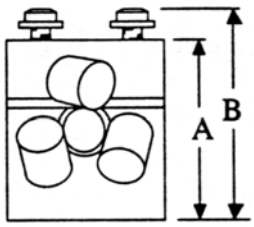
- Rack can be attached to moving or fixed component.
- Generally provide high speed but have "backlash."
- Inexpensive.



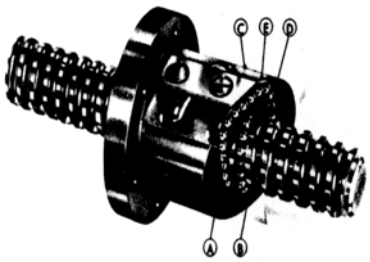
Timing Belts



Roh'lix Drives



Ball Screws



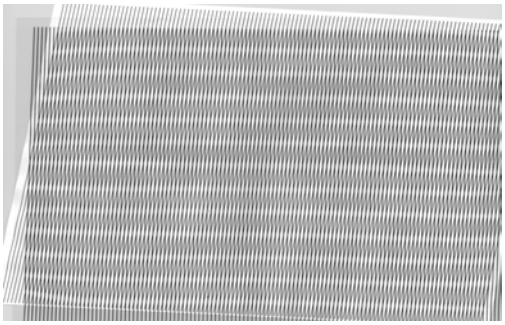
Displacement Transducers

- Most modern machines use a variation of the Heidenhain "moire" scale. These can either be transmissive or reflective.
- "Interferometric Gratings" are possible but rarely used.
- Laser interferometer are supplied on some expensive machines (Moore, Leitz, and Sheffield).

“moire” scales

- Moire scales are usually set up to give A quad B signals (sine and cosine waves). These need to be of equal amplitude and 90 degrees out of phase. Adjustments are provided.
- Scales must be shielded. Read heads are often replaceable and some of them actually are guided by the scale itself.

Moire fringes



Laser Interferometers

- Usually of a simple Michelson configuration.
- Suppliers are Renishaw, Hewlett Packard, Optodyne etc.
- Beam paths are shielded and “plumbing” the beam around the machine is hard.
- “weather” stations are required.

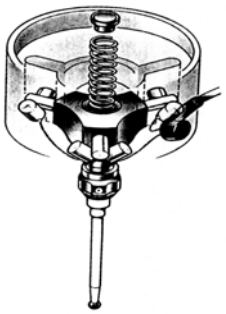
Probes

- The most common probe is still the “touch trigger” switch probe originally marketed by Renishaw.
- Three axis scanning contact probes from Leitz, Zeiss, EMD, Renishaw, etc. are growing in popularity.
- Other probes from triangulation to vision will be discussed later.

The “Original” switching probe

- Kinematic seat of six cylinders is used to contain three rods joined at a common center.
- Rods are spring loaded and joined to probe tip.
- Circuit is made through the balls and rods.
- A force in any direction on the probe tip will cause a rod, or rods, to lift from a seat or seats, breaking the circuit.
- The broken circuit signals the machine to read its scales.

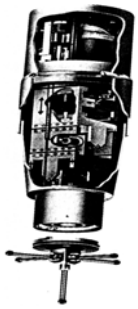
Drawing of a switching probe



Common Scanning Probes

- Most of the common scanning probes consist of 3 flexure mechanisms (often stacked) attached to the probe tip.
- When the probe contacts the part the flexures (one for each axis) bend proportionally to the force in that axis direction.
- Bending is usually measured with LVDTs, strain gages, or optically.

The flexure based Zeiss probe



Control Systems -1-

- Machine types
  - manual.
  - motorized with touch probes and joy sticks.
  - Direct Computer Controlled (DCC) Machines - these are similar to CNC machine tools.
  - CMMs linked with CAD/CAM systems and/or Flexible Manufacturing Systems.
- Controls are different for the different types.

Modern DCC Machines

- Use multiple microprocessor communicating over a 32 bit bus.
- Main operator interface is through a Windows type environment on a PC.
- Axes are controlled and data acquired by other processors (perhaps even DSPs) which contain the servo equations, A/Ds, D/As, and other signal processing.

Machine Programming -1-

- All DCC machines can be programmed in a "teach" mode.
  - A joy stick is used to both locate the part and to teach the machine the locations and the approach paths to the points to be measured.
  - The taught program is "played" back during actual measurement, usually quickly.
  - This method still common for simple measurements.

Machine Programming -2-

- Off line programming - All(?) manufacturers now offer off line programming. Some use special languages such as Quindos (Brown & Sharpe, Leitz).
- Icons for various operations are common.
- CAI (computer aided inspection) systems where the machine is programmed at a CAD workstation are becoming common.

Machine Programming -3-

- Standard specifications have been developed to communicate CMM programs.
- Common is the Dimensional Measurement Interface Specification (DMIS).
- Programming is still evolving rapidly and can be expected to change dramatically in the next few years.

Evaluation Software -1-

- Qualification - all machines have software to qualify (measure the length, size, orientation, condition, etc.) of the probe and make some corrections for its systematic errors.
- Transformation - all machines have software for coordinate transformation from part to machine coordinates and vice versa.

Evaluation Software -2-

- Calculation- core software allows the calculation of substitute geometry for points, planes, circles, spheres, cylinders, cones and torii. Also distances between points, distances from points to planes, angles, etc. That is any "call out" on a drawing except for surface finish.
- Special Software for complex geometries such a gears also exists at extra cost.

Evaluation Software -3-

- Analysis- Modern machines offer software for analysis and reporting. Graphics are common as well as software for comparison of features to tolerances. Interfaces to SPC systems are possible.
- Effective feedback to production machines for process modification is still a research topic.

CMM Basics - Conclusions

- CMMs are complex Mechatronic systems in the true sense of the word.
- They combine precision mechanics with optics, electrics, electronics, sensors, computers, and advanced software to provide accurate and timely dimensional data.