Fixturing/Workholding
What is a fixture?

• A fixture is a device used to “fix” (constrain all degrees of freedom) a workpiece in a given coordinate system relative to the cutting tool.

• Primary functions of a fixture:
  – Location: to accurately position and orient a part relative to the cutting tool
  – Support: to increase the stiffness of compliant regions of a part
  – Clamping: to rigidly clamp the workpiece in its desired location (relative to the cutting tool)
Fixtures

• Routinely used in machining, welding, and manual/robotic assembly operations.

• Types of fixtures:
  – *General purpose*: mechanical vise, lathe chucks
  – *Permanent/Dedicated*: specially designed to hold one part for a limited number of operations; commonly used in high volume production.
  – *Flexible/Reconfigurable*: can be used for more than one part and for multiple operations e.g. modular fixtures, pin array, phase change, etc.
General Purpose Fixtures

Vise

3-Jaw Chuck

6-Jaw Chuck
Dedicated Fixtures

Milling Fixture

Tombstone Fixture
Flexible Fixture: Modular Fixture

Modular Fixture Kit
Flexible Fixture: Modular Fixture

Lot Size

High

Low

Number of Times Job Repeats

Few

Many

Dedicated Fixturing

Modular Fixturing
Flexible Fixture

Bed of Nails Fixture
Grasping

Utah / M.I.T. Hand

Robonaut Nasa Hand
Axiom-based Workpiece Control

- Geometric control
- Dimensional control
- Mechanical control
Geometric Control Axioms

1. Only six locators are necessary to completely locate a rigid prismatic workpiece. More locators are redundant and may give rise to uncertainty.
2. Three locators define a plane.
3. Only one direction of each degree of freedom is located.
4. Each degree of freedom has one locator.
5. The six locators are placed as widely as possible to provide maximum workpiece stability and...
Fixture Design/Planning In Practice (1)

- Many dedicated fixtures for prismatic parts are designed using the “3-2-1” locating principle.
Fixture Design/Planning In Practice (2)

- The “3” in 3-2-1 refers to 3 locators (passive fixture elements) on the primary locating/datum surface.
Fixture Design/Planning In Practice (2)

- The “2” in 3-2-1 refers to 2 locators on the secondary locating/datum surface.
Fixture Design/Planning In Practice (3)

- The “1” in 3-2-1 refers to 1 locator on the tertiary locating/datum surface.
Cylindrical Workpiece

6. Only five locators are required for locating cylindrical workpiece
Dimensional Control

7. To prevent tolerance stacks locators must be placed on one of the two surfaces which are related by the dimension on the workpiece
8. When two surfaces are related by geometrical tolerance of parallelism or perpendicularity, the reference surface must be located by three locators
9. In case of conflict between geometric and dimensional control, precedence is given to dimensional control.
10. To locate the centerline of the cylindrical surface the locators must straddle the centerline
11. Locators should be placed on machined surface for better dimensional control
Example of Reference

Three locators on reference side
Mechanical Control

12. Place locators directly opposite to cutting forces to minimize deflection/deformation

13. Place locators directly opposite to clamping or holding forces to minimize deflection/deformation

14. If external forces cannot be reacted directly via the locators, limit the deflection and distortion by placing fixed supports opposite to applied force

15. Fixed supports should not contact the workpiece before the load is applied

16. Holding forces must force the components to contact the locators
Mechanical Control (contd.)

17. The moment of the clamping forces about all possible centers of rotation must be sufficient to overcome the effect of tool forces and restrict any movement away from locators.

18. Tool forces should aid the workpiece to remain in contact with locators.
Fixture Design/Planning In Practice

- Current approach to fixture design and planning relies on experience and trial-and-error methods → leads to expensive fixtures.

- Thumb rules are often used to design fixtures in practice.

- Need for more scientific methods in fixture analysis and design.
Typical Questions in Fixture Design

• Does the fixture accurately locate the part relative to the cutting tool?
• Does the fixture ensure that the part is totally constrained?
• Can the part be easily loaded into/unloaded from the fixture?
• What is the role of type and number of contacts on fixturatorability of the part?
• What is the minimum clamping force needed to restrain the part during machining?
Kinematic Analysis of Fixtures (1)

- The fixture can be treated as a set of rigid contacts that are fixed in a reference frame.
- The workpiece is treated as a rigid body whose motion is restricted by the contacts.
Kinematic Analysis of Fixtures (2)

- It is of interest to determine the possible motions of the object constrained by the contacts \( \rightarrow \) instantaneous motion properties of the rigid body \( \rightarrow \) displacements, velocities that the object undergoes.
Kinematic Analysis of Fixtures (3)

- The instantaneous motion properties of the object are influenced by the following factors:
  - Shape and number of contacts
  - Relative location of the contacts
  - Relative orientation of the contacts
  - Friction
Types of Fixture-Workpiece Contact

- Common contact geometries include:
  - Point contact e.g. point-on-plane, plane-on-point, line on non-parallel line
  - Line contact e.g. line-on-plane, plane-on-line
  - Planar contact e.g. plane-on-plane

- Assuming that the contact between the object and fixture element (locator pin, clamp, etc.) is always maintained, freedom of motion allowed by each contact depends on the presence/absence of friction.
Effect of Friction

- Impact of friction on the degrees of freedom allowed by different contact types is as follows:

<table>
<thead>
<tr>
<th>Contact Type</th>
<th>Friction</th>
<th>No Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Line</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Planar</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>
Form vs. Force Closed Fixtures (1)

- Fixtures (and grasps) can be also characterized in terms of their “closure” properties.
- **Form Closure**: if the contacts with the object are arranged such that they can resist arbitrary disturbance forces and moments, then the object is said to be form closed (or equivalently, the fixture is said to provide form closure).
- Equivalent statement: a set of contacts provides form closure if it eliminates all degrees of freedom of the object purely on the basis of the geometrical placement of the contacts.
Form vs. Force Closed Fixtures (2)

- **Force Closure**: the fixtured object is said to be force closed if it relies on disturbance forces and moments to maintain contact.

- In practice, most machining fixtures are force closed fixtures because they rely on frictional forces to totally constrain part motion.
Kinematic Analysis of Fixtures (3)

• What are the necessary and sufficient conditions for a fixture to guarantee the following:
  
  – Accurate location $\rightarrow$ Deterministic Positioning
  – No movement $\rightarrow$ Total Constraint
  – Ease of loading/unloading $\rightarrow$ Accessibility/Detachability