PROFESSOR: Now we consider the process of thermo-forming. In this process, we will make a simple circuit apart by heating a flat sheet of polystyrene and then pulling it over a tool under vacuum. After forming, the part is usually trimmed to a final shape.

To begin the process, the flat sheet is loaded into the machine and then clamped into place. The sheet is moved into an oven and heated for a specified amount of time. The oven temperature is under feedback control and the timing of entering and exiting the oven is also under program control.

After residing in the oven the desired time, the sheet is moved over the tool, it comes up to contact the sheet, and the vacuum is applied through the tool. This draws the sheet onto the tool, taking its form and, at the same time, cools the sheet. The part is then removed from the clamps and measured using a vernier caliper. We will look at two different thickness sheets and have two different resonance times in the oven for a total of four different conditions. Run charts for the part diameter can then be plotted noting the effective thickness and heating time.

[MUSIC PLAYING]

Now we consider the process of sheet metal shearing. In this process, we take 5-inch-wide strips of sheet metal and cut off 1-inch-wide coupons to be used in the brake-forming process. The key dimensions for the part are the average width and the taper along the length determined by measuring the width at each end. The cutting is done on a simple treadle shear operated manually.

The cut width is determined by the location of the back gauge, which can be set using the graduations on the gauge. Note that these can resolve to only about 1/16 of an inch. And citing errors are likely to happen.

A sheet is inserted into the shear as shown and pushed into contact with the back gauge. To ensure a square part, the long edge of the sheet should be held flush to the edge fence as shown. If instead we keep the cut edge of the sheet flush to the back gauge, we could not eliminate initial tapered edges on the sheet. As the treadle is pushed down, notice that a clamp comes down to hold the sheet just before the blade moves to cut the sheet.

The part falls off at the rear and should be collected and numbered. The width at each end is then measured using a vernier caliper. Both measurements are recorded so we can get an average width and taper. For this process, we will share both aluminum and steel sheets and create a run chart for each.

[MUSIC PLAYING]

Here, we consider the process of brake forming. The purpose of this process is to bend flat coupons of sheet metal to a finite angle. This is accomplished by applying a three-point load using a punch and die, in this case, mounted in a lathe.

The lathe provides a stiff foundation and, with the tailstock, a means of controlling the displacement of the punch. Here, we see the tooling mounted in the lathe and show the punch moving as the tailstock lead screw is rotated. Notice that the displacement of the punch is determined by the rotations of the hand wheel on the tailstock.

The bend angle is determined by the displacement of the punch relative to the die but will also depend on the thickness and constitutive properties of the sheet. The rotational displacement is measured using the vernier on the lead screw. In this machine, we can resolve 1 part in 100 per rotation. For a lead screw ratio of 1 inch per 10 revolutions, this gives a displacement of 1/1,000 of an inch per line on the vernier.

Here, we see the machine being cycled while forming parts. Notice that, when the load is released, the part shows significant spring back. We can show that this spring back is a function of the thickness, yield stress, elastic modulus, and strain-hardening properties of the sheet as well as the degree of bending. The specifications call for a depth of either 3/10 of an inch or 6/10 of an inch or three or six full revolutions of the lead screw. The key is determining the zero angle point where the punch just touches the sheet and then moving three or six revolutions further in.

As each part is formed, we can measure the resulting angle using the machinist's protractor. This is a difficult measurement and must be made with care. In this case, we can resolve to better than 1/10 of a degree. But it is important to stay tangent to the flanks of the part.

Finally, we record the angle, the material type, and the depth of the punch on a datasheet. A run chart for the process is then plotted. Data is most logically grouped by material and depth since each has a strong effect on the final angle.

[MUSIC PLAYING]

Now we consider the process of injection molding. In this process, we are manufacturing simple snap rings to a specified diameter. We start with clear polypropylene pellets, which are melted and injected into the tool under pressure.

The injection-molding machine is rather complex. It includes a compounding and melding screw, an injection barrel, as well as the tooling and tooling clamp. The pellets move from a hopper into a heated barrel with a single screw.

During the melding phase, the screw rotates and moves rearward, storing the melded plastic in the nose of the barrel. The melding is affected mainly by the mechanical shear on the pellets and not by heat transfer from the barrel. The barrel is brought into contact with one tool half to create a flow path into the tool cavity.

During the injection cycle, the screw first rotates and then moves backward as the plastic is melded. It then moves forward at a specified velocity to fill the mold. Once the mold is filled, the screw piston switches to pressure control. And the additional forward motion, called packing, is caused by the plastic compressing in the mold before it hardens fully.

The two halves of the tool are brought together under the action of a large hydraulic clamping cylinder, which keeps them closed during injection. The tool itself serves to cool the part. And the temperature of the part when the tool opens depends strongly on the hold time in the tool. This time can also be programmed into the machine.

After the hold time, the tool separates, and the part is removed. In the production process, the part would be ejected by a set of actuated pins. But here, it is done manually.

After the part is removed and cooled, it can be measured using a vernier caliper and the diameter recorded. In this experiment, we will vary the injection speed and the hold time to yield four different production conditions. A run chart can then be plotted for all the data, keeping track of the machine settings. Now we consider the process of CNC turning.

[MUSIC PLAYING]

The part to be manufactured here is a simple cylinder of aluminum. The workpiece is a bar of 0.75-inch-diameter aluminum, which is to be turned to 0.675-inch-diameter. After turning three parts of 0.75-inch, length will be cut off from the bar.

The workpiece is clamped in the chuck with a stick out of 3 inches. The turning and cutoff cycles are controlled by the NC controller so the only operator intervention is loading of material and changing of tools. Note that the machine frame for this process is massive so as to minimize any deflection under machining loads. The cycle begins with a single turning pass with fixed spindle speed and feed.

Notice that the longitudinal motion is controlled by a servomotor driving the long-axis lead screw under program control. During the experiment, the operator will change the spindle speed once and the feed rate once for a total of four different operating conditions. After turning, we change to a simple cutoff tool. And a fast plunge cut motion separates the parts.

It is important that each part is captured as it falls so we can tell which part of the bar it was made from-- inner, outer, or middle. Each part diameter is measured using a vernier caliper and recorded in order of production. The spindle speed and feed rate should also be recorded for each part. Run charts are then created for the part in sequence or by location on the bar.