Tube End Forming: Understand Part Function to Determine the Right Tools

Sometimes focusing on the tube's function rather than the forming method can lead you to select an end forming method that optimizes the part cost, particularly if the opportunity involves a new part. The ways to form the tube end boil down to a few basic methods, so understanding their capabilities and limitations is critical to selecting the best process for a particular part. Thinking about creative ways to employ the process can help to improve product performance and reduce process cost. End Forming starts with understanding and narrowing down the tube end forming process. Are you going to need to use ram or segmented tooling. Your tooling choices help form the ID, the OD, or both; and the operation can be manual or CNC. Understanding the processes and their capabilities are the keys to choosing the best one for your application.

The basic end forming methods are segmented tool sizing, ram forming, rotary forming, roll forming, and spinning. The latter three have specific advantages in working around the circumference of a tube, especially where sharp angles and radical diameter changes require working the tube more gradually. The first two work the whole circumference at one time. While they provide a quicker forming cycle, they are limited in their range of applications.

One of the most common types of end forming is a ram type end former. Most often the ram type end forming process securely holds a tube static in a set of clamp dies while a ram tool forms the end of the tube. As the ram tool advances towards the static tube held captive by the clamp dies, the ram tool causes the tubing to cold flow. The path of flow is the path of least resistance. The ram tool simply captivates the end of the tube and then compresses it towards the clamp dies. In this case the unsupported section of the tube between the clamps and the ram tool buckles under the compressive loading on the tube thus forming the bead shown. In this particular case, the surface finish of the ram tool mating features are not critical. Likewise, lubricant in this case is not critical.

Fabricators that need to do end forming have many choices. Even after narrowing the process down to using a ram or segmented tooling, choices abound-the tooling can form the ID, the OD, or both; and operation can be manual or CNC. Understanding the processes and their capabilities are the keys to choosing the best one for the application.

Your company has the opportunity to provide a tube assembly, but it requires end forming—a capability you do not have. An Internet search for "tube end forming" leads to a range of options. How do you sort through them?

If you focus on the function of the tubes to be reshaped, and not on the forming method, it can lead you to select an end forming method that optimizes the part cost, particularly if the opportunity involves a new part. The ways to form the tube end boil down to a few basic methods, so understanding their capabilities and limitations is critical to selecting the best process for a particular part. Thinking about creative ways to employ the process can help to improve product performance and reduce

Figure 1

Ram forming is one of two end forming methods that forms the entire tube circumference at one time.

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This article focuses on applications for which segmented tool sizing and ram forming are the optimal methods, typically high-volume production for basic tube end forms.

Defining the Forming Requirements

Fabricators who need to do end forming frequently ask many of the same questions, whether the project is a part or an assembly of parts. What does the formed tube need to do? Are all of the part's features necessary? Does the current design already assume a specific forming method? Can we make changes to mating parts? Can I achieve the same result with fewer parts?

The tube alloy and production process are important factors regarding the part design and the forming method. Can the material accommodate the necessary amount of deformation? If so, what is the best way to work the material to achieve the end form? Is the tube seamless, or does it have a weld seam? What are the tolerances and the cosmetic requirements according to the print?

Understanding the assumptions behind the assembly's design is necessary for optimizing the end forming process.

For instance, the part design for an automotive exhaust component might be based on a particular assembly method, resulting in a two-piece welded assembly. Focusing solely on the application and cosmetic requirements might alter the part design, leading to a change in the forming method and a significant cost reduction.

After identifying the methods capable of forming a finished part to the customer's specifications, you can evaluate the project's unit production cost, which typically involves the tooling cost, repeatability, cycle time, setup time, and process adjustability (to accommodate material

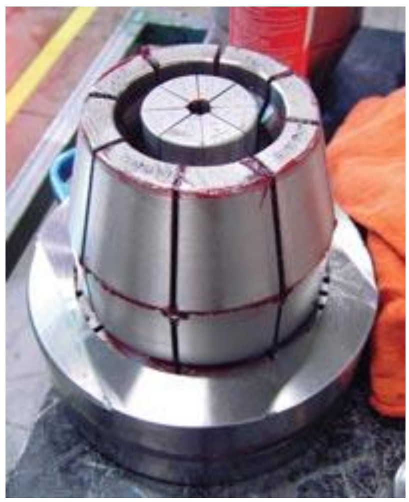

Figure 2

Inside/outside (I/O) tooling has two sets of tools. The inner segments, which are shaped like pizza slices, fit inside the tube. The outer set slips over the outside of the tube. End forming can use an inner tool set, an outer tool set, or an I/O tool set. I/O tooling is more expensive and more precise than inner segments or outer dies.

variations). Another question usually arises at this point: What else can I do with the machine?

Ram Forming Versus Segmented Tool Sizing

Most end forming applications suited to ram forming are also suited to segmented tool sizing. However, these processes have distinct differences.

Ram Forming

Also called bulldozing, ram forming uses an impact process to drive a tapered plug inside or a tapered cup over the outside of a securely held tube end (see **Figure 1**). The tapered angles convert this vertical (axial) force to radial changes in the tube end shape. The process works the full circumference of the tube end uniformly. The tooling is designed to smoothly transition the tube end to the finished contour, and has allowances that compensate for spring back. Hydraulic systems typically are most effective in delivering the power and speed required.

Segmented Tool Sizing.

Segmented tool sizing works the tube circumference radially. For reducing the tube, the process uses a set of segmented dies that look like a ring of pizza slices with the center cut out (see **Figure 2**). The end former pulls a tapered ring over the taper on the outside of the die set, squeezing the dies together to reduce the tube's diameter. Each tooling segment initially contacts the tube at two points. At the end of the process, the segments contact the entire tube circumference.

Expanding the tube relies on a similar approach. Segmented tools, or fingers, start out packed together so they fit inside a tube. A tapered arbor, driven by a hydraulic cylinder, advances through the center of the tooling to spread the fingers uniformly until the tube reaches the finished diameter. Like the external tooling, segmented fingers initially contact the tube at two points.

Finished Part Accuracy

Ram forming, which is a hard-tool method, provides a consistent finished part. However, it cannot compensate for material variations in the tube wall or diameter and it cannot be adjusted to compensate for variations in the amount of spring back. The operator adjusts segmented tooling by changing the cylinder travel distance, which determines how far the dies close or fingers expand. The machine's control system determines the accuracy and repeatability of this process.

A drawback with segmented tooling is the amount it can change the work piece diameter. The standard reduction is about 0.250 in. on diameter with each tooling set. Trying to do more is restricted by physical limitations. For reductions, the tooling can't open up enough to receive the raw tube or close far enough to form the tube without having big gaps between the segments, resulting in significant ridges of material that are difficult to overcome. For expansions, you have the opposite problem. The fingers cannot collapse enough to accept the raw tube or to open (spread) enough to form the finished end.

Cosmetic Considerations

The cosmetic appearance of the finished tube is a chief determinant in selecting ram forming or segmented tooling sizing. The clamping method typically used for ram forming is a set of jaws—a top and bottom that are pressed together. This can mar the tube's surface with clamp marks along the unformed part of the tube. Using a backstop or a collet-style clamp around the tube are some alternative methods for securing the tube.

The segmented tool sizing method works radially and does not develop any axial force, so the tube does not require clamping. However, when the tube's diameter is reduced, the tube material can get pinched between the dies, marring the surface in the formed area. When a tube is expanded, gaps develop as fingers spread, leaving marks around the circumference. A two-hit process (swaging the tube, rotating it, and swaging it again) is a typical remedy.

Segmented Tooling Choices: Inside or Outside Only? Or Both?

If you select segmented tooling, you're not finished. You also have to determine whether you need tooling on the ID only (for an expansion), on the OD only (for a reduction), or both. Using both ID and OD tooling, called I/O tooling, is suitable for expansions and reductions and achieves better roundness (because it flattens the pinch marks) and better definition at the transition between the formed and unformed areas.

An I/O system typically uses back-to-back hydraulic cylinders. One drives the tapered arbor for the fingers and the other drives the tapered ring over the dies. Be aware that I/O tooling more than doubles the tooling cost relative to the cost of ID-only tooling. The additional cost buys greater precision and accuracy.

Segmented Tool Sizing — Digital Versus Manual Controls

You have one more decision to make. If you have determined that segmented tooling in an I/O configuration meets your tube forming requirements, then the last decision is a matter of choosing digital controls or manual controls.

The main difference is that a digital (CNC) system uses encoders to control the travel of the cylinders and thus the movement of the arbor and reducing ring that work the tooling. The operator uses an operator interface (typically a touchscreen) to set a series of coordinates, which define the tooling movements.

This is particularly effective and efficient when the tube end has a dimple from a previous cutoff operation; when the tube end is significantly out-of-round after bending; or when the finished size is actually very close to the raw tube size (a case when the amount of expansion or reduction is too little to overcome the material's elasticity and the tube is likely to spring back to its original size after forming).

In these cases, the operator programs several hits (coordinated tooling movements) that achieve intermediate part dimensions before producing the final end form. In the case of the dimple, the first hit might be an operation to over expand the end of the tube slightly to remove the dimple. The next hit might take the over expanded tube end down to the targeted size. Similar approaches apply to the other scenarios noted above.

Figure 3

This exhaust tip, made on an end forming machine in two hits, formerly was a welded assembly made from two tube sections. Changing to end forming reduced the number of parts and the number of manufacturing steps.

In addition to the multiple-hit capability, CNC enables more precise adjustments to any specific end forming program and typically offers a quicker overall setup process.

In manual I/O sizing, the operator can set proximity switches to define the travel of both hydraulic cylinders, and thus the amount of closing of the dies and opening of the fingers in the forming process. Some systems use hard stops and timers to stop the forward motion of the cylinder and cause it to retract. Timers can be more precise and simpler than the proximity switches, but they put more wear on the hydraulic system. Manual I/O sizing does not have the multiple-hit capability of a CNC machine.

Two Examples

While end forming isn't suitable for every component, two projects that worked well for end forming were aftermarket exhaust pipe tips and a rail made from rectangular tubing.

Exhaust Tips

This particular aftermarket exhaust pipe tip was two parts made from polished 409 stainless steel—one was 4 in. diameter and the other 3 in. diameter. The outlet end was cut at approximately 45 degrees and rolled in (see **Figure 3**).

Manufacturing is increasingly seen as a competitive weapon in the automotive aftermarket parts business, and ram forming offered enticing benefits. The potential for removing one part and one step suggested a lower cost, shorter lead-times, and more consistent part dimensions and appearance.

One point of negotiation with the customer was a change in the part contour—end forming required a longer transition angle between the two diameters. The customer approved, and the part now is formed in a two-step process. Because the tube wall is thin (0.050 in.), guides are necessary to keep the forming tools on centerline with the clamping dies.

Using a machine with a ram tool changer would optimize this even further to be a one-step process. Even without the ram tool changer option, the fabricator made a big improvement by cutting the part count from two to one and the manufacturing steps from three to two.

Tubular Rail Assembly

Another application used segmented tooling to form a rectangular tube end for a slip fit assembly. A series of three of these tubes (1 in. by 3/4 in. by 0.80-in. wall thickness) fit together to form a straight rail approximately 90 in. long. The swaged ends had to be aligned with the length of the tube so the resulting assembly was a straight rail.

The vendor specified this as a ram forming application, which made for a clean-looking reduction. The end form was a rectangle, just like the unformed portion of the tube. However, the tube had a weld seam along one of the short sides, and the ram forming process did not compensate for springback. The ends were crooked and the rail assembly was not straight.

Figure 4

When using segmented tooling to end-form square or rectangular tubing, it is necessary to create a shape that consists of peaks and valleys. These swaged ends are for slip fit assemblies. Segmented swaging, especially for the part on the far right, can ensure a straight and secure fit for such assemblies.

An I/O sizer now swages the tube and controls spring back, resulting in a straight tube. Segmented dies squeeze the tube on the OD, and a custom plug forms the ID. The end form is not a rectangle (see **Figure 4**). This is a typical tradeoff when converting a part from one manufacturing method to another. The part doesn't look the same, but its function improves.

This illustrates the need to find out what the part does, how it does it, and which part features affect its functionality versus those that are merely cosmetic. After determining these factors, you're ready to explore alternative manufacturing methods.