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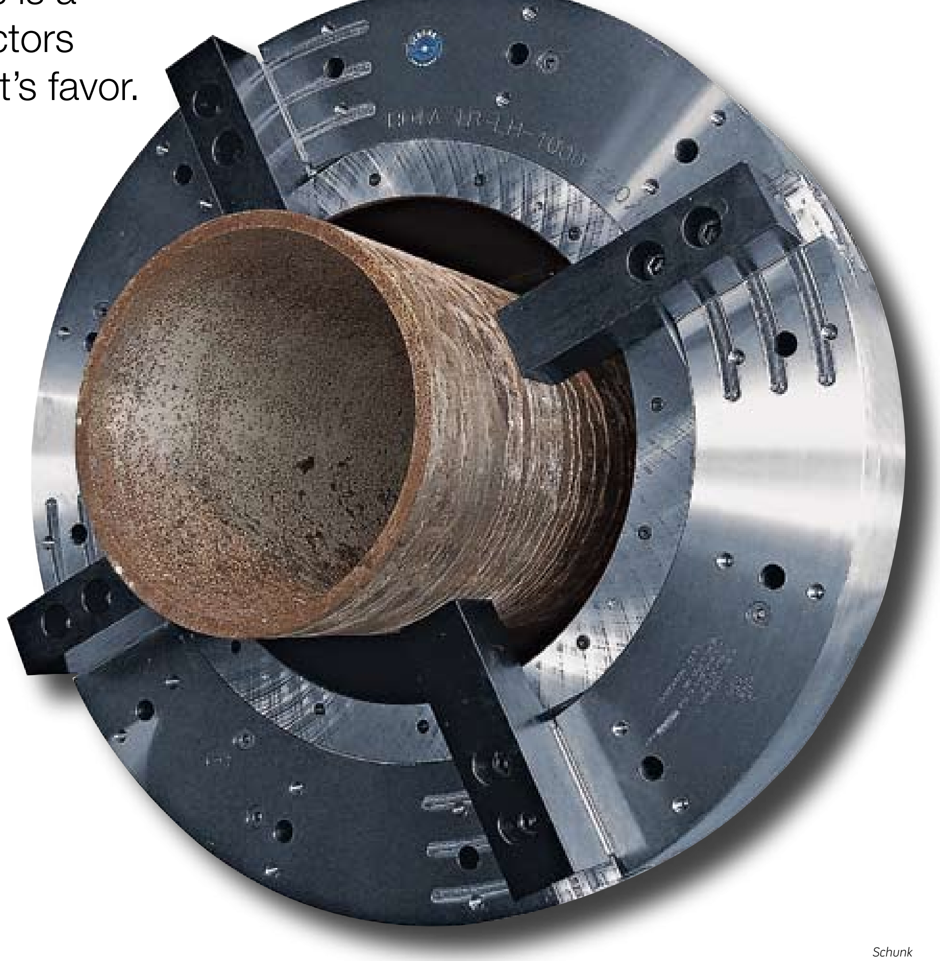
By Joseph L. Hazelton, Senior Editor

BIG Ideas

Holding large workpieces is a challenge, but several factors can work in the machinist's favor.



Schunk

Even massive workholders, including power chucks, may not have the gripping force to keep a large, heavy workpiece from slipping if a machinist tries to slow or stop the workpiece and workholder's rotation too quickly.

Workholding strategies for large workpieces can require special equipment and can challenge conventional machine tools, but machinists can also use large workpieces' properties to their favor. The key is to understand the physics of large parts.

First, it helps, though, to understand what constitutes a large workpiece.

Jay Duerr, vice president and general manager of LMC Workholding, Logansport, Ind., mainly defines a large workpiece by its workholder. If held with a face driver, a shaft is large if its diameter is at least 6". "Above 6", they tend to get much longer than the length of a standard machine," Duerr said.

When held with a chuck, a workpiece at least 18" in diameter would need a custom-made lathe. "Above 18", it gets into specialty equipment," Duerr said.

LMC offers workholders for machining large parts used in the oil and gas, shipbuilding, steel mill and windpower-generation industries.

Adjusting to Weight

A workpiece's size clearly affects the type of machine tool and workholder required, but a parts manufacturer must be mindful of the workpiece's weight to ensure the workpiece is held fast and results in a quality part.

For example, a large, heavy shaft may be spinning at only 1,000 or 2,000 rpm during a turning operation, but the workpiece's weight and speed combine to create a lot of rotational energy. A machinist must account for that rotational inertia when he slows down or stops the workpiece. If he tries to slow or stop it too fast, it may slip in its workholder and therefore be out of position for subsequent machining.

Slippage isn't an issue when machining smaller workpieces, which don't generally overpower the chucks. "They don't have the same mass," Duerr said.

Considerable weight can also be beneficial, however, when machining large, heavy workpieces. "You don't really need a whole lot of holding force because they weigh so much," said Lance Nelson, president of workholding manufacturer 2L inc., Hudson, Mass.

Gerard Vacio of workholding manufacturer BIG Kaiser Precision Tooling Inc., Elk Grove Village, Ill., agreed. "The weight of the part may be sufficient to stabilize its location." Thus, workholders can serve another purpose. "In these

Learn more about holding large workpieces

Read more commentary on workholding of large parts by visiting Joseph L. Hazelton's blog in the CTE Community section online at www.ctemag.com.

applications, workholding may be required to dampen chatter and vibration on large unsupported areas that require machining."

Another benefit of many large workpieces is their ability to support themselves, which may also help a parts manufacturer avoid specialized workholders.

Nelson cited a customer in the shipbuilding industry that creates 20'-wide × 70'-long aluminum plates which are welded together to form an oceangoing ship's hull. He said a series of 8"×12" vacuum chucks spaced underneath these large workpieces is sufficient to hold them. "Usually, these giant parts are able to support themselves," he said. "So they don't need a 20'×70' vacuum chuck."

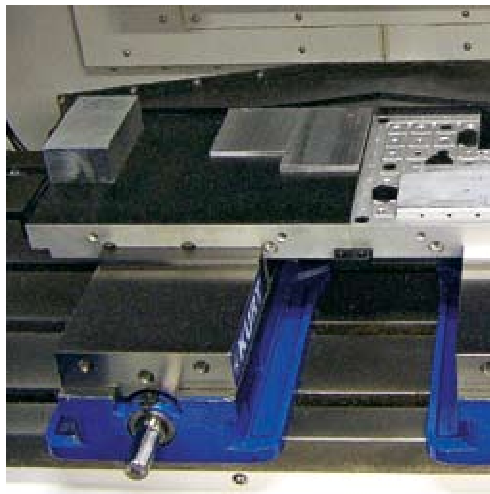
A workpiece that doesn't require support under its entire surface presents another challenge to a parts manufacturer.

Where the workpiece isn't supported, it will deflect during machining. Consequently, the parts manufacturer must decide how much deflection is acceptable, which depends on the part's specifications, and therefore how many vacuum chucks are needed for support.

Machine Tool Capabilities

Large workpieces naturally require machine tools with considerable horsepower and torque to take the workpiece from being at rest to rotating at its desired speed. "The bigger the diameter, the more torque it takes," Duerr said.

Parts manufacturers also need to understand that their turning tools may



Many large workpieces can support their own weight, so instead of a large, custom workholder, a series of smaller, standard workholders, like this vacuum chuck held in a vise, can be spaced out underneath a large workpiece to hold it.

seem to wear much faster than they're used to with smaller workpieces. "The surface footage gets higher exponentially the farther you go out on diameter if rpm remains constant," Duerr said. "You need to program in constant surface footage to compensate for that if possible. A 20" workpiece turning at 1,000 rpm covers much more surface footage than a 10" workpiece turning at 1,000 rpm."

Of course, a machine tool needs enough space in its work area for a large, partly machined workpiece to be turned around so its tailstock end can be brought to the headstock for machining.

It also needs to be able to handle the workpiece's and the workholder's weight. Workholders for large workpieces are

When not being machined

MANUFACTURERS OF LARGE parts face challenges besides ensuring that their machine tools can accommodate the milling, turning and drilling operations.

There's the ancillary equipment, too, including the cranes, lifts and other devices for handling the raw material, work-in-process and finished product.

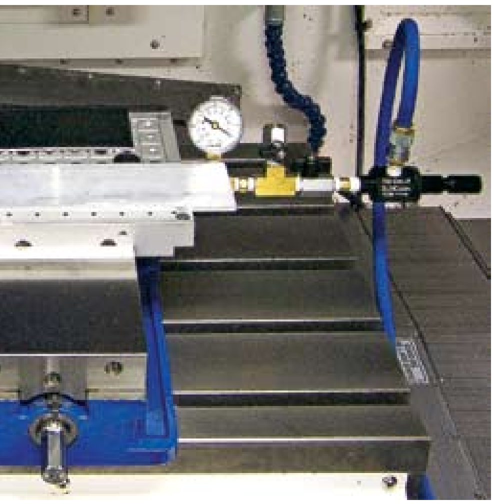
A parts manufacturer looking to make large products must consider a number of questions about ancillary equipment. These questions include:

What material-handling equipment is needed to move the raw workpiece to the machining equipment and load it?

What equipment is needed for handling the workpiece as work-in-process if it must be dismounted and remounted for continued machining?

Certain ancillary tasks for a large workpiece sometimes may not require large equipment, though. LMC Workholding's Jay Duerr said a 4"-dia. chuck can be used to grip a large workpiece and pull it from a heat-treat furnace, for example. He added that a small chuck can also be used for more precise positioning of large workpieces because the chuck can generate enough power for the task. "Think beyond the machining," Duerr said.

—J.L. Hazelton



often large themselves and therefore heavy. For example, a machine tool with a 10,000-lb. capacity won't be able to accommodate a 10,000-lb. workpiece and a 4,500-lb. fixture.

A parts manufacturer also should keep in mind how much space it has off its worktable and how far its spindle can reach across that table. For example, a horizontal machining center may include a rectangular worktable with long sides of 50" and a Y-axis spindle stroke of 25". If a large, rectangular workpiece has long sides that are 50" each, the HMC's tool spindle wouldn't be to reach all along that 50" length. It would be able to reach the midpoint, 25", but the workpiece would have to be rotated for it to be able to reach the other 25".

The situation would be worse if the machine tool could horizontally retract its spindle only 20" from the worktable's edge. In that case, a tool's maximum length would be 20". Rotating the workpiece would allow a 20"-long tool to machine 40" of the 50" dimension. The 10" closest to the workpiece's center would be unreachable. "They have to have a set of [workholders] that allows them to position a workpiece anywhere on the table so they can reach it," said BIG Kaiser's Vacio.

A reach problem may also be solved via an angle plate or a knee on the worktable, tilting the workpiece so the machine's cutting tool doesn't have to travel all the way to the table's center to process the workpiece.

This solution, however, can increase the number of setups needed for machining large workpieces. Parts manufacturers, especially job shops, know that angle plates and knees correctly positioned for a job may need to be changed the next day for a different job. "They constantly, constantly take angle plates and knees on and off," Vacio said.

"You have to position your part where you can get at it effectively and simply. And you just end up doing lots and lots of setups," Vacio said. "They're difficult to get around."

A parts manufacturer may be able to reduce setup time in some applications by using a modular, quick-change pallet system for large workpieces. BIG Kaiser offers such a system, which consists of receivers mounted to a machine table and clamping knobs mounted to the workpiece or workpiece pallet. The workholders have 0.0002" repeatability and can clamp with up to 5,000 lbs. of gripping force.

Workholder manufacturer Schunk Intec Inc. offers a modular system, too. According to Ron Wright, national sales manager for Schunk, Morrisville, N.C., a Schunk customer reduced from 6 hours to 10 minutes its time for locating a large crankshaft mold in a machining center.

Setups, however, can be especially difficult because precisely aligning a large workpiece in a machine tool can be problematic. "Because of the size, it's difficult to get everything straight in the machine," Nelson said.

A machinist may be able to help keep a workpiece aligned by abutting it against a workstop in addition to securing it with other workholders, avoiding the potential for warping. A large workpiece, such as a 70'-long workpiece that will become an


LMC Workholding

A large workpiece can also be a delicate, easily distorted workpiece if manufacturing the end product involves machining thin walls. In that case, a parts manufacturer would need two torque settings for its chuck: one setting for roughing and one for finishing.

Larger workpieces, looser tolerances?

LARGE WORKPIECES MAY BE machined to looser tolerances than small workpieces. Gerard Vacio of BIG Kaiser Precision Tooling Inc., cited aerospace parts as examples of often looser tolerances. "We have customers who have blueprints that say the hole can be within 0.008" or 0.009" of true position," Vacio said. "It will still work."

The looser tolerances can result from the difficulty of maintaining feature-to-feature accuracy on large workpieces. A machine tool can have considerable trouble holding 0.0002" on location from one dowel pinhole to another if the two features are 8' apart.

Accuracy is still necessary in large workpieces, perhaps especially so when the workpiece is an assembly, such as a frame. Vacio cited the big, welded frames in large, heavy cranes, like the ones used to construct high-rise buildings. Those frames may include a number of bores that are sites for pivoting components.

"Once you go and put in all the geometry that goes into that frame so you can mount other components to it, then you are doing some critical machining," Vacio said.

He added that holding the frame for accurate machining can be difficult because it consists of steel plates welded together. It's not solid like a block of raw material. "You can machine [a block] in such a way where you do all your heavy machining and then you do your light machining, and you don't come back and try to do heavy machining on something that's not stable," Vacio said.

Frames, however, may need to be stabilized internally before they can be machined without distorting.

—J.L. Hazelton

airplane wing, may be flexible and therefore may warp if it's held too tightly. "You tighten the vise a little too much, and you bend your part," Nelson said.

Two Settings: Better than One

A large workpiece may become distorted even if its workholder's initial torque setting was correct. This distortion can occur if the workpiece requires two torque settings: one for roughing and one for finishing.

Mike Tweed, manufacturing engineering manager for Baldor Electric Co., Kings Mountain, N.C., cited frame manufacturing as an instance in which a large workpiece required two settings. "We have to chuck at one torque setting when we're rough machining," he said, "and then we have to back off on that torque to finish machine." Reducing torque is needed so the workpiece can return to its normal shape for finishing to its specified dimensions.

The Baldor factory produces thousands of motors a year. A component can weigh up to 3 tons and a motor up to 25 tons. The building consequently includes bridge cranes of different tonnage capacities. Also, the factory's larger motors may be as much as 16'×10'×8'. The motors are for large-scale applications, with small to large ones for underground mining equipment and 2- and 3-ton chiller units for hospitals and apartment buildings. The largest motors are for use in the petrochemical industry.

As Tweed explained, a chuck's torque for roughing can distort a round workpiece so it bulges between the workholder's jaws.

Wright agreed. "Large parts are also commonly distorted when the forces of workholding devices are applied," he said.

Finishing a workpiece, however, involves shallower DOCs and less aggressive speeds and feeds than roughing, so a machinist doesn't need as much torque to avoid moving the workpiece in the jaws or pulling it out of the jaws. He can reduce the setting and thereby allow the workpiece to become round again.

If he doesn't, though, he'll finish the machining while the workpiece is still distorted. The part will return to its natural shape once removed from the lathe, but its machined features may be out of spec, so the part would need remachining or have to be scrapped.

Two torque settings are especially appropriate when a machinist is applying cutting tools to a thin wall on any size workpiece.

Distortion can occur if a large workpiece requires two torque settings: one for roughing and one for finishing.

When using a manual chuck, though, the trick for the machinist is to recall the extra step of changing the torque setting when moving from roughing operations to finish ones.

Which Workholder and Why

Tweed's shop uses face drivers; serrated, hardened jaw chucks; or ring fixtures to hold its large workpieces.

Many production-enhancing strategies, such as reducing setups and shortening cycle times, for small workpieces are the same for large workpieces. Fewer setups are especially desirable when machining large workpieces because they are difficult to dismount and remount due to their size and weight.

Tweed's department uses face drivers in its shaft manufacturing because they permit machining in one setup. A single setup can mean a higher-quality part because a machinist can avoid stackup error. This error occurs when a machinist has to dismount and remount a workpiece meant to be machined from a single centerline and isn't able to remount the workpiece just as he had it during the first set of operations. Its line between the centers will be different than it was when it was originally mounted.

"You're basically dealing with two different centerlines," Tweed said. If the workpiece is cylindrical, its concentricity would be worse; and the more eccentric the shaft, the higher its TIR. If the workpiece isn't cylindrical, the effect of multiple centerlines would be the same: poor concentricity. The final part's quality would suffer. For example, the part's features may not have the right spatial relationship to each other.

Tweed described a technique to properly seat a large workpiece's shaft on a face driver's pin. Proper seating is needed because if it's not right, the driver won't hold the workpiece as it rotates; the workpiece will slip. Proper seating depends on the tailstock pressing the workpiece's center against the face driv-

Baldor

A face driver permits machining of a shaft in one setup, an advantage when the workpiece is large. However, the shaft may slip against the workholder if the shaft includes a diameter more than three times its diameter at the face driver.

er's spring-loaded pin. To help with this seating, a machinist should remove material starting at the tailstock and moving toward the headstock. The tailstock thrust, cutting thrust and their direction combine to force the shaft's center against the face driver.

If the cutting tool starts at the headstock and moves toward the tailstock, though, the cutting thrust's direction pushes the shaft away from the face driver, pulling the workpiece off the drive pin. The tailstock thrust therefore must be increased to compensate.

According to Tweed, the tailstock thrust should be doubled. Consequently, if a tailstock thrust of 4,000 lbs. was sufficient when the cutting tool was machining toward the headstock, then a tailstock thrust of 8,000 lbs. would be needed if the tool were machining away from the headstock.

Tweed added another rule of thumb for machining a shaft in conjunction with a face driver: The shaft's largest diameter shouldn't be more than three times its diameter at the face driver. For example, if the shaft's end by the face driver has a 2" diameter, then the machine tool shouldn't be turning more than a 6" diameter anywhere along the shaft.

If it's turning more than a 6" diameter, there will be too much radial distance between the shaft's axis and the tool's tip, where force is being exerted on the shaft to cut it. The force and distance create too much leverage for the face driver to withstand. The workpiece will consequently slip against the face driver, according to Tweed. "That leverage overcomes your driving force," he said.

Tweed therefore recommended that if a shaft exceeds the three-times limit, then it should be held with a serrated, hardened jaw chuck.

The Baldor factory hardens its jaw chucks so they're more durable. The serrations leave indentations in the workpiece, but they keep it from slipping during machining. “Traditional jaws only rely upon friction,” Wright said. Slippage would—at the least—require a machinist to adjust the workpiece and locate it again before he resumes machining, a considerable amount of lost time. At worst, the workpiece would have to be scrapped.

The Baldor plant mainly uses its 3- and 4-jaw chucks when turning the cast iron brackets and frames for the housings of its electrical induction motors. The brackets support a motor’s rotating assembly, which consists of a rotor and shaft. Each motor’s frame supports the winding, which includes the wound stator. For Baldor’s large motors, the brackets start as workpieces that are up to 12" long and have ODs of 10" to 36" and the frames as workpieces that are up to 80" long and have ODs of 12" to 75".

LMC Workholding

Large shafts often need large steady rests, such as this Atling hydraulic one from LMC Workholding, for sufficient support and holding against cutting forces.

The chucks are set to 10 ft.-lbs. of torque per jaw for roughing and then reduced to 5 ft.-lbs. per jaw for finishing. Both brackets and frames, moreover, are turned while in vertical machine tools rather than horizontal ones because they work with gravity in the former and fight it in the latter.

The Kings Mountain plant uses chucks for workpieces with diameters of up to 20" and ring fixtures for larger diameters.

Baldor's ring fixtures are the male versions, each one a stack of disks of different diameters. The disks are usually made of hardened steel so their diameters don't change over time due to wear from the loading and unloading of workpieces.

Ring fixtures are also used with frames, though not until a frame's second set of operations. After the first set, a workpiece will include machined surfaces that shouldn't be damaged by chucks with serrated, hardened jaws. Tweed said a jaw chuck would still be needed for rotational drive, but it would be applied to the workpiece's nonmachined surfaces. The ring fixture would secure the workpiece's machined diameter. If that diameter is an OD, then the male version of a ring fixture would be applied. If the machine diameter is an ID, then a female version would be used.

There are other types of workholders besides those used by Baldor for its large workpieces. One other type is magnetic chucks, if a workpiece is made from a ferrous material. According to Schunk, though, a ferrous material needs a high iron content to be suited for magnetic clamping.

A large workpiece made from such material may be especially suited to a magnetic workholder. "The more surface contact the work has with the magnet, the greater holding power the magnet provides," Wright said.

Improvising a Workholder

Baldor experienced a particularly challenging job involving a thin wall more than 5 years ago, when it had to manufacture a new frame design for a new generation of enclosed, fan-cooled motors.

The gray 30 cast iron frame came in three sizes ranging from 37" to 52" in length and with a 23" ID, but the frame's top had a 0.120"-thick wall. The frame was secured at its bottom, but there was chatter and out-of-roundness in the stator board at its top. Baldor's normal workholders, including its serrated, hard-jaw chucks and its ring fixtures, couldn't be placed close enough to the frame's top to hold that segment steady during machining.

Baldor solved its problem by designing a custom-made workholder, a cage

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fixture, which was manufactured by a local machine shop. The cage opens and closes like a gate, allowing for loading and unloading of frames, and rotates with the workpiece during its turning operations. At the fixture's top are spring-loaded clamps for radial holding of the OD so the ID can be faced and bored. These clamps dampen vibration at the frame's top so the part won't be distorted or have chatter marks.

"It gets your workholding closer to where you are machining," Tweed said about the cage fixture. "You want to clamp as close to the cutting surface as you can possibly clamp."

> *Fewer setups are especially desirable when machining large workpieces because they are difficult to dismount and remount due to their size and weight.*

Thus, large workpieces can create contradictory challenges. Parts manufacturers must have powerful, often massive machine tools and large workholders to accommodate the workpieces' formidable size and weight. But, like their small counterparts, large workpieces can also be delicate and require special workholders, as Baldor's cast iron frame needed to avoid vibration. **CTE**

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