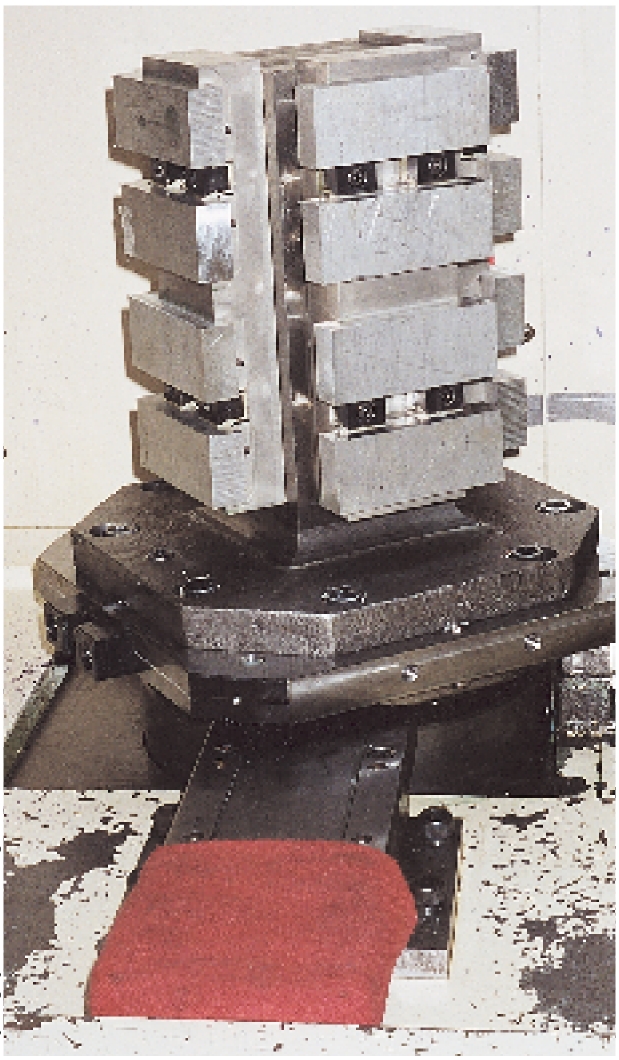
▶ BY TECHNICAL EDITOR CHARLES M. BOYLES, CPE

Rocket Science 101: WORKHOLDING



All photographs: EMS Technologies

Figure 1: Sixteen rectangular aluminum blocks are horizontally arranged on a tombstone for the first set of machining operations.

Proper fixturing is critical when machining aerospace components.

As high technology presses machine shops into the closest-tolerance zone, workholding becomes an integral part of the productivity/profit equation. This is especially true for manufacturers that make parts for aerospace applications, where attention to detail in workholding often means the difference between maintaining required tolerances and producing scrap.

EMS Technologies Inc. is one such manufacturer of aerospace components that realizes the importance of precise workholding, said the company's manager of mechanical production, Terry Newbury. The Norcross, Ga.-based company produces directional devises called "phase shifters" for microwave systems. Among its other components, EMS makes a precision housing that holds a phase shifter and its ferrite toroid—a donut-shaped, iron-impregnated, ceramic element. The rectangular-shaped "waveguide" housing has more than 20 machined surfaces, slots on both ends and multiple tapped holes. The part is characterized by two square beams that retain the ferrite toroid.

The phase shifter's operation largely depends on the mechanical integrity and dimensional stability of the waveguide housing. Any part distortion, or even a burr the thickness of a human hair, can cause the microwave system to malfunction or fail.

Along with functionality, Newbury said EMS's team of managers, designers, manufacturing engineers, shop supervisors and operators had to consider manufacturability, inspection capability, and integration and test feasibility before the part arrived on the shop floor. This included specifying and laying out the fabrication process, which required a complete understanding of the part's critical features, the machining sequence and fixturing.

The purpose of the detailed planning was to reduce the number of times the part is relocated from one fixture or machine to another. When a part moves between fixtures or machines for additional machining operations, the potential for compromising tolerances through misalignment—e.g., oversized or undersized parts, over- or under-torqued screws, twisted or improperly located parts—increases. For the waveguide housing, Newbury said the EMS team refined the workholding requirements down to two part relocations for the entire machining process.

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The housing is machined on a Tsugami FMA3 horizontal machining center equipped with a 62-tool toolchanger. The machine incorporates a material-handling system with 11 pallets that automatically transfer workpieces in and out of the cutting zone. The loading station allows access to the pallets, which permits machinists to mount parts directly on pallets, tombstones or angle plates.

The part has machined surfaces on all sides, and five surfaces have tapped holes. Additionally, the Tsugami HMC accommodates the three sets of operations: roughing the face and two ends, roughing and finishing the backside and the two sides, and finishing the face end—the critical operation.

The Workholding Challenge

The challenge was to eliminate part-to-part dimensional variation and tombstone-to-tombstone variation during machining. This required a highly accurate and consistent mounting system for each workpiece on each of the four sides of every tombstone.

EMS met this requirement by machining the part-mounting blocks on the same Tsugami FMA3 CNC machine it produces the parts on.

For the first of three mounting arrangements, the machining center was programmed to mill the mounting blocks so that each of the four tombstone faces would hold four parts in a horizontal position. With the part-mounting blocks bolted vertically to the tombstones, the blocks were indexed through the machining center on pallets and the spaces for the workpieces were milled, drilled and tapped.

After each mounting-block face was machined, the palletized tombstone was rotated 90°, presenting the next face to the tooling for machining. The parts' mounting arrangement called for a single milled space to accommodate two workpieces and a slot for two Mitee-Bite uniform clamps.

With this arrangement, two separate mounting spaces hold two workpieces each. The workpieces are rigidly held and retained by two outer-milled hard jaws and the two U-clamps. The clamps have an internal taper in which a tapered wedge with a hole accommodates a bolt. As pressure from the bolt forces the wedge into the "U," the clamp's sides push out and apply force to the workpieces (Figure 1). This means four workpieces can be held by the three hard jaws on each mounting block and are locked in place by the wedging action of the clamps. With this fixture, four parts can be clamped by tightening four screws.

When mounted and indexed into the machining area, the faces and ends of the waveguide housing are presented to the cutting tools for the first set of machining operations. In this mounting position, along with milling, the part blank is drilled, bored and reamed to create four holes on the front side, while the rest of it is rough-machined.

The 4"-square tombstones allow fixturing of 16 housings per tombstone during the first set of machining operations. However, the parts can't be clamped the same way for the subsequent sets of operations.

For the second set of machining operations, the housings are mounted vertically on the tombstone, in mounting blocks that are also machined on the Tsugami FMA3. With the parts mounted vertically, only eight pieces can be mounted per tombstone (Figure 2). So, two sets of fixtures are used to accommodate the 16 pieces removed from each tombstone used in the first set of machining operations. Three sides of the housing are machined during the second set of operations.

Part location is critical; two locator pins ensure that every part is mounted and aligned consistently. In this operation, two of the holes become central to

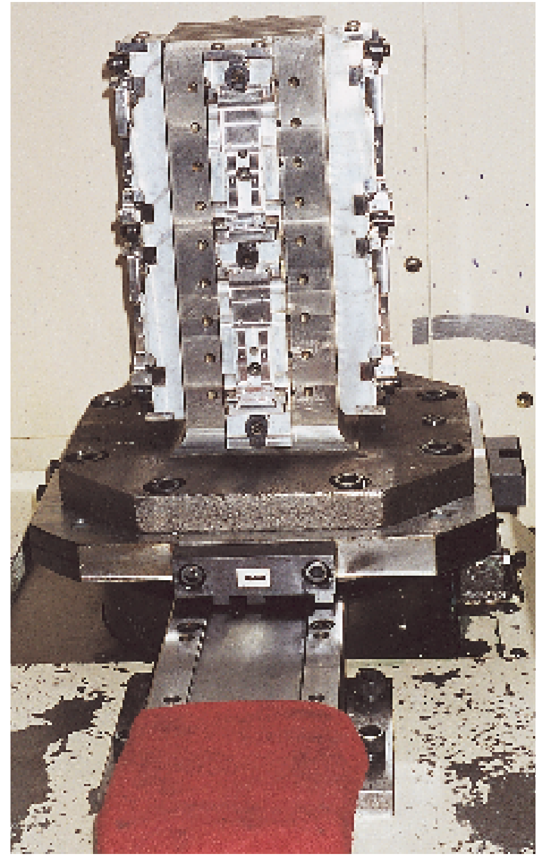


Figure 2: In this vertical orientation, the back of the waveguide housing is machined.

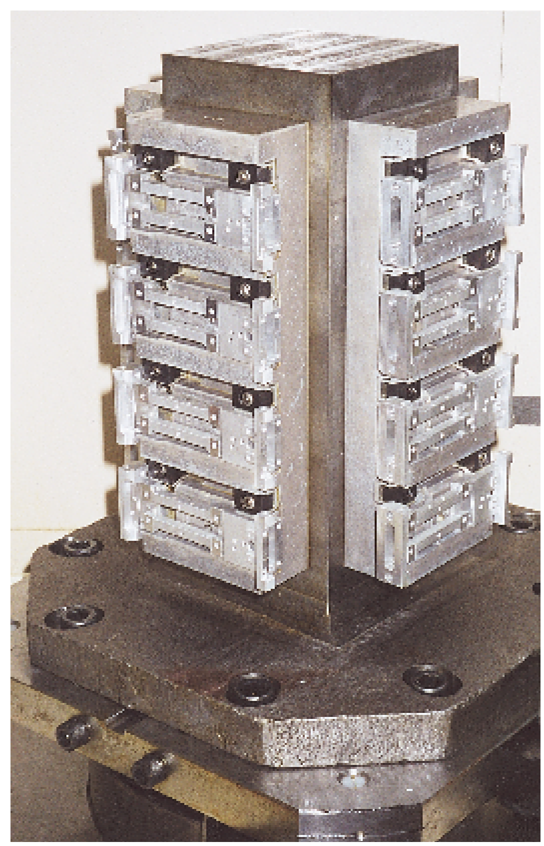


Figure 3: In the final fixturing, the part is again in the horizontal position.

Making waveguide housings

Through a team effort that included designers, manufacturing engineers, machine operators, quality-assurance personnel, assemblers and management, EMS Technologies took a potentially troublesome part—a waveguide housing used in an aerospace part—through a complex process with ease.

Part Characteristics. The machining begins by cutting a piece of 0.625", 6061-T6 aluminum plate in the correct direction—cross-grain to eliminate twisting—into 4"x1.75" rectangles. Openings measuring 0.200"x0.916"x 1.150" must be machined into both ends of the housing. Also, the openings between the bars have to be square to the faces on both ends to machine the opening. The part is then rotated 90°.

The interior space, the area between the two bars (see photograph), has to be flush to -0.001" to the waveguide. There is a 0.001" tolerance for the waveguide's bottom to the four surfaces where the tapped holes are located. The four tapped holes have to be in surfaces that are coplanar within 0.0004".

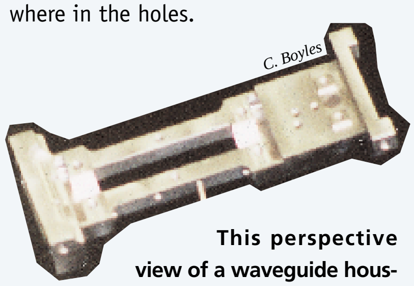
The part has some threaded holes for screws that function as tuning buttons (turning them in and out of the holes tunes the waveguide.) It's critical that burrs are removed to prevent them from interfering with the component's ability to operate correctly. Any metal "hairs" left in the holes act as tuning buttons.

EMS drills and taps the holes, deburrs the inside of the part, rotates the part and deburrs the bottom of the holes, then rotates and retaps the housing to fish out any material pushed back into the hole during deburring.

Basic parameters and constraints. The waveguide design calls for a 0.200"x0.916"x1.150" opening at one end of the housing. To create this, the opening is roughed with a 0.156"-dia., 2-flute, solid-carbide endmill. The machinist relieves this endmill 0.300" back from the end of the tool to prevent its shank from rubbing against the side wall of the cut.

On the sides of the part are four external radii with holes. These holes are +0.062"/-0.000", and within 0.0120" of the inside wall of the waveguide. Starting a 0.062"-dia. hole in a restricted area—at the bottom of the waveguide housing's opening, 1.150" below the starting surface—requires spotting, because the hole's location is near the wall. The spotting tool is a No. 1 center drill with its shank ground down, by centerless grinding, to a diameter of about 0.074" and a length of 1.25". This allows center drilling a starting point with the tool body within 0.012" of the interior wall. True positional tolerance is achieved, making drilling and reaming easier.

The No. 2-56 blind holes on the bottom are critical as well. Here, high-helix taps generate threads, bringing the material out instead of pushing it in front of the tap. This ensures there are no loose metal chips anywhere in the holes.



This perspective view of a waveguide housing illustrates the challenges of space-age machining.

Inside finishing. This operation requires step-cutting the walls by climb-milling with a 0.125"-dia., 60°, 2-flute endmill running at 1,500 rpm and 15 ipm. The depth of cut is 0.004" and the length of cut is 0.225". A challenge of this phase of the production process is the need to index the part 90° and mill the intersection of the other opening within 0.001" of the first opening. The second opening has to be 0.3075" (+0.001") x 0.199" (+0.000"/-0.001") deep. The sequence is repeated on the opposite end of the part.

Additionally, the ends of the part are facemilled with a 0.625"-dia. endmill. There's a 16µin. finish requirement, and flatness, squareness and parallelism are to 0.001".

Rigidity and clamping. These constraints pointed to evaluating part-fixture-tool-machine rigidity, and refining cutter speed to 8,000 rpm with a feed rate of 30 ipm and a 0.004" DOC. EMS needed to design a clamping arrangement to prevent part distortion beyond tolerance limits. Furthermore, the open top of the part did not lend itself to side clamping.

At the end of the bars on the housing are four No. 4-40 holes. The major diameter is 0.1120". Holes are drilled, bored and reamed undersize, to 0.0930". The holes are bored and reamed because reaming establishes the correct hole size, and boring provides true hole positioning.

Furthermore, by using the previously tapped No. 4-40, 2B holes on the part's back face, the machinists is able to attach a steel subplate that can be clamped in the fixture.

Burrs. To avoid manual deburring and provide a uniform edge, a 0.125"-dia., 90°, V-endmill is used to deburr the accessible edges. Additionally, the seven No. 2-56 tapped holes and a 0.250"-dia. bored hole on the face are deburred with a 0.187"-dia. carbide deburring tool mounted on a 0.125"-dia. shank. Retapping immediately after deburring removes the minute burrs that can move back into the tapped holes. The machine tool's rigid-tapping feature ensures exact re-entry and prevents oversized threads.

While the actual machining cost can be sizable, manual deburring can add significantly to the final cost. Therefore, EMS incorporates as much as 95 percent of the otherwise manual deburring into the actual machining operation. The same style of previously mentioned V-endmill is used to put a 0.005" break on edges that require deburring; this operation was programmed into the machining process.

EMS drills and taps the holes and then indexes the part again before a carbide ball burr is applied to the waveguide-housing opening, which comes up against the backside of the holes to deburr the bottom of the holes. Then the part is rotated back again and a tap is run back into the hole to remove any burrs.

—C. Boyles

the finishing operation, since two properly sized pins and two circles provide perfect alignment. As a primary datum, machinists use a round pin as the center and a diamond-shaped pin as the secondary datum. The round pin is used as the "zero" for the x-y datum and the part rotates around that pin.

The diamond-shaped pin has 5° to 10° of arc at the top and bottom points and is used for radial orientation. This combination of pins was used since two round pins would make it too difficult to remove the part from the fixture.

During this second stage, machinists screw a protective plate to the part and then clamp the plate to the mounting block. Without a plate to protect the holes, the part could twist when the screws were tightened, causing the part to fail. Additionally, uniform clamping pressure in the fixture is ensured by using a torque wrench.

In the third and final set of machining operations, four parts per mounting block are arranged horizontally in the finishing fixture (Figure 3). Therefore, the finishing fixture holds 16 pieces, as is case with the fixture for the first set of operations. At this stage, critical features are machined and finished in one fixturing.

When EMS receives a job like the waveguide housing, Newbury said that the company takes the time and makes the effort to refine the process to optimize every operation. To accomplish this, EMS breaks down its customary departmental boundaries, wherein one department does its work then "throws the project over the wall" to the next department. In the case of the waveguide housing, the production process is unique in that a part blank goes on one machine, moves twice and is completed.

Through careful planning, EMS has avoided costly redraws, redesigns and problems on the shop floor as the parts move through the production process, said Newbury.

He added that EMS also avoided the attendant overcharges and late deliveries that are often the outgrowth of incomplete planning.

Workholding was an important part of this planning process. When a production run is finished, the tombstones and mounting blocks are stored until they're needed again.

This is only one illustration of how the performance of the most advanced aerospace technologies depends on effectively applying basic machining principles. Here, the basic principle is workholding.