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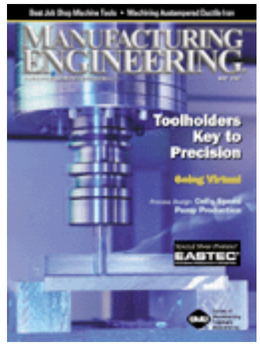

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Cruising the Productivity Highway

Flexible manufacturing helps Harley-Davidson keep customers on the road

By Russ Olexa, Senior Editor

Harley-Davidson Motor Company's new V-ROD motorcycle can permanently take some wrinkles out of your face and add them to your smile.

Imagine having so much demand for your products that customers will wait months for them. Then envision the pressure to meet that demand. This is the unusual

situation the Harley-Davidson Motor Company (Milwaukee) has found itself in for approximately 15 years.

It hasn't always been this way, but today Harley-Davidson products are revered by many motorcycle enthusiasts. Some of their new motorcycles, like their recently introduced V-Rod, even command premium prices because of their scarcity and uniqueness, and can take several months to deliver.

Production of motorcycle crankcases falls on the shoulders of manufacturing engineers like Bob Mueller, manufacturing group leader, who works at the company's Pilgrim Road, Menomonee Falls, WI, plant where they build the Twin Cam 88 1450cc engines.

At one time these engines' crankcase castings were machined in a cell using four two-pallet HMCs with one operator in attendance. But because of the increased engine demand, a more productive way had to be developed. These aluminum crankcase castings are made up of two halves, and are split into two groups. One is an alpha crankcase that doesn't have counterbalancers, and a beta crankcase that does. The beta crankcase is larger than the alpha. Both are available in powder-coated black or silver.

"The new process is identical to the proven process that we've run for the last three years with stand-alone Toyoda FA-550 HMC machines. However, we made some modifications. Instead of having one machine finish the crankcase completely, we have seven Toyoda TH555G Top Center HMCs and one dedicated drilling station. So the crankcase cycle time is divided between these eight machines, and amounts to a few minutes per finished part [made up of a right and left crankcase half]," says Mueller.

Toyoda's Top Center system was designed around a U shape to maximize precious space. Four HMCs on one side face three HMCs and a dedicated drilling station on the other side. On the left of this photo is a transfer vehicle that moves the pallet fixture from one side to the other to continue the cutting sequence.

Except for a dedicated drilling station, each machine is a HMC integrated into a flexible transfer-style line. Toyoda's system is set up in a U-shape with four machines on each side facing each other, and a load/unload station at one end with a pallet-moving system that connects everything. At the other open end is an automated transfer vehicle that takes the pallet from one side of the U to the other, so the pallet doesn't have to make a 90º turn. Between the machines are "ready" positions where the pallets are parked until the machining operations are completed on the pallet in front of them. There are four "ready" positions on each side.

This system gives Harley-Davidson a small footprint, because they've eliminated what would have been a large pallet-changing system surrounding the machines. Pallets move through side doors into the machining area. This approach compresses the space needed for the system. Machines do a small number of cutting tasks and only have 16 tools per tool magazine. Consequently, they are much more like a traditional flexible transfer line than a group of HMCs with a pallet system.

One thing that Harley-Davidson needed in a new machining system was flexibility for production and engineering changes, and the ability to maximize part quality. Each Toyoda HMC Top Center has a full *B* axis (the table rotates) that allows them to do any special contouring required in the future or if there are any changes to hole angles in parts.

The manufacturing process starts when aluminum castings come into the plant from an outside vendor. Castings are powder-coated before machining to eliminate painting and masking operations downstream, which saves time and increases product quality. Harley-Davidson builds to daily production demands with the parts being available to assembly personnel in a finished-goods area. This procedure also allows a first-in and first-out product cycle, helping the company maintain product integrity and quality. A right and left-hand casting is mounted on a special pallet that uses a programmable identification chip. Pallets are moved between stations by a material-handling system.

A verification system integrated into the conveyor line checks which castings are on the pallet and programs the chip so that the machining system knows if its an alpha or beta crankcase.

Besides depending on the machining process to control part tolerances, crankcases are inspected on an hourly basis.

At the Toyoda Top Center, an ABB robot loads the parts into a fixturing station and unloads them after machining. There are cast-in lugs on both halves of the crankcase that allow the parts to be properly fixtured for consistent machining in a picture-frame-type pallet. The pallet allows complete access to the parts' front and rear. Pallets arrive at the load/unload station vertically after machining. They are then rotated into a horizontal position for load and unload. Before the robot unloads the parts, a special fixture-releasing device using DC motors to drive nut runners moves down to the part fixture, unclamps the parts, and then retracts automatically. Before the robot removes the crankcase halves, it has determined from computer information and from the identification chip on the pallet what parts are needed next. Using special robot end effectors, finished-machined halves are removed and replaced with unmachined castings.

With the new parts loaded in a pallet, a locator beneath the pallet pushes the castings against a hard stop to precisely position them in the fixture. Then the castings are clamped. So the system performs a preload and final load to make sure the parts are accurately fixtured. Prior to loading unmachined castings, a coolant and air blast cleans any chips off the pallet locators. Through the identification chip and linked computer system, the machining system knows which parts are being loaded for cutting.

"When the parts come to the first machining center they are probed for proper position. If the casting is properly positioned, the machine's controller accepts the information and continues the cycle. If the casting is out of position, which could damage tools and fixtures, we get an alarm to bypass this pallet," added Mueller.

After each machine finishes its cutting cycle, parts are transitioned to the "ready" position. Once all four "ready" positions are filled, then all pallets transfer to the next machine.

After machining, crankcase halves are placed back on the conveyor system and moved to a washing station. After washing, at the next conveyor station, two dowels are pressed into the crankcase halves for alignment, and then they are joined together. "One thing that is extremely critical for us is the positional accuracy of the bores in the two halves that support the crankshaft. We assemble the two halves by putting in dowels to mate the two halves for an extremely accurate fit. Once the halves are manually fitted together, bolts are added by a robot and tightened in a specific sequence to a predetermined torque," says Mueller.

For secondary machining, Harley-Davidson has three cells using rotary transfer machines to cut the peripheral features. To keep the crankcase features within tight tolerances, the company uses a hydraulic mandrel that locates the two main bores. Then it goes through a five-step fixturing process. A robot picks up the fitted crankcase and places it on a fixture, and it's sequenced through five different locations. "If it's off more than a millimeter, a part-presence indicator will let us know the part isn't in position. Triflex rotary machines produce the features that are on the outside of the crankcase and remove the fixturing tabs that are cast onto the parts," says Mueller.

After final machining, the bolts are removed by a robot, the two halves are separated, and more dowels are added. After they are washed, a pin-stamped part number is added to each half, so if they should be separated, the numbers could be used to match them up. Next, a 100% leak test is done. "We have a reject loop right in front of this area, so if parts don't pass the leak test, they get rejected. If parts pass the leak test, they go on for assembly," adds Mueller.

For quality checks of the Toyoda Top Center pallets that are so critical to producing the crankcase halves, Harley-Davidson uses a CMM stationed next to the Toyoda system. Crankcases produced from each fixture are checked every shift and the data recorded. "Our quality inspection checks critical features on the part back to its cast-in locators. Because we have ten pallets for each series of crankcases, we needed the pallets to be extremely accurate," says Mueller. He added that he was very pleased with the boost in quality that the new Toyoda system gave him. "For several tight true position features, we were trying to achieve over 2 C_{pk}. We thought doing so would be a struggle, but we exceeded that number. We rely on the process of the machine rather than checking all the parts. We do statistical sampling and do the analysis to verify our C_{pk}. This system has also reduced our scrap rate. The repeatability is exceptional. We also have a line of air and hard gages to check the parts every hour," he remarked.

All Toyoda machines have tool-life counters and sensors to detect high-wear or broken tools. Tools are also changed during predetermined cycle periods to help maintain part-size tolerances and quality. If a tool breaks in a part, the part is located and pulled so it doesn't get into the system.

"Crankcases are very complex parts. They have numerous angles, many different hole sizes and stringent true-position requirements. The process we had was divided to balance the cycle times among seven horizontal machining centers and one angle-drill station. So each machine averages six tools, with some redundancy. There are hundreds of dimensions that are machined and checked," says Mueller.

The eighth machine is a special dedicated drilling unit that Toyoda built and designed, which puts in angled oil holes. "We still needed an additional axis to put these holes in. Rather than buy another machine with a fifth axis, we decided to go with a dedicated machine with four drillheads for these oil holes," Mueller added.

Toyoda's TH555G Top Center has an *X*-axis stroke of 500 mm, *Y*-axis stroke of 550 mm, and a *Z*-axis stroke of 510 mm. Top spindle speed is 12,000 rpm with a 22-kW spindle, and a rapid feed rate of 60 m/min.

Here is a beta crankcase partially machined and fit together. The two large holes on the top are for the cylinder heads; the large hole on the side is the crankshaft bore.

"As long as I've been here, we have been constantly increasing our capacity so we can build more motorcycles. We went with the Toyoda Top Center because we needed a system for producing at increased rates. Before the Toyoda system, we would not have been able to meet increased production requirements with stand-alone machining centers. We started looking at manufacturing equipment capable of higher production volume. We looked at many manufacturers, and there is some real strong competition out there. We also did a worldwide search to find the right machine tool. We feel that Toyoda is a solid machine, and we've built a long-term relationship with them through Innovative Machine Tool Sales, the exclusive supplier for Toyoda in Wisconsin. They've supported us very well in many different areas, so dealing with them took a lot of the risk out of bringing in a new machining system. We have Toyoda machining centers that are 12 years old that are just being taken out of production now. The only reason we're replacing them is because we have more productivity with the newer machines," Mueller remarked.

Asked why they used this type of system and not a dedicated transfer line, Mueller said the company really needed the flexibility for part changes that a transfer line wouldn't offer. "We had some transfer lines in the past that didn't allow us to machine the location of the part features as accurately as we needed, and we didn't have the flexibility to change feeds and speeds. Also, we want to remain flexible to accommodate engineering changes. We have that flexibility with the Toyoda system, and it has also given us back-up machines. Seven of the eight machines are identical, so if something goes wrong with one of them, we can off-load some of the machining operations to another machine.

Conversely, if something goes down in a transfer line, it's one link in a chain that stops everything. "I don't believe the transfer line could give us greater production. The cycle times would be based on the feeds and speeds, tooling, and fixture stability. So the feeds and speeds, and the cycle times are going to be similar. But every piece of research we did convinced us that we can have higher uptimes with HMCs than transfer lines. That gives us greater productivity in the long run," Mueller added.

At Harley-Davidson, lean manufacturing is a very important part of the manufacturing process says Mueller. "We've gone to a single-part flow that expedites parts through machining to final assembly, and it takes as little as a few hours. We're gaining jobs and not reducing manufacturing staff. Every system we're putting in is primarily a new system for more part-volume increase. We're just about at 1000 people for this facility and growing. Our automation replaces the repetitive health hazard types of jobs, and we're implementing it with robots wherever justified. We're moving away from the stand-alone cell, where you have operators spending a considerable amount of time loading and unloading machines and checking parts to cells where the operator is considered our quality manager. Verifying part quality is all I want an operator to do, because the machine should run itself," says Mueller.

Harley-Davidson's Pilgrim Road plant builds the big twin engines (alpha and beta) and transmissions. A plant on Capitol Drive in Wauwatosa builds the 883cc and 1200cc engines. Final bike assembly and fabrication are done in York, PA and Kansas City, MO. Today the company produces seven motorcycles in the Sportster family, five in the Dyna-Glide family, the new V-Rod, seven bikes in the Softail family, and six in the touring family.