A Live Tool Makes Stamper's Fantasy a Reality

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A die that can measure thickness and hardness in-process is a fantasy for most stampers. To them, presses are machines that spit out parts. Quite the opposite is true for a growing number of stampers, however. For them, in-process measurements are a reality.

Several manufacturers are already cutting through the noise of the working mechanics inside the press to isolate the force signature of the forming process. Feature extraction software uses data in the force curve to calculate changes in thickness and hardness of the work material, based on an analysis of the pertinent parts of the signature.

The manufacturers' secret is mounting the load sensors in specific stations or segments of the tool, rather than in the conventional locations on the press and die. Sensors on the frame of the press might detect a difference of a few tons, but the resolution is too coarse for precision work. When sensors are at the correct locations in the tool, resolution can be fine enough for a correctly timed tool to measure to thousandths of an inch, said Michael O'Brien, president of Signature Technologies Inc. (Dallas).

The force feedback is fine enough for a controller running signature-analysis software to compare the data to established control limits and take predetermined action in real time when a force measurement wanders beyond a control limit. The controller can activate servomechanisms built into the tool for compensating for minor variations, or it can stop the process and tell the operator that the process has exceeded its control limits. "You now have a living tool," said O'Brien.

The technology that these manufacturers are using to measure variances in hardness and thickness in the die came from a joint research-and-development project between Signature Technologies and Ford Motor Co. (Dearborn, MI). Researchers in the automaker's laboratories were looking for a method to monitor the work hardening of drawn door panels. Because the trend was toward thinner panels to help reduce weight and improve mileage, the automaker was considering draw-hardening them so they would be springy and hard to resist denting.

Controlling the hardening during the drawing process is tricky business, so a reliable method for monitoring the process was needed. Ford's researchers derived and validated the equations for measuring the work-hardening N factor, but did not have the electronics and software to collect and process the data. The company turned to Signature Technologies to supply the required technology. The resulting software monitors the changes in thickness and hardness from nominal values by extracting the necessary data from the force signature and solving the equations in real time.

Ironically, none of the automaker's plants have implemented the technology, primarily because the nature of automotive stamping poses a reliability problem. Electronics need a high degree of protection. "Die setters move tools that weigh 50,000 pounds," said O'Brien. "Putting sensors into presses a little too high and shearing off wires is just too easy."

Implementation at Ford will have to wait for an evolution in wireless technology to occur. Although wireless sensors can report on-off and dimensional data now, they simply do not have enough bandwidth for sending a continuous stream of analog measurements fast enough for real-time calculations. "Think of modems and the Internet," said O'Brien. "When plants upgrade from a dial-up modem to DSL (digital subscriber line) or T1, all of a sudden video becomes a reality. Wireless transducer technology is still in the dial-up modem mode."

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Slow to proliferate

Despite the potential that living tools hold for process control, signature-based process control has been slow to gain acceptance. One of the biggest reasons is a perceived lack of repeatability. "The validity of the signature depends on how the apparatus collects data," said O'Brien. "Many users plug a card in a PC to collect signatures in much the same manner as an oscilloscope does. Those signatures are all based on time instead of machine position. What happens when the press changes speed? They really don't know."

O'Brien questions the accuracy and repeatability of those measurements because any apparatus collecting data at uniform time intervals does not account for the changing speed of the ram and tool throughout the stroke. The crankshaft moves the ram up and down at changing speeds, which increase as the crank approaches 90 and 270 degrees and decrease as it approaches 0 and 180 degrees. Complicating matters is that operators do not always run presses at exactly the same speeds from job to job.

The variable describing the action in a stamping process is force expressed as a function of tool position. Measurements collected at uniform time increments assume constant speed and interpolate force and position. O'Brien disagrees with other vendors who say any error is too small to matter. "If force measurements are going to mean something, they must occur at the same precise location repetitively," said O'Brien. "If you're interpolating, you're giving up sensitivity. You don't know exactly how the measurement compares to the benchmark for the process."

He attributes his ability to measure in thickness, work-hardening and other parameters accurately to measuring force directly as a function of position. To collect enough data during the cycle, sampling resolution is an issue. Measuring to a minimum of a tenth of a degree of crank rotation is generally necessary to capture minute variations in the process.

Although O'Brien said that the technique can reliably measure to thousandths of an inch, he said that this depends on the timing of the die and the investment in engineering. Correlating features in signatures to real units of measure depends on the consistency of the work material, design of the tool and repeatability of position measurements along the stroke. "Producing good measurement data always comes down to dollars," he said. "A system between $13,000 to $15,000 should achieve the vast majority of standards in U.S. manufacturing."

Extracting control data

Using the accurate and repeatable force curves, feature extraction software can calculate a number of useful properties describing both the efficiency of the process and the quality of the parts produced. The most basic of these properties is tool wear, which increases the amount of work necessary to punch a hole, for example. Because work is the product of force and area, tracking tool wear is a matter of monitoring the stream of force measurements from a load cell behind the punch, calculating the area under the force curve and comparing it to a predetermined limit. The controller or other computer can alert the operator when the work exerted exceeds the limit.

One of the limitations of plotting a force signature and calculating the area under the curve is that the computations take time. For the technique to be economical and fast enough to offer real-time feedback in production, software developers make the problem more manageable by writing algorithms that analyze only the most relevant portions of the signature. The technique works because each variation in the process affects the force curve in a particular way and is often more pronounced at a particular region.

Consider tool wear. Sharp corners on the die button and punch transfer the force straight through the material. This produces a fracture and causes the slug to separate cleanly before the tool travels halfway through the material. As the tool dulls, the rounded edges begin to stretch the material. Instead of fracturing cleanly, the material flows into the die button, much like it would during drawing. Dragging the material between the punch and die produces a burr.

The force signature in this case becomes wider and more bell-shaped, and its peak force either rises slightly or falls. Because the wider curve has more area under it, reflecting more work is necessary to punch with a dull tool, Signature Technologies offers a feature extraction utility called Work to track the area under the curve. Threshold Detector, another feature extraction utility for tool monitoring, tracks the trailing edge of the blanking signature for the release point to move later in the stroke, a technique that has proven to be a trustworthy indicator of tool condition.

As the tool continues to wear, it drags increasingly more material until the punch locks and breaks upon withdrawal. Monitoring these withdrawal forces can denote wear, but only after producing a number of parts with burrs. So O'Brien recommends monitoring work and release points instead.

Another feature extraction utility is the one that computes changes in hardness by looking at the leading edge of the curve. Because the slope equals the load's rate of change per unit distance, the slope of the leading edge is related to the hardness of the material. If less stress is created as the tool enters and progresses through the material, then that indicates a soft material. More stress over the same distance means the material is harder.

Because a change in thickness would cause the tool to touch the material earlier or later, depending on whether it was thicker or thinner, yet another feature extraction utility determines these variations from phase shifts in the signature. Signature Technologies recommends watching for phase shifts at the leading edge of the signature as opposed to monitoring peak tonnage to identify thickness variations. Phase shifts are pronounced and repeatable, whereas changes in peak tonnage are not. Consequently, minor variations in material thickness are undetectable by analyzing the signatures' peaks.

The reason for the difference in sensitivity is noise. "The peak is a point of transition," said O'Brien. "The entire press is under load. Then suddenly the load is released and the load direction changes. As the press relaxes, bearing journal play and other mechanical changes in the press, not in the process, appear in the signature as mechanical noise, which can be so loud that fine measurements are impossible. Load monitoring might be able to tell that the material is twice as thick, but it cannot detect a 1% change." So peak readings are unreliable for quality control.

Although Signature Technologies can interpret data from up to 48 sensors, the cost for doing so is expensive. "The power of the feature extraction technology is that one sensor can extract many different features," he said. "By timing the die so a part of the process stands alone in part of the signature, you can extract the critical features and track them." This ability to listen to what the die has to say makes breathing life into it both practical and worthwhile.