APPLICATIONS OF SIGNATURE ANALYSIS TECHNIQUES TO ASSURE RELIABILITY AND IMPROVE PROCESS QUALITY

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This paper explores the use of signature analysis equipment as used with in die strain gauges and other analog devices monitoring for part quality and tool reliability.

Introduction to Signature Analysis

Topics discussed:

1. What is a process signature?
2. Measuring the process
3. Obtaining a signature
4. Information derived from the signature

What is a process signature?

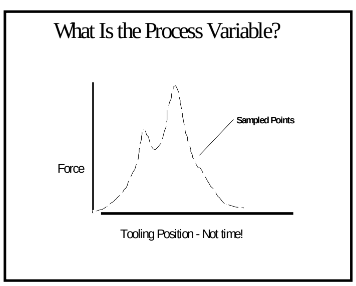


Figure 1

In simple terms, a process signature is an electronic picture of the forming process force pattern. It provides information about the amount of force developed at a specific point of the press rotation. The process is the application of force applied by the tool to the surface of the material. Force varies as a function of tool position through the stroke of the press as seen in *figure 1.*

Measuring the process

Too often the process is only seen as what feeds into the press and what comes out of the press. This is a measurement dilemma. We measure the inputs and outputs of the process, not what goes on the process. Standard die protection techniques examine such things as feed up, part out, buckle, and end of stock (input). These are all indicators if a problem occurs and are very important monitoring tools helping to protect the die and the press from damage. Quality assurance inspects the part produced and assures that at least the end product meets a predetermined standard. Seldom is the stamping process measured through the stroke providing information to the operator on a hit for hit basis. Signature analysis uses analog sensors of many types to measure the process and display it graphically as it occurs. This data provides feedback to warn the operator. The computerized system stops the press, makes adjustments to the press or die, or is used to track the part and eject it when it leaves the tool.

Monitoring the process from the press via strain gauges located on the uprights or the press connections can improve product quality and increase reliability. Gauge or sensor placement is important, the further away the sensors are from where the work is done the less valuable the measurement is. Signal attenuation is created due to the mass of the ram and drive links. Also, there is a great deal of noise generated in the press frame that may override small signals generated in the die. If monitoring for total tonnage is all that is required then measuring from the press uprights is adequate. That is not to say that no information is available from signatures produced from the press uprights, only that it is limited. Certainly, <u>protecting the press from over tonnage is a necessity</u>. Sensors placed on the connecting arms of the press produce a more useful signature due to their proximity to the point where the part is actually formed. However, monitoring the process from the connections has limitations as well. If monitoring for a small punch in a 12 station progressive die it is unlikely that the punch will appear in signatures from either the press uprights or connections. For this purpose, it is best to measure force directly from the punch.

Force is measured by sensors on the press or in the die. As force is applied to the material, data points are gathered and displayed graphically as a signature providing the operator with a visual representation of the process.

Once measured, limit sets are established to identify variations in the process (*figure 2*). The limits and signature can be used as masters and are the baseline for setting up and running the same part in the future.

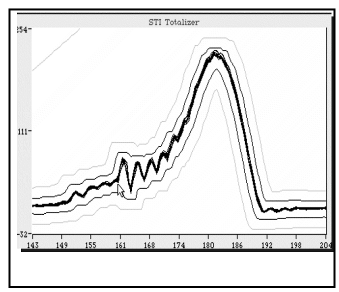


Figure 2

Obtaining a signature

Required Equipment:

1. Resolver
2. Strain gauges or other analog devices
3. Process Monitor
4. Operator interface

The resolver is the feedback device that provides positional information to the monitoring system. Mounting and driving the resolver is critical. The drive mechanism must be either direct, through a spiral coupling from the end of the crankshaft, or by means of a toothed timing belt from the crankshaft. Resolvers for this purpose should not be driven by roller chain.

Strain gauges, piezo electric sensors, and/or other analog devices provide force measurement and dimensional information to the system. These devices are used to monitor tonnage on the press, measure force directly in the tool, and part position along with many other functions.

The process monitor combines the signals form the resolver and sensors (position based data) to produce a signature. It then compares each data point with its limit set producing the appropriate real-time press control command.

The operator interface may be either an integral part of the process monitor or, a separate computer which allows the operator the to communicate with the process monitor and stores master signatures, limit sets, tooling, press, and other desired information.

Information derived from the signature

For a signature to have value it must provide a range of useful information. For instance, the operator may have a problem with changes in material thickness or hardness that affect part quality. These variables can be monitored with signature analysis techniques.

Figure 3 shows how changes in thickness effect the starting position of the signature (phase shift). As thickness increases, the starting position of the signature occurs earlier. Conversely, as material thickness decreases, the starting position of the signature is later.

Figure 4 depicts the effect of material hardness changes on the slope of the process signature. As hardness increases the slope of the signature grows steeper and as material hardness decreases the slope of the signature grows shallower.

Many other aspects of the signature identify process changes. For instance, nitrogen cylinders appear as plateaus on the signature and can be monitored for changes in pressure that indicate the condition of the cylinder. Stripper springs, punches, draw stations, and urethane forms are all areas that can be directly monitored by signature analysis.

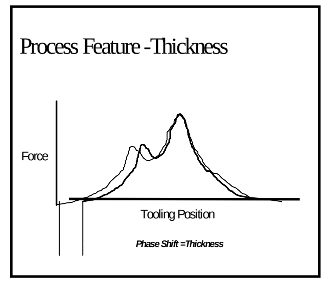


Figure 3

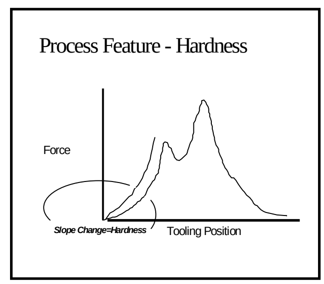


Figure 4

Signature Applications

Some specific examples where signature analysis was used to determine presence and sharpness of punches, the condition of in die taps, part quality, and part position are outlined below.

Example 1

This case demonstrates the differences in data collected from the same process by sensors mounted in different locations on the press. The press is a 200-ton Bliss straight side with sensors mounted both on the uprights and the connections.

The signatures shown are for the same stroke of the press providing a good comparison from the connections and the uprights of the machine. Material feed is left to right. Station one is a blank and draw. This die also incorporates a pierce and urethane form with a pinch trim at the right side of the press.

The signature in *figure 5* is generated by the Left Connection. The blanking operation and the draw are visible in the signature. Since the pinch trim is on the opposite side of the die, it has little effect on the signature. Most of the individual features are visible. Press frame ringing caused by the pinch trim shows up as an oscillation at around 164 degrees.

In the signature for the Left Upright (*figure 6*) the blanking portion is largely lost due to signal attenuation through the mass of the ram and drive links. The draw is still discernible although significantly changed by force oscillations in the press frame. The pinch trim is more prominent even though it occurs at the other end of the die. The only portion of the signature that remains unchanged is the coining hump at 180 degrees.

Looking at the signature for the Right Connection (*figure 7*), of immediate interest is the -5 ton dip at about 135 degrees. This dip corresponds with the 25-ton peak from the blanking operation seen at the same location on the Left Connection (*figure 5*). The draw is not visible but the pinch trim's 30-ton load at 160 degrees is very visible. In the Right Upright (*figure 8*), the draw portion of the signature reappears around 140 degrees but note that the pinch trim and the coining spike are approximately the same size. Comparison of the uprights might indicate a die that is balanced right to left. However, the signatures form the press connections shows a 30 ton left bias at 136 degrees and a 20 ton left bias at 161 degrees.

From the signatures shown in this example the condition of the urethane form station can not be determined.

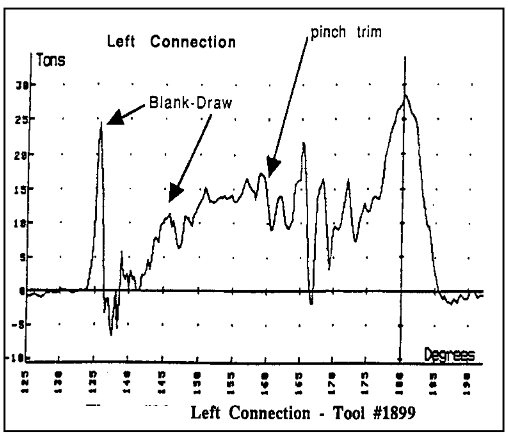


Figure 5

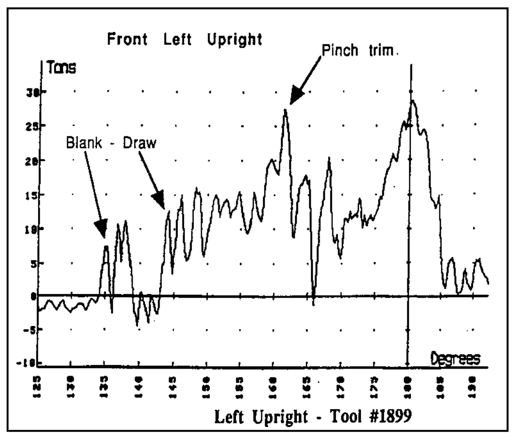


Figure 6

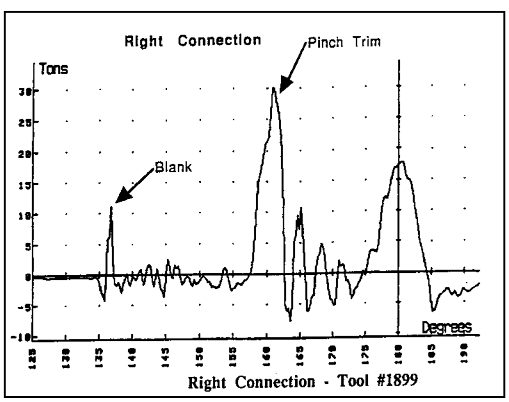


Figure 7

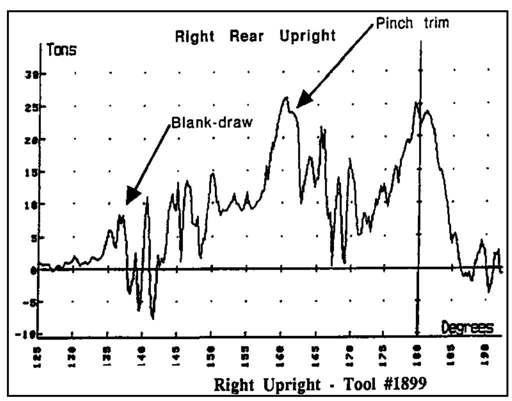


Figure 8

Example 2

The press in *example 2* is the same Bliss press used in *example 1*. The part is a steel cup with a pierced, extruded hole in the bottom. In this case the comparison is made between signatures from the Left Connection and two sensors actually mounted in the die. The two stations that have sensors are the blank and draw and a station containing a pierce and urethane form.

The signature from the Left Connection (*figure 9*) indicates that the blank and draw is the only section of this die performing any work until the coining hump at 180 degrees although this is not the case. Note that the blank and draw portions of the signature in *figure 9* are on the left most tool station and compare with the signature taken directly below the draw ring (*figure 10*).

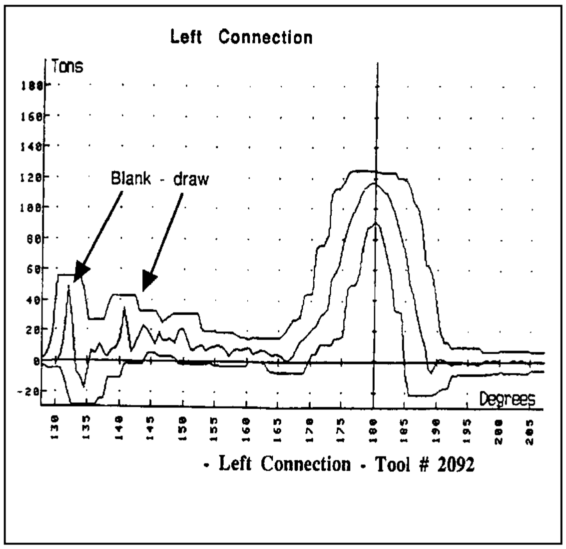


Figure 9

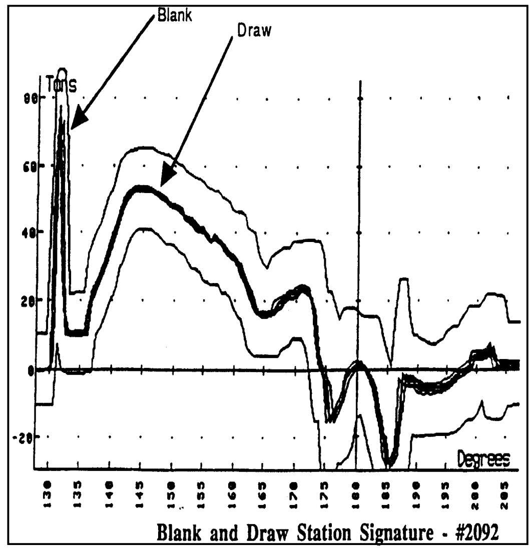
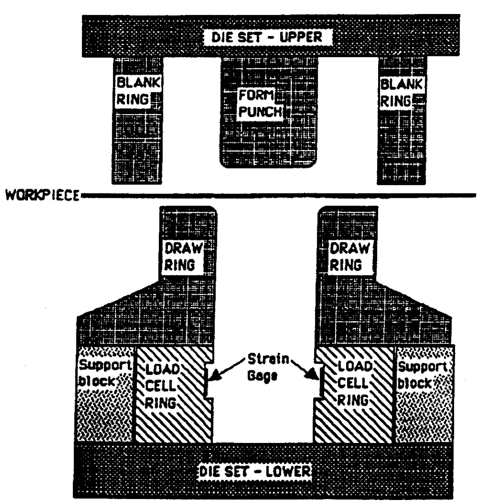


Figure 10



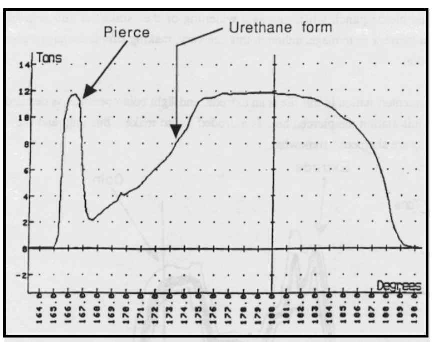
Blank and Draw station Load Cell Arrangement
Figure 11

The in die sensor incorporates strain gauges mounted on the inner bore of the load cell (*figure 11*). Locating gauges in this manner is more sensitive to the drawing load occurring on the inside edge of the draw ring. Force in this case tends to flow in a laminar fashion through the tooling. Load cells employed in this manner are very tricky to calibrate. It is safe to assume that absolute calibration is not required since the value derived from the signature is for comparison rather than absolute measurement. Most important is that the signature is consistent and repeatable. Any changes then relate to the process.

The signature for the Right Connection (not shown) is very similar to that of the Left Connection and creates the impression that little happens in the die until the coining hump begins at 168 degrees. This however is misleading.

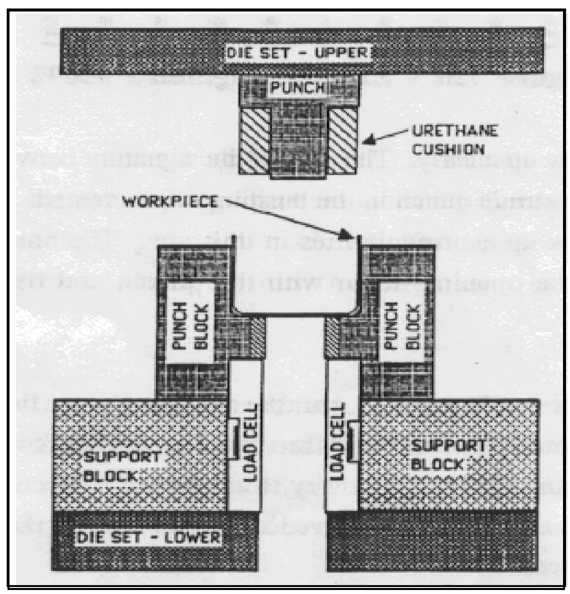
As mentioned in the beginning of this example, there are two stations in this die that do significant work. The blank and draw (already discussed) and the pierce and urethane form (*figure 12*).

The pierce and urethane form load cell is located directly below the punch block with the strain gauges mounted on the outside of the cell as opposed to the inside as in the blank and draw. This station has different sensitivities to the two actions that take place in the station. Both activities are clearly seen in *figure 13* due to the timing of the station. The urethane tends to wear very quickly and this is easily detected as a decrease in force at 180 degrees. The pierce portion of the signature is also easily monitored. As the punch wears and gets dull, the pierce portion of the signature widens. This type of station monitoring is very helpful in predicting maintenance as well as quality control the parts produced.



Pierce and Urethane Form Station

Figure 12



Load cell arrangement -Punch and Urethane Form Station

Figure 13

Examples 1 and *2* demonstrate that there is a significant difference in the amount of information available in the signature as the sensors are positioned closer and closer to the area where forming is performed. In these examples much of the activity in the process is not seen from either the press uprights or the press connections. Only when sensors are placed directly in the die can the station be monitored for performance.

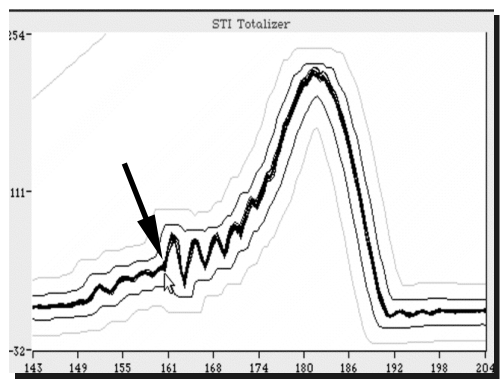
It is obvious material changes and die wears have great influence on part quality. With the use of signature analysis, monitoring for these changes can be accomplished. The value of this technique is twofold: 1.) Tooling is not allowed to deteriorate to the point where poor quality parts are produced (predictive maintenance) 2.) Material changes affecting part quality are identified so that appropriate action can be taken. How often are meetings held to discuss a die problem or a part quality issue where little or no process documentation is presented? In such cases only speculation and educated guesses from very experienced people are the basis for decision making. Documentation, and hence fact based management, comes from monitoring the process which can only be accomplished by adding sensors and monitoring equipment to the press and dies.

Example 3

A part being formed in a progressive die has a small punched hole (.020 diameter) and it is being punched through a .020 to .030 inch wall (*figure 14)*. This situation is difficult to monitor in the die by conventional methods using proximity sensors or optical sensors. An alternative to electronic monitoring might be to perform 100% visual inspection (only about 80% effective) requiring the additional manpower.

Figure 14

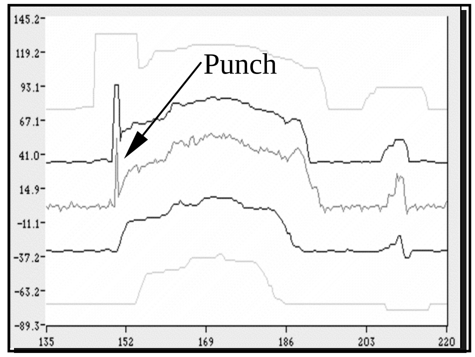
The manufacturer decided to add an in die sensor, to an already existing signature analysis system, monitoring for a broken punch on a hit for hit basis. *Figure 15* shows the signature for the entire tool from the press-mounted sensors. The arrow in the figure indicates the point at which this punching action takes place (determined from die timing). It is impossible in *figure 15* to identify any feature of the signature that will provide useful information about the punch.



Press Signature

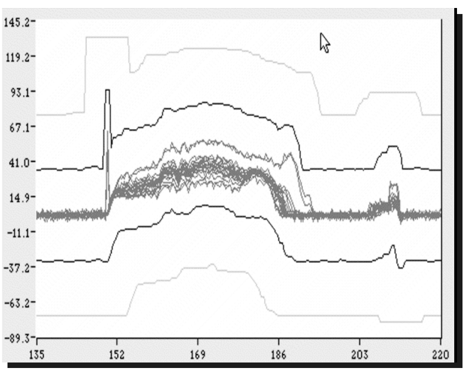
Figure 15

By placing a strain gauge sensor directly behind the punch it is easy to identify that the punch is intact. The signature in *figure 16* shows the presence of the punch and is shown with its limit sets. Notice that the limits are very wide in this example. The wide limit sets are necessary due to the noise generated in this station (*figure 17).*



Punch Signature

Figure 16

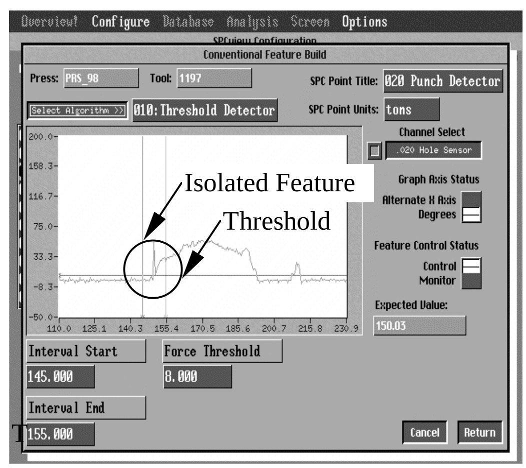


Punch Signatures Overlaid

Figure 17

In *Figure 17* the punch signatures are overlaid one on top of the other. The noise level is clearly seen using this technique and it is clear that a tighter limit set would cause nuisance faults. Therefore, these limit sets cannot be used to signal that the punch is broken and another technique must be employed to stop the press when this punch breaks.

Specialized software, used in some advanced systems, is employed to make this monitoring and control task possible. A specific signature feature, reflecting the punch, is isolated (figure *18*). After isolating the feature a force threshold is set which is crossed once per press cycle when the punch is intact. The system monitors this action and displays the results on an X-bar chart (*figure 19*). A limit set for the isolated feature controls the process. If the punch fails the signature will not cross the threshold and the press is stopped



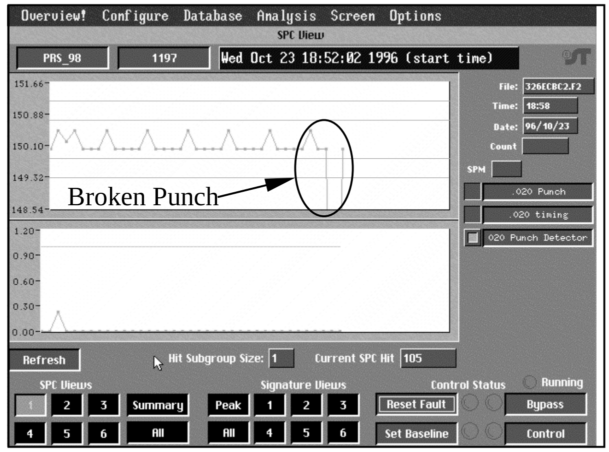
Feature Extraction-Threshold

Figure 18

Each limit set is established by a system administrator and its parameters independently determined. Using specialized software greatly enhances the type of monitoring available and the amount of control the system has of the process and therefore quality control.

Signature feature extraction techniques are used to monitor punch sharpness in larger punches and in die taps. For these applications a software tool, interval work, is used to monitor the area under the curve returning a value which reflects the changes in the amount of work done by the punch.

The manufacturer in this example uses a signature analysis system to stop the press. No defective part ever leaves the tool. As a result, there is no need for hand sorting and inspection vastly improving efficiency and the bottom line.



X-Bar Chart with Control Limits

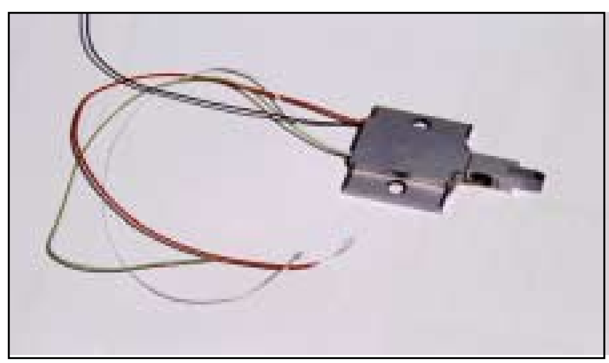
Figure 19

Example 4

This next example is from a high-speed application. The press is a Minster Pulsar running from 500 to 800 SPM. Two (2) parts are formed and merged on the same die. One part is a spring that is formed in one portion of the die and then assembled into the second part being produced in the same die. The spring tension and position are critical to the proper function of the finished product. One hundred percent monitoring of the spring is required by the end user.

An in die sensor is used to measure the force of the spring. Spring pressure must be held to +/- 1/10 Newton. Once assembled the part spring position is measured in a laser station outside the forming area of the die.

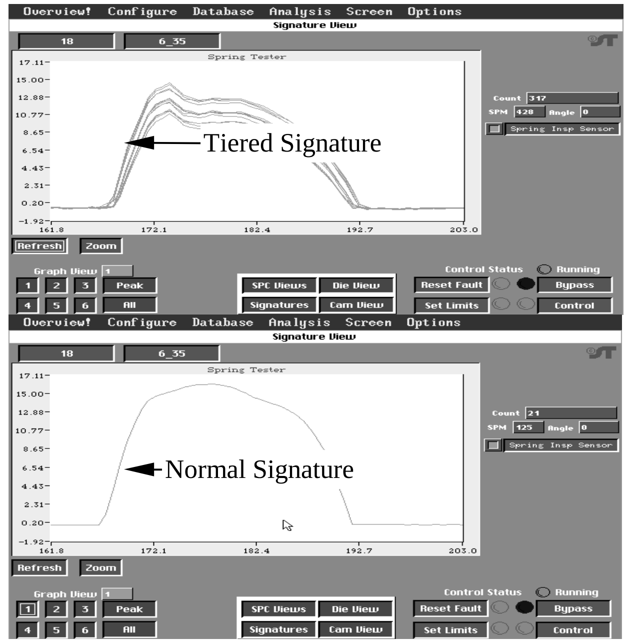
The spring sensor is composed of a custom machined body with calibrated strain gauges attached (*figure 20*). The die is modified to accept the strain link. The sensor monitors each part before insertion into the carrier part. If any part is out of specification the signature reflects it as a violation of the limit set. The system uses this as feedback to track the bad part through the system and ejects it at the outlet of the press.



Spring Sensor

Figure 20

Signature from the in die spring sensor. The sensor produced a tiered signature after the die was adjusted. The die maker, with only two days experience using a signature analysis system, noted that the signature was not as expected and was able to correct the problem. With this window into the process this manufacturer was able to identify and correct a problem that may have gone unnoticed until thousands of parts had already been produced.

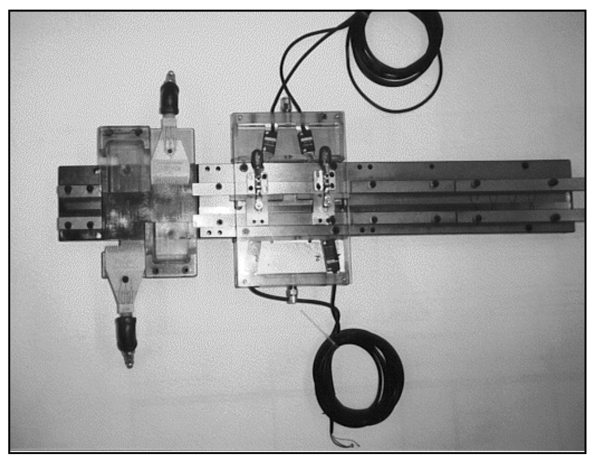


Spring Sensor Signature

Figure 21

The laser station shown in *figure 22* consists of 2 lasers inside a Plexiglas housing. The housing is pressurized to keep dirt and oil from contaminating the lasers and compressed air is used to decontaminate parts before entering the laser station.

Once in the measuring area, laser beams at 2 different locations examine each part. The laser signature is compared against limit sets, if the limits are broken, the system tracks that part and rejects it.

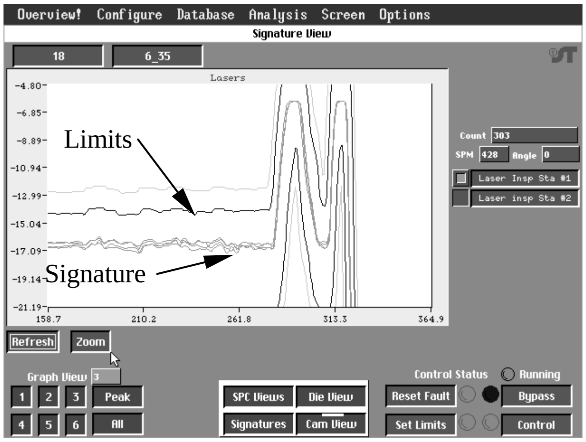


Laser Station

Figure 22

If multiple defects are detected the press is stopped and repairs made before large amounts of scrap are produced.

Figure 23 is the signature of the laser measuring station. The oscillations at about 270 degrees are the movement of the part through the lasers and are not involved in part position measurement. The laser station allows measurement to .0002 inch.



Laser Station Signature with Limits

Figure 23

Conclusion

The examples set forth here are only a few illustration of how some stamping companies are employing electronics to aid in monitoring tool wear, tool breakage, and part quality.

Signature analysis systems provide a window into the die and the process. With real-time process controls the user can identify problem areas before press or tool damage occurs and mountains of scrap are produced.

The stamping industry knows the cost of die damage, press damage, downtime, scrapped parts, hand sorting, etc. *Isn't it timed to examine the benefits of prevention*?

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