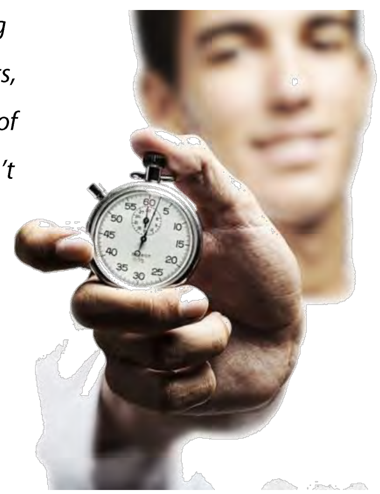
How Using In-process Test Waveforms Reduces Time for Process Optimization and Problem Diagnosis

Part test and process monitoring systems are now commonplace on today's automated production lines. Savvy manufacturers are turning to waveform-based systems, not only for accurate pass/fail measurements to boost part quality but also to more efficiently manage their stations.

Waveform technology provides reliable shortcuts to optimizing processes, determining limits, determining root cause of defects, adding new tests and managing quality spills. This saves days of effort—time that people managing production lines often don't have to spare.



Manufacturing Engineers Need More Time

Manufacturing engineering and process staff is typically overextended in the lean factories of the post-recession. Job one is to keep the line running and every day something unexpected happens. The tools in place to help these engineers be responsive and proactive are often lacking. Hours or days are lost using Excel spreadsheets trying to compare information and come up with answers.

This is due to the lack of useful data from the production line. Typical process monitoring is often simplistic and records only scalar data which reflect what occurred during a process at a specific point in time. The only way to convert a few isolated values into a solid body of data is to run the manufacturing process over many cycles, and analyze the resulting dataset. This process takes a lot of time and effort, yet the resulting dataset still has a fundamental lack of information.

These primitive methods force the manufacturing engineer to use time-consuming trial and error methods to fine-tune processes and correct defects caused by systemic issues with the manufacturing process. Scalar-based process monitoring equipment is designed to look for known issues, so when a new problem crops up, the few values taken during production are unlikely to shed any light on the problem at hand.

Moving to waveforms on the test and monitoring systems across the line helps to take a lot of the manual effort and guesswork out of reporting and making improvements. It also offers significant time savings and great reliability.

How Waveforms Work

A waveform, which captures hundreds or thousands of data points per cycle, is a visual representation of everything that happened during a manufacturing operation on a particular part. Since each process and parts combination is unique, waveforms are often called process signatures. In any controlled process – for example press fitting, leak testing, welding, liquid dispensing – the signature is repeatable and consistent when parts meet specification. A signature that does not match indicates a flawed process and a defective part.

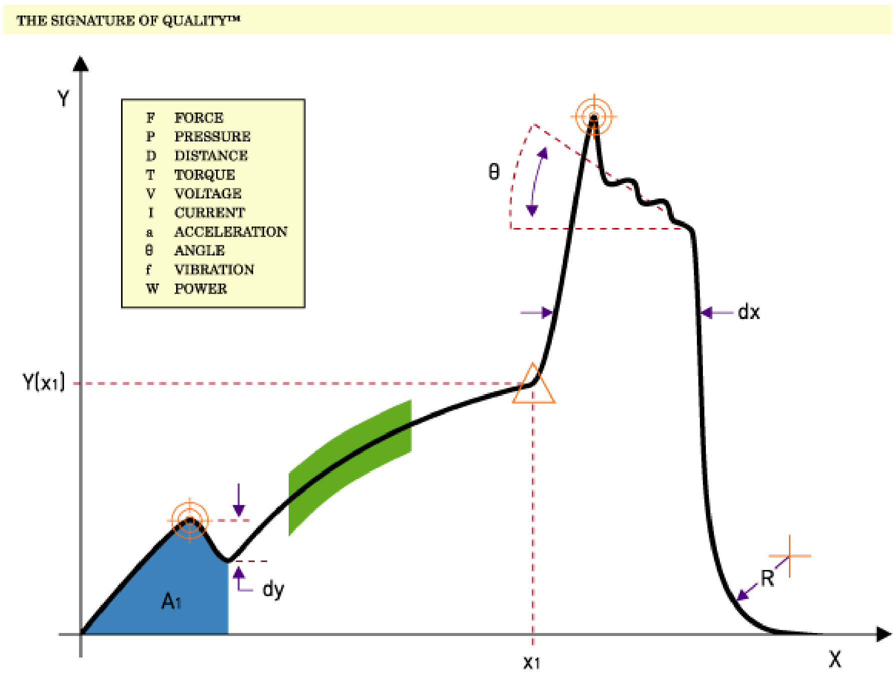


Figure 1: Example of a waveform

In a true waveform-based system, all of this data is collected and stored. The waveforms for each part can be archived against serial number so it is available for future analysis for various purposes, including retroactive testing. Stored data saves time in all sorts of ways, from managing test systems more efficiently, to analyzing large datasets to discover subtle problems more easily.

An Example of Waveform Analysis

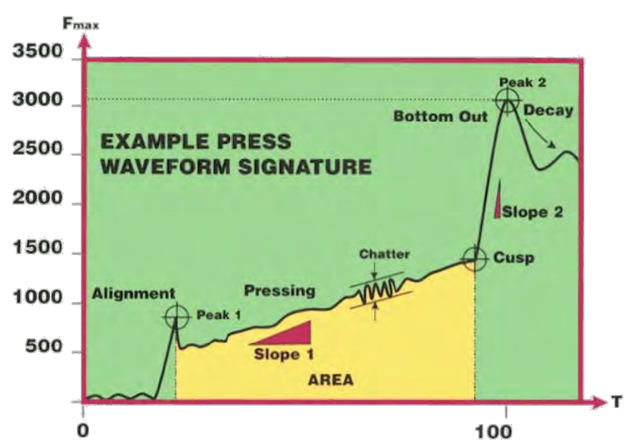


Figure 2: Press-fit waveform

Figure 2 shows an example of a press-fit waveform. Force is shown on the Y axis. Since time is often equivalent to distance, time has been used as the X axis in this case.

At a glance we can see several key features. There is a small spike in pressure as the parts align, and then a constant slope as the parts are pressed together. The area under the curve replaces limits. The shape of the curve reveals the quality of the press-fit operation.

If quality problems are identified in finished products, the manufacturing engineer can quickly identify a few possible causes rather than making wild guesses that take days or weeks of verification reject the wrong theories and discover the true root cause. For example, if the alignment spike is too high or too broad, the parts are likely too far out of alignment to start with and the press needs adjusting. On the other hand, excessive chatter or hills and valleys in the curve during pressing indicate different types of quality problems with the parts themselves.

It is often possible to get advanced warning of impending quality problems. For example the process may produce good parts, yet the manufacturing engineer may notice telltale signs of initial misalignment of parts. The press can be adjusted before a drop in quality is apparent.

When trouble-shooting, a histogram of areas across many press-fit operations may reveal certain types of anomalies leading to root cause, eliminating educated guesses based on a visual inspection. For example, if a certain level of chatter is common with good and bad parts alike, it is unlikely to be the source of the problem.

Real-world Examples of How Waveforms Save Time

Having the entire waveform for each part produced provides an instant visualization of exactly how well the manufacturing process worked and what potential problems may be on the horizon. The following real-world examples illustrate how waveforms are used every day by manufacturing engineers for:

- Limit setting
- Optimizing test cycle times
- Identifying the root causes of defects
- Launching new machines or lines more quickly
- Predicting machine maintenance requirements

Limit Setting

With full waveform data available, setting limits is no longer a matter of guesswork.

An intelligent process monitor such as Sciemetric's sigPOD features in-station SPC that uses production statistics, including all of the data in the waveforms, to calculate optimal test limits. The information is graphically presented and the user can see the results of proposed limit changes before deploying them. Limits can therefore be set more accurately and quickly.

Engineers can opt for additional analysis tools that pull together waveform data from test systems for more sophisticated analysis. Sciemetric's QualityWorX data management software allows you to simultaneously analyze a collection of waveforms, leading to a determination of stable limits without false rejects. A range of tests can be run on the same stored data rather than running additional parts though the process to validate parameters. This saves both the time and expense of running parts and allows for rapid development of tests.

Figure 3 shows an example where the original limit caught two failures in the dataset. What if the limit were lowered? You can see in the graph on the right that the optimized limit would have caught 9 failures, based on the stored dataset. This is an example of how accumulating data combined with greater experience with a process can lead to tightened parameters, with very little time or effort. This in turn leads to improved performance of quality tests.

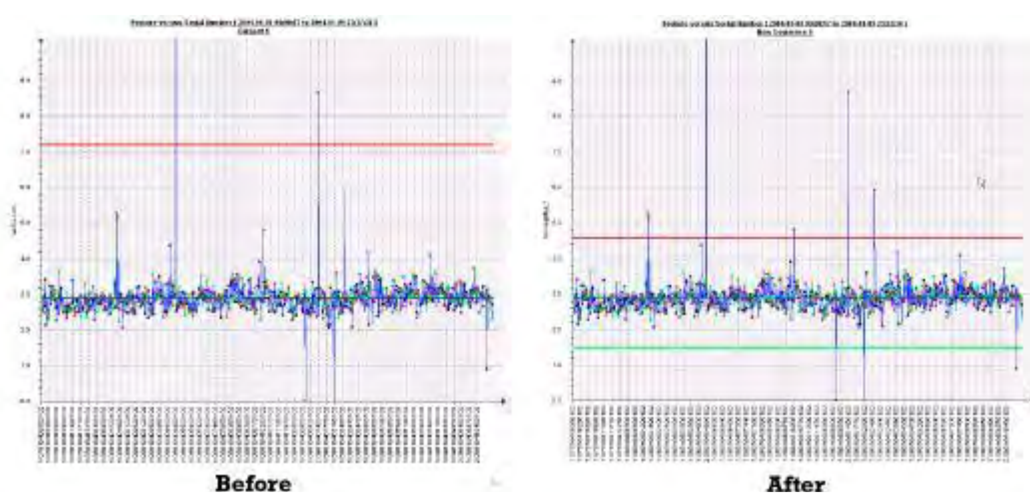


Figure 3: Effect of limit changes using historical waveforms

Optimizing Test Cycle Times

The rate at which a certain test can be performed may limit the pace of the production line. The challenge is to maintain quality standards while optimizing cycle time as much as possible.

Figure 4 is a series of breakaway torque test waveforms, overlaid using QualityWorX, which show how much torque is required to start the rotation of the part. Once in rotation, the torque falls off as running torque takes over. Running torque is not an important part of this test. What is important is that breakaway torque completes with a characteristically fast rise time and that peak torque is not too high.

One curve shows a unit with much too high a breakaway torque. It may be missing lubrication or have the wrong bearings installed. Several other waveforms have the wrong shape (or "signature"), but achieve the same running torque as good units. They are likely missing components.

The important thing to notice is that the test takes over twice as long as necessary to find defective parts. All normal waveforms, along with many of the outliers, have achieved breakaway before the time indicated by the green box. At this point, enough of the signature is captured to differentiate good vs. bad parts.

By adding a new test and terminating the cycle based upon its result, a 7 cycle savings per hour shift was achieved, providing the plant with an increase of 132 parts/month.

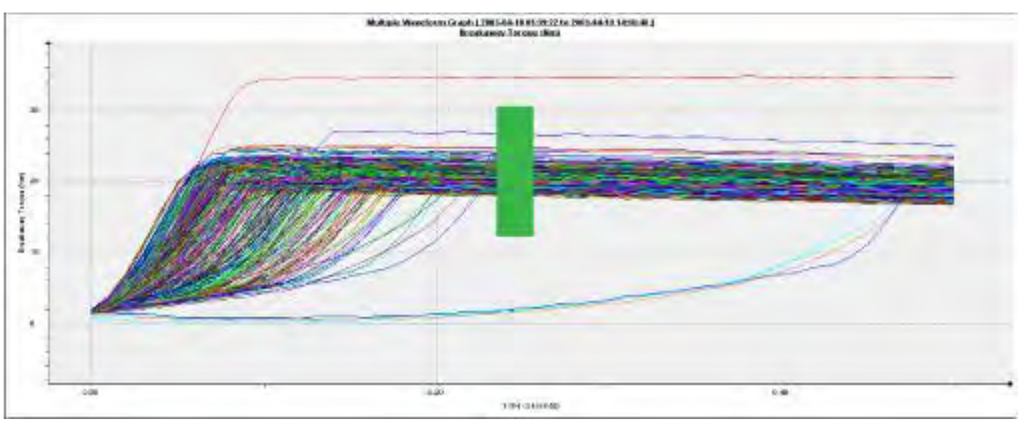


Figure 4: Adjusting cycle time for break-away torque test

Optimizing this test took only minutes.

Identifying the Root Causes of Defects

A newly discovered defect can create havoc on the line. Until the root cause is discovered, an unappealing choice must be made between shutting down the line or risking flawed product reaching customers.

Waveforms provide the key to rapid troubleshooting, leading to discovery of root cause in a matter of hours, compared to days or weeks using scalar data.

While the original test set may appear sufficient to eliminate bad parts, new faults may emerge, passing the in-process test undetected, and leaving the manufacturing engineer with two problems: what is the root cause of the flaw and how can it be reliably detected? Following are a couple of examples.

Example: Cause of High Failure Rate in Throttles

A manufacturer of electronic throttles experienced a high rate of failure during end of line testing, despite parts passing quality checks at every upstream station. The failure rate affect close to 200 engines, representing significant repair costs.

Analyzing the waveforms captured by Sciemetric test equipment during upstream vacuum testing revealed that only total failures (❶ in Figure 5) were being caught. Because only start and stop pressures were used to determine pass/fail in the test (shown by arrows), some defective throttles were still passing the test (❷). These subtle failures were resulting in high repair costs at end of line.

The manufacturer determined that 77% of these subtle failures were due to stuck or sluggish throttles and the remaining 23% were false rejects. The engineers were able to take immediate action: test algorithms and limits on upstream test stations were adjusted accordingly to reduce the number of false rejects. Manufacturing process changes were also undertaken to reduce the number of stuck or sluggish throttles from being produced. In the end, the failure rate was reduced to 0.07% or 10 engines a month. With only minor changes the manufacturer was able to produce an additional 170 engines per month.

The ability to overlay the waveforms to quickly see if there were any anomalies allowed the manufacturer to swiftly address the problem. Without waveforms, it would have taken a great deal of time to recognize the need to add parameters to what had been considered a fairly reliable and simple test.

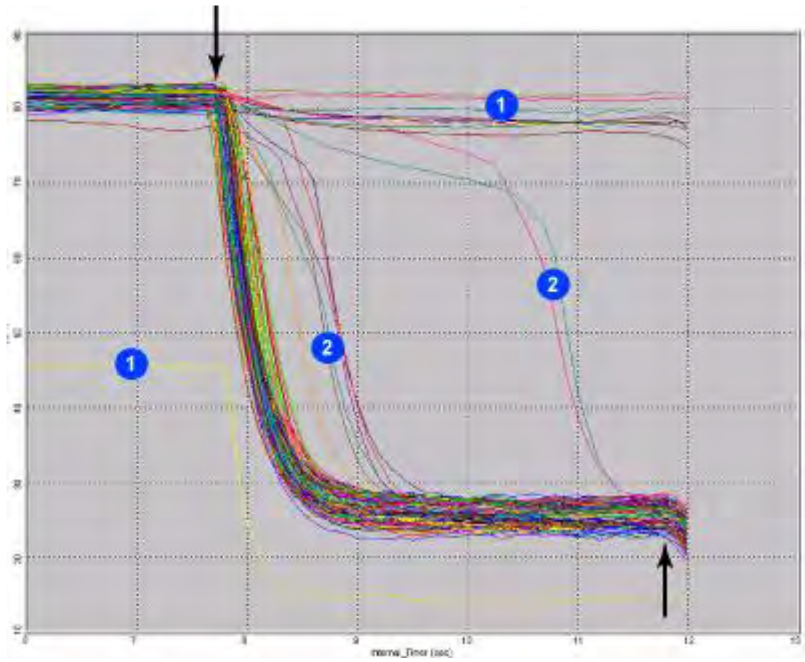


Figure 5: Identifying subtle anomalies that lead to defects

Example: Effects of material change

One manufacturer experienced an elevated rejection rate after substituting lead-based bearings for non-lead bearings. No one had thought that the change in material would have any impact on the in-station test.

By combining data collected by sigPOD and aggregation with QualityWorX, as shown Figure 6, it soon became apparent that the characteristic waveform had changed when the change in material occurred. The amplitude is greater, some of the characteristic resonances have changed, and failures appear quite differently. The test was adjusted to accommodate the change in a matter of hours.

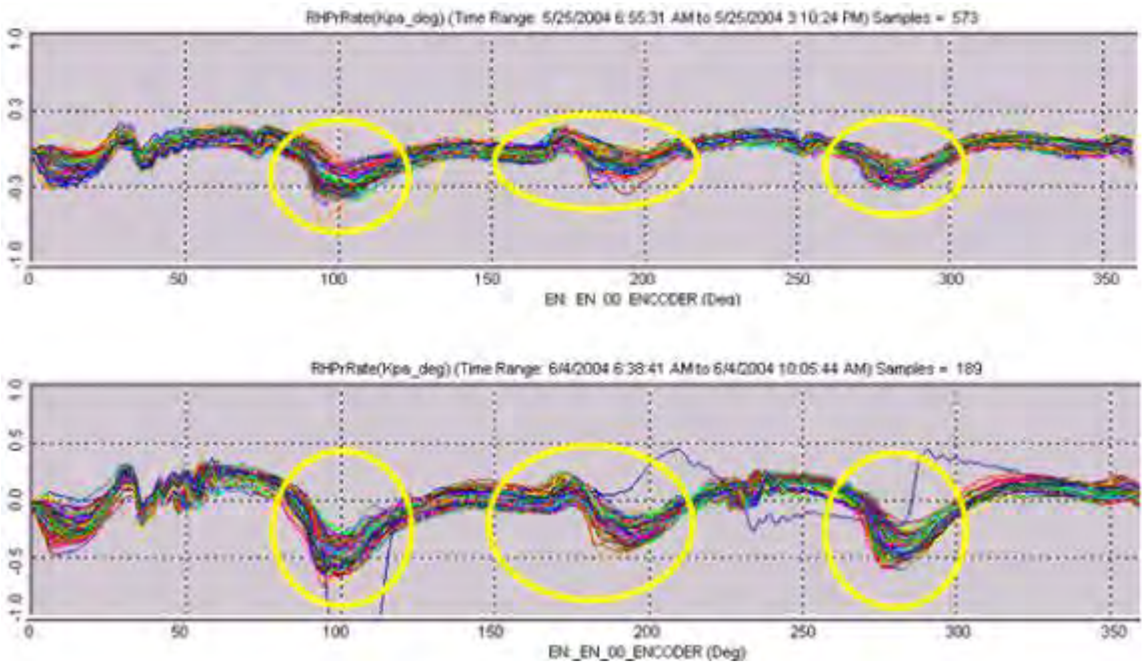


Figure 6: Differences in waveform due to change from lead (top) to lead-free (bottom) bearing

Launch New Machines or Lines More Quickly

One manufacturer is able to launch production lines at locations around the world four times faster using waveform technology. On average, a plant can scale to full production in just 25 weeks. Conservatively, this customer realizes an estimated savings of $4 million per plant in cost of capital alone.

The typical challenge in getting lines into production is to foresee the major start-up problems and create run-off data reports that will be applicable when the equipment moves from the integrator to the plant. Waveforms provide a detailed report of the process and proof of production readiness. With waveform-based test data and using analysis tools such as QualityWorX, the engineers in the example above are able to develop test algorithms for specific defects to accurately set test limits.

- Utilize failure and defect Paretos to identify the top sources of failures
- Conduct "what if" experiments offline to create tests that will catch defects
- Utilize trend data to statistically determine test limits

These engineers are also able to compare machine performance to that of existing lines, applying common metrics to ensure targets are met. With process signatures, it is easy to compare detailed data from before and after the start of full production.

Predict Machine Maintenance Requirements before Defects Are Created

Small but apparent changes in the typical signature for a process can be an early warning sign of impending quality defects.

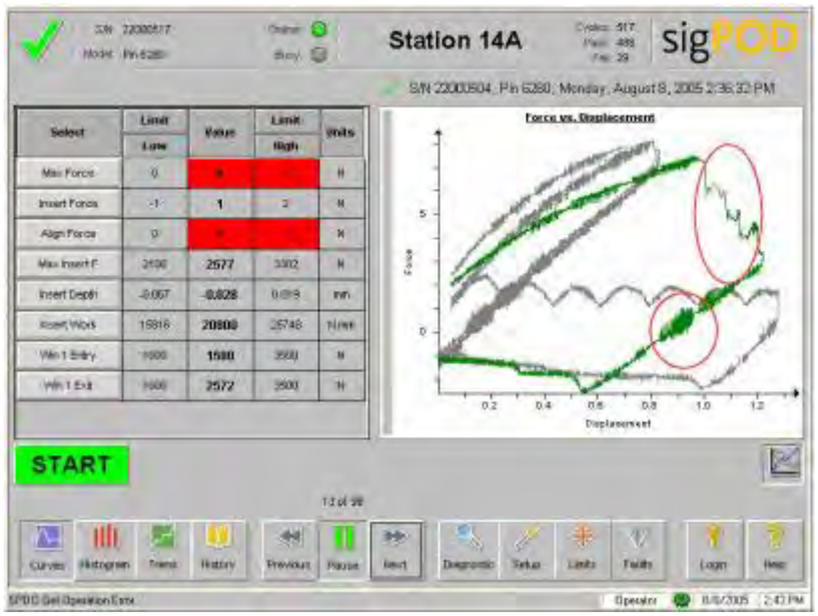


Figure 7: Tracking machine performance

Figure 7 shows a pull and release operation on a polymer. The waveform clearly indicates that a part is slipping from the tooling (green curve, top red circle). It also shows the servo motor is generating too much friction (lower red circle). Neither problem is visible to the naked eye nor is there a noticeable drop in quality, at least not yet.

However, further degradation could affect quality and yield. Equipment maintenance can be completed before experiencing a quality dive. Preventative maintenance at a scheduled time is much less time consuming and disruptive than sudden, unanticipated problems, especially when the tools are not available to quickly determine root cause.

In the case of Figure 7, the operator of the station learned to recognize these degradations in the process signatures and requested maintenance before it caused the machine to be shut down and/or product bad parts.

Conclusion

Waveform data is a true signature of any process that can be measured. This provides deep insight into the health of a process and how effective tests are at catching bad parts. The root cause of newly discovered faults can be quickly determined and appropriate tests developed. These new tests can be applied to historical data to catch and contain quality spills.

Waveform technology can achieve two seemingly divergent goals: reduce production costs while simultaneously improving quality. More importantly, it provides a tool for busy engineers to efficiently address issues and keep the production line running.

If you'd like to hear from our Manufacturing Intelligence Team on how you can use waveforms on your production line to save you time, contact us:

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