Statistical Process Control Applied to Automatic Ultrasonic Inspection

A Paper By

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1 Introduction

The traditional approach to manufacturing is to rely on production to make the required product and for Quality Control to inspect the finished products to screen out those products, which do not meet specifications. That is inspecting quality into production a very costly policy both in terms of cash and customer credibility.

This strategy of Quality Control is wasteful because time, materials and other valuable assets invested in products that are not suitable for the intended purpose. It is much more effective to avoid waste by elimination of production of unsatisfactory products in the first place, adopting a strategy of prevention by identification and rectification of detrimental processes which lead to unserviceable items.

A process control system can be defined as having four key elements, each of which is described below:

1.1 The Process

The process is the combination of people, machines and equipment, raw materials, methods and work shop environment that to combine to produce the final product of acceptable quality.

1.2 Information About Performance

Much information about the actual performance of the process can be learned by analysing the process. Information obtained can show if any action is necessary to correct the process.

1.3 Action on the Process

If action is required it is necessarily future orientated, since it is taken only after an event. But it is essential to alter the status quo and to prevent further deterioration of the process.

1.4 Action in Output

This action is past orientated, since it envisages detecting out of specification products already produced.

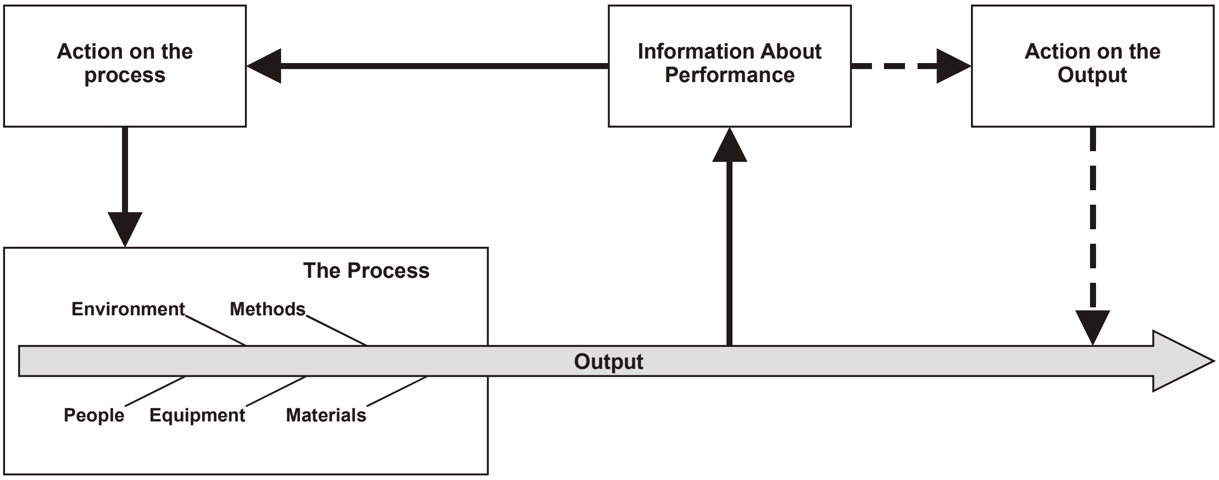

Figure 1 - A Process Control System

1.5 Conclusion

It becomes obvious that inspection followed by action only on the output is an unacceptable substitute for effective ‘right first time’ process performance.

No two products are exactly identical, the differences may be large or small but there will always be differences.

To manage any process and reduced variation must as far as possible be traced to its source. Firstly there needs to be a destination established between common and special causes of variation.

Common causes refer to many sources of chance variation that will always be present in any process.

Special causes refer to any assignable factors which are often irregular and unstable and therefore unpredictable.

In order to have a starting point for improvement of a process it is necessary to be able to measure variations. Access to every product of the process is the only way to obtain absolute precision, but this can sometimes be impractical and costly. It would be more economic to take samples of the product and use the results of practical tests to predict the properties of the whole. Statistics is the tool used to make these predictions. Hence the term Statistical Process Control.

Having looked at the rationale behind SPC, We would now like to examine a real product and its production environment.

2 The Al-Fin Bond Inspection System

2.1 Introduction

The Al-Fin bond is a bond between an aluminium alloy and a ferrous metal. It is this bond that will be inspected using ultrasonics, and will be discussed later. The actual bond area is an alloy of iron and aluminium that has an intermediate chemical composition, of approximately $FeAl_3$.

In diesel engine pistons for the automotive industry, this Al-fin process is used to bond an iron insert in the position where the top piston ring groove will be machined. This is necessary because of the high compression ratio of a diesel engine when compared to gasoline engine and therefore the stress on the top ring groove is that much greater.

In order to monitor the quality of this bond, on a 100% basis, ultrasound is used. There are two fundamental techniques for the inspection of the bond with ultrasound.

2.2 The Transmission Technique

The first is a transmission technique, where a transmitter transducer in the top ring groove generates the ultrasound. In a satisfactory bond the sound passes through the bond area to the second ring groove on one side and through the bond to the piston crown on the other side. Please refer to figure 2.

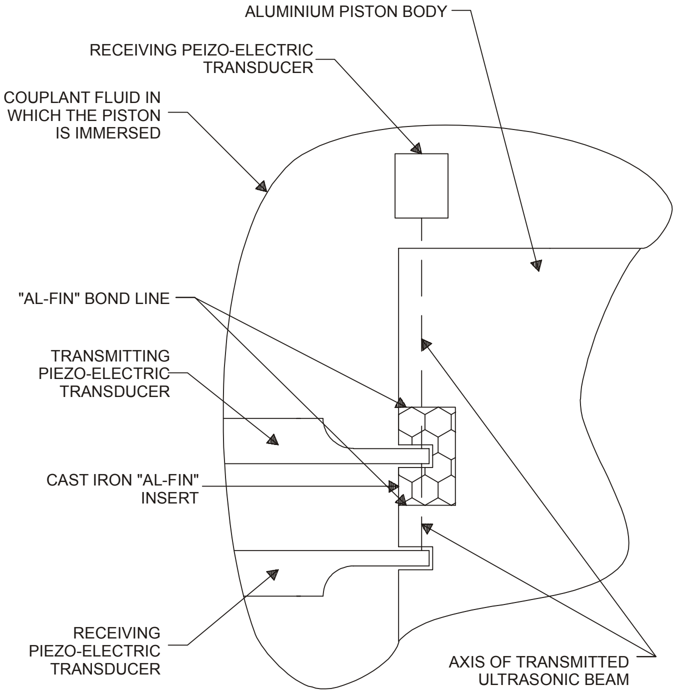

Figure 2 - Principles of Ultrasonic Bond Testing using the Through Transmission Method

2.3 The Pulse Echo Technique

The pulse echo technique may also be used, where the sound is directed at an angle to the bond region and the reflection from the bond obtained. This signal is used to determine bond quality. Please refer to figure 3.

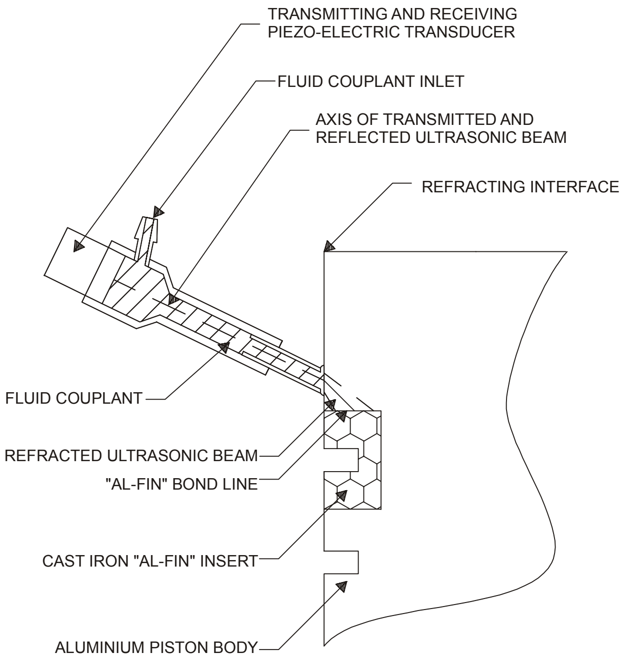

Figure 3 - Principles of Ultrasonic Bond Testing using the Pulse Echo Method

2.4 The Manufacturing Process

The manufacturing process for diesel engine pistons starts in the foundry where the iron insert is pre-heated and then tinned with an aluminium alloy. The tinned inert is placed into a die and the parent aluminium poured to form the casting. Once cooled, the casting has its risers removed and is then rough machined.

At the rough machined stage the bond between the iron and aluminium is tested ultrasonically. The results of this test provide valuable information on the control of the foundry process. Essentially the ultrasonic inspection is an Accept/Reject process but to integrate the ultrasonic system in to the foundry SPC system output data is given regarding the size and location of any defects found. These data can then be related to actual die conditions when the casting was poured, and therefore ensure that the foundry process is controlled to produce the maximum number of good castings for the machining process.

During the rest of the manufacturing process it is possible that small casting bond defects may grow due to the machining stresses experienced during the manufacture of the piston. Statistical information is established as to how the defect lengths may grow. The use of this information gives revised standards that will be used to test the rough machined piston thus ensuring minimum scrap at the final inspection point.

The final machining process of a piston is extremely complex, due to the relatively fragile nature of the bond. It is normal practice to plunge cut over the area of the insert and bond, in an effort to eliminate side load stresses on the bond itself. The bond is therefore once again inspected using the ultrasonic system immediately after the grooving cycle. The objective here is monitoring the wear of the grooving tool, feeding back the inspection information to the manufacturing SPC system. An increase in the size of defect found by this system can be immediately related to the deterioration of the performance of the grooving cycle, most probably the grooving tool itself.

A photograph of the ultrasonic system can be seen below.

The piston is inspected finally at the end of the production line to monitor the final machining process, once again feeding back information to the manufacturing SPC system.

Raw test data for each individual piston is stored within the equipment and collated by proprietary software package or spreadsheet from which control charts may be derived.

3 Process Control

Process improvement using such control charts is a continuous procedure, repeating the fundamental phases of collection, control and capability improvement. First, data are gathered according to a careful plan; then, these data are used to calculate control limits, which are the basis of interpreting the data for statistical control. When the process is in statistical control, it can be interpreted for process capability.

3.1 Collection

The process is run, and data for the characteristic being studied are gathered and converted to a form that can be plotted on a graph. These data might be all or any one of the measured values of a dimension of a machined piece, the number of flaws in a piston, the size of flaws, and the position of flaws.

3.2 Control

Control limits are calculated based on data from the output of the process; they reflect the amount of variation that could be expected if only variation from common causes was present. Control limits are not specification limits or objectives, but are reflections of variability of the process.

The data are then compared with the control limits to see whether the variation is stable and appears to come only from common causes. If special causes of variation are evident, operation of the process is studied to determine what is affecting the process.

3.3 Capability Improvements

After all special causes have been corrected and the process is running in statistical control, the process capability can be assessed. If the variation from common cause is excessive, the process cannot produce output that consistently meets customer needs. The process itself must be investigated and management action must be taken to improve the system.