

Process Integrated Quality Control (PiQC™) for Wire Bonding

Roberto Gilardoni, Sebastian Hagenkötter, Michael Brökelmann
Hesse & Knipps GmbH
Vattmannstr. 6

33100 Paderborn, Germany

Tel. +49-5251-1560-31 , Fax. +49-5251-1560-97 , Email gilardoni@hesse-knipps.com

Abstract

As costs of field failures keep increasing in many fields of electronic applications (e.g. automotive call-backs), achievement of zero failure rates of the goods delivered to the end user becomes an imperative goal to pursue. Current methods of monitoring wire bond quality for both heavy and fine wire applications, however, fall short of finding 100% of all failure modes as they don't monitor every aspect of every wire bond connection. A major reason for this deficiency is that most QC systems only monitor wire deformation and/or use ultrasonic current as a signal to conclude bond quality. "Normal" wire deformation and current characteristics do not guarantee good bond quality in every case. Because different types of bond failures affect the available signals in different degrees, it becomes important to monitor all of them to get a wide decision base. A newly introduced multi-dimensional process integrated quality control (PiQC™) system now offers the capability to monitor a multitude of significant bonding process values for comprehensive wire inspection in achieving 100% quality control in real-time.

Keywords: Wire Bonding, Quality Control, PiQC

1. Introduction

In 2004, Daimler Chrysler started the „zero error initiative“ and wrote: „The electronic has fundamentally changed the originally solely mechanical automobile product during its development. It is the backbone of a vehicle in all its functions. Errors in the hardware or software can have grave effects. In order to avoid the electronic becoming the Achilles heel of the car, the developers of Daimler Chrysler have a clear goal: the zero error in the automotive electronic.“ One important aspect of the reliability of automotive electronics is the reliability of the bonded wires. The highest quality demands often require 100% testing of the bonded wires. Unfortunately the non-destructive test methods previously available all leave a doubt remaining on the reliability of the test itself.

2. Influence Factors on Bond Quality

It is immediately evident that the mechanical settings of a bonder, from the selected kinematics and their controls to the components of the bondhead, have a crucial impact on bond quality. The reproducibility of the process parameters: time, force and ultrasonic power is a crucial condition for guaranteeing constant bond

quality. However, the bonder is only one aspect responsible for bond quality.

The quality of a bond is also influenced by the materials used during bonding; the wedge, the wire, the product i.e. the electronic components and the substrates. The surface properties of the contact surfaces and the mechanical attributes of the assembly (package, die, substrate....) are important and influence the quality of a bond. With regard to the surfaces, organic and inorganic contamination can occur. Mechanical attributes such as the rigidity of the complete assembly and the conditions of product clamping are equally relevant.

Finally there is a human factor to consider, which can lead to errors in the assembly process even so any other requirements are met. Typical examples are a mismatch between the product and the bond program, or a calibration mistake which could lead to bond offsets. Other examples for operator induced errors could be parts loaded to the machine which were already bonded or used for destructive bond quality testing, parts loaded with the wrong orientation or wrong settings to vacuum or air supply leading to insufficient product clamping.

3. Fundamental Assumptions of PiQC™

In the concept phase of a new invention for 100% non-destructive bond quality testing a few

basic assumptions have to be made which serve as the foundation of the test concept. PiQC™ is built on the following 3 basic assumptions:

I) Some bonds will have insufficient quality. Even the “best bonder” can not compensate for all negative influencing factors of bond quality.

II) Every bond of insufficient quality will show some suspicious behavior during welding in at least one of the process feedback signals.

III) If every bond of insufficient quality is detected and filtered out during bonding in a 100% test, the customer will receive good products with 0 ppm failures.

4. Previously Available Control Methods

A series of techniques for controlling bond quality has been developed to gain characteristics with which a bond can be classed as “normal” or “suspicious”. The most commonly known control methods are mentioned below. All of these quality control methods are useful to indicate some of the foreseeable bond failures, but fall short of finding every possible failure. Some of the previously available quality control methods have side effects which cause a loss of throughput or even a risk to the bonds themselves.

4.1 Evaluation of the Transducer Current

One of the elementary methods of bond quality control is the measurement of the current which flows from the ultrasonic generator to the transducer, where the voltage is constant at the ultrasonic generator output. In this case, the ultrasonic current is proportionate to the applied power. This method was presented in 1983 in [Ban83]. The time progression of the current envelope is divided into several intervals which must fulfill certain criteria.

A similar process can be found in [Chan86]. The envelope of the transducer current is also measured here, the qualification of the bonds is carried out according to a regulator which describes typical current envelope progressions. Using these progressions, not only bond errors but also the possible cause can be defined.

An expansion of the measurement procedure was presented in [HE97].

4.2 Evaluation of the Wire Deformation

A second elementary method is the measurement of the progression of the wire deformation. This method was first presented in [MOL87], here however for the ultrasonic welding of enamel insulated wires and plastic. To influence or improve the welding quality, a closed loop control was suggested in Molls work. This method was introduced in [GOE92] with special emphasis on

wire bonding. Wires whose deformation does not lie within the minimum and maximum tolerance values are classed as insufficient. In order to carry out this measurement, a suitable sensor is integrated into the bondhead where the deformation can be continuously measured and recorded by the controls. A similar method was introduced in [MOL97] as a continuation of this method.

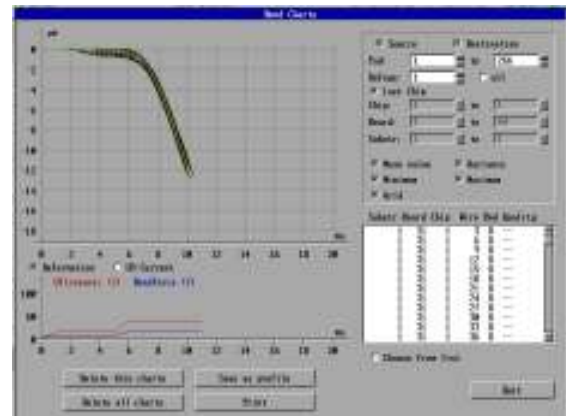


Figure 1 – Example of bond deformation chart

Until now, no reliable quality control has been available. Even though the current is a measurement for the oscillation of the wedge and its influence throughout the process, a direct correlation between the transducer current and the wedge tip movement could not be experimentally proven. It can be said that a good quality bond always fulfils the criteria given in the current curve and takes on a reproducible form. Unfortunately, this can not be said for the reverse. Current curves have been seen where the progression shows no noticeable problems, but the bonds belonging to it were of bad quality. The same applies for deformation. The assumption that a good deformation curve means a good bond is incorrect. Both values are only required conditions but are not sufficient for good bond quality.

4.3 Non-destructive Inline Test Methods

For the special case of heavy wire bonding, non-destructive mechanical testing of the bond quality is possible because the aluminum wire diameters above 100 micron (4 mil) have a high enough tensile strength to survive such tests at a test force large enough to detect a non-stick. Most machine suppliers offer non-destructive 100% testing of the heavy wire bonds as a bondhead integrated function. At predefined moments after forming the first or second bond, the bondhead carries out a controlled move with the wire clamps closed and a programmed amount of force pulling away from the bond. Alternatively an integrated shear test is offered, where the bonder uses the V-groove wedge as a shear tool to apply a programmed amount of force against the side of the bond. In both cases

sensors are integrated in the bondhead to monitor the force and/or deflection of the bondhead during the test. This allows recognition of a non-stick wire, which is removed from the underground during the test.

Neither of the non-destructive test methods can detect all possible bond defects. They both cause a throughput reduction due to the time required for the test. The inline pulltest causes a risk to the heel or the loop shape if the test force is too high. If the test force is too low, the test result is not relevant enough. The inline shear test avoids heel damage but does not really test for heel cracks either.

None of the previously available methods for bond quality control is reliable enough on its own to present a satisfying solution to a zero failure target.

4.4 A Scientific Approach to Bond Quality

In the course of the LASOP-MST [LASOP99] project, funded by the BMBF, the movement of the wedge tip was monitored with a laser optic measurement system. A system for bond quality control was introduced which works as follows:

In a first phase, the ultrasonic power is controlled in such a way that the oscillation amplitude of the wedge increases linear proportionally. In the second phase the ultrasonic power is kept constant, the oscillation amplitude of the wedge is monitored. The envelope of the oscillation follows a set pattern. If the deviation of the envelope is too large, the bond will be classified as insufficient quality. During the third phase, the ultrasonic power is controlled in such a way that the wire deformation increases progressively until the target deformation is reached.

The main disadvantages of using a laser interferometer for the measurement of the wedge tip oscillation are the cost of the instrumentation, the space requirement in the bondhead and additional moving mass which interferes with the dynamics of the bondhead. The results are therefore not directly applicable for automatic wire bonders, but yield at least some information about the suitability of various methods of bond quality control. The LASOP report and several other scientific essays over recent years have shown that the wire deformation is not suitable on its own as a quality indicator. The methods based on current measurement share a similar fate. Regarding a partial closed loop control the LASOP report describes possible methods, fails however to explain why these methods would be suitable for all applications and possible failure types.

One important conclusion from the LASOP report is that the amplitude of the wedge oscillation is suitable for a quality control in wire bonding [LASOP99 p. 132] and represents an important

indicator for bond quality, especially in the first few milliseconds of bonding.

4.5 Measurement of Force and Velocity on the Wedge Tip

The most consequent approach for measuring bond quality is the measurement of the force and the displacement or velocity on the wedge tool. One could then observe the behavior under load of the system as well as the individual bond phases. Unfortunately, measurement of the tangential forces in the contact zone is extremely difficult and measurement of the wedge velocity with a laser interferometer is very expensive making this unsuitable in practice.

During the current measurement described above, the piezo motor is used as a sensor. This method (self-sensing) does not give sufficient results with regard to the movement of the wedge tip because of the relatively large dimensions of the piezo motor. A signal evaluation, in which the wedge tip movement is identified, is obviously not possible without an additional sensor. Such a sensor would need very small dimensions towards the wave spread if the progression of the oscillation of the transducer or the wedge tip is to be recorded. A detailed description of how such a sensor could be integrated to a bondhead without increasing the mass of the bondhead can be found in [HE06].

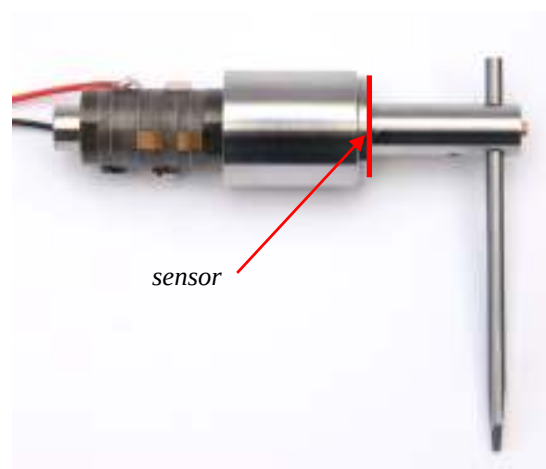


Figure 2 – Example of transducer-integrated sensor [Hesse & Knipps BJ920 transducer]

Experimental installation of a transducer integrated sensor show that the free-oscillating movements of the wedge tip during bonding measured by a laser interferometer correlate well with the signal generated by such a sensor [BROK03]. The sensor delivers the additional measured values with sufficient quality to collect the friction and other effects caused by bonding and to include it in the evaluation of the bond process.

5. PiQC™, Multi-Dimensional Signal Analysis for Evaluation of Bond Quality

The newly developed process integrated quality control PiQC™ includes a transducer integrated sensor. Other previously evaluated signals such as feedback from the ultrasonic generator or wire deformation are taken into account in parallel to the sensor related feedback signals, which allows PiQC™ to evaluate all signals in relation to each other in real-time. Each evaluated signal would be sensitive to some but not all possible bond defects if isolated from the other signals. The sensitivity of the test is vastly increased by considering all signals in parallel.

values serve as the input for a feature extraction system which then calculates a so called quality index Q_i for each signal. A total quality index Q_{tot} for the bond is calculated from the individual indices, under consideration of emphasis, in a signal processing unit (quality evaluation). This total quality index is then saved.

Experiments with this system have shown that the recorded physical values vary significantly with respect to the bond surfaces, substrate materials, stiffness of the system, Eigen modes of the system, wedge and wire selection, especially when using larger wire diameters. These highly application dependant variations of the process values do not allow the use of generic reference graphs as global

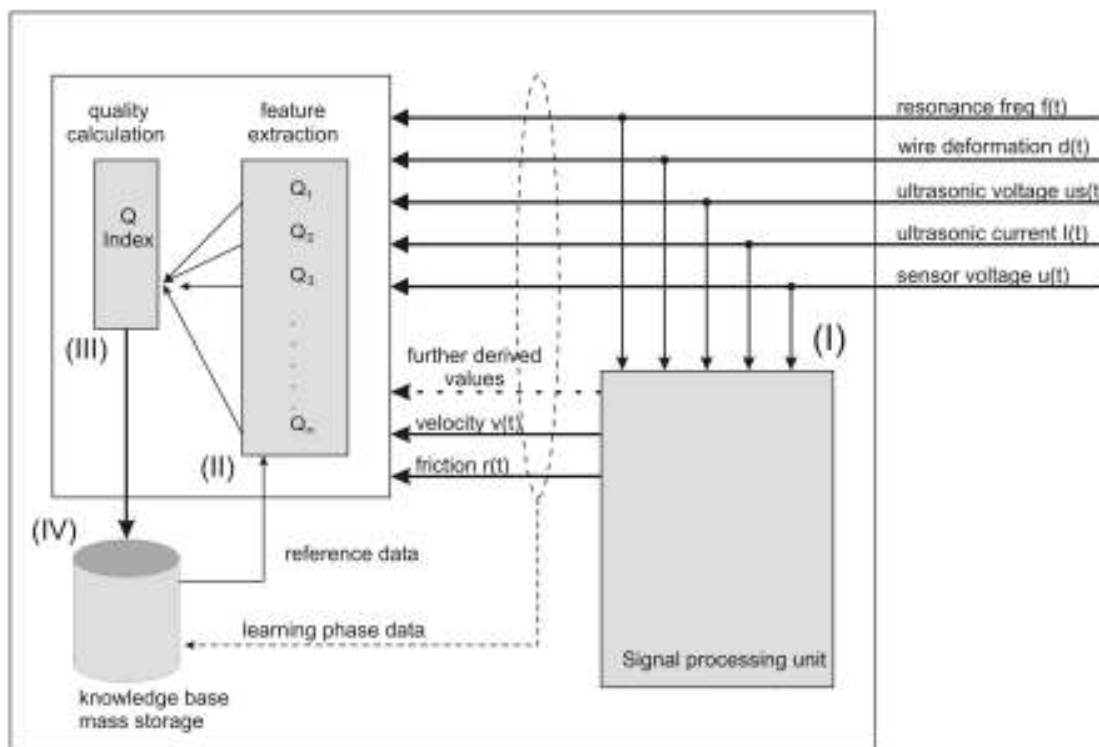


Figure 3 – PiQC™ systematic diagram

Input signals of the process described here come from different sources: the frequency, the phase difference between voltage and current and the ultrasonic current come from the ultrasonic generator. The wire deformation comes from the bondhead kinematics. The mechanical ultrasonic oscillation comes from the additional sensor in the bondhead. Further values based on comparison functions work as input values for the calculation of the quality index. The raw sensor signals observed during welding go through a signal processing unit, which calculates additional derived signals related to the friction and wedge tip velocity. Together with the already mentioned values for current and impedance, wire deformation etc. and the resonance frequency measured in real-time, each of these

reference data on wire bonders. For this reason, optimized reference data has to be recorded for the evaluation of input data for every application.

Assuming the existence of a stable bond process resulting in sufficiently high bond quality, reference data is generated in automatic teach mode for all directly measured or derived values which forms the basis for the calculation of quality indices. Instead of recording a fixed reference graph for different processes, the graphs are generated dynamically by the system itself. A model of the bond formation suitable for judging bond quality is created from measured values using statistical methods.

For the calculation of the quality indices different statistics are applied for the individual measured values depending on the model which would best fit this measurement. The emphasis of the individual

values can be set and the sampling time where these values are observed is automatically adjusted to the bond process. As an example: the progression of the wire deformation is not relevant at the beginning of the bond process because there is no deformation caused by the ultrasonic in this phase. It can therefore be ignored for the first milliseconds of the process. Other physical effects, such as the progression of the friction between the bond partners, are especially important at the beginning of the welding process.

PiQCTM calculates a quality score (index) for each signal or derived value vector which expresses how well the current bond data matches the reference data for this particular signal. Based on a selectable method of calculation a total quality index is calculated from all individual quality indices. This total quality index can consider user defined emphasis on the most fault sensitive signals. The total quality index represents the score for the quality of the bond.

When using a multidimensional analysis of the welding process, the proper man-machine interface becomes a concern. Previously available systems consider a maximum of 2 values and display their timely progression by means of a curve. If upper and lower control limits are defined for each curve, the operator can immediately recognize when the curve leaves the tolerated threshold. Such a display is no longer possible for the described multidimensional analysis, especially since the dimensions of the individual characteristic vectors differ. For this reason the characteristic values are not displayed as a function over time including the tolerances but are shown as a vector with an arbitrary scale indicating the deviation from the reference data. These are the output values of the feature extraction. Only the individual Q_i 's are illustrated.

If, for example, we use seven characteristic vectors, the output of the feature extraction will exhibit exactly seven such values. Being relative values for the correlation between actual and target values, they range from zero to 1 and are displayed in a radar chart (see figure 5 for an example).

5.1 Experimental Confirmation of the System

In many applications, the bond material is enclosed in a plastic housing, which travels automatically through several process machines where it is loaded, clamped and ejected. This mechanical stress can cause wear which may deposit on the bond surfaces. This problem was analyzed on behalf of an automotive manufacturer. The wear particles were purposefully placed on the bond sites before bonding. All contamination was detected by the PiQCTM system.

In this experiment, the measured total quality indices Q_{tot} of the bond wires contaminated with plastic particles displayed values between 0.85 for

very small particles and 0.05 for larger particles. The threshold value for Q_{tot} is typically set below 0.85 which would render those bonds contaminated with very small plastic particles unsuspecting. If one particular feature of the feature extraction is known to respond especially sensitively to the expected contamination, this feature can be given a higher emphasis for the calculation for the total quality index.



Figure 4 – Plastic particle enclosed under bond

In the figure above ($Q_{tot}=0,09$) it can be seen that after shear testing the welding surface underneath the enclosed plastic particle still appears in its original condition, which means that an inter-metallic connection between the wire and the substrate has not occurred. This wire holds a shear force of 1277cN. The average value for the other bonds was 1370cN with a standard deviation of 77cN. Standard methods for quality control would have failed to detect this bond as insufficient. The contamination would not have been detected because the shear force lies within the range of three standard deviations around the average value.

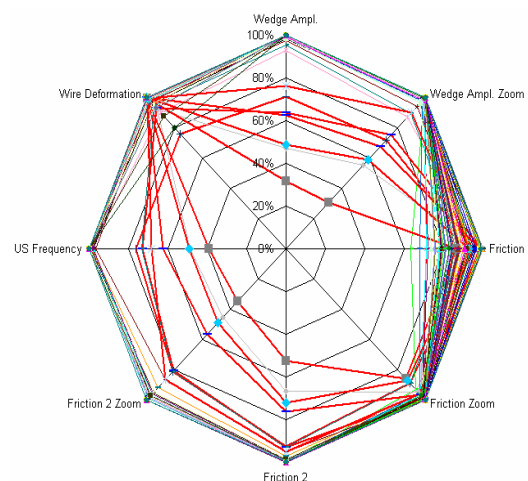


Figure 5 – Example of radar chart quality indices

Some of the output values of the feature extraction are displayed above in the form of a radar chart. It is notable that the wire deformation feature is highly insensitive to this form of contamination. The frequency, wedge amplitude and friction 2

derived value are the strongest indicators in this case.

6. Summary and Outlook

A great number of bond wires with defined substrate contamination or defective surfaces were bonded, evaluated in real-time and classified afterwards by pull and shear tests. The quality evaluation based on the sensor signals shows a good correlation with the measured pull and shear values. The same can be said about the evaluation of the field tests carried out so far.

None of the parameters used have shown the same sensitivity to all of the evaluated failure types. The output values of the feature extraction have instead shown a different distribution in the field of results for different failure types, i.e. different combinations of individual quality indices were found for each of the cases.

The experiments carried out have shown however, that there was no failure type which recorded the measured values inside of each individual threshold. In other words, there was no case where all values were equally insensitive to this failure type. Having access to properties which are only required for bond quality does not rule out their relevance for analysis and monitoring. Only by additionally including the sensor signal and derived measurement values thereof as well as ultrasonic frequency, the system can provide a conclusive output value which can be used reliably to calculate bond quality.

In combination with a machine that provides a high consistency of bonding parameters it is possible, with the described method of multi dimensional process integrated quality control and the respective additional hardware, to carry out quality control in real-time without loss of productivity and with high reliability.

Continuous development work in the field of process analysis will allow enhanced feature extraction as the model is being refined and field feedback is being considered.

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