How to Optimize and Control the Wire Bonding Process: Part I

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ABSTRACT

To help process engineers improve, optimize, and control the wire bonding process, proven statistical analysis tools/techniques are provided to deal with four stages of a process. Part I covers developing a new process. Part II will discuss a process running at low yield, improving a marginally acceptable process, and maintaining process quality.

Wire bonding is an extremely high yield, high speed, automated manufacturing process. Modern wire bonders are capable of bonding 8 to 10 wires/sec and typical monthly throughput can exceed 500,000 devices. It's not unusual to see device yields approaching 99.99 percent with wire yields exceeding 99.999 percent. Total bonding defects are less than 100 parts per million (ppm), but real process optimization is required to achieve and maintain these yields. This article will discuss methods used to improve, optimize, and control the wire bonding process. These include design of experiments, response surface techniques, process capability studies, and control charts for high yield processes.

The use of designed experiments for screening wire bonding process variables and for optimizing the process will be described. They have been used extensively at K&S to establish new wire bonding processes and to design new, high reliability wire bonders such as the Model 1484XQ. They are easy to use and their data are easily analyzed. Process capability (and its relationship to design specifications) is also defined and discussed.

Many engineers have discovered the shortcomings of visual wire bond inspection. A logical alternative has been the use of statistical process control (SPC) control charts, but, unfortunately, conventional charts do not work well for very high yield processes. At defect levels below 1 percent, each defect generated results in an out-of-control signal. A new type of control chart has been proposed by T.N. Goh [1]. It is based on cumulative defects and it sets more appropriate levels for upper and lower control limits.

The combination of optimization methods mentioned above gives a reasonable, structured approach to controlling the wire bonding manufacturing process. With careful analysis of the observed defects and diligent attention to the largest defect generators, these methods will enable defects to be controlled and the process to be stabilized.

To help the reader follow the use of these tools/methods, step by step, we describe four possible situations in which a process needs to be developed, improved, or maintained. They are:

- New process development.
- Improvement of a process running at low yield.
- Improvement and stabilization of a marginally acceptable process.
- Maintaining a process at an acceptable quality level.

As each situation is covered, we will discuss in detail the tools required, provide a brief statistical explanation, suggest further reading, and offer examples.

Developing a New Process

In this section we will describe the development of a new process. This method can be used for a new package type, new die, new wire bonder, etc.

Design of Experiments

Design of experiments (DOX) is a topic within the field of statistics [2]. It provides an efficient, structured approach to the problem of controlling a process with a large number of variables like wire bonding. By enabling one to efficiently explore the bonding process using many variables, designed experiments allow the engineer to determine which of the variables have significant effects on the process. Once they are identified through screening experiments, additional experiments provide mapping of the response surface and lead to efficient process optimization.

In contrast, a traditional method for conducting scientific experiments has been to hold everything constant while changing only one variable at a time. Data variation could then be attributed to the shift in that variable. This method poses two problems: it is very time consuming, and it does not measure the interaction between two variables since they must be varied simultaneously to see the effect. Often these interaction effects are the strongest and most important factors in controlling a process.

The designed experiment described here for creating a new process includes five variables. It allows screening of all five variables with only 19 samples. Using the traditional one variable at a time approach would require over 80 samples! In addition, with DOX it is now possible to measure interaction effects which may prove to be very important.

FIGURE 1

A three variable, two level factorial design. Variable levels are represented by numerals: -1 (low), 0 (center), and 1 (high).

FIGURE 2

Data sheet format for a half-factorial five variable DOX experiment.

Selection of Variables

Several classes of variables can be used in DOX. Some, such as programmable bonding parameters, can be changed easily over a numerical range. Not so with others like types of capillaries (basic designs) and materials (alloys). Programmable variables are selected for initial screening experiments; nonprogrammable, treatment variables are tested using multiple runs of the screening experiment.

To select variables for an initial wire bonding DOX, run the screening experiment using the principal wire bonding variables: ultrasonic power, bond force, temperature, bond time, and velocity. The results (responses) of the initial experiment will identify the major problems or defects. In subsequent experiments variables are chosen to address these problems. For example, if weak crescent bonds are detected, an experiment using crescent bond power, force, and time would be appropriate. Discovery of cratering would result in a choice of first bond variables. Variables with insignificant effects are also useful and eliminating them allows the effort to become more focused.

The level (setting) of each variable in an experiment can cover a large range. However, the intention is not to test the extremes of the process, but to sample a reasonable range of the values of interest. If a variable is significant and the results show that extreme values are desirable, subsequent experiments can explore this new range.

Running the Fractional Factorial DOX

One textbook experimental design that fits the wire bonding process very well is the fractional factorial [3]. It is easy to run and can normally be set up, run, tested, and analyzed in a day.

To illustrate factorial designs let us represent a simple version by the corners of a cube (Fig. 1). The corner points (cells) include all of the possible factorial combinations of three variables at two levels each. The four corners shown as solid balls are the ones that would be required for a half-fraction experiment. The fractional designs select a subset of cells that optimize the validity of the most important statistics (mean, main effects, and two level interactions) while sacrificing the validity of higher level interactions (three level and above). For most engineering work this represents a reasonable compromise.

The screening experiment is actually one-half a full factorial, five variable experiment (2^{5-1}). It requires 16 samples per experiment plus three additional center points. Each center point is the average value for each of the five variables in the experiment. Multiple center points are required in order to estimate process repeatability. Center points also estimate the curvature of the response surface. The difference between the mean of the three samples bonded at the center points and the mean of the 16 factorial points provides an estimate of the response surface curvature.

To begin the experiment, one determines what response measurements are most important to the new process. The responses should not be attribute (good/bad) data, they must be numeric variable measurements. Several different responses may be analyzed at the same time with this method. For example, pull strength data, loop heights, shear test values, and bond placement could all be studied on the same devices. At the end of the experiment, a separate graph/analysis will be produced for each response.

Figure 2 shows the format of the data sheet used for this experiment. Note that one-half of the response cells are not used (blackened). Nevertheless, with the half-fractional design, very little engineering information is lost.

Let us select five variables that are believed to be most important; choose a high, low, and center level for each variable, and write the variable names and levels on the DOX form as shown in Fig. 3. Additional variables can be studied in subsequent runs as insignificant variables are removed.

The letters in each cell only list the variables that are at