APPLICATION OF SIGNAL ANALYSIS TECHNIQUES FOR CONDITION MONITORING OF A WIRE BONDING MACHINE

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Abstract : This paper investigates the technique to monitor the condition of a wirebonding machine that used in the integrated manufacturing (IC) industry. The machine forms the connection between the bonding pad on the die to the contacts of the leadframe. To ensure consistency in the process, defects in the bondhead subassembly can be monitored from the damping signature. For this purpose, the analysis techniques chosen are the correlation function and power spectrum estimation. Thus, the main objective of this paper is to find the signal analysis technique that can uniquely represent the good from the defective machine signatures.

I INTRODUCTION

Machine condition monitoring involves monitoring the condition of the machine by scheduling and performing maintenance based on the change in the condition of the machine. The purpose is to detect and diagnose machine defects or faults in order to perform predictive maintenance (PdM) that is the practice of performing maintenance on a machine based on the operating condition of the machine. Compared to run-to-failure or time-based maintenance [1], it offers advantages by improving machine efficiency and availability and reduces operation and maintenance cost.

For the wire bonding machine, the bond head subassembly is chosen because it is one of the most critical parts of any automatic wire bonder. Failure in the bondhead operating within its set parameter results in bonding rejects related to bondability, bond size, loop height and bond placement accuracy. Current practice is not sufficient to detect the defects on time as rejects are detected only after the bonding process completes [2].

Preliminary studies have shown that any defects or faults in an electromechanical equipment can be correlated to the electrical signatures of the servo system [2]-[3]. By using signal analysis techniques, parameters of the signal can be extracted from the electrical signatures and hence the operating condition of the machine can be determined.

II SIGNAL MODEL

This study looks at the damping signatures of the bond head subassembly of the wire-bonding machine. The damping signature was chosen because it describes the operating condition of the machine, that is, the shape of the signal reflects the condition of the machine [4]. Any distortion or abnormalities in the shape of the signature indicates a problem and corrective measures can be taken to avoid producing further rejects and also unplanned breakdown of the machine. The signature is also similar to all identical good conditioned wire-bonding machines.

The good damping signature of the bond head subassembly can be described by the following discrete-time equation

$$
\begin{aligned}
x(n) &= A && n_0<n<n_1 \\
&= -0.0625A\exp\left(-\frac{(n-n_1)}{m_0}\right)\cos(2\pi f_0 n) && n_1<n<n_2 \\
&= -A && n_2<n<n_3 \\
&= A\left[-1+\left[1-\exp\left(-\frac{(t-n_3)}{\tau_1}\right)\right]\right]\cos(2\pi f_1 n) && n_3<n<n_4
\end{aligned}
\tag{1}
$$

where A is a constant, f_0 and f_1 are the frequencies, and m_0 and m_1 are the time constants for the signal. A damping signature can be divided into three parts namely the fall signal, the rise signal and the steady state part. The fall signal and the rise signal refers to part of the signal from $n_1<n<(n_1+n_2)/2$ and $n_3<n<(n_3+n_4)/2$ respectively. Interval from $(n_1+n_2)/2<n<n_2$ and $(n_3+n_4)/2<n<n_4$ is the steady state signal. Any problem that is encountered by the machine will result in a deviation in the damping signature from that defined in Equation (1). This is characterized by the values of frequencies and time constants that deviates from the system specifications.

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Figure 2 and Figure 3 shows an example of a good and defective damping signature respectively.

III ANALYSIS METHOD

The methods used to analyze the damping signatures are classified as the correlation method and the power spectrum estimation method.

A CORRELATION METHOD

The objective of the correlation method is to measure the similarity between two signals and extract the information present in it. Specifically, the autocorrelation function and the crosscorrelation function are used for this purpose.

B CROSSCORRELATION FUNCTION

The assessment of the similarity between two damping signature samples $x(n)$ and $y(n)$ is carried out by calculation of the raw crosscorrelation functions $R_{xy}(m)$ given by [5]

$$R_{xy}(m) = \sum_{n=0}^{N-|m|-1} x(n+m)y(n) \tag{2}$$

where N is the total number of samples and time lag $m = \pm(0,1,\ldots,N-1)$.

The sequence $y(n)$ is left unshifted and $x(n)$ is shifted by m units in time, to the left for m positive and to the right for m negative.

C AUTOCORRELATION FUNCTION

The measure of dependence of successive damping signature samples $x(n+m)$ on the previous ones $x(n)$ is carried out by calculation of the raw autocorrelation function $R_{xx}(m)$ given by [5]:

$$R_{xx}(m) = \sum_{n=0}^{N-|m|-1} x(n)x(n+m) \tag{3}$$

where N is the total number of samples and time lag $m = \pm(0,1,\ldots,N-1)$.

The magnitudes or shape of the correlation functions can reveal important characteristics of the signals. In this study, the normalized correlation function is more convenient to use compared to the raw correlation function since scaling or the magnitude of the function is independent of the amplitude of the signal.

D NORMALIZED CORRELATION FUNCTION

Unlike correlation function, the normalized correlation is independent of the signal amplitude since it is normalized based on the signal energy.

The normalized crosscorrelation function is defined as [5]

$$\rho_{xy}(m) = \frac{R_{xy}(m)}{\sqrt{R_{xx}(0)R_{yy}(0)}} \tag{4}$$

The normalized autocorrelation function is defined as [6]

$$\rho_{xx}(m) = \frac{R_{xx}(m)}{R_{xx}(0)} \tag{5}$$

The range of value for the both normalized autocorrelation and crosscorrelation function is

$$|0 \leq |\rho_{xx}(m)| \leq 1 \tag{6}$$

$$|0 \leq |\rho_{xy}(m)| \leq 1 \tag{7}$$

A value of 1 indicates the highest correlation while the lowest correlation is indicated by a zero value.

E POWER SPECTRUM ESTIMATION

The power spectrum estimation describes distribution of signal power at various frequencies. The autocorrelation function and crosscorrelation function of a random process characterizes the signals in the time domain. Based on the Wiener-Khintchine theorem, the Fourier transform of the autocorrelation function and crosscorrelation function yields the power density spectrum that provides the transformation from the time domain to the frequency domain.

For the autocorrelation function $R_{xx}(m)$, its auto power spectrum estimate is given by [5]

$$S_{xx}(f) = \frac{1}{N} \sum_{m=-(N-1)}^{N-1} R_{xx}(m)\exp(-j2\pi fm) \tag{8}$$

For the cross correlation function, $R_{xy}(m)$, its cross power spectrum is given by [6]

$$S_{xy}(f) = \frac{1}{N} \sum_{m=-(N-1)}^{N-1} R_{xy}(m)\exp(-j2\pi fm) \tag{9}$$

IV PARAMETER EXTRACTION

To characterize the various damping signatures, a set of parameters is defined for the autocorrelation function and spectrum estimation.

A CORRELATION FUNCTION

Based on the system specifications, the good and defective damping signatures are defined. The good signature is set as the reference signal and other damping signatures are grouped as signals under test. Both damping signatures will produce and different magnitudes or shapes of the correlation function. Hence by computing the autocorrelation function (ACF) and crosscorrelation function (CCF), one can determine whether the machine is in good or in faulty condition.

Since the damping signatures are periodic, at least two cycles of the signals are collected from a predetermined test point on one of the selected card for analysis. For correlation method, the magnitude or shape and time occurrence of the ACF and the CCF at predetermined critical points was noted. From the determined shape, parameters of interests are extracted and are defined as

a. m0w - defined as the difference between the negative lag value and positive lag of the maximum lobe when the ACF/CCF equals zero.

b. min1/min2- defined as the height of test signal side lobe when reference side lobe is minimum at positive lag.

c. max1/max2- defined as the height of test signal side lobe when reference side lobe is maximum at positive lag.

d. mcf- defined as the value of the CCF at zero lag.

Figure 1 shows the distribution of the parameters used in the analysis.

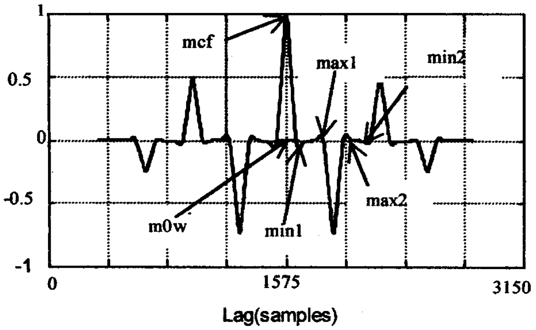

Figure 1 Distribution of correlation parameters.

B POWER SPECTRUM

For the power spectrum estimation that is the auto power spectrum and cross power spectrum, the features of importance are the frequency components present in the signal and the power associated with it. The peak power density (pd) and its frequency (pf) are the extracted parameter for the analysis.

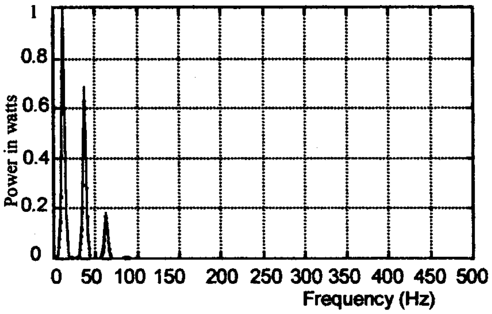

Figure 2 Power spectrum plot.

V RESULTS

About 150 damping signatures are collected by connecting a digital oscilloscope with storage capability to a predetermined test point on the card that controls the operation of the bond head. These real time damping signatures are collected and the analysis is performed using the MATLAB mathematical software.

The analysis done on the damping signatures given in Figure 3 and 4 is described in the Figure 5 to 8. The following table also summarizes the analysis results for different cases of defect signatures.

Signal	Characteristics
Sig 1	Reference damping signature
Sig 2	Oscillations during fall, rise and steady state part of the signal. Defective signature.
Sig 3	No overshoot rise signal. Slight distortion during steady sate. Defective signature.
Sig 4	w-shape distortion during rise, fall and steady state. Large shift between steady state value for rise and fall. Defective signature.

Table 6.1 Damping signature characteristics

signal	mow	min1	max1	Min2	max2
Sig 1	163	-0.057	0.033	-0.023	0.042
Sig 2	253	0.062	-0.073	0.050	-0.041
Sig 3	219	0.014	-0.032	0.018	-0.014
Sig 4	483	0.263	-0.085	0.028	-0.219

Table 6.2 Autocorrelation function

signal	mcf	mow	min1	max1	Min2	max2
Sig 1	1.00	163	-0.057	0.033	-0.023	0.042
Sig 2	0.939	202	0.057	0.012	-0.010	-0.038
Sig 3	0.826	190	0.025	0.042	-0.027	-0.013
Sig 4	0.563	402	0.281	0.307	-0.236	-0.217

Table 6.3 Crosscorrelation function

Sig	pd (watts)	pf (Hz)
Sig 1	1.0000	12.70
Sig 2	1.0000	12.70
Sig 3	1.0000	12.70
Sig 4	1.0000	12.70

Table 6.4 Auto power spectrum

Sig	pd (watts)	pf (Hz)
Sig 1	1.0000	12.70
Sig 2	1.0000	12.70
Sig 3	1.0000	12.70
Sig 4	1.0000	12.70

Table 6.5 Cross power spectrum

The defects represented in the autocorrelation and power spectrum estimation are usually associated with the mechanical and electrical problem associated with the machine. Table 6.1 outlines the most common type of defect signature characteristics of the machine.

Since the damping signature is periodic, its ACF and CCF exhibit the same periodicity, containing large peaks at each cycle of the signal (Figure 5 to 8). As m approaches N, the peaks are reduced in amplitude. From the observation done on the damping signature samples, the min and max values for the reference (good) damping signature exhibits a certain pattern where the max1 and max2 value are positive and min1 and min2 value are negative (Table 6.2 and 6.3). However, the pattern for values of max1/max2, min1/min2 varies for the defective signatures. For the m0w, its value increases in most cases of defect signatures. This is due to the characteristics of the damping signatures.

For the crosscorrelation function, the CCF value at zero lag indicates the similarities of the two signals under observation (Table 6.3). A value of 1 indicates the highest correlation between the two signals. From the analysis done, CCF values of 0.9500 and above are resulted from good damping signatures.

The power spectrum estimation describes distribution of signal power at various frequencies. For the auto and cross power spectrum, the pd and pf values (Table 6.4 and 6.5), are the same for all the analyzed signal. Although there are some oscillatory components associated with the signals, the auto and cross power spectrum could not detect these components clearly as their amplitude are relatively small compared to the maximum value of the signal. Hence the tabulated values given above shows the frequency of the damping signature and it's harmonics.

VI CONCLUSIONS

From the results obtained, condition monitoring of the bond head subassembly of a wire bonding machine can be established through computing the crosscorrelation and autocorrelation function of the damping signatures. By analyzing the extracted parameters from the magnitudes or shape of the correlation function, the correlation techniques can clearly distinguished and represents the electrical signatures consistently. The mcf values given by the crosscorrelation function adds an advantage to this signal analysis technique.

The power density spectrum obtained from the auto power spectral estimate and cross power spectral estimate could not differentiate clearly and consistently between the good and defective damping signatures.

The inter and intra system variability investigated shows that the shape of the good damping signatures is identical for all machines and the shape of defective damping signatures produced by a single machine or a group of identical machines depends on the problems associated with the machine.

VII REFERENCES

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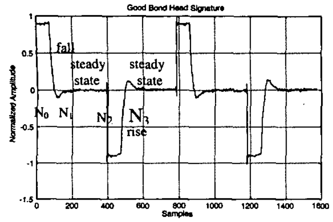

Figure 3 Good damping signature.

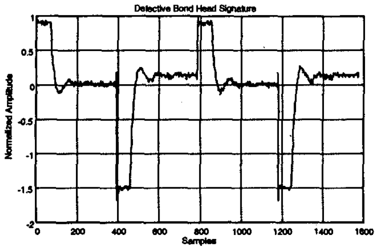

Figure 4 Defective damping signature.

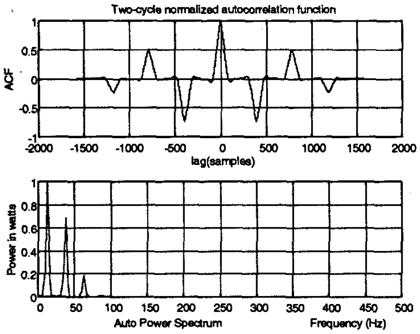

Figure 5 ACF and autospectrum of good damping signature.

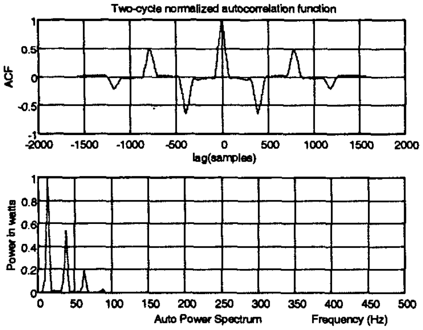

Figure 6 ACF and autospectrum of defective damping signature.

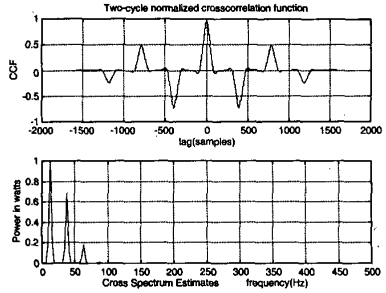

Figure 7 CCF and crosspectrum of good damping signature.

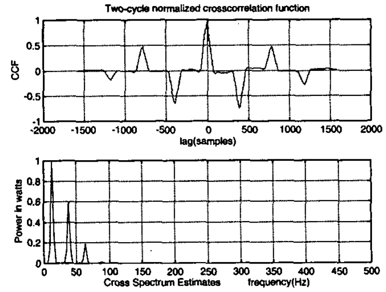

Figure 8 CCF and crosspectrum of defective damping signature.