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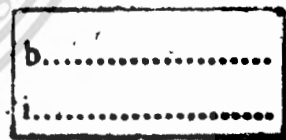
**THE EFFECT OF ULTRASONIC CLEANING ON SOLDER BOND JOINT
DAMAGE**



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หัวข้อวิทยานิพนธ์	ผลกระทบของการทำความสะอาดชิ้นงานด้วยคลื่นอัลตราโซนิก ต่อความเสียหายของจุดเชื่อมต่อระหว่างหัวอ่าน และ ตัวยึดจับ หัวอ่าน
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บทคัดย่อ

การทำความสะอาดชิ้นงานด้วยคลื่นอัลตราโซนิกเป็นที่แพร่หลายในอุตสาหกรรมฮาร์ดดิสก์ไดรฟ์ เพื่อลดการปนเปื้อนระหว่างขบวนการผลิตฮาร์ดดิสก์ไดรฟ์ การออกแบบในปัจจุบัน จำนวนจุดเชื่อมต่อระหว่างหัวอ่าน และ ตัวยึดจับหัวอ่าน ได้ถูกเพิ่มจำนวนขึ้น เพื่อเพิ่มความเร็วในการอ่านข้อมูลในทันกับความจุของฮาร์ดดิสก์ไดรฟ์ที่เพิ่มขึ้น จึงเป็นผลขนาดของจุดเชื่อมต่อระหว่าง หัวอ่าน และ ตัวยึดจับหัวอ่านมีขนาดเล็กลง อันส่งผลให้พบความเสียหายบริเวณจุดเชื่อมต่อดังกล่าวหลังผ่านกระบวนการทำความสะอาดชิ้นงานด้วยคลื่นอัลตราโซนิก

ในงานวิจัยนี้ได้มีการกำหนดลักษณะรอยร้าวของจุดเชื่อมต่อหัวอ่าน และ ตัวยึดจับหัวอ่าน ออกเป็น 3 แบบ คือ แบบ stress line, แบบ small, และ แบบ functional โดย ค่าความต้านทานของหัวอ่าน ที่มีรอยร้าวแบบ functional จะเปลี่ยนแปลงอย่างมีนัยสำคัญในขณะที่ ค่าความต้านทานจะไม่มีเปลี่ยนแปลงอย่างมีนัยสำคัญ สำหรับรอยร้าวแบบ stress line และ แบบ small แต่อย่างไรก็ตาม รอยร้าวแบบ small จะสามารถพัฒนาเป็นรอยร้าวแบบ functional ได้ หลังจากผ่านการทำความสะอาดชิ้นงานด้วยคลื่นอัลตราโซนิก 6 รอบ นอกจากนี้ได้มีการศึกษาผลกระทบของตัวแปรต่างๆ อันได้แก่ กำลัง ความถี่ของคลื่นอัลตราโซนิก และ เวลาในการทำความสะอาดชิ้นงาน ซึ่งพบว่า จำนวนชิ้นงานที่มีรอยร้าวจะเพิ่มขึ้นเมื่อมีการเพิ่มกำลังของคลื่นอัลตราโซนิก หรือ เวลาในการล้าง แต่จะลดลงเมื่อ เพิ่มความถี่ของคลื่นอัลตราโซนิก เครื่องมือวัดที่เหมาะสมในการพยากรณ์อัตราของจำนวนชิ้นงานที่มีรอยร้าวคือ เครื่องมือวัดสัญญาณความดันของคลื่นเสียง

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ABSTRACT

Ultrasonic cleaner widely uses in Head Disk Drive assembly industry to reduce contamination from cleaning part after assembly process completion. With recent Head Gimbal Assembly design, the number of interconnections between slider and suspension is increased to increase storage capacity and transfer rate caused by the smaller solder joint pad. Crack or fracture was found at the solder bond joint after passing through ultrasonic cleaning. In this thesis, three types of crack, straight line crack, small crack and functional crack were introduced based on electrical test failure in terms of resistance change and Scanning Electron Microscopy image. Only functional crack has an effect to resistance change at the electrical tester, while resistance is not a significant change for both straight line and small crack, but small crack can grow to be functional crack after 6 ultrasonic cleaning times. In addition, the effect of ultrasonic cleaning parameter, which are frequency, power and time, on the solder bonding joint crack also studied and reported. Crack rate was increased when ultrasonic power or time increasing, and in contrast crack rate was reduced when the ultrasonic frequency was increased. Moreover, the sound pressure signal measurement method is presented to measure the ultrasonic energy for solder bond joint crack rate prediction.

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First of all, I would like to thank you Assistant Professor Dr. Siridech Boonsang, and Dr. Jatuporn Thongsee my advisor and co-advisor for their helpful suggestions and constant supports during this research at KMITL. I am also thankful to all thesis committee members for their constructive comments and helpful discussions which gave me a better perspective on my own result. I should also mention that my graduate study in King Mongkut's Institute of Technology Ladkrabang was supported by NSTDA, KMITL and Seagate Technology (Thailand) Ltd.

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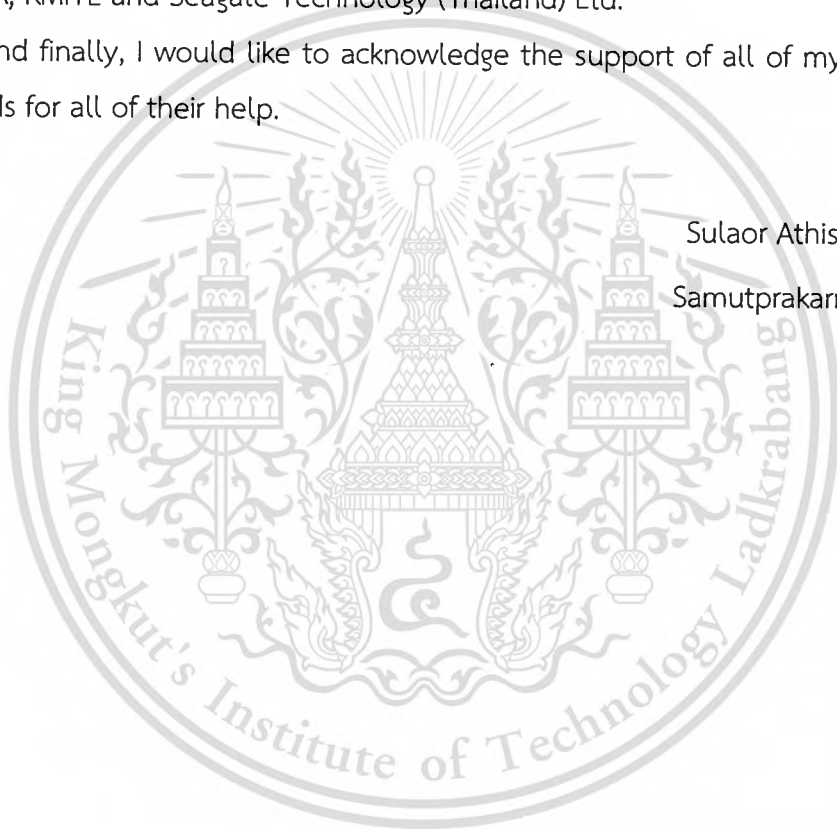


Table of Contents

	Page
Thai Abstract	I
English Abstract	II
Acknowledgements	III
Table of Contents	IV
List of Tables.....	VII
List of Figures.....	VIII
Chapter 1 Introduction.....	1
1.1 Problem Statement.....	1
1.2 Objective	2
1.3 Research Benefit.....	2
1.4 Research Methodology.....	2
1.5 Scope of Research.....	2
1.6 Thesis Organization.....	3
Chapter 2 Literature Review.....	4
2.1 Fundamental of HGA Process	4
2.1.1 Slider Attach to Suspension.....	5
2.1.2 Aqueous Ultrasonic Cleaning.....	5
2.1.3 Pitch Static Attitude (PSA) and Roll Static Attitude (RSA) Measurement	6
2.1.4 Electrical Test	6
2.1.5 Final Visual Inspection	6
2.2 Ultrasonic Cleaning - General Theory.....	6
2.2.1 Theory and Nature of Sound Wave	6
2.2.2 Cavitation and Implosion	7
2.2.3 Benefit of Ultrasonic in Cleaning Process	8
2.2.4 Main Equipment of Ultrasonic Cleaning.....	9

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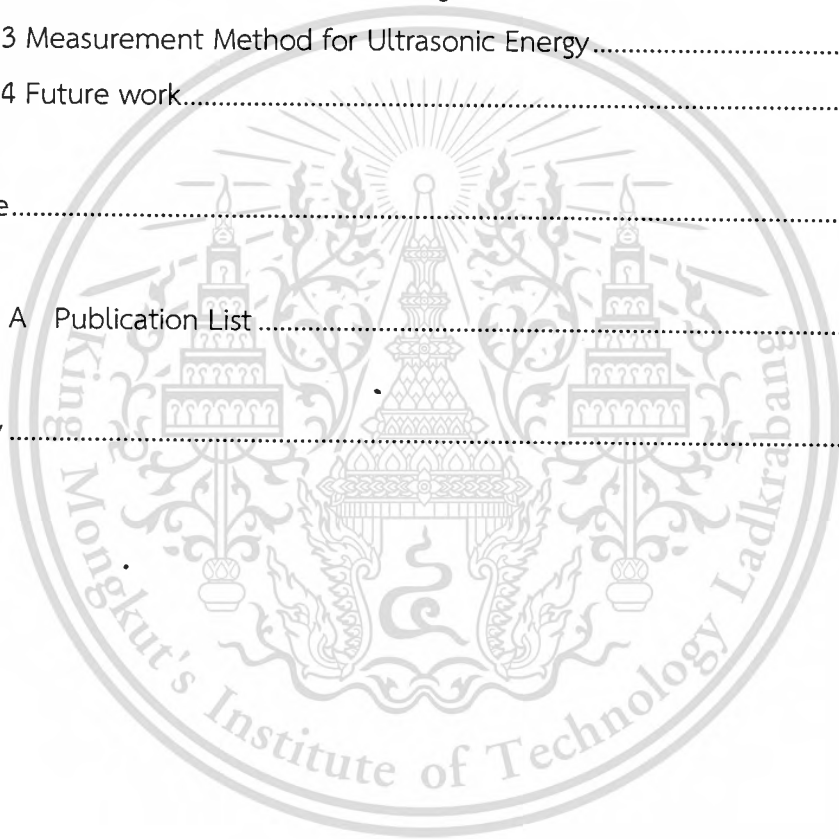
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Table of Contents (Cont.)

	Page
2.2.5 Factors Affecting Ultrasonic Cleaning	11
2.3 Ultrasonic Energy Measurement Principle.....	14
2.3.1 Cavitation Meter.....	14
2.3.2 Sound Pressure Signal Meter.....	17
Chapter 3 Thesis Methodology and Design of Experiment.....	20
3.1 Motivation of Experiment	20
3.2 Solder Bond Joint Crack Characterization	21
3.2.1 1 st Solder Bond Joint Crack Characterization Experiment.....	21
3.2.2 2 nd Solder Bond Joint Crack Characterization Experiment.....	22
3.3 Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint	24
3.3.1 Experiment Methodology.....	26
3.3.2 Experiment Equipment.....	26
3.4 Measurement Method for Ultrasonic Energy.....	28
Chapter 4 Solder Bond Joint Crack Characterization.....	30
4.1 Solder Bond Joint Crack Characterization	30
4.2 Design of Experiment.....	33
4.2.1 Stress Line Crack.....	34
4.2.2 Small Crack.....	37
Chapter 5 Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint Damage....	42
5.1 The Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint.....	42
5.1.1 Effect of Ultrasonic Frequency to Solder Bond Joint.....	42
5.1.2 Effect of Ultrasonic Power to Solder Bond Joint	45
5.1.3 Effect of Cleaning Time to Solder Bond Joint	48
5.2 Measurement Method for Ultrasonic Energy.....	51

Table of Contents (Cont.)

	Page
Chapter 6 Conclusion.....	54
6.1 Solder Bond Joint Crack Characterization	54
6.1.1 Stress Line Crack	54
6.1.2 Small Crack.....	55
6.1.3 Functional Crack.....	55
6.2 The Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint.....	58
6.3 Measurement Method for Ultrasonic Energy.....	58
6.4 Future work.....	58
Reference.....	60
Appendix A Publication List.....	63
Biography.....	69



List of Tables

Table	Page
2.1. Data of Cavitation Meter.....	16
3.1 Design of Experiment Parameters for Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint Damage.....	25
3.2 Design of Experiment Parameters of Measurement Method for Ultrasonic Energy that Impact to Solder Bond Joint.....	29
4.1. Solder Bonding Joint Resistance (Ohms) of Each Crack Types.....	32
4.2. Paired Sample Statistics of Stress Line Crack.....	35
4.3. Paired Sample Test of Stress Line Crack.....	36
4.4. Paired Sample Statistics of Small Crack.....	38
4.5. Paired Sample Test of Small Crack.....	39
4.6. The Summary of Solder Bond Joint Crack Characterization.....	41
5.1. Small Crack Results with Different Ultrasonic Frequency.....	43
5.2. ANOVA Tests of Different Ultrasonic Frequency.....	44
5.3. Small Crack Results with Different Ultrasonic Power.....	46
5.4. ANOVA Tests of Different Ultrasonic Frequency.....	47
5.5. Small Crack Results with Different Ultrasonic Cleaning Time.....	49
5.6. ANOVA Tests of Different Ultrasonic Cleaning Time.....	50
5.7. The Comparison between Cavitation Energy, Sound Pressure and Solder Bond Joint Crack Rate.....	51
6.1 The Summary of Solder Bond Joint Crack Characterization.....	57

List of Figures

Figure	Page
2.1. Head Gimbal Assembly	4
2.2. HGA Process Assembly Process	5
2.3. Sound Wave Diagram.....	7
2.4. Cavitation and Implosion.....	8
2.5. Magnetostrictive Transducer	10
2.6. Piezoelectric Transducer.....	11
2.7. Cavitation Meter Readings Versus Applied Generator Power.....	17
2.8. Sound Pressure Probe and Signal Reading.....	18
2.9. Example of Sound Pressure Distribution In Cleaning Tank.....	18
2.10. Measurement Frequency Rang for Sound Pressure	19
3.1. Flowchart for 1 st Solder Bond Joint Crack Characterization Experiment.....	21
3.2. Flowchart for 2 nd Solder Bond Joint Crack Characterization Experiment.....	24
3.3. Flowchart for Ultrasonic Effect on Solder Bond Joint Crack Experiment.....	26
3.4. “Crest-Ultrasonics” Precision Cleaning System.....	27
3.5. “JEOL” JCM-5000 NeoScope	28
4.1. Image of Solder Bonding Joint Crack from SEM at 150x Magnification.....	31
4.2. Boxplot Chart of Resistant Results of Each Crack Type	32
4.3. Image of Stress Line Crack between 1 and 6 Ultrasonic Cleaning Times.....	34
4.4. Boxplot Chart of Resistant Results of Stress Line Crack Characterization between Before, 1 and 6 Ultrasonic Cleaning Times.....	36
4.5. Image of Small Crack between 1 and 6 Ultrasonic Cleaning Times.....	37
4.6. Boxplot Chart of Resistant Results of Small Crack Characterization between 1 and 6 Ultrasonic Cleaning Times.....	39
5.1. Boxplot Chart of Ultrasonic Frequency Effect to Small Crack.....	45
5.2. Boxplot Chart of Ultrasonic Power Effect to Small Crack.....	47
5.3. Boxplot Chart of Cleaning Time Effect to Small Crack.....	49
5.4. Regression between Solder Bond Joint Crack Rate and Cavitation Energy.....	52
5.5. Regression between Solder Bond Joint Crack Rate and Sound Pressure Signal Meter.....	53

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CHAPTER 1

Introduction

1.1. Problem statement

In data storage industry, the reliability is one of critical concerned parameter. There are many testing steps in Hard Disk Drive components, especially Electrical Test. In Head Gimbal Assembly, solder bonding method, which is one technique provided for interconnect between slider and suspension pad, is provided to join gold bond pad of slider and bonding lead of suspension and then cleaned by the ultrasonic cleaner; most ultrasound frequency range is between 68 – 192 kHz. After part cleaning, Head Gimbal Assembly will send to test by Electrical Test machine. With current Head Gimbal Assembly design, the number of interconnections between slider and suspension is increased to increase storage capacity and transfer rate caused by the smaller solder joint pad. Occasionally, ultrasonic cleaning can cause solder joint damage such as cracking or fracture and interconnect failure.

During ultrasonic cleaning, mechanical oscillation of the solder bonding joint is generated by ultrasonic energy. Aqueous ultrasonic cleaning experiments show that ultrasonic can promote crack on the solder bond joint. The characteristic of solder bonding joint need to be identified based on electrical test and crack characterization by images from Scanning Electron Microscopy (SEM). The effect of the critical aqueous ultrasonic cleaning parameters, which are frequency, power and time on the solder bond joint will also be investigated for more understanding the critical parameters that develop cracks or fracture in the solder bond joint. In addition, two measurement methodology, cavitation and sound pressure meters, will be provided to predict and monitor, ultrasonic energy in cleaner tank that correlated with the solder bond crack rate.

1.2. Objective

To study the solder bond joint crack characterization and understanding ultrasonic cleaning parameters including ultrasonic frequency and power that effected to solder bonding joint of Head Gimbal Assembly, the effect is to cause a crack or fracture to the solder bond joint, and then identifying ultrasonic energy measurement methodology that can predict the solder bond joint damage.

1.3. Research Benefit

- 1.3.1 To obtain Head Gimbal Assembly solder bond joint crack characterization that effect from aqueous ultrasonic cleaning.
- 1.3.2 To obtain aqueous ultrasonic cleaning parameter that effect to solder bond joint crack for Head Gimbal Assembly in order to prevent solder bond joint damage

1.4. Research Methodology

- 1.4.1 To study the solder bond joint crack characterization based on electrical test and Scanning Electron Microscopy (SEM) image
- 1.4.2 To study ultrasonic cleaning parameter including ultrasonic frequency, power and time that effect to solder ball joint of Head Gimbal Assembly.
- 1.4.3 To study two ultrasonic energy measurement tools, cavitation meter and sound pressure meters, which can correlate with solder bond joint damage to develop suitable aqueous ultrasonic energy for Head Gimbal Assembly in order to prevent solder bond joint damage.
- 1.4.4 Research conclusion.

1.5. Scope of Research

This thesis is aimed to study aqueous ultrasonic cleaner theory and main parameters of ultrasonic cleaner in order to understand which parameters that has an effect to solder bonding joint crack rate and select a suitable ultrasonic energy measurement tool for aqueous ultrasonic cleaning in order to develop the suitable

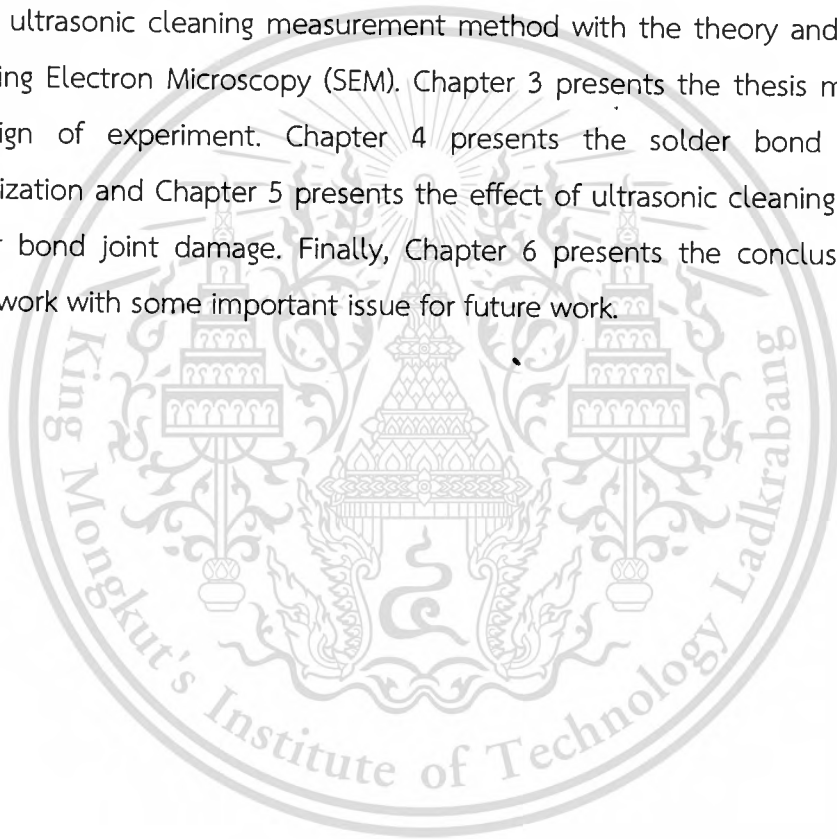
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ultrasonic energy conditions for Head Gimbal Assembly for preventing solder bond joint damage.

1.6. Thesis Organization

This thesis is organized in the following manner. Chapter 2 presents the literature review, Head Gimbal Assembly process flow, principle ultrasonic cleaning, acoustic cavitation and streaming and factor that effect for ultrasonic energy, including ultrasonic cleaning measurement method with the theory and application of Scanning Electron Microscopy (SEM). Chapter 3 presents the thesis methodology and design of experiment. Chapter 4 presents the solder bond joint crack characterization and Chapter 5 presents the effect of ultrasonic cleaning parameters to solder bond joint damage. Finally, Chapter 6 presents the conclusions of this research work with some important issue for future work.



CHAPTER 2

Literature Review

2.1. Fundamental of HGA Process

Head Gimbal Assembly (HGA) is one of the Hard Disk Drive Process. The main process is to assemble slider to suspension by using adhesive and a solder bonding for electrical circuit connection.

Figure 2.1 shows the component of HGA, which consists of suspension and slider. HGA process is the process of attaching a slider on suspension with adhesive and curing, and bonding or connecting between the gold bonding pad on trailing end of the slider with the bonding pad of suspension by solder bond.

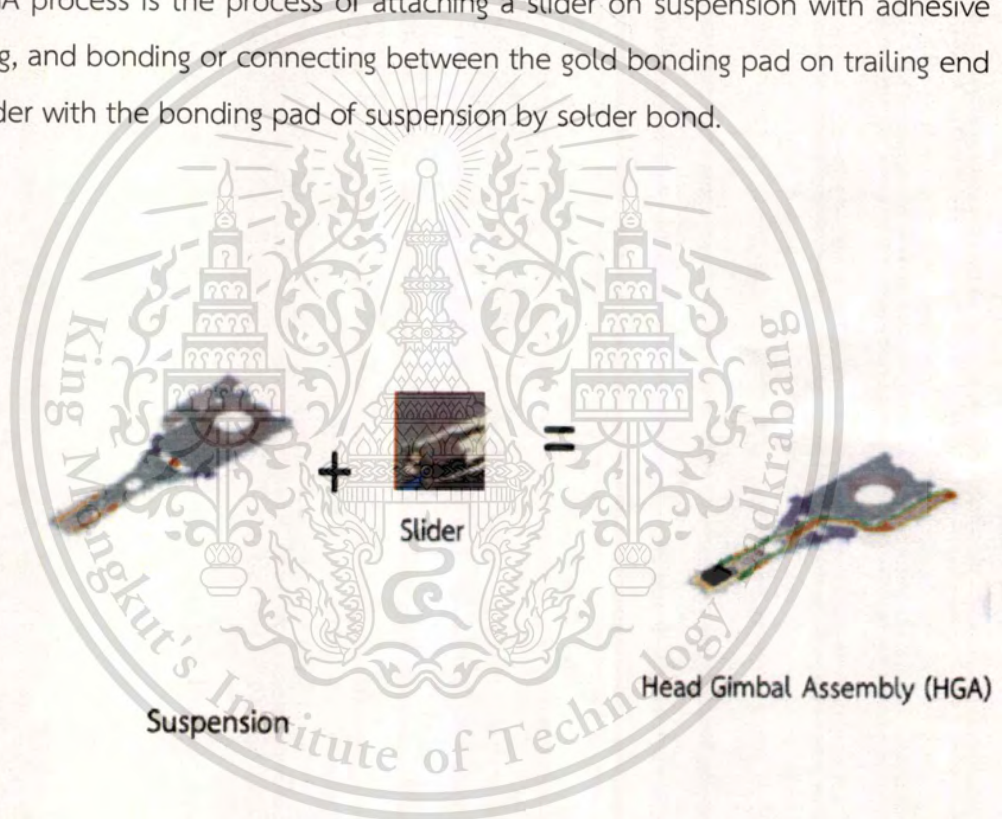


Figure 2.1 Head Gimbal Assembly.

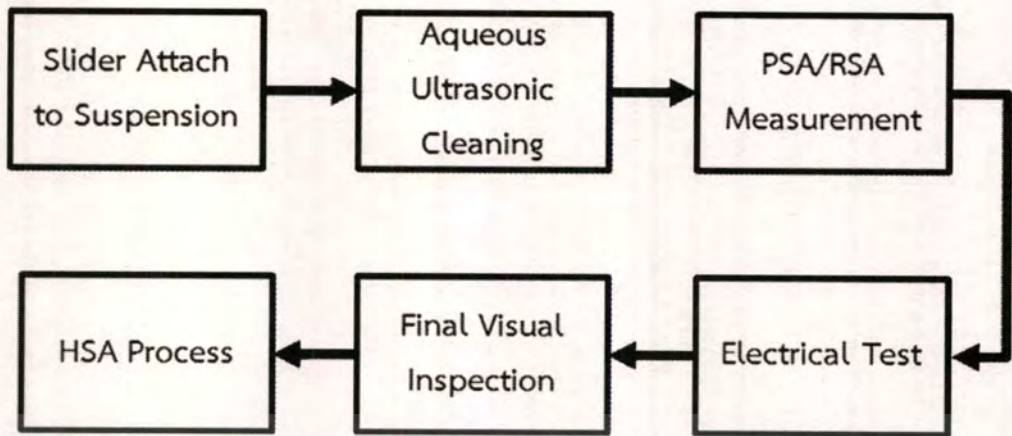


Figure 2.2 HGA Process Assembly Process.

2.1.1. Slider Attach to Suspension

Both slider and suspension load to carrier and then transferring to the assembly line. First, the adhesive is dispensed to the bond tab of suspension and then the slider is attached on suspension by using adhesives. The alignment need to be controlled in this step since the slider alignment to suspension is related to the read/write process and flying performance above media. After that, the part is sent to the thermal or an infrared radiation oven in order to cure the adhesive both temperature and time need to be controlled in this step. Then the gold bonding pad of the slider is connected to suspension by using solder ball for bonding joint. Some HGAs are sampled for solder bonding joint strength, performance test before submission to the Aqueous cleaning system.

2.1.2. Aqueous Ultrasonic Cleaning

Aqueous cleaning is one of important processes in HGA assembly process since many particulate contamination are accumulated during slider attached to suspension process. All particulate contamination is a major cause of yield loss in HGA process. The aqueous ultrasonic cleaning system is a widely used in the HGA process since it is optimized in both cost and time for HGA process. Aqueous ultrasonic cleaning need to be control some critical parameters such as ultrasonic frequency, ultrasonic power and time in order to ensure that the part is cleaned with acceptable cleanliness level and no part damage.

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2.1.3. Pitch Static Attitude (PSA) and Roll Static Attitude (RSA) Measurement

The angular relationship of HGA's Air Bearing Surface (ABS) to HGA mounting surface is measured in this process in order to ensure the both Pitch Static Attitude (PSA) and Roll Static Attitude (RSA), which is one of major parameter that effect on the flying height and read/write process performance, are within specification.

2.1.4. Electrical Test

HGA performance is tested in this step by applying current and simulated the real HGA spins above media on an electrical tester machine. Writer, ability to write data, is tested this step with many testing parameters such as track average amplitude, pulse width at 50%, overwrite, signal-to-noise ratio, bit error rate etc. The good and fail, part is identified in this test.

2.1.5. Final Visual Inspection

Mechanical defects are inspected under scope in order to screen mechanical defected part before sending all good parts to Head Stack Assemble production line.

2.2. Ultrasonic Cleaning - General Theory

Nowadays, cleanliness becomes the necessary requirement for many industries, especially in electronic industry where cleanliness is always important. Many advance cleaning methods have been rapidly developed per cleanliness requirement in a passing several years. A lot of advance cleaning is involved with ultrasonic technology which enhance both speed and cleaning effectiveness.

Ultrasonic is a regular sound wave over human audibility, in generally frequency above 18 kHz are considered as ultrasonic. Normally, in the cleaning process for semi-conductor manufacturing is around 40-100 kHz, but some sonic cleaning in the range of 0.8-0.9 MHz has also used in term Megasonic" cleaning

2.2.1. Theory and Nature of Sound Wave

Per definition in dictionary define that sound is a transmission of vibration through an elastic medium that could be solid, liquid or gas. Sound waves can be

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generated in term of repeating or displacing such as "shock" event or "vibratory" movement.

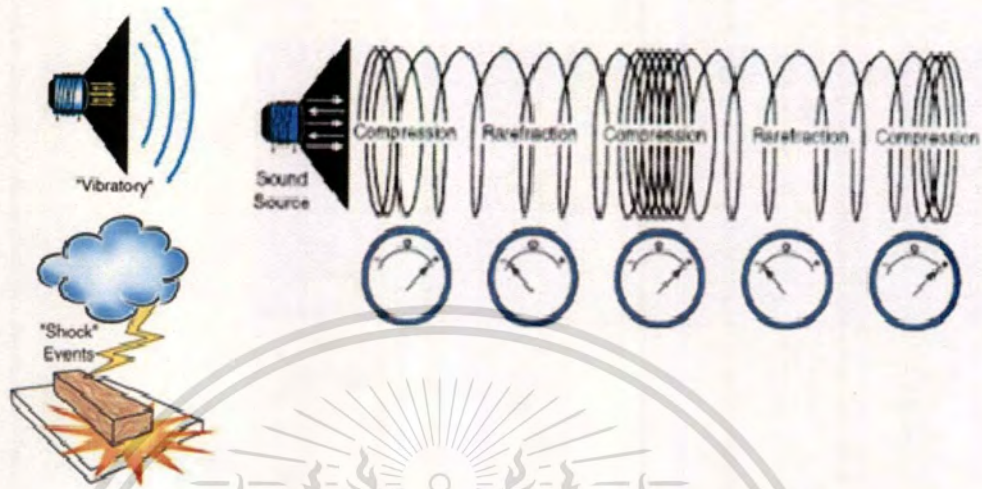


Figure 2.3 Sound Wave Diagram.

The diagram above represents molecules of a sound conducting medium. Sound is a variation in different pressure, a step where pressure increase on a sound wave is called "compression" while a step where the pressure decrease is called "rarefaction".

2.2.2. Cavitation and Implosion

Cavitation is a phenomenon where bubble is born and collapse of either gas or liquid medium. For example, if the liquid pressure drops to a cavitation threshold, cavitation will happen. The bubble will be formed and grow in negative pressure (during rarefaction phase) to its maximum size, then the bubble is collapsing in the compression phase (that follow rarefaction phase) and the violent collapse result in implosion. After that, the cycle repeat, new bubble is formed, grow, collapse and implode. During the cavitation bubble collapse, surrounding fluid will quickly move to fill the space from collapsing bubble, this activity is called "central jet". Both effects from the implosion of the bubble and central jet of fluid are the key of the cavitation process for contaminant removal.

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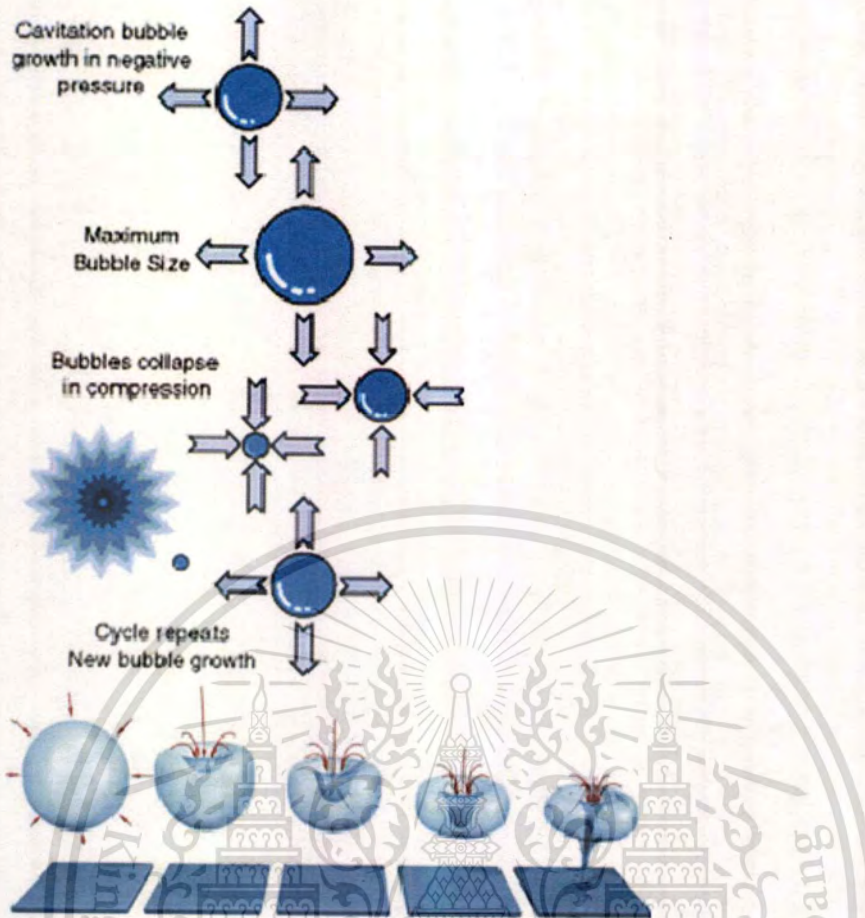


Figure 2.4 Cavitation and Implosion

From the phenomenon of cavitation, can conclude the implosion occur from 3 main combination factor:

- Compression of ultrasonic wave
- Pressure from surface tension of bubble
- Atmospheric pressure on a bubble

2.2.3. Benefit of Ultrasonic in Cleaning Process

The objective of cleaning is to eliminate contamination by dissolution, displacing or both dissolution and displacing. The mechanical property of ultrasonic can support both dissolution and displacing.

To remove contamination by dissolution, it is important to let solvent or chemical contact and dissolve contaminant directly. But after cleaning chemical dissolve the contaminant for a while, a saturated layer will occur and make cleaning

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activity, stop due to the chemical can no longer approach to contaminant. In this case, ultrasonic cavitation and implosion can displace the layer, then chemical can reach the exist contaminant and dissolve them from the part being clean.

For some contaminants that consist of insoluble particle grouping loosely, ultrasonic cavitation can remove them out by displacing from implosive effect. Not only a flat surface, but also the rough surface can be clean by ultrasonic. This can be proved that ultrasonic energy is more effective that the other cleaning method like spraying, brushing, turbulent or air-agitation to clean the complex parts.

2.2.4. Main Equipment of Ultrasonic Cleaning

There are two main equipment, ultrasonic generator and ultrasonic transducer that introduce ultrasonic energy into cleaning.

- Ultrasonic Generator

Ultrasonic generator is an equipment that converts electrical energy from Alternative Current 50 or 60 Hz to be electrical energy at the designed ultrasonic frequency. As we noted, that frequency and amplitude are main factor effect on the effectiveness of ultrasonic cleaning, there are other innovation in ultrasonic generator that may increase cleaning efficiency, for example square wave, sweeping or pulsing.

Square wave output

Applying square wave signal to ultrasonic transducer will result in multi-frequency which able to generate several frequencies at the same time.

Pulse

Pulse is a factor result in turning on /off for ultrasonic energy which can be applied for degassing (the activity of removing gas from liquid to enhance effectiveness of ultrasonic cavitation). At slower pulse rate degassing happen rapidly and has an opportunity to rise to the surface of liquid. But at the quicker pulse rate, the cleaning process will get benefit from repeated energy and implosion of ultrasonic cavitation.

Frequency sweep

Sweep operation is an operation that modulates output frequency around a central frequency which able to reduce the effect of “standing wave” that might damage the delicate parts.

■ Ultrasonic Transducer

There are two general ultrasonic transducer types at this time, Magnetostrictive and Piezoelectric. Both types have the same function to convert electrical power to mechanical power, but different in the way of conversion.

Magnetostrictive Transducer

Magnetostrictive is firstly will transmit electrical energy into a magnetic field, then convert from magnetic field to mechanical. From the efficiency lost in each conversion can be noted that Magnetostrictive is less efficiency than Piezoelectric.

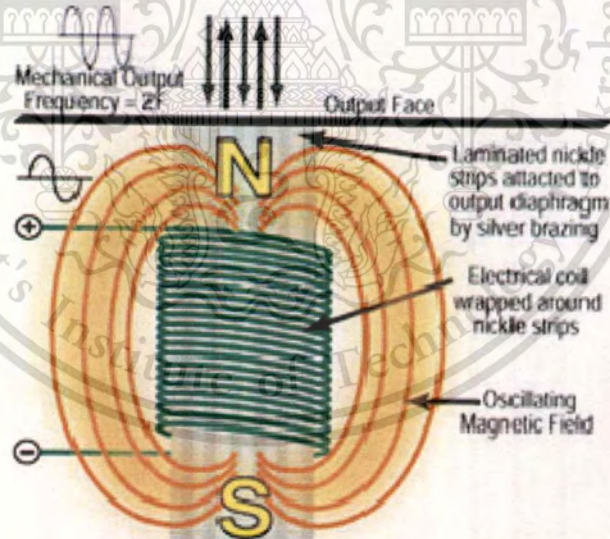


Figure 2.5 Magnetostrictive Transducer

Piezoelectric Transducer

Piezoelectric transducer is a an equipment that converts electrical energy to mechanical energy by the property of piezoelectric effect that occur when a material

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change dimension when apply electrical energy to them. Comparing with Magnetostrictive that can generate maximum frequency around 20 kHz, piezoelectric transducer is much more effective for ultrasonic cleaning.

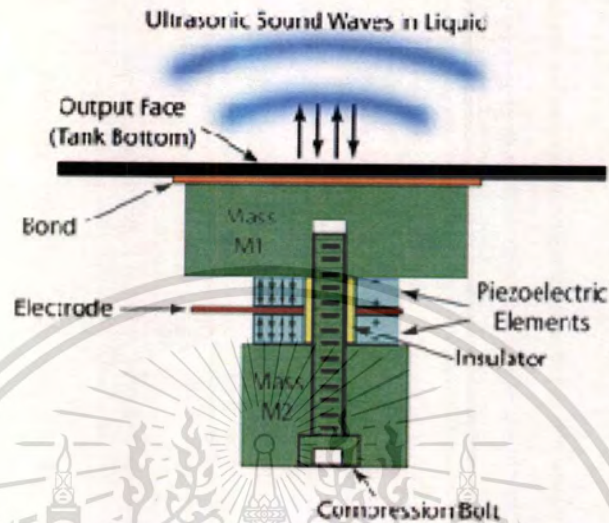


Figure 2.6 Piezoelectric Transducer

2.2.5. Factors Affecting Ultrasonic Cleaning

Generally, there are many parameters such as ultrasonic power, ultrasonic frequency, cleaning time, temperature and chemical that can influence in ultrasonic cleaning results same as other cleaning technology, but some factors must be taken into account to get the most effectiveness from ultrasonic cleaning and some factors must be optimization in order to avoid part damage from cavitation. In order to maximize cavitation of cleaning liquid, some variable like viscosity and gas dissolved should be reduced to gain more effectiveness of cavitation and implosion.

- Ultrasonic Power

Ultrasonic power should be appropriate with entire volume of liquid with the workload. Inadequate ultrasonic power result in less effective cleaning, and the excessive power might cause damage on part. If a wide variety of product have to be clean in the same single cleaning system, ultrasonic power control is necessary for various setting.

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High ultrasound power in liquid is the increase in the number of cavitation per unit volume, high power causes a lot of formation of large amount of bubbles in the liquid which can scrubbing cleaning surfaces effectively. However, the increasing in ultrasonic power is adding stress on the ultrasonic transducer due to dimension of transducer changed during vibration. These factors cause transducers fail and reduced equipment lifetime. In the design, the compromise of this parameter is essential to provide the maximum performance and longevity.

In addition, part exposure to ultrasonic energy and cleaning chemical is also important. Basket or part fixture must be designed to allow area of part being clean and contact with cleaning chemical.

■ Ultrasound Frequency

In the production of gas or vapor bubble completely imploded in a liquid at ultrasonic cleaning require some certain time. In high ultrasonic frequency, the time that needed to create a bubble is longer than available of rarefaction time from sound wave. For example, at 20 kHz ultrasonic frequency, the sound wave cycle time is $25 \mu\text{s}$ ($=\frac{1}{2f}$) with negative pressure peak at $12.5 \mu\text{s}$, at 20 MHz ultrasonic frequency, cycle time is $0.025\mu\text{s}$. Therefore, as the frequency increases creating bubbles cavitation becomes more difficult that is result in smaller cavitation bubble size. At high ultrasonic frequency, there is a small bubble, which is lower scrubbing energy, in contrast at low frequency, there is a large bubble generation in liquid that is stronger scrubbing energy. The normal range of ultrasonic frequency in cleaning application is between 20-500 kHz.

Cavitation is related directly to ultrasonic power while inversely related to ultrasonic frequency. At the higher power, cavitation intensity increase and effect from implosion is more violent from the larger energy. But at the higher frequency cavitation intensity is decreased because of smaller size of bubble and less violent implosion. However, the effect from higher frequency might be compensated by increasing ultrasonic power instead.

■ Cleaning Time

Both ultrasonic power and frequency parameter are the equipment depending parameters. Both parameters are have a limitation for change or adjuste.

due to cost and time of equipment modification. Cleaning parameter is come to be an adjustable parameter for ultrasonic cleaning. In common sense, cleaning effectiveness is increasing when increasing of ultrasonic cleaning time but it need to be optimized with part failure from fatigue.

- Liquid Temperature

Liquid temperature increasing causes a decrease in the intensity of the ultrasound that needed for the bubble formation within the ultrasonic cleaning agent. This is likely due to lower surface tension of the liquid that will lead to a reduction in cohesive forces and energy within the fluid. The cavitation energy is lower near the boiling point of liquid causes an increase in significant vapor pressure, so while the high temperature favors nucleation of cavities, the presence of water vapor within the bubble leads the impact of the explosion during compression so stable cavitation. However, each liquid have and ideal temperature that is maximize the cavitation intensity such as the cavitation of water is most effective at temperature near 70 °C while the caustic water solution has a maximizing cavitation temperature at 80 °C.

- Dissolved Gas and Particulate Matter

Dissolved gas is also the factor that should be contains in liquid as less as possible, because the dissolved gas will block or delay bubble to collapse for implosion. During cavitation phenomenon, there will be both “stable bubble” and “transient bubble” . The transient bubble is a large bubble that growth and implode rapidly, this may not effect from effect of dissolved gas, but the stable bubble is formed in a small bubble size will oscillate many cycle before collapse, this really effect from dissolved gas that might make incomplete process of cavitation. To avoid this problem, the higher temperature can reduce the dissolved gas in liquid.

Ultrasonic cleaning is might not a future cleaning technology, but it widely use as today technology from its effective result. In order to get more or the most benefit from this cleaning process, all relative parameter should be considered carefully to match with purpose of what to clean and enhance cleanliness result from understanding about each parameter or each property of ultrasonic cleaning.

2.3. Ultrasonic Energy Measurement Principle

2.3.1. Cavitation Meter [22]

In almost every cleaning task, it is important to control the amount of cavitation energy. Lack of cavitation energy is resulting in longer cleaning time to achieve a desired cleaning level. To clean or in some cases the desired level. To clean the surface, may not be successful, while excessive power voids near the surface with a delicate texture. Or components that cause damage to the sample surface damage at the surface, including the formation of rocks and / or craters on the surface factors that affect the size of the bubble cavitation and consistent power. Different frequency ultrasonic particular frequency, the higher the less time for the bubble to grow, the result is a small air bubble and reduce energy corresponding cavitation factors affecting use. Energy cavitation is the intensity of the wave ultrasonic (such as pulse width) produced by the transducer (s) in greater detail, the intensity of the wave at a higher cause each point along the wave. Oscillation in the voltage range is large (between transformation and compression) which will produce larger cavitation bubbles cavitation energy and big, so there is a direct relationship between. The intensity of the ultrasonic waves, the water pressure oscillates between cavitation and energy.

One factor to consider is the fact The intensity of the wave Reduces ultrasonic propagation through the fluid cavitation energy so typical function of distance from the transducer. There was also a construction / destruction caused by

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a codec (s) in the bath, depending. Situated within the shower that you may receive an ultrasound arriving in the process of creating a disturbance, creative and in other places it is out of the process of creating destructive interference bucket change. Formed by sweeping the frequency, which will help improve consistency in the shower as a result, parts of the surface that is in place that vary within the bath will be exposed to different levels of power voids. It has been quite challenging to clean surfaces regularly creative / destructive patterns are seen even just one codec to display power is routed through a codec. Primarily because the overall size of the codec bigger. The wavelength of the ultrasound wavelength dimension is larger than the proportion of codecs and it will be seen that the energy will be broadcast in all directions, and creative / destructive interference to occur for several blocks.

Cavitation meters measure the intensity of cavitation energy and frequency of cleaning, ultrasonic and high frequency shower megasonic stream nozzle. and the wafer and single cleaner soak these measures do not hydrophones with sensors tend to filter high frequency. Signature cavitation they measure the acoustic energy and cavitation which the RMS of the intensity of power voids (in watts per square inch) and the frequency of the source of the sound that drove meters allow the distribution. Shower energy within their borders and helping to establish. To ensure In cleaning Effective while minimizing any damage probes can also assess the direction of power voids which. The magazine can be important in applications they can use. To check that the system is functioning properly and seek to influence and load variables are effective in cleaning. The following is a general export of data to be stored in the meter which includes. Memory location, date, time, scan time average power reading, standard deviation, minimum and maximum frequency of reads kHz.

Table 2.1 Data of Cavitation Meter

Location	Date	Time	Scan Time	Average Energy Reading	Standard Deviation	Minimum	Maximum	kHz
1	08/01/07	10:12	0:10	45	1	42	46	41.2
2	08/01/07	10:13	0:20	46	2	42	48	40.5

Test Aluminum foil is a common method sometimes used to evaluate a ultrasonic bath John Kolyer Boeing has written an article on this topic , including one that compared to the use of the foil on . Compared with the measurement of cavitation He said in the article: "Meter that " at one of his shows dramatic improvements in accuracy and time to assessment, bathing, using the measure cavitation "... The energy meter wave will take over the task of monitoring the operation of the tank. " Article also charts his path to measure the power consumption of the unit has changed with the energy difference from the standard.

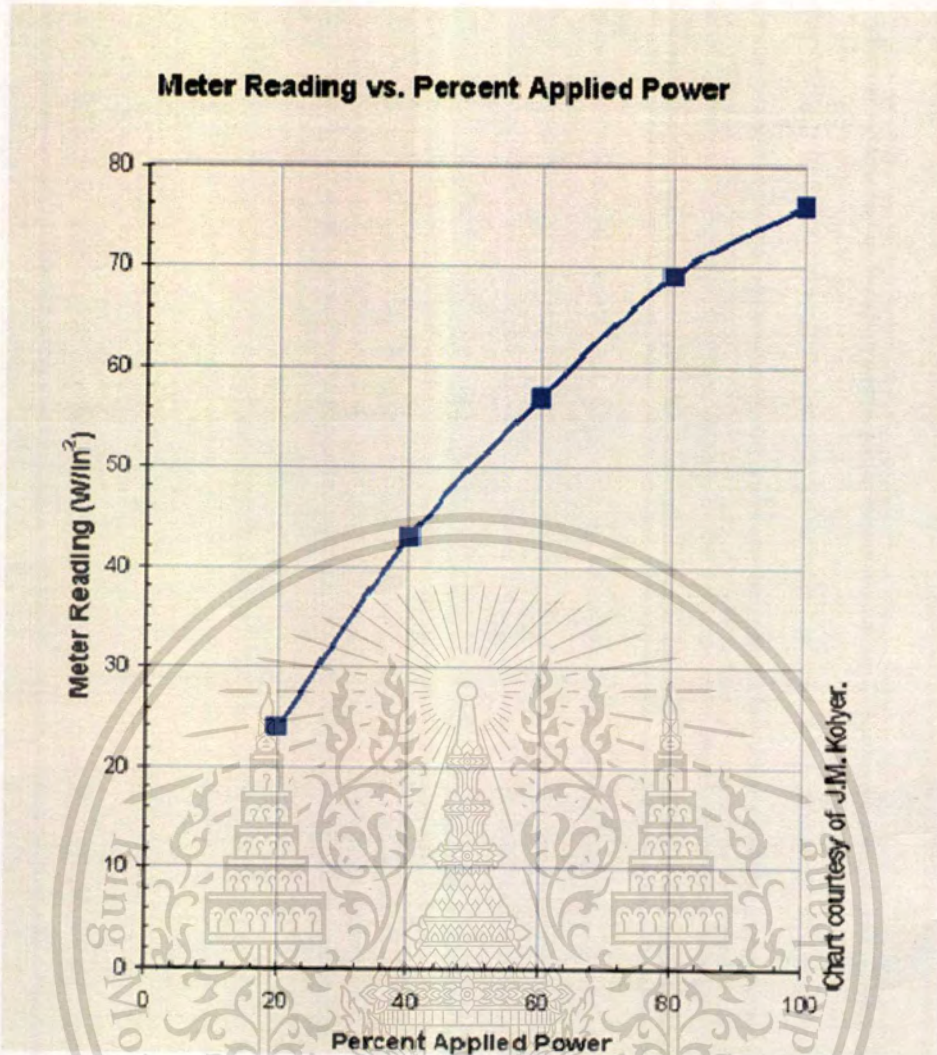


Figure 2.7 Cavitation Meter Readings Versus Applied Generator Power

2.3.2. Sound Pressure Signal Meter [23]

Sound Pressure meter probe contains a piezo-ceramics element that will transmit the received sound pressure (Pa) to voltage (MV) and indicate as DC voltage by monitor. Output DC voltage shows relative sound pressure and it cannot be converted to absolute sound pressure (Pa).

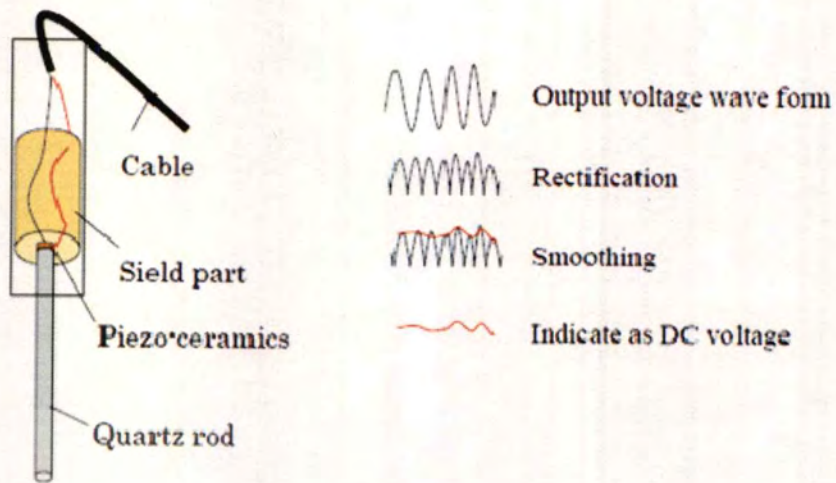


Figure 2.8 Sound Pressure Probe and Signal Reading

Relative sound pressure distribution can be quantified, and failure of piezo-ceramics element where sound pressure decrease relatively can be curbed.

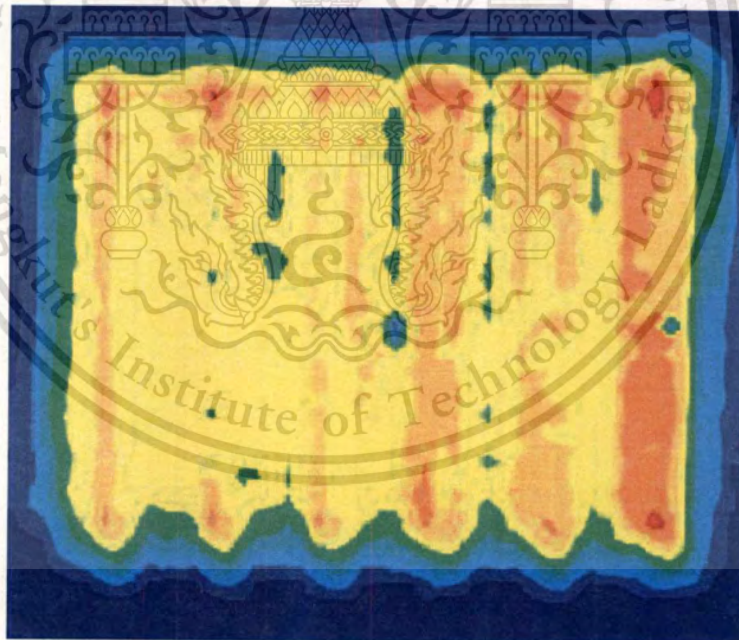


Figure 2.9 Example of Sound Pressure Distribution In Cleaning Tank

The Impedance is different between high and low frequency range. Therefore, output voltage (mV) is also different depend on frequency. The measurement instrument has to adjust the measuring frequency at output voltage adjustment.

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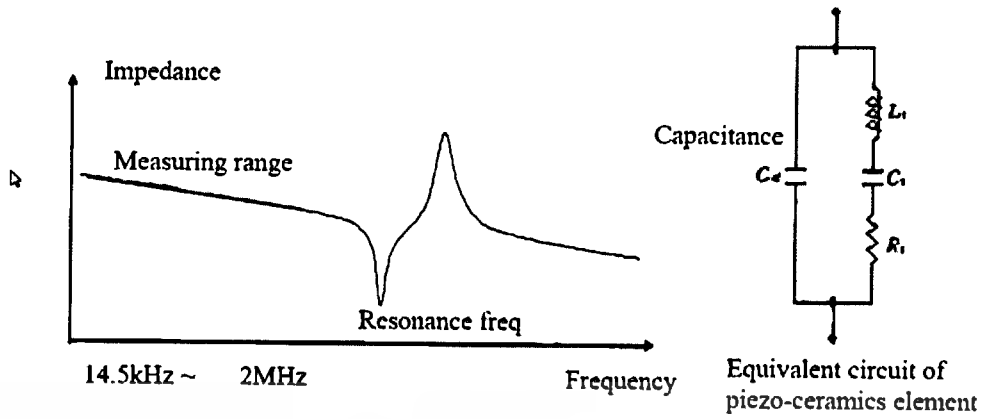


Figure 2.10 Measurement Frequency Rang for Sound Pressure



CHAPTER 3

Thesis Methodology and Design of Experiment

The researcher started with the solder bond joint crack characterization based on resistant results from Electrical Testes and Scanning Electron Microscopy (SEM) in order to classify the effect and severity of the solder bond joint crack to Head Gimbal Assembly. Then a series of details experiments were carried out to test and validate the effect of aqueous ultrasonic cleaning parameters to solder bond joint damage. Finally, two ultrasonic energy measurement methodologies, cavitation and sound pressure meter, were examined and correlated with solder bond joint damage in order to develop suitable aqueous ultrasonic cleaning conditions for Head Gimbal Assembly for solder bond joint damage prevention.

3.1. Motivation of Experiment

Optimizing Head Gimbal Assembly cleaner to reduce solder bonding joint crack required understanding of crack characterization. For normal process, Head Gimbal Assembly is fabricated with automatically process at front of the line and then submit to clean by ultrasonic cleaning before send to perform electrical test for monitoring the quality and reliability of the product. Good and fail part can be detected in the electrical test process. But we found some failures after send Head Gimbal Assembly to next step. This failure cannot be detected by electrical test and may be escape or develop in the next assembly process. Solder bonding joint crack is one of those concerned caused by failure. In our process, we found some solder bonding joint crack characterizations cannot be detected by electrical test, but it can develop and show failure symptom in the next assembly process.

3.2. Solder Bond Joint Crack Characterization

In order to characterize the solder bond joint, both fail and good parts in normal operations and experimental design parts were taken to monitor solder bond joint crack by Bench top Scanning Electron Microscope (SEM) at 150x magnification (NeoScope JCM-5000 by Nikon Instruments Inc.) And then submitted to the electrical tests (Seagate design) for pad resistant measurement.

There were 2 parts of Solder bonding joint crack characterization experiment.

3.2.1. 1st Solder Bond Joint Crack Characterization Experiment

First experiment part was carried out per flowchart in Figure 3.1 in order to characterization solder bonding joint crack in term of Scanning Electron Microscope (SEM) image and then mapping physical image with electrical resistant results by Electrical Tester machine.

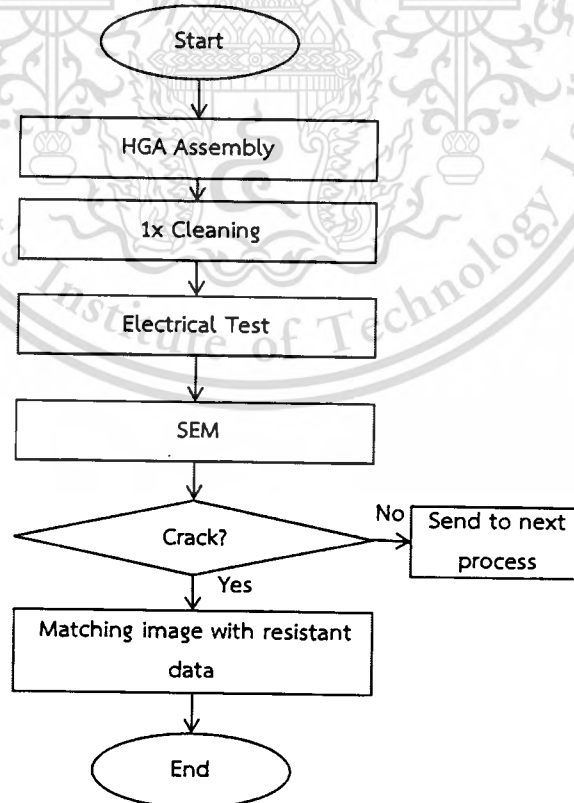


Figure 3.1 Flowchart for 1st Solder Bond Joint Crack Characterization Experiment.

Head Gimbal Assembly parts were built in a normal process, assembly slider and suspension in automation process and then send to clean by aqueous ultrasonic cleaning at following conditions:-

Ultrasonic Frequency	68 kHz
Ultrasonic Power	750 Watts
Cleaning Time	120 second

After completing part cleaning, HGA part were submitted to test at Electrical Tester machine. Then all parts were submitted to Scanning Electron Microscope (SEM) at 150x for physical solder bonding joint verification by SEM image. The solder bonding joint crack image from SEM will be categorized and mapping each solder bonding joint crack type image with electrical resistant results by Electrical Tester.

3.2.2. 2nd Solder Bond Joint Crack Characterization Experiment

Second experiment part was carried out per flowchart in Figure 3.2. Head Gimbal Assembly parts were built in a normal process, assembly slider and suspension in automation process and then send to clean by aqueous ultrasonic cleaning at following conditions:-

Ultrasonic Frequency	68 kHz
Ultrasonic Power	750 Watts
Cleaning Time	120 second

After completing part cleaning, HGA part were submitted to test at Electrical Tester machine. Then all parts were submitted to Scanning Electron Microscope (SEM) at 150x for physical solder bonding joint verification by SEM image. The solder bonding joint crack image from SEM will be categorized and mapping each solder bonding joint crack type image with electrical resistant results by Electrical Tester.

A series of details experiment were carried out to test the validity of both crack types growth in next HGA process that cause the resistant failure. To simulate the production process as the experiment was carried out within the production cycle and selected 15 parts of each solder bonding joint crack types by SEM image. And then, the selected parts were continuing 5 ultrasonic cleaning cycle times in the normal production process, which is a higher cleaning cycle of the Hard disk drive process. The validation experiment was carried out by comparison, both resistant results from electrical tester and a solder bonding joint crack image by SEM between 1 time and 6 ultrasonic cleaning time's cycle by pair T-Test hypothesis.



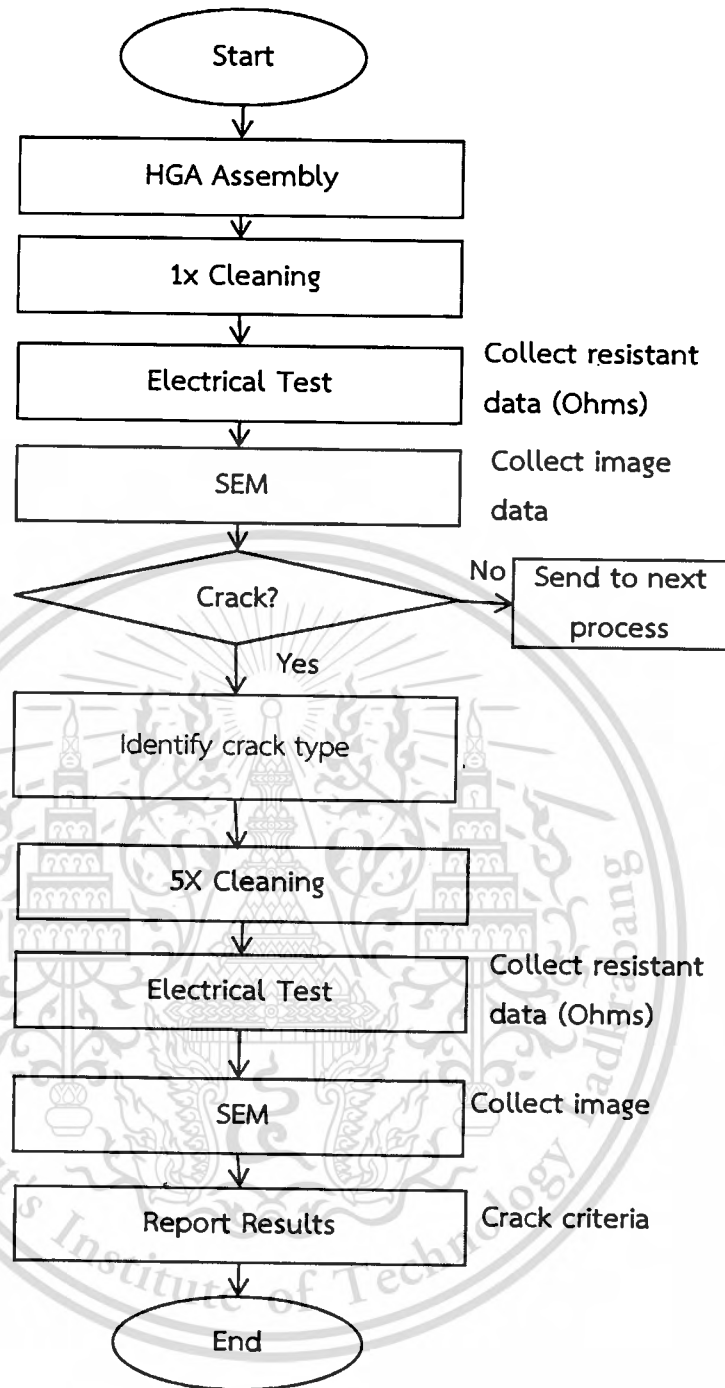


Figure 3.2 Flowchart for 2nd Solder Bond Joint Crack Characterization Experiment

3.3. Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint

To test and validate the effect of ultrasonic cleaning parameters to solder bond joint damage, the three of ultrasonic cleaning parameters, Frequency, Power and Time, were varies in aqueous ultrasonic cleaning system. The different aqueous ultrasonic cleaning parameters are shown in Table 3.1.

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Table 3.1 Design of Experiment Parameters for Effect of Ultrasonic Cleaning
Parameters to Solder Bond Joint Damage

Ultrasonic cleaning parameters	Level
1. Frequency	68 kHz 132 kHz 192 kHz
2. Power	500 Watts 750 Watts 900 Watts
3. Time	0 second (without clean) 60 seconds 120 seconds

The experiments were performed by as following hypothesis:-

Hypothesis 1: Effect of Ultrasonic Frequency to Solder bond joint

In this hypothesis, all factor levels of ultrasonic frequency were varied by a fixed ultrasonic power at 500 Watts and cleaning time at 120 seconds to find out the effect of ultrasonic frequency on solder bond joint crack and then select the worse ultrasonic frequency to do the next experiment staging.

Hypothesis 2: Effect of Ultrasonic Power to Solder bond joint

The ultrasonic frequency that is highest effect of solder bonding joint crack rate was selected as a fixed ultrasonic frequency, then varied ultrasonic power at all levels in order to verify the effect of ultrasonic cleaning power to solder bond joint crack rate.

Hypothesis 3: Effect of Ultrasonic cleaning time to Solder bond joint

One ultrasonic frequency and power condition was selected as at a fixed ultrasonic frequency and power, then varied ultrasonic time at all levels in order to verify the effect of ultrasonic cleaning time to solder bond joint crack rate.

3.3.1. Experiment Methodology

All experiments were carried out in the class 100 Cleanroom. 300 Head Gimbal Assembly per experiment were built and bonded by a solder ball with same machine and setting. Each Head Gimbal Assembly was 100% monitor joint crack before sending to clean by aqueous ultrasonic cleaning by using Ultrasonic tank and generators as following condition:-

Ultrasonic Frequency	68 kHz
	132 kHz
	192 kHz
Ultrasonic Power	500 - 900 watts

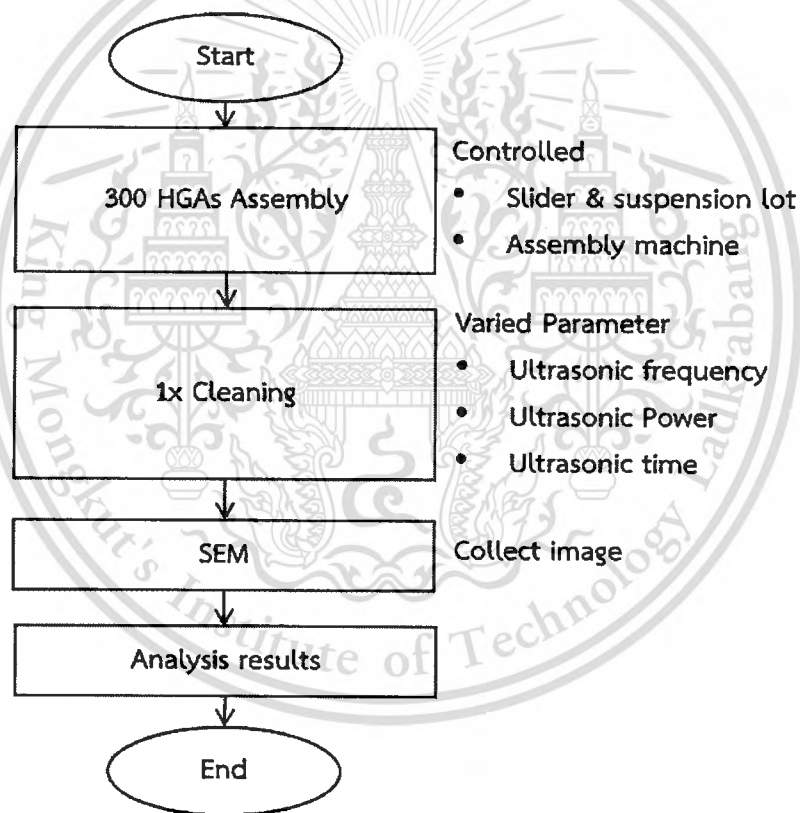


Figure 3.3 Flowchart for Ultrasonic Effect on Solder Bond Joint Crack Experiment

3.3.2. Experiment Equipment

Aqueous ultrasonic cleaning in manufacturing factory, “Crest Ultrasonics” Precision Cleaning System was provided for all experiments. This aqueous ultrasonic cleaning can be changed the ultrasonic frequency by changing ultrasonic generator

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and transducer at bottom of the tank to match with the ultrasonic frequency parameter level. Each ultrasonic frequency can be adjusted ultrasonic power from 400 – 1,000 Watts. DI water was selected as ultrasonic medium. Ultrasonic cleaning temperature was fixed at 50 °C per normal manufacturing setting.



Figure 3.4 “Crest Ultrasonics” Precision Cleaning System

“JEOL” JCM-5000 NeoScope, a Scanning Electron Microscope (SEM), which has a magnification of 10 – 40,000x in Figure 3.5 was selected as solder bond joint crack visual inspection. Magnification of SEM was set at 150x for all experiments.



Figure 3.5 “JEOL” JCM-5000 NeoScope

3.4. Measurement Method for Ultrasonic Energy

The traditional measurement of ultrasonic energy is focused on cavitation energy, which is related to part erosion. The cavitation is trying to measure in many methods, such as “Foil Test” and cavitation meter. There was a study of foil test comparison with cavitation meter by John Kolyer from Boeing [10]. His report demonstrated a perfect matching between foil test and cavitation meter data. Nevertheless, the cavitation energy is not representing overall energy in the cleaning tank. Sound pressure is another measurement that transfer the received sound pressure (Pa) to voltage signal (mV) and indicate as DC voltage by monitor. Sound pressure is a combination of all cavitation energy and resonance due to sound wave.

In the experiment, cavitation and sound pressure meters, were provided to measure the ultrasonic or cavitation energy in the cleaning tank. 300 Head Gimbal Assembly per experiment were built and bonded by a solder ball with same machine and setting. Each Head Gimbal Assembly was 100% monitor joint crack before sending to

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clean by aqueous ultrasonic cleaning with two levels of ultrasonic frequency and power parameters per Table 3.2 with fixed ultrasonic cleaning time.

Table 3.2 Design of Experiment Parameters of Measurement Method for Ultrasonic Energy that Impact to Solder Bond Joint

Ultrasonic cleaning parameters	Level
1. Frequency	68 kHz
	132 kHz
2. Power	500 Watts
	750 Watts
	900 Watts

All levels of ultrasonic cleaning frequency and power were measured by cavitation and sound pressure meters. After the ultrasonic cleaning of the Head Gimbal Assembly, joint crack/fracture was monitored by Scanning Electron Microscope (SEM). Finally, results of cavitation and sound pressure meters of all levels of ultrasonic cleaning frequency and power were compared with solder joint crack rate from visual inspection of Scanning Electron Microscope (SEM).

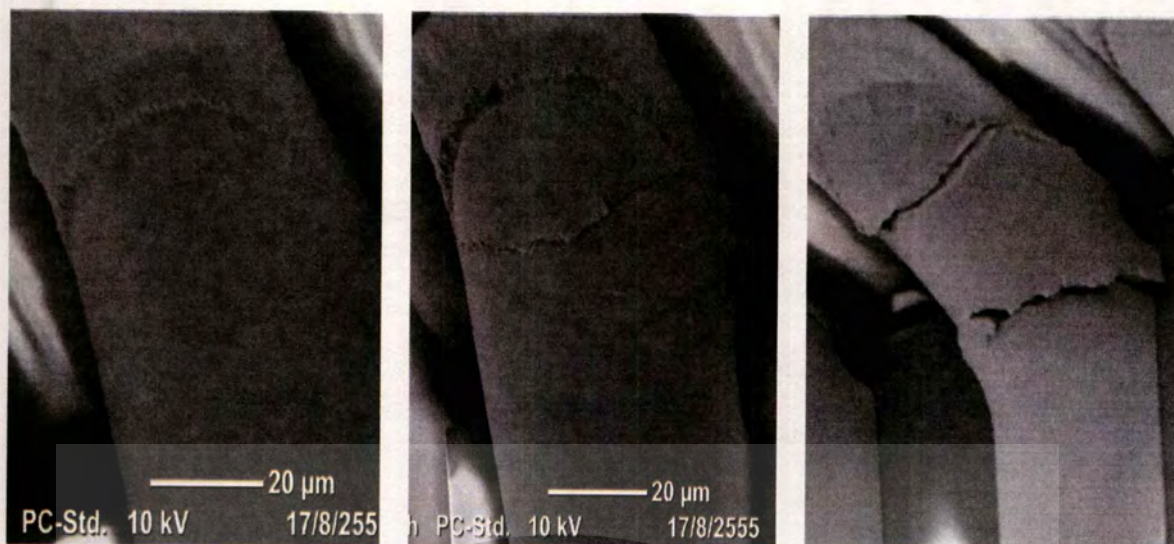
CHAPTER 4

Solder Bond Joint Crack Characterization

The solder bond joint crack characterization is useful to understand the severity of each crack types. After completing Head Gimbal Assembly process, each part was submitted to test both electrical and mechanical performance testers. Some solder bond joint crack failures can be detected by electrical tester and some failures can be escaped or be developed for next Hard Disk Drive process, Head Stack Assembly and Hard Drive Assembly. The solder bonding joint crack can be developed or growth in next Hard Disk Drive process after passing aqueous ultrasonic cleaners is one of critical parameter that impact to Hard Disk Drive yield. To understand each solder bonding joint crack types and their characterization after passing aqueous ultrasonic cleaning can be improved Hard Disk Drive reliability.

4.1. Solder Bond Joint Crack Characterization

In normal processing, Head Gimbal Assembly is fabricated with automatically process at front of the line and then submitted to clean by aqueous ultrasonic cleaning before send to perform electrical test for monitoring the quality and reliability of the product. Good and fail parts can be detected in the electrical test process. Both fail and good HGA parts were submitted to Scanning Electron Microscope (SEM) at 150 times magnification. Each solder bonding joint crack images was matching with electrical test results in terms of electrical resistivity in order to understand each solder boning joints characterization by electrical resistant in electrical tester machine. There are 3 Solder bonding joint crack image types as illustrated in Figure 4.1.



Stress line Crack

Small Crack

Functional Crack

Figure 4.1 Image of Solder Bonding Joint Crack from SEM at 150x Magnification

- Stress Line Crack

From SEM images in Figure 4.1, the stress line crack image is identified as a hairline crack, which the fragments do not come apart because the line of the break is so fine. The hair lines crack may along the solder interface but did not go across whole solder bond joint width or hairlines in the solder material not at the suspension solder interface.

- Small Crack

From SEM images in Figure 4.1, the small crack image is identified as a long crack lines that go across the whole solder bond joint width but no complete solder separation.

- Functional Crack

From SEM images in Figure 4.1, the functional crack image is identified as a complete separation of solder material and suspension pad.

Electrical test results, solder bonding joint resistance (ohms) of each solder bonding joint crack types are shown in Table 4.1.

Table 4.1. Solder Bonding Joint Resistance (Ohms) of Each Crack Types.

	N	Mean	Std. Deviation	Min	Max
Stress line crack	15	73.940	1.361	72.242	76.181
Small crack	15	80.280	4.210	75.890	85.220
Functional crack	15	52.8×10^6	17.2×10^6	1.1×10^6	155.4×10^6

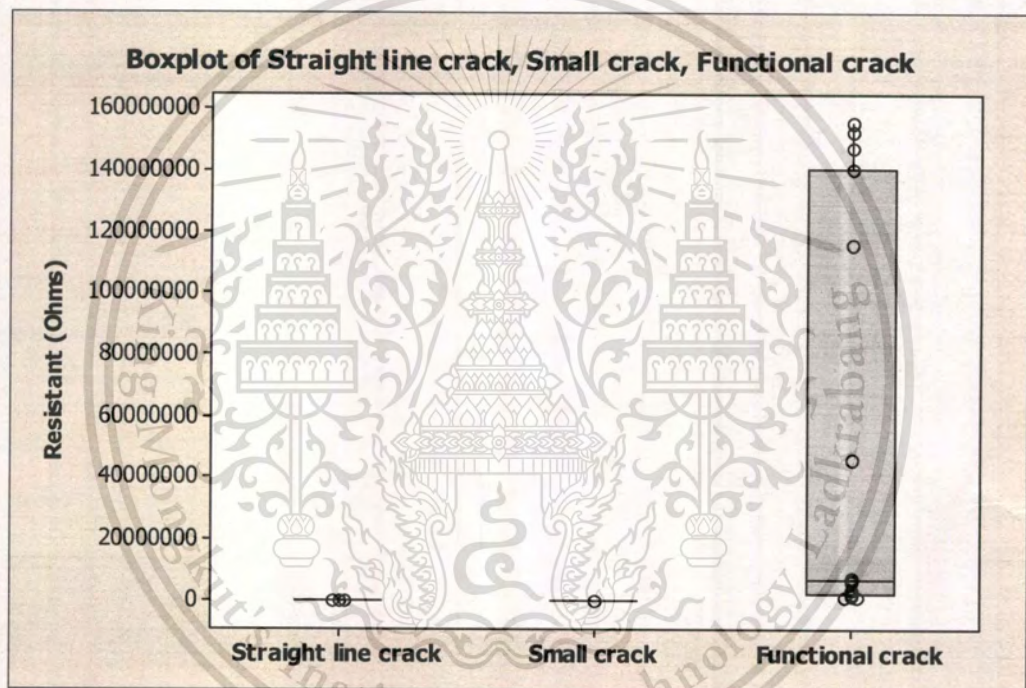


Figure 4.2 Boxplot Chart of Resistant Results of Each Crack Type

From resistant results in Table 4.1 shows that both stress line and small crack resistant were still within specification at $62 < \text{resistant} < 86$ ohms, while functional crack resistant was totally fail specification. The small crack resistant was higher than stress line crack and maximum point of small crack resistant was almost fail specification. In the summary, electrical test process can detect failure part from functional crack, but cannot detect both stress line and small cracks.

To understand both stress line and small cracks risk a series of details experiment were carried out to prove the validity of both crack types growth in a next HGA process that cause the resistant failure. To simulate the production process as the experiment was carried out within the production cycle. 1 time and selected 15 parts of each stress line and small crack by SEM image. And then, the selected parts were continuing 5 ultrasonic cleaning cycles in normal production process, which is a higher cleaning cycle of the Hard disk drive process. The validation experiment was carried out by comparison, both resistant results from electrical tester and a solder bonding joint crack image by SEM between 1 time and 6 ultrasonic cleaning time's cycle.

4.2. Design of Experiment

Total 300 Head Gimbal Assembly was built and bonding by a solder ball with same machine and set up parameters. All Head Gimbal Assembly were 100% monitored joint crack by Field Emission Scanning Electron Microscope (FESEM) before sending to clean by aqueous ultrasonic cleaning in order to insure that no solder bonding crack before cleaning station. Only 68 kHz frequencies of ultrasonic cleaner with 750 watts power, which is a current production process, were used to clean the Head Gimbal Assembly with 120 seconds. After the ultrasonic cleaning, each Head Gimbal Assembly was sent to the electrical test machine to verify bonding resistance, then each Head Gimbal Assembly was submitted to SEM for image scanning in order to measured and recorded crack characterization in terms of crack length and position. Each solder bonding joint crack types was inspected and recorded.

After that, collect 15 Head Gimbal Assembly of each solder bonding joint crack types and sent to clean by Aqueous ultrasonic cleaner for 5 times for identifying each solder bonding crack growth. Each Head Gimbal Assembly type of 5 ultrasonic cleaning times was sent to the electrical test machine again to verify bonding resistant and measured crack characterization by SEM.

4.2.1. Stress Line Crack

From the experiment, both 1 time and 6 ultrasonic cleaning times of stress line crack is illustrated in Figure 4.3. The crack was a little growth but did not develop to small crack per SEM image. Figure 4.2 Single S-Box (no Sub-pipeline) function verification

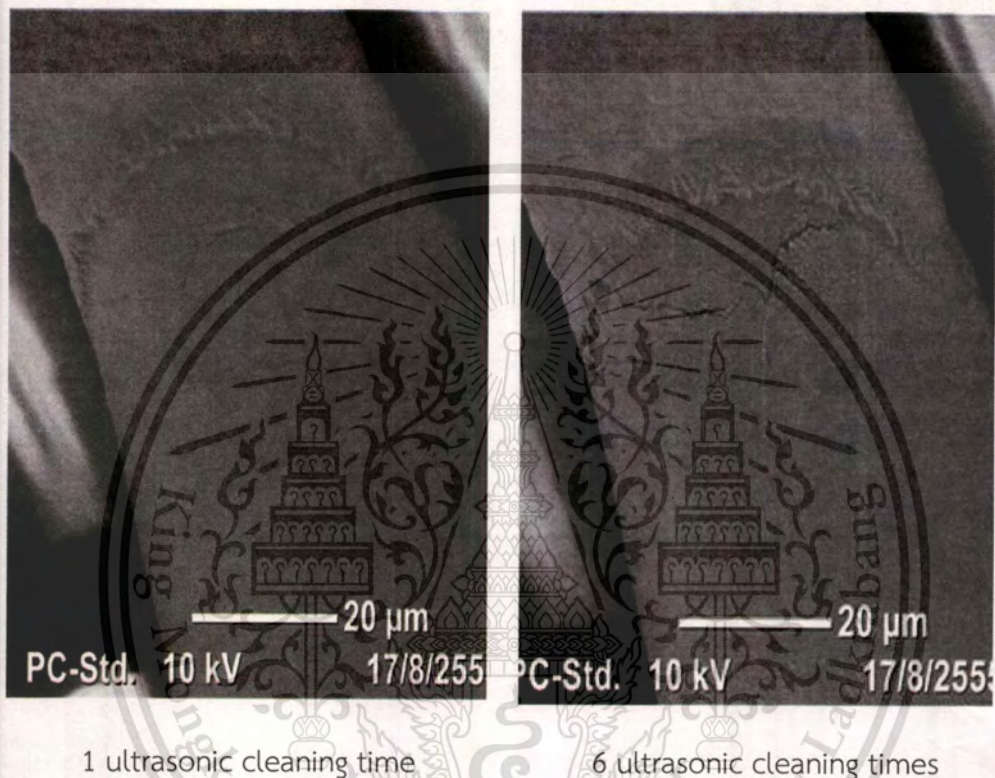


Figure 4.3 Image of Stress Line Crack between 1 and 6 Ultrasonic Cleaning Times.

In the experiments, the electrical test results of each stress line crack Head Gimbal Assemblies were compared and analyzed between before, 1 time and 6 time ultrasonic cleaning conditions. The differences of means of each condition were considered by using Hypothesis test, Pair-T test. The paired t-test is used to determine whether there is a significant difference between the mean of the same measurement made under two different conditions. Both measurements are executed on each unit in a sample, and the test is based on the paired differences between these two values.

Paired t-test was conducted to compare electrical test results of before cleaning and after 1 time ultrasonic cleaning and then before cleaning and 6 times ultrasonic cleaning.

The comparisons were set into 2 hypothesis pair t-tests

1st hypothesis pair t-test was conducted to compare electrical test results of before cleaning and after 1 time ultrasonic cleaning

2nd hypothesis pair t-test was conducted to compare electrical test results of before cleaning and after 6 times ultrasonic cleaning.

Paired Samples Statistics is shown in Table 4.2 and Paired Samples Tests are shown in Table 4.3.

Table 4.2. Paired Sample Statistics of Stress Line Crack.

	N	Mean	Std. Deviation	Min	Max
Before	15	73.790	0.466	73.229	74.500
1 ultrasonic cleaning time	15	73.940	1.361	72.242	76.181
6 ultrasonic cleaning times	15	73.948	1.322	72.290	76.233

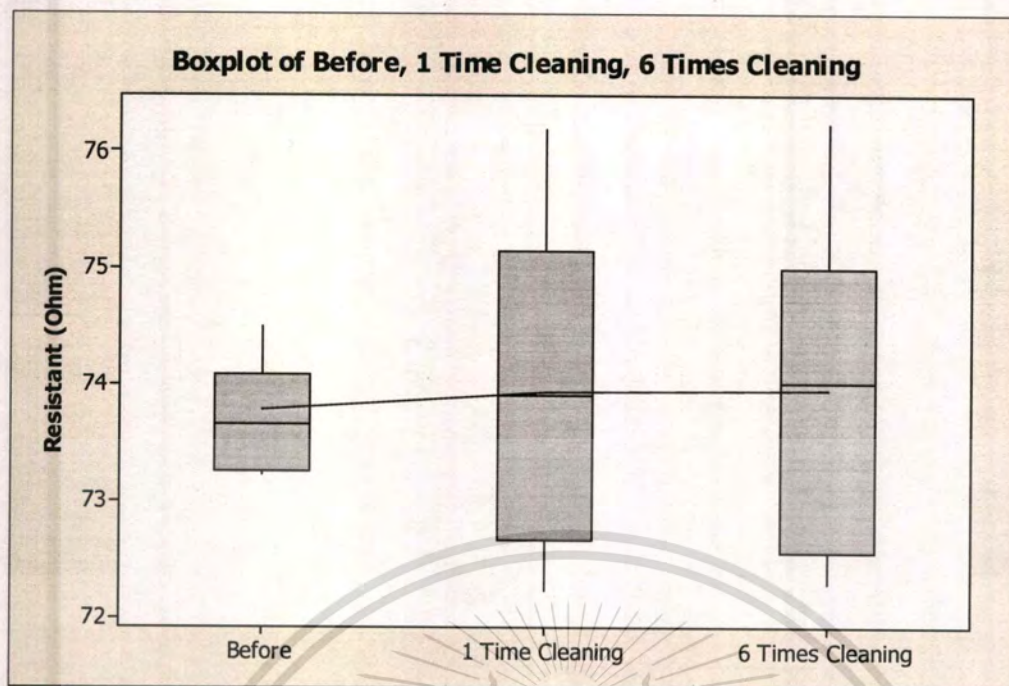


Figure 4.4 Boxplot Chart of Resistant Results of Stress Line Crack Characterization between Before, 1 and 6 Ultrasonic Cleaning Times.

Table 4.3. Paired Sample Test of Stress Line Crack

	Mean	Std. Deviation	Std. Error Mean	95% CI of the Difference		t	P-value
				Lower	Upper		
Before-1 time	-0.150	1.298	0.335	-0.869	0.569	-0.450	0.662
Before-6 times	-0.158	1.250	0.323	-0.850	0.534	-0.490	0.632

1st hypothesis results interpreted that there was not a significant difference in the resistivity results from electrical test for before cleaning (M=73.790, SD=0.466) and 1 ultrasonic cleaning time (M=73.940, SD=1.361); $t=-0.869$, $p = 0.662$.

2nd hypothesis results interpreted that there was not a significant difference in the resistivity results from electrical test for before cleaning (M=73.790, SD=0.466) and 6 ultrasonic cleaning time (M=73.948, SD=1.322); $t=-0.850$, $p = 0.632$.

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Both hypothesis results can concluded that stress line crack was not significant impact to electrical test results in term of resistant after passing 6 ultrasonic cleaning times.

4.2.2. Small Crack

From the experiment, small crack developed to be functional crack, crack apart all pads, per SEM image as illustrated in Figure 4.5.

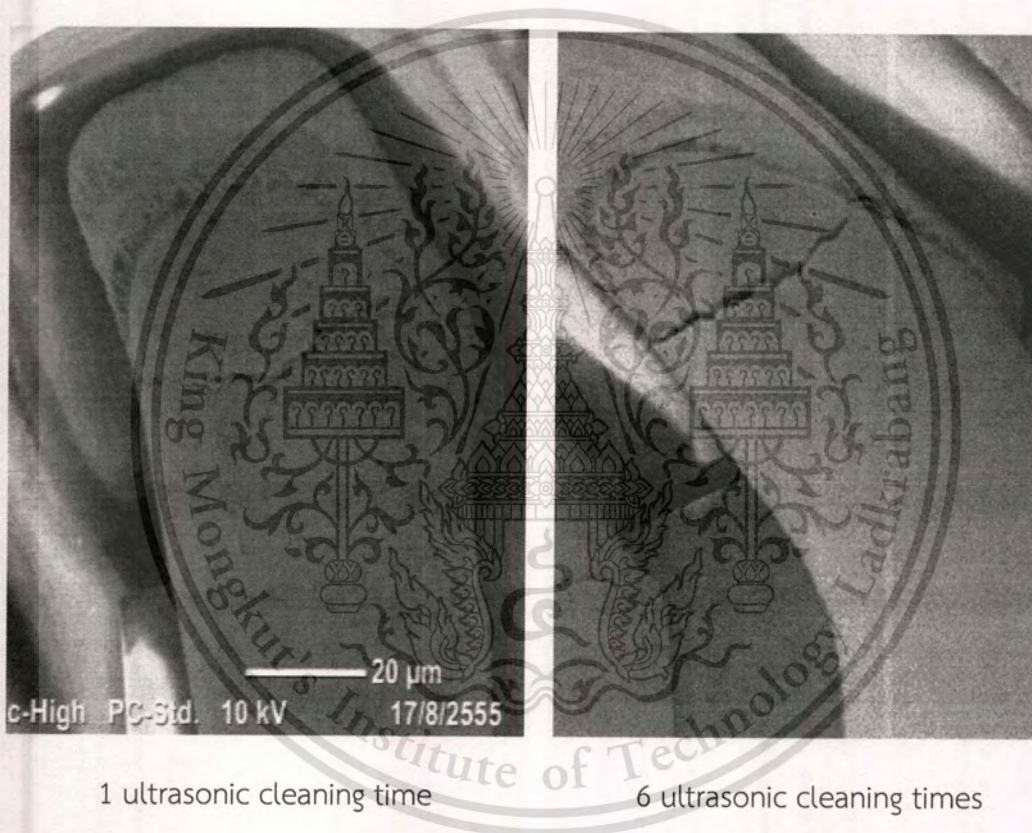


Figure 4.5. Image of Small Crack between 1 and 6 Ultrasonic Cleaning Times.

In the experiments, the electrical test results of each small Head Gimbal Assemblies were compared and analyzed between before, 1 time and 6 time ultrasonic cleaning conditions. The differences of means of each condition were considered by using Hypothesis test, Pair-T test. The paired t-test is used to determine whether there is a significant difference between the mean of the same

measurement made under two different conditions. Both measurements are executed on each unit in a sample, and the test is based on the paired differences between these two values.

Paired t-test was conducted to compare electrical test results of before cleaning and after 1 time ultrasonic cleaning and then before cleaning and 6 times ultrasonic cleaning.

The comparisons were set into 2 hypothesis pair t-tests

1st hypothesis pair t-test was conducted to compare electrical test results of before cleaning and after 1 time ultrasonic cleaning

2nd hypothesis pair t-test was conducted to compare electrical test results of before cleaning and after 6 times ultrasonic cleaning.

Paired Samples Statistics is shown in Table 4.4 and Paired Samples Tests are shown in Table 4.5

Table 4.4. Paired Sample Statistics of Small Crack

	N	Mean	Std. Deviation	Min	Max
Before	15	72.095	0.186	70.601	73.254
1 ultrasonic cleaning time	15	80.280	4.210	75.890	85.220
6 ultrasonic cleaning times	15	2.9×10^6	0.6×10^6	0.6×10^6	7.4×10^6

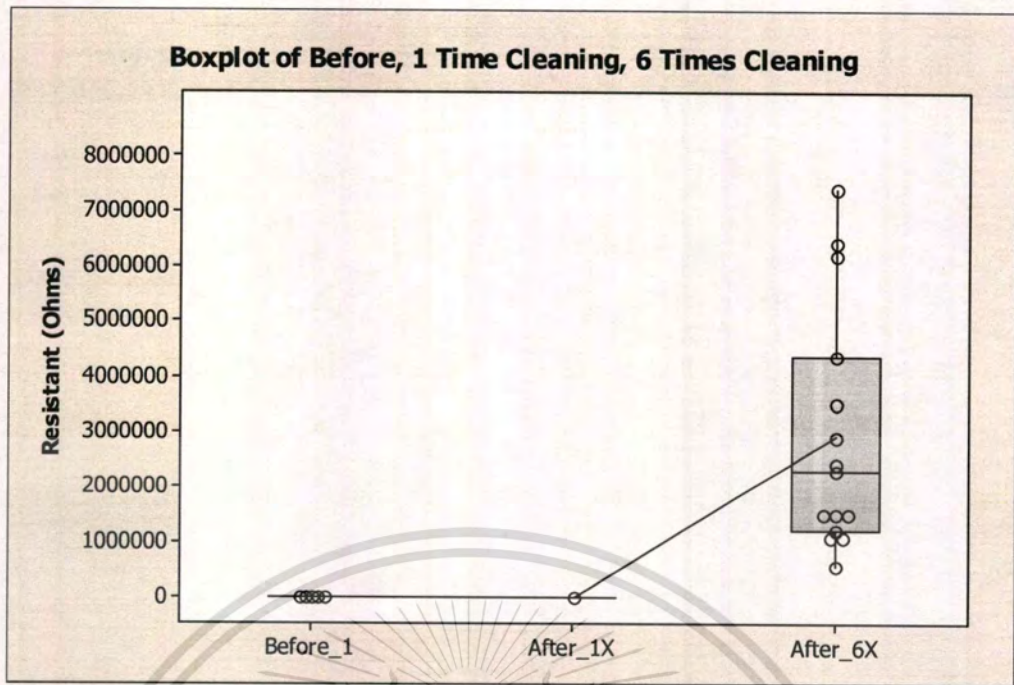


Figure 4.6 Boxplot Chart of Resistant Results of Small Crack Characterization between 1 and 6 Ultrasonic Cleaning Times.

Table 4.5. Paired Sample Test of Small Crack

	Mean	Std. Deviation	Std. Error Mean	95% CI of the Difference		t	df	P-value
				Lower	Upper			
Before-1 time	-8.180	4.150	1.070	-5.890	-5.890	-7.650	14	0.000
Before-6 time	-2.9 x 10 ⁶	2.2 x 10 ⁶	0.6 x 10 ⁶	-4.2 x 10 ⁶	-1.7 x 10 ⁶	-0.580	14	0.000






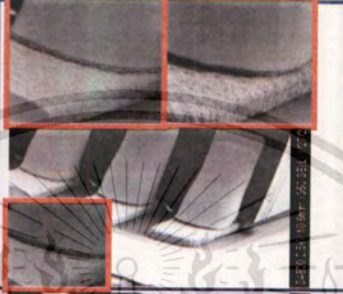


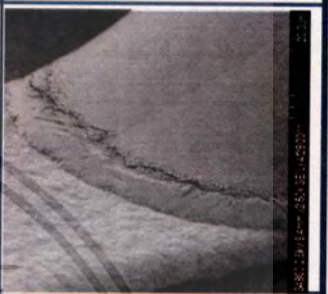
1st hypothesis results interpreted that there was a significant difference in the resistivity results from electrical test for before ultrasonic cleaning (M=72. 095, SD=0. 186) and 1 ultrasonic cleaning time (M=80. 280, SD=4. 210); t=-7.650, p = 0.000.

2nd hypothesis results interpreted that there was a significant difference in the resistivity results from an electrical test for before cleaning ($M=72.095$, $SD=0.186$) and 6 ultrasonic cleaning time ($M=2.9 \times 10^6$, $SD=0.6 \times 10^6$); $t=-0.580$, $p = 0.000$.

Both hypothesis results can concluded that small crack was the significant impact of electrical test results in term of resistant after passing 6 times ultrasonic cleaning.



Table 4.6. The Summary of Solder Bond Joint Crack Characterization

Name	Description	Examples			Impact
Functional Crack	Complete separation of solder material and TGA pad				<p>Higher Risk / Easy Detect</p> <ul style="list-style-type: none"> Resistance significant increased after 1 cleaning time.
Small Crack	Long crack lines that go across the whole TGA width. No complete TGA-solder separation				<p>High Risk / Hard Detect</p> <ul style="list-style-type: none"> No significant resistance change after cleaning Resistance change after additional 5 times cleaning
Stress Line	Hair lines along TGA-solder interface but did not go across the whole TGA width				<p>Low Risk</p> <ul style="list-style-type: none"> No significant resistance change after 6 cleaning times

CHAPTER 5

Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint Damage

The effect of ultrasonic cleaning parameters to solder bond joint damage were studied in this chapter. In Chapter 4, small crack characterization was selected as an interesting solder bond joint damage characterization. Three parameters, ultrasonic frequency, time and power, were selected as a variable parameter while controlling other parameters for the experiment. The Head Gimbal Assembly was built and bonding by a solder ball with same machine and setting. Each Head Gimbal Assembly was 100% monitor joint crack before sending to clean by ultrasonic cleaning at each setting parameter. After that joint crack/fracture was monitored and recorded by SEM, the only small crack joint was recorded and analyzed in this experiment. One-way Analysis of Variance (ANOVA) was provided to determine whether there is a significant effect of each interesting parameter with solder bond joint damage.

5.1. The Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint

5.1.1. Effect of Ultrasonic Frequency to Solder Bond Joint

Total 300 Head Gimbal Assembly was built and bonding by a solder ball with same machine and setting. Each Head Gimbal Assembly was 100% monitor joint crack before sending to clean by ultrasonic cleaning. Different frequencies (68 kHz, 132 kHz, and 192 kHz) of ultrasonic cleaner with 500 watts power were used to clean the Head Gimbal Assembly at 120 seconds cleaning time. After the ultrasonic cleaning of Head Gimbal Assembly, joint crack/fracture was monitored and recorded by SEM. Table 5.1 shows that small cracks were found when ultrasonic 68 kHz frequency is used.

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A hypothesis ANOVA test was conducted to compare small crack results of 3 ultrasonic cleaning frequency levels, 68, 132 and 192 kHz at controlled ultrasonic power at 500 kHz and cleaning time at 120 Sec.

ANOVA Sample test results are shown in Table 5.1 and ANOVA Tests are presented in Table 5.2.

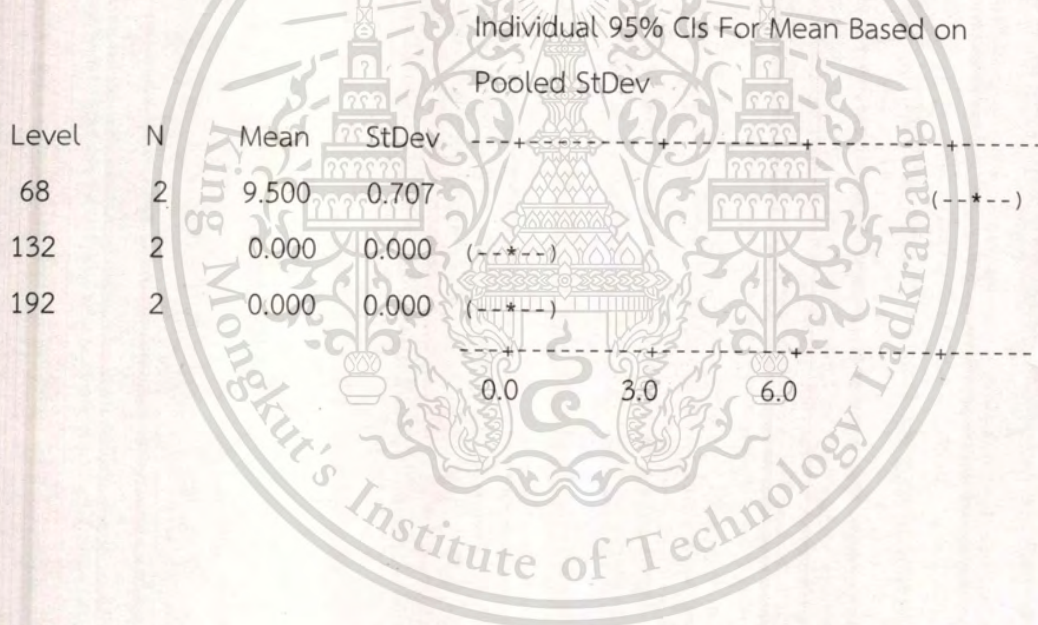
Table 5.1. Small Crack Results with Different Ultrasonic Frequency

Ultrasonic cleaner Frequency	Small crack / Total parts		
	Without Cleaning	Cleaned 120 Sec	
		Trial 1	Trial 2
68 kHz	0	9/300 = 3.0%	10/300 = 3.3%
132 kHz	0	0/300 = 0.0%	0/300 = 0.0%
192 kHz	0	0/300 = 0.0%	0/300 = 0.0%

Table 5.2. ANOVA Tests of Different Ultrasonic Frequency

	DF	SS	MS	F	P
Frequency	2	120.333	60.167	361.000	0.000
Error	3	0.500	0.167		
Total	5	120.833			

S = 0.4082 R-Sq = 99.59% R-Sq (adj) = 99.31%



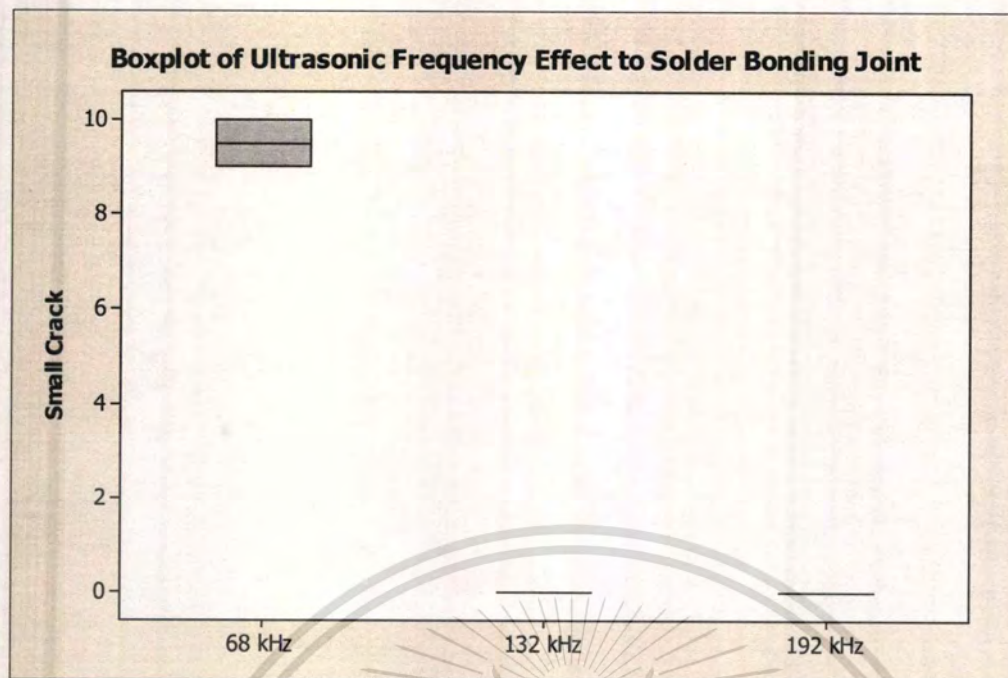


Figure 5.1 Boxplot Chart of Ultrasonic Frequency Effect to Small Crack

A one-way ANOVA was conducted to compare the effect of solder bonding joint crack (small crack) on number of ultrasonic cleaning frequency conditions, 68, 132 and 192 kHz. There was a significant effect of ultrasonic frequency levels, $F = 361$, $p = .000$, which is below 0.05 at 95% confidence interval. Only 68 kHz frequency has an effect to the solder bond joint in term of crack, mean = 9.5, SD 0.707 and 95% CI [8.793, 10.207].

5.1.2. Effect of Ultrasonic Power to Solder Bond Joint

The effect of ultrasonic power to solder bond joint damage was verified, only 1 ultrasonic frequency cleaner, 68 kHz, was selected. 300 Head Gimbal Assembly was built and bonding by a solder ball with same machine and setting. Each Head Gimbal Assembly was inspected crack before sending to clean by ultrasonic cleaning with different power setting (500, 750, 900 Watts) at 120 second cleaning time. Table 5.3 shows that small cracks were increased when power was increased.

Hypothesis ANOVA test was conducted to compare small crack results of 3 ultrasonic cleaning power levels, 500, 750 and 900 Watts with controlled ultrasonic frequency at 68 kHz and cleaning time at 120 sec.

ANOVA Sample test results are shown in Table 5.3 and ANOVA Tests are presented in Table 5.4.

Table 5.3. Small Crack Results with Different Ultrasonic Power

Ultrasonic cleaner Power	Small crack / Total parts		
	Without Cleaning	Cleaned 120 Sec	
		Trial 1	Trial 2
500 Watts	0	9/300 = 3.0%	10/300 = 3.3%
750 Watts	0	24/300 = 8.0%	22/300 = 7.3%
900 Watts	0	38/300 = 12.7%	35/300 = 11.7%

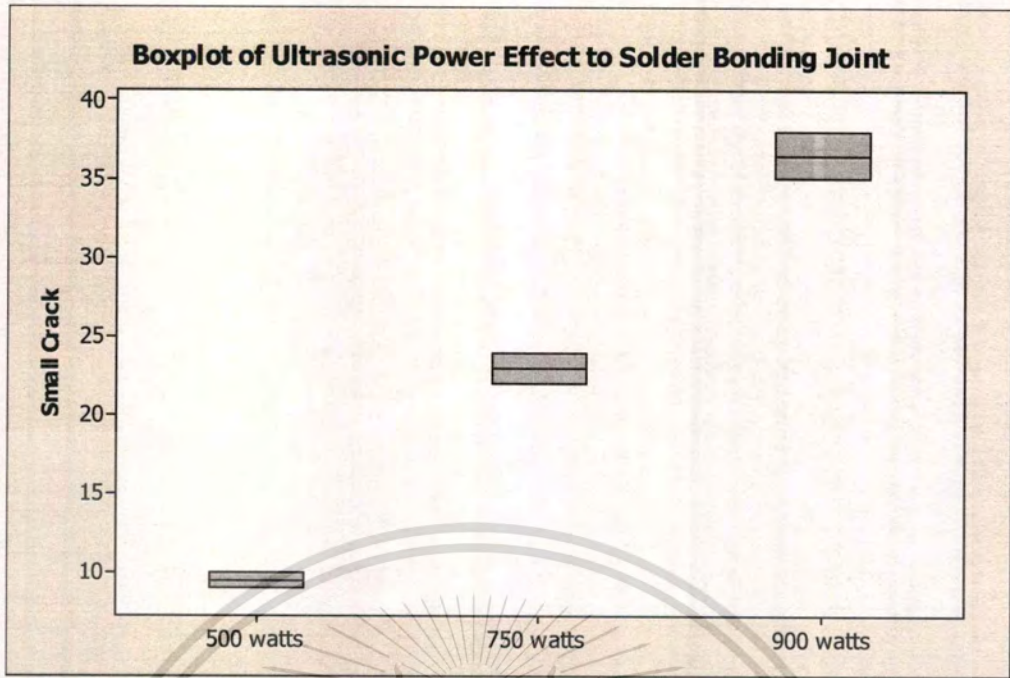


Figure 5.2 Boxplot Chart of Ultrasonic Power Effect to Small Crack

Table 5.4. ANOVA Tests of Different Ultrasonic Power

	DF	SS	MS	F	P
Power	2	729.000	364.500	156.210	0.001
Error	3	7.000	2.330		
Total	5	736.000			

S = 1.528 R-Sq = 99.05% R-Sq (adj) = 98.41%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev	CI
500	2	9.500	0.707	(---*---)
750	2	23.000	1.414	(--*--)
900	2	36.500	2.121	(---*---)

A one-way ANOVA was conducted to compare the effect of solder bonding joint crack (small crack) on number of ultrasonic cleaning power levels, 500, 750, and 900 watts. There was a significant effect of ultrasonic power levels, $F = 156.210$, $p = .001$, which is below 0.05 at 95% confidence interval. Number small cracks were increased when ultrasonic power increase. At 500 watts, ultrasonic power was effected to solder bond joint in term of crack at mean = 9.5, SD 0.707 and 95% CI [8.793, 10.207]. At 750 watts, ultrasonic power was effected to solder bond joint in term of crack in mean = 23.0, SD 1.414 and 95% CI [21.586, 24.414], while at 900 watts, ultrasonic power was effected to solder bond joint in term of crack at mean = 36.5, SD 2.121 and 95% CI [34.379, 38.621].

5.1.3. Effect of Cleaning Time to Solder Bond Joint

The effect of cleaning time to solder bond joint damage was verified, only 1 ultrasonic frequency and power, 68 kHz at 500 watts, was selected. 300 Head Gimbal Assembly was built and bonding by a solder ball with same machine and setting. Each Head Gimbal Assembly was inspected crack before sending to clean by ultrasonic cleaning with different cleaning time 0, 60, 120 seconds at controlled ultrasonic frequency and power at 68 kHz, 500 watts. Table 5.5 shows that small cracks were increased when time was increased

Hypothesis ANOVA test was conducted to compare small crack results of 3 cleaning time, 0, 60 and 120 seconds with controlled ultrasonic frequency and power at 68 kHz 500 watts

ANOVA Sample test results are shown in Table 5.5 and ANOVA Tests are presented in Table 5.6.

Table 5.5. Small Crack Results with Different Ultrasonic Cleaning Time

Cleaning Time	Small crack / Total parts		
	Without cleaning	Ultrasonic 68 kHz, 500 watts	
		Trial 1	Trial 2
0 Sec	0	0/300 = 0.0%	0/300 = 0%
60 Sec	0	6/300 = 2.0%	7/300 = 2.3%
120 Sec	0	9/300 = 3.0%	11/300 = 3.7%

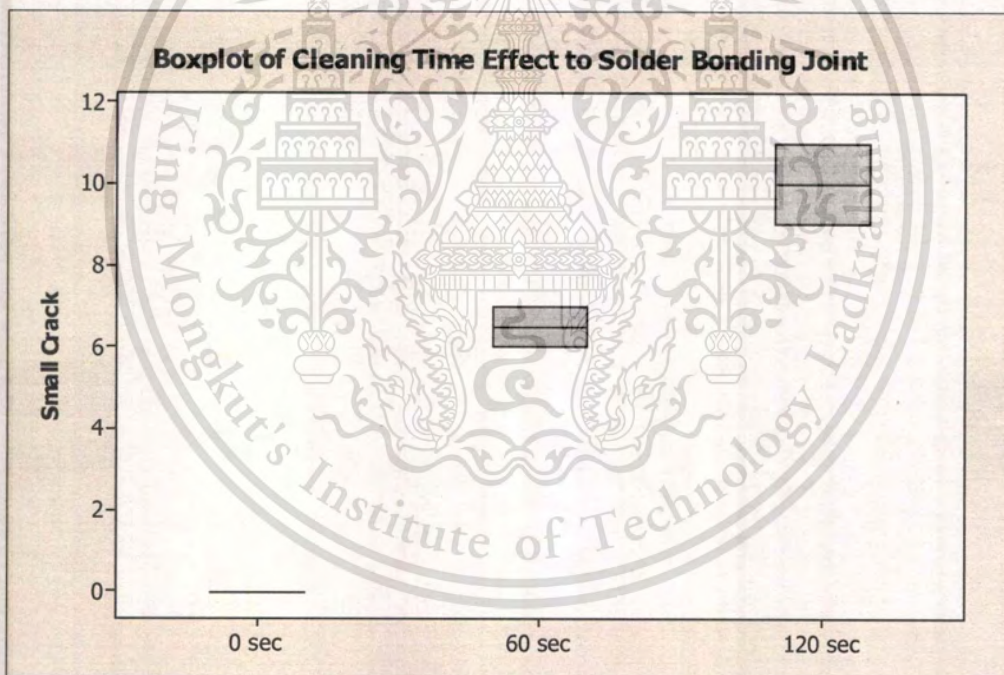
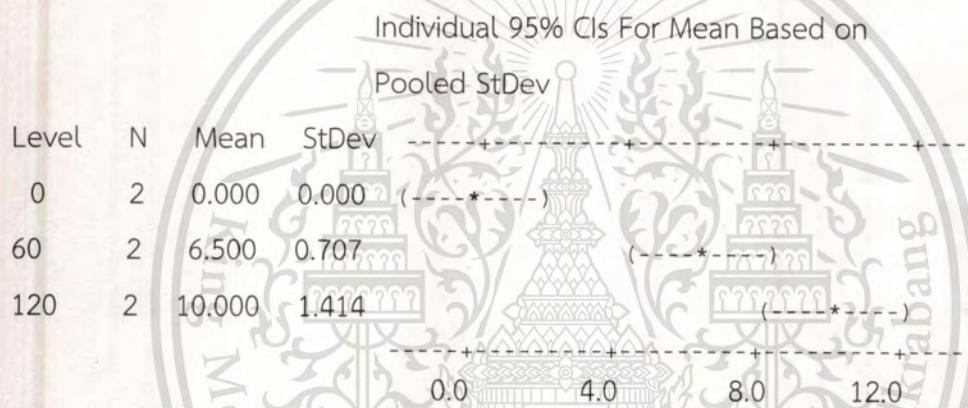


Figure 5.3 Boxplot Chart of Cleaning Time Effect to Small Crack

Table 5.6. ANOVA Tests of Different Ultrasonic Cleaning Time

	DF	SS	MS	F	P
Time	2	103.000	51.500	61.800	0.004
Error	3	2.500	0.833		
Total	5	105.500			

S = 0.9129 R-Sq = 97.63% R-Sq (adj) = 96.05%



A one-way ANOVA was conducted to compare the effect of solder bonding joint crack (small crack) on number of cleaning time conditions, 0, 60, and 120 seconds at controlled ultrasonic frequency and power at 68 kHz, 500 watts. There was a significant effect of cleaning time conditions, $F = 61.800$, $p = 0.004$, which is below 0.05 at 95% confidence interval. Number small cracks were increased when cleaning time increase. At 0 second, there was no solder bonding joint crack found. Otherwise, solder bonding joint crack were found at 60 second cleaning time at mean = 6.5, SD 0.707 and 95% CI [5.793, 7.207], and increasing when cleaning time was increased. At 120 second cleaning time, cleaning time was effected to solder bond joint in term of crack in mean = 10.0, SD 1.414 and 95% CI [8.586, 11.414].

5.2. Measurement Method for Ultrasonic Energy

The traditional measurement of ultrasonic energy is focused on cavitation energy, which is related to part erosion. The cavitation is trying to measure in many methods, such as "Foil Test" and cavitation meter. There was a study of foil test comparison with cavitation meter by John Kolyer from Boeing [10]. His report demonstrated a perfect matching between foil test and cavitation meter data. Nevertheless, the cavitation energy is not representing overall energy in cleaning tanks as see in Table 5.7

Table 5.7. The Comparison between Cavitation Energy, Sound Pressure and Solder

Bond Joint Crack Rate

Ultrasonic Cleaner kHz/Watts	Cavitation Energy (Watt/Gallon)	Sound Pressure Signal (mV)	Small Crack/Total part
132 / 900	45	207	12/300 = 4.0%
132 / 750	41	145	1/300 = 0.3%
132 / 500	38	109	0/300 = 0.0%
68 / 900	130	330	38/300 = 12.7%
68 / 750	114	243	24/300 = 8.0%
68 / 500	105	171	9/300 = 3.0%

The results show that the high frequency (132 kHz) generates lower cavitation energy than the low frequency (68 kHz) at the same power, which is corresponded with the previous paper [9] that introduced that the size of cavitation bubble is depended on the frequency of ultrasonic cleaning. The frequency of ultrasonic wave has a signification effect to cavitation energy. At higher wave frequencies, the sound

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wave cycle time is less for the bubble to grow, which is result in smaller bubbles and a reduction in cavitation energy. The cavitation energy cannot predict the solder bond joint crack rate as see in Table 5.7. At 132 kHz, 900 watts that has lower cavitation energy than 68 kHz, 500 watts, but it observed a higher crack rate.

The sound pressure measurement [23], another tool that provided to measure the ultrasonic energy in cleaner tank, is introduced in this paper to measure ultrasonic energy both cavitation energy and resonant vibration energy in ultrasonic cleaning. The effects of sound pressure measurement of each cleaner frequency and power are indicated in Table 5.7. The results show high sound pressure power has higher solder bond joint crack rate. The sound pressure meter can be provided to predict solder crack rate.

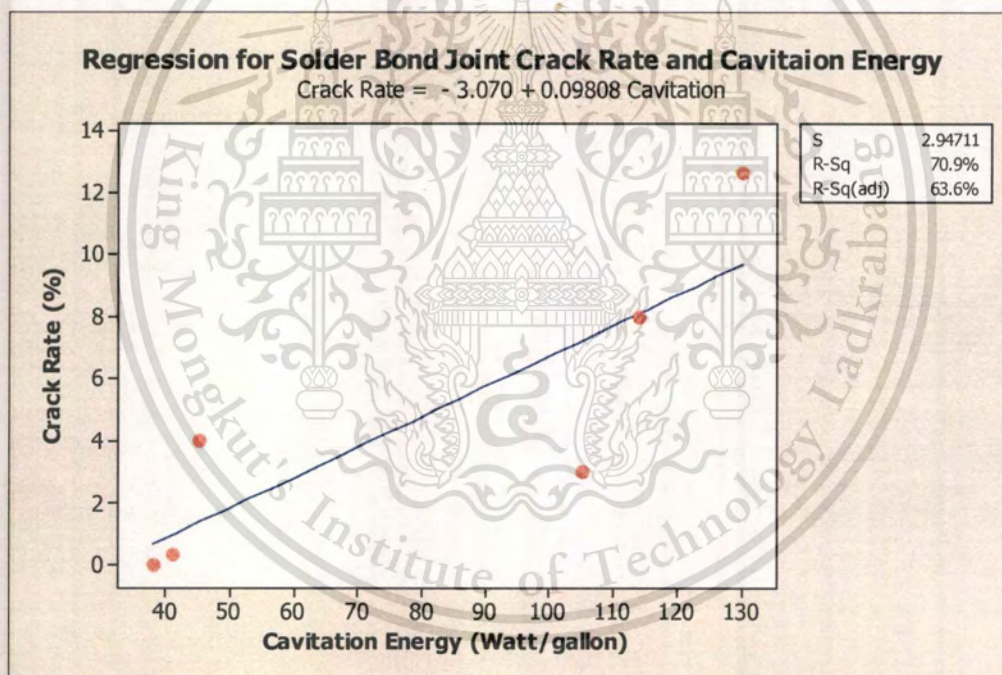


Figure 5.4 Regression between Solder Bond Joint Crack Rate and Cavitation Energy

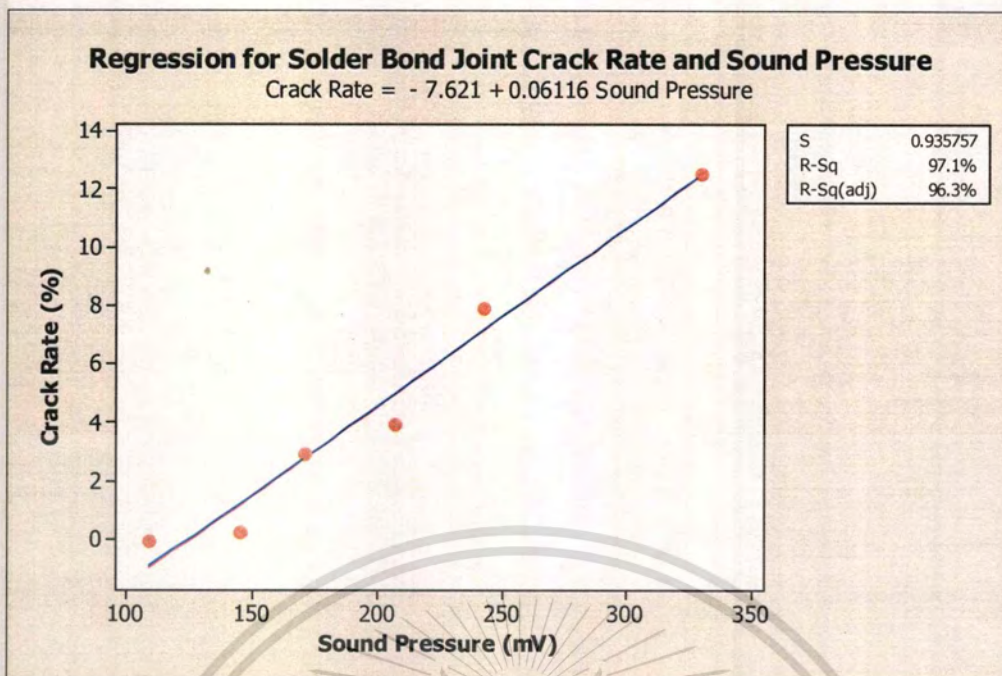


Figure 5.5 Regression between Solder Bond Joint Crack Rate and Sound Pressure
Signal Meter

Figure 5.4. shows the regression equation between solder bond joint crack rate and cavitation energy and Figure 5.5 shows the regression equation between solder bond joint crack rate and sound pressure. Both graphs show that sound pressure is a better tool for prediction solder bond joint crack rate than cavitation energy with R square at 97.1% and 70.9%, respectively

CHAPTER 6

Conclusion

The solder bond joint crack characterization was studied in Chapter 4. Three solder bond joint crack types are classified by using electrical testing and image from Scanning Electron Microscope (SEM). Then the effect of ultrasonic cleaning parameters to solder bond joint damage were examined in chapter 5. Three parameters, which are power, frequency and time, were selected as the variable parameters while controlling other parameters for the experiment. After that, two measurement methods, cavitation energy and sound pressure signal, were examined in order to obtain a good correlation measurement tool for solder bonding joint crack damage. The results of each study are shown in Chapter 4 and 5, and the conclusion is described as followings:-

6.1. Solder Bond Joint Crack Characterization

The results from the study of solder bond joint characterization by Scanning Electron Microscope (SEM) and Electrical test in terms solder bonding joint resistance (Ohm) show that there are 3 types of solder bonding joint characterization

6.1.1. Stress Line Crack

From SEM images, the stress line crack image is identified as a hairline crack, which the fragments do not separate because the line of the break is so fine. The hair lines crack may along the solder interface but did not go across whole solder bond joint width or hairlines in the solder material not at the suspension solder interface. The resistant results from electrical test were still within specification at $62 < \text{resistant} < 86 \text{ Ohm}$.

From the experiments of solder bonding crack development after 6 cleaning times, the study found that the crack was a little growth but did not develop to small crack per SEM image. The hypothesis test results interpreted that there was

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not a significant difference in the resistivity results from electrical test between before cleaning ($M=73.790$, $SD=0.466$) and 1 ultrasonic cleaning time ($M=73.940$, $SD=1.361$); $t=-0.869$, $p = 0.662$ and between before ultrasonic cleaning ($M=73.790$, $SD=0.466$) and 6 ultrasonic cleaning times ($M=73.948$, $SD=1.322$); $t=-0.850$, $p = 0.632$.

6.1.2. Small Crack

From SEM images, the small crack image is identified as a long crack lines that go across the whole solder bond joint width but no complete solder separation. The resistant results from electrical test were a little bit higher than stress line crack, but still within specification at $62 < \text{resistant} < 86 \text{ Ohm}$.

From the experiments of solder bonding crack development after 6 ultrasonic cleaning times, the study found that the crack was developed to functional crack per SEM image. The hypothesis test results interpreted that there was a significant difference in the resistivity results from electrical test between before ultrasonic cleaning ($M=72.095$, $SD=0.186$) and 1 ultrasonic cleaning time ($M=80.280$, $SD=4.210$); $t=-7.650$, $p = 0.000$ and between before cleaning ($M=73.79$, $SD=0.47$) and 6 ultrasonic cleaning time ($M=73.95$, $SD=1.36$); $t=-0.850$, $p = 0.632$. In addition, after 6 ultrasonic cleaning times small crack will develop to be functional crack. The resistant results from electrical test were out of specification at $62 < \text{resistant} < 86 \text{ Ohm}$.

6.1.3. Functional Crack

From SEM images, the functional crack image is identified as a complete separation of solder material and suspension pad. The resistant results from electrical test were out of specification at $62 < \text{resistant} < 86 \text{ Ohm}$.

The results lead to the conclusion that Functional crack was effected to the resistance of the solder bonding joint when test by electrical test while both stress line and small crack were not affecting the resistance of the solder bonding joint when test by electrical test.

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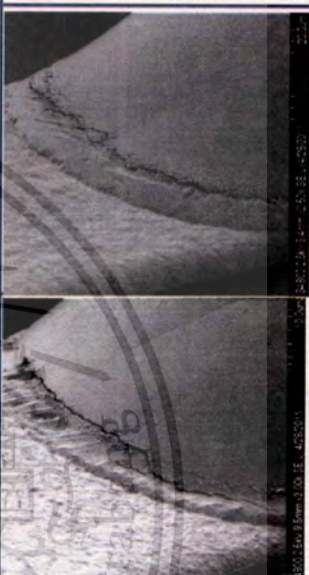
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From the experiments, the study found that the only functional solder bonding joint crack has an effect of the electrical test parameter in terms of bonding resistant, resistant is out of spec. Electrical test can detect Functional crack while cannot detect both Stress line and Small crack. After 6 ultrasonic cleaning times, the maximum cleaning cycle in the Hard Disk Drive process, stress line is not developed to be functional crack but small crack will develop to be functional crack.

In conclusion, Small crack is the most critical crack type since electrical test cannot be detected and it will be developed to be functional crack after 6 ultrasonic cleaning times.



Table 6.1. The Summary of Solder Bond Joint Crack Characterization

Name	Description	Examples		Impact
Functional Crack	Complete separation of solder material and TGA pad			<p>Higher Risk / Easy Detect</p> <ul style="list-style-type: none"> Resistance significant increased after 1 cleaning time.
Small Crack	Long crack lines that go across the whole TGA width. No complete TGA-solder separation			<p>High Risk / Hard Detect</p> <ul style="list-style-type: none"> No significant resistance change after cleaning Resistance change after additional 5 times cleaning
Stress Line	Hair lines along TGA-solder interface but did not go across the whole TGA width			<p>Low Risk</p> <ul style="list-style-type: none"> No significant resistance change after 6 cleaning times

6.2. The Effect of Ultrasonic Cleaning Parameters to Solder Bond Joint

In the thesis results, they lead to the conclusion that solder bond joint crack were came from the combination of resonant vibration and cavitation energy of ultrasonic cleaner, while resonate vibration on the solder bond joint is likely to be the main effect of cracks or damage like Jiang Yuqi [12] had reported in his studied on the effect of ultrasonic cleaning on the bond wire using Finite Element Analysis (FEA). The studied showed that the heel crack of bond wire is induced by resonant vibration. In the experiment of ultrasonic frequency that effect, to develop cracks or fracture in the solder bond joint, different frequency (68 kHz, 132 kHz and 192 kHz) at the same power of ultrasonic cleaning were used to clean the HGAs. Crack/fractures of the solder bond joint are found only at 68 kHz frequency. This result lead to conclude that the solder bond joint can be resonated when cleaner of 68 kHz is used and the solder bond joint is not easy to rent when 132 kHz and 192 kHz ultrasonic cleaning are used because the natural frequency of the solder bond going is not close to 132 kHz or 192 kHz. The failure mechanism of solder bond joint is fatigue fracture.

In addition, at higher power or longer cleaning time generated both more fatigue fracture and higher ultrasonic energy to solder bond joint that the effect of higher solder bond joint crack rate.

6.3. Measurement Method for Ultrasonic Energy

Two ultrasonic measurement methods, cavitation energy and sound pressure signal, are examined in order to obtain a suitable measurement method for predicting the ultrasonic energy that effected to the solder bond joint. The experimental results show sound pressure is a better solder bond joint crack rate prediction than cavitation energy at R square equal to 96.3 and 63.6%, respectively.

6.4. Future work

From this research, the effect of each critical parameter to solder bonding joint crack rate were studied with a suitable aqueous ultrasonic cleaning measurement. More studies of process optimization in term of solder bonding joint crack prevention and cleanliness optimization by a proper design of experiment base

on the effect of each critical parameter should be performed in the future in order to find the suitable aqueous ultrasonic cleaning setting,

In addition, Megasonic cleaning effect to the solder bond joint is another topic for next researcher. New technology of part cleaning such as Carbon Dioxide Cleaning (CO₂ cleaning), Laser cleaning and Plasma cleaning, should perform solder bond joint damage study.



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Appendix A

Publication List

- [1] Sulaor Athisonbodee, Siridech Boonsang, Jatuporn Thongsee, " The Effect of Ultrasonic Cleaning on Solder Bond Joint," Proc. of the 5th Int. Conf. on Data Storage Technology (DST-CON2013), Bangkok, Thailand, February 2013.



DST-CON 2013

The 5 International Data Storage Technology Conference

14-15 February 2013

The Sukosol, Bangkok, Thailand

Conference Topics

1. Recording Head & Media Technology
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4. Automation Technology
5. ESD & Contamination
6. Tribology in HDD
7. Data Storage Technology & Applications
8. Production and Operation Management
9. Mechanical Components Design
10. Other Related Areas

Important Dates

Paper Submission: 30 October 2012

Notification of Acceptance: 30 November 2012

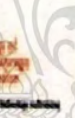
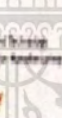
Final Submission: 15 December 2012

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The Effect of Ultrasonic Cleaning on Solder Bond Joint

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Abstract— Ultrasonic cleaner widely uses in Head Gimbal Assembly process of data storage industry to reduce contamination from cleaning part. With recent Head Gimbal Assembly design, the number of interconnections between slider and suspension is increased to increase storage capacity and transfer rate caused by the smaller solder joint pad. Crack or fracture was found at the solder bond joint after subsequent ultrasonic cleaning. No such cracking was found prior to cleaning. Three types of crack were introduced based on electrical test failure. The effect of ultrasonic frequency, power and time also reported. The low ultrasonic cleaning frequency at same power was higher crack rate than high ultrasonic cleaning frequency. In contrast, higher power or cleaning time of ultrasonic cleaning generates higher crack rate. In addition, the sound pressure measure is presented to measure the ultrasonic energy for solder bond joint crack prediction.

Keywords— Ultrasonic cleaning, Solder bond joint failure, Solder bond joint crack, Sound pressure, Ultrasonic energy

INTRODUCTION

In data storage industry, the reliability is a concerned parameter. There are many testing steps in Hard Disk Drive components, especially electrical test. The solder bond joint is one technique provided for interconnect between slider and suspension. In Head Gimbal Assembly, solder bonding is provided to join gold bond pad of slider and bonding lead of suspension and then cleaned by the ultrasonic cleaner; most ultrasound frequency range is between 68 – 192 kHz. After part cleaning, Head Gimbal Assembly will send to test by Electrical Test machine. With recent Head Gimbal Assembly design, the number of interconnections between slider and suspension is increased to increase storage capacity and transfer rate caused by the smaller solder joint pad. Occasionally, ultrasonic cleaning can cause solder joint damage such as cracking or fracture and interconnect failure.

During ultrasonic cleaning, mechanical oscillation of the solder bond joint is generated by ultrasonic and cavitation energy. In this paper, Solder bond was provided to join between slider and suspension in Head Gimbal Assembly process. After aqueous ultrasonic cleaning, cracks were found by Scanning Electron Microscopy (SEM). No crack was found before ultrasonic cleaning.

ULTRASONIC CLEANER

Ultrasonic cleaning is a method of cleaning that uses an ultrasonic device, or a sonicator, to clean delicate objects or

items with intricate parts. The ultrasonic device uses a special cleaning solution and high frequency sound waves to clean the items. Ultrasound ranges in frequency from about 20 to 400 kHz.

In the case of soluble soils, “micro-streaming” resulting from the oscillation of cavitation bubbles that do not implode or the shock waves resulting from the implosion of cavitation bubbles, provide a mixing effect which constantly refreshes the interface between the solvating or emulsifying medium and the soil. This mixing action reduces the time for their thorough interaction to produce a “clean” surface. In the case of non-soluble soils, the pressure resulting from the shock waves produced by the implosion of cavitation bubbles serve to physically displace particles. This displacement breaks the bonds holding the particles to the substrate and moves them far enough away from the substrate, to prevent re-attraction or re-attachment. Once free from the substrate, the particles can be flushed away by rinsing.

The ultrasonic cleaning machine was mainly made up of ultrasonic generator, ultrasonic transducer and cleaning tank, whose overall layout was shown as Figure 1. When the work piece is cleaned, put the cleaning liquid into the tank and also operate ultrasonic. When the ultrasonic generator transfers the AC in 50Hz into ultrasonic frequency (for example 44 thousand Hz) electrical oscillation signal, and then delivers it to the ultrasonic transducer at the bottom of the liquid tank through output cable, the transducer transfers the ultrasonic frequency electrical oscillation signal into ultrasonic frequency mechanical vibration and sends it into the cleaning liquid. The cleaning tank is a container for accommodating the cleaning liquid and to be cleaned objects.

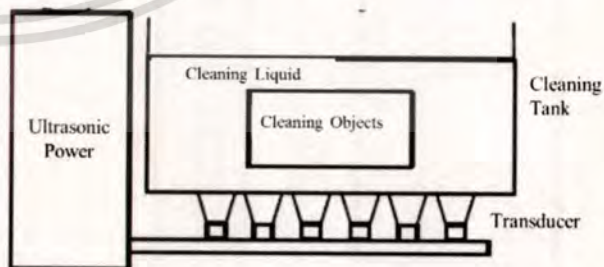


Fig. 1 Ultrasonic Cleaning Machine

CAVITATION

In elastic media such as air and most solids, there is a continuous transition as a sound wave is transmitted. In non-elastic media such as water and most liquids, there is continuous transition as long as the amplitude or "loudness" of the sound is relatively low. As the amplitude is increased, however, the magnitude of the negative pressure in the areas of rarefaction eventually becomes sufficient to cause the liquid to fracture because of the negative pressure, causing a phenomenon known as cavitation. Cavitation "bubbles" are created at sites of rarefaction as the liquid fractures or tears because of the negative pressure of the sound wave in the liquid. As the wave fronts pass, the cavitation "bubbles" oscillate under the influence of positive pressure, eventually growing to an unstable size. Finally, the violent collapse of the cavitation "bubbles" results in implosions, which cause shock waves to be radiated from the sites of the collapse. The collapse and implosion of myriad cavitation "bubbles" throughout an ultrasonically activated liquid result in the effect commonly associated with ultrasound. It has been calculated that temperatures in excess of 10,000°F and pressures in excess of 10,000 PSI are generated at the implosion sites of cavitation bubbles.^[2]

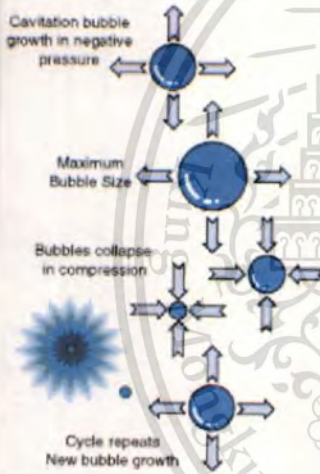


Fig. 2 Cavitation and Implosion

The phenomenon of cavitation and implosion resulting from ultrasonic energy can only occur in a liquid, but does not necessarily occur in all liquids. Physical properties of liquids, including viscosity, surface tension and vapor pressure may affect their ability to support the formation of cavitation bubbles which implode. Aqueous chemistry is ideal liquids for ultrasonic cleaning. The addition of surface active agents promotes penetration of liquids into even the finest surface detail. When it comes to creating cavitation bubbles in proximity to the surfaces to be cleaned, however, there are some impediments to overcome. Cavitation intensity is affected by many variables, but the most important parameters are ultrasonic frequency and power (amplitude)

CLEANING EXPERIMENT

All experiments were performed in the class 100 Cleanroom. 300 Head Gimbal Assembly per experiment were built and bonding by a solder ball with same machine and setting. Each Head Gimbal Assembly was 100% monitor joint crack before sending to clean by aqueous ultrasonic cleaning for fixed cycle. Ultrasonic tank and generators at 68, 72, 132 and 192 kHz with power from 400 – 1,000 watts were used in the experiment. After the ultrasonic cleaning of the Head Gimbal Assembly, joint crack/fracture was monitored. In addition, 2 ultrasonic measurement tools, cavitation and sound pressure meters, were provided to measure the ultrasonic or cavitation energy in cleaning tank and to compare with the solder joint crack rate.

SOLDER BOND JOINT CRACK CHARACTERIZATION

In order to understand the effect and severity of the solder bond joint crack to Head Gimbal Assembly, 3 major crack types are characterized based on electrical test results as follows:-

Straight Line Crack

The straight line crack is the hair lines along the solder interface that can be developed to be small crack and functional crack in the future. This kind of crack cannot be detected by electrical test, only Scanning Electron Microscopy (SEM) that can capture the crack. The characteristic are shown in fig. 3

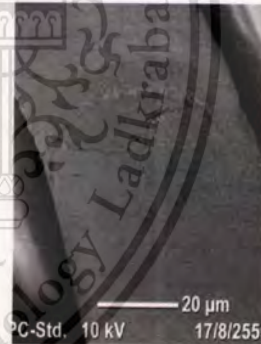


Fig. 3 Straight Line Crack Picture from SEM

Small Crack

The small crack is the crack that more serious than straight line crack. The small crack can be developed to be functional crack in the future. Sometime electrical test can be detected the failure and sometime cannot be detected. The characteristic of small crack are shown in fig. 4



Fig. 4 Small Crack Picture from SEM

Functional Crack

The functional crack is the crack that the most serious, than straight line and small crack. There is a complete separation of solder material and suspension pad. Electrical test from Head Gimbal Assembly process can capture interconnection failure of this kind of crack. The characteristic of functional crack is shown in fig. 5



Fig. 5 Functional Crack Picture from SEM

From 3 types of the crack, small crack is the most concerned with Head Gimbal Assembly processes for electrical test can not 100% detect this kind of the crack and it can be developed to be a functional crack in next hard disk drive assembly process.

EFFECT OF ULTRASONIC FREQUENCY TO SOLDER BOND JOINT

Total 300 Head Gimbal Assembly was built and bonding by the solder ball with same machine and setting. Each Head Gimbal Assembly was 100% monitor joint crack before sending to clean by ultrasonic cleaning. Different frequencies (68 kHz, 132 kHz, and 192 kHz) of ultrasonic cleaner with 500 watts power were used to clean the Head Gimbal Assembly with different cleaner time. After the ultrasonic cleaning of Head Gimbal Assembly, joint crack/fracture was monitored and recorded. Table 1 shows that small crack was found when cleaners 68 kHz is used and increased when cleaning time was increased.

TABLE 1
ULTRASONIC CLEANING RESULTS WITH DIFFERENT FREQUENCY OF CLEANER

Ultrasonic Frequency	"Small" Cracked/Total part		
	Without cleaning	Cleaned 60 sec	Cleaned 120 sec
68 kHz	0	6/300 = 2%	9/300 = 3%
132 kHz	0	0	0
192 kHz	0	0	0

An experimental conclusion for the effect of ultrasonic frequency to solder bond joint could be drawn as follows from the above results:

- The ultrasonic frequency had a significant effect to the crack of solder ball joint. The lower frequency is higher effect to solder bond joint in term of crack
- The cleaning time had a significant effect to the crack of solder bonding joint. The longer time is higher crack observed.

EFFECT OF ULTRASONIC POWER TO SOLDER BOND JOINT

The effect of ultrasonic power to the solder bond joint was verified, only 1 frequency cleaner, 68 kHz, was selected. 300 Head Gimbal Assembly was built and bonding by a solder ball with same machine and setting. Each Head Gimbal Assembly was inspected crack before sending to clean by ultrasonic cleaning with different power setting (500, 750, 900 Watts) at 120 second cleaning time. Table 2 shows that small cracks were increased when power was increased.

TABLE 2
ULTRASONIC CLEANING RESULTS WITH DIFFERENT POWER

Ultrasonic Power	"Small" Cracked/Total part	
	Without cleaning	Cleaned 120 sec
500 W	0	9/300 = 3%
750 W	0	24/300 = 8%
900 W	0	38/300 = 13%

An experimental conclusion for the effect of ultrasonic power to solder bond joint could be drawn as follows from the above results

- The ultrasonic power had a significant effect to the crack of solder ball joint. The higher power is a higher effect to solder bond joint in term of crack

MEASUREMENT METHOD FOR ULTRASONIC ENERGY THAT IMPACT TO SOLDER BOND JOINT

CONCLUSIONS

The traditional measurement of ultrasonic energy is focused on cavitation energy, which is related to erosion. The cavitation is trying to measure in many methods, such as "Foil Test" and cavitation meter. John Kolyer from Boeing^[10] has written articles on this topic, including one that compared the use of the foil test as compared to a cavitation meter. However, the cavitation energy is not representing overall energy in cleaning tank as see in Table 3.

The evidence leads one to the conclusion that the combination of resonant vibration and cavitation energy of ultrasonic cleaner is the likely cause of the solder bond joint crack. Low ultrasonic frequency, 68 kHz, generated higher ultrasonic energy that effect to solder bond joint crack rate than higher ultrasonic frequency, 132 kHz and 192 kHz, at same ultrasonic power. In contrast, higher power and longer cleaning time generated higher ultrasonic energy that effect to solder bond joint crack rate. In addition, two ultrasonic measurements are provided to predict the ultrasonic energy that effected to solder bond joint. Sound pressure is a better solder bond joint crack rate prediction than cavitation energy that provided for corrosion monitoring in ultrasonic cleaning.

TABLE 3

THE COMPARISON BETWEEN CAVITATION ENERGY AND SOUND PRESSURE

Ultrasonic Cleaner	Cavitation Energy	Sound Pressure	"Small" Crack/Total part
132 kHz 750 watts	45	207	12/300 = 4%
132 kHz 500 watts	38	109	0
68 kHz 750 watts	114	243	24/300 = 8%
68 kHz 500 watts	105	171	9/300 = 2%

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The results show that the high frequency (132 kHz) generates lower cavitation energy than the low frequency (68 kHz) at the same power, which is corresponded with the previous paper [9] that introduced that frequency affects the size of the cavitation bubbles and the corresponding cavitation energy is the frequency of the ultrasonic wave. Specifically, at higher wave frequencies there is less time for the bubble to grow. The result is smaller bubbles and a corresponding reduction in cavitation energy. The cavitation energy cannot predict the solder bond joint crack rate as see in Table 3. At 132 kHz, 750 watts that has lower cavitation energy than 68 kHz, 500 watts, but it observed a higher crack rate.

The sound pressure measurement^[11], another tool that provided to measure the ultrasonic energy in cleaner tank, is introduced in this paper to measure ultrasonic energy both cavitation energy and resonant vibration energy in ultrasonic cleaning. The results of sound pressure measurement of each cleaner frequency and power are shown in Table 3. The results show high sound pressure power has higher solder bond joint crack rate. The sound pressure meter can be provided to predict solder crack rate.

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