World Academy of Science, Engineering and Technology
International Journal of Medical and Health Sciences
Vol:9, No:3, 2015

Cleaning Performance of High-Frequency, High-Intensity 360 kHz Frequency Operating in Thickness Mode Transducers

R. Vetrimurugan, Terry Lim, M. J. Goodson, R. Nagarajan

Abstract**—**This study investigates the cleaning performance of high intensity 360 kHz frequency on removal of nano-dimensional and sub-micron particles from various surfaces, uniformity of the cleaning tank and run to run variation of cleaning process. The uniformity of the cleaning tank was measured by two different methods i.e. 1. ppb^{TM} meter and 2. Liquid Particle Counting (LPC) technique. The result indicates that the energy was distributed more uniformly throughout the entire cleaning vessel even at the corners and edges of the tank when megasonic sweeping technology is applied. The result also shows that rinsing the parts with 360 kHz frequency at final rinse gives lower particle counts, hence higher cleaning efficiency as compared to other frequencies. When megasonic sweeping technology is applied each piezoelectric transducers will operate at their optimum resonant frequency and generates stronger acoustic cavitational force and higher acoustic streaming velocity. These combined forces are helping to enhance the particle removal and at the same time improve the overall cleaning performance. The multiple extractions study was also carried out for various frequencies to measure the cleaning potential and asymptote value.

Keywords**—**Power distribution, megasonic sweeping, thickness mode transducers, cavitation intensity, particle removal, laser particle counting, nano, submicron.

I. Introduction

THE constant trend in miniaturizing of disk drive components, low fly height, new technology development such as Heat Assisted Magnetic Recording (HAMR) process to achieve higher capacity disks and stringent cleanliness specification have created a need for higher cleanliness levels in disk drive and its associated industries [1]. Even though lot of changes in the process and technologies but still most of the hard disk drive industries and their component suppliers are using only the frequency ranges from 40 kHz - 192 kHz to clean their components. Although these frequency ranges can remove sub-micron particles but not really meet the cleanliness specified by disk drive industries. So, there is a need to go for higher frequency cleaning to achieve the desired cleanliness level and also to improve the overall process yield. Megasonic cleaning, although widespread use in the semiconductor and other industries but continues to be viewed warily because of damage from the inconsistent surging or fountain effect of the cleaning system [2], [3]. The lack of uniformity and/or damage from the fountain effect minimizes the use of megasonics in disk drive components cleaning, glass wafer cleaning, silicon wafer cleaning and other cleaning processes.

Megasonic cleaning traditionally refers to the frequency above 800 kHz but the frequency above 360 kHz also exhibits virtually all the characteristics of conventional megasonics [2]. However, the uni-directionality, and relative gentleness, of megasonic fields has historically limited its application in cleaning of complex and rugged substrates, such as glass wafers, disk drive components and process-tooling components. A new advancement in megasonic technology termed “Megasonic Sweeping” alleviates this traditional power surges and establishes a uniform power distribution and stronger acoustic field in the tank. When the megasonic frequency is swept at a predetermined rate (+/- 4.5 kHz) it causes each PZT to fire at its optimum natural resonant frequency and generates more even acoustic field in the cleaning tank. The more even and strong acoustic field in the megasonic tank gives more uniform and consistent cleaning. The megasonic frequency also offers the additional benefit of a very thin boundary layer over the immersed surface, which effectively exposes even sub-micron and nano-dimensional particles to the flow of the cleaning liquid [4], [5] thereby remove the sub-micron and nano-dimensional particles effectively from the surface.

In megasonic process the piezoelectric transducers operating in thickness mode at fundamental resonant frequencies are bonded at the bottom of the tank. The thickness mode transducers are excited by an alternating current signal that causes alternating expansion and contraction of the transducers; primarily the expansion and contraction changes the thickness of the transducers. The changes in thickness of the piezoelectric transducers generate the acoustic filed in the cleaning tank. The thickness of the piezoelectric transducers and the radiating plate is carefully selected to achieve more uniform acoustic field in the tank and to avoid tank to tank variations in terms of cleaning.

In this study, the cleaning performance of 360 kHz frequency operating in thickness mode transducers was investigated using various disk drive components. The power distribution was measured for 360 kHz frequency operating in

R. Vetrimurugan is with Crest Ultrasonics, R & D Dept, Penang, Malaysia (phone: +012-583 7018; fax: +604-507 0018; e-mail: vetri_iitm@rediffmail.com).

Terry Lim is with Crest Ultrasonics, Penang, Malaysia (e-mail: Terrylim@crestcn.com).

M.J. Goodson is with Crest Ultrasonics, Trenton, USA (e-mail: MGoodson@crest-ultrasonics.com).

R. Nagarajan is with Indian Institute of Technology, Chemical Engg. Dept, Madras, India (e-mail: nag@iitm.ac.in).

thickness mode piezoelectric transducers and particle removal efficiency was calculated for various frequencies. The experiments are also carried out to see the run to run variation of cleaning process.

II. Experimental Details

All experiments were performed in Class 1000 Cleanroom of the Advanced Ceramics Technology Lab (ACT Lab), Malaysia. For this study, Crest Ultrasonics standard tanks with dimensions 10"x14", 12"x18" and Crest Console™ system with bottom mounted transducers were used. The purpose of this experimental study was mainly to investigate the cleaning performance of 360 kHz frequency operating in thickness mode transducers. To demonstrate the cleaning performance multiple extraction experiments were carried out for various frequencies such as 360 kHz, 470 kHz and 1 MHz. The effect of various frequencies on removal of nano-dimensional particles at final rinse cleaning, run to run variation of cleaning process and uniformity of the cleaning tank was also studied. The frequencies studied for final rinse cleaning was 360 kHz and 132 kHz. The watt density used for 132 kHz is 31 watts/litter and the watt density used for 360 kHz and 470 kHz is 57 watts/lit and 46 watts/litter respectively.

The ppb™ meter and Liquid Particle Counting (LPC) technique was used to measure the uniformity of the cleaning tank. The ppb™ probe is an instrument used to measure the energy density in units W/in^2 of cavitation in liquids [5]. The second physical mechanism, acoustic streaming was not measured in this study, but was visualized. The acoustic streaming pattern and thickness mode piezoelectric transducers are as shown in Figs. 1 and 2 respectively. In liquid particle counting technique the parts are placed at various locations of the cleaning tank and the resultant particles removed are measured. The variables such as temperature of the De-Ionized (DI) water and dissolved oxygen (DO) level were maintained constant for each experiment. The components used for this study was Top cover (stainless steel based material), ceramic spacer, Aluminum metal spacer and e-coated disk separator.

In this study LiQuilaz SO2 particle measuring system (PMS™) was used to measure the particle counts in the DI water and >0.2 µm particle size was reported. This study is also applicable for removal of nano-dimensional particles and removal of particles from other components as well. The experiments were repeated several times and the average of this value was taken to calculate the cleaning efficiency. Maximum cleaning potential with lower asymptote value is the desired function to select the best cleaning process [6]-[8].

III. Results and Discussion

A. Megasonic Power Distribution for 360 kHz Frequency Operating in Thickness Mode Transducers

The power distribution in a cleaning vessel measured by ppb™ meter for 360 kHz frequency operating in thickness mode transducer is shown in Fig. 3. The result shows that the power is more uniformly distributed throughout the entire cleaning vessel. When the megasonic frequency 360 kHz is swept at 4500 Hz each transducer will vibrate at their optimum resonant frequency [7] and thus eliminates traditional power surges and establishes more uniform activity in a cleaning vessel.

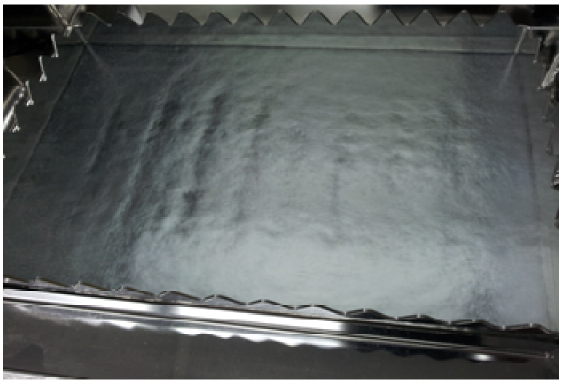

Fig. 1 Uniform cavitation activity in 360 kHz frequency operating in thickness mode transducers

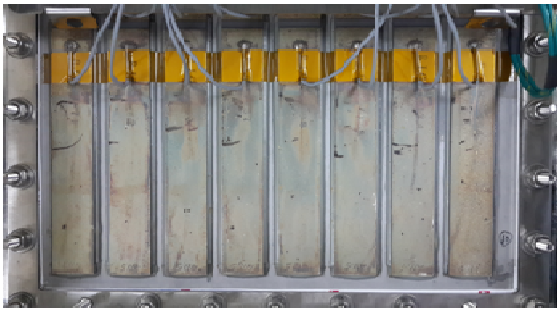

Fig. 2 Thickness mode piezoelectric transducers bonded at the bottom of the tank

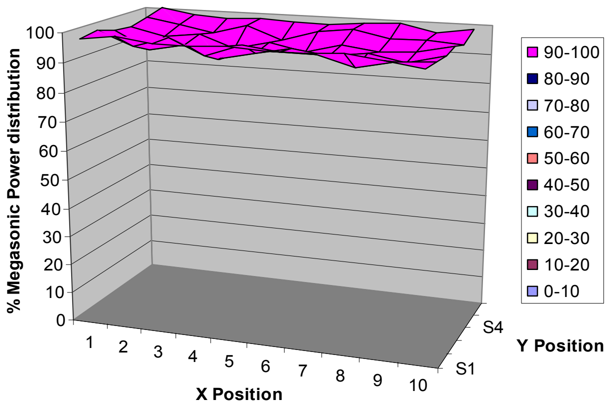

Fig. 3 Megasonic sweeping power distribution pattern in a cleaning vessel for 360 kHz

The uniformity of the cleaning tank was also checked by using LPC technique. The results obtained for aluminum spacer component cleaned at various locations of the tank is shown in Fig. 4. The result shows that the particle removal is more uniform throughout the entire cleaning vessel when megasonic sweeping technology is applied. Even the corners and edges of tanks in systems employing "megasonic sweeping” display particle removal almost equivalent to those prevailing at the center, in the plane perpendicular to the transducer. The presence of sweep renders another dimension to megasonic cleaning. Megasonic Sweeping Technology has overcomes the predominant limitation of non- uniformity of Megasonics. Instead of acoustic power being confined in PZT bonded area now the power was distributed uniformly including edges and corners of the tank.

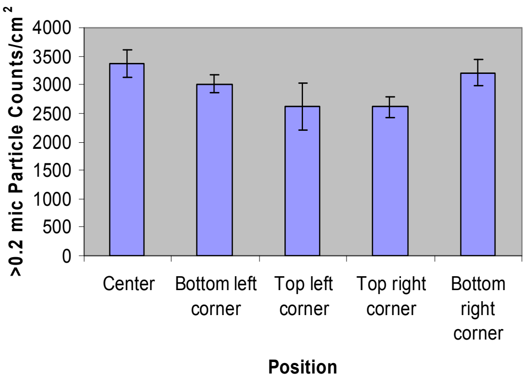

Fig. 4 Particle removal from disk drive AL metal component for 360 kHz

B. Run to Run Variation of 360 kHz Frequency Operating in Thickness Mode Transducers

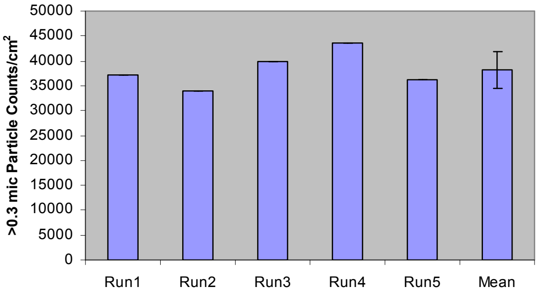

Fig. 5 Run to run cleaning variation for E-coated DSP

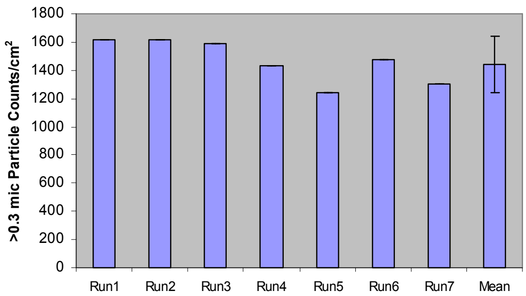

Fig. 6 Run to run cleaning variation for aluminum metal spacer

The run to run cleaning variation obtained for 360 kHz frequency operating in thickness mode transducers is shown in Figs. 5, 6. The experiments were carried out for two different types of parts such as E-coated DSP and aluminum metal spacer. The result indicates that the particle counts obtained for each run is almost same for the given experimental conditions. This is due to the fact that for each and every runs all piezoelectric transducers were operated at their optimum resonant frequency when megasonic sweeping technology is applied thus eliminates the power surges, maximize the cleaning performance and at the same time provides consistent cleaning.

C. Multiple Extraction Comparison of Various Acoustic Frequencies with Respect to Particle Removal Efficiency

In Figs. 7 and 8, particle-count data are presented for an e-coated DSP component, comparing the extraction efficiencies of different frequencies such as 360 kHz, 470 kHz and 1 MHz. The counts are shown as a function of various stages of extraction on the X-axis. The slope of the curve indicates cleaning efficiency, and the asymptotic level indicates degree of erosion. While 360 kHz frequency exhibits the steepest initial slope, hence highest initial cleaning where as 470 kHz and 1 MHz exhibits the lowest asymptote, hence lowest erosion.

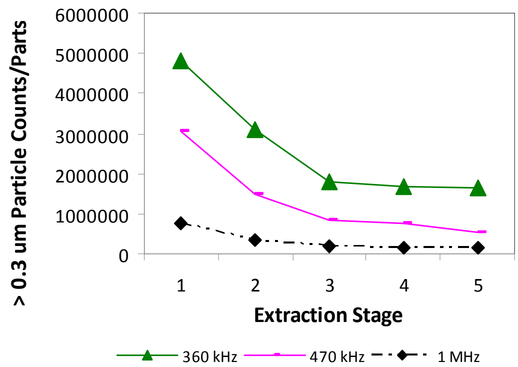

Fig. 7 Multiple-extraction comparison of various acoustic frequencies with respect to particle removal efficiency and erosion propensity for e-coated DSP

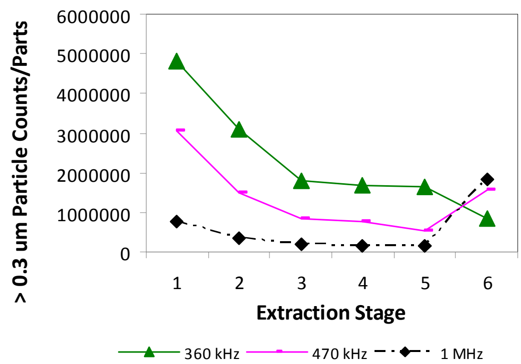

Fig. 8 Multiple-extraction comparison of various acoustic frequencies with respect to particle removal efficiency and 6th extraction was done using 132 kHz, 60W/gallon

From Fig. 7, it can be observed that the extracted particle counts for first stage extraction is significantly high for 360 kHz frequency as compared to 470 kHz and 1 MHz. The 6th extraction in Fig. 8 was done using 132 kHz, 60 w/gallon to check the residual particles remains on the surface based on disk drive industries component cleaning LPC procedure. From Fig. 8, it can be seen that the particle count value of 6th extraction stage is increased for 470 kHz and 1 MHz whereas the particle counts value is decreased for 360 kHz. It indicates 360 kHz frequency operating in thickness mode transducers is generating stronger acoustic cavitational force along with stronger acoustic streaming force which indeed brings down the nano-dimensional particle counts further. These combined forces in 360 kHz frequency may help to enhance the sub-micron and nano-dimensional particles removal from various components. To demonstrate this phenomenon the parts are initially washed with ultrasonic frequencies and finally rinsed with 360 kHz.

D. Performance of 360 kHz Frequency Operating in Thickness Mode Transducers on Final Rinse Cleaning

The experimental conditions used for this study is shown in TI. The surfactant used for washing is 1% CC 2000x.

TABLE I
EXPERIMENTAL CONDITION USED TO INVESTIGATE THE CLEANING PERFORMANCE OF 360 KHZ

No	Washing	Rinsing1	Rinsing2	Rinsing3	Analysis
1	58 kHz	58/132 kHz	132 kHz	360 kHz	LPC
2	58 kHz	58/132 kHz	132 kHz	DI rinse w/o any sonic	LPC
3	58 kHz	58/132 kHz	132 kHz	132 kHz	LPC

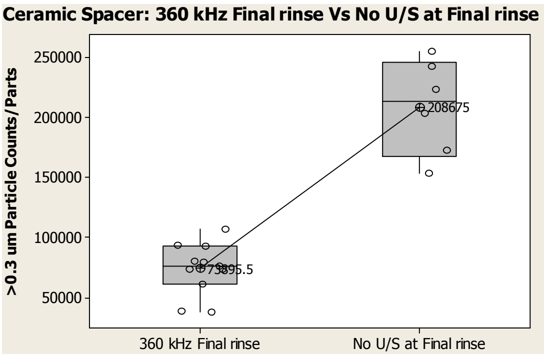

Fig. 9 Particle retain after washing for ceramic spacer

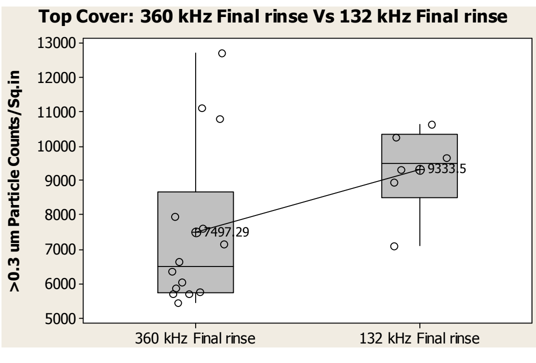

Fig. 10 Particle retain after washing aluminum metal spacer

The performance of 360 kHz frequency operating in thickness mode transducers on final rinse cleaning compared with other frequencies is shown in Figs. 9, 10. The parts tested are ceramic spacer, aluminum metal spacer and stainless steel top cover. From Figs. 9, 10, it can be observed that 360 kHz frequency would be more effective in removal of sub-micron particles as compared to other frequencies. This is due to better combination of acoustic streaming velocity and acoustic cavitational force. These combined forces are mainly helping to enhance the particle removal and also improve the overall cleaning performance. In addition, 360 kHz frequency produce even acoustic field when megasonic sweeping technology is applied and also reduce the thickness of boundary layer [2]-[4]. The result also reveals that 360 kHz frequency operating in thickness mode transducers is quite effective in removal of sub-micron and nano-dimensional particles from variety of surfaces without causing any damage.

The cleaning efficiency obtained for various frequencies at final rinse cleaning is as shown in Fig. 11.

The percent removal efficiency, η (%), can be calculated as follows;

$$\eta(\%) = \left[\frac{N_{cb} - N_{ca}}{N_{cb}} \right] \times 100 \tag{1}$$

where, N_{cb} is the number of >0.3 micron particles before sonic cleaning and N_{ca} is the number of particles after sonic cleaning. For any particular operating condition, three experiments were run, three removal efficiency values were measured, and their average was calculated. The result indicates that the cleaning efficiency is high for 360 kHz frequency as compared to 132 kHz and no ultrasonics at final rinse cleaning.

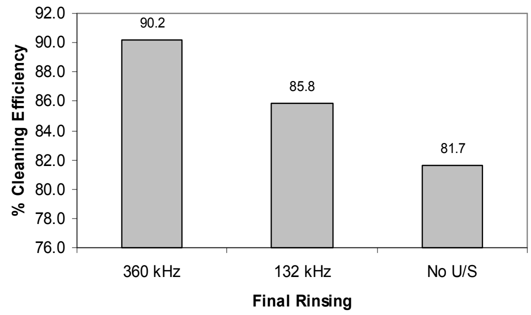

Fig. 11 Cleaning Efficiency comparison of various acoustic frequencies for top cover for particle sizes > 0.3 mic

IV. CONCLUSION

The cleaning performance of 360 kHz frequency operating in thickness mode transducers was demonstrated satisfactorily. An overriding concern regarding uni-directionality of megasonic fields and run to run variation on cleaning process has been addressed satisfactorily through the innovation of sweep-frequency megasonics. Megasonic Sweeping also render more uniform acoustic field in the cleaning tank and higher cleaning efficiency compared to non-sweeping megasonics. The combined forces generated during megasonic sweeping are indeed helping to enhance the particle removal and also helping to improve the overall cleaning performance. The data also reveals that rinsing the parts with 360 kHz frequency gives significantly higher particle removal efficiency as compared to other frequencies.

ACKNOWLEDGMENT

We wish to thank Tjung (Managing Director), Beng Hooi (Manager Sales Dept), and Research and Development team (ACT, Penang) for their kind support for this project.

REFERENCES

[1] Vetrimurugan et al., “Experimental Investigation of Ultrasonic and Megasonic Frequency on Cleaning of Various Disk Drive Components”, International Journal of Chemical Engineering and Applications, Vol.4, No.4, pp. 174-177, 2013.

[2] Goodson, J.M., and Nagarajan, R., “Megasonic Sweeping and Silicon Wafer Cleaning”, Solid State Phenomena, Vol. 145-156, pp. 27-30, 2009.

[3] Nagarajan et al., “Megasonic cleaning to remove nano-dimensional contaminants from wafer surfaces: An analytical study”, Solid State Phenomena, Vol.195, pp.209 – 212, 2013.

[4] McQueen, D.H., “Frequency dependence of ultrasonic cleaning”, Ultrasonics, Vol. 24, pp. 273-280, 1986.

[5] Vetrimurugan, R., and Beng Hooi, N.G., “Study of ultrasonic parameters on removal of contamination from slider surface by using various cleaning chemistry”, International Journal of Chemical and Environmental Engineering, Vol. 3, pp. 392-396, 2012.

[6] Roger, W.W., Nagarajan, R., and Newberg, C.E., “Contamination and ESD control in High-Technology Manufacturing”, IEEE press, John Wiley and Sons, New Jersey, ch. 5, pp. 195-230, 2006.

[7] Goodson, J. M., and Skillman, “Megasonic Processing Apparatus With Frequency Sweeping of Thickness Mode Transducers”, US Patent, Patent No. US 8,310,131 B2, pp. 1-13, 2012.

[8] R. Nagarajan, R. W. Welker, and R. L. Weaver, Evaluation of aqueous cleaning techniques for disk drive parts, *Microcontamination Conference Proceedings*, San Jose, CA, Oct. 1991; 16-18: 312-326.

Vetrimurugan, Place: India, Educational background: PhD in Chemical Engineering, Indian Institute of Technology Madras (IITM), India. Degree awarded year: 2007. Major Field of study: Ultrasonic/Megasonic cleaning and Ultrasonic mixing

Past work experience: 1. Worked as a Research Officer for ISRO (Indian Space Research Organisation) project in IITM for 3 years 2. Worked as a Cleaning and Development Staff Engineer in Western Digital, Thailand for 4 years. 3. Currently working as a Cleaning Application and Development Manager in Crest Ultrasonics, Malaysia for past 3 years. Published more than 20 research papers in various journals and international conferences. Current work mainly involves development of cleaning process for various customers include process optimization, equipment selection, chemistry and waste minimization. Main research area: Applications of Ultrasonic and Megasonics in diverse areas.

Address: No.1536, Jalan Perusahaan, Bukit Mertajam, Penang.

E-mail: vetri_praviswa@act.crestm.com

Lim Teong Kheng (Terry), Place: Malaysia, DOB: 31st August 1973, Education background: B. Eng (Hons), University Science Malaysia. Degree awarded year: 1996. Major Field of study: Mechanical Engineering.

Past work experience: 1. Sales Engineer in 3M, Malaysia. 2. Director in Ideal Dynamic (M) S/B, Malaysia. 3. Executive Vice President (Asia) of Crest Group Inc. Current work involves managing operations in Asia and cleaning application development with customers of various fields.

E-mail: terrylim@crestcn.com

J. Michael Goodson, Place: USA, CEO of Crest Ultrasonics Corporation.

E-mail: mgoodson@crest-ultrasonics.com

Prof. R. Nagarajan, Faculty of Chemical Engineering at Indian Institute of Technology Madras (IITM), India. E-mail: nag@iitm.ac.in