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Megasonic Frequencies Operating in Thickness Mode Transducers on Removal of Nano-Dimensional and Sub-Micron Particles from Ceramic Components

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***Abstract*— This study investigates the cleaning performance of high intensity megasonic frequencies operating in thickness mode transducers on removal of nano-dimensional and sub-micron particles from ceramic components. The effect of various megasonic frequencies such as 280 kHz, 360 kHz and 470 kHz on 3rd stage cleaning and final cleaning was studied for low temperature co-fired ceramic components. The multiple extractions study was carried out for various frequencies to measure the surface cleanliness, maximum cleaning potential and also to see the erosion propensity. Based on multiple extraction study the design of experiments was formed to develop the best cleaning process i.e higher cleaning efficiency and lower standard deviation. The result indicates that 3rd stage cleaning with 280 kHz followed by 470 kHz as final cleaning and 280 kHz followed by 360 kHz final cleaning provides significantly higher particle removal hence higher cleaning efficiency and lower standard deviation as compared to all other frequencies tested. Based on multiple extraction study, longer cleaning time with 40 kHz leads to erosion of the ceramic components. The initial cleanliness is high for 40 kHz and 280 kHz, and maximum cleaning potential is high for 280 kHz and 470 kHz. The erosion propensity value is low for both 280 kHz and 470 kHz.**

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

I.Introduction

A continuing trend in the disk drive industry is that cleanliness standards are becoming more stringent and precisely defined. These tightened cleaning standards are required for each and every components of the disk drive [1-3] to avoid any catastrophic failure of the disk drives. In general higher cleanliness with low sigma is the desired criteria to achieve more reliable products. To achieve higher cleanliness level and low sigma selection of suitable frequency is most important one. There are several parameters affects the performance of cleaning process which includes frequency, sonication power, basket orientation, basket material, temperature, re-circulation rate and so on. Among all the parameters, frequency is the most important single parameter to be considered in maximizing cleaning performance as well as to reduce the sigma.

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Most of the disk drive component suppliers are using frequency ranges from 25 kHz - 75 kHz to clean low temperature co-fired ceramic substrates. Mostly, the ceramic components cleaned by these frequencies are not really meet the desired cleanliness specification and sigma set by the disk drive industries. In order to overcome these issues state-of-the art megasonic frequency operating in thickness mode transducers such as 280 kHz, 360 kHz and 470 kHz was studied on removal of nano-dimensional and sub micron particles from ceramic components. In megasonic process the piezoelectric 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.

There are two basic particle-removal mechanisms in acoustic fields: cavitation, which predominates at lower frequencies (<132 kHz), and acoustic streaming, which is predominant at higher frequencies (> 280 kHz) [4]. Acoustic streaming is a time-independent fluid motion caused by the attenuation of sound wave travelling in the viscous fluid [5]. Acoustic streaming reduces the thickness of hydrodynamic boundary layer on the surface, due to which smaller size particles are exposed to large velocity gradients that leads to drag forces and rolling moments which subsequently overcome the adhesion force between particle and surface [6]. An overriding concern regarding uni-directionality of megasonic fields and run to run variation on cleaning process was addressed satisfactorily through the innovation of sweep-frequency megasonics [7]. 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 [8].

Overall, the cleaning performance of 280 kHz frequency operating in thickness mode transducers was investigated using low temperature co-fired ceramic substrates. In general ceramic materials are very prone to erosion. So, selection of suitable frequency to clean ceramic components are paramount important. To select the best suitable frequency multiple extraction study was performed for various frequency ranges from 40 kHz – 470 kHz. The cleaning performance of 280 kHz and 360 kHz as final cleaning was also studied.

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 280 kHz frequency operating in thickness mode transducers on removal of sub-micron particles from low temperature co-fired ceramic substrates. To demonstrate the cleaning performance multiple extraction study was performed for various frequencies such as 40 kHz, 58/132 kHz, 132 kHz, 280 kHz, 360 kHz and 470 kHz. The effect of various megasonic frequencies on removal of nano-dimensional particles at final cleaning was also studied. The frequencies studied for final cleaning was 280 kHz, 360 kHz and 470 kHz. The watt density used for 280 kHz is 105 watts/gallon and the watt density used for 360 kHz and 470 kHz is 180 watts/gallon and 165 watts/gallon respectively.

Non-ultrasonic extraction method was used to extract the residual particles from the ceramic components and LiQuilaz SO2 particle measuring system (PMS™) was used to measure the particle counts in the liquid. The particle counts reported in this study was >0.3 µm particle sizes. This study is also applicable for removal of nano-dimensional particles from other components as well. The experiments were repeated several times and the average of this value was plotted in the graph. Maximum cleaning potential with lower asymptote value is the desired function to select the best cleaning process [7]-[9].

III. Results and Discussion

A. *Multiple extraction comparison of various acoustic frequencies*

Multiple extraction comparison of various acoustic frequencies with respect to particle removal efficiency and erosion propensity for ceramic components is shown in Fig. 1-Fig. 3. In Fig.1, particle-count data are presented for a ceramic component, comparing the extraction efficiencies and erosion characteristics of three various frequencies. Counts are shown as a function of various stages of extraction on the X-axis. The slope of the curves indicates cleaning efficiency, and the asymptotic level indicates magnitude of erosion.

From Fig. 1, it can be observed that 40 kHz shows steeper initial slope; hence high initial cleaning in 1st extraction stage compared to other frequencies. This may be due to violent implosions of bubbles striking on the substrate. Higher cavitation intensity (low frequency) makes bubble implosions more violent as compared to lower cavitation intensity (high frequency). For lower frequency (high intensity), cavitation is the dominant mechanism, and for higher frequencies (low intensity), acoustic streaming predominates. From Fig. 2, it can be observed that 280 kHz shows significantly steeper initial slope; hence high initial cleaning in 1st extraction stage compared to other frequencies. Both ultrasonics and megasonics frequencies are plotted in the same graph in Fig. 3 to compare the cleaning performance of both ultrasonics and megasonics.

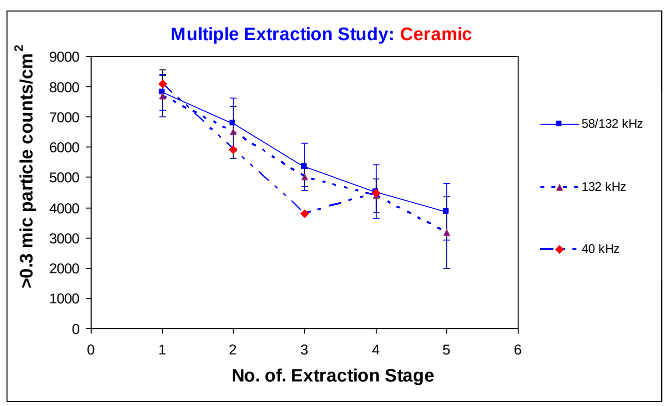

Fig.1 Multiple-extraction comparison of various ultrasonic frequencies with respect to particle removal efficiency and erosion propensity for ceramic components

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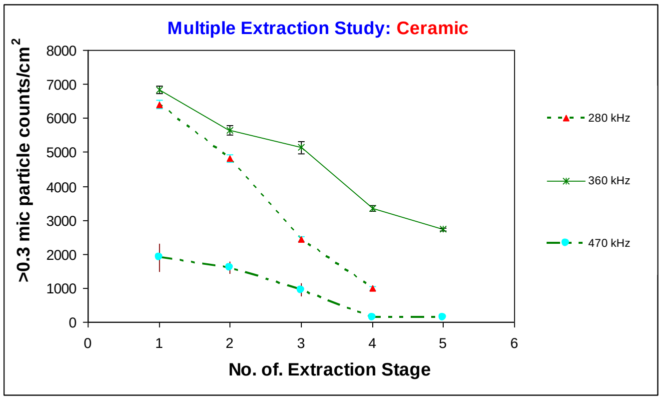

Fig.2 Multiple-extraction comparison of various megasonic frequencies with respect to particle removal efficiency and erosion propensity for ceramic components

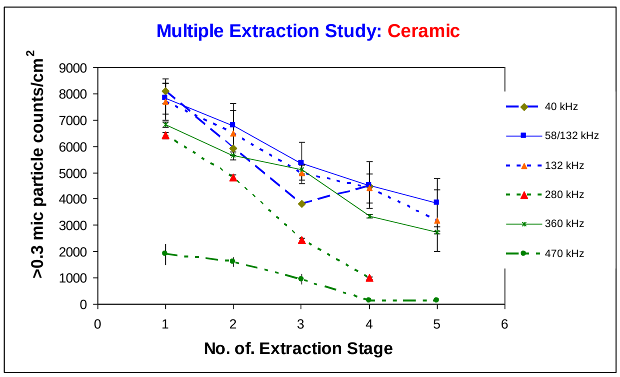

Fig.3 Multiple-extraction comparison of various ultrasonic and megasonic frequencies with respect to particle removal efficiency and erosion propensity for ceramic components

B. Surface cleanliness and maximum cleaning potential comparison of various acoustic frequencies

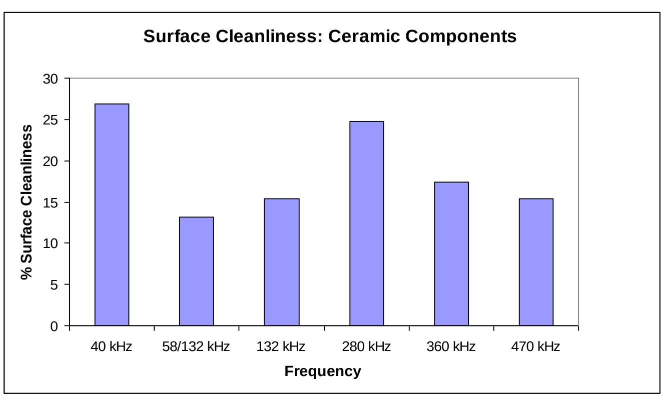

Fig. 4 Effect of various frequencies on surface cleanliness for ceramic components

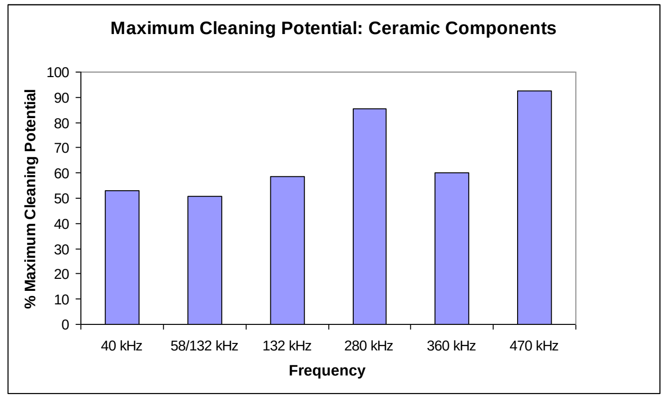

Fig. 5 Effect of various frequencies on maximum cleaning potential for ceramic components

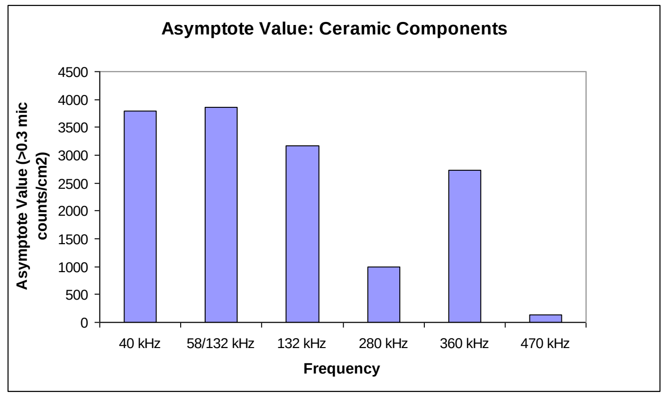

Fig. 6 Erosion propensity for various ultrasonic and megasonic frequencies

The surface cleanliness, maximum cleaning potential and asymptote value obtained for various frequencies is shown in Fig. 4 – Fig. 6. In general the cleanability curves can be described by two different fundamental cleaning factors, the surface cleanabilty, SC and maximum cleaning potential, MCP [9]. The surface cleanabilty is a measure of the relative ease of cleaning materials during early stages of cleaning. The first stage cleaning is calculated by using this formula,

$$SC = \frac{C_0 - C_1}{C_0 - C_a} \quad [1]$$

Where, C_0 is the initial cleanliness, C_1 is the cleanliness after first extraction, and C_a is the asymptotic cleanliness.

From Fig. 4, it can be observed that the surface cleaning is high for 40 kHz and 280 kHz as compared to other frequencies tested. The surface cleaning is almost comparable for 58/132 kHz, 132 kHz, 360 kHz and 470 kHz.

The maximum cleaning potential (MCP) is more representative of the final cleanliness value and the MCP can be defined as follows,

$$\text{Maximum Cleaning Potential} = \left[1 - \frac{C_a}{C_0}\right] \qquad [2]$$

The maximum cleaning potential obtained for various frequencies is shown in Fig. 5. From results, it can be observed that the maximum cleaning potential is high for 280 kHz and 470 kHz, low for 40 kHz and 58/132 kHz and moderate for rest of the other frequencies. From Fig. 6, it can be seen that the asymptote value is significantly low for 280 kHz and 470 as compared to other frequencies.

C. Effect of various experimental conditions on particle removal

The experimental conditions used for this study is shown in TABLE I. Based on multiple extraction study the following experimental condition is formed to see the cleaning performance and to see the process variations. The frequency is set constant for station 1, 2 and the frequency is changed for station 3 and station 4 for all flows.

TABLE I
EXPERIMENTAL CONDITION USED TO INVESTIGATE THE CLEANING PERFORMANCE OF VARIOUS MEGASONIC FREQUENCIES ON FINAL CLEANING

No	*Station1*	*Station2*	*Station3*	*Station4*	*Analysis*
1	40 kHz	132 kHz	280 kHz	470 kHz	LPC
2	40 kHz	132 kHz	132 kHz	470 kHz	LPC
3	40 kHz	132 kHz	280 kHz	360 kHz	LPC
3	40 kHz	132 kHz	360 kHz	470 kHz	LPC

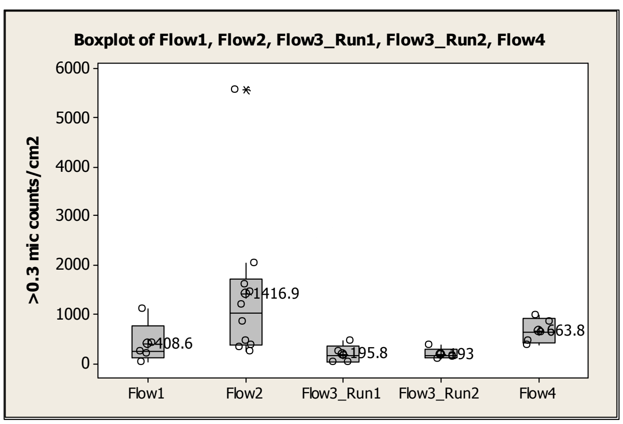

Fig. 7 Particle counts obtained for various experimental conditions

The results obtained for various process flow is shown in Fig.7. The particle counts obtained for flow1 and flow3 is significantly lower; hence higher cleaning efficiency as compared to flow2 and flow4. The standard deviation within the run and run to run is also low for flow3 and flow1 as compared to flow2 and flow4. It clearly indicates that employing megasonic frequency at 3rd stage and final stage cleaning provides higher cleaning efficiency, helps to lower down the sigma and also gives more consistent cleaning. Employing 280 kHz at 3rd stage cleaning gives higher particle removal; hence higher cleaning efficiency as comapred to 132 kHz as 3rd stage cleaning and 360 kHz as 3rd stage cleaning. This may be due to better lifting capabilities of 280 kHz, the loose particles left over by the 132 kHz was more effectively removed by 280 kHz and also the better combination of acoustic cavitation and acoustic streaming effect.

D. Effect of particle removal on 360 kHz Vs 280 kHz as a final cleaning and run to run variations

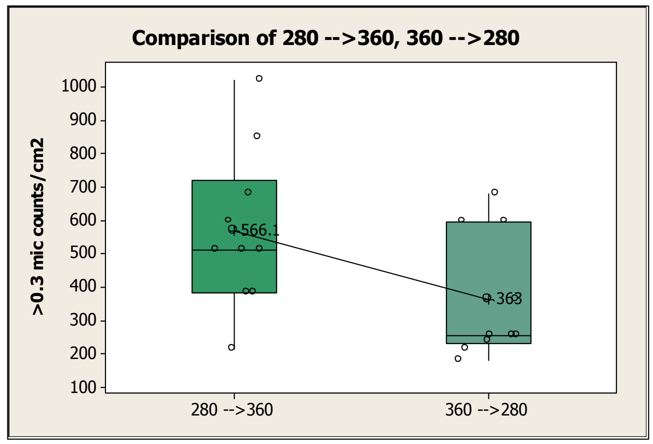

Fig.8 Effect of particle removal on 360 kHz vs 280 kHz as a final cleaning

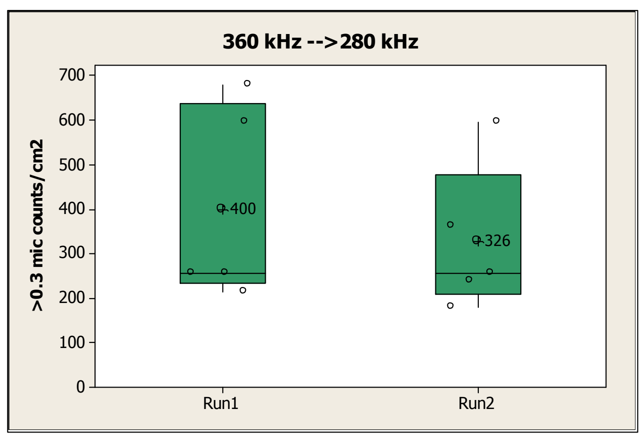

Fig.9 Run to run variations of 280 kHz as a final cleaning

The results obtained for the effect of 280 kHz followed by 360 kHz and 360 kHz followed by 280 kHz is shown in Fig. 8. The particle count is lower for the parts cleaned with 360 kHz followed by 280 kHz as compared to 280 kHz followed by 360 kHz. The run to run cleaning variations obtained for 280 kHz frequency as a final cleaning operating in thickness mode transducers is shown in Fig. 9. 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 without damage the parts.

IV.Conclusions

The cleaning performance of megasonic frequencies operating in thickness mode transducers was demonstrated satisfactorily to clean low temperature co-fired ceramic components. Employing megasonic frequencies such as 280 kHz at 3^{rd} stage and 470 kHz at final stage cleaning provides higher cleaning efficiency as well as lower sigma for cleaning of ceramic components. 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 indeed helping to enhance the particle removal and also helping to improve the overall cleaning performance. The data also reveals that final cleaning with 280 kHz frequency gives lower particle counts hence higher cleaning efficiency as compared to 360 kHz.

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