Experimental Investigation of Ultrasonic and Megasonic Frequency on Cleaning of Various Disk Drive Components

Vetrimurugan, Mike Goodson, Terry Lim, Samiheta, Nagarajan, and J. Siddharth

***Abstract*—This study investigates the effect of frequency on cleaning of various Hard Disk Drive (HDD) components. The disk drive components used for this study was aluminum metal spacer, e-coated disk separator and plastic separator. The frequency used for this study was 58/132 kHz, 132 kHz, 360 kHz, 470 kHz and 1 MHz. In this study multiple extraction method was used to find the cleanability and erodability of the parts and liquid particle counter was used to measure the particle concentration in the extracted solution. The result indicates that dual frequency i.e 58/132 kHz is more suitable for cleaning of aluminum metal spacer and e-coated disk separator, 360 kHz and 470 kHz is more suitable for cleaning of plastic disk separator. The result shows that 360 kHz is the supreme frequency for final rinsing. 360 kHz frequency also found to be a better washing and rinsing frequency for various HDD components. Cleaning the parts with multiple frequencies gives higher cleanability and lower erodability compared to single frequency alone.**

***Index Terms*—Ultrasonic, megasonic, multiple extraction, liquid particle count, maximum cleaning potential, asymptote value.**

I. Introduction

The constant trend in miniaturizing of components in the disk drive, low fly height and new technology such as HAMR processes to achieve higher capacity disks have created a need for higher cleanliness levels. Hard particles or other contaminants in the disk drive components can be cleaned before assemble it into the disk drive. Otherwise, contamination in the level of submicron can cause scratches, smearing in the head and medium leads to disk drive failure. Particle contamination on disk drive components is one of the major causes of low yields in the Hard disk drive and other related industries. To ensure high device yields, surface contamination and defects must be monitored and controlled during the assembly process [1]-[3]. The contamination from the parts may eventually infiltrate disk drives unless an appropriate cleaning process and component cleanliness inspection are implemented [4].

Normally, heavy cleaning is done at parts suppliers and the final cleaning is done before parts are about to enter a disk drive assembly line. In general, aqueous cleaning is the most desirable method for the final cleaning process [5]. The main purpose of final cleaning is to remove loose particles as well as some ionic and organic contamination that could introduce during parts storage, shipping, and handling. Hard particles may cause scratch on disk or head, ionic contamination may cause corrosion on disk or head, magnetic contamination may cause loss of data [6], [7].

So, cleaning of disk drive components is important to remove those contaminants which cause disk drive failure. The factors mainly affects the cleaning efficiency are ultrasonic frequency, Sonication power, Sonication time, cleaning chemistry, oscillation, basket location etc. Among all the parameters, selection of frequency is most important to achieve higher cleanliness.

In this study, a cleaning process was developed to clean various disk drive components using multiple extraction method. The effect of multiple frequencies on cleaning of various disk drive components was also studied. The maximum cleaning potential and asymptote value was calculated for various disk drive components.

II. Experimental Details

All the experiments were performed in Class 1000 cleanroom of the Crest Ultrasonics Lab, Malaysia. The experiments were conducted for various frequencies such as 58/132 kHz, 132 kHz, 360 kHz, 470 kHz and 1 MHz. The watt density used for 58/132 kHz, 132 kHz is 31 watts/litter and the watt density used for 360 kHz, 470 kHz and 1 MHz is 57 watts/lit, 46 watts/litter and 69 watts/litter respectively. In this study an enclosed ultrasonic bath-type tank equipped with bottom mounted transducers was used. The temperature was kept at 28 ^{o}C and dissolved oxygen level was maintained around 40%. The disk drive components used for this study was metal spacer, e-coated disk separator and plastic separator. The components used for this study was shown in Fig. 1.

The component used for this study was come from the same batch of material so that initial cleanliness was approximately the same. It is also important to note that these parts had been precleaned at their respective vendors. For each frequency the experiments were repeated three times and the average of this value was taken to calculate the cleanabilty and erodability parameters. The desirable function was set to maximize the cleanability parameter and minimize the erodability parameter. Actually, this translates into increases cleaning action with minimum damage to the part surface.

In any of the ultrasonic cleaning process some of the part materials also removed along with the contaminants that might be on the part by means of cavitation implosions. It is thus believed that the level of cavitation erosion depends on frequency, part material, exposure time and cleaning

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Vetrimurugan, Terry Lim, and Samiheta are with the Crest Ultrasonics, Malaysia (e-mail: vetri_praviswa@act.crestm.com, terrylim@crestcn.com)

Mike Goodson is with the Crest Ultrasonics, USA.

Nagarajan and J. Siddharth are with the Indian Institute of Technology, Madras (e-mail: mgoodson@crest-ultrasonics.com).

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solution.

The purpose of this experimental study was mainly to investigate the effect of various frequencies from ultrasonic to Megasonic range on cleanabiltiy and erodability parameters using ultrasonic multiple extraction method.

An ultrasonic multiple extractions define the cleanliness and cleanability of a part as measured using ultrasonic extraction to remove residual contamination [8]. In this method the parts were subjected repeatedly to the same contamination extraction procedure. The frequency used for the final extraction was 132 kHz with 60 watts/gallon. The parts are extracted 60 sec for metal spacer and 30 sec for e-coated disk separator and plastic separator. The ultrasonic extraction method utilizes ultrasonic energy to extract particles from a part and the particle concentration in the extraction solution was measured using liquid particle counter (LPC). The particle counter used for this study was particle measuring system (PMS™) and LiQuilaz SO2. This counter can measure the particle sizes from 0.2 um to 2 um. The size of the particles reported for this study was > 0.3 um only.

AL metal spacer   Plastic separator   E-coated DSP

Fig. 1. Disk drive components used for testing

III. Results and Discussion

The effect of frequency on particle extraction for e-coated disk separator is as shown in Fig. 2. The component used for this study was come from same batch of material so that the initial cleanliness was almost same. Eventhough, the incoming contamination level is same but after first extraction the particle count extracted by each frequency is different. The extracted particle count is high for low frequencies and low for higher frequencies. This is due to the fact that the decrease of cavitation intensity with increase of frequency. Higher cavitation intensity (low frequency) makes bubble implosions more violent as compared to lower cavitation intensity (high frequency) hence the particle extraction is high for lower frequencies compared to higher frequencies. For lower frequency (high intensity), cavitation is the dominant mechanism, and for higher frequencies (low intensity), acoustic streaming predominates. Dual frequency operation i.e. 58/132 kHz (mode that combines a cavitational frequency with a streaming frequency) yields higher removal efficiency than single frequency modes of operation [6]. From Fig. 2, we observed that 58/132 kHz shows steeper initial slope; hence high initial cleaning in 1st extraction stage compared to other frequencies.

The 360 kHz frequency also shows better initial cleaning. In case of 1 MHz frequency the initial slope obtained was not so steep. So, the initial cleaning is not good for 1 MHz frequency. As the frequency increases the cavitational force required to remove the particles decreases but the acoustic streaming force increases. It is thus believed that cavitation intensity is the most important factor for contamination removal. Cavitation intensity is higher for lower frequency compared to higher frequency operation. In lower frequency operation, the size of the bubble formed is large compared to higher frequency operation for a fixed power level. Hence, the energy released during collapse, which is a volumetric effect, is higher for lower frequency operation [6]. So, the higher frequencies such as 1 MHz is not suitable for strongly adhered particles but it is suitable for final rinsing to bring down the particle counts further. This frequency is also suitable for erosion sensitive parts and loosely adhered particles.

After final extraction with 132 kHz the count is increased for 470 kHz and 1 MHz which indicates that 470 kHz and 1 MHz may not be the right frequency for cleaning of e-coated disk separator. For 360 kHz, the particle count still goes down after final extraction with 132 kHz which indicates that 360 kHz frequency would be the best option for final rinsing compared to 470 kHz for the cleaning of disk drive components.

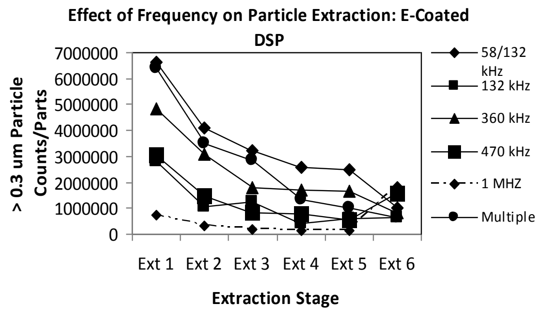

Fig. 2. Effect of frequency on particle extraction for e-coated DSP

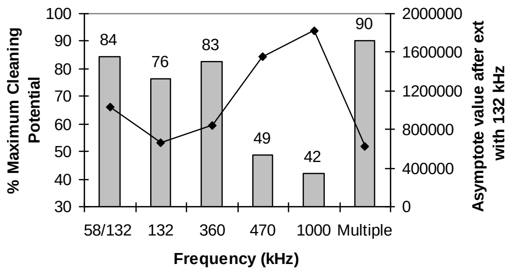

Fig. 3. Effect of frequency on cleaning of e-coated DSP.

After 4th extraction, 58/132 kHz reaches asymptote value (no further cleaning) for >0.3 um particle counts. The result shows that multiple frequency sequence 58/132 kHz → 58/132 kHz →132 kHz → 360 kHz → 360 kHz gives lower particle counts at final extraction; hence high final cleaning compared to single frequency. The frequency 132 kHz shows only fair amount of particle removal compared to other frequencies.

The cleanability of the curves can be described by two different fundamental factors, the surface cleanability, SC and maximum cleaning potential, MCP [8]. The maximum cleaning potential (MCP) is more representative of the final cleanliness value;

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

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

From Fig. 3, we observed that the Cleaning Efficiency is high for multiple frequencies, intermediate for 58/132 kHz, 132 kHz, 360 kHz and low for 1 MHz. In multiple frequency approach a series of cleaning tanks operate at a discrete frequency. Normally, in multiple frequency operation a wide range of particles can be removed. This is due to the fact that the size and number of cavitation bubbles produced in ultrasonic cleaning various with the frequency. As the frequency increases the number of cavitation bubbles increases but the size of the cavitation bubbles decreases [9]. In general lower frequency is more suitable for removal of larger size particles and high frequencies such as 360 kHz, 470 kHz and 1 MHz is suitable for removal of sub-micron particles.

The result shows that 58/132 kHz followed by 132 kHz with 360 kHz as a final rinse gives higher cleaning efficiency compared to single frequency. This is due to the fact that for higher frequency such as 360 kHz the boundary layer thickness is much lower than 58/132 kHz. In case of high frequency i.e 360 kHz the jet and the shock waves produced during bubble collapse goes more closer to the vicinity of the sub-micron contaminant and remove the sub-micron contaminant more effectively from the surface. The thickness of the bounday layer surrounding the part is a function of the ultrasonic frequency in the tank. The higher the frequency, the thinner is the boundary layer [10]. Higher frequencies also helps to avoid re-deposition of particles due to high acoustic streaming velocity. As the frequency increases the acoustic streaming velocity also increases.

The asymptote value obtained for e-coated disk separator is shown in Fig. 3. From Fig. 3, we observed that the asymptote value is low for multiple frequencies compared to single frequency. The asymptote value represents both the limit of cleanliness that can be achieved and the limit of our ability to measure the cleanliness of the surface [8]. Asymptote value is low for multiple frequencies, 132 kHz, 360 kHz and high for 470 kHz, 1 MHz and intermediate for 58/132 kHz. In general steeper initial slope with lower asymptote is the best combination to achieve the better cleanliness.

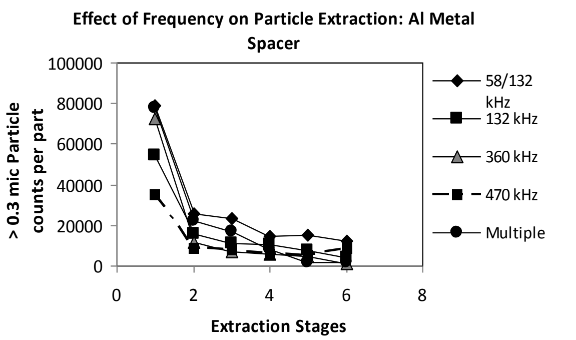

Fig. 4. Effect of frequency on particle extraction for AL metal spacer

The effect of frequency on particle removal for metal spacer is shown in Fig. 4. From Fig. 4, we observed that 58/132 kHz, 360 kHz and multiple frequency shows highest initial slope hence higher initial cleaning compared to other frequencies. The frequencies 132 kHz and 470 kHz shows fair amount of particle removal efficiency. The result indicates that high frequency such as 470 kHz is not suitable for washing of metal spacer compare to 58/132 kHz and 360 kHz but the asymptote value obtained for 470 kHz is low hence this frequency may be more suitable for final rinsing. The reason for this can be the particles are strongly adhered to the surface. Hence, the energy released during bubble collapse for 470 kHz is not strong enough to remove the particles from the surface.

After 4th extraction, 58/132 kHz reaches asymptote (no further cleaning) for >0.3 um particles. Whereas, 132 kHz and 360 kHz have lower asymptote which indicates that the particle counts can be decreased further using these frequencies.

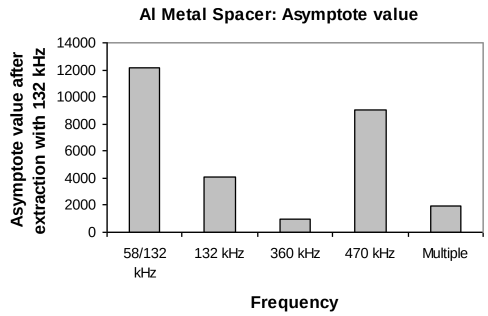

Fig. 5 Asymptote value for various frequencies

The asymptote value obtained for metal spacer is shown in Fig. 5. We observed that the asymptote value is low for multiple frequencies, 360 kHz and high for 58/132 kHz, 470 kHz and intermediate for 132 kHz. An explanation for this was already provided. The data indicates that 360 kHz frequency should be used at final rinse to bring down the particle counts further i.e to achieve lower asymptote value.

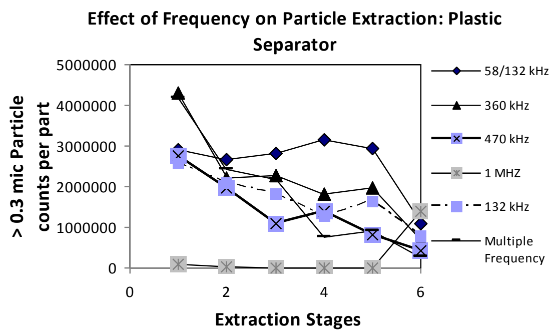

Fig. 6. Effect of frequency on particle extraction for plastic separator

The effect of frequency on particle extraction for plastic separator is shown in Fig. 6. From Fig. 6, we observed that the initial slope is much steeper (high initial cleaning) for 360 kHz compared to other frequencies tested. After 6th extraction with 132 kHz the particle count obtained was low for multiple frequencies (360 kHz→ 360 kHz→ 470 kHz→470 kHz), 360 kHz, 470 kHz and the count is high for 58/132 kHz. For 58/132 kHz the count reaches asymptote after 1st extraction itself and the count increase after 3rd and 4th extraction. It indicates that 58/132 kHz is not the right frequency for removal of contaminants from plastic separator. The erosion of the parts starts from 3rd extraction itself for 58/132 kHz. This may be due to high cavitation intensity. For plastic separator, 360 kHz and 470 kHz found to be the best washing and rinsing frequency for the removal of particles.

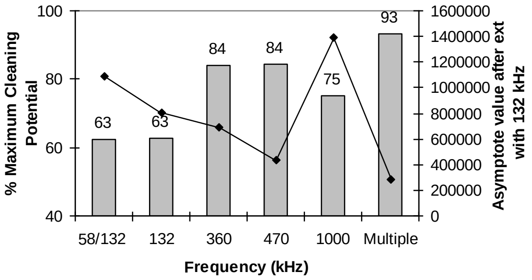

Fig. 7. Effect of frequency on cleaning of plastic separator

The effect of frequency on maximum cleaning potential and asymptote value for plastic separator is as shown in Fig. 7. From Fig. 7, we observed that the cleaning efficiency is high for multiple frequencies compared to single frequency. The cleaning efficiency is also high for megasonic frequencies such as 360 kHz and 470 kHz and low for ultrasonic frequencies such as 58/132 kHz and 132 kHz.

The asymptote value is low for multiple frequencies, 470 kHz, 360 kHz and high for 1 MHz, 58/132 kHz and intermediate for 132 kHz. From Fig. 7, we observed that 360 kHz and 470 kHz is found to be the better frequency for cleaning of plastic separator. The higher frequencies such as 360 kHz and 470 kHz the acoustic cavitation intensity is low but the streaming velocity is high. In case of higher frequencies shedding the particles from the plastic separator is completely eliminated due to low cavitation intensity and high acoustic streaming.

IV. Conclusion

The cleanability and erodability of the part was studied using multiple extraction method. The multiple extraction method is one of the process simulation tool used to find the cleanability and erodability parameters. The result shows that multiple frequencies with 360 kHz at final rinse gives higher cleanability and lower erodability compared to single frequency for metal spacers, e-coated disk separator and plastic separator. The frequency 58/132 kHz gives steeper initial slope; hence high initial cleaning for metal spacer and e-coated disk separator compared to other frequencies tested. Based on the results 58/132 kHz frequency seems to be more suitable for cleaning of particles from hard surfaces such as stainless steel, aluminum etc.

In general, the harder the material, the steeper the initial cleanup curve and the smaller the asymptotic cleanliness. The result shows that 360 kHz is more suitable frequency for both washing and final rinsing. The result also shows that 58/132 kHz frequency is not suitable for cleaning of plastic separator. The cleaning time for this frequency should be optimized to avoid erosion. The frequencies such as 360 kHz and 470 kHz is found to be better frequencies for cleaning of plastic separator. The frequencies 470 kHz and 1 MHz is found to be more suitable for loosely adhered contaminants and erosion sensitive parts. The various combinations of frequencies and different transducer mounting (bottom mount and side mount) will be studied in future.

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Vetrimurugan was born in April 1977 in India. He got his Ph.D in Chemical Engineering, Indian Institute of Technology Madras (IITM), India in 2007. His major field is Ultrasonic/Megasonic cleaning and Ultrasonic mixing. Current work mainly involves development of cleaning process for various customers include process optimization, equipment selection, chemistry and waste minimization. Main research area: Ultrasonic and Megasonic applications

Lim Teong Kheng was born in August 1973 in Malaysia. He got his B. Eng (Hons), in University Science Malaysia in1996. Major Field of study is Mechanical Engineering. Current work involves managing operations in Asia and cleaning application development with customers of various fields.