*Experiments show that temperature and frequency are the most significant parameters in ultrasonic systems.*

# Optimizing Ultrasonic Cleaning for Disk Drive Components

BY ROMAN GOUK

Cleanliness of parts and assemblies has always been an important factor for product yield in the disk drive industry. The challenge is that most disk drive parts are manufactured by conventional material processing methods, such as machining. stamping. and molding. Ultimately, the manufacturing process - normally requiring the use of oils, coolants, and abrasive tools - becomes the primary source of the part contamination, since manufacturing cannot be implemented in a cleanroom environment. The contamination from the parts may eventually infiltrate disk drives unless an appropriate cleaning process and component cleanliness inspection are implemented.

Usually heavy cleaning, such as chemical etching, solvent cleaning, or degreasing, is done at parts suppliers. Final cleaning is normally done before parts are about to enter a disk drive assembly line. In efforts to reduce use of hazardous chemicals, aqueous cleaning has become the most desirable method for the final cleaning process. The main purpose of final parts cleaning is to remove loose particles as well as some ionic and organic contamination that could lx introduced during parts storage, shipping, and handling. Because cleanliness of parts assembled into a disk drive very much depends on the efficiency of the final wash process, it is critical that this process be well optimized.

In the past few years, cleaning processes used in the disk drive industry have undergone significant changes, most due to elimination of CFCs and the shift to aqueous cleaning. Aqueous cleaners depend mainly on mechanical means of particle removal, such an ultrasonic agitation, and the use of different surfactants and water heating to enhance the cleaning action. However, it is not fully understood what variables in an aqueous cleaning process affect parts cleanliness the most.

In general, the ultimate goal of cleaning is to achieve a better part cleanliness level. This, of course, depends on the method used to measure part cleanliness. Ultrasonic extraction is one of the methods currently used by IBM System Storage Division (SSD) to assess the cleanliness level of disk drive parts and assemblies. This method utilizes ultrasonic energy to extract particles from a part and puts them into aqueous suspension. Then, a liquid particle counter (LPC) is used to measure the particle concentration in the extraction solution. [1,2]

There are two advantages of the ultrasonic extraction/LPC method: It can be used to measure cleanliness of irregular geometry parts. offering a way to assess the level to which the part can be cleaned with a given ultrasonic field. The second advantage comes from the fact that one could extract the part ultrasonically a number of times until an asymptote based on LPC counts is reached.

In fact, the method of multiple extraction is used quite extensively at IBM SSD to assess materials/parts cleanability characteristics. The multiple extraction by itself is a small-scale aqueous cleaning process that can be implemented using different ultrasonic tanks, extraction solutions. temperatures, and other parameters. Because of the versatility of this method, an attempt was made to use multiple extraction In conjunction with LPC measurements for the study of parts cleanliness optimization.

## An Experimental Approach

Optimization of any process normally requires identifying process variables (also known as factors) and outcomes (or responses). In aqueous cleaning, the process variables of interest are ultrasonic frequency, surfactant, surfactant concentration and temperature. With the method of multiple extraction being the cleaning process, the measurable outcomes can be defined by two parameters: cleanability and erodability.

As shown In **Figure 1,** the cleanability parameter is the Initial slope of the multiple extraction curve based on the total number of particles extracted after the first and second extractions. Based on the same curve, the erodability parameter is the asymptote to which the number of extractable particles converges after six extractions. In other words, the erodability parameter indicates the erosion level caused by the ultrasonically induced cavitation.

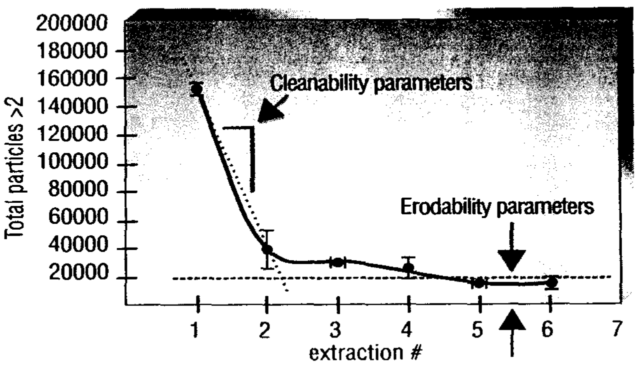


**Figure 1. Typical multiple extraction curve analysis.**

It should be mentioned that any ultrasonic cleaning tends to remove some of the part material along with the contaminants that might be on the part. by means of cavitation explosions. It is believed that the level of cavitation erosion depends on the type of ultrasonics, part material, and the cleaning solution. [1]

With the process variables and outcome parameters defined as described above, a test matrix was constructed **(Table 1),** incorporating a two-level factorial experiment design that can be expressed in terms of a number of experimental runs as 24 (four variables used) when a full factorial is executed.

The purpose of this experimental study was, first, to investigate which of the four variables has the largest effect on cleanability and erodability parameters. Secondly, it was intended to see what the effects on part cleanliness would be if a higher ultrasonic frequency and different type of surfactants and concentrations are used.

As indicated in **Table 1,** 40 kHz and 68 kHz ultrasonic tanks (both from the same manufacturer) were tested. Also, two non-ionic surfactants (A and B) from different manufacturers were used. The effect of temperature on the cleaning process is fairly well understood. and this variable was included in the matrix to compare its effect with other variables and to test the validity of overall experiment results.

| Experiment | Frequency kHz | Surfactant | Concentrated volume % | Temperature °C | Experiment | Frequency kHz | Surfactant | Concentrated volume % | Temperature °C |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 40 | A | 0.02 | 20 | 9 | 68 | A | 0.02 | 20 |
| 2 | 40 | A | 0.02 | 45 | 10 | 68 | A | 0.02 | 45 |
| 3 | 40 | A | 0.05 | 20 | 11 | 68 | A | 0.05 | 20 |
| 4 | 40 | A | 0.05 | 45 | 12 | 68 | A | 0.05 | 45 |
| 5 | 40 | B | 0.02 | 20 | 13 | 68 | B | 0.02 | 20 |
| 6 | 40 | B | 0.02 | 45 | 14 | 68 | B | 0.02 | 45 |
| 7 | 40 | B | 0.05 | 20 | 15 | 68 | B | 0.05 | 20 |
| 8 | 40 | B | 0.05 | 45 | 16 | 68 | B | 0.05 | 45 |

**Table I. Experimental test matrix.**

Part selection for this study was based on two criteria. First, it was Important that the parts come from the same batch of material so that initial cleanliness was approximately the same. Second. the material needed to be representative of that typically used in disk drives. To meet these criteria, aluminum and plastic (ultem) disk drive parts that came in a batch of at least 100 pieces were selected for this study. To minimize part-to-part cleanliness variation, a repeated full factorial [totally

32 experiments for each part type) was run according to **Table I** (page 14). It is also important to note that these parts had been precleaned at their respective vendors.

**The Results**

For each experiment, six multiple extraction tests for two aluminum and two plastic parts were performed. The cleanability and erodability parameters were calculated accordingly. To aid in the experiment design and data analysis, JMP statistical software was used.

A typical JMP output generates a plot of main effects, interactions as well as results of statistical analyses based on the data obtained from experimental runs. **Figure 2** (page 16) shows results generated by JMP, with the third row of plots showing data optimization curves based on the desirability function set in the far right column.

The desirability function was set to maximize the cleanability parameter and minimize the erodability parameter. Physically, this translates into increased cleaning action with minimum damage to the part surface.

The main effect plots should be viewed along with the statistical analysis results shown in Table II. Considering 95 percent confidence level as a criterion for any variable effect to be significant as compared to the standard error, in this case only two variables, frequency and temperature, were found to produce significant effects on the cleanability parameter.

According to these results, higher temperature, 45°C in this case, increased the cleanability parameter for aluminum parts the most, with the t-ratio of 6 ($p > 0.0001$). Also, it was interesting to find that 68 kHz produced a higher value of the cleanability pan-meters as compared to 40 kHz with the t-ratio of 2.47 ($p=0.02$). However, none of the variables had statistically significant effects on the erodability parameter (i.e., none of the t-ratios met the 95 percent confidence level criterion [see **Table II]).**

For the plastic parts, JMP data analysis showed very similar trends in terms of main variable effects for both cleanability and erodability. However, some difference was seen in terms of the t-ratio values for temperature and frequency, As shown in Table II, the t-ratios for temperature and frequency were about equal, whereas temperature produced a dominant effect on cleanability for aluminum parts.

Additional tests were conducted to assess the effect of pure DI water cleaning, as opposed to cleaning in a surfactant solution. The results showed cleaning with a surfactant increases cleanability from about 50 to 100 percent

| | Aluminum parts | | | | Plastic parts | | | |
|---|---|---|---|---|---|---|---|---|
| | Cleanability | | Erodability | | Cleanability | | Erodability | |
| Term | t-ratio | Probability | t-ratio | Probability | t-ratio | Probability | t-ratio | Probability |
| Frequency | 2.47 | 0.020 | 1.25 | 0.22 | 2.95 | 0.007 | 1.2 | 0.239 |
| Surfactant | -0.37 | 0.75 | 1.43 | 0.164 | 1.86 | 0.073 | 1.57 | 0.128 |
| Concentration | 0.47 | 0.640 | 1.19 | 0.24 | -1.06 | 0.300 | 0.32 | 0.748 |
| Temperature | 6.07 | <.0001 | -0.99 | 0.33 | 2.87 | 0.008 | 1.36 | 0.185 |

**Table II. JMP data analysis.**

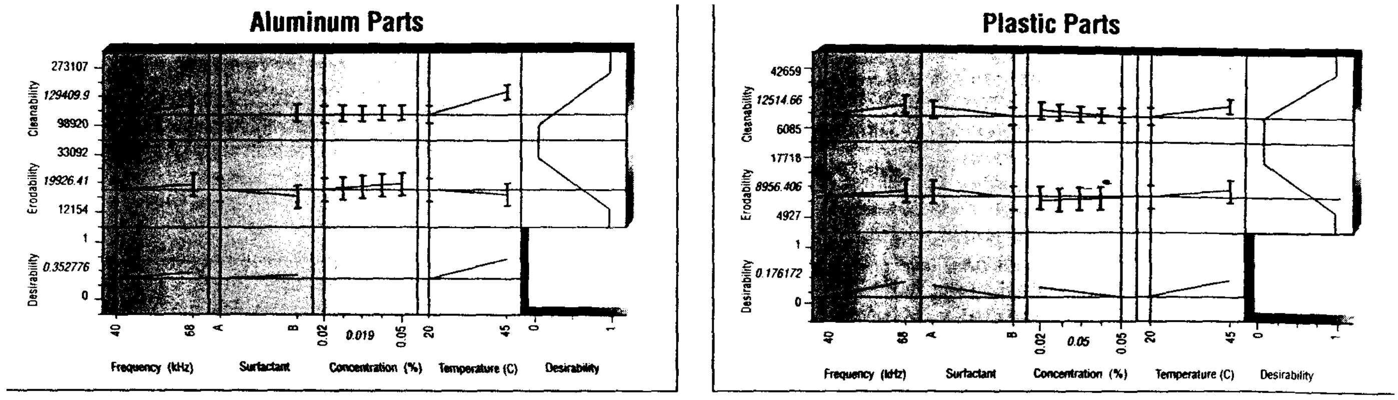


**Figure 2. JMP plots of main effects and optimization results.**

without a significant effect on erodability (**Figure 3**). Although the results of these tests come as no surprise, they, along with the temperature effect, suggest that overall results produced by this study are reasonable.

This appears to confirm that the ultrasonic frequency used in the cleaning baths is a critical variable that could be tuned to improve cleaner performance. In fact, an evaluation study was done to compare performance of different ultrasonic tanks operating at various frequencies. Though the results of this evaluation are reported elsewhere, several findings should be stated here.

Generally, based on the multiple extraction method, higher frequency ultrasonics produces higher cleanability parameter (for aluminum parts); tanks with a well-designed frequency sweep tend to produce lower erodability parameters, which is good because the cleaning effectiveness of such a tank is higher. It was found that ultrasonic tanks that do not utilize frequency sweep designs produce a noticeably higher erosion level and poor cleanability. Although these results are mentioned as general observations, performance of a particular ultrasonic tank may very much depend on the tank design and manufacturer.

## Conclusions

Using the multiple extraction method as the primary process simulation tool gave us the ability to monitor two process parameters: cleanability and erodability. Effects of four process variables - ultrasonic frequency, temperature, surfactant type, and concentration - were evaluated.

The results showed that higher ultrasonic frequency is favorable for achieving a better cleaning process. Higher frequency ultasonics is, however, a general term; individual tank performance may vary between manufacturers. The temperature effect was found to be the most significant parameter for cleaning aluminum parts. Although it is clear that cleaning with higher water temperature helps to achieve greater parts cleanliness, there are some limitations as to how high the temperature can be, based on the cleaner design and materials to be cleaned.

Although the multiple extraction method seems to be fairly effective in identifying key process parameters, it also has some drawbacks. Because the LPC was the primary measuring tool, only particulate contamination could be detected. Use of other equipment, capable of measuring organic and ionic contaminants, would complicate the experimental matrix.

It is possible that the effects of surfactant type and concentration on parts cleanliness did not turn out to be important in this study because the tests were biased to particle contamination, in addition to the parts being relatively clean to begin with. Practical cleaning applications, though, have shown that a surfactant type and concentration could be important for removal of residual organic and ionic contamination.

It was shown that use of surfactants enhances cleaning action; however, rinsing the surfactant off the parts surfaces could be difficult and may be greatly dependent on surfactant type and concentration. **PC**

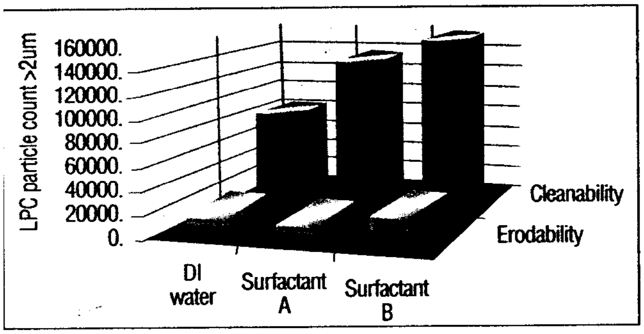


**Figure 3. Surfactant effect on cleanability and erodability parameters (in 68 kHz and at room temperature).**

References

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**Acknowledgements**

*The author wished to acknowledge Dr. R. Nagarajan who suggested the course of this study and provided his useful input for writing this manuscript and Dr. L. Nebenzahl for her support and encouragement in completing this work..*

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