Capability Measurement Analysis for Destructive Testing by Nested Design and improve process using Taguchi DOE

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Abstract

Liquid particle counting (LPC) is used widely in hard disk drive industrial manufacturing. The capability measurement analysis or GR&R is used to evaluate capability of LPC test method. Because the LPC test method is the destructive testing, so the nested design is used in GR&R study. The results of GR&R study show that the GR&R is 81.35% and unacceptable because it exceeded 30% according to the AIAG measurement system analysis criteria. The result of experiment showed that this measurement system must be improved. First, the cause and effect diagram is used to identify the sources of measurement variation. There are 4 main sources of variation; method, environment, part and the different of operator. Finally two main sources of variation (operator and method) are improved by Taguchi DOE. In Taguchi DOE the control factor are the curling time, the position of sample, and the noise factor which is the different of operator. The optimal conditions from Taguchi DOE is curling time be equal to 4 hr and the position of sample is bottom. Furthermore the noise factor is not effective in the measurement process.

Keywords: Liquid particle counting (LPC), Hard disk drive arm, GR&R, Taguchi DOE

Introduction

Liquid particle counting (LPC) has been used commonly as the cleanliness measurement method in hard disk drive industries. The accuracy and precision of the LPC are important in the product quality. We can validate the accuracy and precision of LPC test by the measurement capability analysis or GR&R study.

The measurement capability analysis is generally known as gauge repeatability and reproducibility analysis (GR&R). The GR&R is used to (1) determine the total variability is due to the measurement process, (2) to isolate the sources of variability in the system and (3) to assess weather the measurement process is capable (Richardet al., 2003).

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Standard GR&R study presume that the operator can replicate measurement on the part such as the weighed measurement. However if the testing is destructive such as tensile strength measurement the problem will be complex and difficult to measure the repeatability and the reproducibility. The homogenous bath and nested design has been suggested for destructive gauge capability study (HAN and HE , 2007).

In our study the nested GR&R study was used to analysis the LPC measurement process of hard disk drive arm in which the LPC test is the destructive testing. The results of GR&R study show that the LPC measurement process is not capable. After investigation and conducting pilot experiment the sources of measurement variations are fit in the cause effect diagram. There are four main sources of variation containing method, environment, part and the different of operator. Finally two main sources of variation are improved by Taguchi DOE. In Taguchi DOE the control factor is the curling time and the position of sample that came from the factors in the LPC test method. The noise factor is the different of operator. After improvement the second GR&R study result show that the measurement capability is improved significantly.

Nested GR&R Study

In destructive testing part cannot be measured repeatedly. Cross experiment is not applicable where the nested structure of experiment is required. So, in the destructive gauge capability study, some assumptions need to be made. The assumption is base on the homogenous batch of part. The results of nested design cannot be used to estimate the reproducibility since different operators do not measure the same batch of part. The variability due to reproducibility is confounded with bath -to- bath variability (Montgomery et al., 1993). The statistical model of nested design is

$$Y_{ijk} = \mu + Oi + Pj + \varepsilon k(ij)$$

$$i = 1,2,...,a;\ j = 1,2,...,b;\ k = 1,2,...,n$$

Where Y_{ijk} is the measurement value of the *j*th part measure by the *i*th operator in the *k*th trail. Figure1 show the nested design model. (Richardet al., 2003)

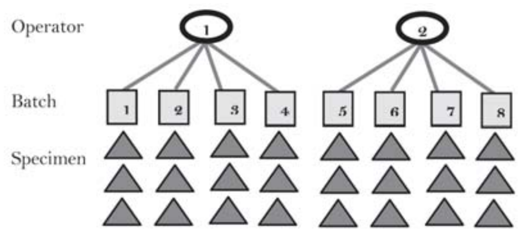

Figure 1. The nested design model

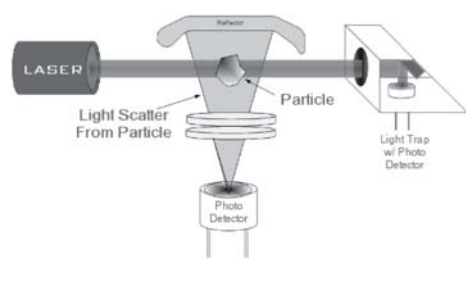

Figure 2. The principle of LPC

Liquid particle counting method (LPC)

Liquid particle counting method can detect the size and count of small particle that contaminate in parts. The principle is the detection of light (laser) scattering by spectrophotometer that passes the particles in liquid. The reflect angle and intensity of signals are convert to size and count of particles (LiQuilaz-S).

The LPC measurement contain with two steps. The first step in testing the cleanliness of irregularly shaped part is the particle extraction (in to liquid). There are three traditional methods: high pressure spray, sloshing or swirling, and ultrasonic extraction. The detail of particle extraction can see in (Dwight Beal, 2004). The second step is the count of particles number that is contained in liquid from first step by the liquid particle counter instrument. The hard disk drive arm coil show in figure3 The LPC test methods for hard disk drive arm coil are:

1. Cut the PCB from the sample and drop the glue into the bearings hole wait for the glue was to dry

2. Clean 1000 ml beaker with DI water using brush.

3. Fill 9000 ml DI water in to beaker then put it in to 68 KHz ultrasonic tank for 1 minute and check the particle in the beaker with particle counter for blank value.

4. Hang the sample and soak it into the beaker with fishing line. Then perform one minute of ultrasonic again. When the ultrasonic finish, remove the sample and put an ultra clean Teflon - coated magnetic bar in to the beaker.

5. Insert in to the particle counter. The number of particle in the sample can calculate by

[particle count - blank] x 900 ml

[10 ml x sample surface area].

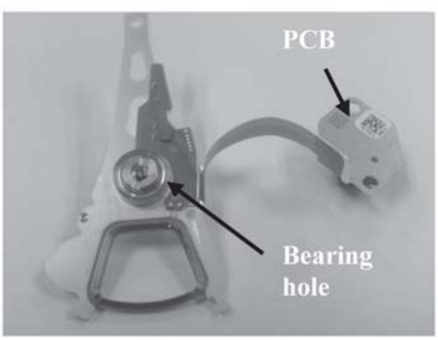

Figure 3. Hard disk drive arm coil

Pilot Experiment to Assess the Measurement Capability

We studied the measurement capability of LPC test with hard disk drive arm coil at LTEC Company. The 20 lots of sample and 2 operators were chosen for the study. The procedures are as follows.

1. The first operator measures the LPC counts for 10 lots in random order and repeats the measurement 3 times (specimens) for each lot.

2. The second operator measures the LPC counts for another 10 lots in random order and repeats the measurement 3 times (specimens) for each lot.

3. The total of 60 LPC counts reporting values were collected. The nested gauge R&R was determines as shown in Figure4 and Table1.

The R-chart in Figure4 shows, the level of variation within each lot appears to be dramatically out-of-control and that the variation from the measurement is high. The ‘X chart shows the process, part, variation.

Figure 4. The graphical result of GR&R study

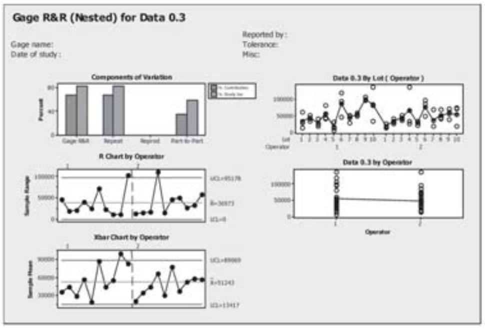

Table 1. Standard deviation result

Source	StdDev (SD)	Study Var (6*SD)	%Study Var (%SV)
Total Gage R&R	24833.4	149001	81.35
Repeatability	24833.4	149001	81.35
Reproducibility	0.0	0	0.00
Lot-To-Lot	17753.8	106523	58.16
Total Variation	30527.0	183162	100.00

Table1 shows which the GR&R is unacceptable because the %GR&R is 81.35% exceeded 30% according to the AIAG measurement system analysis criteria. (AIAG, 2002).The largest relative to the measurement system variability is the repeatability error of 81.35%. The reproducibility estimate to be 0% because the reproducibility is very small when compared with the repeatability. The results suggested that this measurement system needs improvement.

Process Improvement

After investigation the cause effect diagram was drawn showing the various causes which might be affecting the LPC measurement process. Then the experiment was done to confirm the effects of the environment and process variation sources. The hypothesis that the contamination due to the environment. An experiment was conducted to compare the LPC count in to samples, close and open beakers of DI water. If the environment affects the measurement, the LPC counts collected from two beakers must be significant. The two sample measurements were collected from both beakers for 5 days. In environment source experiment we use two sample t-tests and ANOVA to analyze the effect of laboratory atmosphere. With the 2 sample t-tests the null hypothesis is H_0: Average LPC counts (open) = Average LPC counts (close) and the ANOVA null hypothesis is that the mean LPC values of the 5 days of DI water are equal. The result from the experiment showed the significance p-value of 0.014 whereas the two sample t-tests is not significant. This showed that the environment has no significant effect between two beakers but the day different is significant. This means that the measurement made from same source were different. That also means that the atmosphere in the laboratory is very different in the different day. Another experiment was conducted to analyze the affect of DI cleaning conditions in the process of final cleaning machine. The 3 conditions were before cleaning, after cleaned 5000 parts and after cleaned 10000 parts. The ANOVA null hypothesis is that the mean LPC values of the 3 conditions are equal. Parts with same cleanliness were cleaned by those different DI water and test for LPC counts. The null hypothesis was rejected at 0.01 significant. Suggesting that there are different LPC values resulted from using cleaning water at different time.

From Figure5 there are 4 main sources of variation containing the method, environment, process variation and the different of operator. In our study 2 main sources of variation are method and the different of operators are chosen for improvement using Taguchi DOE. The other 2 main sources were controlled by cleaning the parts in with new DI water at final cleaning machine and run the total experiment in 1 day.

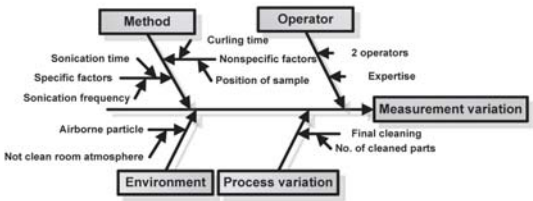

Figure 5. Cause effect diagram of LPC measurement variation

Tguchi doe analysis

Taguchi introduced the concept of robust design and Signal-to Noise ratio. From the series of practical applications, it has been demonstrated that by analyzing these S/N ratio, it is possible to identify the setting of the design factor that is optimal in the sense of reducing variation over noise factor while keeping the response of interest on target. In the experimental control and noise factors were chosen and the Signal to Noise ratio (S/N) is used to analyze the data. There are 3 types of S/N ratio.

1. Smaller- the better
2. Lager- the better
3. Nominal- the best

The levels of control and noise factor are contained in the Orthogonal Array (OA). Orthogonal array depended on the levels and number of factors. There are many orthogonal arrays in Taguchi DOE (Byrne).

From the LPC measurement process method the nonspecific factors of LPC test method are chosen and controlled by cleaning the parts with new DI water at final cleaning machine and run a total experiment in 1 day. The control factors are the curling time, the position of sample and the noise factor which is the different of operator. There are 2 factors with 3 levels each. Table2.demonstrated the Taguchi experimented plan. An experiment with 18 runs of

Table 2. Factors and levels of Taguchi DOE

Factor	Level 1	Level 2	Level 3
Curling time (A)	2 hr	4 hr	6 hr
Position (B)	Bottom	Middle	Top
Operator (noise)	1	2	

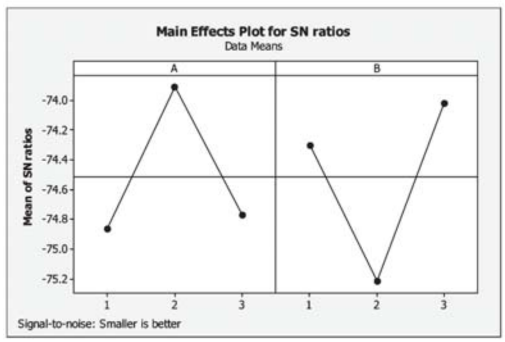

Figure 6. S/N ratio of factor

Taguchi DOE with S/N smaller the better is used to analyze the data. The result in Figure6, showed the graph of S/N ratio where A denotes the curling time factor and B denotes the position of the sample. The S/N ratio for curling time at 2, 4, 6 hour are -74.86, -73.91, -74.77 respectively and for position at bottom, middle, top are -74.30, -75.22, -74.02 respectively. The ANOVA result of noise factor (2 operators) shows that the operators are not statistical significant with the p-value 0.718.

Table 3. ANOVA of noise factor

Source	DF	SS	MS	F	P
Operator	1	0.94	0.94	0.14	0.718
Error	16	111.14	6.95		
Total	17	112.08			

The optimal conditions by Taguchi DOE are curling time that is 4 hr (level 2), Position of sample that is bottom (level 3) because they have a maximum S/N ratio. The different of operators are not effective in the measurement because there are not statistical significant.

VI. Second GR&R Experiment

The second GR&R study was studies on different product. Because we strong believe that the results after the first GR&R study have an effect in GR&R study in the other products. In the second GR&R study product "Nighthawk 1 H arm coil" are chosen. The experiments run with the same method as the first study. Control the environment variation with run the total experiment in one day. The result of the second GR&R study shows in the Table4.

Table 4. Standard deviation result

Source	StdDev (SD)	Study Var (6*SD)	%Study Var(%SV)
Total Gage R&R	901.33	5407.96	65.89
Repeatability	901.33	5407.96	65.89
Reproducibility	0.00	0.00	0.00
Lot-To-Lot	1029.09	6174.54	75.23
Total Variation	1368.00	8207.98	100.00

Table4 show the %SV (%P/TV) is 65.89% reduced from 81.35% but still greater than the standard of 30%. The investigation has been focused on the methodology of the LPC GR&R measurement by considering an effect of DI cleaning water itself at final cleaning. In the past, operators would not consider this factor and will collect parts for GR&R study by gathering HDD arm from different cleaning batch. This will lead to non-homogenous batch variation and violate the destructive testing assumption we made at the beginning.

VII. Conclusions

From the result of GR&R study the LPC measurement process is unacceptable because the %P/TV (%SV) is exceeded 30% by AIAG measurement system analysis criteria. The results suggest that this measurement system needs improvement. The large variations come from the repeatability. The four main sources of measurement variation are listed to cause effect diagram from investigation and conducting experiment. The factors (curling time and position of sample) in LPC method are chosen for the study by Taguchi DOE. The optimal conditions are the curling time is 4 hour and the position of sample is the bottom. The different of the operators are not effecting to the LPC measurement. However we cannot confirm the optimal condition from Taguchi DOE because LTEC company stop the production line of "Nighthawk 1 H hooks up" between the studies. So we are decided to study in another product. Because we strong believe that the results after the first GR&R study have an effect in GR&R study in the other products in the LTEC company. In the second GR&R study product "Nighthawk 1 H arm coil" are chosen. The experiments run with the same method as the first study. Control the environment variation with run the total experiment in one day. The result from the second GR&R study showed the reduction of %P/TV (SV) from the first GR&R study. The %P/TV (SV) is decreased 15.46%. This is show that the cleaning methodology, environment at the final cleaning process has an effect to LPC measurement. The expertises of the operators are also an important aspect. The ongoing research is now investigating the factor of DI cleaning water at final cleaning itself. The parts collected from different cleaning time showed significant cleanliness. This suggested that the homogenous part must be chosen base on cleaning history. The GR&R methodology to select part will be studied and reported systematically.

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