Predictive Maintenance Framework for Hard Disk Media Production

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ABSTRACT

Manufacturing yield control for hard disk media is getting tougher. This is proportional to the tremendous increases of its bit/inch^2 storage capacity. With the significantly difficult lithography process will be involved and drastically increase in number of product total output volume that will be required in near future, conventional maintenance type is no longer feasible. This paper proposes a novel framework for the implementation of predictive maintenance in hard disk media production. A novel technique to visualize the temporal data into pattern that can be trained with machine learning algorithm is introduced. Predictive models were produced after dealing with imbalance datasets issue, ensemble datasets and data cleaning. Experimental results have indicated that the proposed framework is successful.

Keywords
Hard Disk Media, Pattern Media Disk, Predictive Maintenance

1.0 INTRODUCTION

Perpendicular Magnetic Recording (PMR) hard disk media had been introduced to temporarily overcome the limitation of Longitudinal Magnetic Recording (LMR) hard disk media due to the superparamagnetic phenomenon. While PMR Media helps to extend the limitation of LMR from 100 ~ 150 Gbit/inch^2 up to 500 ~ 1000 Gbit/inch^2, however PMR media will start to reach its end by the year of 2010 ~ 2011. Thus, new technology is totally required to fulfill the market demand for the bigger than 1 Tbit/inch^2 hard disk storage capacity (Bandic, Dobisz, Wu and Albrecht, 2006).

Consequently, Pattern Media (PM) disk is needed to overcome the limitation that PMR media inherits from LMR media for a longer period. However, PM disk technology remedy the superparamagnetic phenomenon but yet offers another different issues and challenges that need to be solved before being able to be applied in large scale production. One of the major issues is whether the best lithography technology candidate for PM disk fabrication offer by nanoimprint lithography will be able to surpass the production cost (Terris, Thomson and Hu, 2006).

According to Hofemann (2006), the cost to pattern a single layer at 45m node with 193 nm dry lithography processes is around 20 to 25 USD. However, we need to pattern two layers of them for a single hard disk media and yet to include another additional cost such as process of pre-cleaning, double-sided patterning, etching, post-cleaning, inspection and metrology. Furthermore, the additional cost due to the lithography process must not exceed 1 to 2 USD per disk from existing hard disk media price.

The good news is that, according to Hofemann (2009) the hard disk drive industry in 2007 produced about 800 million magnetic media and it is forecasted to grow nearly 1.8 billion by the time PM disk is in production on 2013. Higher throughput of hard disk media production will definitely pushing the lithography cost way down to the acceptable level price. However, with significantly difficult processes, higher volume and throughput manufacturing lines, better production yield and quality control system are very crucial to maximize the total number of production outputs. Therefore, conventional production equipment maintenance practice is no longer feasible, and hence a proactive type of maintenance practice such as predictive maintenance is unavoidable.

2.0 BACKGROUND OF RESEARCH

2.1 Hard Disk Manufacturing

Figure 1 illustrates the typical process flow of PMR hard disk media manufacturing line. The figure and its explanation is drawn based on the author’s 10 years working experience in the hard disk media manufacturing factory. The process from Mechanical Texture until Surface Finishing performs its specific roles in fabricating a hard disk media, whilst Test & Visual Inspection equipment evaluates the finished disk, and Seal and Packing machine prepare for the good disk to be shipped.

2.1.1 Mechanical Texture

This is the process to create optimum roughness and circumferential cross angle texture pattern. The texturing pattern created assisting the smooth placing of magnetic layer on the substrate disk during sputtering process. The surface

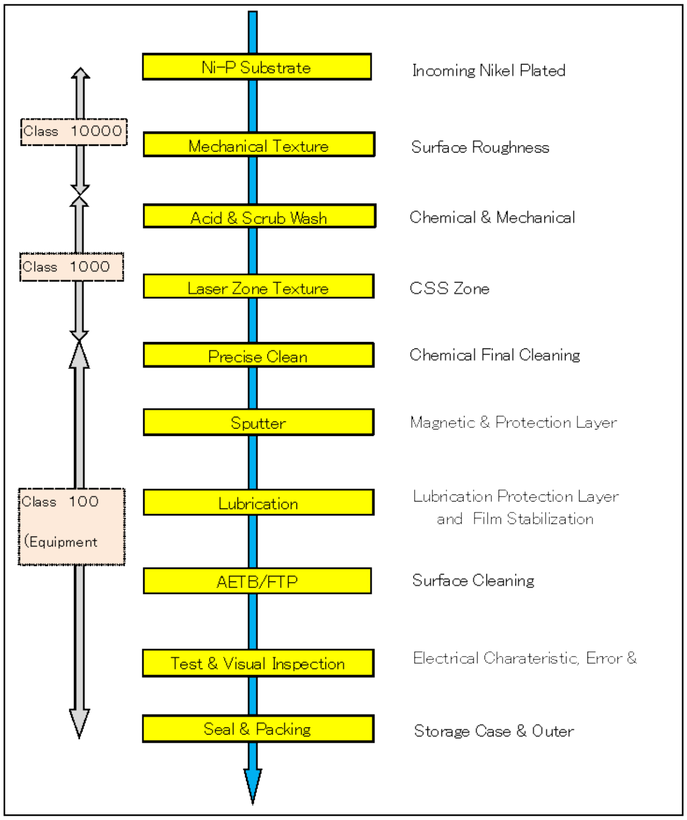

Figure 1: Typical PMR process flow in hard disk media factory

roughness also improves the smoothness of read/write head gliding on top of the hard disk media surface without sticking on it. Engineers need to monitor the equipment configuration to make sure that both side of the disk roughness are uniform. It is important that the texturing remnant on the process materials such as texturing tape and abrasive grain slurry will not cause scratches on the other disk surface.

2.1.2 Acid and Scrub Wash

This cleaning process uses special sponges to mechanically scrubbing and chemically cleans the disk surface from contaminants. Engineers need to make sure that the equipment is clean and configured accordingly. They periodically change the sponges and chemical before it introduces unwanted contaminations and scratches on the disk surface by residual foreign substances.

2.1.3 Laser Zone Texture

Laser zone Texture (LZT) creates a band of bumps texture at the internal diameter area of the disk. The texture is important to create reliable Contact Start Stop (CSS). CSS is the test of the read/write head by the time it is started to move and stop. The LZT zone texture acts as the head parking zone and avoid from the head sticking on the hard disk surface. Engineers need to make sure that the equipment setting creates the bump orientation, pitch, shape, and height are created according to specification.

2.1.4 Precise Clean

This process mechanically and chemically removes smaller contaminants from the disk. It is very important to make sure that the disk surface very clean before sputtering multiple layers of films on the disk surface. Engineers need to periodically monitor and change the *isopropyl alcohol* (IPA) vapour before it can contaminate the disk.

2.1.5 Sputtering

Sputter is the core process of the hard disk media. It is basically creates 3 main thin coating film layers on the disk surface. Chromium layer acts to adhere to the magnetic alloys and enhances magnetic properties, where cobalt layer acts as the magnetic layer to store digital data and the thin and hardens carbon overcoat layer protect magnetic layer from wear and corrosion. Sputter process equipment require highly skill worker to run and monitor the processes. The engineers and technician need to periodically monitor the magnetic properties, film thickness, film uniformity and may others. Proper planned and good quality of periodical sputter equipment maintenance is very important to avoid unnecessary down time (unplanned down time).

2.1.6 Lubrication

Lubrication process coats the lubricant agent on top of the carbon overcoat protective layer. The coating film is performs with a dipping machine where several numbers of sputtered disks hang-over and dipped. The lubrication agent helps to control the disk surface friction resistance and improve the hygroscopic issue. Engineers should monitor the film thickness, stability, concentration, temperature and dipping time parameter in order to holds the optimum characteristic.

2.1.7 Surface Finishing

Surface finishing process uses ultra fine abrasive coating tape material to remove (burnish) microscopic dust or protrusion exists on the disk surface. Finished surface treatment also uniforms the lubricating film. The process must use good quality abrasive coating cloth/tape and properly configured burnishing setting condition. Engineers and technicians need to make sure that the process will not introduce scratches on the disk.

2.1.8 Testing and Visual Inspection

Testing machine measures the electrical signal characteristic to check the existence of microscopic protrusion or surface defect. Visual inspection machine works seeking for scratches or surface defect on a disk surface. Basically tester machine performs Glide High Test (GHT) and Read/Write (RW) test on a disk to decide whether it is to be classified as good or bad disk.

GHT performs to seek for any foreign matter, protrusion, etc. on the disk surface. At a certain disk rotation speed, head raises at certain small amount of height. If any unwanted size of particles or protrusion exists, the head crashed and vibrates. The sensor at the head detects the vibration as signal and makes the counts of the crash as hits count. The head also records the coordinate of the crash location. On the other hand, R/W test checks for the bad magnetic conversion and signal quality characteristic that are exists on certain location of the disk.

The defect detected by GHT and R/W test at certain location of the disk generates visual patterns. For example, if a pattern visibly looks like 'S' thus they name it 'S Pattern Defect'. This information will be uses by Failure Analysis (FA) and Production people as a feedback to find for the potential culprit and to perform process trouble shooting.

2.1.9 Seal and Packing

In this process, the finished good disks are removed out from the process carriers or cassettes (each carrier contains 25 pieces disk) and filled into shipping carriers. The shipping carriers covered with top and bottom cover to protect the disks from contamination. Then, those shipping carriers will be inserted into an aluminum pack (2 carriers per pack). The aluminum packaging with the shipping carriers will be vacuumed, sealed and packed into boxes. The shipping carriers must be very clean and the tightly seal inside the aluminum packing without any air leaking allowed.

2.2 Maintenance Types

Maintenance is define as the process of maintaining an item which is in operating state to prevent it from the transition to failure state or to restore it back from failure to operating state (Krishna, 2008).

This definition in other word is the act of "preventive" and "corrective" maintenance. Furthermore, these two maintenance types can be classified according to the Figure 2 (The maintenance concept, 2007).

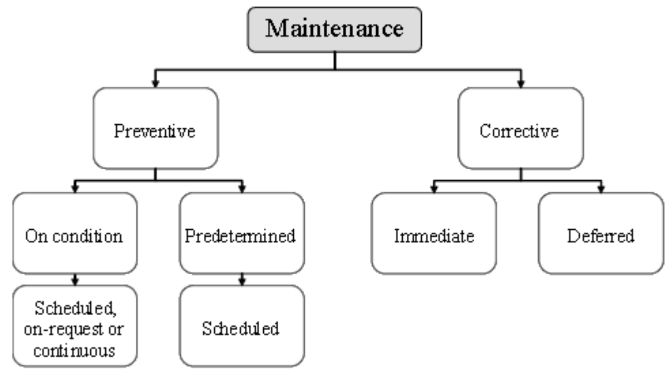

Figure 2: Maintenance class types.

Preventive maintenance is defined as maintenance activities that are carried out at a predetermined periods with the intension to reduce the probability of failure due to the estimated degradation of equipments functioning. Preventive maintenance can be divided into predetermined and condition base/predictive maintenance.

Predetermined maintenance is also called as schedule maintenance where it is carried out in a certain specified time interval without previous condition investigation been taken into account. On the other hand, predictive maintenance can be defined as a maintenance activities that is proactively performs following a forecast derive from the data analysis and evaluation of the equipment degradation parameters.

Finally, corrective maintenance is the maintenance activities performs base on failure driven concept. The corrective action to change the faulty state is being done immediately or delayed according to certain maintenance rules.

2.3 Predictive Maintenance

The condition of all machines degrades from time to time with usage and age and if without maintenance action is taken, this degradation process will end up resulting in a machine failure (Yang, Djurdjanovic and Ni, 2008). Equipment costs contribute the biggest majority of total costs for semiconductor manufacturing. Therefore, maintaining high equipment availability has been considered as one of the major goals in the industry (Sheu and Kuo, 2006).

Corrective maintenance disturbs normal production hour, hence manufacturer will suffer a great loss with some potential safety problems. Predetermined maintenance which demands examination and services base on schedule interval in spite of the condition of equipments, is superfluously a waste of equipment resources, labour cost and production material resources (Huang, Li, and Irwin, 2006).

Equipment failures interrupt the normal manufacturing process and lack of timely maintenance could result in significant loss of productivity hence decreasing the profits of the manufacturer. However, excessive maintenance can eliminate downtime caused by equipment failure, but the cost of maintenance will increase which will reducing profits. Thus, appropriate maintenance strategy is necessary for the equipment to run in the most cost effective way (Yang, Djurdjanovic and Ni, 2008).

Most of the case, 99% of equipment failures are preceded by certain indicator. Thus, predictive maintenance is probably the most economical way to maintain equipments. The idea is to determine equipment status in a real-time manner, and therefore faults can be predicted before they happen. The maintenance activities then can be scheduled as required. It is reported that predictive maintenance reduced downtime, maintenance costs, and unexpected catastrophic failures (Lin and Tseng, 2005).

Predictive maintenance reduces the uncertainty of maintenance according to the needs which was analyzed from the equipment condition. These valuable results could be used as input to an integrated maintenance management system. This enables to pre-plan and pre-schedule maintenance work, reducing inventory costs for spare parts, cutting down unplanned forced downtime and minimizing the risk of unexpected catastrophic failure (Yam, Tse, Li and Tu, 2001)

The ability to predict the equipment preventive maintenance (PM) timing will not only helps optimizing equipment uptime but also minimizing negative impacts on manufacturing production efficiency (Sheu and Kuo, 2006)

3.0 PROPOSED FRAMEWORK

Figure 3 shows the proposed framework for the hard disk media predictive maintenance model. The objective of this predictive model is to predict the defect (the highest contributor) that is likely to occur. Production engineers then will arrange a maintenance schedule on a specific machine that is most likely the root cause of the predicted defect. These defect types vs. machines/process relationships library were compiled by Failure Analysis (FA) engineers.

The historical temporal data of GHT and R/W attributes vs. defect classes generated from tester machine were collected by a program and stored in a database. Normally this data will be used by engineers to be plotted in several numbers of charts then manually identify for any interesting trend and pattern. As the chart is used to visualize the trend and pattern for the eyes of engineers, we introduce a novel technique to visualize the pattern for computer learning algorithm or machine learning algorithm.

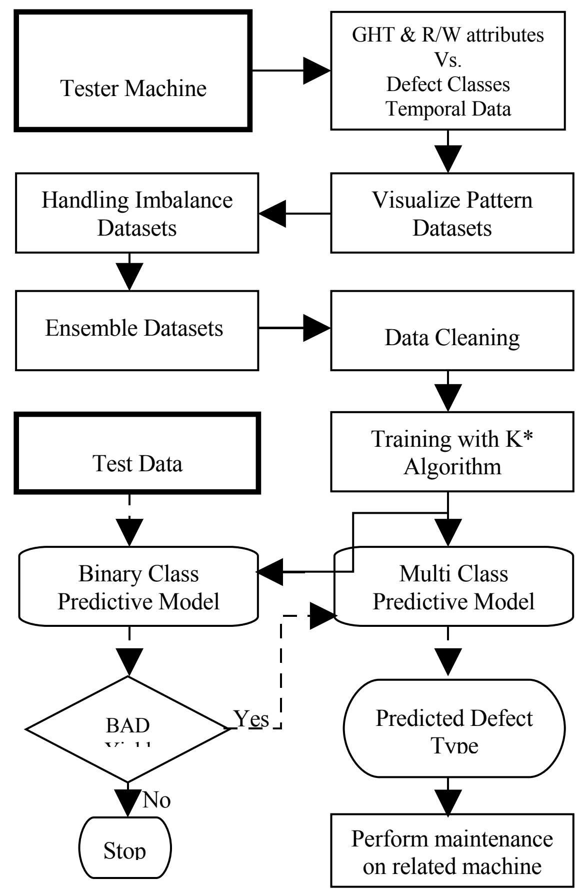

Figure 3: Proposed hard disk media predictive maintenance model framework.

It is a norm that in manufacturing the dataset is susceptible to the imbalance issue. For example in binary class, information from bad yield is less abundance compare to good yield class. This skewness generates bias learning result towards the majority instances (good yield). A synthetically generated data re-sampling technique data will be used in order to balance up the skew datasets. After that we will ensemble various synthetic re-sampling approach to improve its F-score and robustness. The ensemble datasets need to be cleaned by removing any redundant and noisy data with data cleaning algorithm before being trained with learning algorithm. The learning algorithm will then train the datasets to generate Binary Class Predictive Model and Multi Class Predictive Model. The Binary Class Predictive Model will be used for bad yield or good yield prediction (in our case, yield <85% is bad) as a threshold. If yield is detected as good, it will be ignored. If the bad yield is predicted, Multi Class Predictive model predict the likely defect that will be occurred. Base on the defects vs. machines/process library established by FA engineers, production engineers will make an arrangement to perform maintenance on the specific machine or process. The experiments and results of the proposed framework are discussed based on our previous published results, in the following section.

4.0 RESULT AND ANALYSIS

4.1 Binary Visualized Pattern Dataset

Binary visualized pattern dataset were proposed by Megat and Shaidah (2008a). The pattern is represented by the uptrend with '1' and downtrend with '0'. For example, 8 bit visualized pattern will produce 256 set of possible pattern that can be related with each instance attributes. They reported that the combination of K* learning algorithm and 12 bit visualization datasets giving the best result of class precision and recall. They claimed that the novel technique of visualizing the pattern with the proposed binary bit visualization for machine learning algorithm is feasible to be used to predict future manufacturing yield.

However, the bad yield class recall prediction performance was limited at around 30% even with higher visualization bit value. This was due to the imbalance nature of manufacturing datasets. It is a norm that the data produce by manufacturing will have a high degree of skewness between good and bad yield. Re-sampling technique such as Synthetic Minority Over Sampling Technique (SMOTE), random oversampling minority instances and undersampling majority technique was suggested to handle the imbalance dataset issue.

4.2 Handling Imbalance Dataset

Megat and Shaidah (2008c) proposed the application of K* based entropy similarity distance function to be integrated with novel technique of Synthetic Minority Oversampling Technique + Synthetic Majority Replacement Technique (SMOTE+SMaRT). They concluded that that K* based entropy similarity distance function perform better than Value Distance Metrics (VDM) similarity distance function algorithm (Megat and Shaidah, 2008b) for generating new instances from visualized datasets. The novel technique of SMOTE+SMaRT also improved the classification robustness compared to previous (Megat and Shaidah, 2008b) SMOTE +VDM and undersampling approaches.

Even though SMOTE+SMaRT performs better at most of the time, other technique such as SMOTE+Undersampling and Undersampling show their strength at certain test data. Thus to in order to improve the performance further, they suggested to combine several difference datasets which were the best classifiers performers at respective test data, to be trained as one classifier.

They also concluded that a best method on how to handle with the redundant, borderline, noisy instances and also to effectively generate synthetic instances are important in order to improve the class precision without sacrificing class recall of the minority instances

4. 3 Ensemble Datasets

The experiment results done by Megat and Shaidah (2008d) conclude that, multiple base classifiers stacking did not producing better prediction performance to the single data set. However by stacking the multiple data sets, the prediction performance improved better result even with single base-classifier. Multiple stacking data sets performs better by removing the redundant good yield instances with Condensed Nearest Neighbour integrated and K* distance function (CNN +K*) algorithm. However by applying Tomek Link+K* distance function algorithm to remove the noisy and borderline good yield instances, the classifier testing result deteriorate but fixed at a same performance number with different algorithm.

The authors concluded that better prediction performance can be obtained by stacking multiple data sets and keep it up to date to the current and similar (same manufacturing area) batch data sets. It seems that removing noisy and borderline instances with Tomek Links was not successful which causing different algorithm performed the same at lower performance. They suggested than be removed by applying different algorithms (Megat & Shaidah, 2008d).

4.4 Trinary and Quinary Visualized Dataset

On dealing with multiclass classification Megat and Shaidah (2009) compared previous binary visualization technique Megat and Shaidah (2008a) with trinary (base-3 numbers) and quinary (base-5 numbers) to represent the trend pattern of GHT and R/W temporal data. They claimed, the performance of the multi class classification can be improved when all class instances were made higher quantity and balance.

However, the exact balances amongst class instances will not necessarily generate same level of class Precision and Recall (P&R) performance. Hence, they suggest that a study on each class instances behavior on how theirs instances affects the P&R performance is important in order to generate a "healthy skewness". They conclude that, in order to perform better in a higher number of "balanced" multi class instances, quinary visualized pattern is the best technique to be used compare with binary and trinary visualized pattern. The application of SMOTE + SMART to synthetically increase the number of the multiple class instances should be able to increase the overall P&R performance. As previously done with binary class datasets, stacking several difference multiple class datasets may able to generate better P&R and robustness predictive model.

5.0 SUMMARY

The predictive maintenance framework for hard disk media was introduced. With this, it will help future Pattern Media manufacturer to implement better production yield and quality control system through predictive maintenance system, through maximizing the total number of production outputs. This is very crucial for the hard disk drive technology to remain as the leader in memory storage industries.

6.0 ACKNOWLEDGEMENT

This research is supported by Ministry of Higher Education Malaysia under FRGS grant for a project entitled "Intelligent Predictive Maintenance System for Hard Disk Media Manufacturing Using Data Mining Approach".

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