An Investigation of Shipping Comb Failures due to usage in Manufacturing Processes using RCFA and FMEA

Atjanakul W, Chutima S. and Kamnerdthong T.

***Abstract*—**Shipping comb is mounted on Head Stack Assembly (HSA) to prevent collision of the heads, maintain the gap between suspensions and protect HSA tips from unintentional contact damaged in the manufacturing process. Failure analysis of shipping comb in hard disk drive production processes is proposed .Field observations were performed to determine the fatal areas on shipping comb and their failure fraction. Root cause failure analysis (RCFA) is applied to specify the failure causes subjected to various loading conditions. For reliability improvement, failure mode and effects analysis (FMEA) procedure to evaluate the risk priority is performed. Consequently, the more suitable information design criterions were obtained.

***Keywords*—**Shipping comb, Hard disk drive, Root cause failure analysis, Failure mode and effects analysis

I. Introduction

PRODUCT reliability is crucial for both manufacturers and consumers [1]. Reliability engineering is vigorously applied to the manufacturing processes and the products. Chronic and sporadic failure events of systems, machines and components should affect the production cost, the production plan and the production target. Considerable methodologies based on logical disciplines were established to deal with product and/or component failure [2]. RCFA and FMEA are reliability based techniques that eliminate the causes or continuously reduce their potential occurrence [3], [4].

Root cause failure analysis (RCFA) is the sequence of step analysis technique that leads to investigating and solving the problem of component or mechanism reliability problem. This tool is effective for finding the latent causes of component failure, identifying causes of deviation of machine performance, economizing the operating cost and developing the regulation to eliminate reoccurrence of failure [5]. Steps to RCFA performing are event reporting, data gathering, root cause analysis, proposition the corrective action, verifying the actions and reporting. Effective approaches providing graphical analysis are fish bone diagram, sequent-of-event, logic tree and etc. Data gathering is the most important step because incomplete information may leads investigator to achieve the incorrect root causes. Failure Mode and Effects Analysis (FMEA) is the designed evaluation method to specify possible failure modes and their effects on the performance [6]. Typically, FMEA uses historic operating evidence as database for future improvement. This increases product reliability and obtains reasonable product design [7]. FMEA procedure uses risk priority number (RPN), risk index, to determine the failure severity on each area. Improvement strategy would be established following the RPN index. Highest RPN event receives treatment primary. To sustain the procedure, performance review and risk index evaluation must be observed coherently.

This work presents incorporated process of knowledge such as operating review, failure information and experimental investigation into the assessment tools that provide latent cause of failure and identification of failure-risk area needed for design improvement. A case study on the failure of reused tool that is essential in HDD manufacturing process was studied. Combination of RCFA and FMEA approaches is employed to treat the problem sustainably.

II. Characteristic and function of Shipping comb

In hard-disk drive assembly process, Head stack assembly (HSA) is combined with read/write disk, controller, top cover, base cover and fastener to achieve the completely operative hard-disk drive. HSA has the significant and delicate components which are installed on the tips of HSA, called read/write head or slider. Each HSA may consist from 2 sliders up to 8 sliders depend on the capacity of HDD. After sliders were installed, shipping comb is mounted on HSA to protect the slider from undesired contact damaged during the assembly process, storage and transportation. Additionally, shipping comb is utilized to prevent collision of the heads and maintain the gap between suspensions. Semi-conductive composite polymer material (insulated polycarbonate blended with additive of carbon nanotubes and carbon black) is employed for shipping comb to avoid ESD issue. Each comb is reused until failure is detected. HSA components were showed in fig. 1. Shipping comb is functional designed to be a single member that consist of 6 areas as indicated in fig. 2. Comb holder provide the operator holding area of shipping comb and the specifying area for component information such as batch number, related HSA model and manufacturing date. Comb shaft is used as a rotating axis of the component to swings between idle and locked position. The comb datum provides the reference contact position between the shipping comb and the HSA when shipping comb is driven into locked

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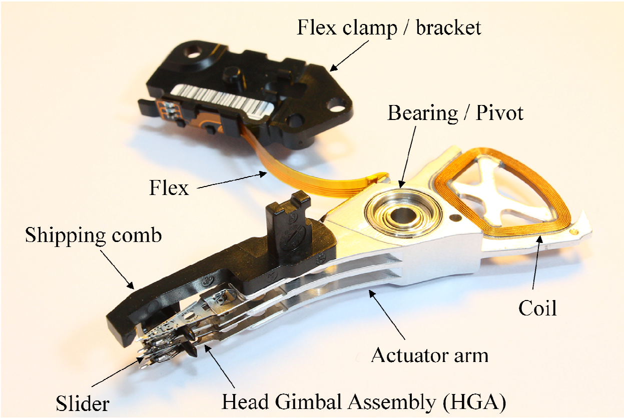


Fig. 1 HSA assembling with shipping comb

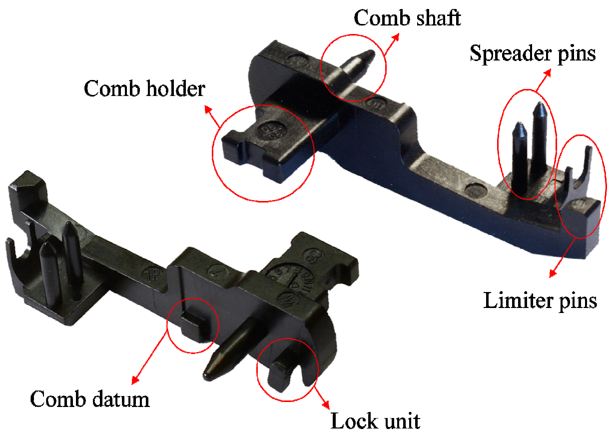


Fig. 2 Shipping comb

position. Lock unit perform the holding action between shipping comb and HSA. Spreader pins is used to maintain the gap between suspensions and prevent collision between the sliders. Limiter pins retain the sliders from surrounding impaction such as operator movements, machines, containers and fixtures.

Two processes of Hard-disk drive production involved shipping comb tool are HSA assembly process and drive assembly process. Comb is introduced to the production line in HSA assembly process where reused and replacement combs are mixed. Damaged shipping comb is rejected during HSA subassembly process by operator using visual inspection. After passed the HSA assembly process, HSA mounted with shipping comb is transport to drive assembly process. In this process, shipping comb is removed out prior to install HSA with others component to obtain the complete hard-disk drive. The removed shipping combs, no matter which HSA model used, were packed together in the Electro Static Discharge (ESD) protected parcel. The parcels were return to the classification procedure to determine the HSA model and packed separately for inspection. Special equipment named go-no-go gauge is used to eliminate failure comb based on the deformation persisted. Passed shipping combs were submitted to the cleaning process. Multi-cleaning methodologies including deionized water, chemical solvent and heated drying

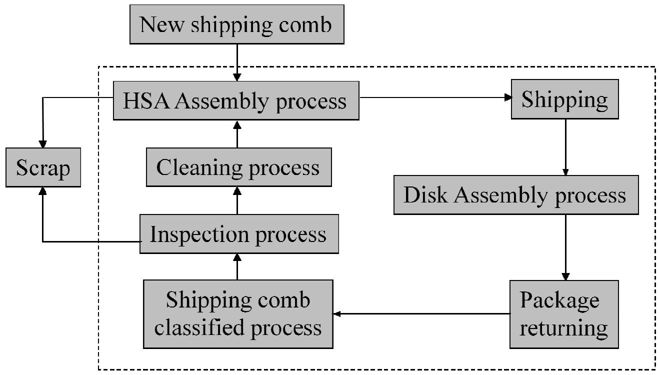


Fig. 3 Cycle of reused shipping comb

were used to clean up the contamination. Cleaned shipping comb were reused in the HSA assembly process again, as shown in fig. 3. All the processes mentioned provide various load types acting on shipping comb through the cycle. These loads were static load, impact load, vibration, heat, chemical load and humidity that influence the failure of shipping comb.

Replace the fail shipping comb by the new shipping comb should increases manufacturing cost. Reliability improvement of the comb is one of the ways to solve the problem. RCFA procedure is applied to HSA assembly process to seek the latent cause of the failure. Due to the complexity of the process, circumspect and careful analysts would be performed by strictly following the RCFA manual. All factors conducting the failure must honestly considered involving the actual root cause indentifying.

III. Assessment

A. Root cause failure analysis

By scoping, an encounter problem is the shipping comb failure under typical use in HSA assembly process. The failure occur on Limiter pins, Spreader pins, Lock unit and Comb shaft which the major failure type is plastic deformation greater than the acceptable range and the minor is fragility. These could affect to the failure of HSA, especially the read/write heads during HSA assembly process. The factors throughout the cycle that may be the cause of shipping comb damage are the shape and dimension of the component, mechanical and thermal loads, chemical treatment and operator handling. These are defined as considered boundary to determine the root cause.

The failure of shipping combs is 4.088 % of average daily used which 1.125 % was found at the inspection process and 2.963 % was found at the HSA assembly process. For the shipping comb failure on each area inspected, 70 % are at the limiter pin, 20% are at the Lock unit, 7.5% are at the spreader pins and 2.5% are at the comb shaft. Damage review indicated that Limiter pins, Spreader pins and Comb shaft are cantilever shaped and having plastic deformation in bending mode. Lock unit shows failure from plastic deformation in bending mode and fracture caused by mechanical load, fatigue load and material creeping. Fig. 4 illustrated failure on each part of the shipping comb.

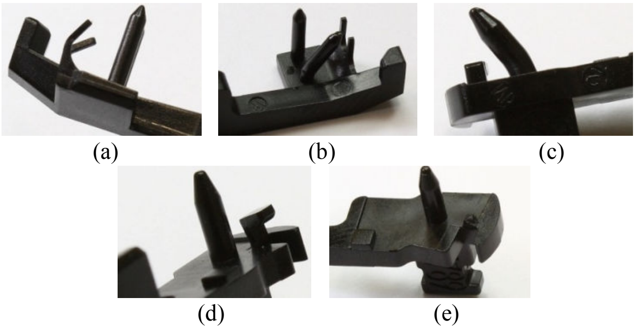


Fig. 4 Failure on (a) Limiter pins (b) Spreader pins (c) Comb shaft (d) Bended Lock unit (e) Broken Lock unit

Design review is to documents the design specification of shipping comb, planed operating condition, detail of inspection instrument, shipping comb's material specification that evaluate the information validity. Review comparison between designed and manufactured shipping comb including the inspection instrument show the consistency of geometries and functions. In cleaning process, chemical detergent and deionized water are used to remove scratched carbon contamination on shipping comb surface. This is essential to avoid the contamination concerned of HSA. Chemical supplier confirm that the product do not react on material properties of shipping comb anyhow.

Moreover, combs are bathed in approximately 50 ^{o}c heated deionized water incorporate with ultrasonic vibration for 15 minutes. Then, combs are blown with 80 ^{o}c hot air for 5 minutes, baked at 65 ^{o}c in the vacuum oven for 5 minutes and blown with 75 ^{o}c hot air for 15 minutes to keep the shipping comb dry. All operating temperatures for drying are lower than the heat deflection temperature (HDE) of material following ASTM D648 standard. Operators handling these combs were trained in their responsibility until get the expertise before actual operation dealing gently with all equipments and products that minuscule size and fragility. Unfortunately, packing of used shipping comb is unorganized, models are mixed and untidy overlaid in the package. This may be one of the factors that involve comb's failure. Design review information is prepared for the validation of application/maintenance review and incorporated with test and measurement to identify the failure causes.

To complete the information, additional measurement and observation were practiced. Thermo gravimetric analysis (TGA) and Fourier Transform Infrared Spectroscopy (FTIR) approaches are tested to confirm the material compound with the supplier datasheet [8], [9]. Difference material properties between tested specimen and supported data sheet may cause failure in normal operation. In fig 5 and 6, results show that tested compound corresponds to supplier designed data.

To study the surface behaviors due to thermal effect, micro-hardness technique was employed to investigate how significance difference the statistic surface hardness level between new and rejected shipping comb is. Vickers hardness indentation (Figure 7) with statistically significance level 0.05 one–way ANOVA (figure 8) was used. New combs show

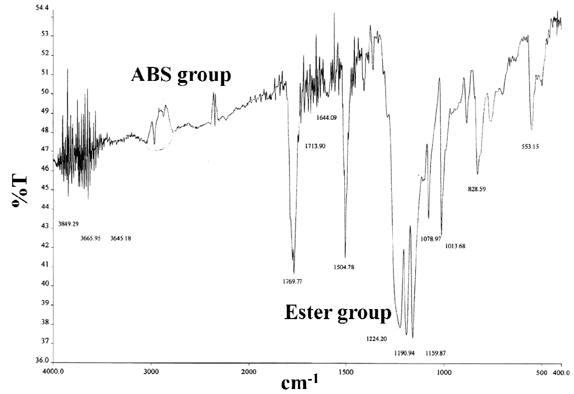


Fig. 5 Result of FTIR experiment

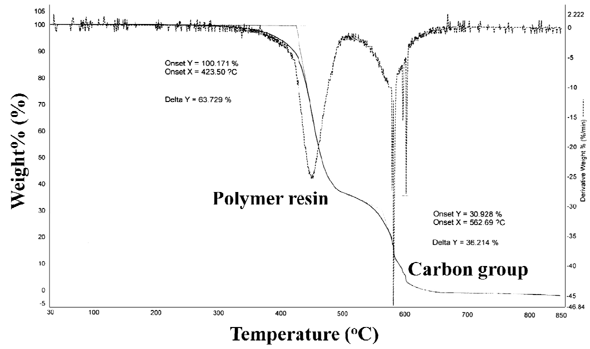


Fig. 6 Result of TGA experiment

lower surface hardness than rejected comb which mean the softer surface as indicated in table 1. Thus, it can conclude that the thermal load in manufacturing process affect the mechanical properties by harden the comb surface. Statistical analysis of tested data illustrated was calculated base on 95% confidence interval. Results of one–way ANOVA indicates significant difference in hardness between new and rejected shipping comb (P-value = 0.02 < 0.05). To ensure that the thermal effect influence the surface hardness variation, shipping comb from same batch were attached to the bases using hot and cold mounting technique as shown in figure 9. Indentation results show statistically significance of level difference.

Crack inspection occurring on lock unit area is performed to investigate the load type related to the failure. The results show fracture behaviors that can be categorize into two mechanisms, instantaneous crack and fatigue crack as shown in figure 10 and 11. Smooth fracture surface take place from the crack initiation to the middle of crack length. When cracking growth reach the critical length under high load, cracking continue dramatically. For polymer which is visco-elastic material, sharp stripe tearing demonstrated the essential characteristic of the instantaneous crack. These fracture type appear approximately 80 percent of all fracture failures. Fatigue cracking results from cyclic stress having peak lower than the ultimate or even the yield strength of the material. Applied cyclic load stimulated the fatigue flaw to propagate from the origin of crack to the critical length, called beachmarks.

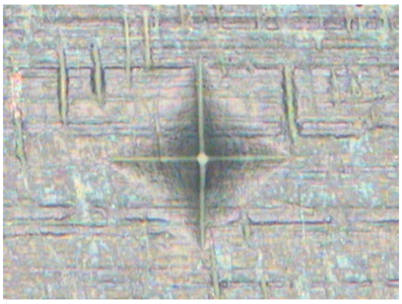


Fig. 7 Visual inspection of Vickers's Micro-hardness testing on shipping comb

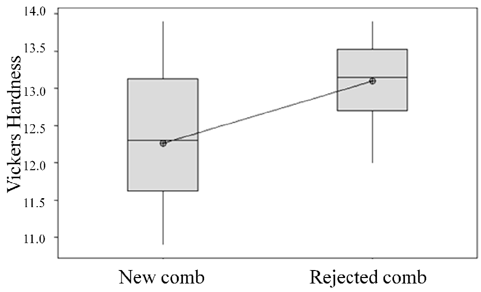


Fig. 8 Statistical analysis of surface hardness using Vickers's micro-hardness testing

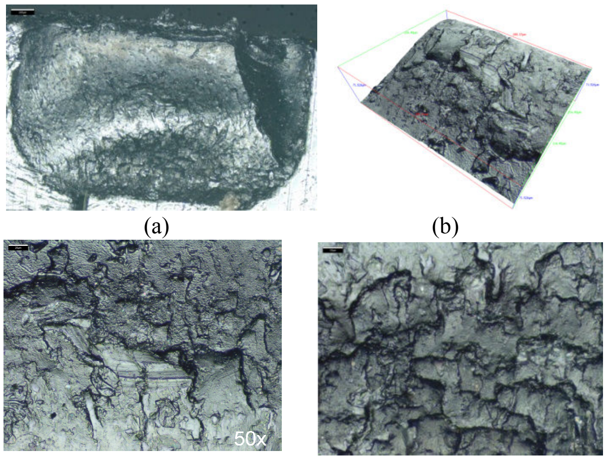
(a) (b)

Fig. 9 Thermal effect evaluations using (a) hot mounting technique (b) cold mounting technique

TABLE I
STATISTICAL DATA OF SURFACE HARDNESS USING VICKERS'S MICRO-HARDNESS TESTING

Type	New comb	Rejected comb	Difference (%)
Mean	12.267	13.094	6.32
Median	12.3	13.15	6.46
S.D.	0.843	0.569	-

Data analysis process of problem root cause requires all of the information collected from the previous step. The data categorized methods providing investigator the easy-to-understanding and the logical illustration are fish bone diagram and logic tree [10]. Fish bone diagram uses to present the group of possible failure cause depending on each factor as shown in figure 12. Logic tree is effective tool providing list of failure modes and their caused hypotheses [11]. First step, state or event of failure would be listed. After that, the event mode presents how the event has occurred. The hypotheses of



(a) (b) (c) (d)

Fig. 10 inspection of instantaneous fracture on lock unit (a) Crack overview (b) 3D surface scanning (c) Smooth fracture surface (d) Sharp stripe fracture surface

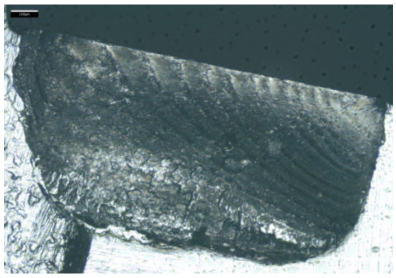


Fig. 11 Inspection of fatigue fracture on lock unit

each event mode representing how the preceding events can occurred are listed in the lower level. For problem solving, all hypotheses would be verified using suitable method. Only hypotheses that are accepted with verification would be proved in root cause level. Three stages of root cause level consist of physical root cause, human root cause and latent root cause. In many cases, investigator stops analysis at this stage when imperfect information is considered. All physical roots are the visible roots that need to prove for the fact. Human root cause, the second stage, is the wrong action or decision of human that induces the failure. Conclusion that failure comes from human root may affects the productivity and RCFA supporting. Latent root cause is the organization system making operator do the wrong decision or performing. These include policies, operating procedure, maintenance procedure, stores, purchasing practice production and design specification. Analysis results show that static load, impact load and fatigue load are the major physical loads conducting the failures. Thermal load causes material degradation that accelerates the failure under major loads. Intensive operator training and supervising are the way of failure reduction as shown in fig.13 and 14. However, modified design for better reliability focusing on the area that high risk of failure is the long-term solution.

B. Failure Mode and Effects Analysis

As procedure mentioned above, application of FMEA to the

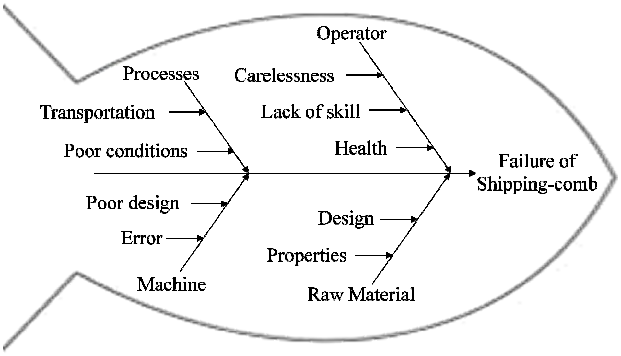


Fig. 12 fish bone diagram of shipping comb failure cause

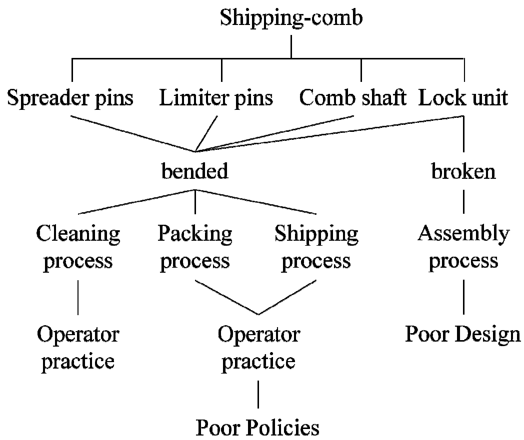


Fig. 13 Logic tree of shipping comb failure

failure of shipping comb component is presented in table II. All areas on shipping comb including their function, failure mode, failure effect and failure cause were listed. Severity of

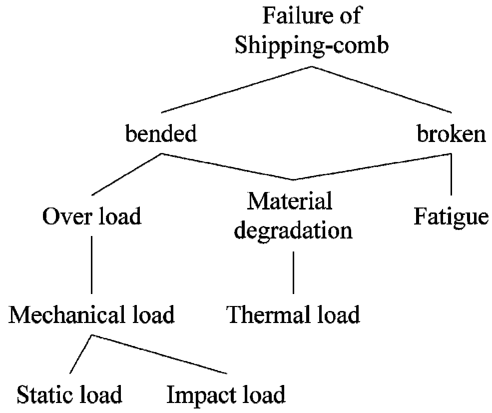


Fig. 14 Logic tree of shipping comb loading

failure, occurrence of failure and detection of failure of each failure mode is specified. Failure information refers to RCFA results. Finally, risk priority number is calculated by multiplying the severity of failure, the occurrence of failure and the detection of failure number. Damage on limiter pin area showed the maximum RPN. Clearly, damage of limiter pin, the component nearby the read/write head, has the highest chance to harm read/write head. Lower RPN failure are damage on lock unit area in over-deformation type, damage on Spreader pin, damage on lock unit in fragile type and damage on comb shaft, respectively.

IV. Conclusion

RCFA technique is utilized as a searching the tool to expose the failure causes of shipping comb employed in HDDI. Major processing loads including static load, impact load and fatigue load incorporated with thermal load carry out the failure.

TABLE II
FMEA WORKSHEET OF SHIPPING COMB COMPONENT

Part No.	Component	Function	Possible failure	Failure effect	Failure reason	Severity of failure	Occurrence of failure	Detection of failure	RPN
1.	Limiter pin	Protect heads from collision	Bended	Danger for heads	Overloaded	10	9	2	180
2.	Lock Unit	Lock shipping comb with HSA	Bended	Loose	Overloaded or fatigue	8	7	2	112
			Broken	Loose	Overloaded or fatigue	8	3	2	48
3.	Spreader Pin	maintain the gap between suspensions	Bended	Danger for heads	Overloaded	10	4	2	80
4.	Comb shaft	Fulcrum of rotation	Bended	Jam	Overloaded	7	2	2	28

Intensive operator training and supervision is the essential factor for comb reliability improvement. Operator practices reveal the chances of casual action that lead to shipping comb's failure in cleaning process, packing process and shipping. Additionally, FMEA technique helps investigator to specify the failure-risk area of shipping comb that may harm to HSA. Due to the high failure fraction and RPN, the design improvement should be perform on limiter pin and lock unit. Modification of material properties including shape and dimension is the appropriate design criterions. The effects of dimension and shape of spreader pins mounted into HSA been investigated in the literature. More strengthening spreader pins might threaten the manufacturer allowance and the HDD performance [12]. Thus careful design improvement must be performed.

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REFERENCES

[1] D.N.P.Murthy, T.Østera and M.Rausand, "Component reliability specification", Reliability Engineering & System Safety, Volume 94, Issue 10, October 2009, pp 1609-1617.
[2] Luca Del Frate, Sjoerd D. Zwart, Peter A. Kroes, "Root cause as a U-turn", Engineering Failure Analysis 18, 2011, pp 747–758.
[3] Han-Xiong Lia and Ming J. Zuob, "A hybrid approach for identification of root causes and reliability improvement of a die bonding process—a case study", Reliability Engineering and System Safety 64, 1999, pp 43–48.
[4] Senthilnathan Subbiah, O.P. Singh, Srikanth K. Mohan, Arockia P. Jeyaraj, "Effect of muffler mounting bracket designs on durability", Engineering Failure Analysis 18, 2011, pp 1094–1107.
[5] R. Keith Mobley, "Root Cause Failure Analysis", 1999.
[6] Frank Rath, M.S.I.E., "Tools for Developing a Quality Management Program: Proactive Tools (Process Mapping, Value Stream Mapping, Fault Tree Analysis, and Failure Mode and Effect Analysis)", Int. J. Radiation Oncology Biol. Phys., Vol. 71, No. 1, Supplement, pp. S187–S190, 2008.
[7] Carla Estorlio and Richard K. Posso, "The reduction of irregularities in the use of process FMEA", International Journal of Reliability Management, vol. 27, Issue 6, pp. 24-27, 2010.
[8] Bok Nam Jang, Charles A. Wilkie, "A TGA/FTIR and mass spectual study on the thermal degradation of bisphenol A polycarbonate", Polymer Degradation and stability 86, 2004, pp 419-430.
[9] B. Jaleh, P. Pavin, N. Sheikh, F Ziaie, M. Haghshenas, L. Bozorg, "Evaluation of physic-chemical properties of electron beam-irradiated polycarbonate film", Radiation Physics and Chemistry, 2007.
[10] Brussee W. Statistics for six sigma made easy. Cause-and-effect fishbone diagram. Kindle Book, McGraw Hill Company; 2004.
[11] R.J. Latino and K.C. Latino, Editors, "Root cause Analysis: Improving Performance for Bottom-Line Results", CRC Press, FL, 2006.
[12] Chutima S., Kamnerdthong T., Atjanakul W. and Jaidee K., "A Study of HGA Behaviors after Mounted with Shipping Comb", The 23rd Conference of the Mechanical Engineering Network of Thailand, 2009.