A Case Report on Root Cause Analysis of No-Go Parts in Refrigerator Factory

Sujin Wanchat[1], Pongsatorn Sittiwachmatee[2], Nattapon Chantarapanich[1*], and Weerachai Chaiworapuek[3]

[1]Industrial Production Technology Research Group, Department of Mechanical Engineering, Faculty of Engineering at Sriracha, Kasetsart University, Chonburi, Thailand
[2]Mechanical and Design Engineering Graduate Program, Faculty of Engineering at Sriracha, Kasetsart University, Chonburi, Thailand
[3]Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand
E-mail: sujin@eng.src.ku.ac.th, pongsatorn_s@yahoo.com, nattapon@eng.src.ku.ac.th*, fengwcc@ku.ac.th

***Abstract*—This paper studies the causes of customer complaint to a refrigerator manufacturer. No-Go (NG) product in manufacturing process not only affects the manufacturing cost but also increase problem about waste management. Main potential cause was identified with Quality Control (QC) tools and Failure Mode and Effects Analysis (FMEA), and it was weakness of legs of cooling blower shroud after injection process and unintended dropping of the blower in assembly station. To proof the hypothesis, the first stage of investigation with Finite Element Analysis (FEA) was performed with the drop test at the height of 0.8 m with impact angle of 45 degrees from the level of an assembly table. According to convergence testing of the FE analysis, the results were well consistent with the found defection. The FEA exhibited the stress of the model of dropping height was 135.6 MPa which almost reached the ultimate stress of the blower material. Therefore, an improvement was done by setting the assembly level at 10 cm lower to diminish the kinetic energy of unintended dropping while transferring. After the improvement was made, no any of NG products was found.**

***Index Terms*—Seven QC Tools, FMEA, Finite Element Analysis, Blower, Refrigerator.**

I. Introduction

A general issue which always accompany with the all types of manufactured products is a customer complaint due to products quality that does not meet the necessary standards. This issue affects directly on the manufactures in terms of reputation and investment cost. In general, there are three main factors which must take into account: quality, cost, and delivery, as shown in Fig. 1. Among all three factors, the most important factor to be considered first is quality. Therefore, to obtain product quality which satisfies customer requirements, the manufacturers must apply suitable systems to control their manufacturing process.

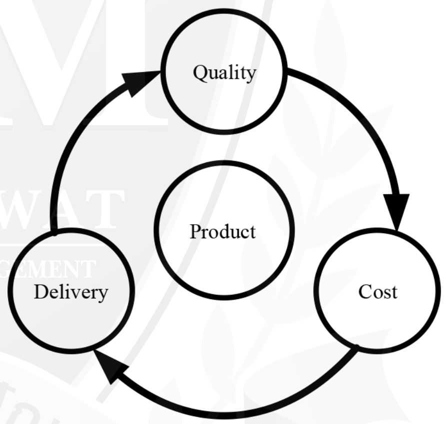


Fig. I. Three main factors for production.

The case described in this paper is of a refrigerator manufacturer. One indicator determining success of the factory is to reduce the customer complaint relating to inefficient operation of the blower in the refrigerator which may directly impact on satisfaction of the customers.

As a result, it is desirable to keep product quality in standard to maintain company reputation by solving the quality problem. However, general solutions for an industrial problem are often made by using experience of technicians to evaluate the causes of the problems which is usually ineffective. Therefore, this paper adopts QC Tools, FMEA, and FEA altogether to analyze the problem in both technical and management oriented facets [1-6].

Form the described problems above; analysis has been made to improve both the manufacturing process and therefore the finished product.

II. Data Collection and Analysis

This research began to collect symptoms of fault products found from complaints of customers for a nine-month backdate, from December 2013 to November 2014. This information was categorized into percentage and then analyzed with QC tools and FMEA. Next, the factory was examined to prove the hypothesis of FMEA.

A. NG PART DATA COLLECTION AND ANALYSIS

Most of the problems detected are ice adhesion, plastic debris clogging, broken wires, and broken leg of cooling blower shroud. The percentage of these problems were 1.6, 4.6, 5.2 and 13.7 respectively, as shown in Fig. . The problem which can be clearly specified and has second priority is broken leg of cooling blower shroud; physical damage is shown in Fig ш. Hence, this problem is considered to be solved first.

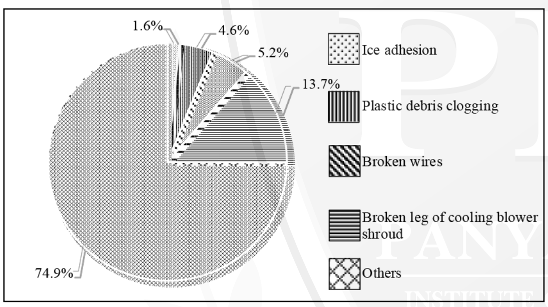


Fig. II. Percentage of problems found in fault products collected for nine months.

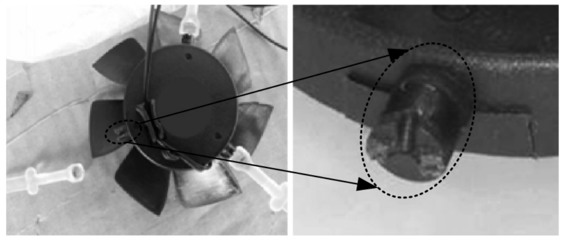


Fig III. Position where leg of cooling blower shroud is broken.

Analyzing the Probability of the Problem with QC Tools and FMEA

In the first step of Six Sigma DMAIC, brainstorming is adopted to examine root causes of the broken leg using cause-and-effect diagram as displayed in Fig.VI, one of seven QC tools. After team investigation is operated, four main root causes are found: 1) the blower leg is too small, 2) improper setting up conditions for injection, 3) improper package, and 4) unintended impact during assembly.

FMEA in the second step is tabulated in Table I. The RPN column shows that unintended impact during assembly has the highest priority which its value is 180. This is because during inspection of the assembly process, it was found that the operators used conveyor table to transfer finished part in the assembly station with height of 0.8 m above ground, as seen in Fig. There is high chance that finished part will fall to the ground which results in mechanical failure. The authors decided to use Finite Element Analysis (FEA) to verify the hypothesis of unintended impact during assembly.

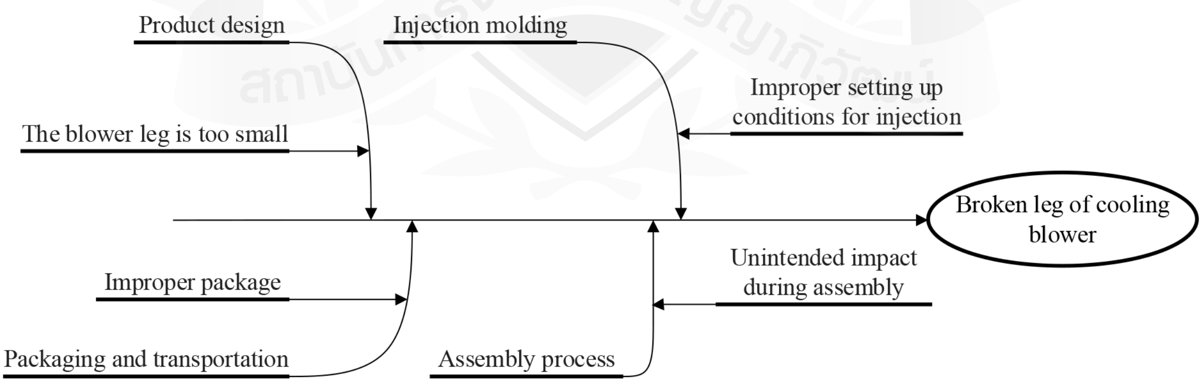


Fig. IV. The cause-and-effect diagram used to investigate root causes of the broken leg of cooling blower.

TABLE I
FMEA Used to determine the highest priority among four main root causes

Process	Potential Failure Mode	Potential Failure Effect	Severity Rating	Potential Cause of Failures	Current Process Control	Occurrence Rating	Detection Rating	Critical Characteristics	RPN
Product design	The blower leg is too small	Broken leg	6	- Improper product design	None	2	3	N	36
Injection molding	Improper setting up conditions for injection	Broken leg	6	- Improper mold design - Improper conditions for injection	Inspected at QC unit	2	4	N	48
Assembly process	Unintended impact during assembly	Broken leg	6	- Improper operating proximity	None	5	6	Y	180
Packaging and transportation	Improper package	Broken leg	6	- Improper package is used during transportation	Inspected at QC unit	6	3	N	36

Fig. V. The improper installed position of a blower packaging box and the level of assembly table.

III. Prove Of The Hypothesis

A. 3D CAD Creation

Before performing FEA analysis, it is necessary to create 3D model of a workpiece in detail as closely as possible to the real object to obtain the best approximated results. The 3D model of cooling blower shroud with three legs is shown in Fig. 1.

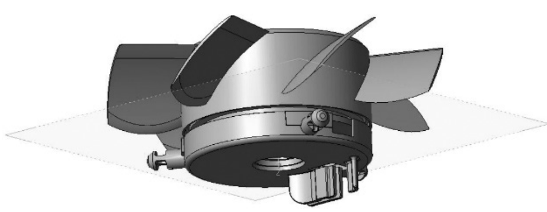


Fig. I. The 3D model of cooling blower shroud with three legs.

B. Material Properties for FEA Analysis

To analysis with a Computer-Aided Engineering (CAE) not only, the exact size of the workpiece has to be known, but also its material properties. In this experiment, 30% glass fiber reinforced Polybutylene Terephthalate (PBT-30GF) is a raw material used to make the blower shroud where some essential mechanical properties of PBT-30GF are shown in Table II.

TABLE II
Mechanical properties of PBT-30GF in SI unit [7]

Mechanical Properties	Range	Average value
Tensile Strength, Ultimate	20.0 - 186 MPa	121 MPa
Tensile Strength, Yield	82.7 - 155 MPa	119 MPa
Elongation at Break	1.00 - 130 %	3.51 %
Elongation at Yield	2.00 - 5.00 %	2.97 %
Modulus of Elasticity	0.824 - 15.0 GPa	9.49 GPa

The stress-strain curve tested at temperature of 23 °C is shown in Fig. II. There is no obvious yield point. Therefore, the 0.2% offset method is employed to determine the yield strength. Then, the stress-strain relation in the plastic deformation region can be found in Table III.

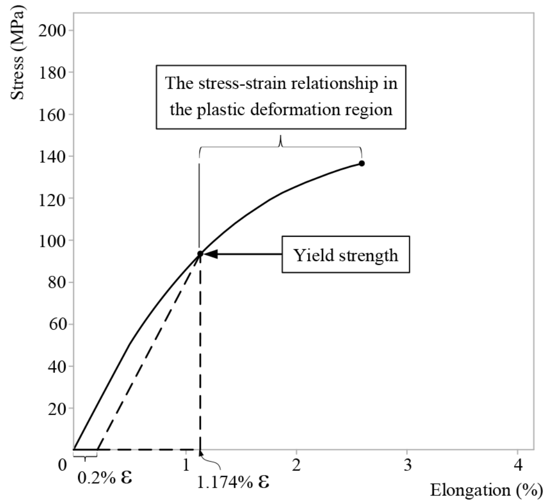


Fig. II. The stress-strain relation in the plastic deformation region of PBT-30GF at temperature of 23 °C [8].

TABLE III
THE STRESS-STRAIN RELATION IN THE PLASTIC DEFORMATION REGION OF PBT-30GF AT TEMPERATURE OF 23 °C

% $\varepsilon_{plastic}$	σ, MPa
0.0%	94.0
0.1%	99.0
0.2%	103.9
0.3%	108.1
0.4%	111.7
0.5%	115.5
0.6%	118.4
0.7%	121.2
0.8%	124.0
0.9%	126.1
1.0%	128.2
1.1%	130.3
1.2%	132.1
1.3%	134.2
1.4%	135.6

Since FEA test is a time-consuming process, it is necessary to find the appropriate element size that is commonly known as convergence testing. For preliminary investigation of this case, the authors used the height of 0.8 m and the impact angles 45 degrees model as shown in Fig. III. The four-noded tetrahedron elements with size of 1.1, 1.6, 1.7, 1.9, and 2.0 mm are experimented to achieve optimal element size [9-10]. Table IV shows the convergence testing which is obviously seen that no significant change in stress level for element sizes smaller than 2.0 mm. So, the element size of 2.0 mm is chosen as a controlled element size.

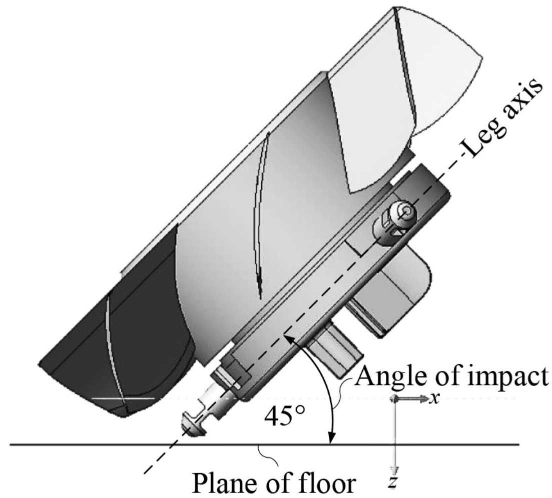


Fig. III. Leg of cooling blower shroud with impact angles at 45 degrees.

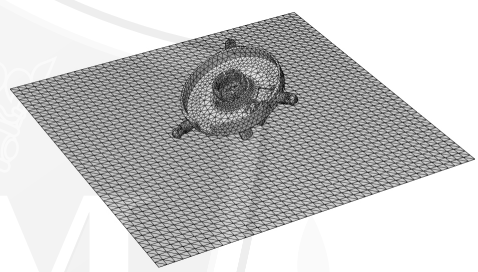


Fig. XI. The FE Model for impact tests.

TABLE IV
EXPERIMENT RESULTS AT VARIOUS SIZE ELEMENTS WITH DROP HEIGHT OF 0.8 M AND IMPACT ANGLES AT 45 DEGREES

Element Size, mm	Number of Elements	Maximum Stress, MPa
1.1	34,302	135.6
1.6	19,362	135.6
1.7	17,235	135.6
1.9	15,275	135.6
2.0	14,110	135.6

Since an impact angle smaller than 25 degrees will cause a shroud fin break before the leg and if an impact angle smaller than 45 degrees, a blower blade will break before the leg as well. Therefore, in order to save time for more investigations, the researchers selected 2.0 mm elements for impact tests with the impact angles of 25 degrees and at the height of 0.5, 0.6, 0.7, and 0.8 m as shown in Fig.. One of the results is shown in Fig. X.

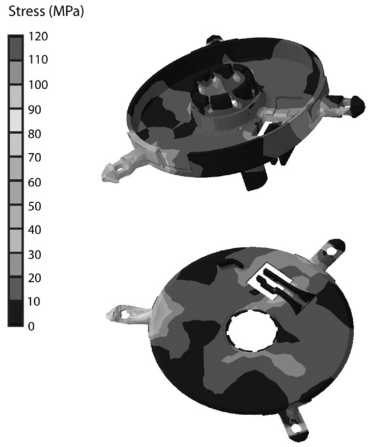


Fig. X. FEA result of stress distribution on the cooling blower shroud where element size is 2.0 mm, drop height is 0.8 m, and impact angle is 25 degrees.

The whole experimental results in combination of the drop heights and impact angle of 25 degrees are tabulated in Table V.

TABLE V
THE WHOLE EXPERIMENTAL RESULTS IN COMBINATION OF DROP HEIGHTS AND IMPACT ANGLE OF 25 DEGREES

Drop Heights, m	Maximum Stress, MPa
	Impact Angle, degrees
0.5	99.0
0.6	111.0
0.7	111.0
0.8	135.6

All experimental results in Table V have the same maximum stress beyond the yield strength of PBT-30GF that is 94.0 MPa as shown in Table III.

C. Results after Improvement

To solve the highest priority of causes that cause NG products, due to the FEA result, the assembly line is improved by reducing kinetic energy that the leg of blower shroud will absorb. Hence, the level of the assembly table was reduced by 10 cm and the direction of placing the workpiece box is changed to ease ergonomically working.

After improvement, the amount of NG products had been monitoring for three months, and there was no report about broken leg of cooling blower shroud taken into account and the FEMA after improvement is shown in Table VI.

IV. Discussions

All the maximum stresses from FEA in Table IV are beyond the yield stress and reach the maximum stress of PBT-30GF. This indicates that falling of blower at height of 0.8 meters will lead to breakage of blower leg. In addition, the position of the maximum stress observed in FEA in Table IV was the same as position of the broken leg as shown in Fig. 3. Therefore, unintended impact during assembly is a major root cause of broken leg of the cooling blower shroud.

In the following experiment as the results shown in Table V, this indicates that the lower levels from installed position of the assembly table will not make broken leg of the cooling blower shroud from unintended impact from falling during assembly process. However, the leg will still be deformed because all maximum stresses are beyond the yield strength of PBT-30GF.

The improvement was done by minimizing kinetic energy that the leg of blower shroud will withstand; as a result, the level was reduced by 10 cm. Then, tracking of the amount of NG products had been monitoring for three months, the number of RPN in Table VI is reduced significantly from 180 to 90. This implies that the solution is correct. Therefore, the process analysis tools are effective to determine the root causes of the problems rather than a group of unsystematic humans experience; and for continuous improvement, all the remaining three main problems should be fixed to minimize NG products in the further study.

Even though, the reactive improvement by reducing the height of the assembly level provides no breakage, but if the cooling blower shroud falls, it still be deformed. Moreover, it is non-ergonomic operation if the level of an assembly table height is reduced less than 0.5 m. So, the alternate preventive adjustment is to further rearrange the assembly station for well ergonomic operation to keep the workpiece from unintended falling.

Conclusions and Recommendation

This paper utilizes seven QC Tools and FMEA to determine major root causes of NG products of refrigerated cooling system. According to 13.7% of collected complaints, the broken leg of cooling blower has the second priority after others unidentifiable causes. So, this research selects it to be solved first. With the RPN of 180 from FMEA, the unintended impact from falling during assembly process was suspected as the main cause of broken leg, and it was set as the hypothesis of this study. After validating with FEA that simulated blower shroud fell from height of 0.8 m above the floor, the maximum stress value of 135.6 MPa occurred consistently around the position of real broken leg.

Finally, the improvement in this paper is the reduced height of 10 cm from the previous assembly level, to guarantee when the product falls into the ground it will not be broken. However, since deformed leg also dissatisfies customers, this issue should take into the cause of NG product as well in the further study.

TABLE VI
FMEA Used to determine the highest priority among four main root causes after improvement

Process	Potential Failure Mode	Potential Failure Effect	Severity Rating	Potential Cause of Failures	Improving Method	Occurrence Rating	Detection Rating	Critical Characteristics	RPN
Product design	The blower leg is too small	Broken leg	6	- Improper product design	–	–	–	–	–
Injection molding	Improper setting up conditions for injection	Broken leg	6	- Improper mold design -Improper conditions for injection	–	–	–	–	–
Assembly process	Unintended impact during assembly	Broken leg	6	- Improper operating proximity	Reducing the level of assembly table down for 10 cm	3	5	Y	90
Packaging and transportation	Improper package	Broken leg	6	- Improper package is used during transportation	–	–	–	–	–

Acknowledgement

The authors would like to thank International Scientific Journal of Engineering and Technology (ISJET) committee, Panyapiwat Institute of Management (PIM) for invited the authors to submit the manuscript. The authors also appreciate Faculty of Engineering and Faculty of Engineering at Sriracha, Kasetsart University for supporting the software used in this research.

References

[1] P. F. Wilson, L. D. Dell, and G. F. Anderson, "Root Cause Analysis: A Tool for Total Quality Management," 1st ed., Milwaukee, WI: ASQ Quality Press, 1993.

[2] J. Bhattacharya. "Root Cause Analysis – A Practice to Understanding and Control the Failure Management in Manufacturing Industry". International Journal of Business and Management Invention. [Online]. 3(10), pp. 12-20. Available: http://www.ijbmi.org/papers/Vol (3)10/Version-2/B03102012020.pdf. 2014.

[3] S. Jevgeni, S. Eduard, and Z. Roman. Framework for Continuous Improvement of Production Processes and Product Throughput. Procedia Engineering. [Online]. 100, pp. 511-519. Available: http://www.sciencedirect.com/science/article/pii/S1877705815004257. 2015.

[4] A. H. Hu, C.-W. Hsu, T.-C. Kuo, and W.-C. Wu. Risk evaluation of green components to hazardous substance using FMEA and FAHP. Expert Systems with Applications. [Online]. 36(3), pp. 7142-7147. Available: http://www.sciencedirect.com/science/article/pii/S095741740800571X. Apr. 2015.

[5] N. Xiao, H.-Z. Huang, Y. Li, L. He, and T. Jin. (2011, Jun.). Multiple failure modes analysis and weighted risk priority number evaluation in FMEA. Engineering Failure Analysis. [Online]. 18(4), pp. 1162-1170. Available: http://www.sciencedirect.com/science/article/pii/S1350630711000288. Jun. 2011.

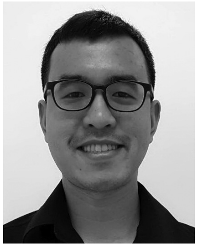
[6] H. R. Feili, N. Akar, H. Lotfizadeh, M. Bairampour, and S. Nasiri. Risk analysis of geothermal power plants using Failure Modes and Effects Analysis (FMEA) technique. Energy Conversion and Management. [Online]. 72, pp. 69-76. Available: http://www.sciencedirect.com/science/article/pii/S0196890413001325. Aug. 2013.

[7] MatWeb. [Online]. Available: http://www.matweb.com/index.aspx. 2017.

[8] PlasticsPortal Global Home. [Online]. Available: https://www.plasticsportal.net/wa/plasticsEU~es_ES/function/conversions:/publish/common/upload/engineering_plasics/Ultradur_brochure.pdf. 2016.

[9] S. I. Sadaq, A. R. Junaidi, V. S. Kumar , J. G. Konnully, and S. S. Qadiri. Impact Test on Motor Cycle Helmet for Different Impact angles using FEA. International Journal of Engineering Trends and Technology. [Online]. 12(6), pp. 278-281. Available: http://www.ijettjournal.org/archive/ijett-v12p254. 2014.

[10] E. Tapie, E. Tan, Y. Guo, and V. Shim. Effects of pre-tension and impact angle on penetration resistance of woven fabric. International Journal of Impact Engineering. [Online]. 106, pp. 171-190. Available: http://www.sciencedirect.com/science/article/pii/S0734743X1630183X. Aug. 2017.



Sujin Wanchat serves currently as a faculty member at Faculty of Engineering at Sriracha, Kasetsart University, Thailand. He received B.Eng. in Aerospace Engineering from Kasetsart University, Thailand, M.Eng. in Mechatronics from Asian Institute of Technology, Thailand, and Ph.D. in Mechanical Engineering from Khon Kaen University, Thailand.

Pongsatorn Sittiwachmatee is currently an engineer in private company. He has graduated B.Eng. and M.Eng. in Mechanical Engineering from Kasetsart University.

Nattapon Chantarapanich currently serves as a faculty member at Faculty of Engineering at Sriracha, Kasetsart University, Thailand. He received B.Eng. in Aerospace Engineering from Kasetsart University, Thailand, M.Sc. in Mechanical Engineering from Thammasat University, Thailand, and Ph.D. in Biomedical Engineering from Prince of Songkla University, Thailand.

Weerachai Chaiworapuek currently serves as a faculty member at Faculty of Engineering, Kasetsart University, Thailand. He received M.Sc. in Mechanical Engineering from University of Dublin, Ireland, M.Eng. in Mechanical Engineering from INSA-Lyon, France, and Ph.D. in Mechanical Engineering from Kasetsart University, Thailand.