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PRACTICAL APPLICATION OF SIX SIGMA METHODOLOGY TO REDUCE DEFECTS IN A PAKISTANI MANUFACTURING COMPANY

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All over the world six sigma is being adopted as a quality improvement approach towards zero defects. Unfortunately, the adoption of six sigma methodology in manufacturing companies is very rare in developing countries due to various challenges. This study demonstrates the practical use of the six sigma Define, Measure, Analyze, Improve and Control (DMAIC) cycle by conducting a case study at a manufacturing company in Pakistan. The potential problem was the external leakage defect in the refrigerator during its production stage. The objective of this study was to improve the process by adopting six sigma DMAIC approach to identify and eliminate the root causes that produce defects in the final product. Project charter, Pie chart, Bar chart of faults, Suppliers Input Process Output (SIPOC), Voice of Customer (VOC) and flow process map were used to define the problem, its scope and process routing. Pareto chart was used to identify sub defects and sigma level was calculated for the existing process. Feed rate, capillary action of filler material, cleanliness, visual inspection and unsuitable heat input were the major causes of external leakage. Cause and effect matrix was used to rank the identified causes. Further, design of experiment (DoE) was performed to improve the process by conducting different alterations in the parameters. In order to control the process, failure mode and effect analysis (FMEA) sheet was prepared to sustain the process improvements. The FMEA control plan needed to be revised at specific time intervals to attain continuous process improvement. This six sigma DMAIC cycle produced a 30% overall reduction of external leakage defect and service call rate (SCR) was improved with lower complaints from customers.

Key words: six sigma DMAIC cycle, case study

INTRODUCTION

The concept of six sigma was presented by Motorola and General Electric (GE) in the 1980's as an innovative set of management techniques to assist both companies. Both companies benefited with the use of newly innovative technique by improving their production efficiencies and better control over the processes. Since the successful implementation and better performance of six sigma in both companies in 1999, numerous other companies adopted this technique as a part of their management strategies [1]. Six sigma is now a widely used and well accepted method which can eliminate root causes of the unwanted variations and provides good control of the process. The main focus of six-sigma is on process control, continuous improvement, customer needs, statistical analysis and business growth [2-6]. Most widely used approach of the six sigma is DMAIC cycle i-e Define, Measure, Analyse, Improve and Control is a five-step six-sigma improvement model adopted by manufacturing and service organisations to improve their current capacities of existing processes [7-12]. There are variety of the supporting tools which can be used at various phases of the six sigma methodology. Table.1 shows the most frequently used tools under six sigma DMAIC cycle. Practical Implementation and use of six sigma methodology is still challenging for manufacturing companies in developing countries. Considering the fact, Pakistani manufacturing industries are also lacking in the adoption and use of six sigma tools and techniques. Thus, this study had made an attempt to show the practical use of six sigma methodology by conducting a case study at a manufacturing company. Various tools and techniques were used through different phases of the six sigma DMAIC cycle.

CASE STUDY

Dawlance is a private limited company which is one of the top electronic and premier home appliance manufacturers in Pakistan having many products. Products of the company are refrigerator, washing machines, freezer, split air conditioner, microwave ovens. Due to the increasing rate of defects from the calculation of service call rate (SCR), company wants to reduce defects to sustain its competitive position in the market.

METHODS

To solve the problem of external leakage in refrigerator Model No: 9166, the project team had used the six sigma DMAIC approach for the improvement. The various tools and techniques that were used under the six sigma DMAIC cycle are shown in Figure.1. The most valuable

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Table 1: Six Sigma DMAIC tools and techniques

Steps of DMAIC	Activities required	Tools and techniques	Sources
Define	Identify customers and requirements (CTQs) Define problem, objectives and benefits Define team and resources Evaluate support from organizational Define project plan and constraints Establish process map	Process flowchart Project charter SIPOC diagram Critical to quality (CTQ) Voice of customer (VOC), Quality function deployment (QFD)	[13] [14] [15] [16]
Measure	Describe defect, unit, opportunity and metrics Develop map of the focused areas Plan to collect the required data Select the metrics Data collection Measure sigma level and process capability	Data collection Process flowchart Process sigma calculation Benchmarking	[13] [15] [14] [17]
Analyse	Describe performance goals Recognise non-value/value-added activities Determine major variations caused Identify root causes	Scatter plot Histogram Pareto chart Cause and effect diagram Regression analysis	[13] [15] [17] [16] [18]
Improve	Determine potential mitigation actions Set tolerance limits Re-check and improve proposed solution	Mistake proofing Brainstorming Failure mode and effect analysis (FMEA)Design of experiments Pugh matrix	[13] [15] [17] [14]
Control	Develop and confirm a control and monitoring system. Design procedures and standards Do documentation and finish the project Communicate and celebrate the success	Poka-Yoke Statistical process control (SPC) Failure mode and effect analysis (FMEA) Cost savings calculation	[13] [15] [18]

tools and techniques include cause and effect analysis, process mapping, histogram, control chart, process capability analysis, FMEA and Poka-yoke. It seems that tools that offer graphical representation, recognize root causes of bottlenecks are easily adoptable as compared to more complex and sophisticated tools and techniques [17]. Thus, study has selected the most recommended and widely adopted tools and techniques.

RESULTS AND DISCUSSIONS

Define Phase

This phase defines the problem, process mapping, scope and effect of the problem for both external and internal customers. The tools used by the project team in this phase are Project charter, SIPOC, VOC, flow process map, trend chart. The project charter shown in Table.2

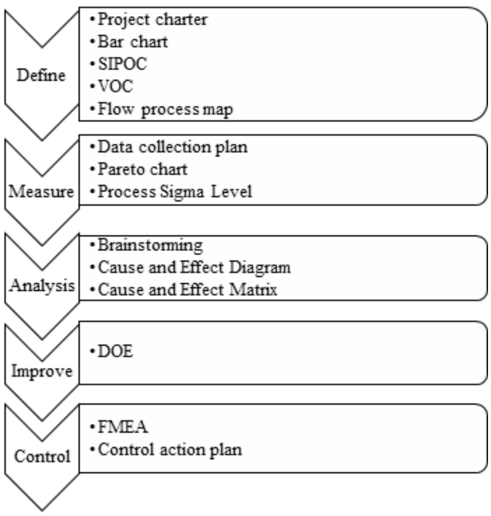

Figure 1: Methodology flow chart

Table 2: Project charter

Deptt. Name	Quality Assurance, Quality control, QMS, IQC
Project location	A large-scale manufacturing unit of refrigerator, Landhi industrial area Karachi
Project start date	May 2020- May 2021
Business case	Improvements in service call rate (SCR), Rework time in terms of cost, that will satisfy the customer, improve the quality.
Project title	Reduce the external leakage defects by using six sigma methodology
Team member	Six sigma project team, QC-QA Department
Project stakeholder	All employees of QMS(QC/QA) department, brazing department
Subject matter expert	Manager, assistant manager of quality department
Phases of project	Define phase, Measure phase, Analyse phase, Improve phase , Control phase

was made by the project team under the supervision of assistant manager Quality and co-reviewed by the top management. The anticipated outcomes from the implementation of DMAIC methodology were to identify the root causes of weak brazing and to identify control action plan for the improvement of process capability and reduce defects rate. Figure.2 shows the bar chart of SCR of complaints. The external leakage of gas in refrigerator was having highest defect rate of 26% in refrigerator Model No: 9166 based on the historic data. Thus, six sigma team selected this model for further assessment to reduce the external leakage defects.

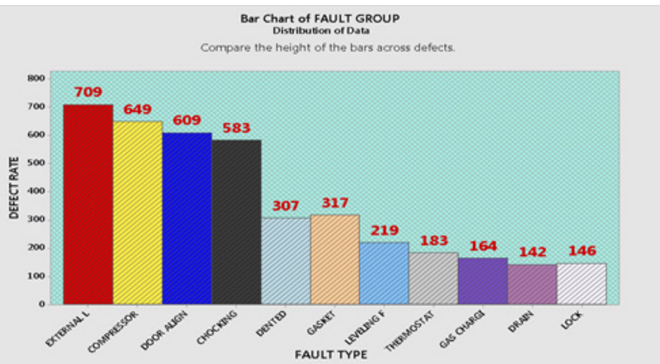

Figure 2: Bar chart of fault group

To understand the main root causes of the problem of external leakage associated with Brazing stations, a flow process map was made by six sigma project team with consultation of the internal experts shown in Figure.3. To have more in depth understanding of the whole process and its different elements SIPOC was prepared as shown in Table.3. Further voice of customer (VOC) was established for both internal and external customers of the company considering their requirements. The six sigma team made the VOC with coordination of the quality department and by communicating with the external customers is shown in Table.4.

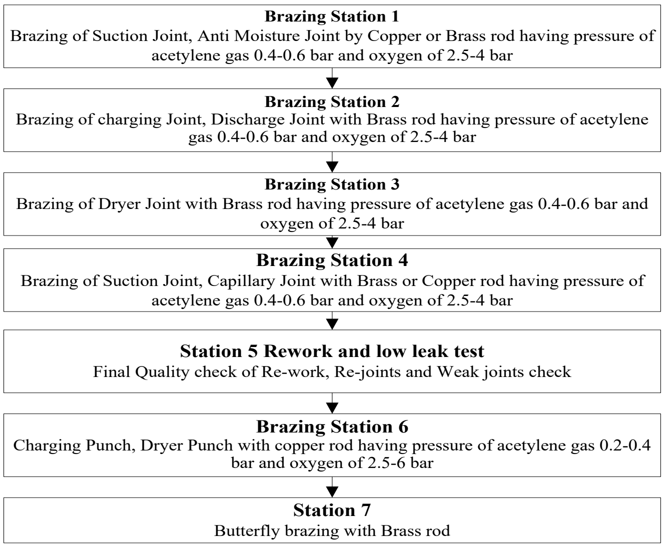

Figure 3: Flow process map of Brazing process

Measure phase

The purpose of Measure phase was to identify the current performance level of the process and its sigma level. The data collection was done to measure the process inputs and outputs. The Pareto analysis was used in this phase to prioritize the sub defects and determine the most critical defects that were causing the company to pay for the cost of poor quality. The team used sigma level calculations to find out the sigma level of the process and also to set the target of increasing sigma level. To study the defects and sigma level calculations, around 12 months data was used. Total defects per million opportunities (DPMO) considering top and bottom limits value was 1509.2. Then to convert DPMO into sigma level following formula was used to calculate the current sigma level;

Table 3: SIPOC

Suppliers	Inputs	Process	Outputs	Customers
IQC (Incoming quality control)	Compressor: Panasonic (R134a) Model: SFK57C11RLX	Mount compressor on refrigerator with sleeve and screws.	Compressor fixed on refrigerator body.	Condenser fixer
Condenser fixer	Condenser: Make: China Material: Iron	Mount the condenser by using spacer and screws.	Condenser mounted on the refrigerator body.	Compressor accessories fixer (Capacitor, over load, Relay)
Compressor accessories fixer	1. Capacitor: (4μF ±5%, 450V~) 2. Over load 3. Relay	Mounting the capacitor, overload and Relay on the specified place of compressor in refrigerator body	Compressor is mounted with accessories on the refrigerator body.	Brazing Station 1
Brazing Station 1	1. Gas Supply Oxygen gas (4.0 ~ 9.0 Bar) , Acetylene gas(0.5 ~ 1.0 Bar) 2. Torch handle with gas regulator. 3. Twin-flame fork torch 4. 4Brass Pro alloy rod (2x1000mm)	1. Joint the extra suction pipe 2. Anti-condenser joint 3. Rare condenser joint	Completed joint of extra suction pipe, anti-condenser joint and rare condenser joint.	Cleaning section
Cleaning section	Nitrogen gas	Cleaning of condenser and evaporator by using nitrogen gas at 5 bar pressure.	Cleaned the condenser and evaporator.	Brazing station 2
Brazing station 2	1. Filter-drier 2. Gas Supply 3. Oxygen gas (4.0 ~ 9.0 Bar) , Acetylene gas(0.5 ~ 1.0 Bar) 4. Torch handle with gas regulator. 5. Twin-flame fork torch 6. Brass Pro alloy rod (2x1000mm)	1. Joint the filter-drier with charging line. 2. Joint the filter-drier also with condenser. 3. Rare charging joint 4. Anti-condenser joint 5. Discharge joint	Completed joint of filter-drier, rare charging, anti-condenser and discharge joint on the refrigerator body.	Brazing station 3
Brazing station 3	1. Gas Supply 2. Oxygen gas (4.0 ~ 9.0 Bar) , Acetylene gas(0.5 ~ 1.0 Bar) 3. Torch handle with gas regulator. 4. Twin-flame fork torch 5. 4Brass Pro alloy 6. rod (2x1000mm)	1. Joint the capillary with Filter-drier. 2. Joint extra suction pipe. 3. Joint the suction line.	Completed joint of capillary with filter-drier, joint of suction pipe and the joint of suction line on the refrigerator body.	Coupler connector

Suppliers	Inputs	Process	Outputs	Customers
Coupler connector	Coupler	Mount the coupler on gas charging line for charging nitrogen gas in compressor.	Coupler is mounted on charging line of compressor.	Power cable connector
Power Cable Connector	Wire Cable	Connect Wire Power Cable at specified place of the compressor.	Wire cable connected with compressor for supply power.	Gas charging station
Gas charging station	Vacuuming pump Gas charging machine	Connect the vacuuming pump to the refrigerator compressor for vacuuming. Connect the Charging pump to the refrigerator compressor for R134a gas charging.	Gas charged in the refrigerator.	Braze Punch station
Braze punch station	1. Gas Supply Oxygen gas (4.0 ~ 9.0 Bar) , Acetylene gas(0.5 ~ 1.0 Bar) 2. Torch handle with gas regulator. 3. 3Twin-flame fork torch 4. Copper rod (2x1000mm)	Punching the filter-drier	Refrigerator.	Low leak test
Low leak test	Inficon machine Sensing probe	Place the sensing probe near the joint which detect the leak joint at 0.1 gram per year on without load.	Refrigerator for check of function	Function test
Function test	AC supply 220V	Check the function of refrigerator	Function tested Refrigerator	High leak test
High leak test	Inficon machine Sensing probe	Place the sensing probe near the joint which detect the leak joint at 0.1 gram per year on with load.	Finished product	Packing station

Table 4: Voice of customer

S.No	Customer Name	Type	Voice Of Customer (VOC)
1.	Refrigerator Assembly line	Internal	Perfect brazed joints
2.	Quality Control (QC) Department	Internal	No leakage found between the joints
3.	Distributer	External (intermediate)	Unit free of Defects
4.	End User	External (End)	Better customer satisfaction

Process Sigma level = 0.8406 + SQRT(29.37 – 2.221 * (ln(DPMO))

Process Sigma Level = $0.8406 + [\sqrt{29.37 - 2.221 \{\ln(DPMO)\}}]$

$= 0.8406 + [\sqrt{29.37 - 2.221 \{\ln(1509.2)\}}]$

$= 0.8406 + [\sqrt{29.37 - 2.221 (7.32)}]$

$= 0.8406 + [\sqrt{29.37 - 16.3}]$

$= 0.8406 + [\sqrt{13.07}]$

$= 0.8406 + 3.615$

Sigma Quality Level = 4.45

The determined sigma level could deviated up to ±1.5, so after recommendation of experts 1.5 was subtracted to get practical sigma value which was 2.96.

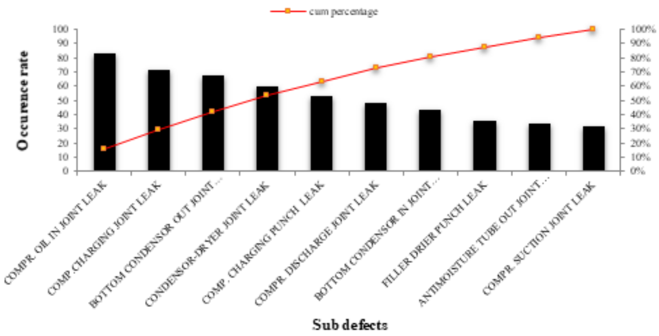

Figure 4: Pareto analysis

Pareto analysis is shown in Figure.4, it was observed that compressor oil joint leak, compressor charging joint leak, bottom condenser and condenser dryer joint leak were most serious sub defects that were causing the external gas leakage in the refrigerator.

Analyze phase

The analyze phase helped in identifying the main root causes and their effects. Thus, in this phase team had used a cause and effect diagram which is one of the basic and remarkable quality tools in assessing the real root causes of the problem is shown in Figure.5. To rank the root causes once identified, cause and effect matrix was used as shown in Table.5. The project team sat along with experts and carefully assigned the weights to each cause based on expert's opinions. Details of the experts are shown in Table.6.

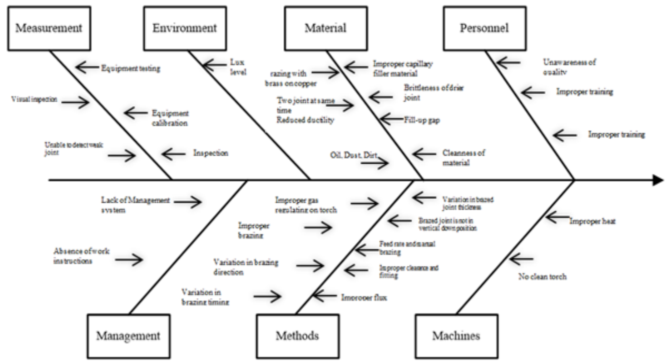

Figure 5: Cause and Effect diagram

Results of cause and effect matrix showed that improper capillary action of filler material, feed rate, brittleness of filter drier joint, cleanliness were the major causes that resulted in external leakage defect in refrigerator.

Table 5: Cause and Effect matrix

Correlation Rating:		≥1=The cause remotely affects the process output. ≥5=The cause has a moderate effect on the process output. ≥9=The cause has a direct & strong effect on the process output.	
Weighted by Importance		9	
Item#	Process Input	Output External Leakage	Score
		Priority ranking	
1	Unskilled Workers	5	45
2	Improper capillary action of filler material	9	81
3	Unfavourable heat input	8	72
4	Feed rate	9	81
5	Inadequate training	5	45
6	Brittleness of filter drier joint	9	81
7	Cleanliness	9	81
8	Fit up gap	8	72
9	Equipment testing	8	72
10	Inspection	8	72
11	Low leak test	7	63
12	High leak test	8	72
	Total	93	837

Table 6: List of experts involved

S.no	Post	Department	Job description
1	Assistant Manager	QMS	Improve Quality Standards
2	Assistant Manager	QMS	Inspecting problems of floor
3	Quality Inspector	Lab testing	Testing of instruments
4	Assistant Manager	IQC	Inspection of income material
5	Process Engineer	Assembly line	Control the process
6	Shift In-charge	Assembly line	Control the workers

Improve phase

The Analysis phase helped the team to identify the inputs that might affect the strength of the joint which ultimately caused the failure. Thus, in this phase to optimize the process performance and improve process quality, Design of Experiment (DoE) was performed using Minitab software. The experiment was aimed to investigate the effect of four input factors (Feed rate, pressure of oxygen, pressure of acetylene, filler material) on the output strength of joint (Measured in Mega Pascal). These input factors might affect the output i-e strength of the joint, so the experiment is designed to find out which are the most important input factors and to quantify their effect. A "2-level full factorial design" approach of DoE is used. Process specifications and 2 level experiments for brazing process and are shown on Table.7 and Table.8 respectively. Each level represents one trial and total sixteen trials were run during the experiment as shown in Table.9, there were four input factors and each experiment was set at two different levels. The Pareto and Normal Effect Plots showed the main input parameters which have a statistically significant effect on the process output. The effect plot indicates that the filler material (D) and the interaction of feed rate, pressure of oxygen, pressure of acetylene, filler material (ABC) all have effect on process output (strength of joint).

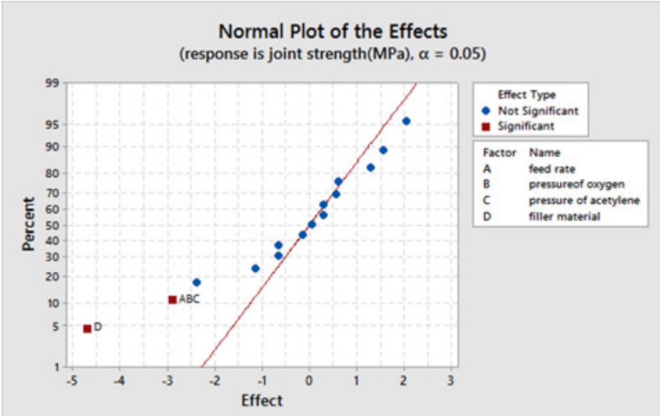

Figure 6: Normal plot effect

Table 7: Process specifications

Brazing parameters	Gas Pressure	Nature of flame
Brazing type: Manual torch brazing. Diameter of filler material 2mm. Length of filler material rod1000mm. Temperature produced 600 to 700 degree centigrade	The oxygen and acetylene pressures for brazing are as follows Acetylene = 0.05 ~ 0.10 MPa (0.5 ~ 1.0 Bar) Oxygen = 0.4 ~ 0.9 MPa (4.0 ~ 9.0 Bar)	Natural flame: best type of flame for joining copper joints 1. Light blue 2. Inner cone

Table 8: DoE levels

Factors	Units	Nominal values	Level 1	Level 2
Feed rate	Seconds	5 second	4 second	6 second
Pressure of Oxygen	Bar	4.0~9.0 Bar	5.0	7.0
Pressure of Acetylene	Bar	0.5~1.0 Bar	0.6	0.8
Material			Brass	Copper

Table 9: DoE trials

StdOrder	RunOrder	CenterPt	Blocks	feed rate	pressure of oxygen	presure of acetylene	filler material	joint strength (MPa)
2	1	1	1	6	5	0,6	cooper	105,0
12	2	1	1	6	7	0,6	brass	99,0
1	3	1	1	4	5	0,6	copper	105,0
11	4	1	1	4	7	0,6	brass	98,0
13	5	1	1	4	5	0,8	brass	99,0
4	6	1	1	6	7	0,6	copper	108,0
3	7	1	1	4	7	0,6	copper	102,0
7	8	1	1	4	7	0,8	copper	109,0
5	9	1	1	4	5	0,8	copper	98,2
9	10	1	1	4	5	0,6	brass	103,0
6	11	1	1	6	5	0,8	copper	106,0
15	12	1	1	4	7	0,8	brass	100,0
16	13	1	1	6	7	0,8	brass	99,6
10	14	1	1	6	5	0,6	brass	101,0
14	15	1	1	6	5	0,8	brass	102,0
8	16	1	1	6	7	0,8	copper	106,0

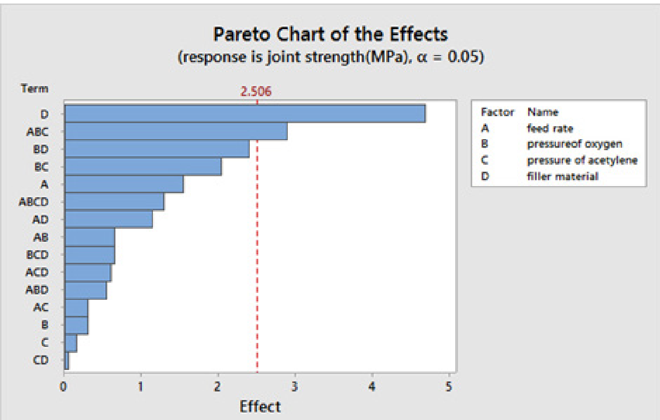

Figure 7: Pareto chart effect

The main effect plot shows that the average joint strength increased from around 101.5 to 103.5 when the feed rate was increased from 4 to 6 seconds. The average joint strength also increased from 100 MPa to 105MPa when copper filler material was used instead of brass.

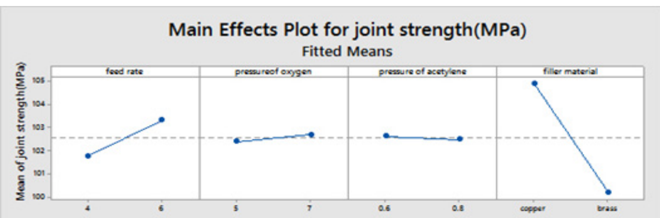

Figure 8: Main effect plot

The results of the design of an experiment on Brazing process can be seen above. The experiment concludes that the feed rate and filler material (Copper) are important parameters that affect the strength of joint.

Control Phase

After the identification of the root causes of the problem and their possible solutions it was time to standardize the process and sustain the changes that were proposed. The team made the use of the FMEA approach to create standardized documents for monitoring and improving the process by integrating it in daily production activities as shown in Table.10. Major actions recommended to improve the process were Inspection by mirror, brazing with brass, cleaning of tube with nitrogen at 5bar pressure and standard time per joint in order to control the process continuously.

CONCLUSIONS AND FUTURE RESEARCH DIRECTION

Six sigma is a statistical, systematic and data driven methodology for reducing the defects rate of any process. In this study, six sigma DMAIC approach was adopted in a manufacturing company to reduce the defect rate of external leakage in the refrigerator during its production process. Improper capillary action of filler material, feed rate, brittleness of filter drier joint and cleanliness were the major causes that resulted in external leakage defect in the refrigerator. Major actions recommended to improve the process were Inspection by mirror,

Table 10: FMEA

Process	Process function	Potential Failure Mode	Potential Failure Effects	Potential Causes	Current Controls	Actions Recommended	Responsible
Brazing	1. Joint the extra suction pipe 2. Anti-condenser joint 3. Rare condenser joint	improper filling of materials into meting parts Capillary action doesn't occur even though the braze alloy melts, melting temperature of brass is quite a bit higher than copper, allowing the brass to reach the needed temperature of 850-890°C without burning actual pipe. Place the raw material at dirty and open area, Male practice, Improper selection of filler material Improper selection of mirror.	formation of joint is not uniform Low strength of joint External leakage of gas Weak joint Rework cost External leak of gas The braze alloy balls up The braze alloy failed run into the joint The braze alloy flows away Brittle of filter drier joint Rework cost Weak joint External leakage Low strength Not trace properly leak joint by visual inspection	Feed rate Unfavorable Heat Input Improper Cleanliness Brittleness of filter-drier joint Visual Inspection	Standard time per joint Pressure regulator, Increasing braze time Cleaning of the tube by nitrogen at 5bar pressure. Brazing with brass Inspection by mirror	1. Improve cleaning methods to ensure removal of contaminants. 2. Improve protective atmosphere quality. 3. Change position of the part /brazer to encourage the braze alloy to run into the joints. 4. Replace manual method of brazing by induction brazing machine. 1. Increase time at heat 2. Increase braze temperature. 3. Check for improper or insufficient cleaning. 1. Check cleaning process. and clean the filler metal (clean brass rods). 2. Look for surface contaminants left from poor cleaning. 3. Check the atmosphere quality and improve it, if necessary. 1. Using copper filler material rather than brass for filter drier joint. 2. Try changing the form of the alloy Using a high magnifying glass mirror to visualize the joint properly	Six Sigma team members

brazing with brass and cleaning of tube with nitrogen at 5bar pressure and standard time per joint in order to control the process continuously. Based on the data as shown in Figure.2 total defects for the selected model of refrigerator were 709 defects/year, which makes around 2.8 defects/day considering working days of the company. After the adoption of mitigation actions during the improve and control phase of the DMAIC cycle the defect rate per day was reduced by 0.84 defects/day, which cumulatively makes around 30% (i-e 210 defects) defects reduction on annual basis. Lower number of the defects of external leakage in production at brazing stations, ultimately reduced customer's complaints and improved SCR. Further, this study could be extended to investigate the defects in production process of compressor, door alignment and other subsequent major defects with more extensive data.

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