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Optimization in MIG Welding by Using Six Sigma Tools

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Abstract

Six sigma methodology leads to business excellence by improving process quality and reducing variations. It's a philosophy which enables processes to produce defect free products. A refrigerant manufacturing company was facing increased operational cost, low quality, and increased lead time due to high defect rate in Metal Inert Gas (MIG) Welding. This paper presents an empirical study about the implementation of six sigma Define, Measure, Analyze, Improve and Control (DMAIC) methodology in MIG Welding facility of Heat Ventilation and Air Conditioning (HVAC) manufacturing plant. Critical factors were identified and analyzed by using Ishikawa diagram and hypothesis testing. Fitted linear model was used to identify optimal setting of process parameters. After-effects of project reduced the defect rate up to 25% operations cost (US $ 0.8 Million), and customized the sigma level from 2 to 4 sigma.

Keywords: Six Sigma process; MIG welding; Excellence; Cause and effect diagram; Hypothesis testing; DMAIC; Fitted linear model

Introduction

Organizations are looking for the ways to improve their business process in order to stay in competition and to win a delightful customer stream in competitive and fast growing market. In this regard, six sigma is a key methodology which has not only attracted the world-class business giants to adopt this business excellence methodology, but also the researchers to fulfill their quest for knowledge.

Six sigma is a well-structured method which focuses on manufacturing nearly perfect products and services with great stability. Since the development of six sigma business excellence methodology (1999), it is defined as, "a business excellence methodology that focuses on elimination of variations or defects in any business process focusing on the outputs which are vital for customer". Sigma *σ*, is a Greek alphabet which is used by the statisticians to measure variability in any type of business process. Process capability of any organization is analyzed by sigma level of its operating business processes Six sigma methodology is developed by Bill Smith at Motorola in 1980s and it achieved a difficult target of gaining 3.4 defects per million defects [1]. Six sigma have been successfully applied in different fields like, Manufacturing, Higher Education, and Services etc. and it achieved excellence by improving business process in 1995, when General Electric Co applied it in its business processes. Six sigma application was firstly limited to the manufacturing sector but in the recent era its application has covered almost every department and every sector of any organization aiming at diminishing the variations which are the real devils in any process [2].

Most common perception when talking about six sigma methodology is DMAIC methodology. DMAIC methodology is used when existing processes are not clinching the customer specifications. There are two six sigma methodologies, one which focuses on process improvements is well known as DMAIC (define, measure, analyze, improve and control) and the other one targets the robust design ameliorations is defined as DFSS (design for six sigma). Originally developed business improvement strategy was DMAIC, which is used for improving an existing process when it is not meeting customer needs. DMADV (define, measure, analyze, design, verify) was instituted by General Electric. There are various strategies which are used beside DMAIC and DMADV such as IDOV (identify, design, optimize and validate) and DIDES (define, initiate, design, execute and sustain) [3].

According to Amit Yadav, "Six Sigma implementation in automobile and manufacturing sectors can bring breakthrough, especially DMAIC technique that addressed in depth issues of process" [4].

The original problem solving process for Six Sigma developed by Motorola was MAIC. Later, DMAIC instead of MAIC was advocated by GE where D stands for "definition". For DFSS methodology, there are different approaches in use such as DMADV (define-measure-analyze-design-verify), IDOV (identify-design-optimize-validate) and DIDES (define-initiate-design-execute-sustain).

Literature Review

A literature review was undertaken with an objective of identifying the past history of various improvement initiatives carried out to address process-related problems. A detailed literature review was undertaken in Six Sigma with an objective of identifying the type of improvements carried out by different people in various organizations to address process-related problems.

Antony et al. study "Application of Six Sigma Methodology to Reduce Defects of a Grinding Process", As a result of the project, the rejection level of distance pieces after the fine grinding process has been reduced to 1.19% from 16.6% [5].

Dhamija, et al. in 2014 research on the implementation of six sigma on welding process in manufacturing company by using DMAIC. The rework process has been decreased from 16% to 5% i.e. before application of Six Sigma the number of rework pieces were 643 and after using this approach no. of rework pieces decreased to 171 as a

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result rework cost has also been decreased from 2051 to 545 Indian Rupees. Sigma level has also been improved from 3.2 to 2.5 [1].

Robert Holtz Paul Campbell implemented Six Sigma in Ford's management and maintenance facility. This project projects have saved $7,500 annually in the PM of vehicle lifts and $40,000 annually in the UM of exhaust fans [6].

Sekhar and Mahanti, "Confluence Six Sigma, simulation and environmental quality", The integrated application of Six Sigma and simulation has been successful in reducing particulate emissions from 200 milligram per cubic meter to less than 20 milligram per cubic meter and sulphur dioxide emissions from 45 milligram per cubic meter to less than 4.5 milligram per cubic meter thus reducing air pollution [7].

Andrew Thomas, applied lean six sigma in a small engineering company – as a model for change, as a result the following savings have been identified to date; Rejection rate reduced on the pilot line of 55 per cent indicating a potential saving over the year of £29,000. Cost of rejection before LSS=£69,000, cost of rejection after LSS=£36,000. Cell OEE increased from 34 to 55% and 31% increase in parts per hour from the production system. Throughput before LSS was 15 parts/hr. and throughput after LSS=22 parts/hr. Equating 2,800 additional parts per annum. Energy usage reduction of 12 per cent per annum from 23,000 to 21,500 KWh. In conjunction with the OEE performance increase, the TPM program reduced equipment downtime to 2% from 5% based on nominal operating hours of 2,000 per annum. Hours downtime before LSS=100 hours that 5% of total. After implementation of LSS hour's downtime reduced to 40 that is 2% of total. This project proved to be highly successful primarily through the substantial improvement made in foam production but also through the cost benefit ratio achieved (outlay of £4,800 compared to the total savings made of over £40,000 in the first three months of implementation) [8].

Jaideep Motwani documented, "A business process change framework for examining the implementation of six sigma: a case study of Dow Chemicals", Dow Chemicals, which implemented six sigma on a corporate-level in 2000, achieved its target of $1.5 billion in cumulative EBIT (earnings before interest and taxes) gains by the end of 2002 [9].

Ricardo Pires de Souza, (2013), "Implemented Six Sigma project in a 3M division of Brazil", it was found that production cycle time decreased by 11.7 percent, CSI increased from 93.9 to 97 percent and inventory turnover from 4.9 to 9 turnovers, three months after project implementation [10].

Lean Six Sigma is the theoretical verification of conceptual model of process improvement that is followed all over the globe, however there are deficiency of its implementation in small and medium sectors due to lack of clear road, cost and understanding. Success of six sigma implementation is mainly depend on organizational culture [11].

DMAIC Methodology

For this study DMAIC Methodology had been adopted. Define phase includes business case, problem statement, scope and objective of Study. Measure phase is about measurement of current situation by collecting relevant data to both process and problem. Analyze the problem by cause and effect in order to segregate the vital few input variables. Improvement phase develop counter measures i.e. by optimizing the key input variables. Control phase is about sustainability of improvements by building robust process controls. This study includes A3434 CLD material which is used in manufacturing of HVAC.

Define phase

Define phase includes problem statement, business case, project selection, drawing assumption about the potential key performance indicators & scope of the project. All the assumptions were based upon historical data. Multiple techniques like Brainstorming, Pie, bar chart, Project Charter and Critical to Quality matrix can be used in defining phase [12] but in this study define phase is started using development of project charter (Table 1).

Measure phase

The vital function of measure phase is to efficiently measure the current performance of business processes and begin assessing it. Multiple techniques can be used for this purpose which include but not limited to Pareto diagram, Control charts, SIPOC, Gauge R & R, Process map and Statistical process control [12]. For better understanding of current situation; process mapping was used (Table 2).

To measure whether or not our measurement system is capable in assessing process performance or evaluating potential process improvements gauge R& R Study (Figure 1) was conducted. On the basis of results, it can be concluded that our measurement system is not capable. Total gauge variation is greater than general standard (Figure 1).

Process Capability was measured by analyzing 50 different samples of defects and performing Poisson process capability analysis (Figure 2).

TEST 1; One point more than 3.00 standard deviations from center line. Test Failed at points: 17, 18, and 19 (Figure 3).

Pareto analysis conducted on calculated results that shows the Spatters and Welding Penetration contributed almost 80% of total defects that's why they were targeted to get bigger financial impacts (Figure 4).

Project Title	Optimization in MIG Welding by Using Six Sigma Tools				
Business Case:	From (Dec 2017 to 1st Week of July 2018) due to high defect rate company faces loss of revenue, customer satisfaction and reputation. High defect rate resulted into an average loss of US $2 million monthly (Total number of defects*Total time of repaire*Piece rate). By lowering the defect rate upto 30% company can save upto US $0.8 million Per month.				
Problem Statement:	Defect rate in the MIG welding of Condenser Assembly distributor in HVAC was very high. Penetration of MIG welding joints into the distributors and large spatters on the distributor surface resluted in huge reworking & defective product in most scenarios.				
Objective:	Reducing defect rate upto 30% of total defect rate.				
Metrics:	Primary Metric Defect Rate=(Total defects/total inspected)*100 Secondary Metric=Productivity				
Project Scope:	Welding Operation				
Project Team:	Zahid Anwar, Muhammad Mudassar Sharif, Yousaf Ayub, Amar Abbas and Munir Ahmed				
Milestone List:	Define Phase	Measure Phase	Analyze Phase	Improve Phase	Control Phase
	2nd Feb 2018	16th Mar 2018	24th April 2018	30th May 2018	6th July 2018

Table 1: Project Charter.

Supplier	Input	Process	Output
W.H Supplies CKD to MIG Welding	Welding Jigs	Setting jigs on Workstation	Jig Setting
Jig Station	Distributor A & B	Clamping of Jigs on Distributor	Distributor Clamping
D-Bracket Supply	Distributor Brackets	Setting distributor Brackets on Jig	Bracket Clamping
Bracket Clamping	MIG Welding Gun	Gun Preposition	Gun prepositioning for Welding
Gun Pre-Positioning	Gun Angle Setting	MIG Welding Spatters A & B	Welding of Distributor A&B

Table 2: SIPOC Diagram.

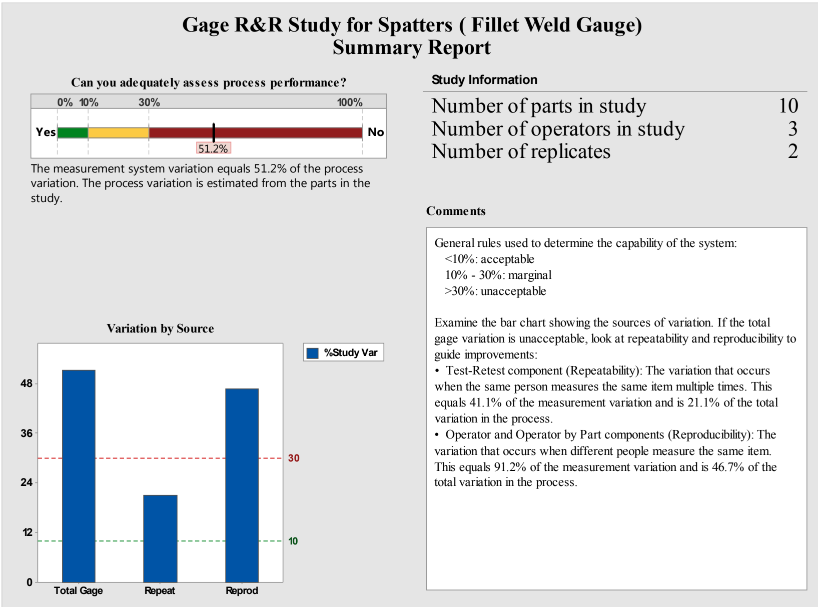

Figure 1: Gage R &R Study.

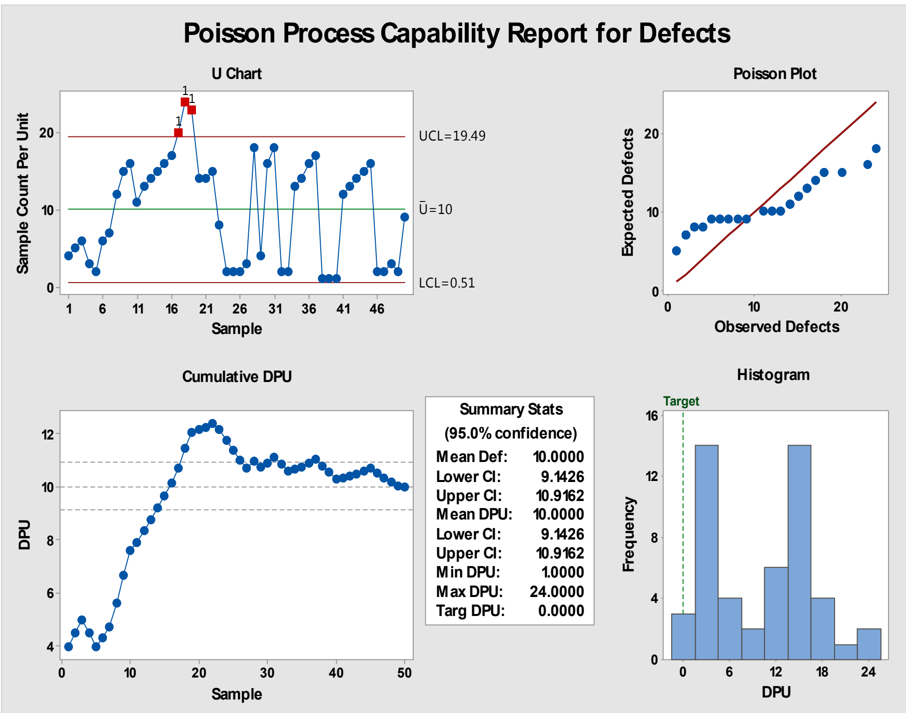

Figure 2: Poisson Process capability Analysis.

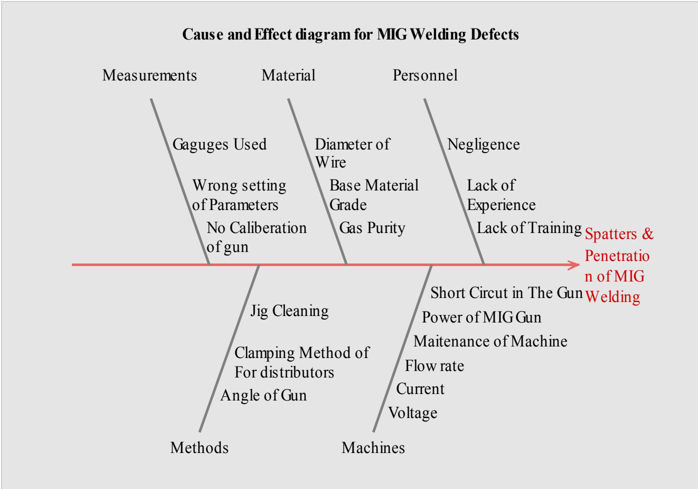

Figure 3: Root-Cause Analysis.

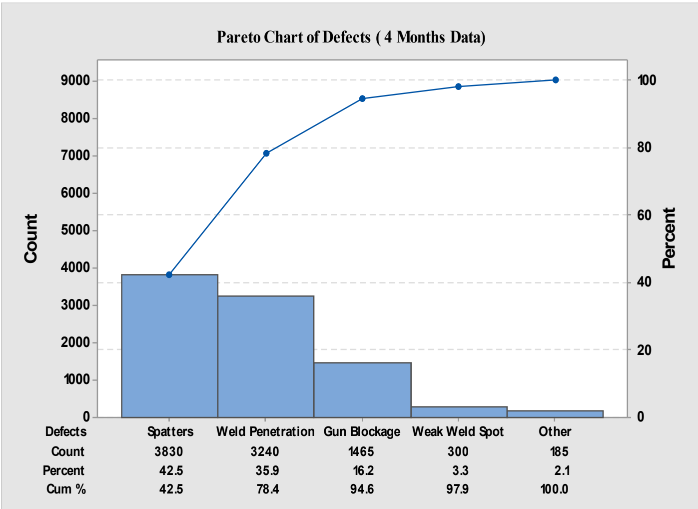

Figure 4: Pareto Analysis.

Cause and Effect (Ishikawa) Diagram identified the potential causes of MIG Welding process defects by using brainstorming and focusing on man, method, machine, measurements and environment [13]. Expert Judgement & concensuses between team voltage, current, flow rate of gas and angle of the MIG welding gun were finalized for further analyses (Figure 4).

Sigma level calculation: Sigma level is given in Table 3.

Total Defects=	9020
Total Inspected=	27000
Opportunity per unit=	1
Total No of Defect Opportunity=	27000
DPU (Defects/unit)=Total Defects/Total Produced=	9020/27000=0.334
DPO (Defects per opportunity)=Total Defects/Total Produced*No. of opportunities of defect=	0.334
Yield=1-DPO=	1-0.334=0.67
DPMO=DPO*1000000	340000

Table 3: Sigma Level 2.

Analyze phase

One way ANOVA is used to analyze whether two groups are different or not, which one is better? Analysis of variance was used to find out whether different settings of voltage, current, flow rate and angle of MIG welding have significant effect on the defects creation or not.

Data was collected by using different voltages and keeping all three factors constant. Null hypothesis was all means are equal while alternative hypothesis was at least one mean is different. Significance level was $\alpha=0.05$. Equal variances were assumed for the analysis. There were 6 Subgroups levels of Voltage 3, 5, 6, 7, 8, and 9 voltage test. P-value< 0.05 which shows factor is significant in Figure 5. Also the mean value of defects created is different at different levels of voltage making it significant (Interval Plot) (Figure 6).

Analysis of variance for flow rate of argon gas was also performed. In analysis, flow rate of gas was varied keeping all other factors constant. There was high difference between the mean values of defects created (Box and Interval Plot). Also P-value<0.05 shows that our null

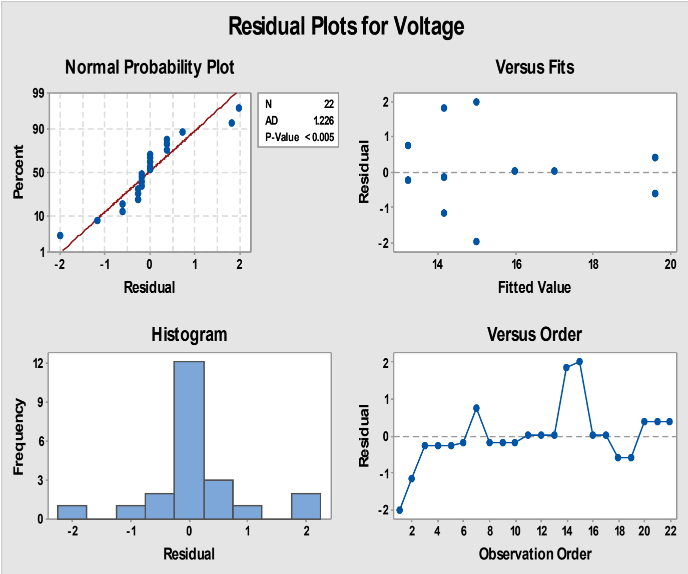

Figure 5: ANOVA Residual Plot of Voltage.

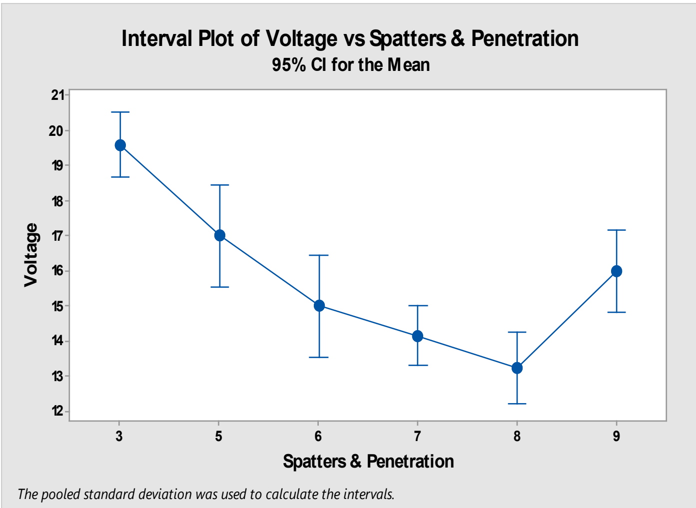

Figure 6: ANOVA Box Plot of Voltage.

hypothesis is rejected. Null hypothesis assumed that all means are equal while alternative hypothesis was assumed that at least one mean is different. ANOVA Factor includes total 6 levels that were tested 15, 16, 17, 18, 19 and 20 CFH. P-value was 0.014 which is <0.05 making the factor significant in Figure 7.

One way ANOVA analysis between current and defects conducted at different setting; keeping current and all other three factors constant. Box plot showed a large difference in mean value of defects created. Also the P-Value=0.027 is for current after analysis of data using Mini-tab. P-value <0.05 shows that there is significant effect of current on spatters creation which is needed to be optimized in order to reduce defects (Figure 8).

9 Random levels for current were adjusted that were 80, 85, 90, 95, 97, 105, 110, 115, and 120 Ampere (A). After Analysis of variance p-value was 0.027 in Figures 9 and 10.

ANOVA between the angles of MIG welding gun was performed using Mini-tab. Gun angle was varied keeping all other three factors at constant value. P-Value<0.05 at different levels of gun angle depicts that's this factor is significant. Null hypothesis assumed that all means are equal while alternative hypothesis at least one mean is different. Significance level was $\alpha=0.05$. Equal variances were assumed for the analysis. Total level of variable was 3 and their values were 45°, 60°, and 90°. Analysis of Variance showed in Minitab was 0.041 which is less than 0.05 making factor significant in Figures 11 and 12.

Improvement phase

All the significant factors were optimized through 2k Factorial design and fitted linear model for optimization of process parameters. After designing the experimental runs and measuring the output variable by using fillet weld gauge. The output was measured in the number of spatters on a distributor which are above the acceptable

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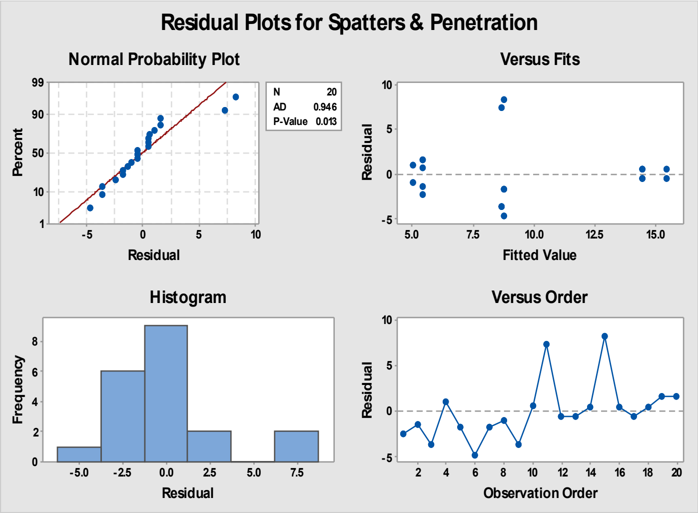

Figure 7: ANOVA Box Plot of Flow Rate (CFH).

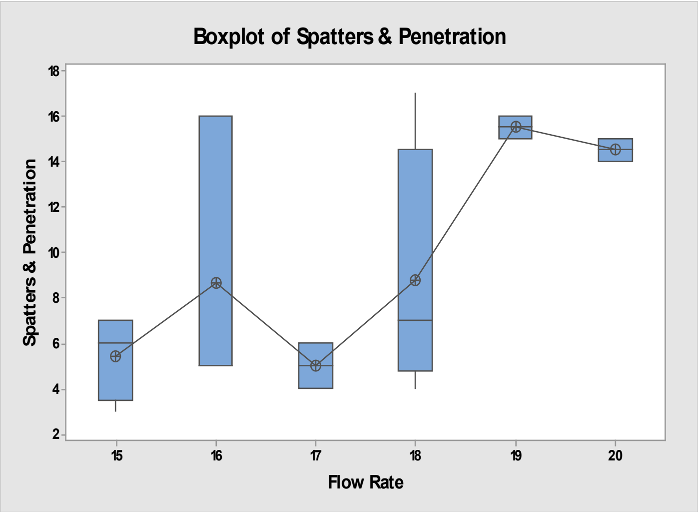

Figure 8: ANOVA Residual Plot of Flow Rate (CFH).

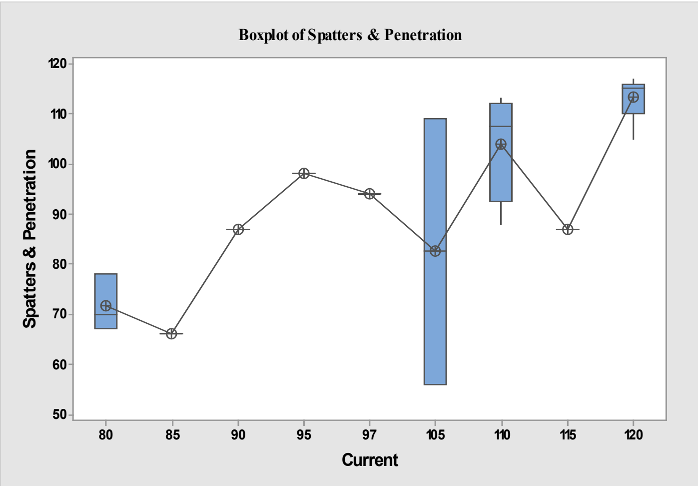

Figure 9: ANOVA Box Plot of Current (Ampere).

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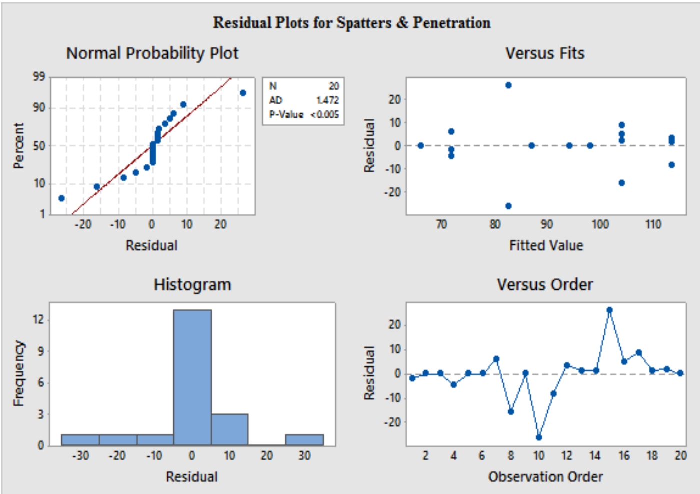

Figure 10: ANOVA Residual Plot of Current (Ampere).

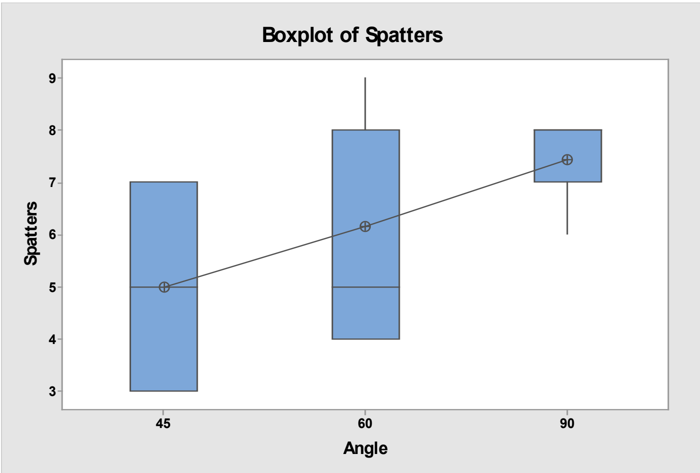

Figure 11: ANOVA of MIG Gun Angle (Degree).

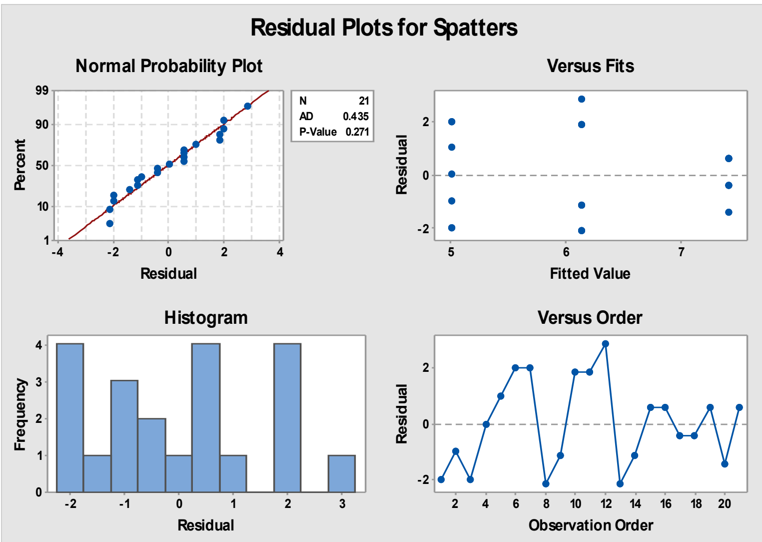

Figure 12: ANOVA Residual Plot of MIG Gun Angle.

thickness level of 1 cm. Results show that number of spatters are minimum when current is 200 Ampere, voltage is 25 volt, gas flow rate is 25 CFH and MIG Gun Angle is 45° and after this setting number of spatters are minimum when current is 200 Ampere, voltage is 22 volt, gas flow rate is 22 CFH and MIG Gun Angle is 45° (Figure 13).

Control phase

SPC is very strong set of tools with numerous kinds of control charts each with unique application. A C-chart was drawn to assess whether our process defect rate is within the defined defect rate specifications or not after implementation of optimal solution of current is 200 Ampere, voltage is 25 volt, gas flow rate is 25 CFH and MIG Gun Angle is 45°. The results of monitoring the process shows that process is capable as compared of its previous un-controlled behavior. After applying the improved parameters and all the process controls a data was collected for 10 days and C-chart of defects was drawn (Figure 14).

Furthermore, Failure Mode and Effect Analysis were used when new controls were being defined in existing process and identifying potential failure modes. Failure mode and effect analysis includes every

StdOrder	RunOrder	CenterPt	Blocks	Current	Voltage	Flow Rate	Angle	No of Spatters
1	1	1	1	80	13	22	45	8
18	2	0	1	140	19	23.5	52.5	7
5	3	1	1	80	13	25	45	9
12	4	1	1	200	25	22	60	10
19	5	0	1	140	19	23.5	52.5	11
17	6	0	1	140	19	23.5	52.5	12
14	7	1	1	200	13	25	60	13
16	8	1	1	200	25	25	60	14
13	9	1	1	80	13	25	60	16
2	10	1	1	200	13	22	45	3
4	11	1	1	200	25	22	45	4
8	12	1	1	200	25	25	45	2
10	13	1	1	200	13	22	60	7
9	14	1	1	80	13	22	60	7
15	15	1	1	80	25	25	60	8
3	16	1	1	80	25	22	45	9
6	17	1	1	200	13	25	45	8
7	18	1	1	80	25	25	45	9
11	19	1	1	80	25	22	60	9

Figure 13: Results of Spatter using DOE 2^k Factorial Design.

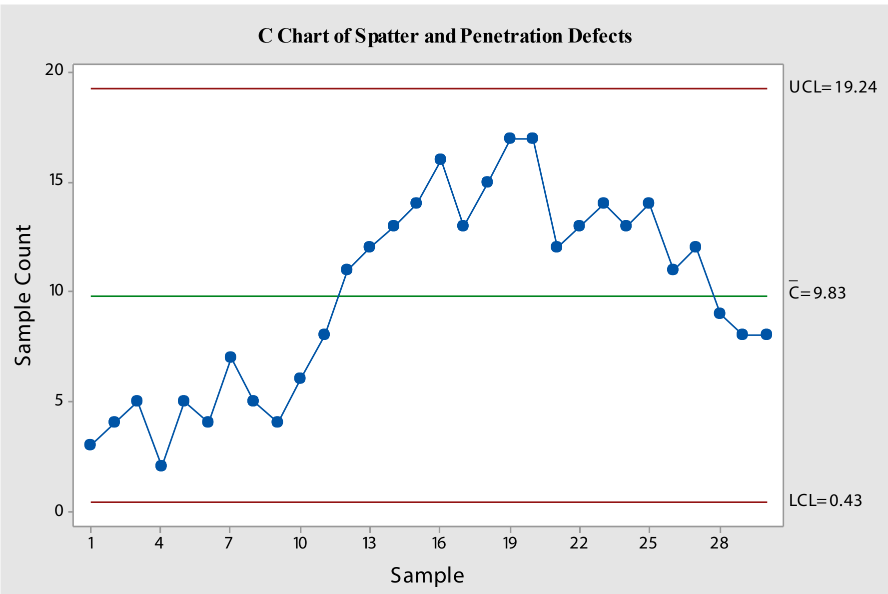

Figure 14: C-Chart of Spatters/Penetration Defects.

Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Current Process Control for prevention	Current process control for Detention	Detention	RPN	Recommended Action(s)
Material as per Specification	Wrong Material	Final Product out of Specs	8	Parts mixing because of excessive inventory	4	Separate Bins placed	MIG welding Jig	2	64	Storage of only required amount of CKD in bins
Process Standard Parameters	Un-standardized process Parameters	Spatters & Penetration	9	Process is not being monitored	4	Flow meters and gauges	Spatters on Distributors	6	216	Standardize process by using 6 sigma & train on it
Spot position as per standard	Spot position not as per standard	Weak weld Joint	8	Negligence of worker	4	MOS for welding	Visual Inspection	3	96	Training of operator/ Increase skill level
Welding at standard position/ alignment	Welding not at proper position/ alignment	Final Assembly not possible	8	Distributor not aligned at 90 Degree	2	Tri-Square	Welding Jig	3	48	Periodic calibration of jig
				Brackets not seated properly in jig	2	Cleaning of jig	Use of locating pins	3	48	
Distributor not melted after welding	Distributor melted	Leakage	8	Over processing/welding for more than required	3	None	Visual Inspection	3	72	Training of operator/ Increase skill level
Spatters not Enter into slots and holes of distributor	Spatters Enter into slots and holes of distributor	Blockage/Clogging of Condenser	8	Welding not performed at standard parameters/ Wrong angle	3	None	Visual Inspection	2	48	Optimal Process Parameters Setting
		Difficulty in M-Tubes insertion	5						30	
No Big spatters on the surface	Big spatters on the surface	Appearance not good	4	Welding not performed at standard parameters	4	None	Visual Inspection	2	32	Same control as for above process
				Nozzle size not as per standard		None	Visual Inspection	2	32	Use Nozzle of required length

Table 4: Failure Mode and Effect Analysis (FMEA).

process in MIG Welding of distributors, their potential failure mode, causes and recommedned controls for the sustainability of improved process (Table 4).

Conclusion

Six Sigma DMAIC methodology is very robust to minimize the variation in existing processes. Six sigma is structured approach to identify, measure, analyze the problem to improve the current process and define controls for long term benefits. This paper helps improving the MIG welding problems in HVAC manufacturing organization. After the completion of this research the tangible and in-tangible benefits are listed as:-

1. Improved Quality rate, productivity and reduced lead times
2. 25% defects were reduced as compared to pre-project defect rate
3. A net saving of US $0.8 million annually to the organization
4. Improved six sigma Level from 2 sigma to 4 sigma level of MIG welding process.

References

1. Dhamija A, Saini N, Shukla OJ, Misra AK (2014) Sigma level improvements in MIG welding using DMAIC approach. Sop Transactions on Statistics and Analysis 1.
2. Kaushik P, Khanduja D, Mittal K, Jaglan P (2012) A case study: Application of Six Sigma methodology in a small and medium-sized manufacturing enterprise. The TQM Journal 24: 4-16.
3. Desai DA, Antony J, Patel MB (2012) An assessment of the critical success factors for Six Sigma implementation in Indian industries. International Journal of Productivity and Performance Management 61: 426-444.
4. Yadav A, Sukhwani VK (2016) Quality improvement by using Six Sigma DMAIC in an industry. International Journal of Current Engineering and Technology pp: 41-46.
5. Gijo EV, Scaria J, Antony J (2011) Application of Six Sigma methodology to reduce defects of a grinding process. Quality and Reliability Engineering International 27: 1221-1234.
6. Holtz R, Campbell P (2003) Six Sigma: Its implementation in Ford's facility management and maintenance functions. Journal of Facilities Management 2: 320-329.
7. Sekhar H, Mahanti R (2006) Confluence of Six Sigma, simulation and environmental quality: An application in foundry industries. Management of Environmental Quality: An International Journal 17: 170-183.
8. Thomas A, Barton R, Chuke-Okafor C (2009) Applying lean six sigma in a small engineering company–a model for change. Journal of Manufacturing Technology Management.
9. Seow C, Motwani J, Kumar A, Antony J (2004) A business process change framework for examining the implementation of Six Sigma: a case study of Dow Chemicals. The TQM Magazine.
10. Souza RPD, Hékis HR, Oliveira LAB, Queiroz JV, Queiroz FCBP, et al. (2013) Implementation of a Six Sigma project in a 3M division of Brazil. International Journal of Quality & Reliability Management 30: 129-141.
11. Sreedharan VR, Raju R (2016) A systematic literature review of Lean Six Sigma in different industries. International Journal of Lean Six Sigma 7: 430-466.
12. Thakore R, Dave R, Parsana T, Solanki A (2014) A review: six sigma implementation practice in manufacturing industries. International Journal of Engineering Research and Applications 4: 63-69.
13. Anderson NC, Kovach JV (2014) Reducing welding defects in turnaround projects: A lean six sigma case study. Quality Engineering 26: 168-181.