Investigation and improvement of vehicle A/C system compressor noise by 6sigma approach

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Abstract

Recent developments on the vehicle engine noise show that tonal sounds such as a compressor noise is audible if its sound is 7-9dB higher than level of masking noise. Therefore, the acoustic performance of air-condition (A/C) compressors becomes more important for passenger comfort during engine idling and run up. The air conditioning system compressor noise is transmitted to interior cabin in both air-borne paths and structure-borne paths of the compressor pipes. The compressor is driven by the engine and it has also a high interaction with the other components of the system such as Expansion Valve (TXV), Electric cooling fan, Condenser and Evaporator. Therefore, to make a proper NVH design of the air conditioning system in terms of customer satisfaction, it is necessary to consider all these interactions when determining the type of compressor. In this study, the noise problem induced by the A/C system compressor was investigated by Six Sigma approach to determine solution alternatives. The air conditioning system was examined in detail as a cooling process in order to determine individual factors of each system components affecting the compressor noise issue. The most important factors are defined by Cause and Effect matrix to simplify the working model. The effect of each factor/input on internal noise level was measured with the microphones and accelerometers based on the pressure increase in the A/C system. A correlation analysis is performed between these factors/inputs and interior noise level to define high correlated factors of each system component. Besides, a regression analysis is performed to identify the compressor noise generation model (equation describing the noise model) based on these highly correlated factors. A series of experiments is designed (DOE) on these regression model to find out the optimum solution to improve compressor noise problem perceived in the vehicle cabin.

Keywords: Air conditioning compressor, Structural- borne noise, Airborne noise

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1. Introduction

HVAC systems are designed to provide thermal comfort inside the car cabin based on air circulation through various components: flaps, thermal exchangers, blower, ducts, etc. Due to current packaging constraints on the HVAC, as it is placed in the car cabin under the dashboard, four main HVAC designs are available: centered, centered with lateral blower, half- centered and lateral. HVAC components are gathered in four blocks for a centered HVAC unit: air inlet, blower, thermal and distribution blocks. During HVAC operation, air is collected at windshield's base outside the vehicle or inside the car cabin in recirculation mode. Passing through the air inlet block, air is blown and filtered. Then, in the thermal block, air is heated or cooled by the thermal exchangers. Finally, in the distribution block, air is blown into car cabin areas [1].

The passenger compartment's interior noise and thermal performance are essential criteria for the driving comfort of vehicles. The air-conditioning system influences the both criteria. It creates comfortable thermal conditions. On the other hand, the noise radiation of the air-condition system's components can be annoying. The blower, the air distribution ducts and the registers affect air rush noise. In some cases, the refrigerant flow creates hissing noise. Such noise has a great influence on vehicle acoustical comfort and on overall quality perception of a vehicle. Therefore, the acoustic performance of air-condition compressors becomes highly important for passenger comfort [2].

The compressor noise issue arises as a tonal sound at the working frequency of the compressor when the engine is idling as it can be seen in Figure 1 and it becomes audible if it is about 7-9dB higher than the level of masking noise level of engine. Besides, compressor noise issue is also evaluated in run-up maneuver in terms of critical order of the compressor harmonics.

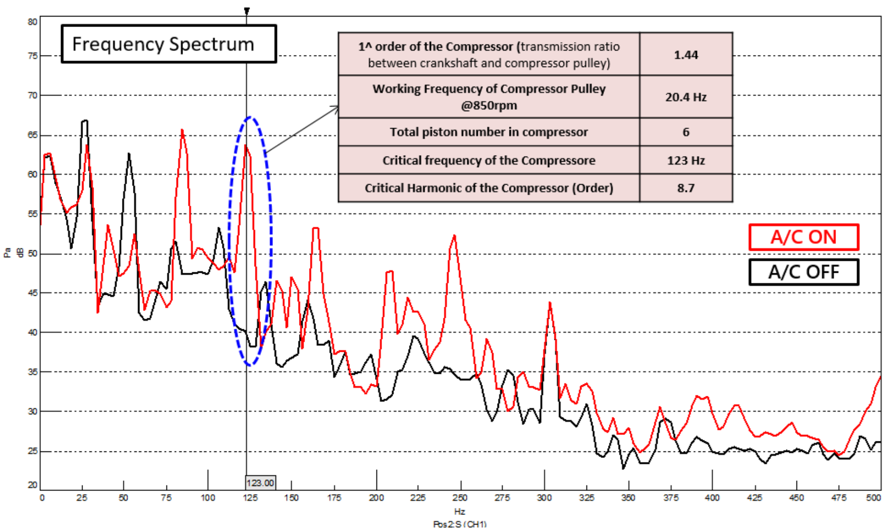

Figure 1. A/C compressor noise at engine running in idle

In this study, the compressor noise problem is investigated by 6-sigma approach. The Six Sigma is a disciplined, statistical-based, data-driven approach and a continuous improvement methodology for eliminating defects in a product, process or service. It was developed by Motorola in the early to mid-1980s based on quality management fundamentals, and then became a popular management approach at General Electric (GE) in the early 1990s. Hundreds of companies around the world have adopted Six Sigma as a way of doing business.

In the traditional approach, engineers focus on finding the root cause by measuring vibration transmission from the compressor to the vehicle body by examining the relationship between these vibrations and interior noise levels (at driver's ear position) on frequency basis. Besides, Transfer Path Analysis (TPA) is another method used to define the root cause of the noise problem. By means of TPA, one can mathematically evaluate noise contributions from their source, along their transfer paths and all the way to the receiver as it is seen in Figure 2.

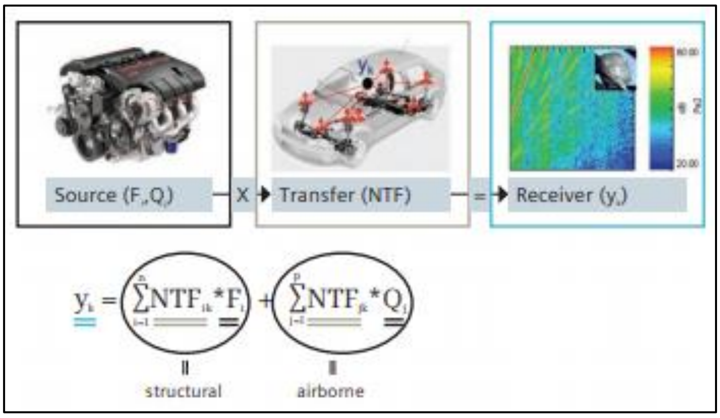

Figure 2. The source-transfer-receiver model

However, Six sigma approach starts from a SIPOC diagram which allows one to examine the whole process from the supplier to the customer. Thanks to this diagram, all the possible factors affecting the A/C system noise level are predetermined. Then, the contribution of each factor on A/C system noise level and the effect of interaction of the factors with each other are tested with DEO (Design of Experiment). In six sigma approach, the obtained data from more than one sample/vehicle are evaluated with statistical analysis methods such as correlation and regression and the most effective source, transmission path, design variables etc. are determined. As a result, the most appropriate/optimum solution in terms of cost and quality can be determined.

2. A/C System Noise Phenomena

The air conditioning compressor driven by the engine with a common belt works as a vibration source due to the internal pressure changes (pulsation) in the system when the AC System is activated and the vibrations on Compressor are transmitted through the AC Pipes and its fasteners to the vehicle body. Here, these transmitted vibrations from compressor to the vehicle body are perceived as structural borne noise and vibration in vehicle cabin. Besides, the compressor is a sound source that emits noise that is transmitted by the air to the vehicle cabin. This Compressor noise might be perceived in both Engine idle and run-up conditions, which may be confused with the engine noise by the customer.

A system with a six-cylinder compressor was analyzed in this study. The main frequency of the compressor appears to be 123Hz for engine idle condition and the main order of A/C compressor noise appears to be 1.44 as shown in Table 1.

Table 1. The critical frequencies and harmonics of the A/C system

1st order of the compressor (transmission ratio between crankshaft and compressor pulley)	1.44
Working frequency of compressor pulley @859rpm (859/60 x 1.44)	20.6 Hz
Total piston number in compressor	6
Critical frequency of the compressor (20,6 x 6)	123.6Hz
Critical harmonic of the compressor (order) (1.44 X 6)	8.7

The main compressor harmonics (Order 1.44 and Order 8.7) are shown in Figure 3. The noise level at the working frequency of the compressor (see Figure 4) is more important in the maneuver of engine running in idle while the noise level at compressor harmonics are considered in run-up maneuvers.

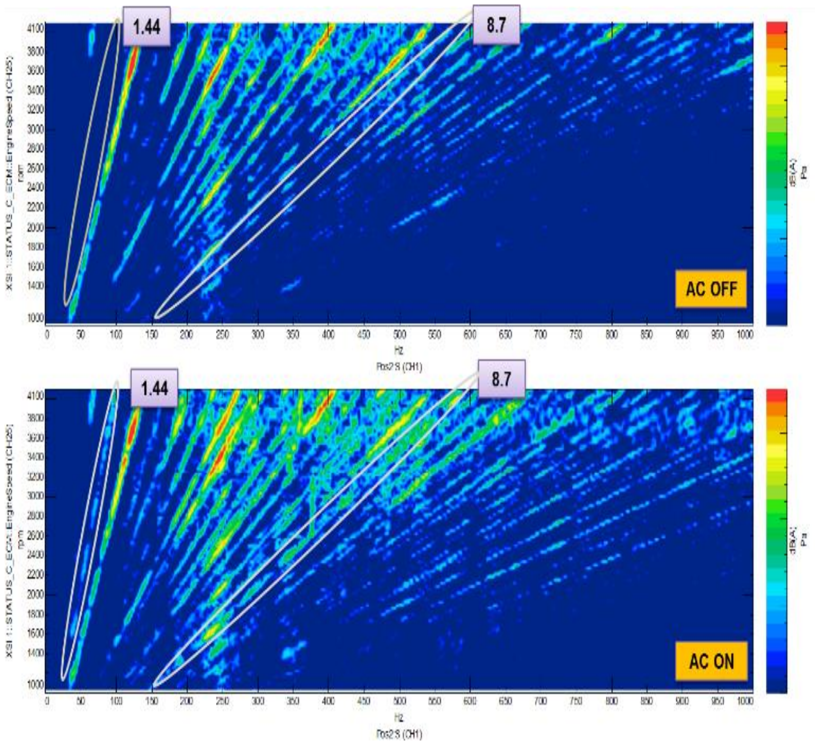

Figure 3. The color map graph of the interior noise levels in partial open throttle (POT) in neutral maneuver

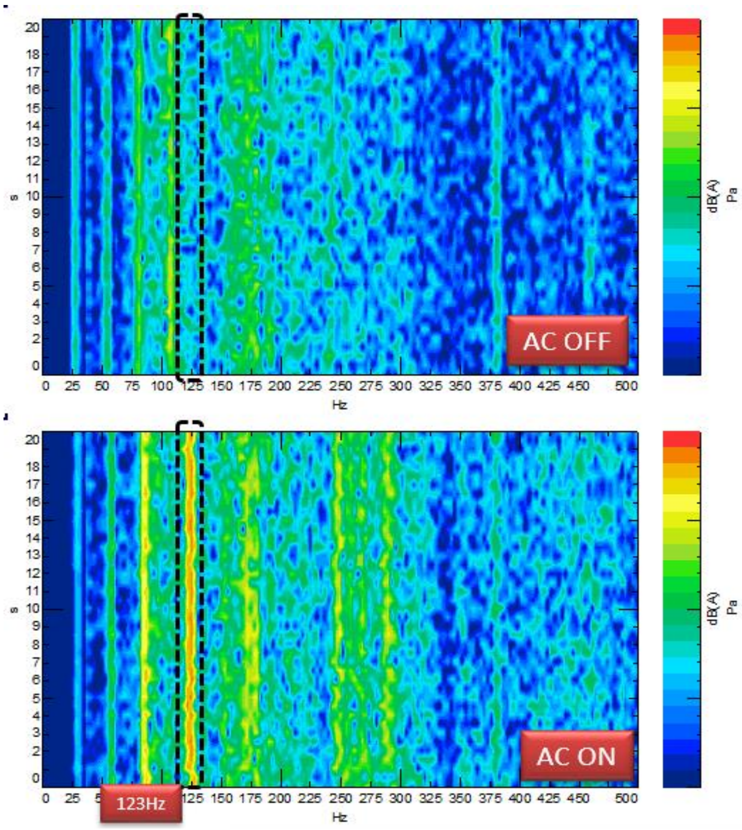

Figure 4. The color map graph of the interior noise levels when the engine is running at idle.

3. Problem Definition

During the objective and subjective evaluations, a noise problem induced by the air conditioning system was detected. Interior noise levels were measured by the microphones located at driver's ear position on different eleven vehicles in both maneuvers of engine running in idle and partial open throttle (POT) maneuver in neutral (from 1000 rpm to 4000 rpm) to reveal the current situation. The system pressure is settled at a specific value, which represents working conditions of the compressor to provide repeatability of the test and tests were performed for both A/C ON and A/C OFF conditions. A/C system components are shown in Figure 5.

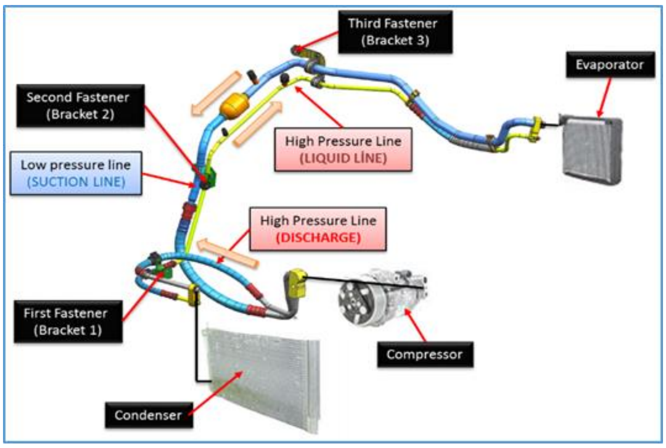

Figure 5. A/C system components

A sample measurement representing A/C ON & OFF difference is shown in Figure 6. The difference between the noise levels of two conditions (A/C ON and A/C OFF) is desired to be ≤ 2dB(A).

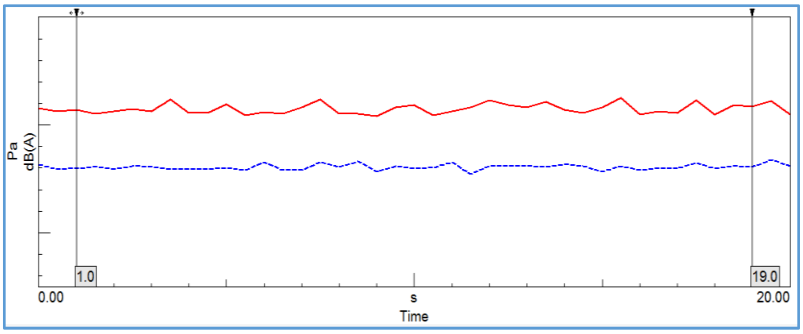

Figure 6. The interior noise level for both A/C ON and OFF conditions

The statistical data analysis results of the interior noise levels executed with Minitab software are presented in Figure 7. The average level of all vehicles in the basket for difference in noise levels between the situations of A/C ON and A/C OFF is 4,7 dB(A) with a standard deviation of 0,6.

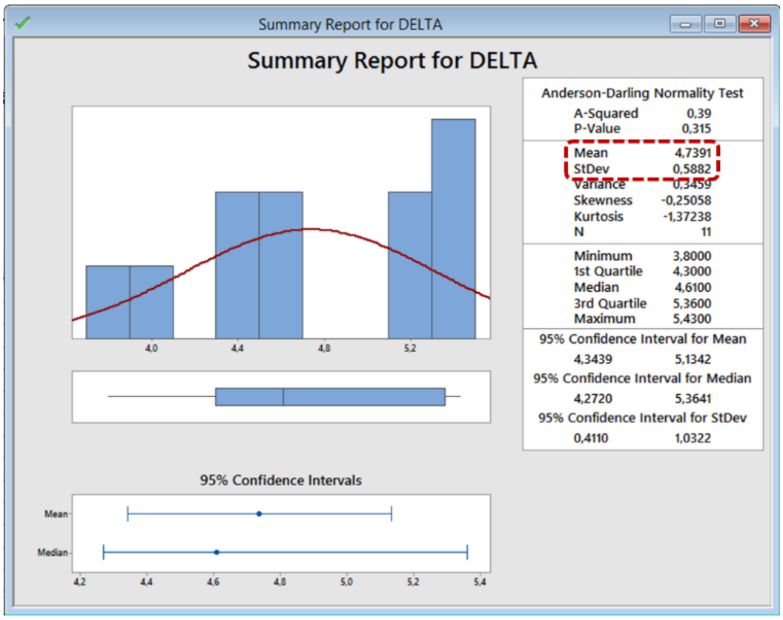

Figure 7. The Descriptive Statistic Analysis results performed to identify current situation (Minitab)

The SIPOC diagram, which is given in Figure 8, was prepared for the A/C system.It is a tool to understand the coverage of a complex problem. This tool was used to identify all contributors as shown in Figure 9. In this project, the A/C system was considered as a cooling cycle process while system components were considered as Input and the interior noise level was considered as Output.

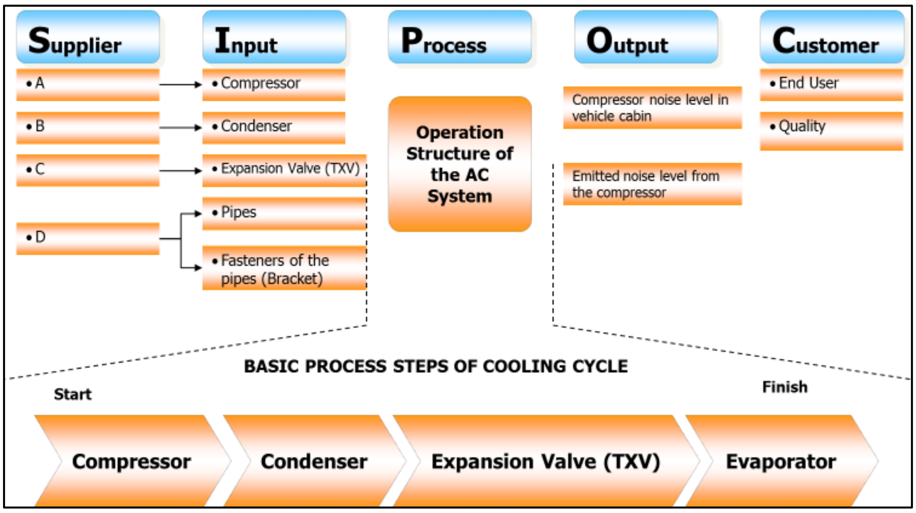

Figure 8. SIPOC diagram of the problem

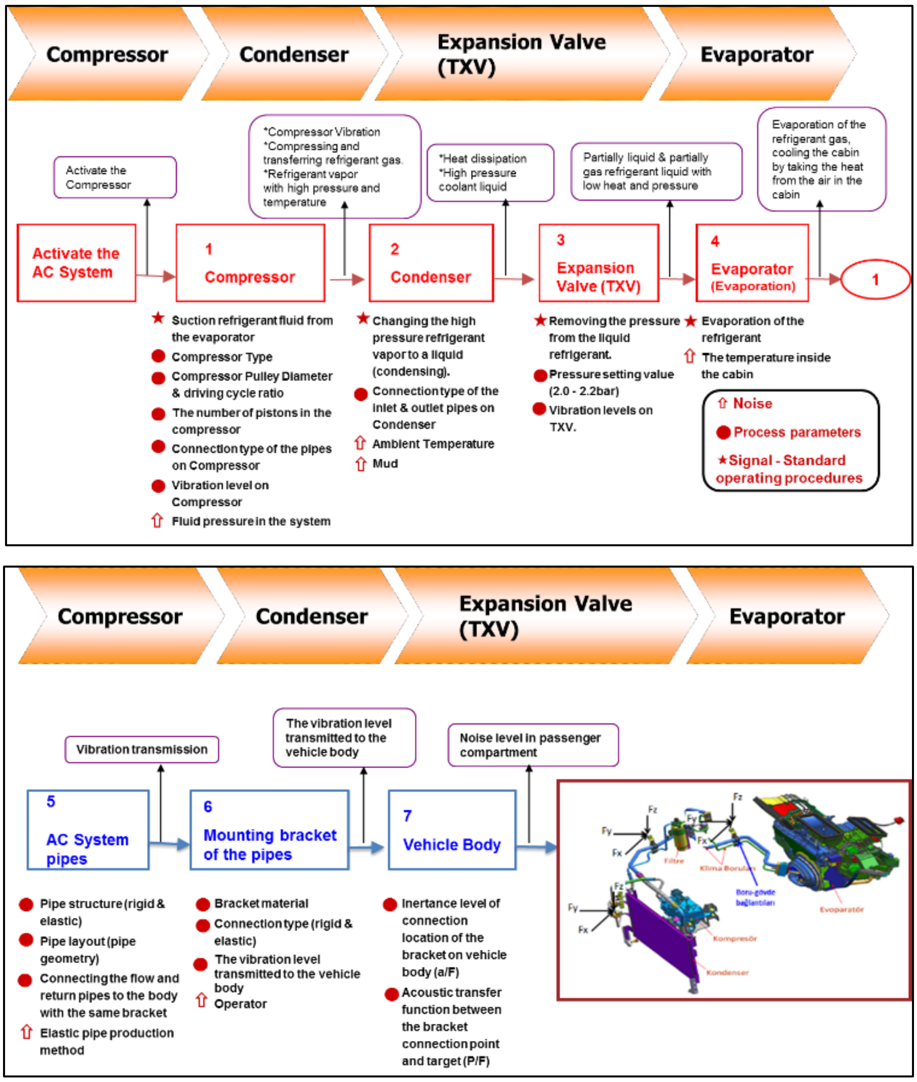

Figure 9. The factors for each component in the system affecting the noise problem.

8 steps have been defined for the whole process as follow and the factors of each step have been defined.

- A/C activation
- Compressor
- Condenser
- Expansion valve (TXV)
- Evaporator
- A/C system pipes
- Mounting brackets (fasteners)
- Vehicle body

These factors were divided into three group as Noise, Process parameters and Standard operation factors. Noises are uncontrollable parameters. Process parameters are those with strong effect on output while standard operations are factors those represent the nature of the process.

To define the importance level of the inputs/factors on noise problem, a cause and effect matrix was prepared as in Table 2 to simplify the model. A cause and effect matrix (C&E matrix) helps to discover which factors affect the outcomes of Six Sigma initiative. It provides a way of mapping out the flow of values from input factors of the system through the process or product outputs. With these visible and quantified relationships, one can readily discover the most-influential factors contributing to output.

Table 2. Cause and Effect Matrix

	Importance for Customer	9	3	7	
	OUTPUTS	Perceived noise level in the cabin	Emitted noise level from the compressor	Perceived vibration level in the cabin	
	INPUTS				**TOTAL**
1	Suction refrigerant fluid from the evaporator	1	1	1	19
2	Compressor Type	9	3	9	153
3	Compressor Pulley Diameter & driving cycle ratio	5	3	5	89
4	The number of pistons in the compressor	5	3	5	89
5	Connection type of the pipes on Compressor	5	3	5	89
6	Vibration level on Compressor	9	5	9	159
7	Fluid pressure in the system	9	3	9	153
8	Changing the high-pressure refrigerant vapor to a liquid (condensing).	1	1	1	19
9	Ambient Temperature	3	3	3	57
10	Connection type of the inlet & outlet pipes on Condenser	5	1	5	83
11	Removing the pressure from the liquid refrigerant.	1	1	1	19
12	Pressure setting value (2.0 - 2.2bar)	5	3	3	75
13	Vibration level on TXV	9	5	3	117
14	Evaporation of the refrigerant	1	1	1	19
15	Pipe structure (rigid & elastic)	9	3	9	153
16	Pipe layout (pipe geometry)	9	3	5	125
17	Connecting the flow and return pipes to the body with the same bracket	9	3	1	97
18	Elastic pipe production method	5	1	5	83
19	Bracket material	5	3	5	89
20	The vibration level transmitted to the vehicle body	9	5	9	159
21	Connection type (rigid & elastic)	9	3	9	153
22	Inertance level of connection location of the bracket on vehicle body (a/F)	9	3	9	153
23	Acoustic transfer function between the bracket connection point and target (P/F)	9	3	9	153

The followings are Cause and Effect matrix with 23 inputs and 3 outputs results in eight major contributors (substances over 150 points in the table).

1. Compressor type
2. Vibration level on compressor
3. Fluid pressure in the system
4. Pipe structure (rigid or elastic)
5. Vibration levels transmitted to the vehicle body
6. Connection Type (Pipe fastener type – rigid or elastic)
7. Inertance level of connection location of the fasteners on vehicle body (a/F)
8. Acoustic transfer function levels between the connection point of the fastener and the target (P/F)

4. Measurements

In the measurement step of the six-sigma approach, the team prepares a data acquisition plan to start collecting data for the key specification of eight factors determined in problem definition step.

As output of the problem, the interior noise level was measured by the microphone located at driver's right ear position. As input of the problem, the emitted sound level by the compressor was measured by a microphone placed 5cm away from the compressor. To monitor the vibration transmission from compressor to vehicle body, eleven 3D-accelerometers were placed for the measurements as shown in Figure 10. In Figure 11, the accelerometers placed at third fastener location can be seen.

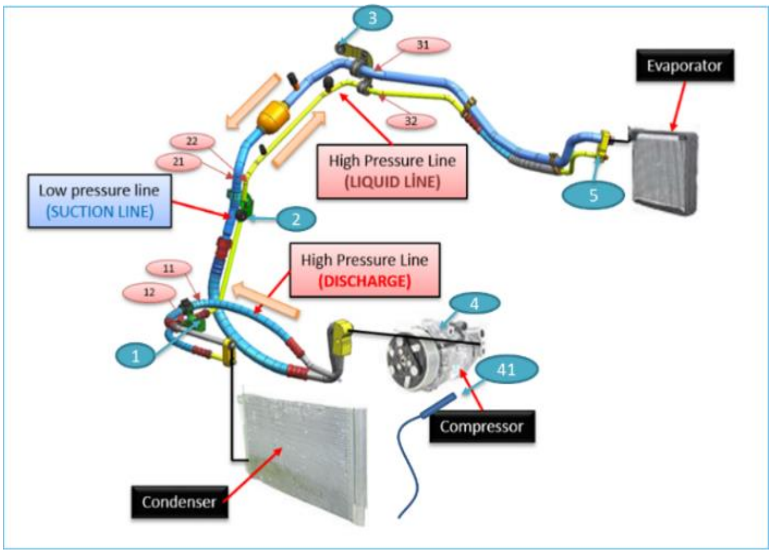

Figure 10. A/C System structure & measurement points

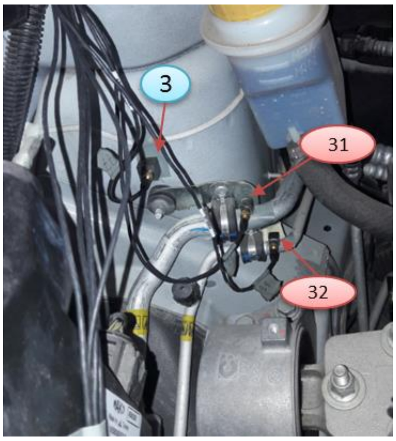

Figure 11. accelerometers placed at third fastener location

The related data were acquired for A/C compressor OFF&ON conditions with the pressure increments in operation range of the compressor. Measurements were carried out in the following maneuvers for both A/C compressor OFF and ON conditions.

- Stationary vehicle with engine running at idle (0 to 20 seconds)
- POT maneuver in neutral (from 1000rpm to 4000rpm)

During the measurements, the air ventilation speed is set initially to the speed of the fan to avoid the effects of possible noises in the air ducts, which is caused by the air circulation in the channels (this is one of the other performance issue of HVAC system). Besides, during the measurement, the system pressure had to be monitored by the pressure transducers installed to high side service ports and the measurements should be made at a specific pressure value determined by the HVAC team for the vehicle. To do this, the electrical connection of the cooling fan is removed from the vehicle and controlled by external Power supply.

The overall RMS levels of output and each input were calculated for the relevant time and revolution intervals (in maneuvers). The difference (Δ) between the levels in Compressor ON and OFF conditions were calculated for each input6 and output. The final data set comprises 280 data blocks for two microphones and eleven accelerometers with eight different pressure settings.

4.1. Correlation analysis

Correlation is a bivariate analysis that measures the strength of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient (r_{xy}) varies between +1 and -1. When the value of the correlation coefficient lies around ± 1, then it is said to be a perfect degree for the association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. The direction of the relationship is simply the + (indicating a positive relationship between the variables) or - (indicating a negative relationship between the variables) sign of the correlation.

To determine whether the correlation between the variables is significant, the p-value is compared with the selected significant level. Usually, a significance level (denoted as α or alpha) of 0.05 works well. An α of 0.05 indicates that the risk of concluding that no correlation exists is 5%. If the p-value is less than or equal to the significance level, then one can conclude that the correlation is statistically significant.

In this study, a Pearson correlation analysis was done with a %95 significance level ($\alpha = 0.05$) between the output (interior noise level – Pos2) and the thirty-three inputs (one microphone and eleven accelerometers data, vibrations are measured in three directions X-Y-Z). Basically the relationship level (correlation coefficient) is defined as r_{xy} and if the absolute value of the correlation value is higher than 0.8, then there is a very strong linear relationship between the two variables.

$$r_{xy} > \pm 0.8 \rightarrow \text{Strong relation}$$

In the Figure 12, the correlation result between the output (interior noise level) and the emitted noise level from compressor is given.

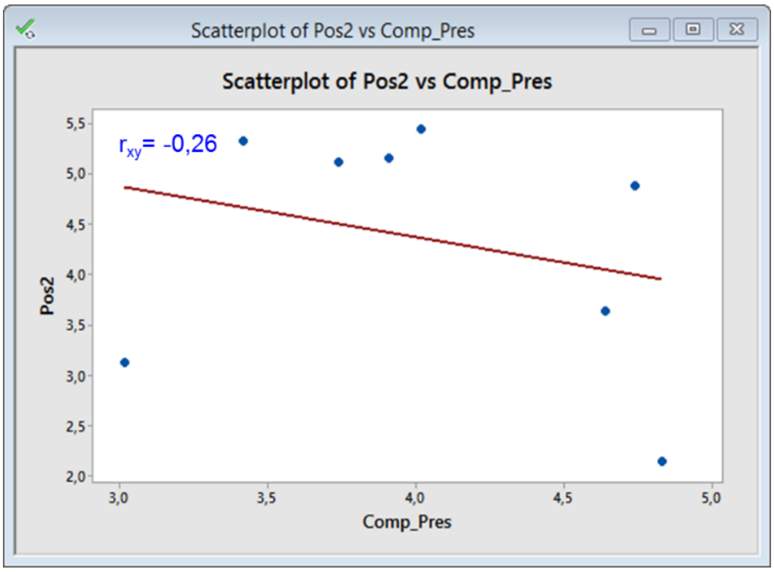

Figure 12. Correlation result between the output (interior noise level) and the emitted noise level from compressor

As shown in the Figure 12, the relationship between two variables is very weak. That means, the noise problem induced by the A/C system is not an airborne noise and cannot be solved by applying an acoustic insulator. On the other hand, as shown in the Figure 13, it can be said that there is a perfect degree of association between the two variables, which are the interior noise level and the vibration level in the Y direction of the body connection of the First Fastener. In the Table 3, Pearson correlation results are given for each input.

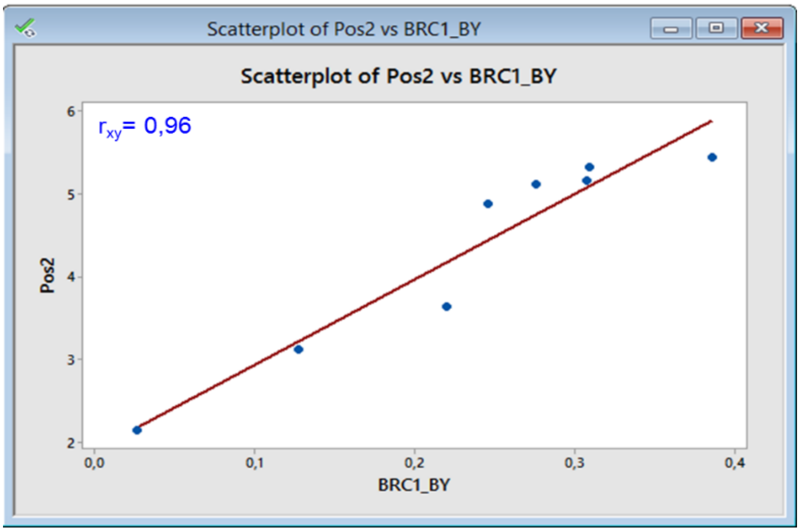

Figure 13. Correlation result between the output (interior noise level) and the vibration level at First Fastener

Table 3. Correlation analysis results

Input	Output Interior Noise Level		Input	Output Interior Noise Level	
	r_{xy}	α		r_{xy}	α
Comp_Pres	0.26	0.519	BRC1_PD Y	0.95	0.000
BRC1_B X	0.90	0.002	BRC1_PD Z	0.97	0.000
BRC1_B Y	0.95	0.000	BRC1_PL X	0.97	0.000
BRC1_B Z	0.93	0.001	BRC1_PL Y	0.92	0.001
BRC2_B X	0.81	0.014	BRC1_PL Z	0.94	0.001
BRC2_B Y	0.78	0.020	BRC2_PL X	0.78	0.020
BRC2_B Z	0.86	0.006	BRC2_PL Y	0.80	0.017
BRC3_B X	0.50	0.206	BRC2_PL Z	0.42	0.290
BRC3_B Y	0.32	0.434	BRC2_PS X	0.63	0.092
BRC3_B Z	0.55	0.150	BRC2_PS Y	0.69	0.090
C X	0.97	0.000	BRC2_PS Z	0.70	0.049
C Y	0.95	0.000	BRC3_PL X	0.65	0.060
C Z	0.94	0.000	BRC3_PL Y	0.72	0.040
TXV X	0.43	0.280	BRC3_PL Z	0.72	0.040
TXV Y	0.88	0.030	BRC3_PS X	0.68	0.060
TXV Z	0.88	0.003	BRC3_PS Y	0.77	0.025
BRC1_PD X	0.95	0.001	BRC3_PS Z	0.77	0.024

The inputs of rxy>0.8 have the highest relationship with interior noise level (output). These are the vibration levels on the compressor, at first fastener connection on the vehicle body and on the Liquid and suction pipes which are connected to the vehicle body with the first fastener (Bracket-1).

4.2. Regression analysis

If a strong relationship between a process input variable is correlated with a key process output variable, the input variable could then be considered a key process input variable. The equation Y = f(x) can express this relationship for continuous variables, where Y is the dependent variable and x is the independent variable. The parameters of this equation can be determined by using regression techniques [3].

In some instances when the data of an experiment is plotted, almost all the points fall on a straight line or smooth curve and the analysis of the relationship between the variables is straightforward because it can visually be determined. In most experiments, however, the data points are "scattered" when plotted due to experimental or other types of errors, and there arises the question of what is the "best" line or curve to represent the relationship. A further important question after an estimation of a relationship is, "How good is this relationship for the purpose of predicting or estimating?" [4].

The regression analysis was carried out between the output and the inputs that have a high correlation with output. The regression model (interior noise level equation) of noise problem induced by the A/C system is shown in Figure 14.

Regression Analysis: Pos2 versus BRC1_BZ; BRC1_BY;

Stepwise Selection of Terms

α to enter = 0,05; α to remove = 0,05

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	9,6283	9,6283	66,11	0,000
BRC1_BY	1	9,6283	9,6283	66,11	0,000
Error	6	0,8738	0,1456		
Total	7	10,5021			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0,381620	91,68%	90,29%	86,59%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1,908	0,329	5,80	0,001	
BRC1_BY	10,30	1,27	8,13	0,000	1,00

Regression Equation

Pos2 = 1,908 + 10,30 BRC1_BY

Figure 14. The regression analysis results

The vibration levels at first fastener connection on the vehicle body is the main factor for the interior noise level. The interior noise level induced by the A/C system can be reflected with this regression model by 90% (R-sq (adj)).

5. Design of Experiment (DOE)

The vibrations at first fastener are caused by the compressor vibrations and transmitted through the discharge pipe to the vehicle body, those are perceived as noise in vehicle cabin. Therefore, Compressor vibrations, vibrations transmitted through the discharge pipe and the vibrations at first fastener location are found to be the main factors for noise problem under investigation (see Figure 15).

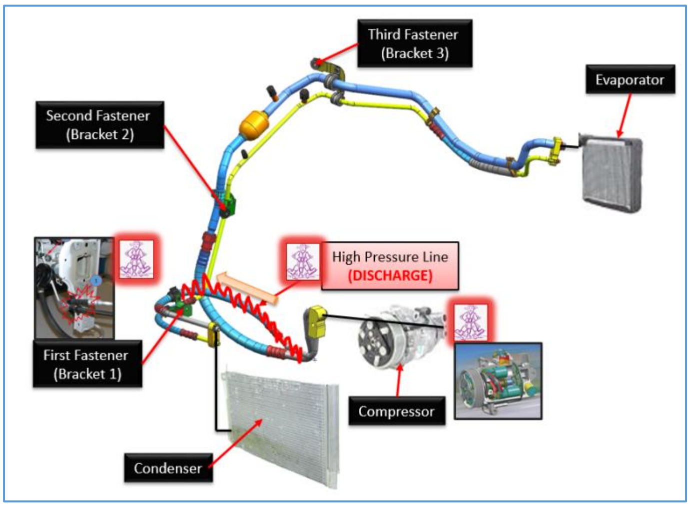

Figure 15. The main factors for noise problem

Generating improvement alternatives need creative thinking coupled with statistical tools. Design of experiments (DOE) is one of the tools used for determining the best solution alternatives [5]. In DOE model, two alternative solutions (level) were determined for each factor as it seen in Table 4.

Table 4. DOE factors and levels

Factors	**Level of Factor**	
1.Compressor vibrations	Actual compressor	New compressor
2.Vibrations transmitted through discharge pipe	Mass application on pipe	Actual pipe
3.Vibrations transmitted through bracket-1	Actual bracket	New bracket type

The two levels of the factor of compressor vibration were the actual and new compressors. Actual compressor was a variable displacement compressor with 120cc and six pistons while the alternative compressor was also a variable displacement compressor with 140cc and six pistons. Two levels were determined for the factor of vibrations transmitted through Discharge Pipe that are actual pipe and a new pipe with additional mass. Two levels were determined for the factor of vibrations transmitted through first fastener (Bracket 1) that are actual bracket and new bracket with higher vibration filtering capability. The alternative solutions is given in Figure 16.

Figure 16. Solution alternatives (levels).

The combinations in Table 5 were created by the General Full Factorial Design matrix to measure the impact of each level (alternatives) to the interior noise level.

Table 5. DOE combinations

Factors and Levels			
Combinations	Compressor	Discharge Pipe Vibration	Bracket 1 Vibration
1	Actual Compressor	Mass Application	New Bracket
2	Alternative Compressor	Mass Application	New Bracket
3	Alternative Compressor	Actual Pipe	New Bracket
4	Actual Compressor	Actual Pipe	New Bracket
5	Alternative Compressor	Mass Application	Actual Bracket
6	Alternative Compressor	Actual Pipe	Actual Bracket
7	Actual Compressor	Mass Application	Actual Bracket
8	Actual Compressor	Actual Pipe	Actual Bracket

These combinations in Table 5 were tested on the vehicle in the following maneuvers for both A/C compressor OFF and ON conditions;

- Stationary vehicle with engine running at idle (0 to 20 seconds)
- POT maneuver in neutral (from 1000rpm to 4000rpm)

The difference (Δ - delta) between the interior noise levels in A/C Compressor ON and OFF conditions were calculated for each combination that are given in Table 6.

Table 6. DOE results

Noise Level @ Driver's Ear position	IDLE CONDITION	Acceleration in Neutral
	Delta	Delta
Combinations	RMS - dB(A)	RMS - dB(A)
1	1.70	3.41
2	1.46	1.14
3	1.40	0.96
4	1.68	3.34
5	1.53	0.38
6	4.86	0.98
7	1.85	2.72
8	5.44	4.23

The Multi-Vary Chart was used to examine the relationship between the output (interior noise level) and the each level of each factor. In the Figures 17 and 18, DOE results are shown for both the stationary vehicle with engine running at idle and the POT in neutral maneuvers.

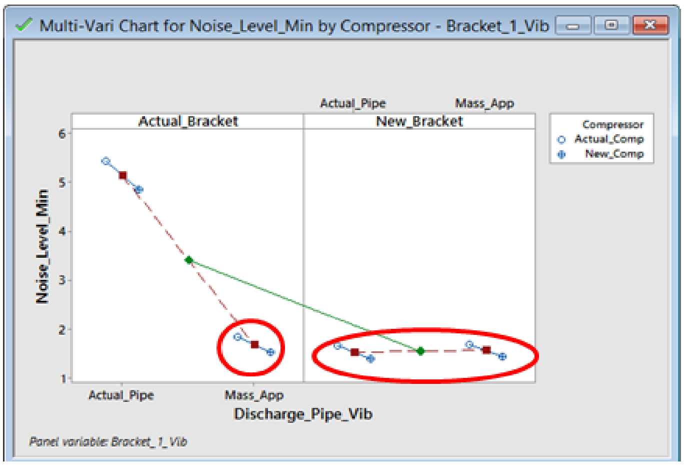

Figure 17. DOE results with Multi-Vari Chart at engine idle

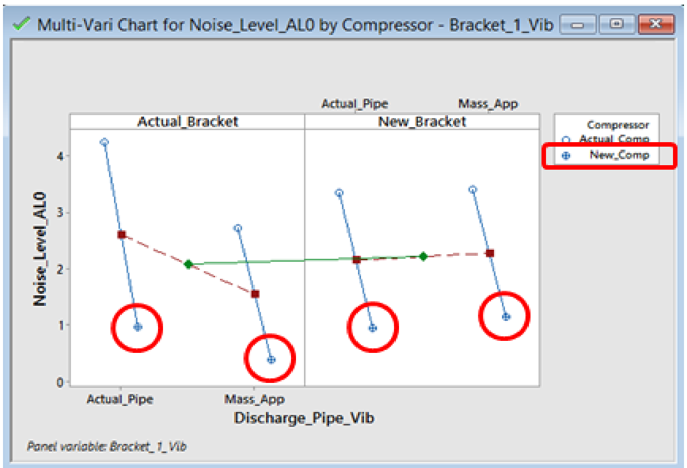

Figure 18. Examine of DOE results with Multi-Vari Chart for slow run-up

As it is seen in Figure 17, Mass application solution alone reduces the interior noise level (Difference in noise level of A/C ON and OFF conditions) from 5.5 dB(A) to 1,9 dB(A) while the new bracket solution alone reduces the noise level from 5.5 dB(A) to 1.6 dB(A). However, as it is seen in Figure 18, neither Mass application nor new bracket solutions alone was not enough to reduce noise level below the target value in the maneuver during partially open throttle maneuver (POT) in neutral. During POT maneuver in neutral, only the alternative compressor solution brings improvement that achieves the target value.

DOE Response Optimizer Analysis was carried out to determine the combination that gives optimum solution for both maneuvers. Target values was set to 0 dB(A) and the Upper Limit value was set to 1.5 dB(A).

In the Figure 19, the optimum results for both maneuvers and the combination that provides these optimum values can be seen.

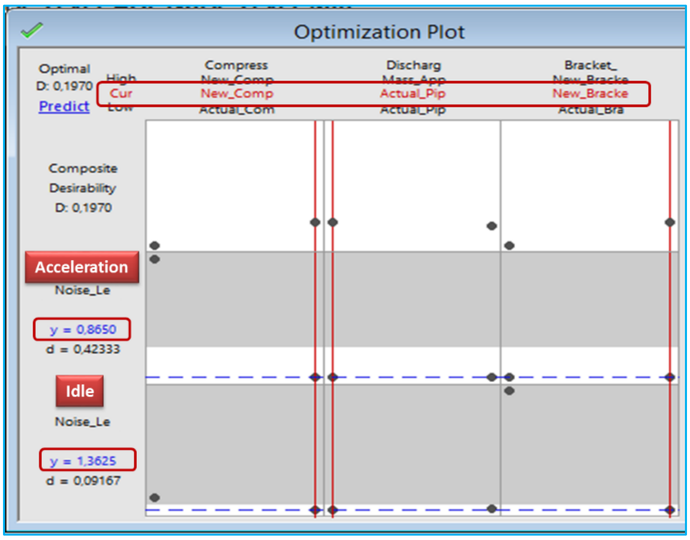

Figure 19. DOE response optimizer results

The combination (solution) consists of a New Compressor, a New Bracket and an Actual Discharge Pipe gave the best solution for both maneuvers. The interior noise level (difference between A/C compressor ON and OFF conditions) was reduced from 5.5 dB(A) to 1.36 dB(A) in maneuver of engine running at idle while it was reduced from 4.2 dB(A) to 0.9 dB(A) during POT maneuver in neutral.

6. Result and Discussion

In the correlation analysis, no correlation was observed between the emitted noise level from the compressor and interior noise level while there are strong correlation between the interior noise level and vibration levels indicated in Table 2. That means, the noise problem induced by the A/C system was not an airborne noise and cannot be solved by applying an acoustic insulator. It is necessary to study on vibration sources and vibration transfer paths.

The regression analysis which was carried out between the output (interior noise level) and the inputs (factors in Table 2 which have a strong correlation, $rxy > 0.8$) shows that the vibration levels at first fastener connection on vehicle body is the main factor for the interior noise level. These vibrations at first fastener were caused by the compressor vibrations and transmitted through discharge pipe to the vehicle body that was perceived as noise in vehicle cabin. Therefore, Compressor vibrations, vibrations transmitted through Discharge pipe and the vibrations at first fastener location were found to be the main factors for noise problem under investigation.

For these three main factors, the solution alternatives were determined and the impact of each alternative on the interior noise level was measured by the DOE method. DOE results showed that;

- As it is seen in Figure 17, Mass application solution alone reduces the interior noise level (Difference in noise level of A/C ON and OFF conditions) from 5.5 dB(A) to 1.9 dB(A) while the new bracket solution alone reduces the noise level from 5.5 dB(A) to 1.6 dB(A).
- However, as it is seen in Figure 18, neither Mass application nor new bracket solutions alone is not enough to reduce noise level below the target value in the maneuver during partial open throttle maneuver in neutral. During

POT maneuver in neutral, only the alternative compressor solution brings improvement that achieves the target value.

- The combination (solution) consists of New Compressor, New Bracket and Actual Discharge Pipe gives the best solution for both maneuvers. The interior noise level was reduced from 5.5 dB(A) to 1.36 dB(A) in maneuver of engine running at idle while it was reduced from 4.2 dB(A) to 0.9 dB(A) during POT maneuver in neutral.

7. Conclusion

The air conditioning compressor noise problem perceived in vehicle cabin was examined by Six Sigma approach. The components (inputs) of A/C System were analyzed in detail to find out the factors affecting the noise problem by the SIPOC diagram in which A/C system was considered as a cooling cycle process. By the C&E matrix, the importance levels were defined for each factor to simplify the model.

The correlation analysis was performed between the output (interior noise level) and the each input (factors) to define factors with high correlation with internal noise. The regression analysis was performed to determine the transfer function equation that defines the interior noise level with these factors. According to the correlation results, it was seen that the noise problem was not an air-borne (no correlation with emitted noise from the compressor) but it was a structure-borne noise problem (strong correlation with vibration levels at the points indicated in Table 2).

The Design of Experiments (DOE) was performed to define the best solution alternatives. In DOE model, two levels (alternative solutions) were determined for each factor and the best solution for both maneuvers were defined by the DOE Response Optimizer analysis.

As a result, interior noise level was reduced with this solution about 4 dB(A) and the required target value was achieved. The same effects were also perceived subjectively.

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