Improvement in Quality of Automotive Shock Absorber using Statistical Analysis

Vishesh Joshi
Master of Science in Industrial Engineering Program
Sanjay Maheshwari
Master of Science in Automobile Engineering Program
Ahad Ali
Industrial Engineering Program
A. Leon Linton Department of Mechanical, Robotics and Industrial Engineering
Lawrence Technological University
Southfield, MI 48075, USA
vjoshi@ltu.edu, smaheswa@ltu.edu, aali@ltu.edu

Abstract

This paper presents a new mechanistic mannequin to study the complicated and exceedingly nonlinear process damping force in chatter vibration. In the developed model, a feedforward neural network is used to model cutting pressure components. The method damping pressure due to the interface between the tool flank and machined floor is estimated thru the calculation of the volume of the work material displaced by using the tool flank. To suitable calculate the volume of the displaced work material, the vibration of the device relative to the workpiece is solved the usage of the equations of movement iteratively until a convergence criterion is satisfied. The study has proven that the developed mannequin is tons higher than preceding models in the evaluation of dynamic behaviors of the nonlinear manner damping force in chatter vibration.

Keywords
Automotive Suspension, Damping Force, Quality Tools.

1. Introduction
Road irregularities usually purpose vibration in floor vehicles. This vibration is undesirable because it can cause discomfort to passengers and drivers, and even harm to the vehicle systems. For these reasons, developing a well-performed vehicle suspension system has grown to be a urgent want (Cao 2011), (Sun 2007). There are three sorts of vehicle suspension systems: passive suspension, active suspension, and semi-active suspension. Passive suspension, which uses passive shock absorbers composed of passive springs and traditional hydraulic dampers, has been widely used because of its simplicity and low cost. Passive suspension, however, which has fixed parameters, cannot vary its damping or stiffness in response to specific road conditions (Sun 2013).

The apparent benefit of lively manage is that it can offer controllable lively pressure to deal with distinct road conditions and thus enhance experience comfort (Sun 2015). However, the employment of the active force might also deteriorate the stability of the suspension device if the force control is not appropriate. The fail-safe, excessive strength consumption, and excessive fee of actuators also limit its sensible usage. A semi-active suspension system can remedy all these problems. Semi-active suspension can range the parameters of its shock absorbers, such as stiffness and damping, in order to reply to changes in avenue condition and supply the preferred alleviation while the use of a small amount of energy and having a low fee (Choi 2007).

Suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems must support both road holding/handling and ride quality, which are at odds with each other. Figure.1 shows the cut section of telescopic type suspension, a telescopic suspension consists of two parts that house all the mechanisms, an outer tube and inner tube. The system consists of spring and a damper filled with fork oil that provides resistance when they move. In this type of suspension, the slider bar of the inner tube is attached to the clamp, inner tube consists of spring which rests on base valve assembly, base valve assembly is a combination of piston rods and valves which help for oil flow in inside of suspension.

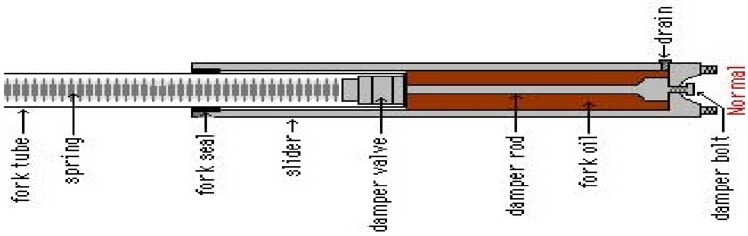

Figure 1. Shock Absorber of a car

The function of suspension is not just to soften the ride by spring compression but also to damped the oscillation after the jerk. So damping force is the major technical criteria for suspension. Suspension damping is the process of controlling or stopping the spring's oscillation, either when it compresses or rebounds (usually both). This typically works by introducing a hydraulic cartridge into the mix, with a fluid and some controlled valving. As the spring is compressed, damping fluid (usually oil) moves through a series of valves from one chamber to the next. By forcing the fluid through different size and shape ports, shims and tunnels, the damping cartridge can control the compression and rebound speed or stop it altogether. This is all done so the spring doesn't compress or bounce back too quickly.

The damping force is testes by damping force testing machine. Dampening force of a shock absorber is directly proportional to velocity and this parameter needs to be precisely controlled. A small variation of 1mm in a stroke of 100 mm for 100rpm can result in a variation of 10% in dampening force. Dampening force can be evaluated in the field orientation i.e. Vertical or Horizontal or at any angle between horizontal to vertical and can be locked at any position as per requirement. A signal equivalent to frequency and amplitude is created in a function generator which is fed to the controller. Machine response signal is also fed to the controller. The error signal between the two signal creates differential pressure resulting in the movement of the actuator corresponding to programmed frequency and amplitude thereby completing the close loop. Test setup of damping machine is shown in Figure.2

A Typical Test Set Up Comprises Of -

1. Load Frame with side jacks (Optional-Arrangement for tilting up to 90°)
   - Dynamic Hydraulic Actuator
   - Load Cell
   - Displacement Transducer
2. Hydraulic Power Pack with Electrical Control Cabinet
3. Module with servo valve, high pressure filter, gas filled accumulators
4. Recording System includes
   - Signal Conditioning and Controlling Unit
   - Computer for Controlling and Data acquisition
   - Control and Analysis Software

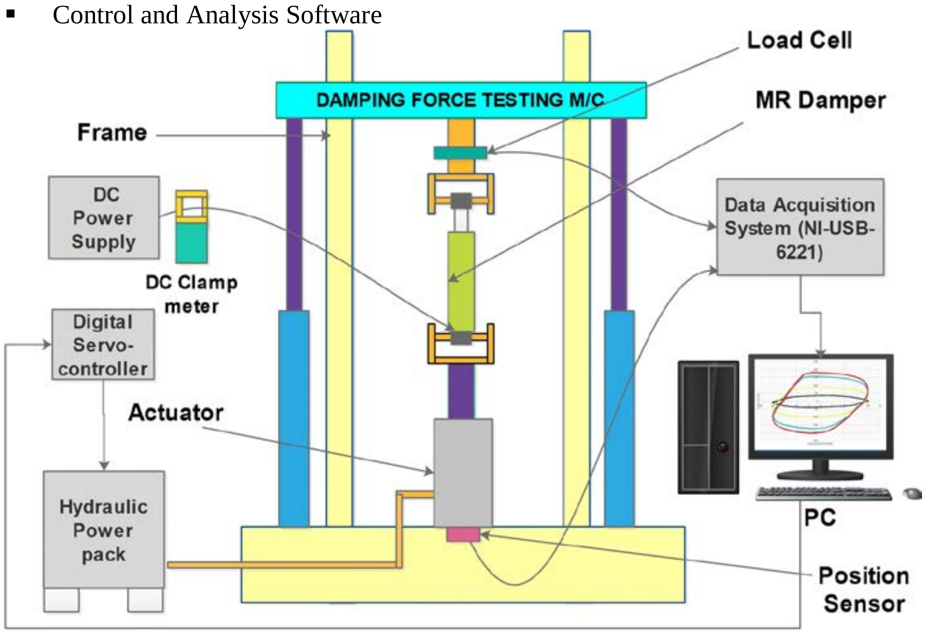

Figure 2. Damping force testing machine

Suspension is a part of an automobile that negates most of the forces that the car gets from driving on the road The work of a suspension is to provide comfort to the cabin, make sure the car stays in contact with the ground and that the driver has control over the tires at all points which is just achieved by having contact with the road. So, it is important for a suspension to function adequately, but it is an assembled component so there are always some failures due to man, machine or method that are used for the process. The main problem with suspension is that it doesn't give the accurate damping all the time. The main components of suspension are damper and spring. Because of the damper the damping force comes into role and it is not as per specification because of various reason. The main purpose of this paper is to mitigate the cause of inappropriate damping force using quality tools. The entire assembly process of suspension assembly is described in this paper.

2. Literature Review

In the literature, various papers record that the FACTS devices improve the steadiness of the system, the place the incorporation of a professionally designed sub synchronous damping controller can correctly suppress the sub synchronous Resonance. The lack of manipulate (i.e. in fixed compensation) is the major disadvantage of series compensation. Indeed, the series compensation can be achieved by using suitable aggregate of passive elements and energetic FACTS controllers. (Venkateswarlu 2018). One of the especially important factors to efficiently reap perfect control performance is to have an accurate damping force model which can capture the inherent hysteresis conduct of ER or MR dampers. Especially, a greater accurate damper mannequin is required in the consciousness of an open-loop manage which is effortless to implement and cost effective evaluating with a closed-loop control. So far, numerous damper models have been proposed to predict the field-dependent hysteresis behavior of electrorheological or magnetorheological dampers. Consequently, the fundamental contribution of this work is to endorse a hysteresis damper model which can be effortlessly built-in with a manage system. To achieve the goal, a cylindrical type of MR damper, which can be applicable to a middle-sized passenger vehicle, is adopted and its hysteresis conduct is experimentally evaluated in the damping force versus piston speed domain (Choi 2000). Passive fluid shock absorber affords easy and high-quality solution for comfort and managing of the vehicle. These convert vibration strength into warmth by throttling viscous fluid via restrained orifice and are widely used in automobile suspensions. Furthermore, the fluid damper can be tuned via altering the fluid glide vicinity to vary the vibration isolation performance (Jugulkar 2016). There are three kinds of car suspension systems: passive suspension, active suspension, and semi-active suspension. Passive suspension, which uses passive shock absorbers composed of passive springs and traditional hydraulic dampers, has been extensively used due to the fact of its simplicity and low cost. Passive suspension, however, which has constant parameters, cannot range its damping or stiffness in response to extraordinary avenue conditions. This obstacle skill that the passive suspension is only positive in a slender frequency vary (Sun 2007).

2.1 Quality Improvement

To improve the vibration reduction performance of vehicle suspensions, variable stiffness has also been tried. (Youn 1995) developed a variable stiffness suspension by using a semi-active air spring to range the suspension stiffness amongst three discrete values. The experimental result tested the effectiveness of variable stiffness on vibration manipulate. However, the use of variable stiffness air springs is intricate due to the fact the air pressure needs to be managed by means of an air pump, which can be complicated and expensive. In the case study (Arokiasamy 2013), the statistical device known as Taguchi sturdy graph was once used for evaluation of various vital technique parameters. They Deployed Six Sigma alongside with Taguchi robust design to analyse a range of painting method parameters that affect the quality characteristics, after intensified implementation the optimized manner parameters were done that result in decreased defect rate. Moreover the jerking problem can occur due to spillage of oil from the tube, which is caused by dirt in the tube which settles on the inner oil valves, so to eliminate that ultrasonic cleaning has been implemented by (Mohd 2012).In addition to it in case study (Srinivasan 2014), The L27 orthogonal array (OA) had been constructed with three elements and levels, results of experimentation had been analysed through using Analysis of Variance (ANOVA) and multivariate regression which identifies the condition of optimality on peel off and blisters in the pre-treatment process.

2.2 Tools

In the simulation of paper (Kubler 1996), an actual shock absorber is used as hardware and excited through a hydraulic actuator. Its damping force and action are measured directly and are fed lower back to the Pareto Analysis of the car model in real time. The random process of the ground roughness is generated the usage of an Improved Hypothesis representation technique. Moreover, before the implementation of the method error prevention system, carried out the mechanical transformation on the positioning placement desk which is needed to make sure that each tooling can only be placed in the set function on the tooling table from the mechanical structure. The shock absorber goes through various assembly areas, so to make sure every parameter and every assembly is maintained interlocking is suggested between the process by (Poornamohan 2012). A position sensor then is established on the tooling table. The sensor is used to discover whether the tooling is positioned in the specific position, and each one is uniquely numbered by using the sensor (Qian 2019). (Pugna 2015) presents an innovative answer for enhancing a meeting procedure in a car organization in Romania through the usage of Statistical Thinking and DMAIC Six Sigma methodology. The main factors effecting the problem were carried out with the Pareto Analysis in real time which showed the main technical difficulty of the challenge which was more highlighted deep by using Fish Bone Diagram which lead to focus on the main area and bring the process of taking measurements more logical. Furthe rmore to check whether the process of the manufacturing is in control or not or to look out the nature of the procedure X bar & R Chart is adopted which directly focus on the concentration of the process whether its under control or needs to put more effort to be brought under control. Similarly using DMAIC Six Sigma methodology (Kumar 2008) used the same analysis like Pareto Analysis and Mean control charts to systematically improve shopfloor production quality and costs. Even project charter was also taken into use to define the main increment in cost and decrement in quality of shopfloor production and ultimately figured out the differences between the original problem and the advanced solution from Flow charts and Process Capability Analysis. These papers motivate to use the quality control tools in this paper ultimately to make optimally alleviating the process to get better results.

3. Project Charter

The first step of any project is to develop a robust project charter. A project charter clearly identifies problem statement, scope, measurable goals, business case, team members and project leaders & sponsors. It’s an essential tool to keep projects aligned and focused on the objectives within acceptable cost and time constraints (Figure 1).

Table 1. Project charter

<table>
<tr><th colspan="2">Project Charter</th></tr>
<tr><th colspan="2">Improvement in quality of Automotive Shock Absorber by using Quality tools</th></tr>
<tr><th>Problem Statement</th><th>Scope</th></tr>
<tr><td rowspan="2">High customer return of suspension as damping force values are out of specifications.</td><td>IN: Using online software tools to analyse current behaviour.</td></tr>
<tr><td>OUT: Results will be depending on the observations on the behaviour of the manufacturing plant. So, no other adulterate will be added</td></tr>
<tr><th>Objective Statement</th><th>Timeline</th></tr>
<tr><td>The objective of this project is to Reduce the customer return of Automotive shock absorber by using quality tools.</td><td>Hassle Modelling: 09/20/2020
Data Collection: 10/5/2020
Improvement development: 11/15/2020
Results: 12/3/2020</td></tr>
<tr><th>Business Case</th><th>Team Member</th></tr>
<tr><td>Reduction in customer return will lead to strong business relation and the solution can be benchmarked and can be deployed across other suppliers.</td><td>Sanjay Maheshwari, Vishesh Joshi
Graduate students of Lawrence Technological University
Professor: - Ahad Ali</td></tr>
</table>

4. The Quality Control Methodology

The quality of product or provider is making sure if suitable designing method is followed. This designing procedure wishes to be backed by way of terrific process sketch supported by using a appropriate technological know-how which confirms to necessities of customers. Quality manipulate ensures that defects and blunders are averted and ultimately eliminated from the procedure or product. Therefore, first-class manipulate must include planning, designing, implementation, gaps identification and improvisation. In this case we have used process flow diagram which explains the whole process of manufacturing and testing of Shock Absorber, Fishbone diagram which is used to figure out the main effects which can affect the Shock absorber damping force, Graphical Summary to give technical details of the nature of the present situation. Furthermore, important tools like pareto chart, $\overline{X}$ & R chart, DOE and Hypothesis test to pinpoint the main factors and ameliorate it more to bring the process under control and make the shock absorber more optimal.

4.1. Process Flow Diagram

Furthermore Figure.3 shows the process flow diagram of suspension assembly line. Initially to start the study of project detailed process was understood, below is the process diagram of suspension assembly, it starts with cleaning of all the child parts, the whole assembly is categorized in two more sub-assemblies one of piston rod assembly and one base valve assembly then after filling the oil in the tube damping force testing is done and then the assembly is grooved and pass thru few more steps to the dispatch followed by final inspection area.

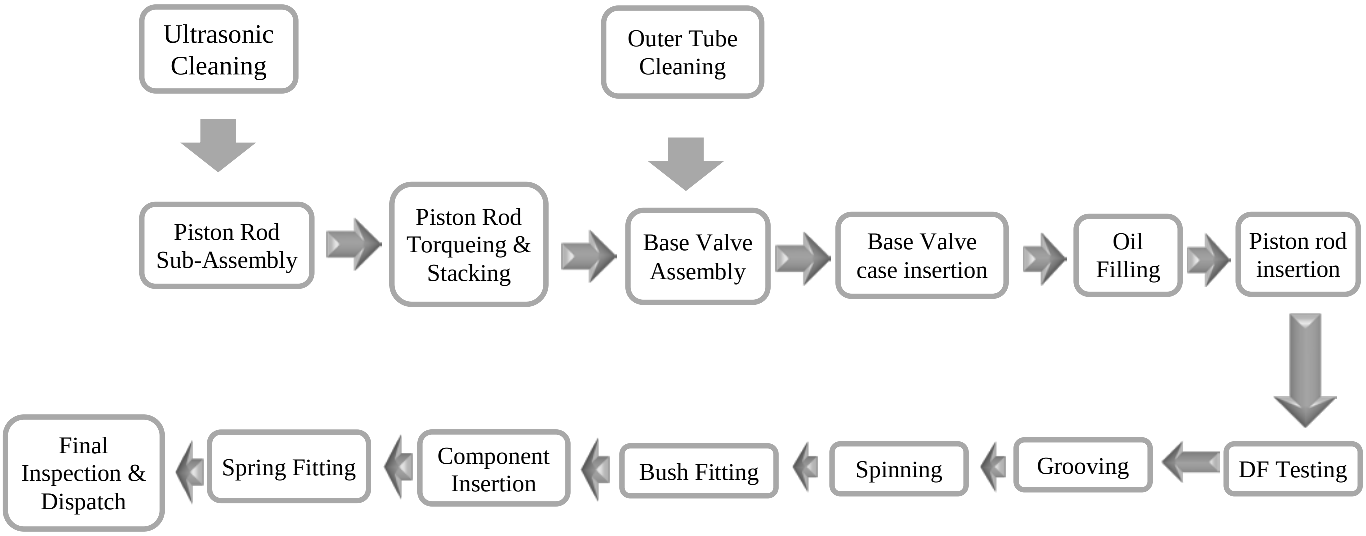

Figure 3. Process Flow chart of the manufacturing and testing of Shock Absorber

4.2. Fishbone Analysis

A reason and effect diagram, regularly called a “fishbone” diagram, can help in brainstorming to pick out possible causes of a hassle and in sorting thoughts into useful categories. A fishbone layout is a visible way to look at cause and effect. It is a more structured method than some other tools handy for brainstorming causes of a trouble (e.g., the Five Whys tool). The trouble or impact is displayed at the head or mouth of the fish. Possible contributing motives are listed on the smaller “bones” below a number purpose category. A fishbone diagram can be helpful in figuring out possible motives for a trouble that might now not otherwise be considered by directing the group to look at the classes and suppose of alternative causes. Include group individuals who have personal knowledge of the tactics and systems involved in the problem or match to be investigated. Once the process is studied thoroughly, process analysis is done with the help of fishbone analysis as shown in Figure.4, as it is assembly process it includes man, machine, method, and material and for this purpose fishbone analysis fits best, it can give desired output analysis in the areas of failure. Fishbone analyses consist of four major factor man, machine, method, and material. For the above-described process, all the possible critical criteria were plotted on fishbone diagram.

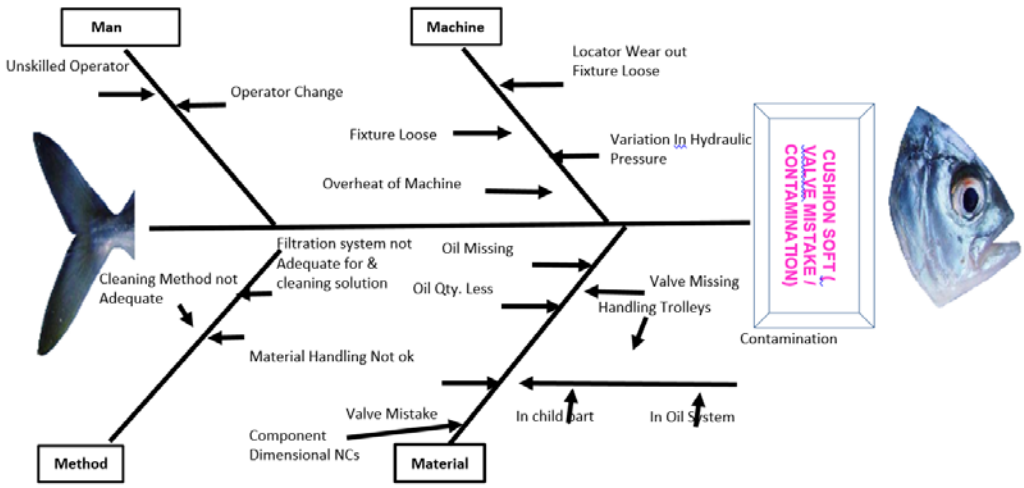

Figure 4. Fishbone Diagram for Shock Absorber Damping Force

The common causes of suspension failure are leakage once the oil gets leaked the performance of suspension gets lowered it cannot give damping effect, from the fishbone analysis it can be predicted that unskilled operators can be one of the reasons, the cleaning method may not be adequate, and the material handling can also be the probable cause for the suspension failure. To assure these projections strong data analysis of damping force and contamination content of the assembly is required.

Once a preliminary list of critical elements was developed, the next step was to align these elements to customer requirements through Voice of Customer (VOC) survey. VOC identifies and prioritizes fundamental requirements of the project. Customers were surveyed to determine critical elements and rank importance relative to their respective area. Results from the survey were then translated into VOC functional measurements (Figure 3). VOC results clearly identified three main requirements to achieve business objectives. results indicated customer requires in three main areas 1) Accuracy, 2) Timeliness and 3) Consistency respectively.

4.3. Data Collection

Data was then collected based on the identified criteria to determine impact of each metric and to what extent each had on the overall effectiveness of the project. Table 2 shows 200 cases of damping force which were collected while testing which is then reflected in the process pareto chart as identifying failure in man, method and material as the main contributors as a percentage of perceived process failure. It is collected from tier-1 automotive supplier making suspension for two- wheeled gearless motorcycle. On the suspension assembly line, the company have damping machine which tests damping force of suspension with the help of load cell, and it has a display screen which shows the value of damping force according to the given specification. For data analysis Minitab software is used.

Table 2. Data Collection of Damping Force

Damping Force Value Spec 575±96 (479-671)									
455	401	410	498	550	445	514	433	526	542
514	548	566	410	581	467	613	632	636	653
700	665	703	706	550	705	667	690	698	650
526	546	490	420	589	469	601	620	641	647
522	545	562	591	700	480	601	628	648	653
405	409	460	423	570	485	463	545	470	460
537	600	577	440	710	470	616	637	652	657
464	558	576	583	586	490	619	634	643	641
547	716	580	589	760	584	747	622	646	655
541	578	564	410	588	416	603	636	657	669
557	575	571	597	755	400	622	627	644	662
480	700	470	415	598	503	637	633	658	664
559	568	563	593	713	516	634	623	656	661
542	567	561	430	608	511	639	634	659	663
450	750	460	588	716	519	623	631	651	669
559	561	579	460	606	512	633	623	644	668
557	750	450	597	750	513	628	635	649	662
547	576	589	585	609	504	634	633	648	661
700	460	470	650	720	506	620	625	655	667
680	680	581	599	703	508	624	637	653	633

4.4. Graphical Summary

Use Graphical Summary to summarize numeric information with a variety of records such as the pattern size, mean, median, and trendy deviation. You can additionally describe the distribution of the facts with graphs, behavior an Anderson-Darling normality test, and achieve confidence intervals for the mean, standard deviation, and median.

It is “the approach of analysis which performs graphing by way of taking the enter from information tables”. Graphical evaluation is used to calculate statistics, integrals, tangents, and interpolations. Graphical analysis can be done by using developing the graphs, histograms, statistics tables and FFTs (Fast Fourier Transform). It can operate automatic curve fits. It additionally adjusts the curves (or graphs) for the required parameters. It is viable to evaluate distinct parameters and the contrast of a range of parameters can understand without problems in graphical analysis.

Graphical analysis plays a enormous role in electrical engineering. Graphical evaluation has numerous functions in electrical systems. The traits of many parameters in electrical systems such as current, voltage, torque, power, speed, and effectivity are analyzed by means of graphical analysis easily. Efficiency, voltage guidelines of various machines are compared, and the excellent computing device is chosen by way of graphical analysis. The load and demand curves in transmission, and distribution structures can be analyzed with graphical analysis. The output curves of evaluation perform a critical position in power system. Further, the analysis is useful in awaiting the future traits to maintain the stability of complicated systems.

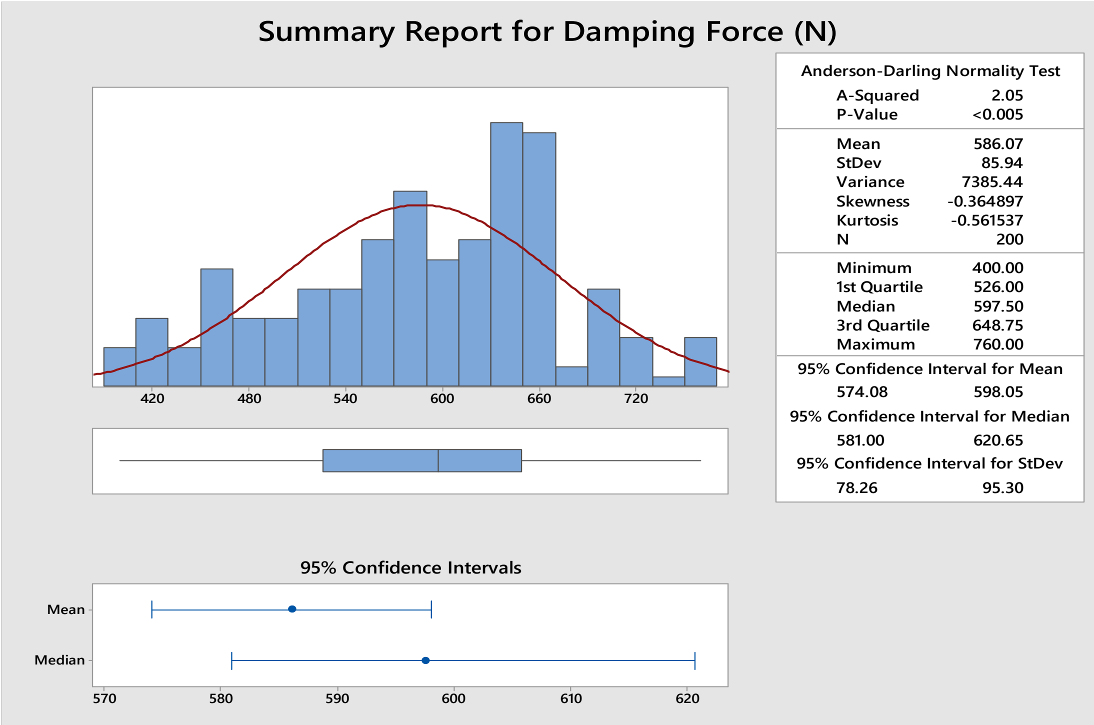

Figure 5. Graphical Summary of Damping Force (N)

In Figure 5, the graphical summary shows the value of damping force is not consistent and keeps on fluctuating, it is more diverted towards the higher specification limit in few samples and out of higher data limit for other few samples. To further support this judgement more analysis for the branched process is required. To study the error of individual process pareto analysis is done. Here, the mean of the damping force is 586.07 N and standard deviation consist of 85.94 which follows the normal distribution curve.

4.5. Pareto Chart Analysis

After getting the data, pareto analysis is done, A Pareto chart is a type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the cumulative total is represented by the line. By doing pareto analysis the graph showed the percentage contribution of each problem, which can help to prioritize and understand the criticality pf each problem. Table.3 shows the breakage of data into each problem, it can be seen that frequency of operator mistake is high as compared to others followed by cleaning method which further contributes of around 20% of the problem, for material handling problem the frequency of occurrence is 30 and for cleaning cycle breakage show 25.

Table 3. Total defects and frequency of defects

Category	Frequency	Cumulative %
Operator Mistake	80	40%
Cleaning Method	40	60%
Material Handling	35	77.5%
Cleaning Cycle	25	90%
Others	20	100%

From figure 6, pareto analysis it can be seen that contamination is the other major source of failure so to measure the contamination level Millipore testing system is used. For detailed analysis, few samples were taken from the customer return slot and were tested for Millipore testing, below is the data. The fluid is getting polluted by the operators mistake which leads to more fluctuation of the damping force as their cleaning method is not effective. Therefore, 60% of the whole case is due to operators mistake and their cleaning method which leads to get contamination.

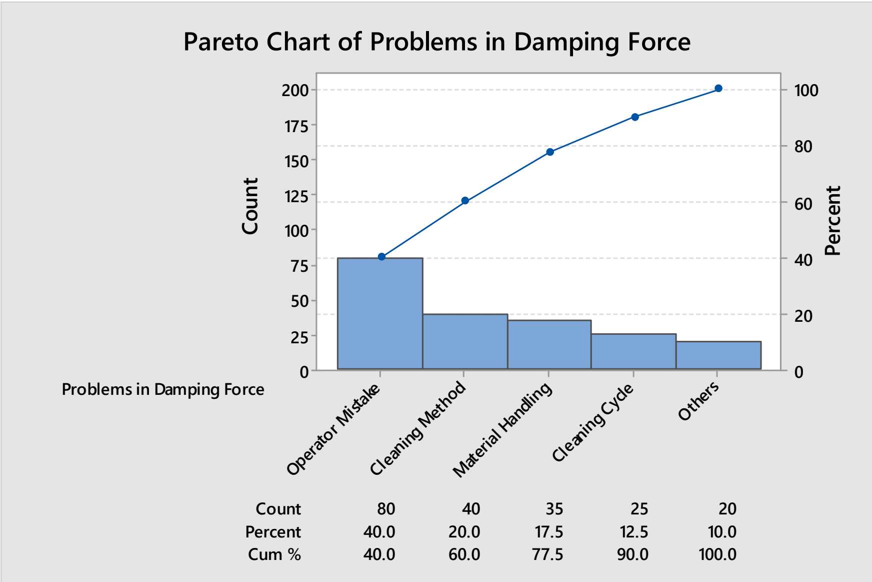

Figure 6. Pareto Analysis for Shock Absorber Assembly

It was clear that the three-major metrics to required adjustment to meet expectations. From the process flow chart, a cause and effect diagram were created to help determine root cause of potential "failures" in key metrics. Once compiled, investigations were initiated to understand what process differences existed between data points well within limits and close to, or beyond limits. The thought process was to reduce variation and implement standard operating methods found in preferred results and use as best practice standards. Implementing and plotting against this standard would forecast anticipated results. This would simulate elements discovered/action implemented.

The proposed suspension assembly consist of base valve assembly which has three valves of 0.1mm thickness and it gets assembled by operator's hand, as the thickness of valve is too thin it gets missed by human hand, so instead of three just one or two valves get picked up and that assembly cannot give a proper oil flow which further leads to inadequate damping effect.

The other major problem with assembly was contamination, which gets stuck in orifice valve which has holes in it for oil flow and because of contamination the oil flow was not enough which gave jerking effect to the vehicle. This contamination was lead because of other sub process like child part cleaning method, cleaning cycle and improper material handling. The child parts are cleaned by ultrasonic cleaning method, the chemical solution which is used to clean the parts gets filtered via 25micron filter so particles below 25microns were getting passed thru and gets settled in child parts and leads to contamination. Other possible way of contamination was trolleys which carry outer tubes of suspension, trolleys have vertical rods for holding the outer tube, the inner side of outer tube goes on top of that rod and sometimes because of metal to metal contact the chips or burs of rod gets substituted inside the inner tube and while functioning of suspension that chip gets stuck in the valve and results in failure of suspension.

4.6. Statistical Data Analysis of actual case

In industrial statistics, the $\overline{X}$chart is a kind of Shewhart manage chart that is used to monitor the arithmetic potential of successive samples of regular size, n. This form of manipulate chart is used for traits that can be measured on a continuous scale, such as weight, temperature, thickness etc. For example, one might take a sample of 5 shafts from manufacturing every hour, measure the diameter of each, and then plot, for each and every sample, the common of the five diameter values on the chart. In this case, the control limit, Upper control limit, and Lower manage restriction of each $\overline{X}$ and R Chart. With the assist of the formulas each of them is calculated and figured the required manner whether it is in manipulate or not.
The evaluation is done as followed with the given formula:

$$\overline{X} = \frac{\sum (X_1 \ldots X_n)}{n}$$

n is the number of observations
n= 200

$\overline{X} = \frac{117213}{200}$

$\boldsymbol{\overline{X}}$**= 586.065**

$$\overline{R} = \frac{\sum (R_1 \ldots R_k)}{k}$$

K=200

$\overline{R} = \frac{45710}{200}$

$\boldsymbol{\overline{R}}$**= 228.55**

Upper control limit:

$UCL_X = \overline{X} + A_2 * \overline{R}$

UCL_X= 586.065 + 0.308*228.55

UCL_X=656.5

Lower Control Limit:

$LCL_X = \overline{X} - A_2 * \overline{R}$

LCL_X= 586.065 - 0.308*228.55

LCL_X= 515.6

Upper Control Limit:

$UCL_R = \overline{D_4} * \overline{R}$

UCL_R =1.777 * 228.55

UCL_R =406.1

Lower Control Limit:

$LCL_R = \overline{D_3} * \overline{R}$

LCL_R= 0.223 *228.55

LCL_R= 50.966

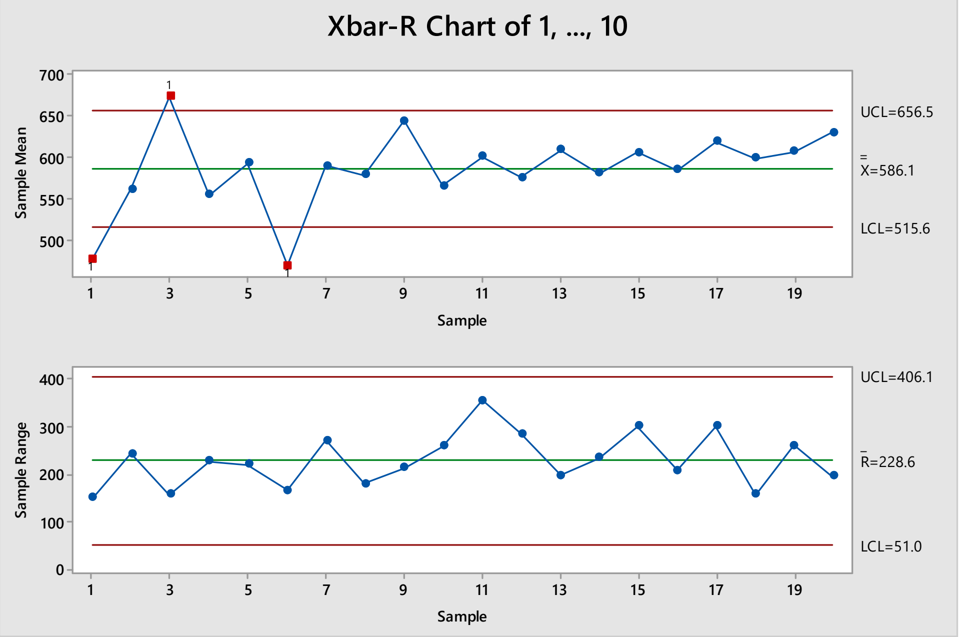

Figure 7. $\overline{X}$ & R Chart for Damping Force

In this $\overline{X}$ chart most of the values lies near the control limit of the range chart. Some are over the control limit while some are lower the control limit. In figure 7 it can be seen that 1 sample value is over the control limit and 2 samples are lower the control limit. Therefore, the process is not in control and need to solve the issue and improve it again. Here also It can be many reasons which are affecting the process, but it needs to be solved so that the process can be in control and the Damping force can be brought under optimal level. In this Range chart all of the values lie near the control limit of the range chart. Some are showing little fluctuation, but also there is a clear tendency of improve the damping force as the time passes, showing that there is a systematic problem which causes this situation.

4.7. Hypothesis Testing

Statistical hypothesis testing is the use of statistics in determining between two (or more) distinct chances in order to get to the bottom of an trouble in an ambiguous situation. Hypothesis trying out produces a particular selection about which of the probabilities is correct, primarily based on data. The technique is to collect information that will help determine amongst the chances and to use careful statistical evaluation for extra energy when the answer is now not apparent from simply glancing at the data.

The word "population" will be used for both situations in the following descriptions. Statistical analysts look at a speculation via using measuring and analyzing a random pattern of the populace being analyzed. All analysts use a random populace sample to look at two splendid hypotheses: the null Hypothesis and the Alternative hypothesis. The null speculation is typically a speculation of equality between populace parameters, e.g., a null hypothesis may additionally country that the populace imply return is equal to zero. The alternative speculation is efficiently the contrary of a null hypothesis, e.g., the population suggest return is now no longer equal to zero. Thus, they are together exclusive, and only one can be true. However, one of the two hypotheses will normally be true.

Here in this case the 200 samples of Damping force of shock absorber is being worked under hypothesis test where the null hypothesis is μ=586.07 and the alternative hypothesis of the 200 samples are $\mu\neq$586.07. So, after doing the hypothesis tests the result is given below:

One-Sample T: Damping Force (N)
Descriptive Statistics

N	Mean	StDev	SE Mean	95% CI for μ
200	586.07	85.94	6.08	(574.08, 598.05)

μ: mean of Damping Force (N)
Test

Null hypothesis	H_0: μ = 586.07
Alternative hypothesis	H_1: $\mu \neq$ 586.07

T-Value	P-Value
-0.00	0.999

So as a result of hypothesis test for 200 samples, the mean values can be 586.07. Therefore, the null hypothesis cannot be rejected as P-value is greater than 0.05 and it shows that new data needs to calculate again after solving the contamination problem and the whole $\overline{X}$ and R Chart have to be created which tells if the process comes under control or not.

4.8. Design of Experiment

Design of experiments (DOE) is described as a branch of applied statistics that deals with planning, conducting, analyzing, and deciphering managed tests to evaluate the elements that manage the cost of a parameter or crew of parameters. DOE is a powerful statistics collection and analysis device that can be used in a variety of experimental situations. It lets in for more than one enters elements to be manipulated, figuring out their impact on a desired output(response). By manipulating more than one inputs at the same time, DOE can identify vital interactions that may also be neglected when experimenting with one element at a time. All viable mixtures can be investigated (full factorial) or solely a component of the viable combos (fractional factorial).

Table 4 shows the factors which are affecting the Damping force of the shock absorber which gives minimum and maximum outcome to optimize the experiment and its calculations. Here the response part is given as the uniformity of the Damping force which is effect by different values of Total Length of cylinder, temperature and

Pressure. Moreover, these factors and responses are dependent to each other unaware about the condition of the material of the product which gives the main issue factors which needs to be solved by calculating pareto chart, regression equation and the main effect plots.

Table 4. Data for Design of Experiment for Damping Force

StdOrder	RunOrder	CenterPt	Blocks	Total Length (mm)	Temperature (K)	Pressure (p.s.i)	Damping Force (N)
1	1	1	1	302.2	-40	260	575
2	2	1	1	306.2	-40	260	596
3	3	1	1	302.2	130	260	585
4	4	1	1	306.2	130	260	581
5	5	1	1	302.2	-40	360	579
6	6	1	1	306.2	-40	360	590
7	7	1	1	302.2	130	360	595
8	8	1	1	306.2	130	360	578

Total length is set between 302.2 to 306.2 as the tolerance of the length needs to be between these values and the damping force will differ as the displacement of the cylinder changes because of the total length. On the other hand, temperature is set to be -40 to 130 K which remains in the tolerance of the shock absorber and finally the pressure exerted while pushing the cylinders down which is set to be 260 to 360 psi.

Analysis of variance (ANOVA) is a statistical technique that is used to take a look at if the means of two or more organizations are considerably one-of-a-kind from every other. ANOVA tests the impact of one or more elements by using evaluating the means of specific samples. In Figure 8 Analysis of Variance for damping force is carried out where the main factors are been figured out with the combination which helps to dig more in the main factors effecting the damping force.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value
Model	7	446.875	63.839	*
Linear	3	18.375	6.125	*
Total Length (mm)	1	15.125	15.125	*
Temperature (K)	1	0.125	0.125	*
Pressure (p.s.i)	1	3.125	3.125	*
2-Way Interactions	3	427.375	142.458	*
Total Length (mm)*Temperature (K)	1	351.125	351.125	*
Total Length (mm)*Pressure (p.s.i)	1	66.125	66.125	*
Temperature (K)*Pressure (p.s.i)	1	10.125	10.125	*
3-Way Interactions	1	1.125	1.125	*
Total Length (mm)*Temperature (K)*Pressure (p.s.i)	1	1.125	1.125	*
Error	0	*	*	
Total	7	446.875		

Source	P-Value
Model	*
Linear	*
Total Length (mm)	*
Temperature (K)	*
Pressure (p.s.i)	*
2-Way Interactions	*
Total Length (mm)*Temperature (K)	*
Total Length (mm)*Pressure (p.s.i)	*
Temperature (K)*Pressure (p.s.i)	*
3-Way Interactions	*
Total Length (mm)*Temperature (K)*Pressure (p.s.i)	*
Error	
Total	

Figure 8. Analysis of Variance for Damping Force

R2 is the percentage of variant in the response that is defined by using the model. It is calculated as 1 minus the ratio of the error sum of squares (which is the version that is not explained by means of model) to the complete sum of squares (which is the whole variant in the model).
The model summary in figure 9 shows the model summary that the regression scale model is fully feasible and 100% of the value shows that the model gives full results to the factors of the damping force.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Figure 9. Summary of Design of Experiments for Damping force of a Shock Absorber

Regression is clearly finding a mathematical relationship between variables. Ideally, in a DOE, one tries to maintain the changes in the factors independent of each other. Regression methods except the gain of layout and forethought will have much less strength than a related controlled, designed experiment. Figure 10 shows the regression equation made with the tolerance of the total length of the shock absorber cylinder, temperature of the shock absorber and the pressure exerted by it while testing. So, with the with the help of this equation ideal damping force of the shock absorber can be carried out evaluating it.

Regression Equation in Uncoded Units

Damping Force (N) = -2682 + 10.74 Total Length (mm) + 7.611 Temperature (K)
+ 8.142 Pressure (p.s.i) - 0.02529 Total Length (mm)*Temperature (K)
- 0.02676 Total Length (mm)*Pressure (p.s.i)
+ 0.01369 Temperature (K)*Pressure (p.s.i)
- 0.000044 Total Length (mm)*Temperature (K)*Pressure (p.s.i)

Figure 10. Regression Equation for Damping Force

The Pareto chart suggests the absolute values of the standardized results from the biggest effect to the smallest effect. The standardized results are t-statistics that check the null hypothesis that the impact is zero the chart also plots a reference line to point out which consequences are statistically significant. Figure 11 shows that the damping force is not only getting effected due to contamination but majorly due to improper total length and fluctuation in temperature. Now from this pareto chart it is figured out that we need to work on maintaining total length of the cylinder and the temperature of the shock absorber while applying the force on the cylinder. As, length increase the temperature is increase which effects and damages the damping force of the cylinder.

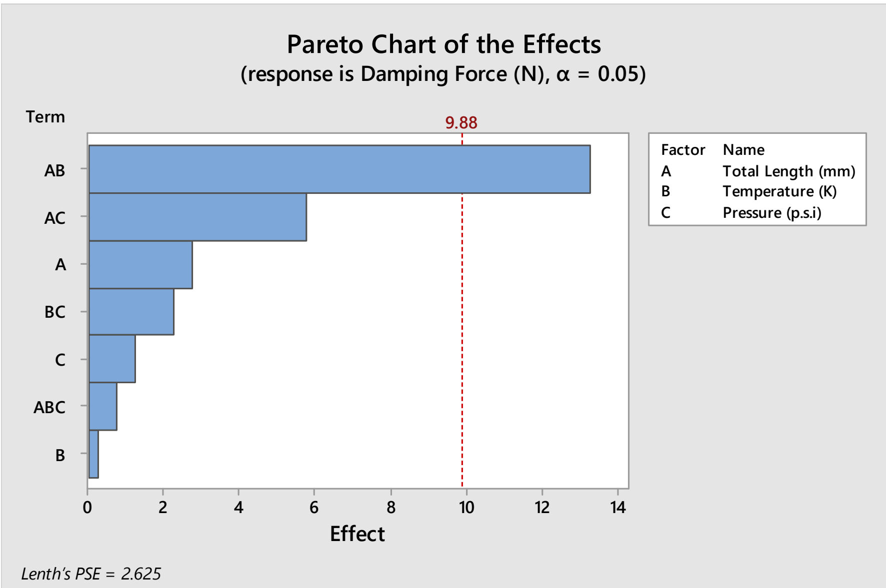

Figure 11. Pareto Chart for the effect of the Damping Force

The Main Effect plots are the imply response of each degree factors related with the aid of the line. When the horizontal line presents, there is no important impact present. When the line is a small deflection from horizontal it may additionally considerably affect the response. Stepper slope in the line illustrates the higher magnitude of the important impact. Figure 12 shows the main effect of the design of experiment for the damping force where the total length of the cylinder is increasing, the damping force is increasing as well. Similarly, with little increase in pressure, the damping force is increasing rapidly. On the other side, as the temperature decreases, the damping force increase. So, as a conclusion, total length and pressure is directly proportional to the damping force of the shock absorber while the temperature is inversely proportional to the damping force.

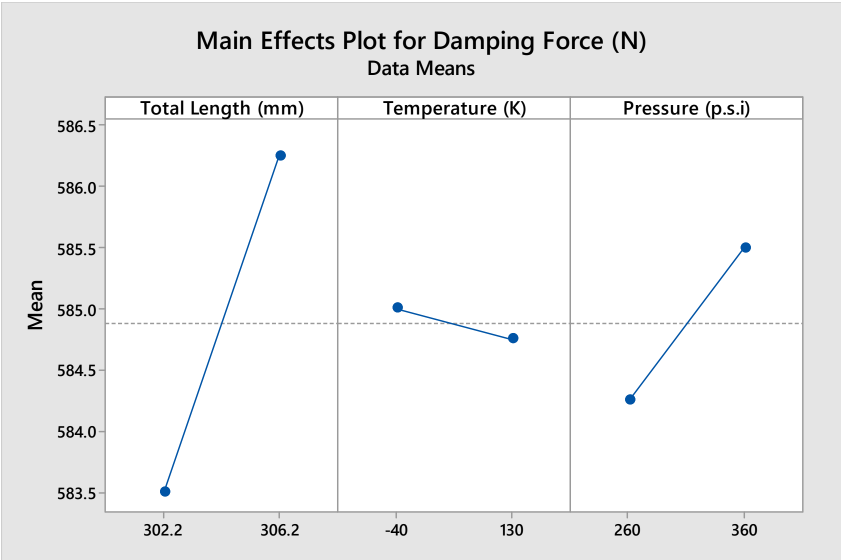

Figure 12. Main Effects Shown by each effect for Damping force

5. Improved data collection

Table 5 shows 200 cases of damping force which were collected while testing after the contamination is reduced to neglect the other particles to enter inside. On the suspension assembly line, the company have damping machine which tests damping force of suspension with the help of load cell, and it has a display screen which shows the value of damping force according to the given specification.

Table5. Data for Damping Force generated from Design of Experiments

Improved Data of Damping Force generated from Design of Experiment (N) (Spec 575±96 (479-671)									
502	555	572	598	599	613	614	633	626	642
514	548	566	598	581	614	613	632	636	653
521	553	574	586	586	609	603	638	656	655
526	546	565	588	589	610	601	620	641	647
522	545	562	591	596	610	601	628	648	653
534	556	574	592	587	613	617	639	652	658
537	542	577	597	594	604	616	637	652	657
538	558	576	583	586	607	619	634	643	641
547	562	564	589	583	608	604	622	646	655
541	578	564	583	588	619	603	636	657	669
557	575	571	597	596	614	622	627	644	662
551	561	566	594	598	603	637	633	658	664
559	568	563	593	611	613	634	623	656	661
542	567	561	582	608	611	639	634	659	663
547	579	563	588	618	619	623	631	651	669
559	561	579	594	606	612	633	623	644	668
557	577	597	597	604	613	628	635	649	662
547	576	589	585	609	604	634	633	648	661
542	562	594	587	617	606	620	625	655	667
552	567	581	599	615	608	624	637	653	633

6. Control Phase

After imposing the upgrades introduced in Improve Phase, there were 200 samples measured of shock absorber. There were carried out assessments to discover the random character of the sample data, assessments to discover and take away outliers, has been assessed whether the information acquired through measurement came from an everyday distribution and also were assessed warning signs of method functionality. To asses if the improved technique is in control or not, the one hundred measurements had been plotted on a $\overline{X}$ & $\overline{R}$ charts, revealing that regarding both $\overline{X}$ & $\overline{R}$ charts the method used to be in manipulate.

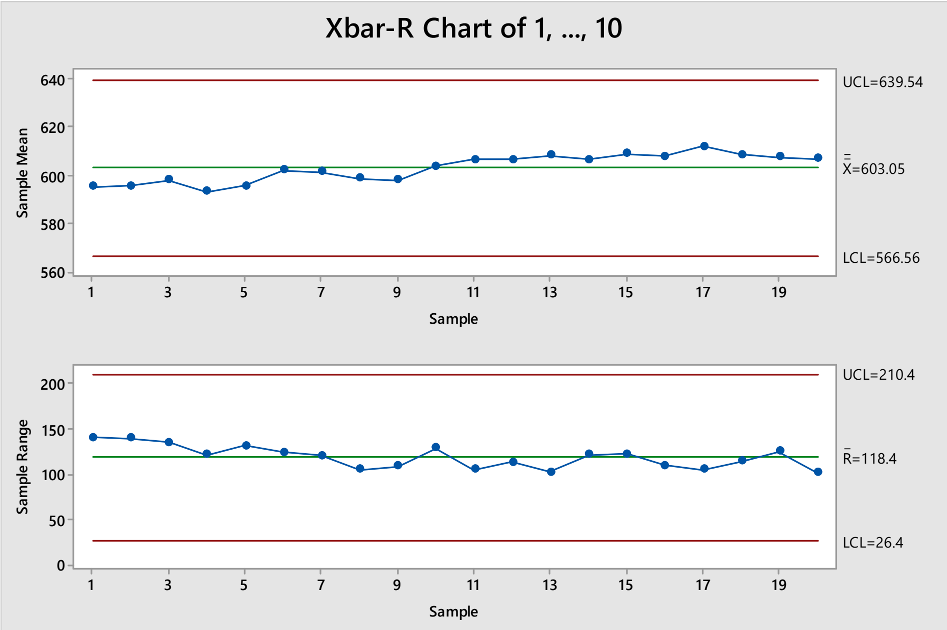

Figure 13. Main Effects Shown by each effect for Damping force

The result in figure 13 shows that after the improvement in contamination reduced to low level, the damping force is tested to be near the mean value of 603.05 N. All the averages of the damping force shows that no point is out of the control limit. Hence, the process is brought under control which means the quality of manufacturing and the shock absorber itself is improved.

7. Results and Discussion

To overcome the above-described problem, we proposed the few possible solution which can lead to quality improvement of the process. In figure 14, for valve missing problem, we can implement a valve dispensing machine which can dispense required number of valves each time and operator can pick that up from dispenser for assembly, in this way it can be eliminated and can give proper damping.

Figure.14 Automatic Valve Dispensing Machine

In figure 15, for ultrasonic cleaning machine along with 25 micron we can place 10-micron filter which further purifies and drags away all the impurities which were carried after getting filtered with 25-micron filter. In this way there won't be any contamination which can be stuck in the child parts. Also, the cleaning cycle can be doubled for further proper cleaning.

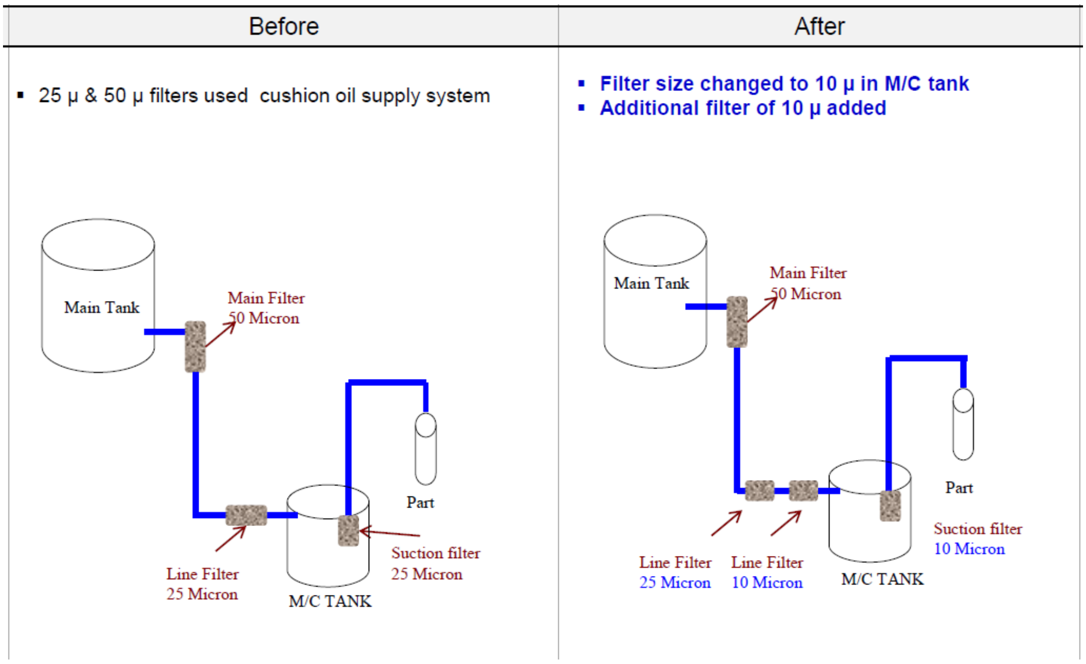

Figure.15 Before and after of ultrasonic cleaning machine

For material handling, the tubes were carried from inner part with rods, instead of that the tubes can be held from outer ring with slots on trolley instead of rods, in this way there won't be any metal-to-metal contact and no burs or chips will be left inside the tube.

7. Conclusions

An analytical model of the manner damping force in Shock Absorber has been presented in this paper. To accurately predict factors of damping force components, a feedforward neural network is adopted in this approach. Good settlement between the neural prediction and experimental verification of the Damping forces has been shown. The process damping force is got from the calculation of the resistance force produced by the stress discipline inside contamination of the fuel in the oil, which is also proportional to the total length, temperature, and pressure of the force. An algorithm for the calculation of the volume of the displaced work material has been presented. The consequences bought from this model can satisfactorily describe dynamic cutting phenomena generated via the process damping force. In other words, a useful mannequin to check out the process damping effect in Shock absorber reducing has been developed in this study. It must be pointed out that the impact of the system damping pressure is extremely essential in the modeling of shock absorber forces in contamination removal processes. The model developed in this paper can be without problems utilized in automobile with the testing effect irrespective of the factors like temperature and pressure which leads to reduction in contamination and hence keeping oil pollution free.

References

D. Cao, X. Song, and M. Ahmadian, "Editors' perspectives: Road vehicle suspension design, dynamics, and control," *Vehicle Syst. Dyn.*, Dec. 2011.

L. Sun, X. Cai, and J. Yang, "Genetic algorithm-based optimum vehicle suspension design using minimum dynamic pavement load as a design criterion," Mar. 2007.

W. Sun, H. Gao, and O. Kaynak, "Adaptive backstepping control for active suspension systems with hard constraints," *IEEE-ASME Trans. Mechatronics*, Jun. 2013.

W. Sun and H. Gao, "Vibration isolation for active suspensions with performance constraints and actuator saturation," *IEEE-ASME Trans.Mechatronics*, Apr. 2015.

S.-B. Choi and Y.-M. Han, "Vibration control of electrorheological seat suspension with human-body model using sliding mode control," *J. Sound*, Jun. 2007.

S. Venkateswarlua , M. Janaki a,∗ , R. Thirumalaivasana , Nagesh Prabhub "A review on damping of torsional interactions using VSC based FACTS and subsynchronous damping controller" 2018.
S.-B. CHOI AND S.-K. LEE "A hysteresis model for the field-dependent damping force of a magnetorheological damper."
Lalitkumar Maikulal Jugulkar1,2, Shankar Singh1 and Suresh Maruti Sawant3 "Analysis of suspension with variable stiffness and variable damping force for automotive applications" 2016.
L. Sun, X. Cai, and J. Yang, "Genetic algorithm-based optimum vehicle suspension design using minimum dynamic pavement load as a design criterion,", Mar. 2007.
I. Youn and A. Hac, "Semi-active suspensions with adaptive capability," Feb. 1995.
R. Kubler, Theorie und Experimente zur Parameter- L identi$kation von StoSdLampfer, University of Stuttgart, Institute B of Mechanics, Forschungsbericht FB-30, Stuttgart, 1996
Shide Qian, "Design and Application of Fault Prevention System for Automobile Shock AbsorberAssembly Process Based on RFID" 2019
Arokiasamy Mariajayaprakash, Thiyagarajan Senthilvelan, Krishnapillai Ponnambal Vivekananthan, Optimization of shock absorber parameters using failure mode and effect analysis and genetic algorithm, International Journal of Industrial Engineering, 2013
K.Srinivasan, S.Muthu, N.K.Prasad, G.Satheesh "Reduction of paint line defects in shock absorber through Six Sigma DMAIC phases" 2014
Mohd sufian bin jamaludin "a study of the causes of bouncing problems of shock absorber"
Pinjarla.Poornamohan, Lakshmana Kishore.T "DESIGN AND ANALYSIS OF A SHOCK ABSORBER" 2012
Adrian Pugna, Romeo Negrea, Serban Miclea "Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company" 2015
Sameer Kumar, Michael Sosnoski "Using DMAIC Six Sigma to systematically improve shopfloor production quality and costs" Opus College of Business, University of St Thomas, Minneapolis, Minnesota, USA 2008

Bio

Vishesh Mahendrabhai Joshi is a student of Lawrence Technological University pursuing Master of Science in Industrial Engineering. He was graduated from Rai University, Ahmedabad, India, having Major in Bachelor of Technology in Mechanical Engineering. He has done 2 Internships for Heat exchanger and Color die machine manufacturing industry. Moreover, he has worked for 1.2 years as Design Engineer in Heavy Engineering Unit and worked for 7 months as production engineer in heavy Engineering production Unit. He is member of IEOM and ASME.

Sanjay Maheshwari is a Validation Engineer, holding a degree in Master of Engineering in Automotive Engineering at the Lawrence Technological University, Michigan, USA. He earned B.E. in Automobile Engineering from Lok Jagruti Institute of engineering and Technology, India. He has published journal on Advanced Steering Mechanism System. Sanjay has done research in Wireless charging of an automotive in Lawrence Technology University. He is member of SAE. He worked as a Quality Engineer in Automotive Manufacturing company which had him proficient in Aluminum castings, Suspension system and Braking system. He was a participant of SAE BAJA India. He has done projects on IC engine Modification, Working model of Hydrogen fuel powered automobile.

Ahad Ali is an Associate Professor and Director of Industrial Engineering Program and Director of Smart Manufacturing and Lean Systems Research Group, A. Leon Linton Department of Mechanical, Robotics and Industrial Engineering at the Lawrence Technological University, Southfield, Michigan, USA. He earned B.S. in Mechanical Engineering from Khulna University of Engineering and Technology, Bangladesh, Masters in Systems and Engineering Management from Nanyang Technological University, Singapore and Ph.D. in Industrial Engineering from University of Wisconsin-Milwaukee. Dr. Ali was Assistant Professor in Industrial Engineering at the University of Puerto Rico - Mayaguez, Visiting Assistant Professor in Mechanical, Industrial and Manufacturing Engineering at the University of Toledo and Lecturer in Mechanical Engineering at the Bangladesh Institute of Technology, Khulna. He received an Outstanding Professor Award of the Industrial Engineering Department, University of Puerto Rico -Mayaguez, (2006-2007). He has published 50 journal and 121 conference papers. Dr Ali has conducted research projects with Chrysler, Ford, DTE Energy, New Center Stamping, Whelan Co., Delphi Automotive System, GE Medical Systems, Harley-Davidson Motor Company, International Truck and Engine Corporation (ITEC), National/Panasonic Electronics, and Rockwell Automation. His research interests include manufacturing systems modeling, simulation and optimization, intelligent scheduling and planning, artificial intelligence, predictive maintenance, e-manufacturing, and lean manufacturing. He has successfully advised seven doctoral students. Dr. Ali has involved with many international conference committees. He is serving as an Executive Director of IEOM Society International and Conference Co-Chair of the International Conference on Industrial Engineering and Operations Management and hold events in Dhaka, Kuala Lumpur, Istanbul, Bali, Dubai, Orlando, Detroit, Rabat, UK, Bogota, Paris, Washington, DC, Pretoria, Bangkok, Pilsen, Toronto, Costa Rica, Sao Paulo and Riyadh. Dr. Ali has visited 20 countries for professional events. He is a member of IEOM, INFORMS, SME and IEEE.