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Identification and Regulation of Vacuum Drop in Brake System of a Vehicle

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Abstract:- This paper explains about one of the crucial problems that can be faced in an electric vehicle. Brake ineffectiveness that is brake system failure can occur due to different possible reasons that are mentioned below in the paper. To solve this problem we have considered data of 560 vehicles. Vehicles brake oil was manually filled earlier which it has consumed almost 15 minutes in production line, whereas the machine can fill the oil by removing the entrapped air in the system through creating vacuum in just 5 minutes. The results show the 3 times improvement in the production rate of an electric vehicle industry after solving the root-cause and making it completely automatic. Different methods of approach like torque test and vacuum drop test were performed on the brake system to identify the root-cause of the problem. The approach towards the problem has involved in detail design analysis which helped in identification of the root-cause. Hydraulic brake systems have unique oil of different grades they are dot 3, dot 4 and dot 5 or dot 5.1. The chemical composition of the fluids also changes according to their classifications. Here we used DOT 3 oil as brake oil, and performed the analysis.

I. INTRODUCTION

A. General introduction

Brake fluid is a liquid solution used in hydraulic brakes. Normal braking requires more effort when comparing with hydraulic brake system. Viscosity is very important factor in brake fluids. Proper viscosity index needs to be maintained in various temperatures. Fluids with high viscosity are not preferable to use as brake fluids. DOT 3, DOT 4, and DOT 5 are some of the most common brake fluids that we use in a vehicle. Brake fluids must have high boiling point to avoid vaporization within the lines. The life span of brake fluid can be predictable up to 18 months, it is preferable to change after this duration. Brake fluids are responsible for protecting the parts of brake system from corrosion as there is a chance of moisture entering into the system. The working of the brake fluid is, when force is applied on the brake pedal it effects the master cylinder and in return it creates pressure in the fluid. The pressurized brake fluid will be pushed into the brake lines. The harder we press the brake pedal the more pressure will be generated. The brake fluid flows through the brake lines until it reaches the wheel cylinder on each wheel. At this point the pressurized fluid forces the piston inside the brake cylinder and the piston expands the brake pads that are responsible for generating the friction and eventually stops the vehicle. To complete the entire process there shouldn't be air inside the brake system. If air is present in the system, then the effective application of brakes cannot be observed and that leads to brake ineffectiveness. This is the main problem that we have identified in the brake system that is presence of air. This entire report provides appropriate solution to overcome the brake ineffectiveness and brake sponginess problem.

B. Problem Statement:

Identified Brake ineffectiveness in vehicles, observed vacuum drop failure in brake system of electric vehicles through brake oil filling machine. The acceptable range should be less than 3.10mbar, but identified huge variance from 3.10mbar to 995.8mbar. Recorded data and observed that 92% are manually filled. Using brake oil filling machine we can complete the required work in 5 minutes, but due to vacuum failure in brake system it took 15 minutes to complete one vehicle, which results in increase of the production time and decreases the production rate.

C. Background of the problem:

Maximum of the vehicles have brake ineffectiveness issue after filling brake oil in the brake system of an electric vehicle. It is very important as it helps in application of brakes. Before filling oil we must ensure that there is no air present inside the system, the reason behind creating negative pressure is to provide efficient brake. If air is trapped inside the system, then we can identify brake sponge which decreases the effectiveness of the brakes. This might trouble the driver in applying the brakes. The vacuum drop has to be maintained less than 3.10mbar to avoid brake sponge. Vacuum drop data was recorded for different vehicles from 04/01/2022 to 14/02/2022. The data explains the number of vehicles that are manually filled and machine filled. It has been recorded that only 8% are machine filled. This improves production time, as maximum are manually filled and also manual filling involves the manpower. Manual filling consumes 15 minutes for each vehicle where it decreases the 3 times production speed.

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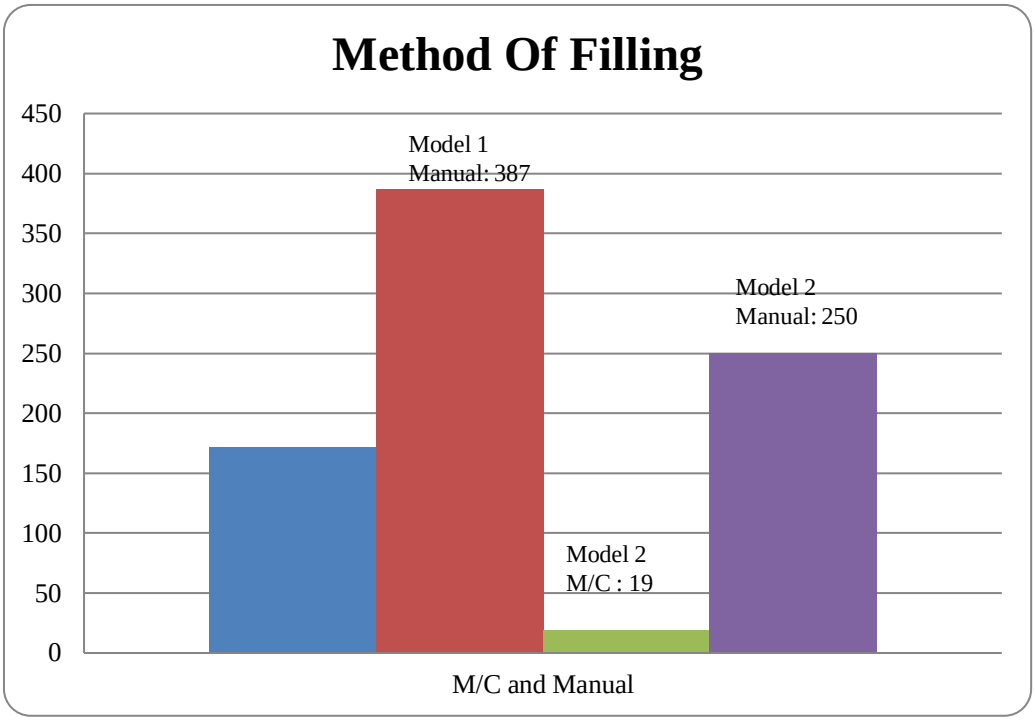

Fig. 1: Machine Time vs Manual Time taken to fill a vehicle

Figure 1 shows the time taken for filling the vehicles manually and also with machine. Manually it takes 15 minutes and with machine it takes 5 minutes.

The following data explains the number of vehicles manually filled and machine filled.

Figure 2: The count of two vehicles of different models that are manually filled and machine filled. In both model 1 and model 2 maximum vehicles are manually filled due to the brake system failure.

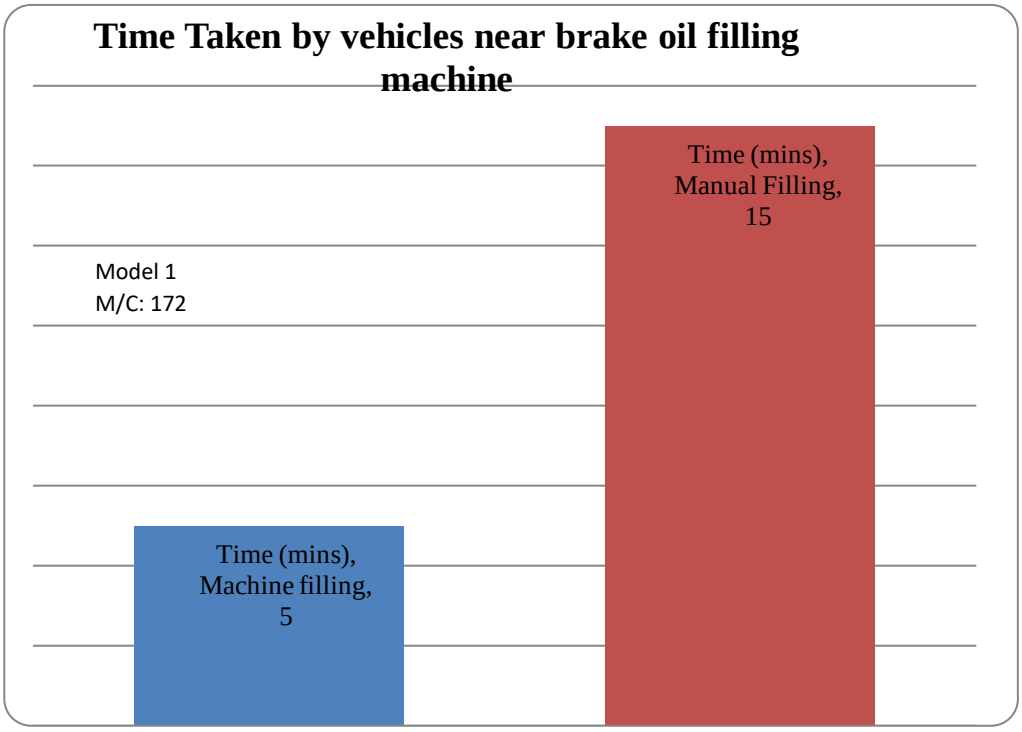

Fig. 2: Model 1 and Model 2 Manual filling vs Machine filling

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II. WORKING PRINCIPLE OF BRAKE OIL FILLING

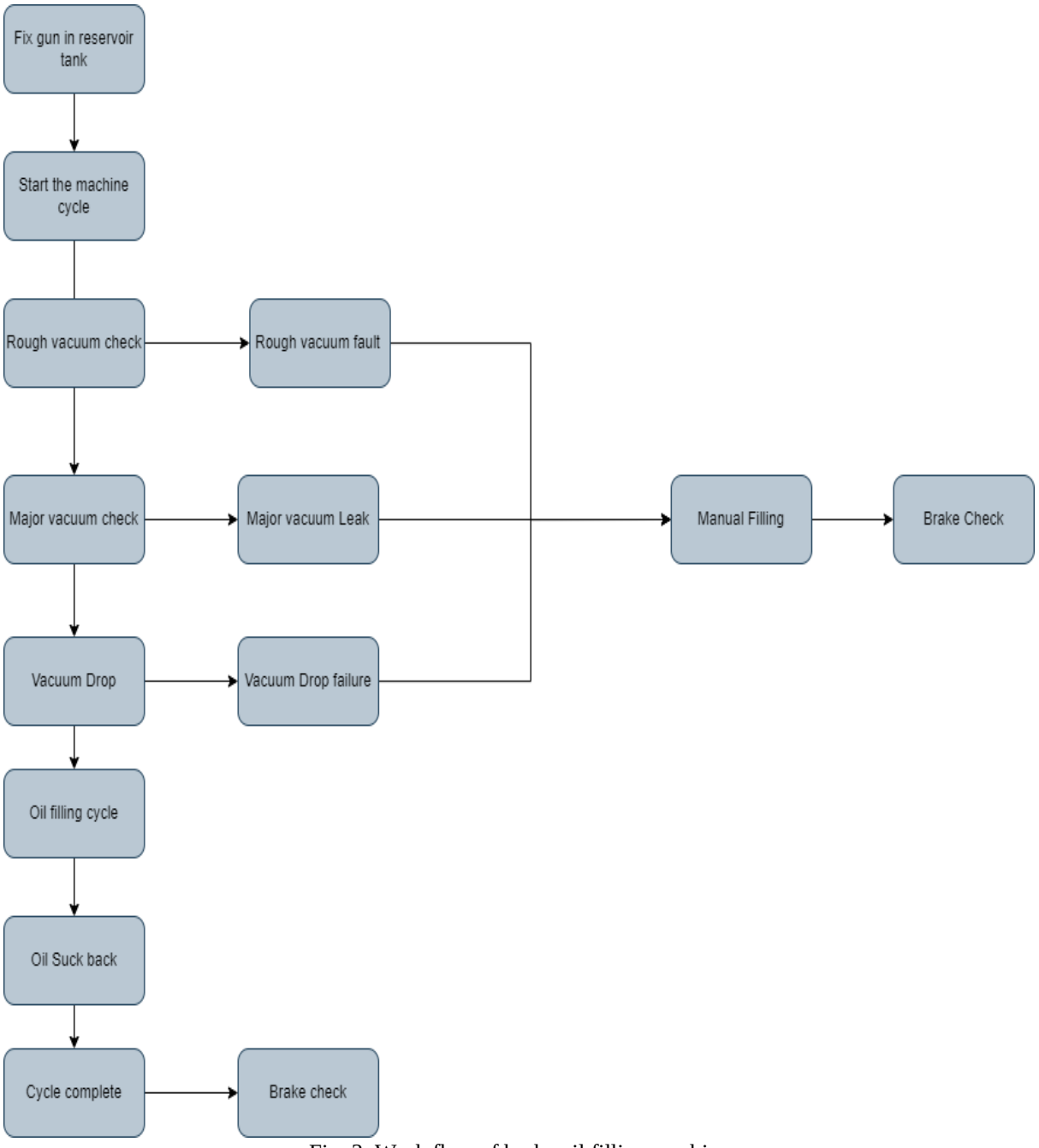

Fig. 3: Work flow of brake oil filling machine

Figure 3 is the working principle of the brake oil filling machine. Machine will only complete the cycle once it passes all the main three cases that is rough vacuum leak, major vacuum leak, vacuum drop.

The hydraulic brake system should ultimately depend on the brake fluid that is either dot 3 or dot 4.If air is present inside the system, as air is compressible and hence brake becomes less responsive that indicates in spongy feel of the brake pedal.

Brake fluids are polyglycol nature hydroscopic that is they can absorb moisture from the surrounding air, results in lowering the boiling point of the fluid of 5 percent, this may occur after three years of the service life. Important point is that due to the over usage of brake fluid even after reaching its boiling points there are chances for the formation of gas pockets on the top of the wheel cylinder. Also, in worst case presence of vapor in the system can push back the fluid into the reservoir that results in brake failure, to avoid such dangerous situations manufactures recommend changing the brake oil for every 18 months. Dirt is one of the enemies of hydraulic system, it consists of operations depends upon the cleanliness and effective seal. For this reason, the area of brake system is maintained clean.

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A. Post Manual Filling Process

After manual filling there is chance of air being trapped inside the system. This is confirmed by applying the brake. Almost all the vehicles observe the air entrapment after manual filling them. To remove the air that has been trapped inside the system, there are few check points in the brake system near the brake plates where we can remove the entrapped air. For three-wheeler vehicles there are three points. This purging of air from the hydraulic system is referred as bleeding, this can be performed only after some part is disconnected so that air can leave the system as fluid pushes it away the reason behind is fluids are incompressible in nature. For this purpose, there are bleed valves with bleeder screws provided in the wheel cylinders. The air is trapped by attaching a bleeder tube connected to the bleeder valve and the other end is connected to a closed jar. If the air bleed valve is opened then the brake system is pressurized by repeatedly depressing the brake pedal, which pushes the fluid through the brake system along with the air bubbles into the jar. Flow of bubbles can confirm that there is presence of air inside the system. When bubbles no longer appear the bleeder screw is tightened, and brake spongy issue will be resolved. This process is performed on all the bleed valves to remove the air present in the system. Care must be taken while handling the brake fluids as they can damage the painted surfaces. The other reason for brake spongy is Fluid vaporization.

B. Current Situation:

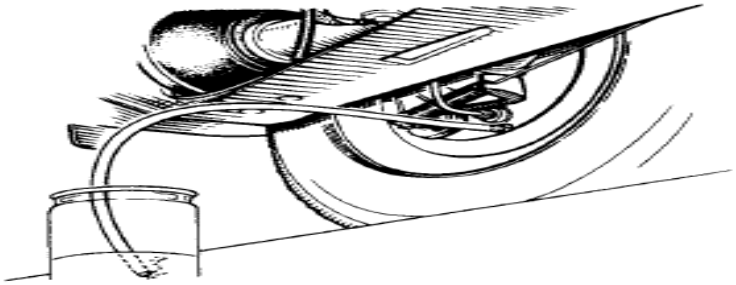

Fig. 4: post manual filling air removal

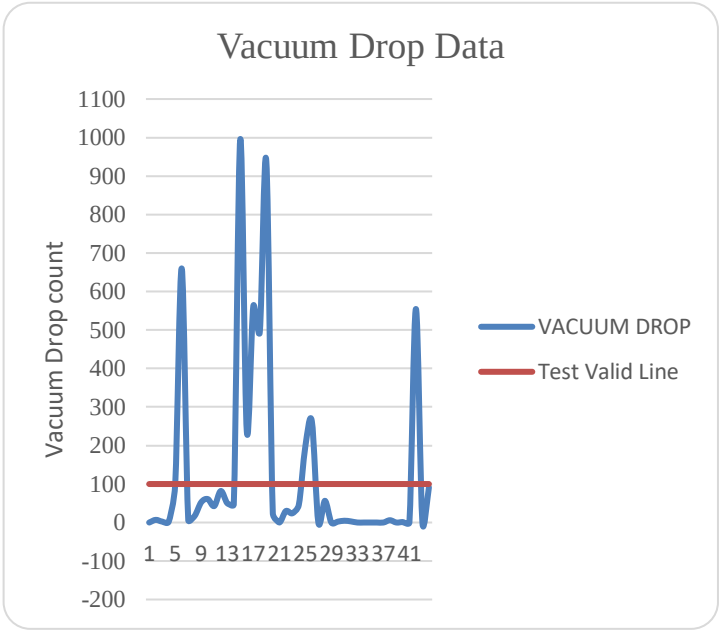

Fig. 5: Vacuum Drop Data with Test valid line

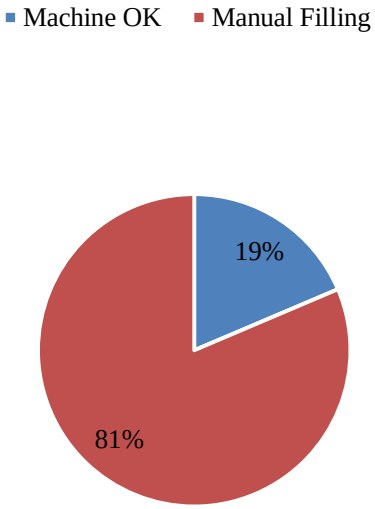

Fig. 6: Manual filling vs machine filling

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The above figure 5 clearly explains about the variance observed vacuum drop of both model 1 and model 2, from graph and pie chart only 19% vehicles are machine filled and other 81% are filled manually for 43 vehicles. This count has to be controlled which must be less than 3mbar, brake effectiveness can be observed till the vacuum drop is up to 12mbar. To perform the test we have considered test valid line till 100mbar. The table 1 below provides the vacuum drop count and method of filling for 43 vehicles. "-" indicates the vacuum drop is more than 995mbar.

VACUUM DROP (mbar)	FILLING METHOD
-	MANUAL
6.90	M/C
2.33	M/C
2.18	M/C
100.5	MANUAL
659.6	MANUAL
6.13	M/C
17.53	MANUAL
52.73	MANUAL
60.89	MANUAL
42.78	MANUAL
81.91	MANUAL
50.11	MANUAL
46.86	MANUAL
995.23	MANUAL
237.15	MANUAL
561.96	MANUAL
495.64	MANUAL
938.7	MANUAL
24.18	MANUAL
-	FULLY MANUAL
29.71	MANUAL
23.94	MANUAL
45.9	MANUAL
197.29	MANUAL
263.12	MANUAL
-	MANUAL
56.49	MANUAL
-	MANUAL
2.34	M/C
4.65	M/C
2.90	M/C
-	MANUAL
-	FULLY MANUAL
-	FULLY MANUAL
-	FULLY MANUAL
-	FULLY MANUAL
5.92	M/C
-	FULLY MANUAL
1.31	TEST VEHICLE
-	MANUAL
554.7	MANUAL
-	MANUAL
91.40	TEST VEHICLE

Table 1: Vacuum drop data and Method of filling for 43 vehicles

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C. Justify the choice:

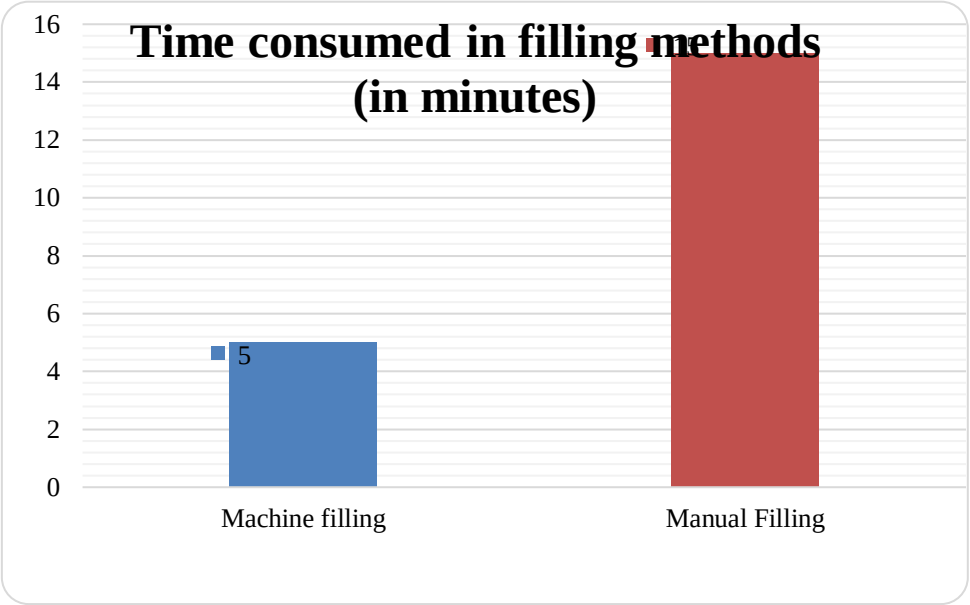

Fig. 7: Time consumed in filling vehicle using Machine and Manual

Figure 7: explains the amount of time consumed in filling the brake oil.

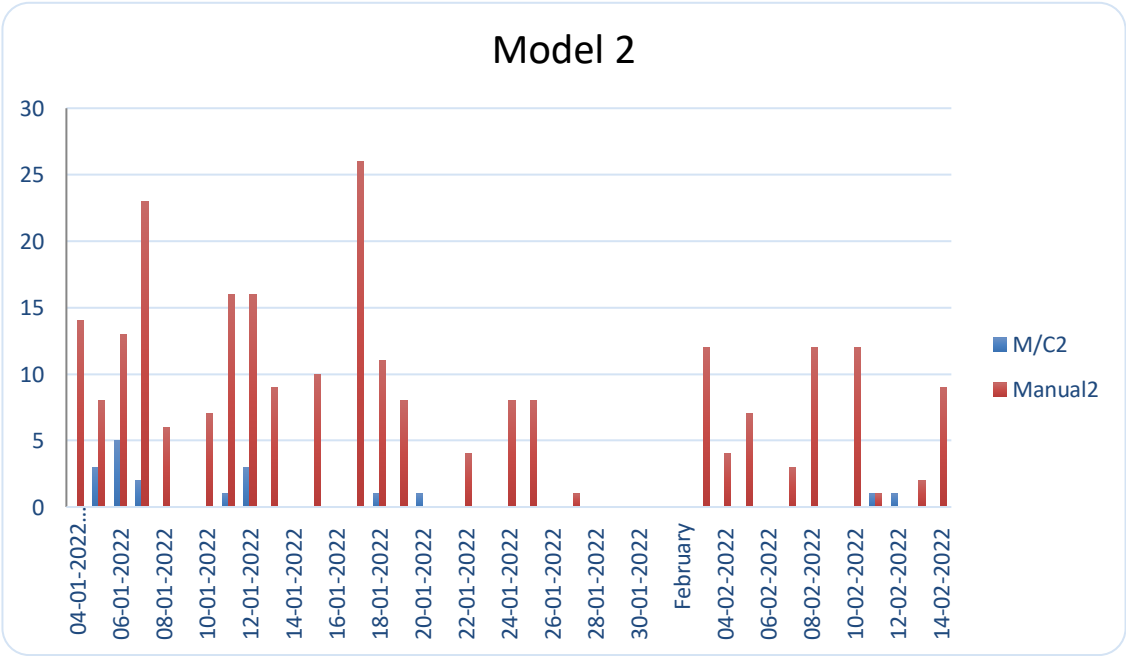

Fig. 8: Data of Model-2 vehicle Machine filling vs Manual filling

Figure 8 shows the data of model 2 vehicles from 4th January to 14th February 2022. Maximum of the vehicles are filled manually, due to the entrapment of air in the brake-system

From the data provided, maximum vehicles are manually filled. Each vehicle consumes 15 minutes of the production time. This even requires more manpower, for further analysis we have considered model 2 vehicles.

III. LITERATURE SURVEY

- J. H. Manley et al (1989) investigated and performed vacuum leak test on various fluids such as alcohol, acetone, ether, illuminating gas using metal vacuum system. It is interesting to observe that the desired results of the liquid corresponds to the order of both vapour pressure and viscosity.
- David G. Coleman et al(2011) investigated on the design of brake line bleeding device

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- **Siegrist Eric et al(2013) designed two-stage master brake cylinder, uses a primary and secondary pistons that displays various volumes in each stages providing a by-pass control valve that adjust the transition.**
- Chinonye Medline Maduka et al(2015) investigated Microbial growth in brake fluids bacterial growths in brake fluids were studied. Bacteria separated from allied brake fluids, out of 10 bacterial isolates six were gram negative and four were gram positive. Microorganisms in brake fluid could be the cause for clogged filters, brake lines, pads and other failures.
- F. Felli et al(2016) investigated on hydraulic brass components that were subjected to structural failure. These are caused by metallurgical defects in comparison with over-stresses in service which are easily identified.
- Malur Srinivasan et al(2016) investigated and compared fracture and fracture toughness of five different cast irons in consideration of their chemical composition, matrix microstructure, and graphite morphology.
- Navneet Sharma et al (2016) investigated on toxicity of brake oil it is composed of toxic glycols and ethers that are colourless, odourless with wide spread commercial use. The brake fluid is transmission fluid that composed of several glycols like ethylene glycol, diethylene glycol, polyethylene glycol and glycol ethers.
- **S. Nadanasabapathy et al(2020) investigated on analysis of fluid behavior inside the brake lines in non anti-lock braking system. The fluid particles inside the brake system are affected by the presence of turbulence which results in pulsation effect on the brake pedals. To prevent the turbulence inside the brake line of brake system, one may remodel the brake system design by decreasing the bends and modify with proper brake fluid.**
- Shakti Saurabh et al(2020) investigated on Cylinder Leak Analysis Detection using Cylinder Pressure. Significant impact was seen on cylinder pressures with different load conditions that captured cylinder health degradation due to leakage.
- V.S. Shaisundaram et al (2020) investigated the implementation of vacuum braking system in four-wheeler. The integral arrangement of vacuum tank for application of the brake, these are used for both light and heavy vehicles that are built with assist of hydraulic brake system. System operations of air braking system gave better results comparing them with vacuum brake system.
- Bhaskar pal et al(2021) investigated and designed structural Analysis of A Two-Wheeler Disc Brake to decrease the deformation and provide a base for improvement in thermal characteristics. Increase in the area of the slots could aid heat dissipation.

IV. METHODOLOGY

We considered two approaches to identify the root cause

- SMART analysis
- FAULT TREE analysis

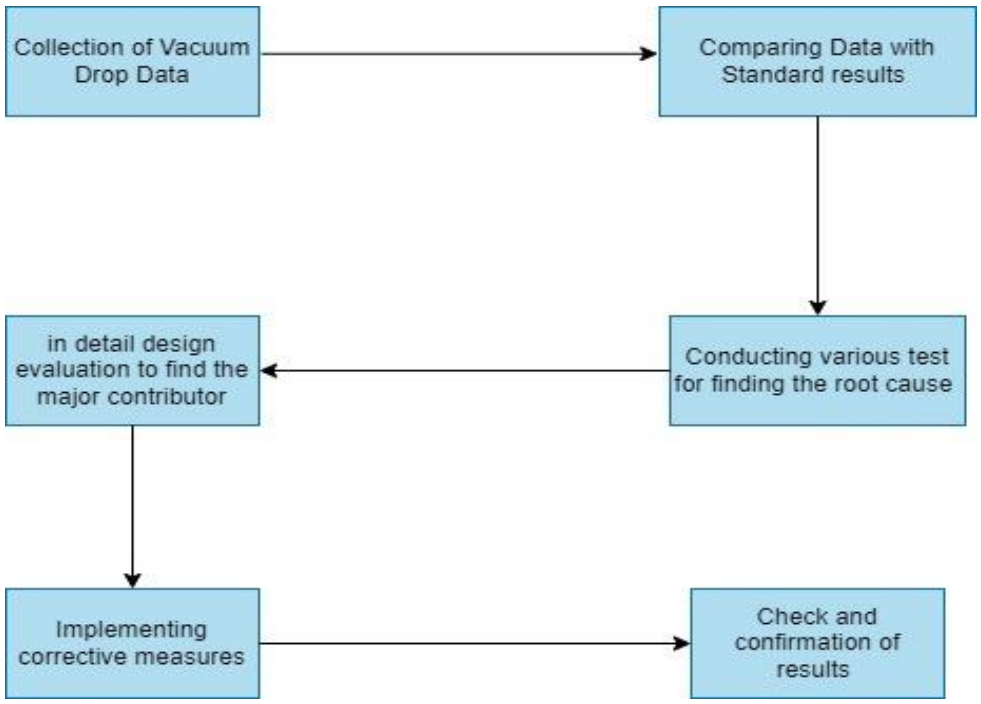

Fig. 9: Project Work Flow

A. Select the Target:

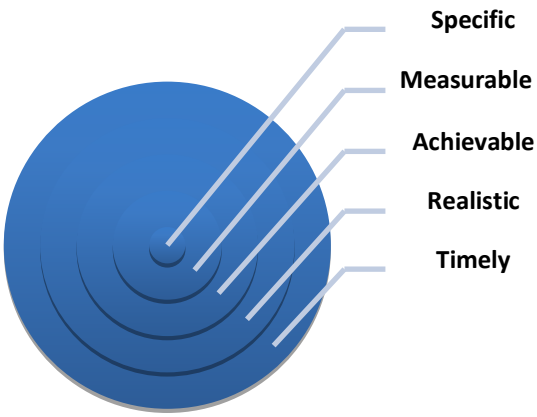

Fig. 10: SMART Analysis Approach

B. Specific:

- The target that I wanted to achieve is to regulate vacuum drop of vehicles and to make them filled automatically using brake oil filling machine.
- This can be achieved by performing different tests on the vehicle brake system.
- This has to be achieved in the time period of 3 months.
- This can decrease the company's production time and can improve the production rate 3 times and increases the profit rate to the company.

C. Measurable:

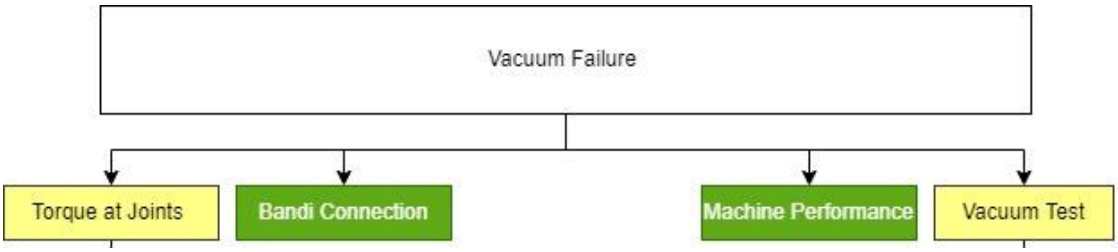

Fig. 11: Fault Tree Analysis for initial stage

- Two vehicles need to be considered for the analysis on the brake system. Individual analysis must be performed on each brake assembly.
- The fault tree analysis explains that these four can be the contributors for the vacuum drop in the brake system. Bandi connection and machine performance are arranged according to the standards that are checked. Other two that are torque at joints and vacuum test in brake system can be the reason behind the vacuum drop failure

D. Achievable:

- This can be achieved by performing the torque test and vacuum drop test on the brake system of the vehicles individually.
- The other method to achieve is to consider only the brake assembly of vehicles brake cable and to perform the tests on each joint to identify the problem accurately.

E. Realistic:

- 8% of vehicles are machine filled so we can confirm that the goal is realistic, and it is reachable only when we identify the major contributor to the problem in the brake system of an electric vehicle.
- Torque analysis and vacuum drop test on the brake assemblies can be performed within 60 days.

F. Timely:

- Within 3 months, we can perform torque test, vacuum drop test, and design analysis on the vehicle's brake system and can record the observations after implementation of changes in the brake system.

V. EXPERIMENTATION

To perform experiment, I have considered the Fault Tree analysis where I understood that the trouble shooters that can be are joints and vacuum leak at joints. In order for confirmation, I have performed torque test and vacuum drop test.

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In FTA the ones in green color have met the standards and the yellow are in testing stage.

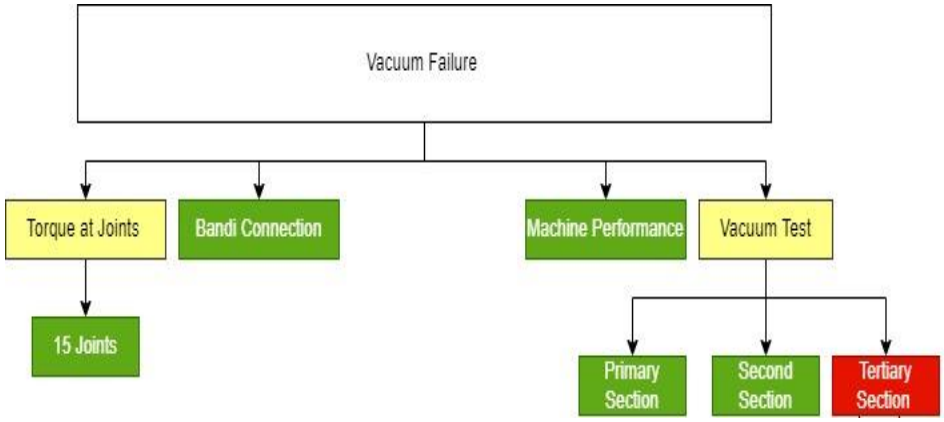

Fig. 12: Fault Tree Analysis for intermediate stage

Joints	Original Torque	Actual Torque
Reservoir hose clip1	4.5Nm	Torque Gun
Reservoir hose clip2	4.5Nm	Torque Gun
Master cylinder hose clip1	4.5Nm	Torque Gun
Master cylinder hose clip2	4.5Nm	Torque Gun
Master cylinder brake cable joint1	16Nm±0.8	15.2Nm
Master cylinder brake cable joint2	16Nm±0.8	15.2Nm
Brake hose joint	16Nm	15.2Nm
Front two-way connector (S1&S2)	16Nm	NP
Rare two-way connector	16Nm	NP
3-way connector LH	16Nm	15.47Nm
3-way connector RH	16Nm	NP
3-way connector F	16Nm	NP
Banjo Bolt	16Nm	Click Tool
Brake Drum LH	16Nm	NP
Brake Drum RH	16Nm	Click Tool

Table 2: Torque Test

- By torque test we can confirm that all the joints have enough torque which blocks and avoids the air leakage.

A. Vacuum Drop Test:

- We must perform the vacuum drop test on the complete brake cable to identify the leakage.
- Here in performing the vacuum drop test, brake cable has been divided into three major sections.
  - ✓ Primary section
  - ✓ Secondary section
  - ✓ Tertiary section
- Dividing the brake cable and performing vacuum drop test separately gives us easy and better identification of leakage at the joints.
- In primary section we consider cable from reservoir to front two-way connector. We can be able to identify the leakage at reservoir, cylinder joints, front wheel, and at the two-way connector.
- In secondary section we consider cable from front connector to rare connector.
- In tertiary section we consider cable from rare connector to the brake plates.

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- Three trails were considered for each section, to get appropriate results.

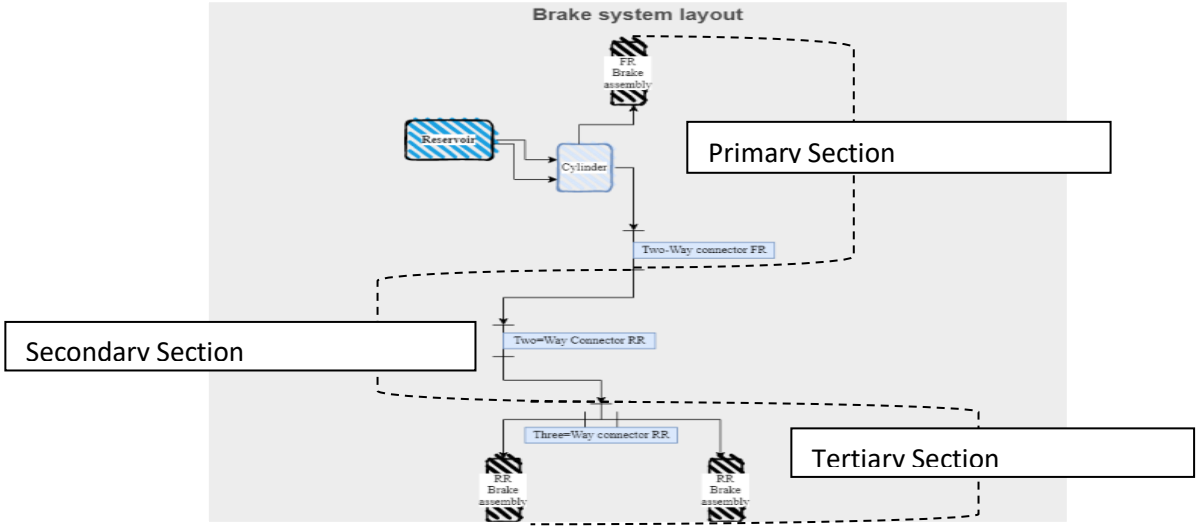

Fig. 13: brake bandi line with three sections

B. Primary Section:

	Trail 1 (mbar)	Trail 2 (mbar)	Trail 3 (mbar)
Rough Vacuum	2.85	1.01	1.01
Major Vacuum	0.67	1.01	0.66
Vacuum Drop	4.42	1.01	4.07

*****From the reading we can confirm that the primary section of Ev's brake cable maintains proper vacuum drop and the test results got passed as the vacuum drop is <3.10mbar±4.0

C. Secondary Section:

	Trail 1 (mbar)	Trail 2 (mbar)	Trail 3 (mbar)
Rough Vacuum	1.08	2.85	3.10
Major Vacuum	0.74	0.54	0.58
Vacuum Drop	1.90	1.39	2.09

*****From the reading we can confirm that the secondary section of Ev's brake cable maintains proper vacuum drop as the vacuum drop is <3.10mbar±4.0

D. Tertiary Section:

	Trail 1 (mbar)	Trail 2 (mbar)	Trail 3 (mbar)
Rough Vacuum	2.42	2.46	2.02
Major Vacuum	0.94	0.91	0.69
Vacuum Drop	20.18	18.59	21.12

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VACUUM DROP	METHOD OF FILLING
3.18	Machine OK
1.58	Machine OK
1.58	Machine OK
1.90	Machine OK
2.84	Machine OK
7.63	Machine OK
4.53	Machine OK
15	Manual
2.19	Machine OK
2.29	Machine OK
7.4	Machine OK
2.09	Machine OK
4.51	Machine OK
1.50	Machine OK
1.81	Machine OK
2.50	Machine OK
3.18	Machine OK
1.58	Machine OK
1.58	Machine OK
3.26	Machine OK
7.04	Machine OK
2.47	Machine OK
3.54	Machine OK
2.54	Machine OK
3.39	Machine OK
2.13	Machine OK
3.27	Machine OK
4.28	Machine OK
1.47	Machine OK
2.53	Machine OK
2.60	Machine OK
2.89	Machine OK
4.48	Machine OK
3.11	Machine OK
1.09	Machine OK
1.81	Machine OK
3.21	Machine OK
2.42	Machine OK
2.66	Machine OK

Table 3: Vacuum drop data and Method of filling for 43 vehicles after modification

*From the reading we can confirm that the tertiary section of Ev's brake cable failed to maintain the vacuum drop so further analysis can be focused on the tertiary section of the Ev brake cable.

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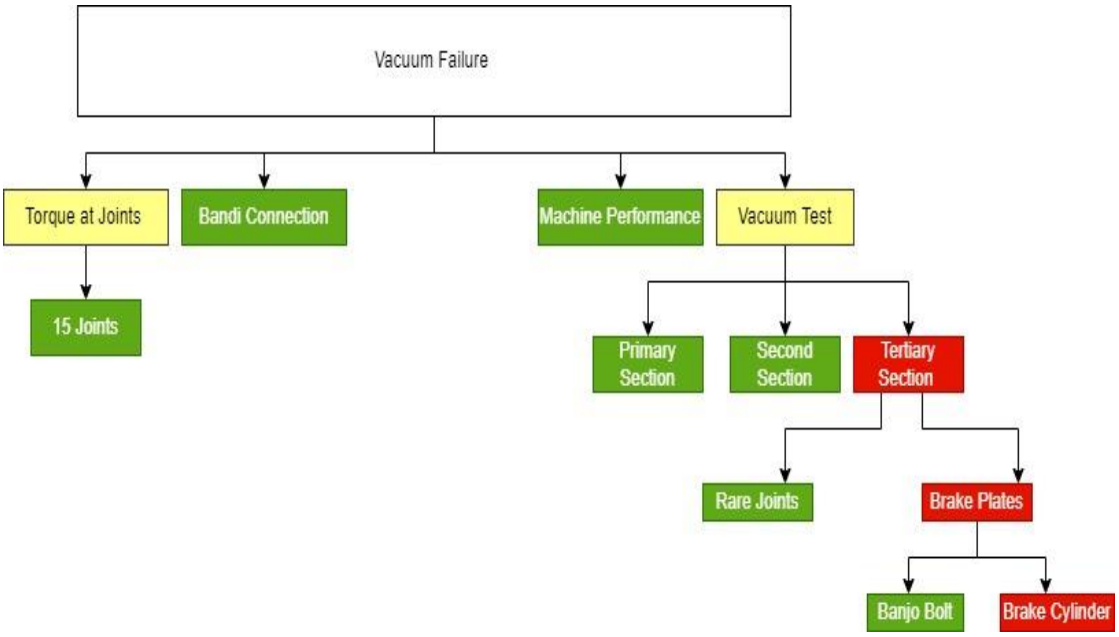

Fig. 14: Fault Tree Analysis for advance stage

- Tertiary section consists of rare connector and brake plates. Vacuum drop test was performed on the tertiary section by removing the brake plates.
- Noticed that brake cable alone is maintaining the vacuum drop. The main problem for vacuum drop might be brake plates. Detached the brake plates and dismantled the brake plates
- Opened the cylinder and identified the presence of grease in them.
- Compared other company's brake plate cylinder with the testing brake plate cylinder and noticed that instead of grease they have applied less viscous lubricant.

Inside the brake system cylinders there is a spring which acts as a piston. The piston expands due to the brake oil and further it expands the brake lining which generates friction on the wheels, here the application of grease provides us the lubrication to the spring to avoid the damage on the cylinders. Worn piston seals made out of rubber will wear out and become brittle due to age. A lip cut on seal will allow fluid to leak past the pistons. Poor brake response sign it's time for a replacement. A leaking wheel cylinder compromises the braking power of your vehicle. Grease acts as lubricant is to reduce friction and wear of material here the supplier company is using syntheso glep 1 grease. This is typically used in the automotive industry as assembly grease for brake and clutch systems for linear motion in contact with brake fluids DOT 3, 4 and 5.1. Viscosity is the main property that we consider in the fluids. It defines the thickness of the fluid that is explains about the flow of fluid. Viscosity is the internal resisting force in between the layers of fluid. Grease is more viscous when compare with oil. Therefore, when grease is applied in the cylinder, the holes were blocked due to the grease and the air leakage test performed at supplier end is different comparing with ours, they are passing the air through the cylinders at 6bar-10bar of pressure which in return pushes the grease to settle inside the holes. At our end we are performing the vacuum test where the grease cannot be sucked out of holes as we use less pressure comparatively.

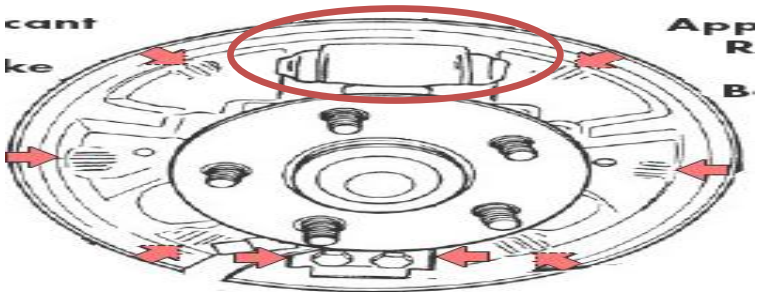

Fig. 15: Brake Plate

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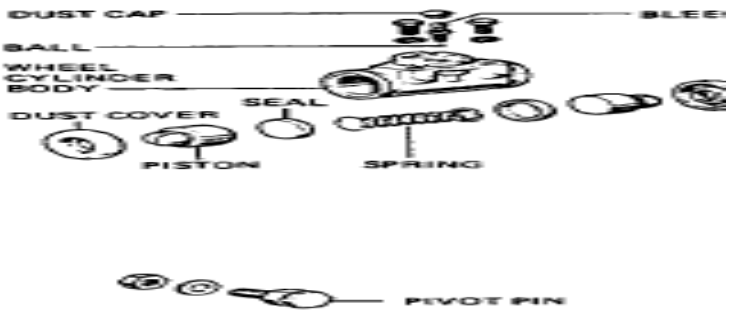

Fig. 16: Brake cylinder parts

VI. RESULT AND DISCUSSION

Grease is observed in the inner walls of the cylinder. This can be one of the reasons for the vacuum drop count. When the machine sucks the air to create vacuum in the brake system, the grease in the cylinders is blocking the holes so there the machine identifies the air inside the brake system which results in high vacuum drop. To confirm the root cause, we have ordered 40 brake plates from the supplier which doesn't contain any grease in them. Brake plates assembled in Ev's and the result attained within the vacuum drop limits and the vehicle got machine OK.

VII. CONFIRMATION OF RESULTS

After the approval of the DCR, Vacuum drop test was performed on the 40 samples. The acceptable limit is 4.0mbar, when test was performed, we noticed that vehicles brake performance was good at 6mbar, 8mbar, 10mbar, and 12mbar the results in the table shows that almost all vehicles have passed the test.

Figure 17 explains that the percentage of machine ok vehicles are more comparing with manual filling vehicles

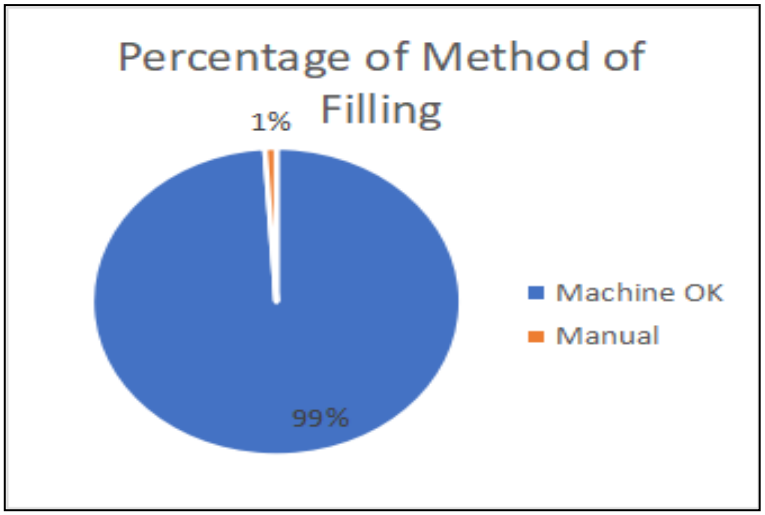

Fig 17: Percentage of Method of filling after modifications

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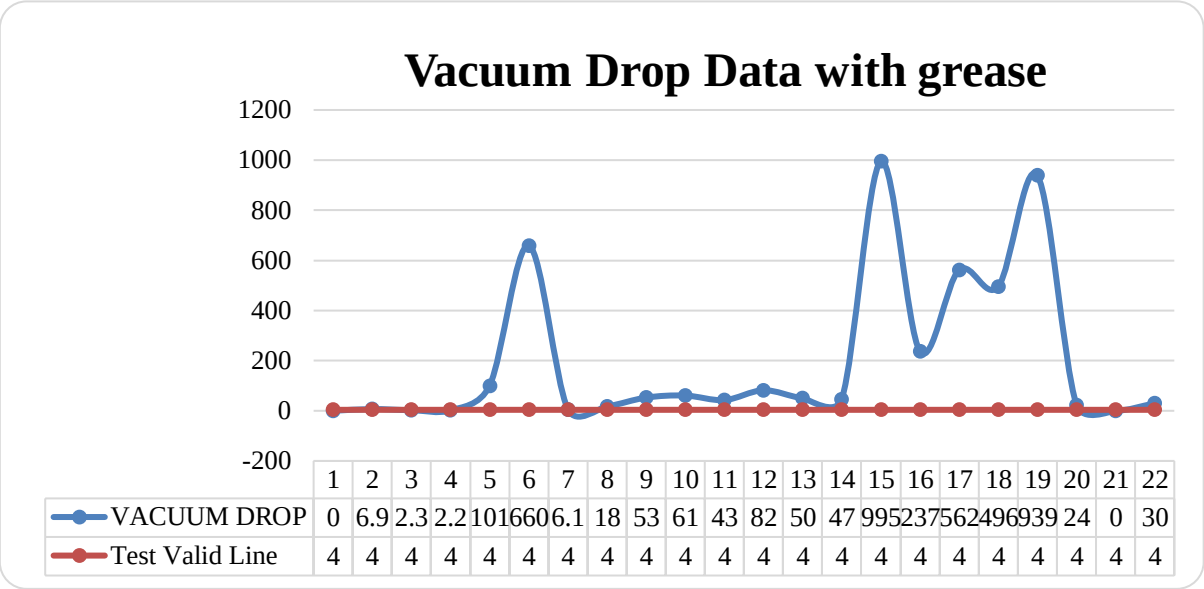
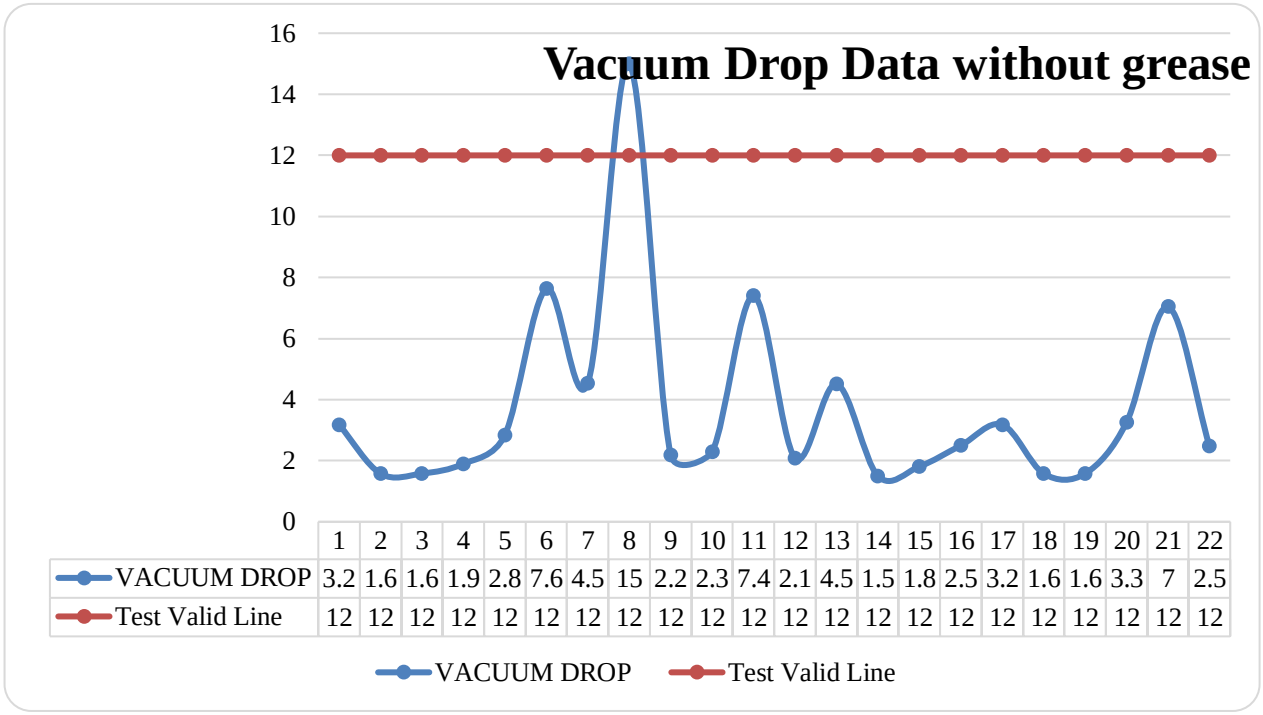


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
VACUUM DROP	0	6.9	2.3	2.2	101	660	6.1	18	53	61	43	82	50	47	995	237	562	496	939	24	0	30
Test Valid Line	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Fig 18: the variance in the vacuum drop before removal of grease from the brake cylinder



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
VACUUM DROP	3.2	1.6	1.6	1.9	2.8	7.6	4.5	15	2.2	2.3	7.4	2.1	4.5	1.5	1.8	2.5	3.2	1.6	1.6	3.3	7	2.5
Test Valid Line	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

Fig. 19: shows the regulation in vacuum drop after removal of grease from the cylinders

*when test was performed, we noticed that vehicles brake performance was good at 6mbar, 8mbar, 10mbar, and 12mbar, so parameters has been changed.

VIII. CONCLUSION

Viscosity plays important role in fluids, Dot 3 fluid was used for performing the analysis on brake system of an electric vehicle. We have identified grease inside the cylinder which is more viscous when compared with DOT 3 oil. Through vacuum drop test we confirmed that grease inside the cylinder is the major contributor for the blockage of air in the brake system. Below graphs show the difference in vacuum drop of vehicles. Due to the presence of grease in brake system, vehicles have observed major vacuum leak and brake sponginess. Removal of air from the brake system after filling it with brake oil consumes 15 minutes of production time, comparing with machine filling. Almost all the vehicles have passed the vacuum drop test after removal of grease from the brake cylinders. The 40 samples gave good results that improved 3 times productivity of the company.

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