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Quality Improvement Through Root Cause Investigation of Brake Spongy Defect And Kaizen Technique

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ABSTRACT
Brake spongy defect was a major defect detected in function inspection line, plant - 2 of Toyota Kirloskar Motors Pvt. Ltd. It is a phenomenon of soft feeling and more free play of brake pedal. Manual testing of relay and brake fluid level sensor in cars were consuming unnecessary time. Therefore, testers were required to assess their functionality. Studies have been carried out on brake squeal, effect of brake faults on vehicle dynamics, vibration analysis on brake pad, effect of brake hose fluid consumption on pedal feel, etc. Investigations on the brake spongy defect, relay tester used to analyze relays in cars and brake fluid level sensor tester used to analyze brake fluid level sensor in cars have not been reported. Therefore, the objectives of the project work were identification of root causes of brake spongy defect, development of relay tester circuit and brake fluid level sensor tester circuit.
Data analysis followed by study of brake system assembly processes and brake fluid filling process were carried out. Root cause analysis tools namely Fish bone diagram, Reality charting, Inter-relationship diagram (ID), Current Reality Tree (CRT) were used as problem solving tools. The results obtained from these tools were compared and the best tool was selected. Actual root causes were determined after further discussions. In order to develop tester circuits, basics of relays and brake fluid level sensor were studied thoroughly and multiple circuits were developed. These circuits were compared and optimized.
Brake pedal low, brake line blockage, tightening defects, member wrong judgment, excess clearance between brake pad and rotor, excess clearance between brake shoe and brake drum were the root causes of brake spongy defect. Verification of brake pedal position before fluid filling, cleaning of brake tubes by blowing air, calibration of torque wrenches before the start of first shift, holding the brake tubes in position while assembling, use of a digital force measurement gauge during inspection of brake pedal, clearance of 0.3094 mm between brake pad and rotor, clearance of 1.3179 mm between brake shoe and brake drum were the counter measures. It was estimated that brake spongy defect reduced by 93% after the implementation of these counter measures. Relay tester and brake fluid level sensor tester were successfully implemented. It was estimated that the investigation time reduced by 8.4 minutes by the implementation of relay tester and root cause investigation related to brake system became much easier and considerably faster by the implementation of brake fluid level sensor tester.
Keywords: Quality, Data, Current Reality Tree, Inter-relationship

INTRODUCTION
Brake pedal spongy is a soft feeling and more free play of brake pedal when it is operated by the driver. In other words, when the driver applies force to the brake pedal the driver feels less resistance and more movement from the brake pedal than the driver expectation. So instead of a smooth and

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coordinated braking effort, the driver must compensate for the difference between the expected and actual brake pedal feel. Since the phenomenon is a deviation from normal vehicle performance, it is a major defect affecting the braking performance of a vehicle. It is observed in plant 2 that produces Etios and Corolla passenger cars. Root Cause Analysis (RCA) is the process of identifying causal factors using a structured approach with techniques designed to provide a focus for identifying and resolving problems. Tools that assist groups or individuals in identifying the root causes of problems are known as root cause analysis tools. Every failure happens for a number of reasons. There is a definite progression of actions and consequences that lead to a failure. Root Cause Analysis is a step-by-step method that leads to the discovery of faults or root cause.
During Root cause investigation of defects related to electrical system of cars it is necessary to verify the functioning of relays. It is possible to verify relay by swapping it with another relay of same size present in the car. After this is done, if the problem is rectified, it can be concluded that the problem was with the relay. If the problem still exists, it can be concluded that the relay is properly functioning and further investigation of the problem has to be carried out. In the former case, a new relay is required to be brought from parts storage place which is far away from the investigation department and assemble it in the circuit. Therefore, this approach consumes unnecessary idle time. The latter case would lead to forgetting to put back the relay from where it was taken and make things further worse. Also, according to Toyota production System it is not recommended to make changes to a system which is already correct. Manual testing of brake fluid level sensor consumes unnecessary time. Therefore, development of relay tester and brake fluid level sensor tester is a Kaizen activity.

LITERATURE REVIEW

H Straky et al. [1] investigated the influence of faults in the braking system on the dynamic vehicle behaviour and the steering inputs of the driver required to keep the vehicle on the desired course. Simulation of the vehicle dynamics together with the real hydraulic brake system was carried out. From the analysis, it was shown that small faults like brake-fluid loss (leakage) or air-blisters in the hydraulic subsystem of the brake system have a negligible effect on the vehicle dynamics, comparable to the effects of changes in road surfaces or a small shifting of the center-of-gravity of the vehicle. These influences are subconsciously corrected on the vehicle path without attributing to brake system faults. Such faults remain undetected and entire brake circuit failure occurs consequently. Therefore, it was concluded that such small faults should be detected early to warn the driver.
Ibrahim Ahmed et al. [2-4] analyzed automotive drum brake squeal using complex Eigen value methods. The results of Finite Element Analysis showed that changing the contact stiffness of the drum-lining interface play an important role in the occurrence of the squeal. Moreover, decreasing the lining coefficient of friction would decrease the occurrence of the squeal. It showed also that both the frequency separation between two systems modes due to static coupling and their associated mode shapes play an important role in mode merging. It was noted that squeals are most likely to occur when the eigenvectors and Eigen values of the brake drum and shoes are close to the coupled vibration frequency to confirm that the coupling between different modes was necessary to form instabilities.The results confirmed that the eigenvectors of the leading and trailing brake shoes are independent from each other with the same natural frequency.
S Oberst et al. [5] carried out design of experiments using a noise dynamometer to determine the influence of geometrical parameters (namely, the number and location of slots) of brake pads on brake squeal noise. The experimental results were evaluated with a noise index and ranked for warm and cold brake stops. These data were analyzed using statistical descriptors based on population distributions, and a correlation analysis, to gain greater insight into the functional dependency between the time-averaged friction co- efficient as the input and the peak sound pressure level data as the output quantity. The correlation analysis between the time-averaged friction coefficient and

peak sound pressure data was performed by applying a semblance analysis and a joint recurrence quantification analysis. Linear measures were compared with complexity measures (nonlinear) based on statistics from the underlying joint recurrence plots. Results showed that linear measures cannot be used to rank the noise performance of the four test pad configurations. On the other hand, the ranking of the noise performance of the test pad configurations based on the noise index agrees with that based on nonlinear measures: the higher the nonlinearity between the time-averaged friction coefficient and peak sound pressure, the worse the squeal. These results highlighted the nonlinear character of brake squeal and indicate the potential of using nonlinear statistical analysis tools to analyse disc brake squeal .

O.P.Singh et al. [6] analyzed the failure of Brake drum, brake panel and brake drum liner during high-g braking on spoke wheels of a motorcycle. The brake drum and the panel were found to have seized during high speed brake applications. Excessive wear on the drum liner made of cast iron was also observed. Metallurgical analysis (chemical analysis, hardness test and microstructure analysis) of the liner revealed that excessive wear on the liner was not due to any change in material properties. Hence, further steps were taken to investigate the problem. An experimental testing methodology was developed to simulate these failures. For the same material, testing conditions, and design specifications of cast and spoke wheels, no failure was observed in the cast wheels. This unusual failure was further investigated using three-dimensional steady state finite element analysis (FEA) of both cast and spoke wheels. The methodology adopted for determining the thermal and structural boundary conditions have been described in detail. Energy balance methodology was employed to determine the heat flux values on the drum liner. The structural boundary conditions are determined experimentally and validated with FEA. The predicted temperature from FEA for cast and spoke wheels compares reasonably well with the experiments. It was found that the failure of the brake system in the spoke wheels was due to excessive thermal expansion of the brake panel and the drum beyond the specified limit. An optimum range of labyrinth clearance between the brake drum and the brake panel was recommended for the brake system of cast and spoke wheels.

Y.K.Chang et al. [7] established a numerical model for the prediction of brake judder due to wear and rust. The numerical model simulated the variation of disc thickness in the time domain. It was found that variations in the thickness of brake discs caused by wear and rust were the main reason for brake judder.

T.Yildiz et al. [8] carried out stress analysis of ventilated brake discs using Finite element method. Three different ventilated brake discs, the cross drilled disc, the cross-slotted disc, and the cross-slotted with a side groove disc, were manufactured, and their braking force performances were investigated experimentally together with a solid disc. Stress analyses were subsequently performed by the finite element method. Analyses results showed that the maximum stress generations were formed on the ventilated discs in comparison to the solid disc. However, these comparisons indicate that the application of varying force distributions along brake pads reduces the stresses on ventilated discs by 8.8% to 19.1%.

Naji et al. [9] **studied** the brake fad on drum brakes. Since drum brake components are fully enclosed inside the brake assembly, they are subjected to comparatively higher temperature than disc brakes. High temperature of the drum brake shoe may cause brake fade and eventually lose effectiveness. Fading is the result of too much heat build-up within the drum.

Paolo Castelini et al. [10] carried out vibration and acoustic analysis of brake pads for quality control. Two procedures were used for the damage detection of brake pads presenting two kinds of defects, i.e. cracks and braking material detachments. Both the procedures were based on the monitoring of the pad structural resonances that changes in presence of defects. The first procedure employed a Laser Doppler Vibrometer (LDV) for the measurement of the vibration velocity of the pad forced into vibration by means of an impact hammer. The second one, instead, used a system based on four microphone probe developed by SenSound and called SenQC system since was made for quality control. Both the techniques allowed to recognize damaged pads from the good ones from a sample of 37 elements. The sensitivity of the procedure to environment temperature was also studied, since the structural resonance could be influenced by this parameter. The sensitivity analysis to temperature was performed by using the LDV technique and by repeating the measurement on four different pads (two good and two damaged). The temperature was varied from 15 to 30°C with a resolution of 2°C in order to monitor the complete range of the environmental temperature that can be reached in working conditions in the production line.

Saeed Abu Alyazeed Albatlan [11] investigated the effect of fitting a brake pipe with different inner diameters to each wheel at the rear axle on the brake performance.

Theoretical analysis and road tests were conducted and applied on a Fiat 128 vehicle to investigate the changes in brake efficiency and brake force balance. The theoretical and experimental results showed the improvement of the car brake efficiency and the brake balance when fitting a brake pipe with the same inner diameter for each rear wheel.

David Antanaitis et al [12] studied automotive brake hose fluid consumption characteristics and its effects on brake system pedal feel. The paper introduced the basic construction of automotive brake hoses, the test methodologies and test results used to quantify brake hose fluid consumption under various operating conditions, and it illustrated the influence of hose performance at the vehicle-level using simple analyses on an example race track-capable sports car.

Aliabadi et al. [13] performed stress analysis by FEM to the crimped portion of hydraulic pressure brake hose in order to promote the development of the automobile hoses more efficiently.

T.K.Bera et al. [14] studied an antilock braking system using an on–off control strategy to maintain the wheel slip within a predefined range. A modelling technique called bond graph was used to integrate models in different energy domains and control systems. The bond graph model of the integrated vehicle dynamic system was developed in a modular and hierarchical modelling environment and is simulated to evaluate the performance of the ABS system under various operating conditions.

Ali Belhocine et al. [15] analysed the thermal behaviour of the full and ventilated brake discs of the vehicles using computing code ANSYS. The numerical simulation for the coupled transient thermal field and stress field was carried out by sequentially thermal- structural coupled method based on ANSYS to evaluate the stress fields and of deformations which are established in the disc and the contact pressure on the pads.

Ahmed M. El-Garhy et al [16] proposed a Fuzzy Logic based Life-Extending Control (FLEC) system for increasing the service life of the ABS. FLEC achieved significant improvement in service life by the trade-off between satisfactory dynamic performance and safe operation. The proposed FLEC incorporated structural damage model of the ABS. The model utilized the dynamic behaviour of the ABS and predicted the wear rates of the brake pads/disc.Based on the predicted wear rates, the proposed fuzzy logic controller modified its control strategy on-line to keep safe operation leading to increase in service time of the ABS.

Thee et al. [17] patented a computerized relay tester which comprises a bar code reader, a test circuit for determining an actual value of an operational characteristic of the relay, and a memory for storing reference values for the operational characteristic for a plurality of relays. The test circuit is operative to automatically measure the actual voltage or current values at which “pickup” or “drop away” occurs in the relay under test, by sensing an inductive voltage “spike" caused by movement of the relay armature. Based on signals from the bar code reader, a reference value for the particular operational characteristic under test are retrieved from memory. The actual value is then compared with the reference value to determine whether the relay is functioning properly, and the relay tester outputs an indication of the operational state or condition of the relay.

Ledbetter et al [18] patented a mini-relay signal tester designed to simplify, speed up and test the operation of ‘mini’ or ‘reed’ relays which are suspected of intermittent failure. These types of relays are extensively used in memory and gate- array testing systems and their failure can cause the semiconductor devices being tested to be erroneously rejected. The relay tester dynamically

exercises the relay being tested by application of a square- wave input signal to its coil. The square wave input reference signal driving the relay coil is then compared to a square wave output 'test' signal which is generated by the contacts of the relay being tested. The signals are compared on a dual- trace oscilloscope. When difference between signals exceeds acceptable standards the relay is rejected.
It can be concluded from the above discussed literature review that studies have been carried out on brake squeal, effect of brake faults on vehicle dynamics, vibration analysis on brake pad, effect of brake hose fluid consumption on pedal feel, etc.However, no research have been done on Brake Spongy Defect. Patents for relay tester were found. One, to sense voltage spike caused by the armature movement and the other to simplify, speed up and test the operation of 'mini' or 'reed' relays which are suspected of intermittent failure. However, no relay tester used to test relays in cars was found patented.

PROJECT METHODOLOGY

The methodology adopted for the project work is as follows:

- Studying the working of hydraulic brake system. Understanding clearly brake spongy defect. Collection of defect data and its analysis.
- Studying and analyzing brake system evacuation and fluid filling process. Determining the effect of the process on the initial brake pedal travel. Determining any change points in the process that would cause brake spongy defect.
- Carefully observing and studying brake system assembly processes. Determining any change points in the process that would cause the brake spongy defect.
- Applying different Root Cause Analysis (RCA) tools in order to determine the actual root causes. Comparing and discussing the obtained results. Bench marking of the most appropriate tool. Determining actual root causes after further discussion and brain storming. Determining counter measures and implementing them. Ascertaining the effect of counter measures on the occurrence of defects.
- Developing different designs of relay tester circuit and brake fluid level sensor tester circuit. Selecting the most appropriate design.

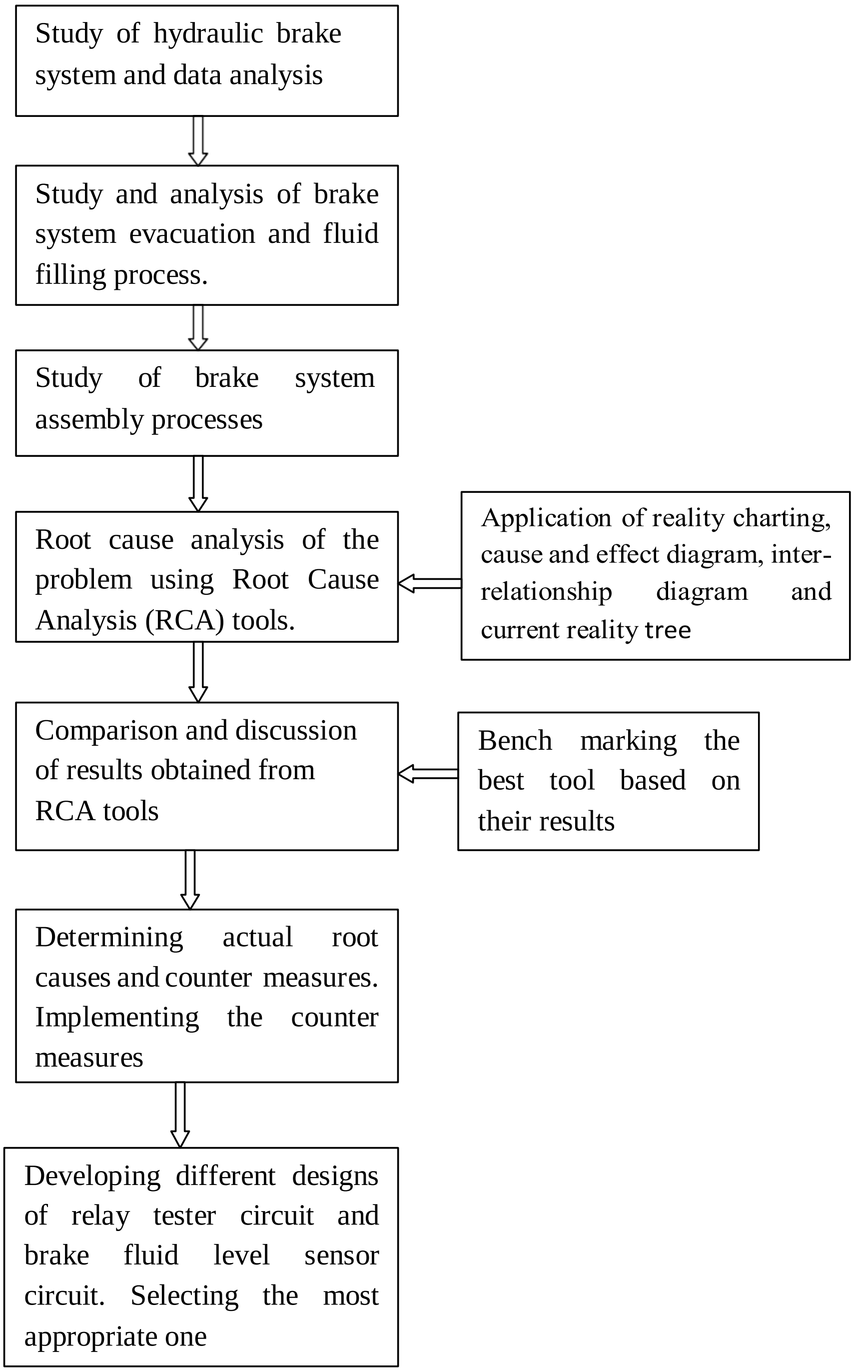

Figure 1: Project methodology

Determination of actual root causes of brake spongy defect and counter measures

As per the ranking of the root cause analysis tools used, Reality Charting was bench marked and selected as a reference for final discussion on the root causes. Reality charting provided eight root causes namely Brake pedal low, brake line blockage, improper gun to hose joint, damaged gun seal packing, tightening defects, excess clearance between brake pad and rotor, excess clearance between brake shoe and rotor and member wrong judgment. These possible causes are discussed one by one here.

1) Cause : Brake Pedal Low

During brake line evacuation and fluid filling process it was observed that the brake pedal were in

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low position. There was no any check point for this, or in other words before vacuum bleeding and fluid filling, brake pedal position verification was not being done. This may lead to improper brake line vacuuming and there is no any poke yoke system to indicate this. The technical reasons for this is as explained below with suitable sketch:

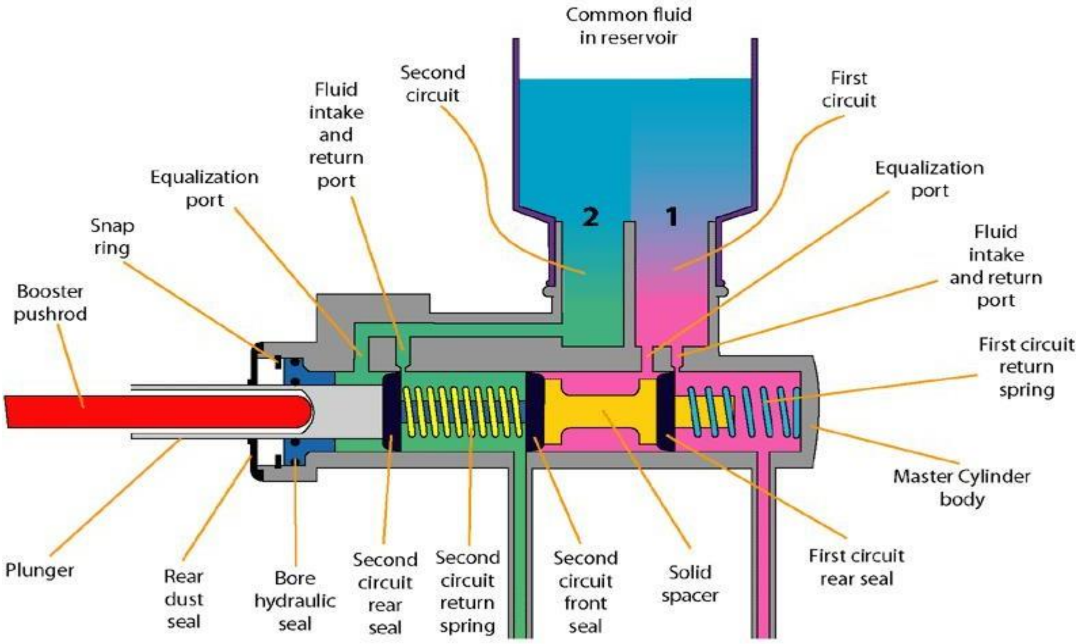

Figure 2: Brake master cylinder

When the brake pedal is in extreme up position, brake booster push rod is in a position such that the fluid intake and return ports for both front and rear ends are open. If, brake pedal is in slightly depressed position, the brake booster push rod will slightly move forward and close the fluid intake and return ports or at least partially close them. This will lead to improper vacuuming of the brake line but it would not be indicated by the poke-yoke system because it only senses the vacuum pressure created inside the brake line for 40 secs but not the volume of space evacuated. The brake fluid reservoir attached to the master cylinder is connected to clutch master cylinder through a flexible hose. When the clutch pedal is in extreme upper position, the push rod remains in home position, due to which both inlet port and compensating port remains in open position. During vacuuming process, it creates vacuum pressure in all components since compensating port is in open position.

Counter measure: Before beginning the brake system evacuation and fluid fill process, the brake pedal position was verified. If it was in pressed position, then it was pulled back and kept in correct position.

2) Cause: Brake Line blockage

Blockage in brake line would lead to improper vacuuming which would not be indicated by the poke-yoke system of fluid filling equipment. This would lead to air in brake line and eventually brake spongy.

Counter measure: Before assembling the brake tubes, air was blown into it in order to clear out blockages if any.

3) Cause: Damaged Gun Seal Packing

Gun seal packing is used for sealing brake fluid reservoir so that vacuum pressure does not leak while creating vacuum. If brake fluid filling gun is not clamped properly to the brake fluid reservoir, leakage of vacuum pressure occurs. To detect this problem the mock model of reservoir is made

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by closing the three ports excluding to port and top port is used for placing brake fluid filling gun to check whether vacuum pressure drops or not after developing vacuum pressure inside the mock reservoir. If the pressure sensor detects the drop in vacuum pressure this indicates there is a problem in gun seal packings and it as to be replaced. This procedure has to be done prior to the beginning of every shift. Currently it is done only prior to the beginning of first shift. During fluid filling process if vacuum pressure leak occurs due to damage in gun seal packings the process gets aborted but it is time consuming to identify why the vacuum pressure has leaked. Therefore this mock model of reservoir helps in eliminating that by pro actively identifying the defect. But, since this abnormality is identified and resolved in fluid filling stage itself, this doesn't contribute to brake spongy defect. Therefore 'damaged gun seal packing' is not a root cause for brake spongy defect.

4) Cause: Improper gun to hose joint

Improper gun to hose joint will also lead to leak of vacuum pressure. In such cases fluid filling process will abort and the problem is identified and rectified by the maintenance department. However, this leads to line stop and loss of production time. To prevent this from occurring, vacuum test is done using mock model of reservoir at the beginning of first shift as mentioned in the previous section. If the equipment shows vacuum error, then the maintenance department checks gun top seal gun to hose joint, etc and rectifies if any problem is found. Therefore 'improper gun to hose joint' is not a root cause for brake spongy defect.

5) Cause: Tightening Defects

Defects can arise due to non-standard tightening procedures. During brake system assembly process in trim line and chassis line 1, different joints are tightened using torque wrenches as shown in Table 1.

In order to tighten these different joints appropriate torque wrenches are to be used so that the target torque is achieved. If there is any variation, it can be only within the specified range. Torque below the lower limit of 13 Nm would cause leaks in the joints and torque above the upper limit of 23 Nm would damage the threads and would consequently lead to fluid leak. To ensure this, quality department once in every two hours checks the assembly torque using digital torque wrench. If torque was not achieving the target that particular joint was tightened. Succeeding and preceding five vehicles are checked for torque in the same joint. If the torque is not achieved for these vehicles, torque wrenches are recalibrated.

Improper mating of two brake tubes occurs if they are not assembled at zero degree to the horizontal plane. Low torque may result if torque is applied without click sound confirmation. Cross threads lead to thread damage and this in turn leads to fluid leak. In such cases required torque can be applied using torque wrench. But the wrong thread goes undetected.

Counter measure: Torque wrenches were calibrated everyday to a target torque of 18N- mm.Rough handling of torque wrenches to be avoided. Brake tubes must be held in position while assembling them in such a way that their axes are parallel to each other. Initially hand tightening was carried out until two to three threads are visible and then tightened by wrench.

Table 1: Tightening torque for different joints

Joint name	Target in Nm	Range in Nm
Front left brake tube to ABS actuator	18	13-23
Front right brake tube to ABS actuator	18	13-23
Rear left brake tube to ABS actuator	18	13-23
Rear right brake tube to ABS actuator	18	13-23
Two brake tubes from ABS actuator to brake master cylinder	18	13-23
Two rear brake tubes to 2 way	18	13-23
Two Flexible hose connecting to front brake tubes	18	13-23
Two Flexible hoses connecting to rear brake tubes	18	13-23
Clutch tube to CMC side	18	13-23
Clutch tube to Accumulator bottom	18	13-23
Clutch tube to Accumulator LH side	18	13-23

6) Cause: Member Wrong Judgment

Brake spongy defect data was compared with offline repair data and it was found that 8 vehicles were wrongly detected as having spongy brake pedal. This is because the pedal inspection is manual and the training level and perception of pedal feel varies from one member to the other.

A defective vehicle was taken to R & D and it was found that the brake line had air content less than the specification limit. Clearance between brake pad and rotor was optimim.Clearance between brake shoe and brake drum was also optimum. Digital pedal force measurement gauge was used to check the pedal force and it was close to the standard, i.e. 50N .Therefore it was clear that the brake pedal of the vehicle was normal and it was misjudged as having spongy defect. Errors as

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explained above happen due to insufficient training given to team members and such manual inspections can be done accurately only by experience.

Counter measure: Force measurement gauge was used to quantitatively measure brake sponginess in the function inspection department. If the force applied read less than 45N, then the vehicle was declared as having brake spongy defect.

7) Cause: Excess clearance between brake pad and rotor

As per the company standard, brake pedal free play should not exceed 3 mm. In order to limit the Brake pedal free play at 3mm it was required to find out optimum clearance between brake pad and rotor.

When a force of F_d is applied on the brake pedal, the force output received at the brake pedal assembly is greater than the applied force and is equal to the applied force multiplied the lever ratio of brake pedal assembly.

Work done on the brake pedal, W_d = Force applied on the brake pedal (F_d) × Displacement of brake pedal

$W=X\times3=3X$ N-mm (6)

Output force of brake pedal assembly is equal to force applied on brake pedal multiplied by the lever ratio.

$F_{bp}= (F_d) \times (L_2/L_1)$ (7)

$= 3X \times (440/145)$

$= 3.0344X$ (8)

Output force of brake pedal assembly acts on the master cylinder hydraulic piston. Pressure = force/area (9)

Pressure acting on master cylinder piston, $P_{MC}= F_{bp}/A_{mc}$ Master cylinder diameter, D_{mc}= 25.44 mm

Area of master cylinder $A_{mc} = (\pi/4) \times (D_{mc})^2$

$= (\pi/4) \times (25.4)^2= 506.7075$ mm^2

$P_{MC}= F_{bp}/A_{mc} = (3.0344X)/506.7075 = (5.988 \times 10^{-3}X)$ N/mm^2

Applying Pascal’s law

$P_{MC}=P_{cal}=P_{WC} = (5.988 \times 10^{-3}X)$ N/mm^2

Pressure on the caliper, $P_{cal} = F_{cal}/A_{cal}$ Diameter of caliper cylinder, D_{cal} = 45.4 mm Area of caliper cylinder, $A_{cal}= (\pi/4) \times (45.4)^2$

$= 1618.8313$ mm^2

$F_{cal}= P_{cal} \times A_{cal} = (5.988 \times 10^{-3}X)$ N/mm$^2\times$ 1618.8313 N= (9.6935X) N

$W_{cal}= F_{cal}$ × distance the brake pad moved

(9.6935X) × displacement of brake pad (10)

Comparing equation (6) and (10)

3X= (9.6935X)) × displacement of brake pad Therefore, displacement of brake pad = 0.3094 mm

Counter measure: The clearance between brake pad and rotor should be less than 0.3094 mm

8) Cause: Excess clearance between brake shoe and brake drum

During assembling rear brake drum the clearance between brake shoe and brake drum is adjusted. Improper alignment of brake shoe and brake drum causes more clearance between the brake shoe and brake drum. This results in more distance for the brake shoe to touch the brake drum. If the brake shoe does not touch the brake drum it causes more brake pedal free play. Due to this brake spongy occurs.

As per the company standard, brake pedal free play should not exceed 3 mm. In order to limit the Brake pedal free play at 3mm it is required to find out optimum clearance between brake shoe and brake drum.

When a force of F_d is applied on the brake pedal, the force output received at the brake pedal assembly is greater than the applied force and is equal to the applied force multiplied the lever

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ratio of brake pedal assembly.
Work done on the brake pedal,

W_{d} = Force applied on the brake pedal (F_d) × Displacement of brake pedal
W=X×3=3X N-mm (11)
$P_{MC}=P_{cal}=P_{WC}$ = (5.988 × 10^{-3}X) N/mm^2
In rear brake drum
Pressure acting on rear drum wheel cylinder, $P_{wc} = F_{wc}/A_{wc}$ Area of rear drum wheel cylinder, A_{wc}= (π/4) × (D_{wc})^2
= (π/4) × (22.22)2
= 380.1327 mm^2
$F_{wc} = P_{wc} \times A_{wc}$ = (5.988 × 10^{-3}X) × 380.1327= (2.2762X) N $F_{cal}= P_{cal} \times A_{cal}$ = (5.988 × 10^{-3}X) × 1618.8313 N= (9.6935X) N
$W_{wc}= F_{wc}$ × displacement of brake shoe
= (2.2762X) N × displacement of brake shoe (12)
Comparing equation (11) and (12)
3X= (2.2762X) N × displacement of brake shoe Therefore, displacement of brake shoe = 1.3179mm
Counter measure: The clearance between brake shoe and brake drum should be less than 1.3179 mm Defect Trend after implementing the counter measures

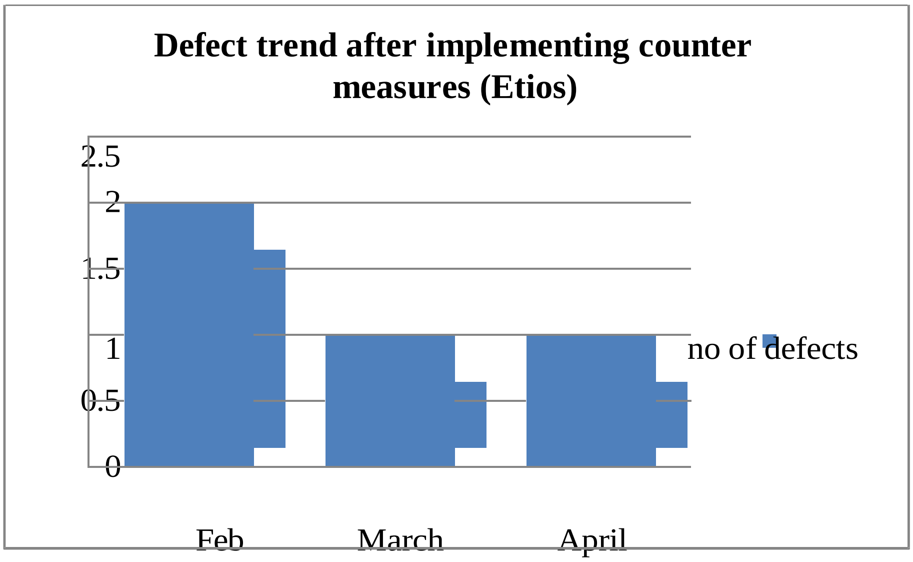

Figure 3: Defect trend after implementing counter measures

Counter measures were implemented and it was found that the occurrence of defects reduced. A check point was introduced during brake line evacuation and fluid fill process in order to check the position of brake pedal before filling the fluid. The brake pedal had to be pulled back to its original position if it was low. A digital force measurement gauge was used while inspecting brake pedal so that wrong judgment of the defect can be reduced. Members were educated about the consequences of rough handling of torque wrenches and improper assembly of brake tubes. Torque wrenches were calibrated daily before the beginning of first shift. Air gun was used to blow air into brake tubes at 4-5 Mpa before assembling it on to the vehicle.
The number of defects for Etios cars was 2, 1 and 1 in the month of February, March and April respectively. As for Corolla cars there was no any defects witnessed in these three months. The bar graph shows the percentage reduction of defects in Etios cars. Average number of defects in the year

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2012 was considered against average number of defects in 2013 for the months of February, March and April. It is found that the defects reduced by 93 %.

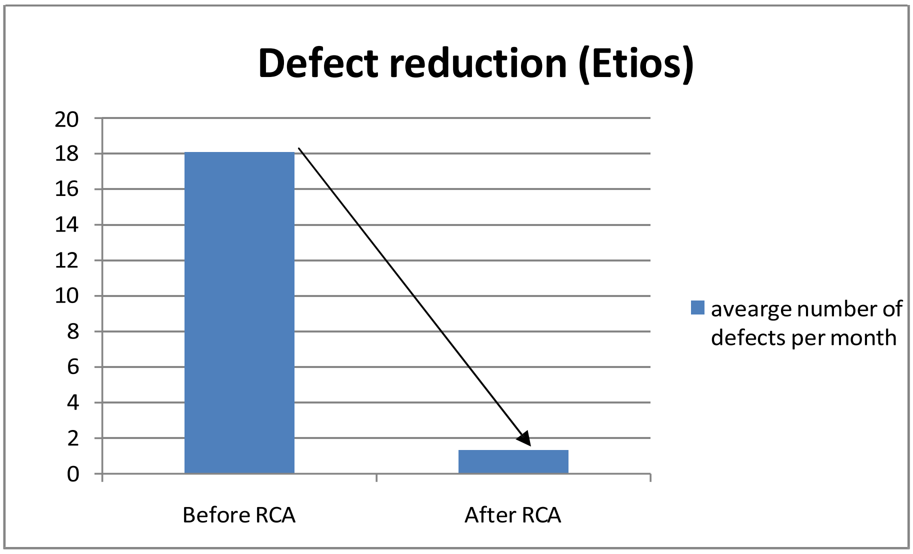

Figure 4: Reduction of defects

Advantages of using relay tester
1) Time saved:
Without relay tester the only recommended method to test relay is to bring a fresh working relay from parts storage area and replace it with the suspected relay.
Let time spent on this activity be t
t = 2(distance between investigation area and parts storage area/normal walking speed of human)
$t = 2(d/s)$
d = 350 metres = 0.35 km s = 5 km/hr
Therefore,
$t = 2(0.35/5) = 0.14$ hr $= 0.14\times60 = 8.4$ minutes.
2) More than one size of relay can be tested.
3) The new method of testing relay is standardised and the operating steps is as below:
- Remove key from the key cylinder.
- Connect positive of relay checker to positive terminal of the 12v DC battery.
- Connect negative of relay checker to negative terminal of the 12v DC battery.
- Insert the relay to be checked in relay checker.
- Switch on the relay checker.
- Check the lamp glow. If the lamp glows relay is in working condition, otherwise the relay has to be replaced.

CONCLUSION
Quality improvement activities were done in quality inspection department of Toyota Kirloskar Motors Private Ltd, by carrying out root cause investigation of brake spongy defect and development of tester circuits for functionality testing of relays and brake fluid level sensor. The root causes for brake spongy defect were found out and counter measures were determined and implemented. The following conclusions were arrived at:
- Brake pedal position analysis before starting the brake line evacuation and fluid filling process was recommended and was implemented. If the pedal was low, it was suggested to pull back to the correct position.

➢ In order to prevent tightening defects, torque wrenches were calibrated daily. Rough handling of torque wrenches was avoided. Brake tubes were held in position while assembling them in such a way that their axes are parallel to each other. Initially hand tightening was carried until two to three threads are visible and then tightened by wrench.

➢ Compressed air was blown into the brake tubes before assembling. This will prevent brake line blockage and thus facilitate proper vacuuming.

➢ Optimum clearance between brake pad and rotor required in order to prevent brake spongy defect was estimated to be 0.3094 mm. Optimum clearance between brake shoe and brake drum required in order to prevent brake spongy defect was estimated to be 1.3179 mm.

➢ Occurrence of brake spongy defect reduced by 93% after the implementation of counter measures. Relay tester and brake fluid level tester were developed and implemented. Investigation time reduced by 8.4 minutes by the implementation of relay tester and root cause investigation related to brake system became much easier and considerably faster by the introduction of brake fluid level sensor tester.

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