

First Pass Yield Improvement by Eliminating Base Plug Leakage in Feed Pump Manufacturing

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Abstract: Base plug leakage caused by the inefficient tightening of the base plug in the feed pump of a diesel engine is the common problem in the field. The leakage of fuel is mainly due to the inefficient sealing of copper washer which is used to seal base plug and feed pump housing. A case study has been done in the industry to reduce the rejection of feed pump due to leakage of fuel through base plug in diesel engine. In this paper an effort is made to identify the factors which cause the leakage of fuel by using why-why analysis. It is found that some significant factors are the main cause in the feed pump assembly causing the major problem. Hence a trial on the present design is made and suggested the improved design by providing an undercut in copper washer landing area of the base plug.

Keywords: Feed pump, Base plug, Copper washer, torque meter.

1. Introduction

Diesel engines have changed dramatically over recent decades in order to provide higher power density, better fuel efficiency, and greater reliability. Clean, uncontaminated lubrication oil is a key to maximum fuel system performance and longevity for modern diesel engines. Without high quality of assembly and sealing system, leakage of fuel can lead to costly repairs and engine downtime. Due to leakage of diesel oil from base plug will cause more usage of fuel which in turn would cause lesser mileage of the vehicle. More important than the new engines that are being designed to get better fuel efficiency and control emissions proper assembly of sub-components have to be made to any vehicle's success.

2. Literature Survey

2.1 Feed Pump

Feed pump is a frequently essential component in heavy diesel engines or other internal combustion engine device, rail road stock, aircraft, marine, motor cycles. Many engines do not require any fuel pump at all, requiring only gravity to feed fuel from the fuel tank through a line or hose to the engine. In applications where there is an insufficient height difference or a large distance between the fuel tank and the fuel-injection pump, a pre-supply pump (Bosch type designation FP) is fitted.

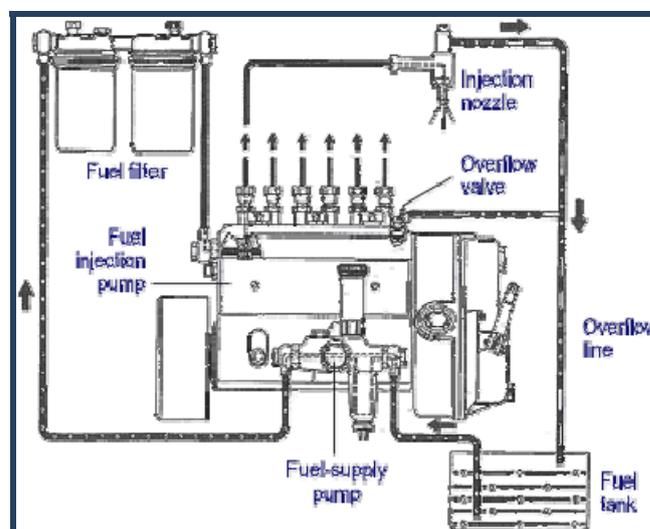


Figure 1: System Overview

This is normally flange mounted on the in-line fuel-injection pump. Depending on the conditions in which the engine is to be used and the specifics of the engine design, various fuel line arrangements are required. Feed pump is normally flange mounted on the in-line fuel-injection pump. Depending on the conditions in which the engine is to be used and the specifics of the engine design, various fuel line arrangements are required. If the fuel filter is located in the immediate vicinity of the engine, the heat radiated from the engine can cause bubbles to form in the fuel lines. In order to prevent this, the fuel is made to circulate through the fuel-injection pump's fuel gallery so as to cool the pump. With this line arrangement, the excess fuel flows through the overflow valve and the return line back to the fuel tank.

2.2 Base plug leakage

The Base plug leakage mainly happens due to the improper tightening of the base plug. Copper washer plays an important role in sealing between base plug and feed pump housing. Without proper tightening of the base plug it leads to fuel leakage which affects the performance of the vehicle.

Presence of Base plug leakages causes the following issues in a smoothly running vehicle:

1. The base plug leakage will cause more usage of fuel which in turn would cause lesser mileage of the vehicle
2. Due to leakage, the pressure at which the fuel needs to be transmitted to the fuel injection pump will vary, which in turn would cause immense pollution and emission from the vehicle.
3. Failure in the feed pump results in dead cylinder and immense power loss.
4. Leakage would result in less suction pressure, which would imply less fuel supply, this would cause more air in the cylinder than fuel resulting in lean burning.
5. One of the most important features of a diesel system is that it provides air at high pressure which is hindered due to the pressure of leakage.

The above mentioned reasons are the major causes for a customer to come up with complaints regarding the Base plug leakage in a fuel injection pump. The company (BOSCH) has received complaints from customers/clients on a global forum, requiring immediate rectification or eliminating of this particular leakage.

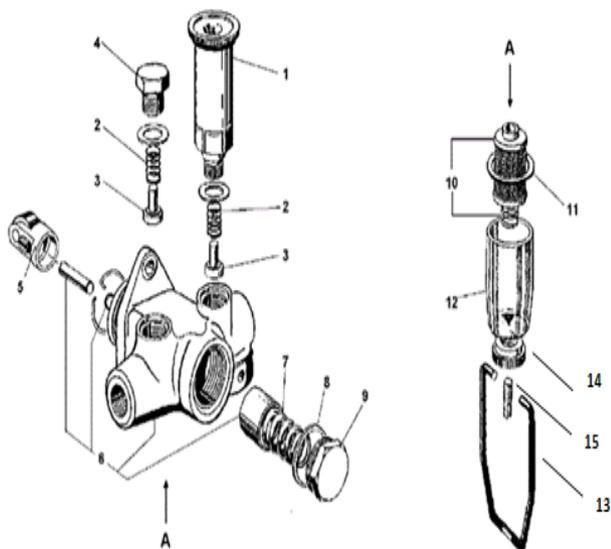


Figure 2: Exploded view of feed pump

Components of feed pump

- | | |
|-----------------------|-------------------------|
| 1. Hand primer | 9. Base plug |
| 2. Spring | 10. Plastic filter mesh |
| 3. Nylon valve | 11. Rubber Gasket |
| 4. Fitting nut | 12. Filter bowl |
| 5. Roller tappet body | 13. Wire clip |
| 6. Sliding pin | 14. Round nut |
| 7. Compression spring | 15. Headless screw |
| 8. Copper washer | |



Figure 3: Base plug & Base plug leakage

2.3 Why-Why analysis for root cause:

The 5-Why method of root cause analysis requires you to question how the sequential causes of a failure event arose and identify the cause-effect failure path. ‘Why’ is asked to find each preceding trigger until we supposedly arrive at the root cause of the incident. Unfortunately it is easy to arrive at the wrong conclusion. A Why question can be answered with multiple answers, and unless there is evidence that indicates which answer is right, you will most likely have the wrong failure path. You can improve your odds of using the 5-Why method correctly if you adopt some simple rules and practices.

The 5-Why method helps to determine the cause-effect relationships in a problem or a failure event. It can be used whenever the real cause of a problem or situation is not clear. Using the 5-Whys is a simple way to try solving a stated problem without a large detailed investigation requiring many resources. When problems involve human factors this method is the least stressful on participants. It is one of the simplest investigation tools easily completed without statistical analysis. Also known as a Why Tree, it is supposedly a simple form of root cause analysis. By repeatedly asking the question, ‘Why?’ you peel away layers of issues and symptoms that can lead to the root cause. Most obvious explanations have yet more underlying problems. But it is never certain that you have found the root cause unless there is real evidence to confirm it. You start with a statement of the situation and ask why it occurred. You then turn the answer to the first question into a second Why question. The next answer becomes the third Why question and so on. By refusing to be satisfied with each answer you increase the odds of finding the underlying root cause of the event. Though this technique is called ‘5-Whys’, five is a rule of thumb. You may ask more or less Whys before finding the root of a problem (there is a school of thought that 7 ‘whys’ is better; that 5 ‘whys’ is not enough to uncover the real latent truth that initiated the event). Implied in the Five Whys root cause analysis tool, though not often stated openly, is the use of a cause and effect tree-known as a Why Tree. The method is also called Fault Tree Analysis. It is best to build the Why Tree first so that the interactions of causes can be seen. Sometimes only one cause sets off an event, other times multiple causes are necessary to produce an effect. The Why Tree for even a simple problem can grow huge, with numerous cause-effect branches.

Note how each answer becomes the next question. It is vital that each Why question uses the previous answer because that creates a clear and irrefutable link between them. Only if questions and answers are linked is there certainty that an effect was due to the stated cause and thus the failure path from the event to its root is sure.

3. Problem Definition

The Base plug leakage causes so many issues in a smoothly running vehicle. So that performance of the fuel injection pump will drastically get reduced. Due to leakage it will affect the functioning of the feed pump. Failure in the feed pump would result in dead cylinder and immense power loss.

The loss of power and dead cylinder put together would result in loss of fuel economy largely. Leakage would result in less suction pressure, which would imply less fuel supply.

4. Methodology

4.1 Cause & Effect Diagram (ISHIKAWA DIAGRAM)

The Fish bone diagram, designed after observation as well as hands on experience at the plant depicting the major and minor causes for current problem at hand (Base plug leakage) is as shown below.

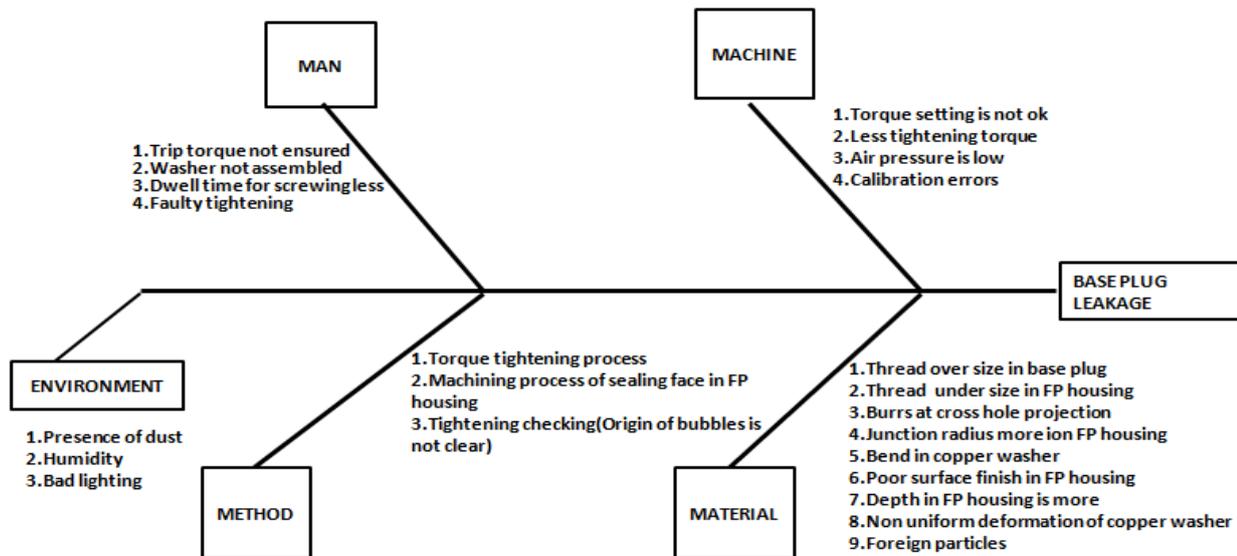


Figure 4: Fish bone diagram for base plug leakage

The Fishbone diagram has been of immense help and a very important tool used to reach to the root causes of the problems have at hand. The causes were easily found upon observation which not only helped me to reach to the conclusion as to what the causes were but which were the major causes and which were the minor causes.

4.2 Validation of Causes

Validation of causes implies determination of the significance of various causes after the identification of these causes. It is important for me to determine the most significant and the less significant causes so that more time can be spent on the ones that affect the process ultimately than wasting time on less significant causes. Identifying systematic failure mechanisms that cause significant yield loss is a primary yield ramp activity. This task is rendered especially difficult for products made with sub-one-hundred nanometer technologies due to the subtle designed-process interactions that create transient systematic failure mechanisms. The impact of this difficulty is felt in prolonged ramp cycles and missed market windows for advanced products. A volume diagnostics methodology proposed earlier was seen to resolve this difficulty with highly accurate localization of systematic failures within the design

and with an order of magnitude faster time to results compared to traditional approaches. This work presents a few examples of the success of the design-centric volume diagnostics approach in identifying subtle design-process interactions that lead to systematic yield loss. It also demonstrates the statistical validation of the process changes introduced to eliminate this yield loss.

Table 5: Validation of causes

CAUSE DESCRIPTION	SPECIFICATIONS	ACTUAL VALUE	REMARKS
Torque setting NOT OK	80 N-m	82 N-m	Calibration is done once every shift NOT SIGNIFICANT
Air pressure is LOW	5 bar	7 bar	Should not be less than 5 bar NOT SIGNIFICANT
Washer not assembled	-	-	NOT SIGNIFICANT
Dwell time for screwing is less	3 sec	3 sec	NOT SIGNIFICANT
Thread oversize in Base plug	M26*1.5	M26*1.5	1 out of 4 is faulty SIGNIFICANT
Thread under size in FP housing	M26*1.5	M26*1.5	NOT SIGNIFICANT
Junction radius is more in FP housing	0.3	0.3	Change the radius to 0.2 MOST SIGNIFICANT
Bend in copper washer	-	-	NOT SIGNIFICANT
Poor surface finish in FP housing	-	Every component inspected has burrs	MOST SIGNIFICANT
Depth in FP housing is more	1.2 mm to 1.8 mm	All copper washers were in the range specified	To keep the copper washer above the housing to ensure no damage to housing when torque is applied i.e, housing depth less than 1mm MOST SIGNIFICANT
Gap between copper washer and housing	-	-	NOT SIGNIFICANT
Foreign particles	-	-	NOT SIGNIFICANT

4.3 Why-Why analysis:

The table:5 showing the significant and insignificant causes for the base plug leakage. The root cause for the problem is found by doing Why-Why analysis and corrective action is taken.

4.3.1 LESS TIGHTENING TORQUE

• WHY? Insufficient air supply and pressure

The required pressure of 5 bars from the source is not achieved. This pressure is checked (Validated) using a torque verifying meter. Any pressure of less than 5 bars directly results in ineffective sealing due to non-uniform deformation of the copper washer.

• WHY? Direct supply from its source

The drop in pressure is mainly attributed to the supply lines from the pressure source. We know that pressure drops as it travels through distance. This fall in pressure has a direct implication on the sealing required in terms of air gaps that may result due to uneven deformation of the copper washer due to less pressure supplied to the torque meter.

• WHY? No intermediate air storage device/equipment/calibrator

The air is supplied directly from the source to the torque meter. This has been the construction of the plant layout which has been used for a long period of time. Earlier the base plug leakage could be (was) negligible but as the organization strives to achieve better efficiency in terms of

mileage there is always the need to establish a change in the layout of the plant.

• WHY? Old method/Conventional method used

The root cause is identified as the use of traditional method. It proposes a need to change the nature in which the air is supplied from the source to the torque meter.

a) **Root Cause:** Old method/conventional method used

b) **Corrective Action:** Intermediate compressed air storage tank

c) **Reason:** Intermediate air storage device to ensure no pressure loss occurs in the supply of air to the torque meter. The air when supplied to the torque meter through a compressed air storage tank ensures no drop in pressure of the air. This is very advantageous to the setup as it uses air at the required pressure. The storage tank also fits the plant layout without making it clumsy. When tested, the pressure achieved at the torque meter was around 7 bars and the deformation of the Cu washer was more than satisfactory.

d) This resulted in tight sealing at the washer-feed pump surface interface ensuring no leakage from the base plug.

e) **Type of Action:** Process change at BOSCH

4.3.2 FP Housing Corner Radius R0.3 is More

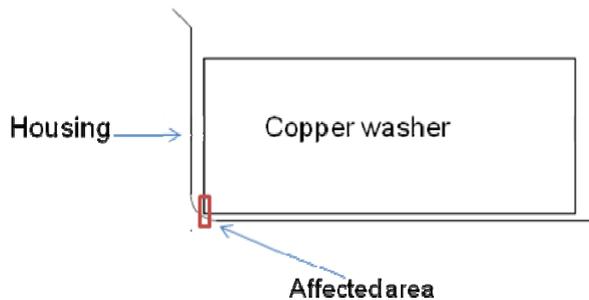


Figure 6: Copper washer alignment with FP housing

- **WHY? Washer seating at the area R0.3 does not provide effective sealing**

The feed pump corner radius is 0.3mm. The radius induces a gap when the copper washer is assembled to the feed pump. The gap created leads to ineffective sealing at the junction.

- **WHY? R0.3 creates uneven holding of Cu washer**

The uneven holding of Cu washer is mainly due to the fabrication specifications that have been over a period of time. The Cu washer dimensions are a standard therefore, need to validate the corner radius of the feed pump as a cause for the ineffective sealing.

- **WHY? Chances of R0.3 exceeding due to radius tool wear out**

The manufacturing specification with a tool tip of 0.3 mm is used. The amount of feed pumps manufactured with this tool in a day is 1500. There is a very high probability that over the course of manufacturing the pumps in a day the tool tip may become blunt and fall outside the specifications required. This will further increase the corner radius to a value greater than 0.3 mm causing ineffective sealing.

- **WHY? Presently radius tip used is R0.15**

The casual analysis will estimate the present use of tool tip with a radius of 0.15mm as the root cause. It establishes the need to alter the tool tip radius of a lower value to eliminate leakage.

- a) **Root Cause:** FP housing corner radius tip used is R0.15
- b) **Corrective Action:** Using a tool radius tip of 0.10mm against 0.15mm
- c) **Reason:** A tool tip radius of 0.10mm will decrease the area at the washer seating location at the feed pump. The decreased area will ensure no air gaps are induced when the Cu washer is assembled. On supplying pressure to the torque meter a complete deformation of Cu washer is achieved. This seals the assembly by closing all the air gaps at the base plug region that are present when a tool tip radius of 0.15mm is used. Therefore, a tight seal is obtained eliminating all possible leakages.
- d) **Type of Action:** Design and manufacturing change at supplier (SS industries).

4.3.3 Poor Surface Finish at FP Housing Washer Seating Area

- **WHY? Circular burrs observed on seal face**

Circular burrs indicate the machining process used in manufacturing the component associated i.e., feed pump. Circular burrs are an outcome of machining process using cutting tools. Burrs are a part and parcel of machining process. Avoiding burrs can involve changing tools from time to time. In such a case, it increases the machining lead time.

- **WHY? Present machining process is turning with a single point cutting tool**

The machining process deployed for a long period of time is with the use of single point cutting tool. The use of single point cutting tool induces uneven pressure distributing during cutting resulting in machining defects.

- **WHY? Design/manufacturing requirement**

The root cause can be classified as the manufacturing and design requirement which is stated by the designers at the beginning. This process needs to be altered or changed for another process yielding better finish.

- a) **Root Cause:** Present machining process is turning with a single point cutting tool design/manufacturing requirement
- b) **Corrective Action:** Plunging operation against cutting operation
- c) **Reason:** The traditional method of using a single point cutting tool enforces manufacturing defects like burrs due to unequal pressure distribution during cutting. A manufacturing change in terms of plunging needed to be incorporated in the process. In plunging operation the entire surface is exposed to the cutting tool at the same time. The tool is exposed to larger and even surface area. This type of operation eliminates all possible burrs. Therefore ensures tight sealing at the interface eliminating leakages.
- d) **Type Of Action:** Manufacturing change at supplier

4.3.4 Washer Seating Depth in FP Housing Is More Than Cu Washer Thickness

- **WHY? FP housing depth dimension is 1+- 0.2 (i.e., 0.8mm to 1.2mm)**

The feed pump housing depth ranges from 0.8mm to 1.2mm. The depth ensures the seating of the Cu washer. Any change in depth of the region will affect the sealing with respect to the Cu washer.

- **WHY? Due to new tool depth maintained at max. side i.e., 1.2mm**

When a new tool is used, the dimension is always maintained at highest tolerance of 1.2mm. As the tool wears due to machining there is a change in the dimension. It increases the depth at the housing area. This increase the depth causes gaps resulting in leakage.

- **WHY? Cu washer thickness is 1+-0.1 (i.e., 1 to 1.1mm) where as FP housing dimension is 1.2mm leads to ineffective sealing**

The height of Cu washer is 1.1mm. When the depth of feed pump at the washer seating area is maintained at 1.2mm, it implies that the Cu washer will lie below the feed pump and when the torque is applied it directly falls on the feed pump instead of the washer thereby causing air gaps in the region resulting in leakage.

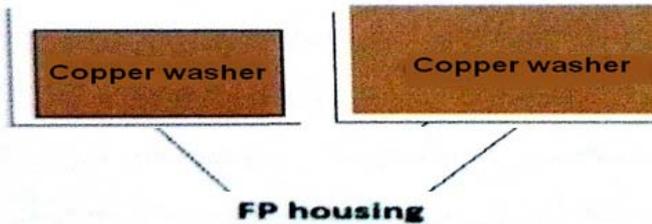


Figure 7: Change in height of copper washer

- a) **Root Cause:** Copper washer thickness is $1+0.1$ (i.e., 1 to 1.5mm) where as FP housing dimension is 1.2mm needs to ineffective sealing
- b) **Corrective Action:** Change depth in feed pump at Cu washer area to less than 1mm
- c) **Reason:** To ensure torque is applied completely on the copper washer and not on feed pump thereby ensuring uniform deformation of Cu washer. At the start of the manufacturing process the feed pump depth is maintained at 1.2mm. But over the course of manufacturing the depth may increase due to tool wear to a value above 1.2mm. When such a case is evident, the torque directly rests on the feed pump instead of the washer causing damage to the region. To avoid this damage, the feed pump depth should

be reduced to value below 1.1mm so that Cu washer is always at a height above that of the feed pump.
d) **Type of Action:** Design and manufacturing at supplier

4.4 Design Change in Base plug

By doing all the above continuous improvement process using Why-Why analysis, the copper washer deformation caused by the base plug is observed. The deformation which made on the copper washer was not uniformly distributed and we cannot tighten the base plug more than $80+20$ N-m, because it may leads to housing breakage or damage if it tightened further. So under these boundary conditions change in the design of copper washer landing area in the base plug to give a better and uniformly distributed deformation is made. Hence by doing this, the same amount of tightening torque is applied on copper washer, such that the reduced land area in base plug giving a cutting action on the copper washer and with more pressure making the copper washer to get bulged at the inner side of bore and getting uniformly sealed at the outer circumference area.

In the present design the area of contact is more so pressure is not uniformly get distributed on the copper washer, whereas in the proposed design by reducing the land area with the same amount of torque, pressure got uniformly distributed with a better sealing effect. So design change in copper washer landing area in the base plug is made and reduced the copper washer landing area by providing an undercut of 0.8mm.

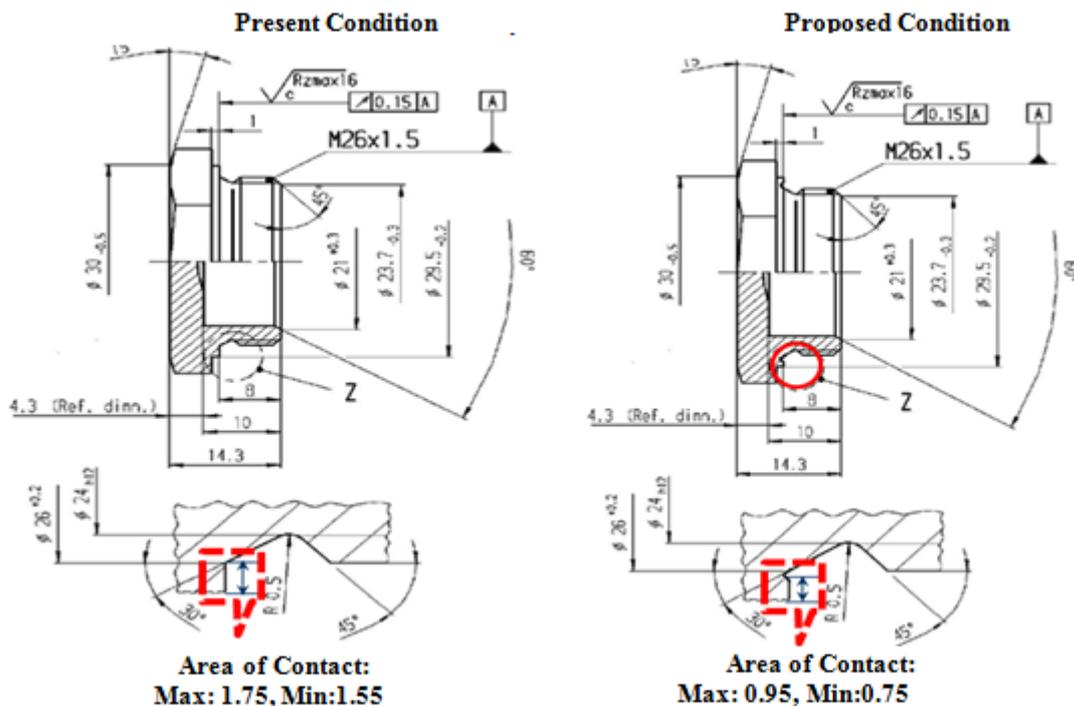


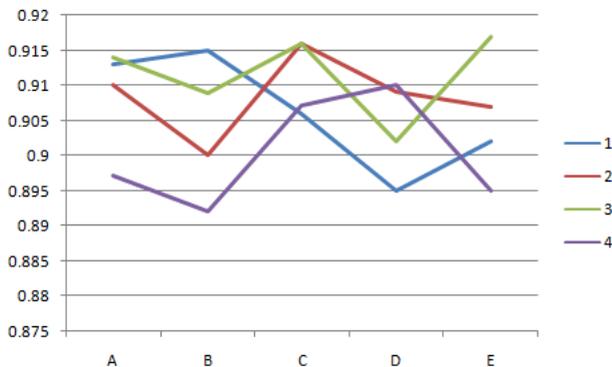
Figure 8: Present & Proposed base plug design

The above figure showing the present and proposed design changes in base plug, where in the proposed design an undercut of 0.8mm is made to give better deformation and to obtain good sealing effect by the copper washer.

Deformation observed at five respective points of four Copper washers by using Present base plug design, measured by dial stand.

Table 9: Deformation values of present design

Sl. no	A	B	C	D	E
1	0.913	0.915	0.906	0.895	0.902
2	0.91	0.9	0.916	0.909	0.907
3	0.914	0.909	0.916	0.902	0.917
4	0.897	0.892	0.907	0.91	0.895



Graph 10: Deformation distribution



Table 11: Deformation values of proposed design showing present base plug & deformed Cu washer

Deformation observed at five respective points of four Copper washers by using proposed base plug design, measured by dial stand.

Table 12: Deformation values of proposed design

Sl. no	A	B	C	D	E
1	0.865	0.867	0.865	0.862	0.86
2	0.86	0.862	0.865	0.863	0.86
3	0.862	0.86	0.864	0.865	0.865
4	0.865	0.867	0.862	0.86	0.868

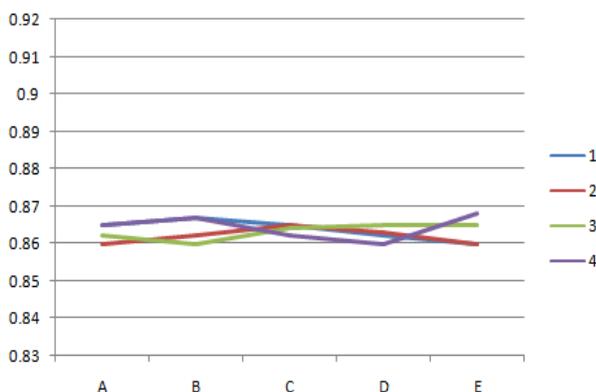


Figure 13: Deformation distribution

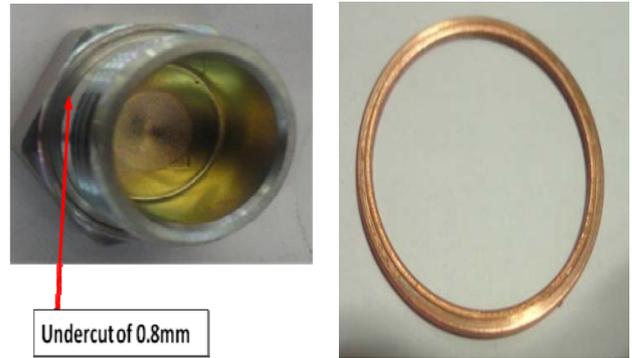


Figure 14: Showing proposed base plug & deformed Cu washer

5. Implementation and Result

The design change in base plug made the copper washer to deform uniformly and resulted in a better sealing effect. The undercut of 0.8mm on the copper washer landing area with the same 80+20 N-m tightening torque, gives uniform deformation on the copper washer.

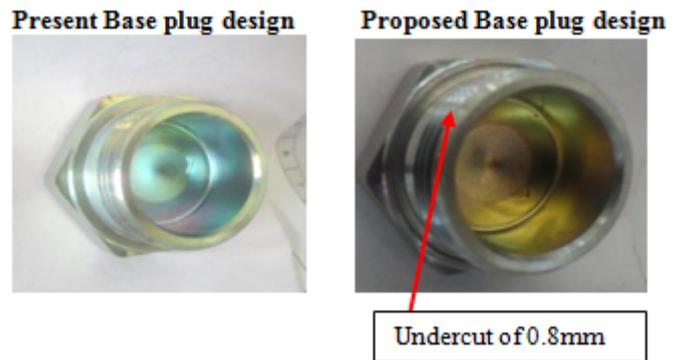


Figure 15: Present & Proposed base plug design

On implementing the proposed base plug design, the first pass yield is improved from 95% to 98% where scrap and rework is also reduced. Also base plug leakage is resolved with the better sealing effect.

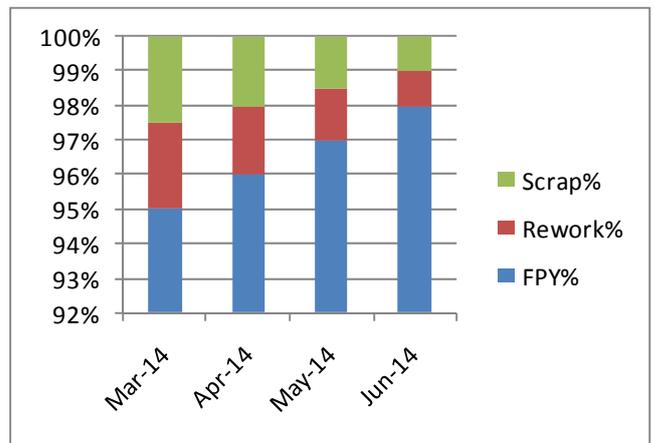


Figure 16: First pass yield improvement

6. Conclusion

On doing the Why-Why analysis the major root cause is found and respective action is taken to resolve it. The design change in plunger made the copper washer to get deforms uniformly and to provide a better sealing effect between base plug and feed pump housing with the same tightening torque of 80+-20 N-m. Also first pass yield is improved from 95% to 98% with the reduced scrap and rework.

7. Acknowledgment

I express my sincere gratitude to the management of **Bosch Ltd**, for giving me an opportunity to do my internship, here by acknowledge my sincere and heartfelt gratitude to my mentor **Mr. Sridhar G N, Deputy Manager, Manufacturing engineering Dept**, and all **members of feed pump Dept, Assembly Dept, and Quality Inspection Dept** of **plant #2** for all their assistance during my internship.

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