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OPTIMIZING RELIABILITY: "SOLUTIONS FOR EXTENDING ROLLER AND SHOE LIFESPAN IN COMMON RAIL FUEL INJECTION PUMPS"

Ramesh Veerasamy[*a]
[*a]RAMS Sheetmetal Engineering, Dandenong. Victoria, Australia
*** Corresponding author email address**: sales@ramssheetmetal.com.au

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Abstract
The objective of the paper to fulfill the customer requirement through quality, cost, delivery and service by the manufacturer. Never ending quality improvement is now recognized as essential for any organization. The objective of this project is to analyze, identify root cause, study and implement the change for a customer quality concern in hydraulic head, one of the parts in high pressure common rail fuel injection pump part. I attempt here to present the objective of the project a unique and workable approach to that method we have adopted. In spite of many improvements (DLC Coating) on the roller to improve the wear, TATA motors, one of the main customers of us is complaining on roller and shoe wear on the common rail fuel injection pump. The complaint recorded as 30 to 40IPTV considering the period of 24 MIS. This wear directly affects the working function of pump and finally leads to pump seizure. With the back ground i have taken up this project. We have planned to collect all the data about this complaint. Finally we the team had analyzed and identified the root cause and identified the scope of improvement to be done on Hydraulic head one of the fuel injection part where the roller has contact with this part in order to eliminate the roller and shoe wear. So the scope of my project will be fully based on analyzing the possible root cause, study possible changes, improvement in design, implement the change, validate and monitor the performance and analyze the future scope of work.

Keywords: Brainstorming, WHY-WHY analysis, Manufacturing feasibility analysis, Product design, Product development, Design reliability testing, wear level assessment.

1. Introduction

It is common knowledge that the “Diesel” is an economical long-lasting vehicle. But few people are aware of the fact that it was the fuel injection pump from Delphi, which finally put the diesel engine on the road. In a diesel engine the fuel is injected into the combustion chamber near top dead center, and ignition occurs spontaneously. The fuel injection system shown in the figure 1, therefore has to fulfill the following functions. In the realm of modern automotive engineering, the Common Rail Fuel Injection Pump stands as a cornerstone of efficient diesel engines, operating at the heart of power and performance. Within this intricate mechanism lie crucial components—rollers and shoes—fundamental to its functionality. However, the challenges of wear, stress, and degradation placed upon these components demand a constant quest for reliability optimization. The quest to extend the lifespan of rollers and shoes within Common Rail Fuel Injection Pumps is an on-going pursuit in the automotive industry. As these pumps play a pivotal role in delivering precise quantities of fuel at high pressure, their reliability is paramount for the engine's efficiency and longevity. Any degradation or malfunction of these components can significantly impact performance, fuel economy, and emissions. This exploration into optimizing reliability delves deep into the intricate world of fuel injection systems, particularly focusing on the innovative solutions geared towards extending the durability and lifespan of rollers and shoes. By addressing the challenges of wear, friction, and material fatigue, engineers and researchers aim to revolutionize the longevity and performance of this crucial component. The journey involves a multidisciplinary approach, incorporating advanced materials science, precision engineering, and cutting-edge technologies. From novel material compositions to innovative design strategies and advanced manufacturing techniques, a myriad of solutions is being explored to bolster the robustness and resilience of rollers and shoes within Common Rail Fuel Injection Pumps. This comprehensive endeavor not only aims to enhance the reliability of these essential components but also contributes significantly to the overall efficiency, sustainability, and reliability of diesel engines. Through this pursuit of longevity and reliability, the automotive industry seeks to push the boundaries of performance while ensuring longevity and sustainability in a rapidly evolving technological landscape. Join us on this journey as we unravel the strategies, advancements, and breakthroughs driving the evolution of reliability in Common Rail Fuel Injection Pumps, specifically focusing on the pivotal role played by rollers and shoes in shaping the future of automotive engineering.

Back ground and field data, One of the worst field quality problems faced in supply of fuel injection system is roller and Shoe Scuffing failure in the High pressure system. Unless other failures, when we faced the roller and shoe failure we need to change the entire common rail system

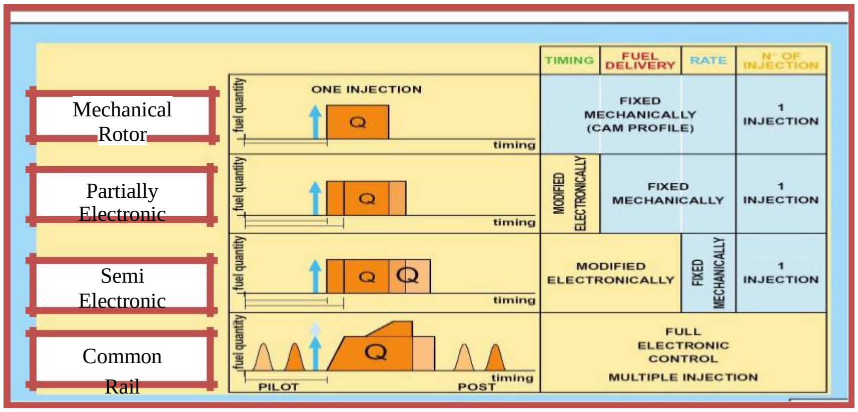

Fig. 1 Comparison with conventional injection systems

. This roller and shoe failure leads to following problems

- Free replacement of Change of Complete Common rail system when the pump failed in warranty period.
- Increase in high free warranty replacement cost
- Leads to severe customer dissatisfaction

The following Data shows the number of failures faced in each variety of pumps. Number of failures will be measured in terms of Incidence per Thousand Vehicle (IPTV). This IPTV is broadly classified as 3MIS, 6MIS, 12MIS, 18MIS, 24MIS where MIS stands for Monthly Incidence. These data's are collected from the field quality problem reported across the country on various service centers.

2. Methodology

To conduct a design study, analyze and develop optimal solution for the problem reported. This can be effectively done through proper selection of analysis of problem through brain storming, WHY-WHY analysis, on each parameter which can contribute to the roller and shoe failure. Also in the above process two points are taken into account; one is to identify the root cause and optimal solution for the problem and the second make a detailed manufacturing feasibility analysis in order to make it as robust process. First and fore most things in a project is to understand the problem clearly and its importance so that work can be directed properly. This phase describes the methodology applied for finding a way to define a product to do its intended function as per design analysis.

2.1 Brainstorming and Root cause identification

Brainstorming is a creative process aimed at generating a large number of ideas within a group. It's often used to explore potential solutions, improvements, or strategies related to a specific issue. Root cause identification is a systematic process used to determine the underlying causes of a problem. It aims to go beyond addressing symptoms and get to the fundamental issues that need correction. By combining brainstorming with root cause identification shown in the figure 2, create a comprehensive problem-solving approach that involves both creative thinking and systematic analysis, leading to more effective and sustainable solutions.

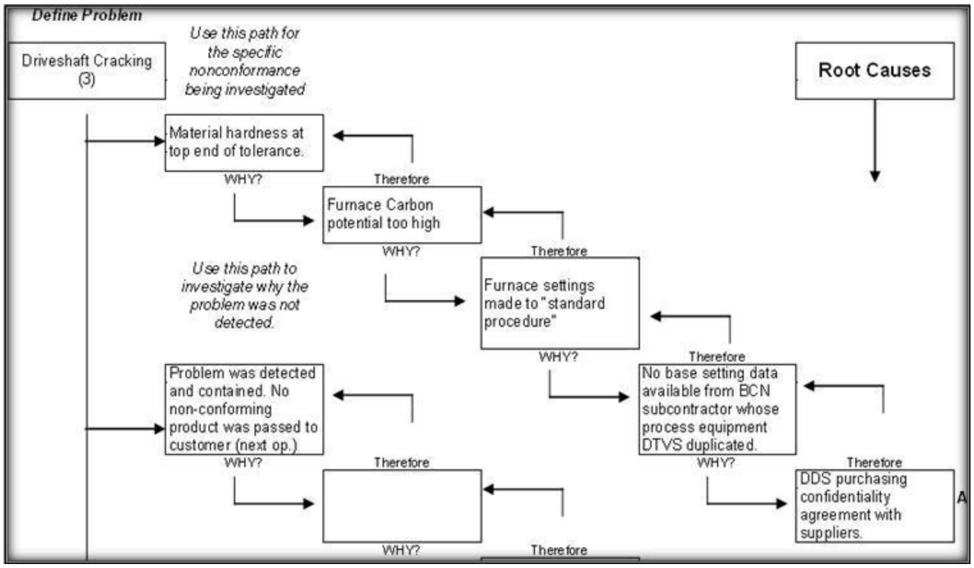

Fig.2 Brainstorming and Root cause analysis

2.2 Prototype development

2.2.1 Positive Parallelism on Hydraulic head Shoe slot–Some facts

When the roller keep on pressing the plunger in gets in contact with the hydraulic head. During the movement there is a friction in between roller contact surface and hydraulic head. This is illustrated in the below diagram. Positive parallelism in the context of hydraulic head shoe slots refers to the beneficial relationship between certain designs elements within a hydraulic system, specifically concerning the shoe slots. Shoe slots are features in hydraulic systems that accommodate the shoes of a hydraulic pump or motor.

Positive parallelism aims to ensure that these shoe slots are properly aligned and positioned to optimize the functioning of the hydraulic system. When the shoe slots are in a state of positive parallelism, several advantages can be observed:

From Reduced Wear and Tear, the proper alignment of shoe slots ensures that the shoes of the hydraulic pump or motor operate smoothly against the cam surface, minimizing friction and reducing wear on the components. From Improved Efficiency, Optimally aligned shoe slots lead to better contact between the shoes and the cam surface, enhancing the efficiency of the hydraulic system by minimizing energy loss. From Enhanced Performance, the Positive parallelism helps in maintaining consistent and balanced performance of the hydraulic system, ensuring that the shoes operate evenly and effectively. From Extended Component Lifespan, the Reduced friction and wear due to positive parallelism can contribute to a longer lifespan of the hydraulic system components, leading to decreased maintenance and replacement costs. Achieving positive parallelism involves precise engineering and meticulous alignment of the shoe slots within the hydraulic system during installation and maintenance. It's crucial to ensure that these slots are positioned accurately to reap the benefits of improved performance and durability in hydraulic machinery.

As shown in the figure 3, the positive draft angle in the component leads to more friction between the hydraulic head and Cam roller and shoe. This friction leads to the more wear on the hydraulic head during running which leads to pump failure.

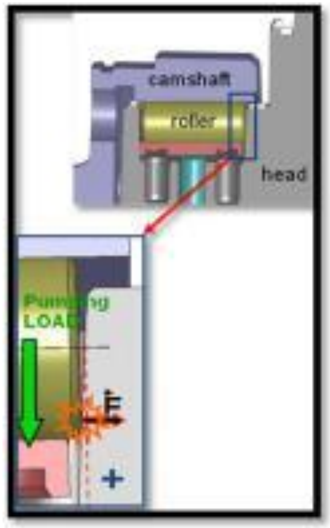

Fig 3. Extra friction in RS due to Positive draft angle

2.2.2 Design analysis

In drawing this draft angle is maintained in terms of Parallelism (spec 0.05mm) on the hydraulic head shoe slot face which contacts with roller and shoe. So it is allowed in manufacturing process default to make the positive draft angle. When it is analyzed on the field failure pumps, those hydraulic heads with more positive draft angle got more failures. This clearly shows that failure due to positive draft angle on the hydraulic head face. So this issue needs some design change in order to improve the process. Definitely we need to go for suitable design selection test. It is found that negative draft angle on the Component will give better results for the so the final outcome after the root cause analysis was remove the parallelism (0.05mm) on the component. In place of parallelism, it is decided to incorporate some draft angle in order to ensure the negative angle on the hydraulic head face.

2.2.3 Shoe slot drilling operation

Following operations are carried out in shoes lot drilling operation. The component orientation during drilling operation is as shown in the below mentioned figure 4, figure 5and figure 6.

Fig. 4 Component orientation In shoe slot drilling

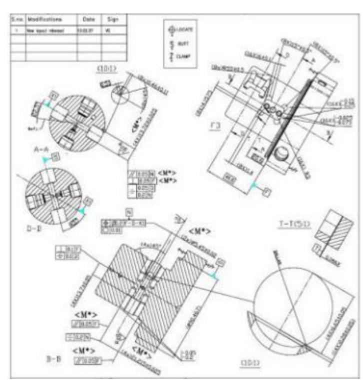

Fig. 5 Operation Layout for Existing Drawing

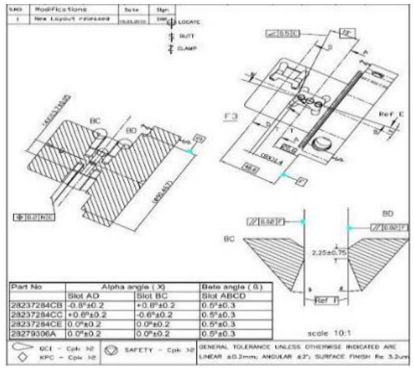

Fig 6. Component layout for modified operation

It is decided to introduce following negative draft angle on the component and to do a design selection test to identify which version will give most desirable result compared to the existing one. When manufacturing is concerned, it is not recommended to incorporate a negative draft angle on the component. Since there is sharp edge at the top of shoe slot it may lead to damage on the component when the component is subjected to inspection. So in order to avoid the manufacturing process difficulties it is recommended to have some land on the top of the hydraulic head face to check the dimension and also to avoid component damage.

In Each hydraulic head there will be four shoe slots and in each slot a set of roller &shoe, Plunger was fitted. So when the cam is rotating it constantly get in contact with roller & shoe and presses it, which in turn presses the plunger which develops a very high pressure on the fuel. This modification was applied to four shoe slots on the hydraulic head. In turn in each shoe slot there will be two sides one is head side and another in TP parts side. This modification was applied to both sides of the each shoe slot. So a suitable tooling drawing was made in order to manufacturing the new development heads.

2.3 Tool Development

As described in Chapter number 2.2.2 and 2.2.3 the operation sequence was modified in order to get a positive draft angle in hydraulic head. Earlier two end mill was used to finish the entire shoe slot milling operation. Now one more tool with a negative angle in build on the tool was introduced in order to form the angle on the component. Initially draft angle and land was controlled with two different tools. shoe slot land was controlled with dia 5.9 finish milling drill. And draft angle was controlled by new different tool. When the operation was performed a large variation in the shoe slot land was observed. This is because the two dimensions were controlled by three different tools. So it accumulates large amount of process variation. With three different tools the land value was varied from 0.5 mm to 3.5mm against the specification of 2.25±0.75mm.Hence it is decided to go for a combination cutter which controls both land and draft angle. Figure 7 shows the combination cutter which was developed in order to control the dimension with single tool. This tool forms the draft angle and land above the draft angle in a single pause so that the process variation was reduced and specified dimension was achieved.

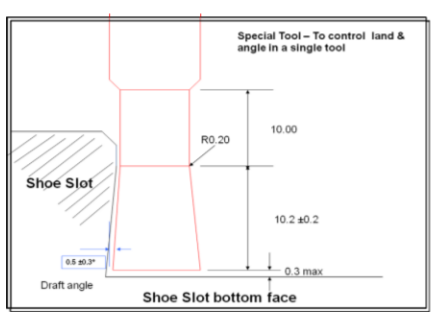

Fig 7.New Tool drawing for modified operation

3. Design Selection Test

In order to validate any design change it is necessary to do some short validation test.so it is defined to perform a same kind of validation for analyzing the performance. Here with the test specification is clearly defined. So as per the designed specification the hydraulic head was made and assembled as a pump. Once the Pump is assembled its undergone a series of End Of Line Testing (EOLT) in order to ensure its meeting the required functional requirements (Flow, Pressure, etc.) So this test was carried out and the new modified calculation shown in figure 8, shoe slot hydraulic head fitted pump meeting all the functional requirements.

Four pumps were manufactured with modified design and four pumps were manufactured with old design. All the 8 pumps are put in validation test bench and test was performed as per the described test frequency. Each pump was run for10hours and at the end of test each pump was removed from the testing rig.

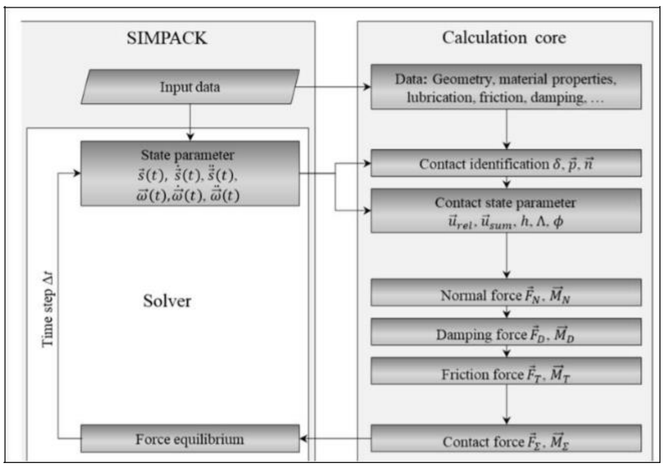

Fig 8. Flow chart of contact force calculation between rolling elements

4. Results and Discussions

The visual analysis of the hydraulic head shoe slot after 10 hours of validation testing is performed well. Four pumps with existing design and four pumps with new design was dismantled and analyzed for amount of wear. Both sides of each hydraulic head shoes lot are examined in microscope. Based on the visual observation lot of improvements on the wear were observed. In the existing design complete shoe slot face was worn out. Wear on complete shoe slot face was observed. In parallel subsequent roller also had similar wear as in shoe slot. In the modified design wear was observed only on the top face of the modified shoe slot (Say approx. 4 mm). In parallel only a slight amount of wear was observed in Roller also. The amount of wear on the hydraulic head shoe slot shown in the figure 9, and subsequent roller was less in modified design compared to existing design. Same kind of observation was made in all the four hydraulic head and respective shoe slots. Once visual analysis is performed, metrology analysis has to be performed in order to perform the quantitative analysis to evaluate the amount of wear in each slot. Before and after testing the shoe slot profile where the negative draft angle was incorporated. This profile was traced in Surface finish Tester (SURFCOM1500 SD). The example of shoe slot profile traced for the full length (say 10.00 mm approx) wear measurement performed in surface finish tester. After performing the wear measurement on both the sides of the shoe slot those points was converted into a excel graph in order to find the amount of wear on the shoe slot.

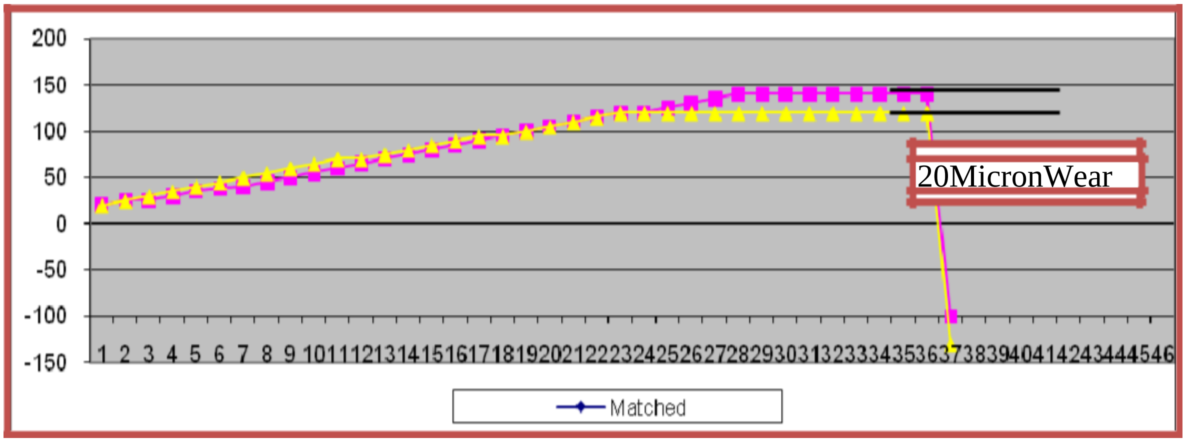

Fig. 9 Sample for wear measurement

The below Figure 9(a) and 9(b) shows the sample wear measurement performed in one of the shoe slot. The Pink color profile shows profile before testing and yellow color shows the profile after testing. This analysis was performed in all the shoe slots and the results are given below.

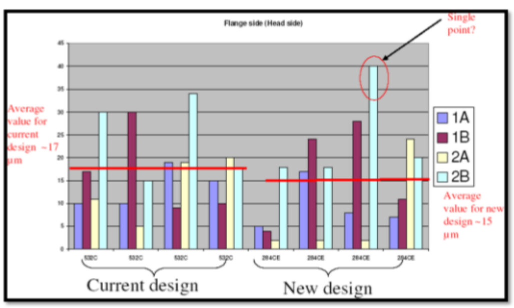

Fig 9 (a). Wear level on hydraulic head after testing in Head side-15µm

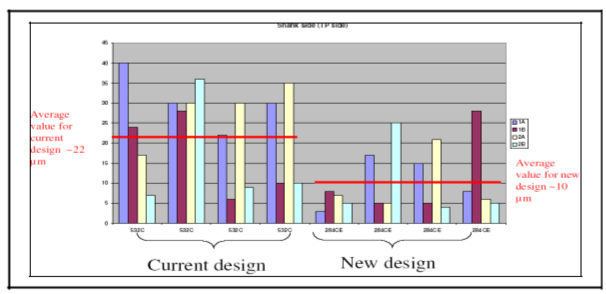

Fig 9 (b). Wear level on hydraulic head after testing in Head side- 10 µm

5. Conclusions

Based on the results obtained it is clearly showed that hydraulic head with negative draft angle on the shoe slot will leads to reduced Roller and shoe wear. Based on the results all the necessary steps are taken in order to implement this change in the current machining process. Finally with overseeing the base work about the roller and shoe failure the change review board (Delphi power train systems) finally approved the work and cleared the drawing for regular production and supply part to customer. The findings strongly indicate that adjusting the hydraulic head to have a negative draft angle on the shoe slot significantly reduces the wear and tear on both the roller and shoe components. These results prompted a thorough evaluation to integrate this modification into our existing machining process. After comprehensive measures were taken, the proposed alteration underwent rigorous scrutiny by the Change Review Board at Delphi Power Train Systems, who, after overseeing the foundational research on roller and shoe failures, approved the proposed changes. As a result, the updated design has been cleared for regular production, ensuring the supply of improved parts to our customers.

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