Quality Improvement of Pumping Element used in Diesel Fuel Injection Pump

Nagarjun.S*, Dr.H.N.Divakar, Raghuveer Prasad*****

* Department of Industrial and Production Engineering, The national institute of Engineering Mysore 570 008
** Department of Industrial and Production Engineering, The national institute of Engineering Mysore 570 008
*** Department of Quality Management and Methods, Bosch Ltd Adugodi Bangalore 560030

Abstract- Pumping element is an important component of a diesel fuel injection system. This project was carried out in Bosch. Ltd Adugodi, Bangalore. Using Pareto analysis, defects with highest percentage rejections are found. Barrel bore taper more and Honing Lines rejections were 2.5% and 1.8% respectively in the year 2013. Root cause analysis is done using Shainin Technique. Reason for the cause is analyzed and the solution is found. The solution is optimized by analyzing the Physics behind the problem. Optimized solution is validated for a calculated batch over particular period. After validation the solution is incorporated for daily production. The rejections were brought down by more than half.

Index Terms- FPY, Diesel Fuel Injection Pump, Pumping element, Shainin Technique

I. Introduction

Diesel engines have become the most popular power packs for heavy duty vehicles and equipments such as trucks, tractors, passenger vehicles, gensets, etc. as the diesel is one of the most efficient and energy dense fuels available today [1]. Nevertheless, the diesel engine has several great advantages, the quality production and maintenance of critical components of engine system has become yet a challenging task. Diesel Fuel Injection Pump (DFIP) System- the heart of the diesel engine is one such critical system [2].

The quality of the product has become the dominant criteria to acquire the global market. BPS is the leader in quality production by deploying advanced quality measures in its manufacturing processes and thus, satisfying the customer [3]. It has been possible through continuous improvement and proactive quality maintenance techniques like Shainin System, Failure Mode Effect Analysis (FMEA), Six Sigma, etc., in the production processes.

The quality of the product may be quantified in terms of money (INR), First Pass Yield (FPY), part per million (ppm), etc. There is a need to employ a simpler and efficient tool along with the traditional seven quality tools in order to achieve Six-sigma quality in manufacturing industries [4]. Failure of parts, products, or systems in the field can cause major damages - such as production loss, rework, warranty claims, and even image loss of the organization in the market.

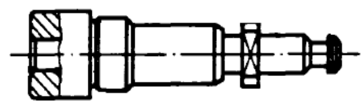

Fig.1. Pumping Element

2. METHODS

2.1 Pareto Analysis

Pareto analysis is a formal technique useful where many possible courses of action are competing for attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective actions that deliver a total benefit reasonably close to the maximal possible one. Pareto is commonly referred to as "80/20" rule, under the assumption that, in all situations, 20% of causes determine 80% of problems.

The important defects that occur during the production of pumping elements are barrel bore taper more, honing line in barrel, element sticky, barrel with wrong taper, ungrounded shoulder of barrel, Element rusty, dimensions out in the groove of a plunger, etc. When the percentage defects for various defects in the year 2014 were drawn, barrel bore taper more and element sticky were found to be of major concern and were contributing 80% of the defects.

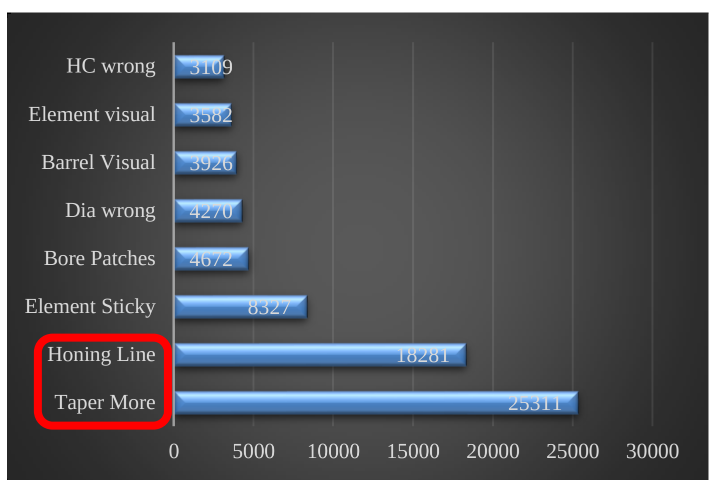

Fig.2.1 Pareto of defects in the production of Pumping element

Pareto analysis shows that honing lines and taper more defects which constitutes 20% of the type of defects is the cause for the

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80% the total defectives. Pareto law suggests that these two defects should be concentrated upon. This technique saves resources like money, time, etc. If we divert our attention to trivial matter then our resources get wasted. If we concentrate on Pareto causes then the rejection can be brought down by more than half, which is actually the aim of the project then there will be a considerable decrease in the overall rejection.

2.2 Green Y: Barrel bore Taper more

Pumping element is made up of two components barrel and plunger. Barrel is analogous to the cylinder of a pump and plunger to a piston. The percentage rejection of barrel more taper defects in 2013 is 2.5%, the target of this project is to bring it to 1.8%. The barrel undergoes the following process:

1. Drilling
2. Boring
3. Reaming
4. Inscription Stamping
5. Electro chemical machining
6. Heat treatment
7. Honing
8. Profile grinding
9. Lapping
10. Durr Cleaning
11. Inspection

The defects are detected only after inspection. At inspection the barrels are inspected for their bore diameter, bore taper and various other characteristics. The specification of bore diameter depends upon the element and varies from 5mm to 10mm. The tolerance of the bore diameter is +6µ to -2µ irrespective of bore diameter. The specification of taper for bore diameter is 0 to 1.5µ when measured from collar end. If the taper is more then there will be excess gap between barrel and plunger which results in leakage of the fuel to the lubrication oil of the pump. This results in thinning of the lubrication oil which in turn results in wear and tear of the pump. The operations prior to inscription stamping are done by the supplier. The defects may be generated at the supplier or in honing or during lapping only as all other process do not machine the barrel bore.

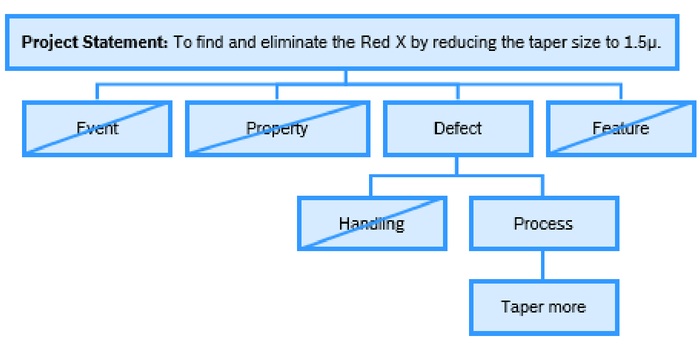

Fig.2.2 GreenY categorization as defect in process

The above figure shows that the Taper more defect comes under process. Hence the defects is generated in the production process which may be machine or measurement system.

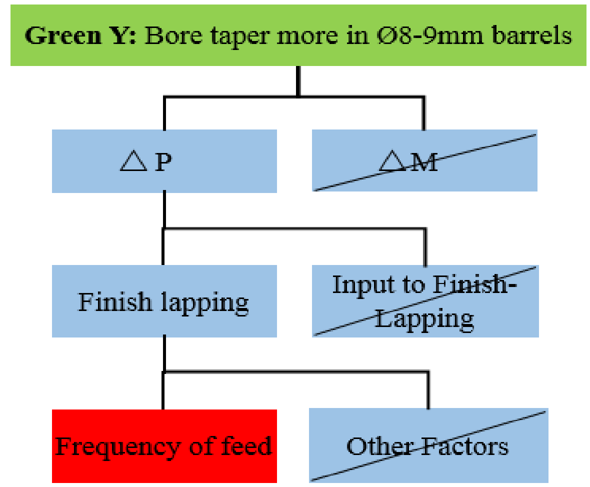

Fig.2.2.2 Solution Tree of Taper More

The above figure shows that initially the source of defects is found out in the process and not in the measurement, this is done by using a tool called Isoplot.

2.2.1 Isoplot

Ten components are taken randomly from a process, it is measured in two different measuring instrument which is taken randomly. The measurements are plotted on a graph sheet taking the measurements of one measuring instrument in one axis and the other in the other axis. The graph will look as follows below

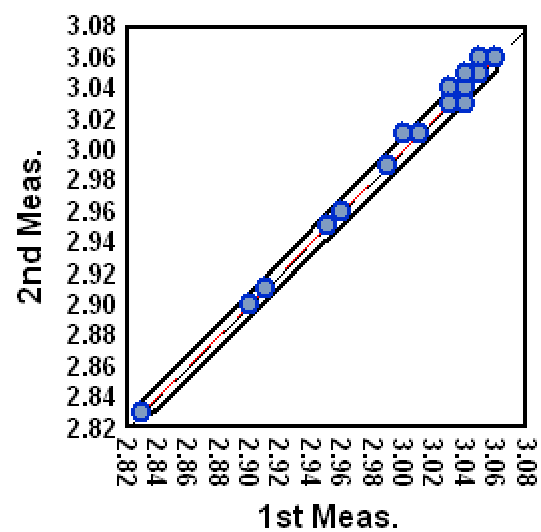

Fig.2.2.1 Graphical representation of Isoplot

A line is drawn bisecting the two axes. The second farthest point from this lines is considered and a line parallel to the middle and passing through this point is drawn. A line parallel to this extreme line and equidistance from this mid line is drawn. This two lines are joined by a semicircle at the end these semicircles include the extreme points in both the direction of the middle line.

Delta P is the value which represents the variation in process. The distance between the arcs gives delta p. Delta M represents the variation in measurement system. It is the perpendicular distance between the two extreme parallel lines. Delta P / Delta M is called as the discriminating ratio (DR). If DR is ≥ 6 then the process should be concentrated upon and if its < 6 then the measurement system is the culprit for the defects. The graph is drawn and DR is calculated and it is 9.2 which is greater than 6 hence the defects are getting generated in the process.

2.2.2 Converge - Active Multi-Vari

Active Multi-Vari is a Shainin tool used to find the process, which is generating the defects. The assumption made in the active multi-vari is that the probability that only one machine will be producing defects at a given time is high. The procedure is to take 200 barrels from a single batch of supplier. All the barrels are numbered and divided into 4 groups namely A (1-50), B (51-100), C (101-150) and D (151-200). A and B groups are mixed and given for a single honing machine for processing. C and D groups are mixed and given to another honing machine for processing simultaneously. After honing the groups are separated. A and C groups are mixed and given for lapping. B and D groups are mixed and given for lapping to another machine. All the groups are given for inspection and the percentage defects are noted for different groups separately.

If the rejection in all the groups are similar then the probability of defects being generated at the supplier is high. If the defects are only in group A and B or C and D then the probability of defects being generated in honing process is high. If the defects are only in A and D or B and C then the probability of defects being generated in lapping is high. If the pattern of defects is other than the above mentioned then that trail is discarded and new trails are carried out. If the rejections are coming in one of the above three pattern only for three times, then the process that connected with that pattern is said to be producing defects.

2.2.3 Experiment Details

The trails were carried out and results are tabulated bellow

Table 2.2.3: Results of Active Multi-Vari

Trail No.	A	B	C	D
1	2%	0	0	4%
2	0	0	0	0
3	0	2%	2%	0
4	0	4%	4%	0
5	4%	0	0	2%

The rejection are either in A and D or in B and C. This pattern as discussed before points the cause towards lapping process.

2.2.4 Funnelling

100 barrels are numbered and given for lapping process. The changes which are done in the lapping i.e. application of paste and the application of feed is noted down. The one to one correspondence between defects and lapping technique is noted.

Type	Sequence rejection of Taper More									
B041	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20
	21	22	23	24	25	26	27	28	29	30
	31	32	33	34	35	36	37	38	39	40
	41	42	43	44	45	46	47	48	49	50
	51	52	53	54	55	56	57	58	59	60
	61	62	63	64	65	66	67	68	69	70
	71	72	73	74	75	76	77	78	79	80
	81	82	83	84	85	86	87	88	89	90
	91	92	93	94	95	96	97	98	99	100

Fig.2.2.4 Defects generating sequence

When the interval of application of paste is high, Taper more defects are generated. It is found that the irregular feed is the root cause for taper more.

2.2.5 Feed

Lapping is a process used to prepare fine surface finish. Tool in the form of a sleeve which is made up of cast iron is inserted to a mandrel with a taper. The sleeve has a slit. A push up is inserted to hold the sleeve in place. Sleeve and the mandrel has a taper but in opposite direction. A cotter mechanism is used to pull the mandrel, due to pushup the sleeve will be in its place and due to taper and slit it expands which is called feed. A hand lever is used to operate the cotter mechanism. After machining of a particular number of barrels the feed is given to compensate the wear of the sleeve so that a particular diameter of barrel is obtained.

2.2.6 B vs C Test

Better vs Current test is done to check whether the root cause is correct or not and further funnelling is done. Following are the B vs C test results. Each trail is done for 100 barrels.

Table 2.2.6: Results of B vs C Test

Trail No.	Frequency of feed	Frequency of application of paste	% rejection of Taper more
1	10	8	9%
2	10	2	8%
3	4	8	1%
4	4	2	0

The above result shows that the Frequency of application of paste is the Red X. In Shainin a term called RedX is used which is analogous to root cause. Red X is that factor when controlled reduces the rejection by more than half.

2.3 Green Y: Barrel Honing Lines

As the name indicates Honing lines are the lines generated during honing operation. Honing operation generates barrels with surface finish of Rz 2µ hence the surface is rough which results in the wear of the element during its operation. As the rejection of honing lines is high the barrels with poor surface finish but lying within the specification that is in the border is high. This results in poor quality. The percentage rejection of barrel bore is 1.8%. The target of the project is to bring the rejection by half.

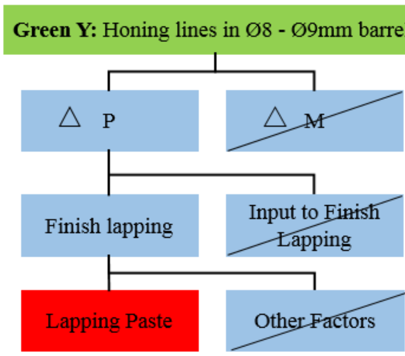

Fig.2.3 Solution tree of Honing Lines

2.3.1 Kappa Study

As the defect is an attribute Kappa study is done on measurement system. If the kappa value is ≥ 0.9 then the measurement system is capable, if it is between 0.9 and 0.7 then it is conditionally capable and if its lesser then 0.7 then it is not capable. In our case the kappa value was found out to be 0.93 which means that the measurement system is capable and the defects are being generated in the process.

2.3.2 Converge - Active Multi-Vari

Table 2.3.2: Results of Active Multi-Vari

Trail No.	A	B	C	D
1	9	0	0	7
2	0	0	0	0
3	0	5	7	0
4	0	0	0	0
5	10	0	0	10

The above result shows that the defects are generated in Lapping operation.

The defects that are rejected as honing lines are actually not honing lines but barrels with poor surface finish as a result of lapping. The reason for which the poor surface finish are many. Micro analysis of "Honing lines" specification of Rz is 0.7µ

Table 2.3.2: Rz of defective barrels

Trail No.	Collar	Middle	Shaft
Honing lines	0.9	0.17	0.25
Pseudo Honing lines	0.83	0.97	1.1

As we can see barrels which are rejected as honing lines and the other pseudo honing lines, honing lines barrels have out of specification Rz only in one region of the barrel whereas the pseudo honing lines barrels have out of specification Rz throughout the barrel. Through discussion it is found out that the reason for pseudo honing lines rejection is the contamination of lapping paste. There are two types of lapping one is pre-lapping and the other is finish-lapping. Pre-lapping is a process which mainly concentrate on material removal and it uses a paste which is Red in color as the chief content is aluminum oxide. Finish–lapping is a process where the roughness and straightness is concentrated and it uses green paste which chiefly contains chromic oxide. Chief contaminants of finish-lapping paste is the pre-lapping paste, grinding mutt or sand. All the contaminants enhance material removal rate. The contamination is done deliberately at most times as the material removal rate is high and the cycle time decreases which means the time of machining is less.

2.3.3 B vs C Test

Red and green lapping paste is mixed and a trail is done.

Table 2.3.2: Results of Active Multi-Vari

Trail No.	No of components	Paste used for Lapping	Percentage rejection of Honing Lines
1	200	Contaminated by red paste	10%
2	200	Pure	0

From the above table it is clear that the contamination of paste results in the generation of Barrel bore honing lines. Micro analysis of the above defective barrels were done and found that its characteristics were same as that of the barrels having pseudo honing lines. Hence it can be concluded that the contamination of paste is the root cause for Barrel bore honing lines.

3. Bulk Validation

A machine is assigned for 1 shift daily for 1 month. The results from this machine is noted down for that particular period. The bulk validation showed that there was a reduction in the taper more defects by 62% and honing lines rejection by 53%.

4. Conclusion

The overall defects in the production of pumping element was brought down by 36%. The quality of the pumping element in turn of the pump is increased. Satisfied customer.

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Authors

First Author – Nagarjun.S, MTech Scholar, The National Institute of Engineering Mysore, nagarjun9689@gmail.com.
Second Author – Dr.H.N.Divakar, Professor and Head, Department of Industrial and Production Engineering, The National Institute of Engineering Mysore, hndivakar@Yahoo.co.in.
Third Author – Raghuveer Prasad, Deputy Manager, Bosch Ltd and Prasad.raghuveer@in.bosch.com.