

## International Journal of Innovative Research in Science, Engineering and Technology

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# Ramp Up of Fuel Control Unit and Pump with a Foreign Drive Production Volume in Assembly Line

Giridhar MP<sup>1</sup>, G.R. Rajkumar<sup>2</sup>

P.G Student, Department of Mechanical Engineering, RV College of Engineering, Bengaluru, India<sup>1</sup>

Associate Professor, Department of Mechanical Engineering, RV College of Engineering, Bengaluru, India<sup>2</sup>

**ABSTRACT-** The project was taken in a fuel control Unit and fuel injection pump manufacturing plant. PF 51 Pump and fuel control unit is mainly used in automobiles. The manufacturing of PF 51 pump involves different machining and assembly operations. The manufacturing of fuel control unit involves various stations in which small parts are assembled and being checked. Here pseudo rejections and non-pseudo rejections are present which needs to be solved. The comparison of the data before and after solving the rejections with tools like First pass yield and Overall equipment effectiveness are done. Rejections in an Assembly operation was resulting in increased production loss. The main aim of this study is to identify the root cause for the major rejections and optimize the machining operations to decrease the rejections. The critical machining operations and rejection details were collected to understand the reasons for rejections. By the study plunger grinding specification was optimized.

**KEYWORDS:** Fuel Control Unit, First Pass Yield, Overall Equipment Effectiveness, PF 51 Pump, Diesel fuel injection, Rework standard, Barrel, Plunger.

### I. INTRODUCTION

Fuel control unit FCU helps to control the flow of fuel from fuel tank to the pump. This FCU has a ZME which is an electric control device in which sufficient current is applied and according to that the pressure in inlet, outlet and overflow connectors are varied and thus controlled by an overflow valve for the functionality of the whole system. FCU acts as a moderator between PF pump and the fuel tank. [1] The amount of extra fuel in the common rail is sensed by this ZME in FCU and thus prevents the flow of fuel from fuel tank and when in need of more fuel ZME sense the need and provide the required amount of fuel from the fuel tank. Flow control valves are offered by most hydraulic equipment manufacturers. [2] Valves of this type can be adjusted manually or automatically using sensors, controllers and actuators. The primary function of a flow control valve is to maintain a constant flow rate, regardless of the pressures prevailing at the inlet and outlet of the valve. PF stands for "Pump with a Foreign drive". In it the foreign drive is the plunger that pushes the diesel fuel forward to the pressurized delivery tube via normal delivery valve. PF pump is used in single cylinder diesel fuel engines. PF Diesel fuel pump is the first technology diesel fuel pump that delivers diesel to the engine cylinder in atomized form at moderate pressure. [3] The process of the PF diesel fuel injection pump begins with the rotation of the cam on the cam-shaft. The cam-shaft rotates by the virtue of the engine shaft the diesel fuel is supplied to the pump via fuel supply port to the pump barrel where the plunger reciprocates. The fuel intake and reciprocating of the plunger are mutually corresponding, i.e. when plunger goes down, fuel is supplied in the barrel and when the plunger goes up, the fuel gets into the barrel relatively at low pressure. [3]

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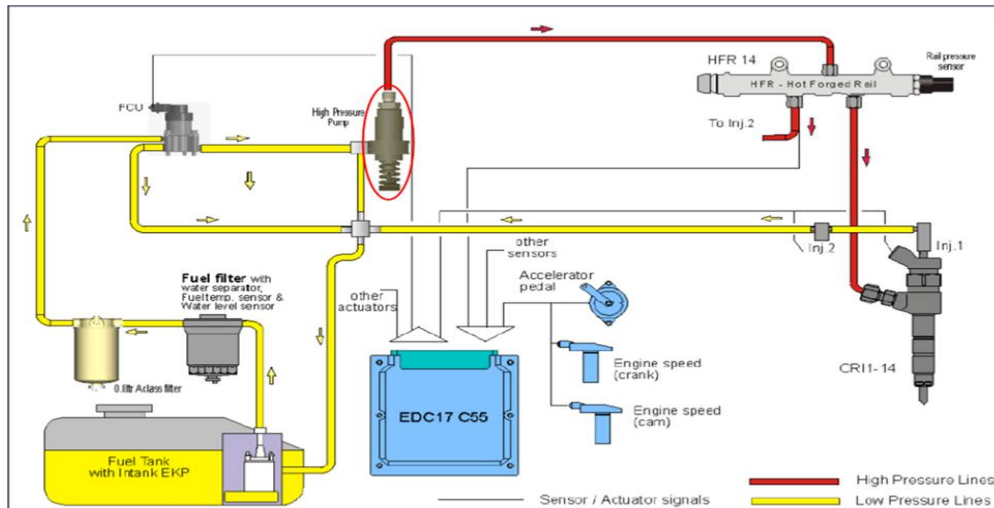


Fig 1 PF 51 Pump System Layout

Initially it was necessary to understand the different processes involved in the manufacturing of the PF51 pump. Value stream mapping was done and the critical machining operations were listed down. The main machining operations were honing for barrel and grinding for plunger. And the operation parameters and material flow were completely studied.

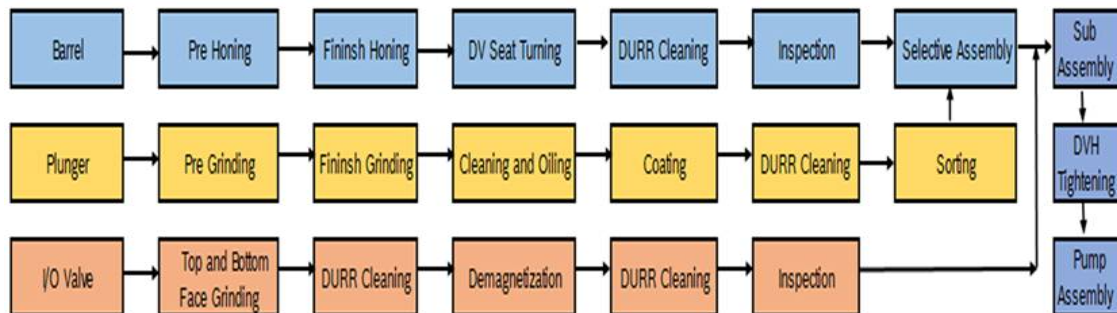


Fig 2 Value stream of PF-51

Initially it was necessary to understand the different processes involved in the manufacturing of the fuel control unit. Value stream mapping was done and the critical assembly operations and the test benches were listed down. The main assembly operations include connector pressing and zmc assembly and auto tightening and the test benches are functional testing and air leak testing. The operation parameters and material flow were also completely studied for value stream mapping.

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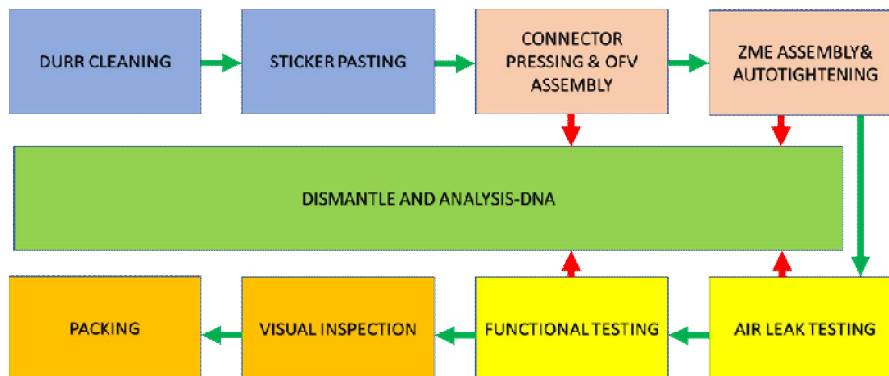


Fig 3 Value stream of PF-51

First pass yield (FPY), also known as throughout yield (TPY), is defined as the number of units coming out of a process divided by the number of units going into that process over a specified period of time. The significance really comes into play when we talk about reworks. In most facilities, reworks can be a huge time and cost burden on final production.[4] The OEE measurement tool was developed from the TPM concept launched by Nakajima. The goal of TPM is to achieve zero breakdowns and zero defects related to equipment. The TPM concept puts much attention on production equipment's, since they have a high influence on quality, productivity, cost, inventory, safety and health, and production output. It is a three-part analysis tool for equipment performance based on its availability, performance, and quality rate of the output.[5]

## II. LITERATURE SURVEY

Presently, industrial as well as scientific centres are mostly interested in flow control valves with proportional solenoids, because they allow for a smooth adjustment of the flow rate in a feedback loop. Proportional flow regulators are produced by many well-known worldwide companies like Bosch-Rexroth, Vickers, Brevini, PQS Technology and PONAR Wadowice.[6] It can also be used in different types of engines ranging from 1 – 16-cylinder engines. The process of the PF diesel fuel injection pump begins with the rotation of the cam on the cam-shaft. The cam-shaft rotates by the virtue of the engine shaft.[7] On certain degree of rotation of the cam, the plunger of 5.5mm diameter attached to the cam reciprocates corresponding to the degree of rotation of the cam and the spring attached to the plunger actuates. PF pumps cater to a wide range of applications ranging from agricultural equipment's, industrial engines, automotive, commercial vehicle, railways, marine engines etc.[8]

There are very high scopes of modifications in it and thus number of elements that are integral part of this pump can be modified for better fuel efficiency like spring, plunger, valve, lubricating oil, housing, delivery tube etc. [9] Diesel fuel injection pumps with external drive are called as PF pumps, i.e. The cam which drives the pump is a separate part and it's not a part of the pump. In it the foreign drive is the plunger that pushes the diesel fuel forward to the pressurized delivery tube via normal delivery valve. PF type of injection pumps are single cylinder, single acting, constant stroke type pump. [10] An analysis was done to understand the working and importance of the quality metrics, First Pass Yield and Quality Notifications per Module, to understand the reasons for its stagnation over the past couple of years at the assembly plant. Further these metrics were tested using data from the ERP software (SAP), other tailor-made software packages and from discussions and interviews with assembly floor people and the manufacturing and quality engineers.[11] This study analyses the literature regarding OEE, selects four main methodologies for its evaluation and examines the underlying differences between them. A real-life case study is analysed to illustrate problems arising during data collection and the differences in results obtained, together with traceable conclusions for improving the performance of production systems, both in traditional and in innovative industrial plants, following Industry 4.0 principles.[12] One of the measurements of manufacturing systems is Overall Equipment Effectiveness (OEE). This

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paper reviews OEE, discusses the throughput losses from the three factors of OEE, and explores the hidden information in OEE. The new method considers not only the output of a manufacturing system but also the influences from its upstream and downstream systems. Therefore, the new method can reveal the true fulfilment and competence of a manufacturing system, which can guide improvement efforts. [13]

Although manufacturing companies increasingly acknowledge the environmental impacts of their activities disregarding where in the supply chain these occur, a factory perspective is still predominant within the environmental management practices of organizations. The adoption of life cycle perspective in the Manufacturing industry is essential to develop consistent strategies that leads to decrease environmental impacts of product systems The concept is further illustrated with a research scale production line.[14]Aluminium cast alloy that is Al-Si, abnormal states silicon adds to give great casting characteristic aluminium alloy generally utilized as a part of building structure and it has light weight, consumption obstruction and good thermal conducting material it is utilized as a part of Fuel infusion pump on the grounds that amid fuel pumping task pump will achieve certain temperature to disseminate warm from the pump it ought to be high warm directing material it has property to disperse more warmth into air [15].

### III. METHODS AND PROCEDURE

#### a) FCU ASSEMBLY LINE

There are pseudo and non-pseudo rejections in the fuel control unit assembly line. We use the shop floor management cycle to know the route cause of rejection and how severe it is. Based on that three stations pseudo rejections are solved. A non-pseudo rejection is also solved which is due to the contaminant in the piston of metering unit. The rejections are due to miscellaneous reasons. The rejections are to be controlled and solved to deliver quality products to customer. Pseudo rejections can be considered as fake rejections. The part is rejected in the station because of the machine problem. The part produced is actually not a bad part, due to the uncertainties in the test bench it is showing rejection.

1. In ZME Assembly & Auto tightening station the metering unit is assembled on to the housing. Three screws are used for this and the machine will tighten the ZME with the specified amount of torque and angle. The test bench was having repeated rejections and the ZME was getting rejected which made the piling up of metering unit components. The rejected components were taken to dismantle and analysis station and then reworked then the parts were getting ok in the respective assembly line station. The main aim concentrates on the torquing and angular rejections. The torque values were all within the range for the screws one and two but for screw three the torque values where less than the limit. Thus, a model to perform the required function by solving the pseudo rejections and economical without periodic replacements was made in catia.

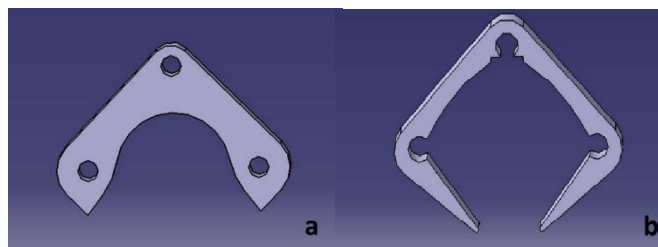


Fig 4 Catia model of ZME tightening and screw a) old holder b) new holder

2. Air Leak testing is the test bench for checking whether the fuel control unit has any leakage. The pneumatic circuit in the test bench passes air at certain specifications to the housing and then the leakage values are shown in the fukuda unit. The fukuda unit used is FL-611 Series which has specifications of testing pressure at  $5.5 \pm 0.4$  bar and the max leakage permitted is 1.4 cc/min. Leak measured by pressure difference between the master and work in Fukuda unit.

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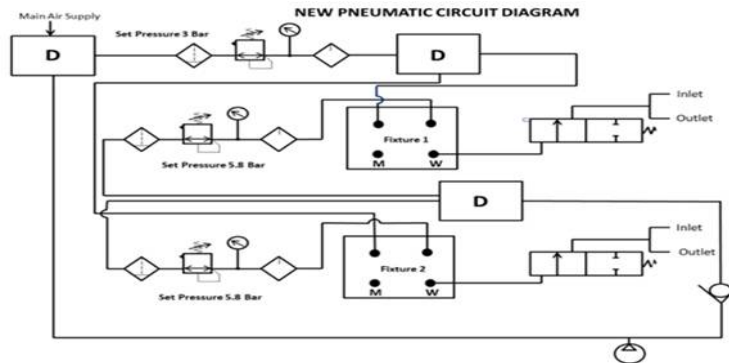


Fig 5 New Pneumatic Circuit Diagram

The pressure variation in the fukuda unit and the whole pneumatic circuit was the reason for the rejection. From the specifications it was understood that the Filter, Regulator, Lubricator (FRL), which is also called pressure service unit causes variation in the pressure. Thus, the modification of the pneumatic circuit was done with automation studio software. There was only one filter, regulator, lubricator (FRL) to control the pressure or the flow of air to the fukuda units. So individual control was not impossible. In order to solve the problem, the number of FRL units were increased to two and thus the required pressure is supplied to each fixture and the drop-in pressure is controlled. The non-return valve was included between the distributor and compressor. So, by designing the new circuit the rejections were controlled and solved.

- In Functional testing by using shop floor management cycle, the detailed study of the functional testing station in assembly line is done. There are two check points for the test bench. The current is applied at 1500mA and 500mA and the test bench is run. The rejection pattern is studied and the corrective action was confusing as we have three pressure parameters to be controlled to avoid pseudo rejections. Some of the other specifications include outlet flow, inlet flow and overflow. This is the most sensitive test bench and have a bottleneck cycle time in this station. The above permissible values are similar for all the eight types and the same test bench with four fixtures is used. All the fixtures showed rejections at different test points and the results were not easy to correlate. The variation of pressures at 1500mA for seven trials were done. The combination of all parameters has to be checked in all four fixtures for better results. A comparison considering all the parameters of the test bench are considered. The variation of pressures at 500mA for seven trials were done. The combination of all parameters has to be checked in all four fixtures for better results.

Table 1 Parameters and rejections at different check points

TYPE	ZME current(mA)	Inlet pressure P1(bar)	Inlet flow Q1 (l/h)	Outlet Pressure P2(bar)	Outlet flow Q2(l/h)	Overflow pressure P3(bar)	Overflow Q3 (l/h)
F002 FU0 001	1500	5.5 ±1.0	<250	1 ± 0.4	150±20	0.4± 0.2	70±40
	500	5.5 ±1.0	<170	1 ± 0.4	< 4	0.4± 0.2	120±30
1	1500	5.62	219.7	1.08	147.31	0.4	72.39
	500	5.93	132.14	0.87	1.18	0.52	133.32
2	1500	5.56	244.38	1.18	152.34	0.47	92.04
	500	5.9	168.37	0.84	0.32	0.6	168.68
3	1500	5.45	214.89	1.14	143.29	0.38	71.6
	500	5.71	128.92	0.73	0.37	0.49	129.29
4	1500	5.4	215.98	1.11	137.72	0.37	78.26
	500	5.7	139.57	0.25	0.32	0.5	139.89
5	1500	5.65	218.38	1.04	143.23	0.41	75.15
	500	5.99	134.81	0.56	0.91	0.52	135.71
6	1500	5.46	244.4	1.12	145.52	0.36	98.87
	500	5.69	154.84	0.64	0.32	0.46	155.15
7	1500	5.48	234.16	1.11	130.74	0.37	103.42
	500	5.71	150.48	0.65	0.33	0.46	150.81



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The hydraulic circuit was studied and using certain customer specifications of the discharge rate the inlet pressure was found out were rejections won't happen. The exact range was to be found out because the changeover can cause again change of the values. The exact value to avoid the pseudo rejection in the functional test bench is mentioned in the hydraulic circuit. The inlet pressure, outlet pressure and the overflow pressure values to avoid rejections and to make the part ok is done successfully by calibration of test bench. The calibration fluid used is ISO standard 4113 and the inlet, outlet, and overflow pressures will be  $5.4, 1 \pm 0.4, 0.4 \pm 0.2$  bar respectively.

Non- Pseudo rejections are rejections in the component that is being produced. The part can be rejected in the station or it cannot be rejected. The part produced is actually a bad part, due to the defects or the failure of any of the part. The quality checked ok pump was also selected. Swapping trials between the best of best (BOB) and worst of worst (WOW) fuel control unit was done. The swapping results were tabulated and analyzed. The parts were swapped between the BOB and WOW and the results were tabulated as per the table below. The parts are swapped one by one started with housing to ZME. The metering unit, ZME was found to be defective. The ZME was dismantled in the dismantle and analysis test bench and thus the parts were observed and the possible reasons for rejections are analyzed. The ZME piston was tested under the fully automated TL5000 Ergo microscope with a numerical aperture of 0.9. There was contamination in the zme piston and SEM study was conducted to find out the range of contamination level and the reason for the non-pseudo rejection was found out. The ZME piston was contaminated with foreign particles.

### b) PF-51 ASSEMBLY LINE

It was important to collect the details of the rejections by understanding the reasons for rejection. Based on dimension PF-51 pump consists of two variants i.e. Ø6 and Ø7 type. Details of the rejection was found by collecting the details from different machining and assembly operation lines. The rejections were collected with respect to machining and assembly operation and reason for rejection was noted for 20 shifts.

Table 2 Machining and assembly operation rejection details

Date	Shift	Sl. No	Part Number	M/C 1 Honing Dia 6		M/C 2 Honing Dia 7		Selective Assy Dia 6		Selective Assy Dia 7		Remarks	Remarks
										Housing	SA		
03-09-2018	Shift 1	1	PF51(79)			263	23			155	0	Taper rejection, Spindle rejection	N.A
		2	PF51(81)	290	0			209	14			N.A	Taper rejection
	Shift 2	1	PF51(79)			370	3			416	0	Spindle Rejection	N.A
		2	PF51(81)	228	2			280	0			Taper rejection, Spindle rejection	N.A

Trials of changing the plunger grinding specification was done. The plunger grinding specification was widespread i.e. the interval was more. Due to different interval in the plunger grinding, plunger class was mixing up. The specification for grinding of plunger was fixed to 6.6690 microns to 6.9710 microns. The interval was selected based upon the operator and planner feedback. The plunger specification was fixed for all the shifts. Process validation was conducted in order to verify the defined grinding specification. The validation was conducted for 5 different shifts and details were noted. A batch of 1200 pcs of plungers were grinded in the specified grinding specification and sent to vendor for coating. The coated plungers received from the vendor was sorted based upon the dimension into different classes and the result was revived by pareto analysis.

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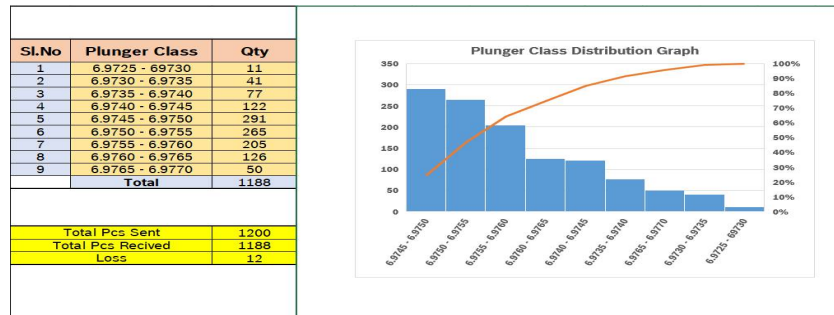


Fig 6 Pareto Analysis for Plunger Class Distribution

From Pareto analysis we understood that by adopting to defined plunger grinding specification (6.9690 – 6.9710) the maximum spread of the class can be minimised. This minimised spread of plunger helps to build good inventory of plungers and minimised plunger class interval improve the process as well as productivity. This mismatch was resulting in widespread of plunger class distribution in sorting. Work instructions at SA was updated to maintain a min quantity of 200pcs of plunger in each interval.

## IV. RESULTS AND DISCUSSION

In case of Fuel control unit assembly line, the first pass yield improvement was considered in January 2019 for a period of 9 working days. Total number of pumps accepted = 7335, Total number of pumps rejected = 760. Total number of pumps produced in one-month duration = 7335 + 1944 = 9279. The first pass yield increased from 79.04 % to 90.41%.

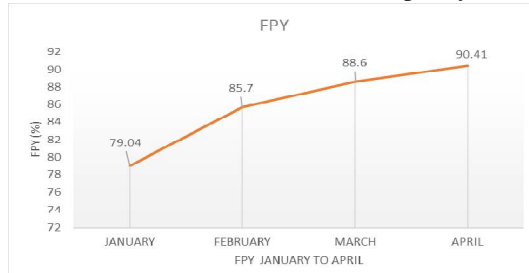


Fig 7 FPY increase from January to April

Based on that the overall equipment effectiveness can be calculated. All other time calculations remain same. This value remains same for all the months and the calculation per month is required. The overall equipment effectiveness of the extreme months shows the variation of the values from 54 % to 82 %.

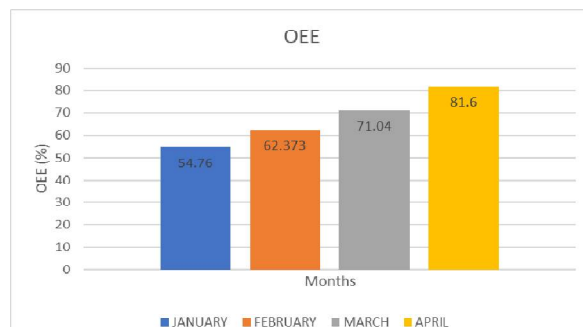


Fig 8 OEE values from January to April

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For PF-51 assembly line the changes made in the value stream, the output at selective assembly was measured by conducting first pass yield at selective assembly. 100 pcs of plungers are assembled in selective assembly station and the no of attempts to match the barrel and plunger is noted. The results show that first pass yield at selective assembly is 69%.

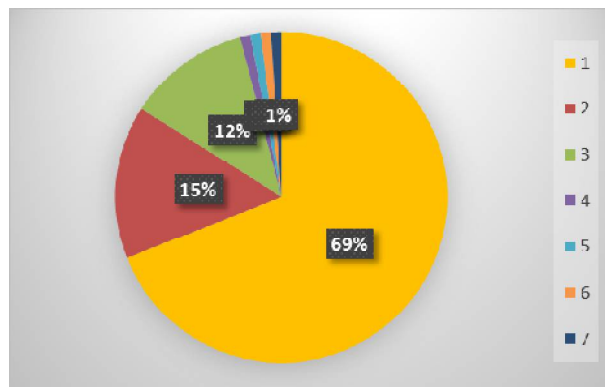


Fig 9 Details of FPY of PF-51

### V. CONCLUSIONS

The project aimed at ramp-up of fuel control unit and pump with foreign drive production volumes in an assembly line. The fuel control unit assembly line pseudo and non-pseudo rejections were solved using miscellaneous techniques. To justify that the rejections are controlled a solved, comparison of OEE, FPY for fuel control unit assembly line before and after solving the root causes were studied and depicted. For PF-51 Pump only the first pass yield was considered. The FPY of PF-51 increased.

In air leak testing station, the pseudo rejections were solved using the new pneumatic circuit and maximum leakage permitted must be 1.4 cc/min. In functional testing station, the inlet pressure, outlet pressure and overflow pressure must be 5.4 bar,  $1 \pm 0.4$  bar, and  $0.4 \pm 0.2$  bar respectively. The pseudo rejection was solved as the root cause was the contamination in the ZME piston. The First Pass Yield was increased from 80% to 90% by solving the pseudo rejections in the fuel control unit assembly line. The Overall equipment Effectiveness was increased from 54% to 82% by solving the pseudo rejections in the fuel control unit assembly line.

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