FAILURE ANALYSIS OF PICK-AND-PLACE'S BRAKE PROBLEM THROUGH MULTIFACTORIAL EXPERIMENTS

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ABSTRACT

A Pick-And-Place Test Handler is known for its technology to precisely place a device from one tray pockets to another, depending on its programmed configuration. However, whether a particular pick tip moves down during pick-and-place operations depends on the effectiveness of the Brake Mechanism of a Pick Body Assembly.

A major problem that caused an interruption on the customer site has been reported where the Pick Body Assemblies were observed moving in Z direction when they shouldn't.

Several hypotheses and potential contributing factors have been produced by investigating the affected module, and by studying the standards of Pneumatic Brake Mechanism and its components. By utilizing multifactorial experiments on the limited resources, the root cause was traced to the uncontrolled application of grease that caused contamination on the main components of the brake system.

1. 0 INTRODUCTION

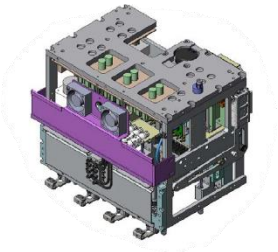
A Pick-and-Place (PnP) Test Handler is a machine used in the system-level test and final test for all sorts of Integrated Circuits (ICs). The primary function of a PnP Test Handlers is to facilitate the precise positioning of ICs onto test sockets or contact points, enabling comprehensive testing of their functionality and performance. It not only enhances testing accuracy but also significantly increases the throughput of semiconductor testing, contributing to improved overall efficiency in the manufacturing workflow.

A PnP Test Handler consists of 5 major assemblies: Power or Control Area, Input / Output (I/O) Area, Leg Assembly Area, Testsite (TS) Area, and the Top Compartments. The Dual Pitch PnP Head assembly inside the Testsite Area is responsible for picking of ICs from tray pockets with one XY pitch spacing and then place in tray pockets with a different pitch spacing. It must be able to lower all pick tips at once, or selected tips to finish picking or placing partial rows. Also, it must provide indication when parts are not on tips as expected. This not only allows the software to fill in for missing device during place operations, but also to notify operators that a part was missing from a tray.

This study will focus on the failure analysis of the problem that occurred in the Dual Pitch PNP Head Assembly that resulted in a major customer complaint because of the interruption on the manufacturing line. It will discuss the experiments conducted to identify the contributing factors, to test the proposed hypotheses, to determine the root cause of the problem, and to create improvements that will eliminate the possibility of problem recurrence.

1.1 A Dual Pitch PnP Head Assembly

A Dual Pitch PnP Heads precisely pick devices from a tray or boat having one XY pitch spacing between device pockets and then precisely place the devices in a tray or boat having a different XY pitch spacing between pockets. The heads contain 2 rows of pick tips. The front row tip spacing is adjustable in X Pitch but fixed in Y Pitch. The rear row is adjustable in both X and Y Pitch. The two rows have independent X Pitch drive.



A1	A2	A3	A4	X Pitch Row
B1	B2	B3	B4	Y Pitch Row

Fig. 1. A 3D illustration of a Dual Pitch PnP Head Assembly and its Pick Tip Layout.

1.1.1 X-Pitch Assemblies and Pick Body Assemblies

The Dual Pitch PnP Heads have 8 Pick Body assemblies arranged in two X-Pitch rows (4 pick bodies per row). Each of the 2 X-Pitch rows has its own X-Pitch motor, and the 2 motors are driven independently of one another.

The front row of pick bodies is referred to as the "Master X-Pitch Assembly", and the individual pick bodies are designated as B1 starting at the left, to B4 at the right.

The rear row of pick bodies is referred to as the "Slave X-Pitch Assembly", and the individual pick bodies are designated as A1 starting at the left, to A4 at the right.

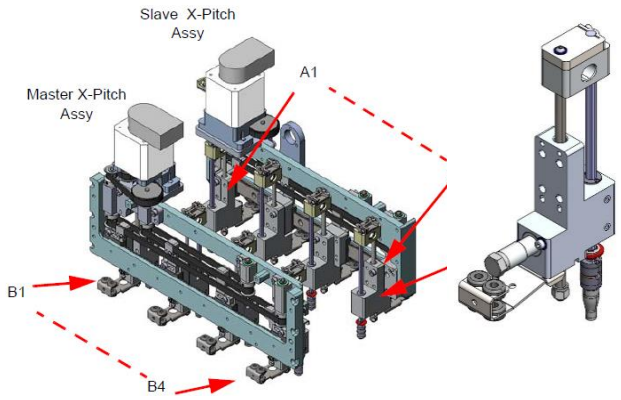


Fig. 2. A 3D illustration of X-Pitch Assemblies and Pick Bodies.

1.1.1.1 Pick Tip Control

All pick bodies are linked to a single Z motor and pusher mechanism. However, whether a particular pick tip moves down during pick-and-place operations depends on the setting of a software-controlled pneumatic brake mechanism and a magnetic clutch in each pick body.

1.1.1.2 Pneumatic Brake Mechanism

The Pneumatic Brake Mechanism consists of a piston riding in a cylinder inside the pick body base, and a return spring seated in the cylinder which pushes out on the cylinder. The brake shaft runs through the pick body base and through a hole in the piston. At both top and bottom sides of this hole, there is an eccentric counterbore, which provides a seat for an eccentric O-ring.

When air pressure is applied to the cylinder, it pushes the piston brake assembly inward and releases the brake shaft from the 2 eccentric O-rings.

When air pressure is released, the return spring pushes the piston brake assembly out causing clamping force by the 2 eccentric O-rings that hold the brake shaft.

Figure 3-5 shows the mechanical components of a Pneumatic Brake Mechanism inside a Pick Body Assembly and its operation details.

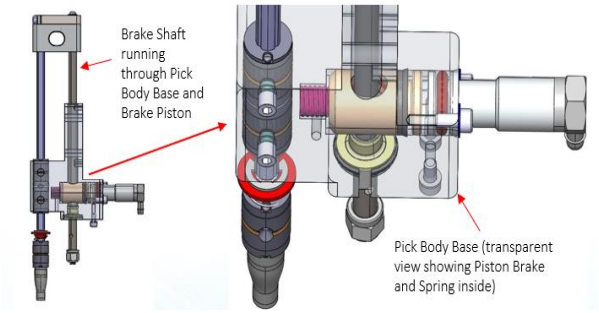


Fig. 3. A 3D illustration of a Pneumatic Brake components inside the Pick Body Assembly.

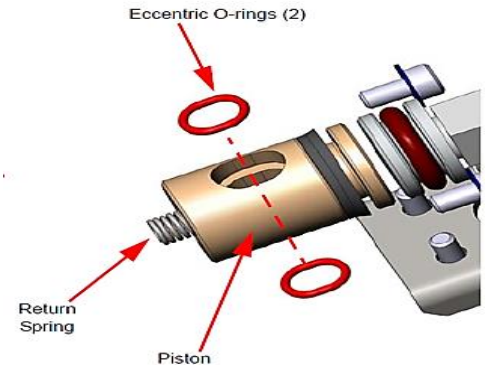


Fig. 4. A 3D illustration of a Piston Brake Assembly.

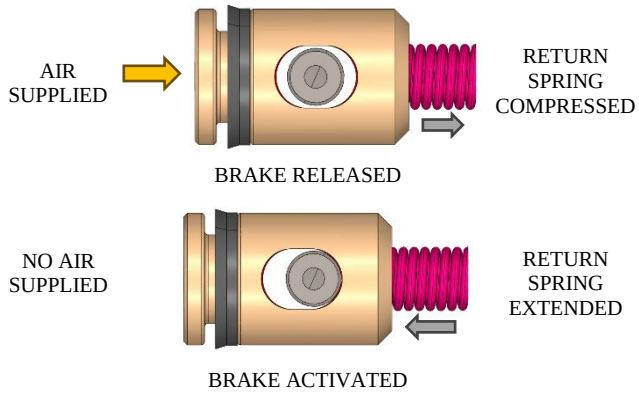


Fig. 5. Pneumatic Brake mechanical components detail and operation.

1.2 The Problem

A functional issue arose on the customer site during hot cycle run where the PnP Test Handler was left running overnight. It was observed that some of the pick bodies are moving in Z direction when they shouldn't. The service engineers inspected the PnP Head assembly with power off and no Compressed Dry Air (CDA) applied, and it shows that the pick body A1 freely drops while B4 and A4 are dropping

gradually, and the rest of pick bodies appeared to be good as shown in Figure 6.

Fig. 6. The actual image of the defective PnP Head showing several Pick Bodies moved in Z direction unintentionally.

To contain the problem, the service engineers performed several actions including the replacement of the Pick Body assembly components particularly the Piston Brake assembly, but the problem persists during the re-test.

The problem was solved after the replacement of the Spline Shafts which are suspected not exhibiting pre-loaded Spline Nuts.

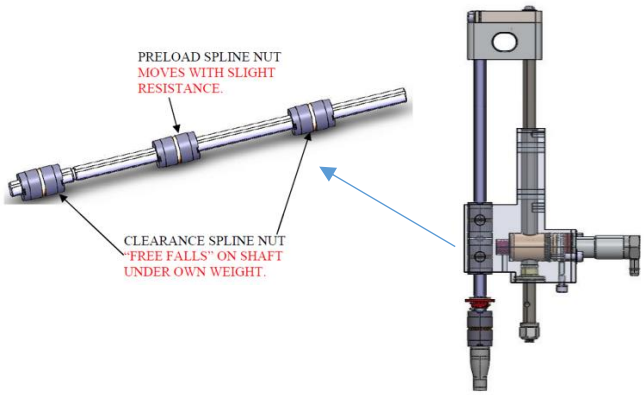


Fig. 7. A 3D illustration of Spline Shaft and Spline Nuts orientation.

Considering the discussed Pneumatic Brake Mechanism above, these Spline Shaft and Nuts orientation should have no effect on the problem nor its solution. The pneumatic brake system of a pick body assembly can only be compromised if there is a defective part on the pneumatic brake mechanical components or contamination happened on its assembly.

2. 0 REVIEW OF RELATED WORK

Not applicable.

3.0 METHODOLOGY

To identify the true cause of the problem, several hypotheses were formed, and a series of multi-factor experiments have been conducted.

3.1 Materials Used in the Experiments

- 2 Units of Pristine PnP Head Assembly
- 8 Pcs Pick Body Assemblies
- 8 Pcs Brake Shafts
- 16 Pcs Piston Brake Assemblies
- Test System Cart
- Test Cable Assemblies
- Pneumatic Test Fixture
- Silicon Based Grease
- Automatic Grease Dispenser
- Ø 0.25 mm Nozzle

3.1 Pneumatic Brake Test Process

The following are the processes performed to test the effectiveness of Pneumatic Brake on a PNP Head Assembly.

3.1.1 Weight Test

A weight test is performed after the assembly of Pick Body and in-between Final Test processes. A tool with specific weight is installed to the end of the Pick Body to check whether the pneumatic brake could withstand its downward force. Failure will be declared if the brake shaft drops, otherwise, the test will result as good.

3.1.2 Z Motion Test

This test is added to check the effectiveness of the Pneumatic Brake of the Pick Body Assembly after it was integrated on the PNP Head Assembly. It is done by manually pushing down the Z Bar Pusher that holds all Pick Bodies in two X-Pitch rows. The brake shafts of the Pick Bodies should not drop along with the Z Bar Pusher, or else the test result will be declared as failed.

3.1.3 Drift Test

Drift Test or marathon run is conducted to determine whether the PNP Head Assembly will fail over time, normally it is run for over 2 straight hours. An error will be prompted on the Test System Cart if it detects any irregularity.

3.1.4 Brake Counter Test

The Brake Counter Test is performed after the drift test to check if the Pick Body assemblies are moving in Z direction synchronously without any delay. It is usually run in 100 cycles.

3.2 Hypothesis 1

Based on the observation of service engineers on site during the failure, the spline shafts of the failed Pick Bodies exhibited no preloaded spline nuts, causing the Pick Body Assemblies to drop unintentionally.

3.2.1 Hypothesis 1: Initial Analysis

Referencing to the material datasheet of spline shaft and nuts, the average clearance of a pre-loaded nut is around -0.002~ +0.001 millimeters. This amount is too little to hold the weight of the pick tips. The preload is applied to the ball spline to reduce the vibration impact, and therefore, increase its service life and accuracy. The absence of preload value should have no effect on the pneumatic brake of a Pick Body Assembly.

3.2.2 Hypothesis 1: Experiment

To prove the correctness of the initial analysis, two-factor experiments have been performed using 8 Pick Body assemblies and Pristine PNP Head assembly.

- Factor 1: Spline nuts are arranged without preload and installed in Pick Bodies A1, A2, A3, B1, B2, B3.
- Factor 2: Spline nuts are arranged following the correct orientation and installed in Pick Bodies A4, B4.

Table 1 shows the result of this 2-Factor experiment.

Table 1. Summary of Hypothesis 1: Experiment Results

FACTOR	1	1	1	2	1	1	1	2
TESTS	A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4
1st Weight Test	✓	✓	✓	✓	✓	✓	✓	✓
Z Motion Test	✓	✓	✓	✓	✓	✓	✓	✓
Brake Counter Test	✓	✓	✓	✓	✓	✓	✓	✓
2nd Weight Test	✓	✓	✓	✓	✓	✓	✓	✓

✓ No brake failure ✗ Brake failed.
The Brake Counter Test ran for 100 cycles.

Based on the data gathered after the experiment, all pick bodies with factors 1 and 2 did not exhibit any brake failure during and after the tests.

3.3 Hypothesis 2

Indicated on the problem report of the service engineer that after replacing the Piston Brake Assembly, the problem persisted. This eliminates the factor of having non-compliant or damaged Piston Brake Assembly components.

What's left is the integrity of the Brake Shaft. It is a Ø4.0 mm fabricated part that is made of stainless steel, it undergone part's level inspection which proves that it is compliant with the required specifications.

Eliminating the factors of non-compliant parts, the investigation led to the possibility that the Pneumatic Brake System components are contaminated with lubricants.

3.3.1 Hypothesis 2: Initial Analysis

The main mechanism of Pick Body Assembly brake system relies on the 2 pcs of Viton O-rings that hold the Brake Shaft when the Compression Spring is extended. This Brake Shaft is made of Stainless Steel while the O-rings are made of Viton or Fluoroeslastomers. Any lubrication between the Brake Shaft and O-rings will significantly reduce its friction, causing the brake system to fail.

Referencing to the process instruction of Pick Body Assembly, the application of Silicone Based Grease on the lips of the U-Cup Seal of Piston Brake Assembly is required to reduce the friction between it and the Pick Body Base which is made of aluminum. Figure 9 shows the grease application on the U-Cup Seal of Piston Brake Assembly and its movement inside the Pick Body Assembly during machine operation.

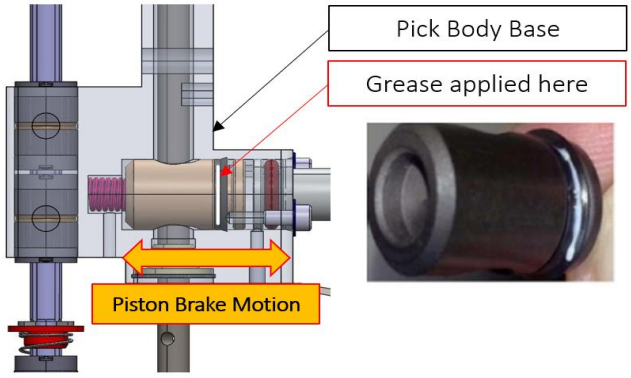


Fig. 8. A 3D illustration of Piston Brake motion and the actual application of Silicon Based Grease in the U-Cup Seal of a Piston Brake Assembly.

Given the subjective amount of the grease applied in the U-Cup Seal and its distance from the Brake Shaft and O-rings which is approximately 6.0 mm, plus the in-out movement of Piston Brake Assembly during the machine operation, it is possible to assume that the grease has been transferred from the U-Cup Seal to the Brake Shaft and eventually on the O-rings which adds lubrication between the Brake Shaft and O-rings that cause deterioration of the Pneumatic Brake System.

3.3.2 Hypothesis 2: Experiment 1

To test the validity of the second hypothesis, a little amount of grease was intentionally applied to the surface of Brake Shafts to test if a brake failure will happen. See figure 9.

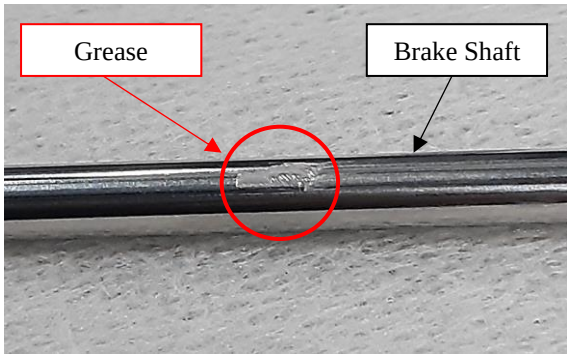


Fig. 9. An actual image of Grease applied intentionally to the Brake Shaft.

- Factor 1: Grease is applied intentionally to the Brake Shaft of Pick Body A1.
- Factor 2: Pristine Brake Shaft is used on Pick Body A2 to A4 and B1 to B4.

The experiment ran in 4 cycles of Weight and Z Motion Test, 200 cycles of Brake Counter Test and 1 hour of Drift Test.

Table 2. Summary of Hypothesis 2: Experiment 1 Results

FACTOR	1	2	2	2	2	2	2	2
TESTS	A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4
1st Weight Test	×	✓	✓	✓	✓	✓	✓	✓
1st Z Motion Test	×	✓	✓	✓	✓	✓	✓	✓
1st Brake Counter Test	✓	✓	✓	✓	✓	✓	✓	✓
2nd Weight Test	×	✓	✓	✓	✓	✓	✓	✓
2nd Z Motion Test	×	✓	✓	✓	✓	✓	✓	✓
Drift Test	✓	✓	✓	✓	✓	✓	✓	✓
3rd Weight Test	×	✓	✓	✓	✓	✓	✓	✓
3rd Z Motion Test	×	✓	✓	✓	✓	✓	✓	✓
2nd Brake Counter Test	✓	✓	✓	✓	✓	✓	✓	✓
4th Weight Test	×	✓	✓	✓	✓	✓	✓	✓
4th Z Motion Test	×	✓	✓	✓	✓	✓	✓	✓

✓ No brake failure × Brake failed.
Each Brake Counter Test ran for 100 cycles.

Table 2 shows that brake failure happened on Pick Body A1 which has grease on the Brake Shaft.

3.3.3 Hypothesis 2: Experiment 2

To further test hypothesis 2 along with hypothesis 1, another set of experiments was conducted using the combination of the following factors.

- Factor 1: Spline Nuts are arranged without preload.
- Factor 2: Small amount of grease is applied to the Brake Shaft.
- Factor 3: Smaller amount of grease is applied to the Brake Shafts.
- Factor 4: Smallest amount of grease is applied to the Brake Shafts.
- Factor 5: The Brake Shaft of Pick Body A1 which has applied grease during experiment 1 was cleaned and reused.
- Factor 6: Pristine Spline Shaft and Nuts was used.

Table 3 shows the results of this 6-Factor experiment.

Table 3. Summary of Hypothesis 2: Experiment 2 Results

FACTORS	1 & 5	1 & 2	1 & 3	1 & 4	2 & 6	3 & 6	1	6
TESTS	A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4
1st Weight Test	✓	×	×	✓	×	×	✓	✓
1st Z Motion Test	✓	✓	✓	✓	×	×	✓	✓
2nd Weight Test	×	×	×	✓	×	×	✓	✓
1st Brake Counter Test	✓	✓	✓	✓	✓	✓	✓	✓
2nd Z Motion Test	✓	✓	✓	✓	×	×	✓	✓
3rd Weight Test	×	×	×	✓	×	×	✓	✓
Drift Test	✓	✓	✓	✓	✓	✓	✓	✓
3rd Z Motion Test	✓	✓	✓	✓	✓	✓	✓	✓
4th Weight Test	✓	✓	✓	✓	×	×	✓	✓
2nd Brake Counter Test	✓	✓	✓	✓	×	×	✓	✓
4th Z Motion Test	✓	✓	✓	✓	×	×	✓	✓
5th Weight Test	✓	✓	✓	✓	×	×	✓	✓

✓ No brake failure × Brake failed.
Each Brake Counter Test ran for 100 cycles. The drift test ran for 2 hours.

Though inconsistent, the result shows that the brake failure occurred only on the Pick Bodies with applied grease (A2, A3, A4, B2, B3, B4). The Pick Body A5 which was used during experiment 1, though cleaned, also exhibits a brake failure, this is because the grease from its Brake Shaft has been transferred to the O-rings in Piston Brake Assembly during machine operation.

3.4 Grease Application Control

Despite the results of the experiments that grease contributes to the occurrence of Brake Failure problem, its application cannot be totally removed from the process of Pick Body Assembly because of its importance in the reduction of the friction between the U-Cup Seal and the Pick Body Base. An additional step shall be taken to ensure that the grease will only remain on its preferred location and will not be transferred to the Brake Shaft that will eventually cause brake failure on the system.

An Automatic Grease Dispenser can be used to control the application of grease, the missing variables are the amount and the location needed for application.

3.4.1 Grease Application Control: Experiment

A series of experiments using the Automatic Grease Dispenser and Ø0.25 mm nozzle with the following factors shown in figure 11 were done to identify the standard requirements. Each dot of nozzle contains 0.02 ml grease.

- Factor 1: 6 dots of grease applied on the lips of U-Cup Seal.
- Factor 2: 6 dots of grease applied on the body of U-Cup Seal.
- Factor 3: 8 dots of grease applied on the lips of U-Cup Seal.
- Factor 4: 8 dots of grease applied on the lips of U-Cup Seal.
- Factor 5: 4 dots of grease applied on the lips of the U-Cup Seal avoiding the shaft hole, then was spread around using tip toe swab.

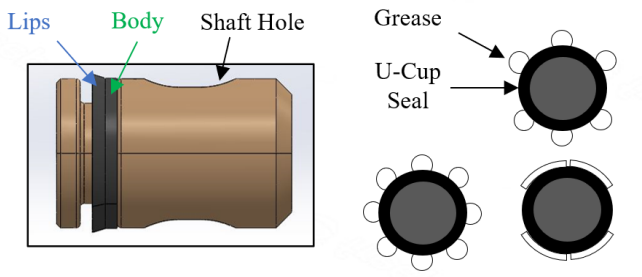


Fig. 11: Different applications of Grease on U-Cup Seal during experiments.

A total of 16 Piston Brake Assemblies were installed into 2 PnP Head to complete the experiments. Each PnP Head ran for 72 hours Drift Test where Weight Tests are performed after every 24 hours to check the brakes effectiveness. Table 4 and 5 show the results of experiments on each machine.

Table 4. Summary of Experiment Results on Machine 1

MACHINE 1								
FACTORS	1	2	1	5	5	2	1	2
TESTS	A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4
1st Weight Test	✓	✓	✓	✓	✓	✓	✓	✓
2nd Weight Test	✓	✓	✓	✓	✓	✓	✓	✓
Weight Test (24 hrs)	✓	✓	✓	✓	✓	✓	✓	✓
Weight Test (48 hrs)	✓	✓	✓	✓	✓	✓	✓	✓
Weight Test (72 hrs)	✓	✓	✓	✓	✓	✓	✓	✓

✓ No brake failure × Brake failed.
The 1st Weight Test is performed after sub-assembly of Pick Body and the 2nd Weight Test is performed after integrating it into the PNP Head.

Table 5. Summary of Experiment Results on Machine 2

MACHINE 1								
FACTORS	3	4	3	5	5	4	3	4
TESTS	A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4
1st Weight Test	✓	✓	✓	✓	✓	✓	✓	✓
2nd Weight Test	✓	✓	✓	✓	✓	×	✓	×
Weight Test (24 hrs)	✓	✓	✓	✓	✓	✓	✓	✓
Weight Test (48 hrs)	✓	✓	✓	✓	✓	✓	✓	✓
Weight Test (72 hrs)	✓	✓	✓	✓	✓	✓	✓	✓

✓ No brake failure × Brake failed.
The 1st Weight Test is performed after sub-assembly of Pick Body and the 2nd Weight Test is performed after integrating it into the PNP Head.

4.0 RESULTS AND DISCUSSION

The series of experiments conducted to test the hypotheses and identify the true cause of Pneumatic Brake System failure of a Pick Body Assembly concluded that the factors related to the grease application are the main contributor of the problem. The results of the experiments also invalidated the initial assumption that the loss of preload in Spline Nuts is the cause of brake failure.

Table 6 shows the number of failures encountered for each factor suspectedly related to the problem.

Table 6. Summary of Failures Count for Known Factors

FACTORS	COUNT
Failures related to Preload of Spline Nuts	0
Failures related to Grease Application	36

Though grease is deemed as contributing factor of brake failure, its application cannot be eliminated in the process of assembly because it provides dynamic lubrication between metal and rubber surfaces to reduce its friction and enhance the service life of the assembly components. The use of an Automatic Grease Dispenser and the appropriate nozzle helps to control the process and eliminate the subjectiveness of the application method.

Table 7. Summary of Experiments Results for Grease Application Control

QTY[a]	TYPE[b]	LOCATION[c]	RESULT[d]
6	Dot	Lips	3 / 3
6	Dot	Body	3 / 3
8	Dot	Lips	2 / 3
8	Dot	Body	2 / 3
4	Spread	Lips	4 / 4

[a] Quantity of grease multiplied by 0.02 ml. [b] Application type using an Automatic Grease Dispenser. [c] Part of U-Cup Seal where grease is applied. [d] Quantity of sample passed over total tested samples.

The experiments results shown in Table 7 concluded that having 4 dots of grease applied on the lips of the U-Cup Seal avoiding the shaft hole and was spread around using tip toe swab has the highest effectiveness with 4 passing samples. Though the application of 6 dots also does not exhibit any failure, it may result in the wear-and-tear of the part of U-Cup Seal that has no grease applied.

5.0 CONCLUSION

This study finds that even a little amount of grease or lubricant could be detrimental to the function of an assembly or a system if not properly applied. Its application methods could be critical if not thoroughly considered. The use of an automatic device could eliminate the need for subjective judgment caused by human inconsistencies. This study also proves that several results could be produced using less resources by conducting multifactorial experiments.

6.0 RECOMMENDATIONS

The proper application of consumable items such as grease and lubricants shall not be neglected during the design and development of the product. More experiments using advanced technologies shall be conducted to observe the behavior of grease inside an assembly during machine operation to further improve its application method and to effectively define its component's compatibility.

7.0 ACKNOWLEDGMENT

This study would not have been accomplished without the contributions of my colleagues in PIMES/ATS Engineering and the support of PIMES/ATS Management.

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