Process Evolution

through

Integration of Shainin and Taguchi

- A Case Study in

Alternator Manufacturing

by

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Contents

1.0 Overview of Lucas - TVS

1.1 Lucas–TVS Auto Electrical plants

- ✓ Established 1961, originally a joint venture between Lucas Plc UK and TVS, wholly owned since 2001
- ✓ Four decades of leadership on Indian Market
- ✓ 7 plants in India, main plant in Chennai with 2600 employees
- ✓ Product development capability: 80% of revenue from In-house developed products
- ✓ Technical Collaboration
  - *Mitsubishi Electric*: Geared Starters / Internal Fan Alternators
  - *Denso*: Ignition Systems, Two Wheeler Starters
  - *YDK Japan:* Blower Motors

1.1 Other Plants

Rewari, Haryana

Chakan, Pune

Nettappakkam, Pondy

TV Koil, Pondy

Pant Nagar, Uttarakhand

Maraimalai Nagar (Near Chennai)

1.2 Product Range

Products	Annual Units (In Lacs)
Alternators	25.30
Starters	33.90
Two Wheeler Starters	38.00
Wipers	22.10
Compressor Motors	4.70
Ignition Coils	13.50

1.3 Blue Chip Customer Base

PASSENGER CARS

MARUTI SUZUKI, TATA, Mahindra RENAULT, HYUNDAI, FIAT, Ford, HONDA, HM, WABCO, GM

COMMERCIAL VEHICLES

TATA, Mahindra, FORCE MAN, MAN FORCE TRUCKS Pvt. Ltd., IVECO, DENSO, Ashok Leyland, Mercedes-Benz, KAMAZ, CVG COMMERCIAL VEHICLE GROUP, EICHER

Tier 2

Mercedes-Benz, Audi, VW, BMW, MANDO, PEUGEOT, HYUNDAI

PACCAR, Mack, VOLVO, JOHN DEERE

1.3 Blue Chip Customer Base

PICK UPS & SUVs

TATA, FORCE MAN, PROTON, BAJAJ, Mahindra

BUSES & COACHES

TATA, Ashok Leyland, Mahindra NAVISTAR

TWO-WHEELERS

TVS, HERO HONDA, HONDA, BAJAJ, ARCTIC CAT

TRACTORS

Mahindra, SWARAJ ENTERPRISE, TAFE, JOHN DEERE, SAME DEUTZ-FAHR

ENGINES

KOHLER, Kirloskar, GREAVES, TATA

CONSTRUCTION

CATERPILLAR, LARSEN & TOUBRO, KOMATSU, bemi, Telcon

1.4 Recognitions & Awards

TS 16949 | OHSAS 18001 | ISO 14001 | Deming Award

JIT Innovation Award from JIT Management Lab, Tokyo
JIT Grand Prix Award from JIT Management Lab, Tokyo (Thrice)
Frost & Sullivan – Platinum Award for Manufacturing Excellence
BIS – Rajiv Gandhi National Award
Energy Conservation Award

1.4 Recognitions & Customers Awards

Quality

- **Maruti Suzuki** Best Warranty Improvements 2009
- **Maruti Suzuki** - VA/VE Award, 2006
- **Maruti Suzuki** - Vendor Performance Award for Quality, 2004-05
- **Ford** - Q1 Award, August 2006
- **Hyundai Motor India** - Best Quality Performance Award , 2008-09
- **Hyundai Motor India** - 100 PPM Award, 2003
- **Mahindra** - Best Quality Performance Award (FES), 2006-07

Performance

- **Maruti Suzuki** Vendor Upgradation Award, 2011
- **Maruti Suzuki** Best Vendor Upgradation Award, 2010
- **Maruti Suzuki** Best Vendor Upgradation Award, 2009
- **Maruti Suzuki** Best Supplier Support Award, 2008
- **Maruti Suzuki** - Best Supplier Support Award, 2007-08
- **Maruti Suzuki** - Best Vendor Award, 2006
- **Maruti Suzuki** - Superior Kaizen Performance Award, 2004
- **Mahindra & Mahindra** – Annual Commodity Award, 2011
- **Ashok Leyland** - Outstanding Performance in Management, 2007-08
- **Cummins India** - Excellent Performance Award, 2007+2008
- **Cummins India** - Best Performer Award, 2003
- **Honda Motorcycles and Scooter India** - Achievement Award 2008-09
- **Honda Motorcycles and Scooter India** - Best Supplier Award, 2005
- **Hyundai Motor India** - Overall Best Performance, 2004
- **Tata Motors -** Enduring Relations Excelling Together Award, 2008

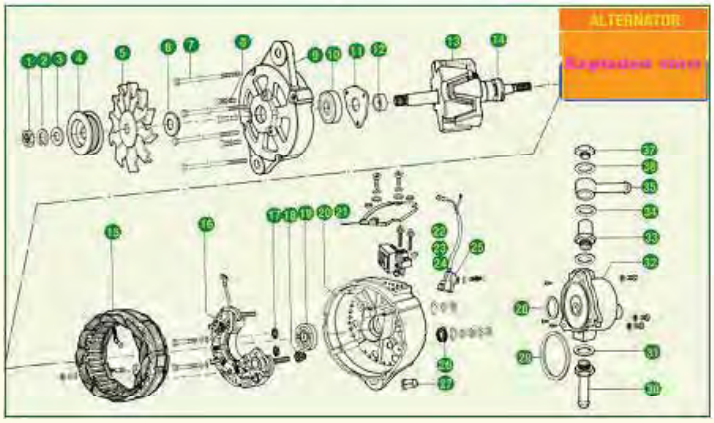
Case Study -

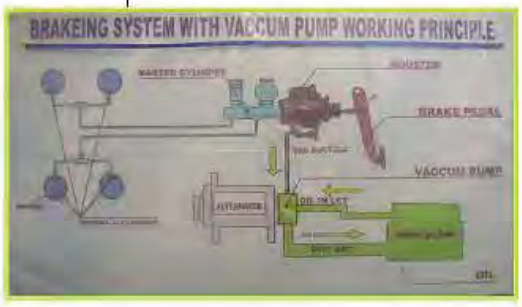
2.0 Introduction about Alternator

2.0 Alternator - Introduction

Alternator – Electric power

Vacuum Pump – Vacuum power





3.0 Problem Definition

3.1 Case Study – Problem Definition

Problem Statement

- Poor First Pass Yield during Pilot Production Trial Run of a New Product Introduced

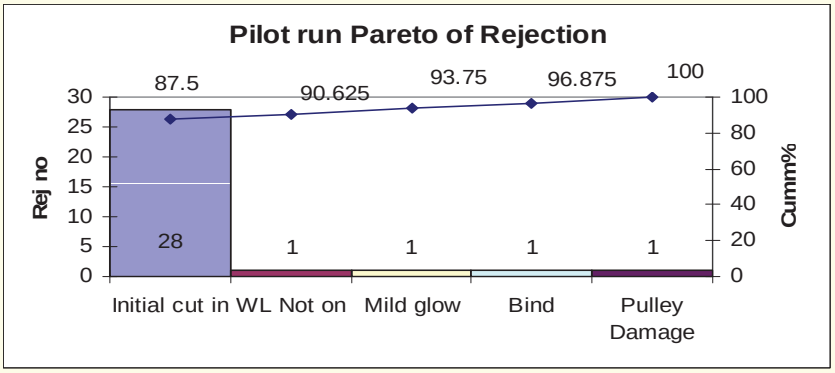
Expected Yield	Actual Yield
> 95 %	< 85 %

Pilot run rejection data

Qty Produced = 200

Qty Rejected = 32

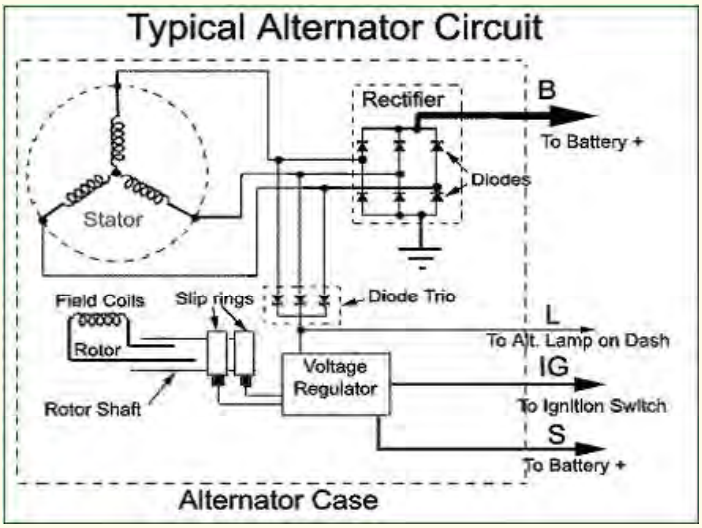
88% of rejection due to Initial Cut in Failure



3.2 Case Study – Problem Definition

What is Initial Cut In Failure ?

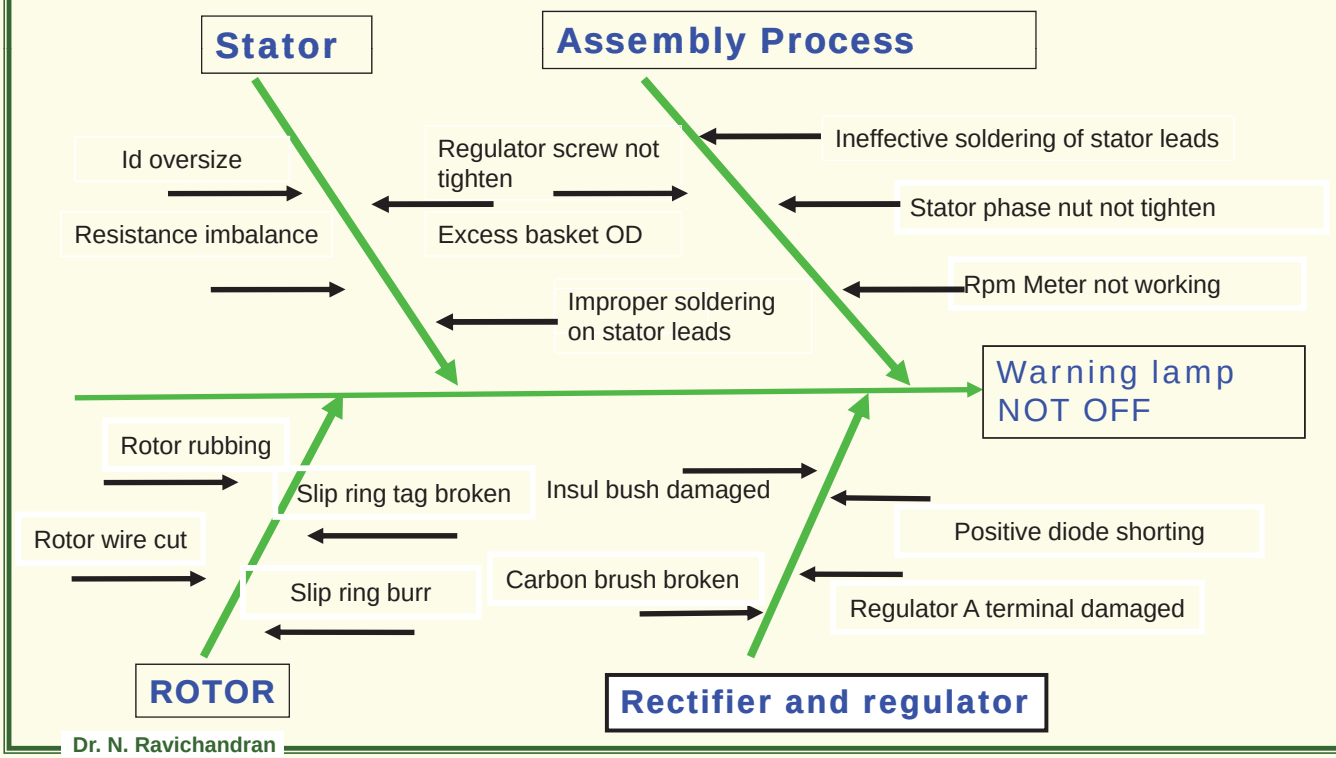
- When alternator is generating sufficient Threshold Current – the warning lamp on the Dash Board is OFF – indicating to the driver proper functioning of alternator. The failure to produce this current is called Initial cut in failure – **Warning Lamp Not OFF**



4.0 Diagnostic Approach – Shainin Method

4.1 Case Study – Cause Analysis

Cause & Effect Diagram:



4.2 Case Study – Cause Analysis

Diagnostic Approach:

Conventional Approach

- Check Conformance to Standards & Specifications
- Identify the cause by conducting Fresh experiments
- Fresh Experiments conducted with pre determined levels for Specified factors - to avoid failure phenomenon
- The factors and their levels are chosen based on Experience & Knowledge

Shainin Clue Generating Approach

- Identify the Cause from the existing Good & Bad
- Select BOB – Best of Best & WOW - Worst of Worst from the existing lot
- Conduct Designed Experiments using these BOB & WOW to Identify the Culprit cause.

Since Pilot Run - all the parts have been checked for conformance prior to assembly.

Hence, to cut short time & effort Shainin Approach is Preferred

4.3 Case Study – Shainin Approach

Shainin Component Search : This is a diagnostic study by Elimination

- A pair of BOB & WOW Selected
- First phase of Elimination – Identify which is contributing

  Using D/d Ratio by disassembling & reassembling Twice - BOB / WOW

  - Assembly Process — If D/d Ratio < 1.25
  - OR
  - Constituent Parts — If D/d Ratio > 1.25
- Second phase of Elimination – Identify which part is contributing by Swapping parts by pre determined Priority between BOB & WOW.

  - Good becomes BAD
  - AND
  - Bad becomes Good

  } When the Culprit part is interchanged

The Decision of transition from Good to Bad & vice versa is not based on Design Specification limit but by new control limits determined for each pair of BOB & WOW

- Capping Run – confirming the Finding

4.4 Case Study – Shainin Approach

Shainin Component Search: Elimination Phase 1

	BOB WL Current O/P	WOW WL Current O/P
Initial assembly	0.31	0.08
After 1st re-assembly	0.39	0.06
After 2nd re-assembly	0.28	0.05
Median	0.33	0.065
Range	0.11	0.03

Specification of WL current O/P

> 0.12 amps

D / d Test:

Difference between the medians (**D**): 0.33 – 0.065 = 0.265

Average range (**d**) : (0.11+0.03) / 2 = 0.07

D/d = 0.265 / 0.07 = 3.785 > 1.25

Inference: **Assembly Process is not Culprit**

4.4 Case Study – Shainin Approach

Shainin Component Search: Elimination Phase 2

Control limits for Swapping : This is not same as Specification

Control limit BOB = Median of BOB +/- (2.776/1.81)d
BOB :- Min = 0.2227, Max = 0.4375;
Control limit WOW = Median of WOW +/- (2.776/1.81)d
WOW- Min = -0.0423, Max = 0.1723

Priority for Swapping : This is based on Knowledge & Experience

1. Rotor assembly
2. Regulator Rectifier Assembly
3. Stator Assembly

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4.4 Case Study – Shainin Approach

Shainin Component Search: Out put measured with parts interchanged

1	First Reaaseembly	0.32	0.06
2	Second reassembly	0.28	0.05
3	ROTOR INTERCHANGE	0.23	0.06
4	Bring back to original	0.25	0.05
5	RECTIFIER & REGULATOR	0.29	0.08
6	Bring back to original	0.32	0.06
7	STATOR ASSY	0.06	0.32
8	Bring back to original	0.3	0.07
9	Capping Run	0.07	0.31

Hence Stator is the Culprit RED X

Inference:

Total Reversal when Stator is Interchanged

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4.5 Case Study – Shainin Approach

Shainin Paired Comparison : To Identify the Product Feature Contributing to the Defect

- Six pairs of BOB & WOW Selected
- These pairs are compared in all aspects – whether specified in the design or not
- Significance of each feature compared is decided using " Tukey End Count Test"

The response of each feature compared is arranged in either ascending or descending order. The no. of continuous good or bad at either end is called the top & bottom end counts.

The Significance level of each feature is based on the total end count which is sum of top & bottom count :

If the Total End count is	
6	then Confidence level = 90%
7	then Confidence level = 95%
10	then Confidence level = 99%
12	then Confidence level = 99.7%

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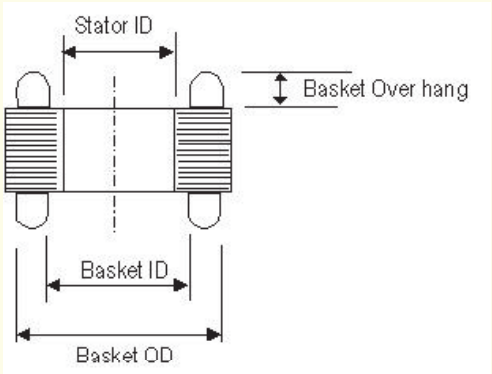
4.5 Case Study – Shainin Approach

Shainin Paired Comparison :

S.No.	Stator Basket OD	Stator Basket ID	Stator Overhang	Stator ID	ID ovality
G 1	119.10	99.2	15.24	95.39	0.07
G 2	119.20	99.16	15.35	95.37	0.06
G 3	118.95	99.17	15.39	95.38	0.065
G 4	119.18	99.21	15.49	95.37	0.055
G 5	119.14	99.36	15.65	95.39	0.06
G 6	118.98	99.24	15.47	95.38	0.065
B 1	118.93	99.14	15.45	95.44	0.05
B 2	118.99	99.2	15.33	95.43	0.065
B 3	119.1	99.18	15.21	95.44	0.06
B 4	119.13	99.32	15.31	95.43	0.07
B 5	119.17	99.22	15.27	95.425	0.065
B 6	119.08	99.29	15.55	95.44	0.065

Features Compared



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4.5 Case Study – Shainin Approach

Shainin Paired Comparison : Response Arranged in Descending order

	S.No.	Stator Basket OD		Stator Basket ID		Stator Overhang		Stator ID		ID ovality
	G2	119.2	G5	99.36	G5	15.65	B1	95.44	G1	0.07
	G4	119.18	B4	99.32	B6	15.55	B3	95.44	B4	0.07
	B5	119.17	B6	99.29	G4	15.49	B6	95.44	G3	0.065
	G5	119.14	G6	99.24	G6	15.47	B2	95.43	G6	0.065
	B4	119.13	B5	99.22	B1	15.45	B4	95.43	B2	0.065
	G1	119.1	G4	99.21	G3	15.39	B5	95.425	B5	0.065
	B3	119.1	G1	99.2	G2	15.35	G1	95.39	B6	0.065
	B6	119.08	B2	99.2	B2	15.33	G5	95.39	G2	0.06
	B2	118.99	B3	99.18	B4	15.31	G3	95.38	G5	0.06
	G6	118.98	G3	99.17	B5	15.27	G6	95.38	B3	0.06
	G3	118.95	G2	99.16	G1	15.24	G2	95.37	G4	0.055
	B1	118.95	B1	99.14	B3	15.21	G4	95.37	B1	0.05
Top end count	2		1		1		6		0.5	
Bottom end count	0.5		1		1		6		1	
Total end count	2.5		2		2		12		1.5	

Inference:

- Stator ID is the only feature contributing significant @ 99.7 % confidence
- If the ID of the stator core is near to the top limit of the speciation – the defect occurs

ID Spec: 95.33 to 95.44 mm dia

5.1 Case Study – Shainin Validation

Shainin B vs C Test : To validate the finding

- Six pairs of units build fresh to confirm the finding

Six presumed Bad units → Assembled With → the significant part conforming to (WOW) Bad unit values & other parts random

Six presumed Good units → Assembled With → the significant part conforming to (BOB) Good unit values & other parts random

- Tukey test applied to the response of these pairs:

Six presumed Bad units → If Results into → Actual Bad units

Six presumed Good units → If Results into → Actual Good units

Validates the earlier Finding

5.0 Root Cause - Validation

5.1 Case Study – Shainin Validation

Shainin B vs C Test :

Response from Suspected "C" and Better "B" Process

6nos with Current (C) and 6 nos with claimed Better Process (B) are tightened in random order	C1	95.44	NOT OK
	C5	95.44	NOT OK
	C3	95.435	NOT OK
	C6	95.435	NOT OK
	C2	95.43	NOT OK
	C4	95.43	NOT OK
	B5	95.4	OK
	B2	95.39	OK
	B4	95.385	OK
	B1	95.38	OK
	B3	95.375	OK
	B6	95.37	OK

Tukey Test on Response

B1	95.38	OK	6 / 6 OK
B2	95.39	OK	
B3	95.375	OK	
B4	95.385	OK	
B5	95.4	OK	
B6	95.37	OK	
C1	95.44	NOT OK	6 / 6 NOT OK
C2	95.43	NOT OK	
C3	95.435	NOT OK	
C4	95.43	NOT OK	
C5	95.44	NOT OK	
C6	95.435	NOT OK	

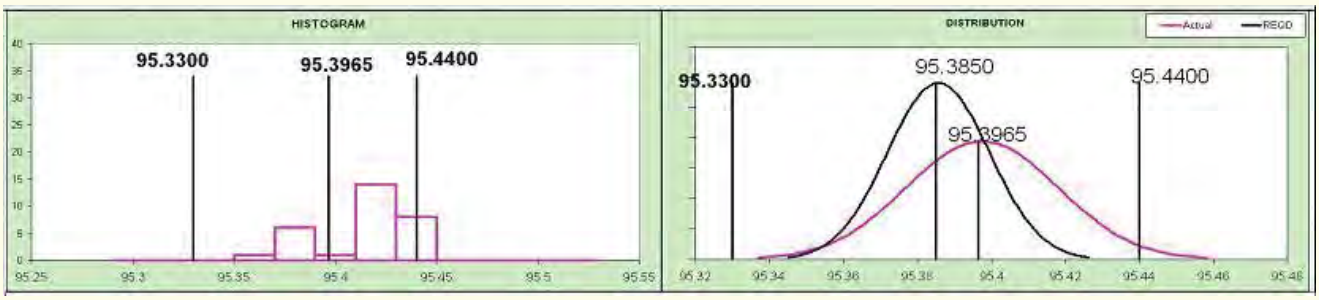
Inference: If the ID of the stator core is near to the top limit of the speciation – the defect occurs – this is validated.

Thus the Root cause of the defect is Validated

5.2 Case Study – Root cause

Stator ID Variation – Root cause :

Process Capability of Stator ID:



Cp = 1.44 Cpk = 1.25

Root Cause:

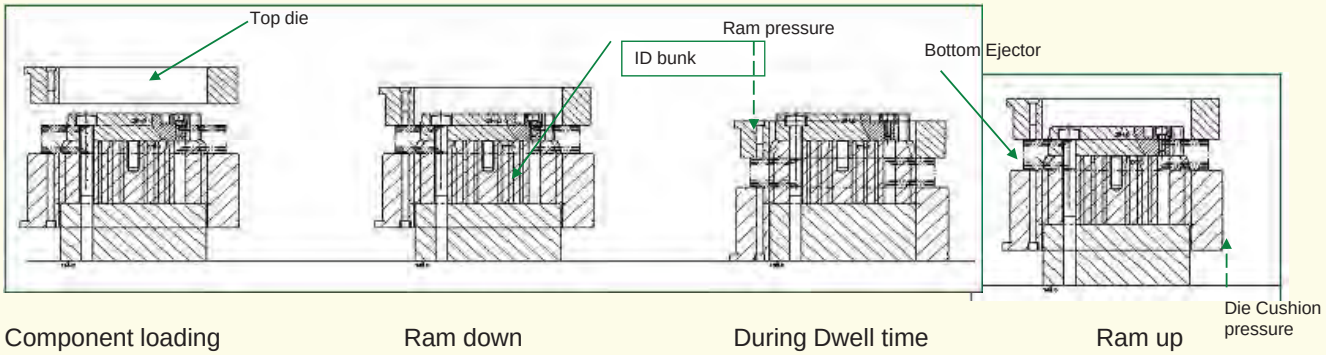
- Stators having ID near to the design target are Good.
- Whereas ID near to the top limit but still within specification are leading to defect
- And Stator ID population spreads up to the top limit of the specification

6.0 Improvement approach – Taguchi Method

6.1 Case Study – Improvement

Stator ID Manufacturing Process :

It is a coining process done in 250 ton hydraulic press



Component loading | Ram down | During Dwell time | Ram up

Factors affecting variation / Consistency in Stator ID :

1. **Ram Pressure**
2. **Dwell time**
3. **Diecushion pressure**
4. **Initial pack thickness of stator before coining**
5. **Coil hardness of stator material**

It is decided to conduct experiment at different levels of these known factors to identify significance

6.2 Case Study – Improvement

Improving Stator ID :

Selecting Levels of Factors & Response :

Factor		Level 1	Level 2
A	Ram Pressure	100 bar	160 bar
B	Dwell Time	3 Sec	5 Sec
C	Hardness	112 Bhn	119 Bhn
D	Die Cushion ejection pressure	5 Bar	20 bar
E	Pack Thickness	0.78 mm * 30 layers	0.81 mm * 31 layers
Interactions considered			
AB	Ram pressure & Dwell time		
AC	Ram pressure & Hardness		

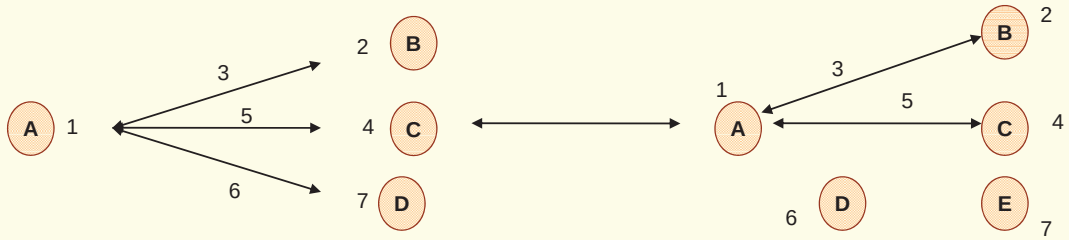
- Levels of factors and their interactions are selected based on domain knowledge and experience
- It is decided to measure Stator ID and ID ovality as Response

6.2 Case Study – Improvement

Improving Stator ID :

Experiment Design :

Taguchi L8 OA design is chosen – based on the no. of factors, their levels / interactions and Deg. Of freedom



	A	B		C		D	E
Factors	Ram Pr	Dwell time	1*2	Hardness	1*4	Die cushion	Initial pack
Column No.	1	2	3	4	5	6	7
Exp 1	1	1	1	1	1	1	1
Exp 2	1	1	1	2	2	2	2
Exp 3	1	2	2	1	1	2	2
Exp 4	1	2	2	2	2	1	1
Exp 5	2	1	2	1	2	1	2
Exp 6	2	1	2	2	1	2	1
Exp 7	2	2	1	1	2	2	1
Exp 8	2	2	1	2	1	1	2

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6.2 Case Study – Improvement

Improving Stator ID :

Experiment Response Table :

Factors								Response				
	Ram Pr	Dwell time	1*2	Hardness	1*4	Die cusion	Initial pack	Stator ID (mm) 95.33 - 95.44		ID Ovality (mm) 0.1 Max		
								Replication		Replication		
Column	1	2	3	4	5	6	7	A	B	A	B	
Exp 1	1	1	1	1	1	1	1	95.30	95.2	0.075	0.04	
Exp 2	1	1	1	2	2	2	2	95.29	95.38	0.07	0.025	Burr noticed
Exp 3	1	2	2	1	1	2	2	95.38	95.325	0.035	0.05	Burr noticed
Exp 4	1	2	2	2	2	1	1	95.40	95.39	0.055	0.045	
Exp 5	2	1	2	1	2	1	2	95.33	95.29	0.065	0.065	
Exp 6	2	1	2	2	1	2	1	95.00	95.315	0.045	0.05	Burr noticed
Exp 7	2	2	1	1	2	2	1	95.39	95.38	0.04	0.045	Burr noticed
Exp 8	2	2	1	2	1	1	2	95.33	95.34	0.04	0.04	

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6.3 Case Study – Improvement

Experiment ANOVA Table :

ANOVA TABLE- Stator ID

Source	SS	DOF	Mean Square	F_0	F_{tabld}
Ram pressure	0.0004	1.0000	0.0004	0.6677	
Dwell time	0.0062	1.0000	0.0062	11.7774	
1 & 2	0.0000	1.0000	0.0000	0.0267	
Hardness	0.0000	1.0000	0.0000	0.0030	5.3200
1 & 4	0.0015	1.0000	0.0015	2.8516	
Die cushion	0.0000	1.0000	0.0000	0.0742	
Initial Thickness	0.0003	1.0000	0.0003	0.5015	
Error	0.0042	8.0000	0.0005	1.0000	
Total	0.0126	15.0000			

Only Dwell time is Significant for Stator ID

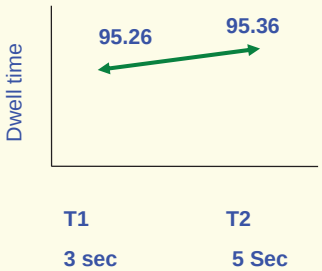
ANOVA TABLE - ID Ovality

Source	SS	DOF	Mean Square	F_0	F_{tabld}
Ram pressure	0.0000	1.0000	0.0000	0.0069	
Dwell time	0.0005	1.0000	0.0005	1.9931	
1 & 2	0.0001	1.0000	0.0001	0.3379	
Hardness	0.0001	1.0000	0.0001	0.5586	5.3200
1 & 4	0.0001	1.0000	0.0001	0.3379	
Die cushion	0.0003	1.0000	0.0003	1.1655	
Initial Thickness	0.0000	1.0000	0.0000	0.0069	
Error	0.0018	8.0000	0.0002	1.0000	
Total	0.0028	15.0000			

No factor is Significant for ID Ovality

6.4 Case Study – Improvement

Selecting Optimum Levels :



- From the Response graph the optimum level of the significant factor is chosen
- Dwell time of 5 Sec yields response closer to the design target
- The levels of other factors are chosen by studying the response table and based on Technical and economic feasibility etc..
- It is observed at Die cushion pressure of 20 bar – burr is noticed hence not chosen
- Further the hardness & initial pack are noise factors within the specified tolerance band and are not significant – hence the allowable tolerance band is chosen as optimum.

Recommended levels of factors :

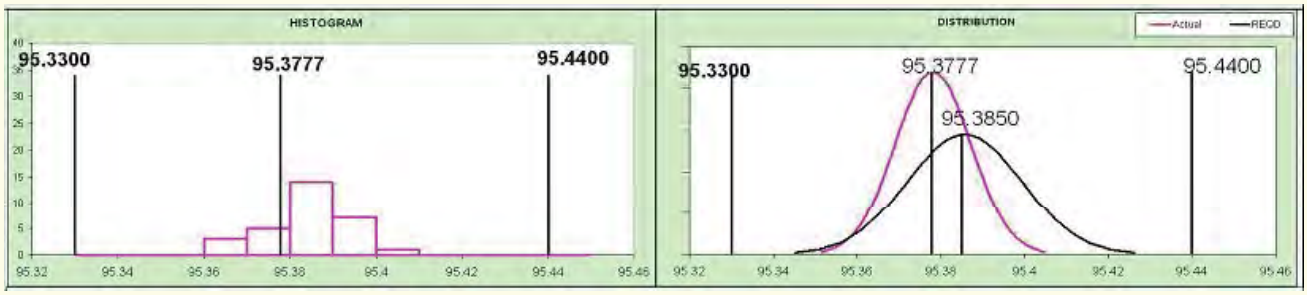
Ram pressure = 160 bar
Dwell time = 5 sec
Die cushion pressure = 5 bar

7.0 Result Validation

7.1 Case Study – Result Validation

Confirmatory experiment at Optimum Levels (Stator manufacturing) :

- An experiment run at optimum level & process capability observed



	Cp	Cpk
Before	1.44	1.25
After	2.02	1.75

Inference:

The selected Optimum levels have yielded the desired reduction in variation

7.2 Case Study – Result Validation

Confirmatory Second Production Trial Run (Alternator Assembly):

- Alternators assembled with stators manufactured from new process – with some stators selected near to the top limit of the improved population

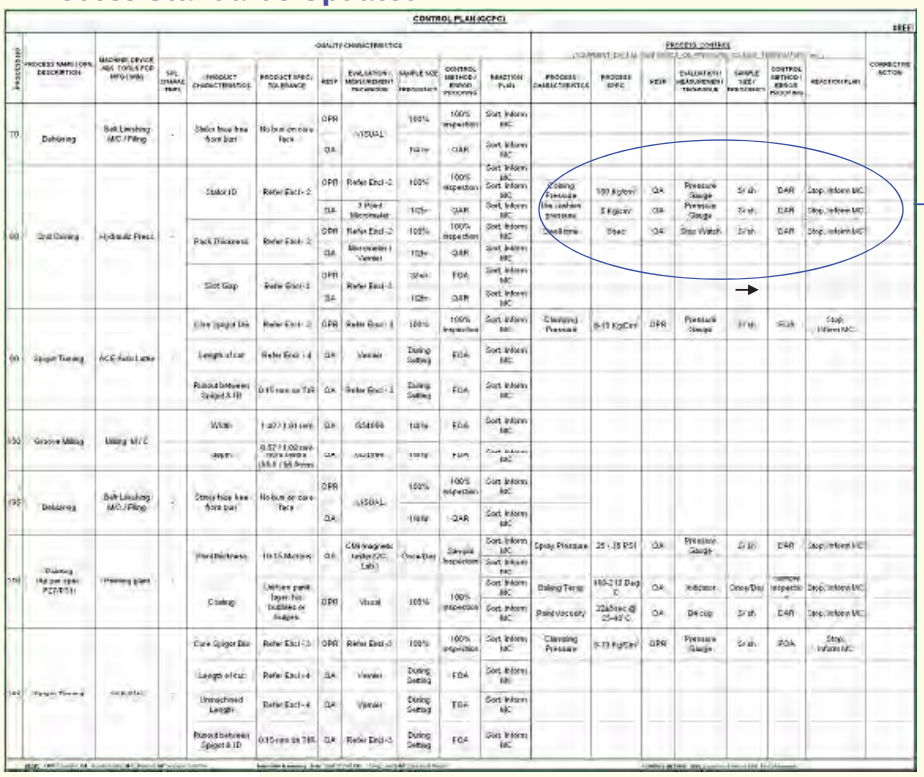
	Before Improvement	After Improvement
First pass Yield	84 %	98 %
Qty Produced (Nos)	200	200
Qty Rejected (Nos)	32	4
Failure Modes		
Initial Cut in Failure - W lamp Not OFF (Nos)	28	Zero
W lamp Not ON(Nos)	1	1
Mild Glow (Nos)	1	1
Bind (Nos)	1	
Pulley Damage (Nos)	1	
Through bolt damage		1
Brush Broken		1

Improving Stator ID Process Capability has Eliminated top ranked defect and has improved First Pass Yield of the Assembly

8.0 Standardisation

8.1 Case Study – Standardizing Improvement

Process Standards Updated:



CONTROL PLAN (GCPC)

PROCESS CHARACTERISTICS	PROCESS SPEC	RESP	EVALUATION / MEASUREMENT TECHNIQUE
Coining Pressure	160 kg/cm2	OPR	Pressure Gauge
Die Cushion	5 kg/cm2	OPR	Pressure Gauge
Dwell Time	5 Sec	QA	Stop watch

9.0 Conclusion

9.1 Case Study – Conclusion

Summary:

- Initial Production trial run of a new product – yielded low first pass yield.
- Major contribution of defect being from Initial Cut in Failure – Warning Lamp Not Off
- Cause & effect diagram indicated contribution from both process as well as parts.
- Shainin Clue Generating Experiments conducted - to quickly funnel down to the culprit
- Variation from the design target of Stator ID is identified as the root cause
- Taguchi L8 OA conducted to optimize the factors affecting the Stator ID
- The optimum levels improved the process capability
- The improved process capability Eliminated the Defect
- Second production trial run confirmed the findings
  – Paved way for PPAP and Production Ramp up without delay

9.2 Case Study – Conclusion

Inference :

- A new product with new performance standards – demands new process standards.
- A process standard acceptable to previous products – not acceptable to new product
- Shainin clue Generating tools – enhances the process of identifying the unknown cause
- Shainin Clue generating tools – questions the design specification also
- Shainin Tools generates clue from the available product & process
- Taguchi OA enhances the optimization process once the unknown cause is identified

Future Study :

- Taguchi Parameter designed experiment is to be conducted – to make the process more robust – irrespective of variation in noise factors.
- A study for integrating various problem solving tools are required.

10.0 Overview of Shainin Tools

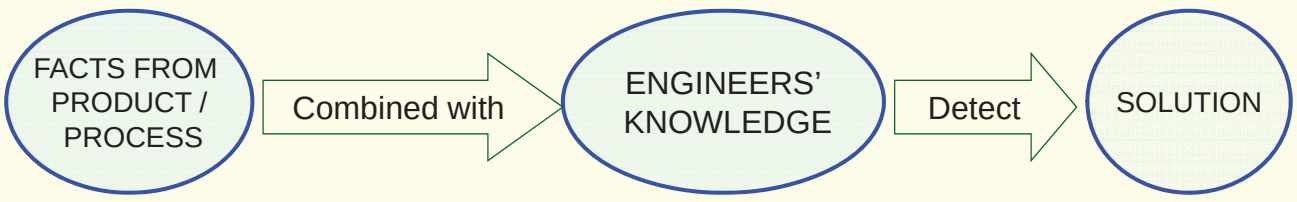
10.1 Overview of Shainin Tools

SHAININ PHILOSOPHY

DO NOT LET THE ENGINEERS DO THE "GUESSING"

LET THE PARTS "DO THE TALKING"

DETECTIVE APPROACH TO SOLUTION



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10.2 Overview of Shainin Tools

CLUE GENERATING TOOLS

MULTI - VARI

TO FILTER CYCLICAL ; POSITIONAL & TEMPORAL VARIATION

COMPONENT SEARCH

TO FILTER PRODUCT PARAMETERS WHEN COMPONENTS ARE INTERCHANGEABLE

PAIRED COMPARISON

TO FILTER PRODUCT PARAMETERS

CONCENTRATION CHART

TO FILTER VARIATION WITHIN UNIT

PRODUCT PROCESS SEARCH

TO FILTER PROCESS PARAMETERS

TO FILTER OUT UNIMPORTANT VARIABLES

WHEN VARIABLES ARE UNKNOWN & MANY

Dr. N. Ravichandran

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10.3 Overview of Shainin Tools

FORMAL DOE

VARIABLES SEARCH

5 TO 20 VARIABLES

FULL FACTORIAL

4 OR FEWER VARIABLES

B vs C TEST

ONE VARIABLE

TO HOME IN ON RED X - ROOT CAUSE

WHEN VARIABLES ARE KNOWN

Dr. N. Ravichandran

10.4 Overview of Shainin Tools

VALIDATION TOOL

B vs C TEST

TO CHECK PERMANENCY OF IMPROVEMENT

TURNING THE PROBLEM ON & OFF

WHEN ROOT CAUSE IS KNOWN

10.5 Overview of Shainin Tools

OPTIMISATION TOOLS

SCATTER PLOTS

WITH NO INTERACTION OF FACTORS

RSM RESPONSE SURFACE METHODOLOGY

WITH INTERACTION OF FACTORS

TO FIND REALISTIC SPECIFICAITONS & TOLERANCES

TIGHTEN THE TOLERANCES OF IMPORTANT VARIABLES

OPEN UP TOLERANCES OF UNIMPORTANT VARIABLES

10.6 Overview of Shainin Tools

Salient Learning Points

- MOST UNSUSPECTED CAUSES ARE REVEALED USING CLUE GENERATING TOOLS.

- CONFORMANCE TO SPECIFICATION DOES NOT MEAN FREE OF DEFECT.

Thank You