June 21, 2011 (Tuesday) 55th EOQ Congress

CONCURRENT SESSIONS **Tuesday 13:30 – 17:30**
KEMPINSKI HOTEL CORVINUS **Erzsébet tér 7-8, Budapest V.**

REGINA BALLROOM III. **Tuesday 15:30 – 17:30**

12.2. MANAGEMENT OF QUALITY OR QUALITY OF MANAGEMENT II.

Session Chair: ***Asbjørn Aune***, *Norwegian University for Science and Technology, Norway*

17.00 **Process Evolution through Integration of Shainin and Taguchi**
A Case Study in Alternator Manufacturing
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Process Evolution through Integration of Shainin and Taguchi

A Case Study in Alternator Manufacturing

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Abstract:

To attain world-class standards, use of scientific tools having "right response and ease of use" is required. There is no single tool or technique to achieve this – it requires integration of various tools complementing one another. This case study, explains how a practical shop-floor problem is resolved through process evolution in a similar manner.

Alternator manufacturing involves a complex set of manufacturing process, from component through sub assemblies to the final assembly. When a new product is introduced, the manufacturing ramp up is an important phase as it is a learning phase to understand the product / process relationship and improve the yield, which are normally low in the beginning. During introduction, the product and process standards are initially decided based on the Historical Knowledge. It is during the initial production and ramp up phase, the problems are surfaced – requiring quick understanding of the product / process relationship, which leads to quick evolution of the process / product. In this case study, one such evolution of the manufacturing process during a new product introduction is explained. It is observed during the pilot production run, that certain proportion of the final product is not performing to the required level, even though all the elements are conforming to specification. This is resolved through evolving the process standards to match the product performance. Shainin Clue – generating tools are used to identify the culprit among the conforming components / sub assemblies and the final assembly process. Having understood the causal relationship and the requirement of the process, Taguchi OA technique is used to optimize the process. .

This use of complementing tools has lead to evolution of improved process, which also enhanced the electrical performance of the Alternator. The Integrated use of various tools provides scope for future research – in process evolution and improvement.

Keywords: Shainin Technique, Taguchi orthogonal Array, Component Search, Paired Comparison, B vs C test.

1. Introduction:

The function of an alternator is to generate electrical power to operate electrical accessories in the automobile and also to charge the battery when the automobile is running. The alternator has mainly four structural parts the Stator, rotor and two aluminum brackets to hold them together, one on Driven End (DE) and one on Slip Ring End (SRE). The rotor is held in between bearings one on each bracket and rotates inside the stator (Fig 1). In addition, an alternator has a Regulator to regulate the excitation voltage which in turn decides the output power and a Rectifier to convert the generated AC power into DC. The driver of an automobile is informed, whether the alternator is generating the required power or not, through a “Warning Lamp” in the Dash board. After switching on the battery key this lamp will glow and after starting the automobile this lamp will get switched OFF once the required power is generated. Hence if this lamp is not getting switched off – it means alternator is not giving the required output power.

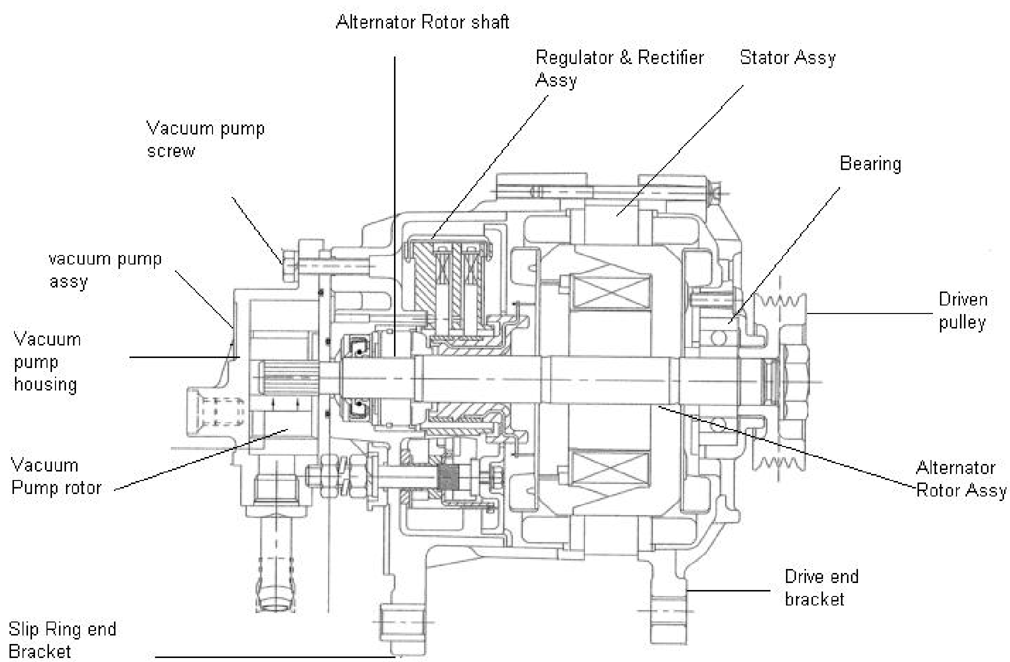


Fig 1 : Alternator Sectional View

2. Problem Statement:

The assembly line of alternator has nearly 20 stations and at the end of the assembly, the performance of the alternator is tested. When introducing a new product, the rejections at the end of line testing is high during the pilot production run. The major phenomenon for rejection is “Warning lamp Not Off”.

When the alternator starts rotating, at the initial cut-in speed of 1790 RPM, it should generate more than the threshold current of 0.1 Amps – to switch off the warning lamp in the dash board. But it is observed 15% of the alternators assembled are generating less than 0.1 amps.

3. Problem Analysis:

The cause & effect diagram of this phenomenon (Fig 2) indicates – this problem may be due to either the assembly process or the constituent sub assemblies. Since this is the pilot production run of a new product – every component / sub assembly is checked 100% for conformance prior to assembly. Hence this rejection may not be due to non-conformance of constituent components. It may be due to either the assembly process or the variation within the tolerance band itself. Since ramp up is planned immediate, this problem is to be solved without any delay. In order to quickly funnel down to the culprit it is decided to use "Shainin technique" of problem solving.

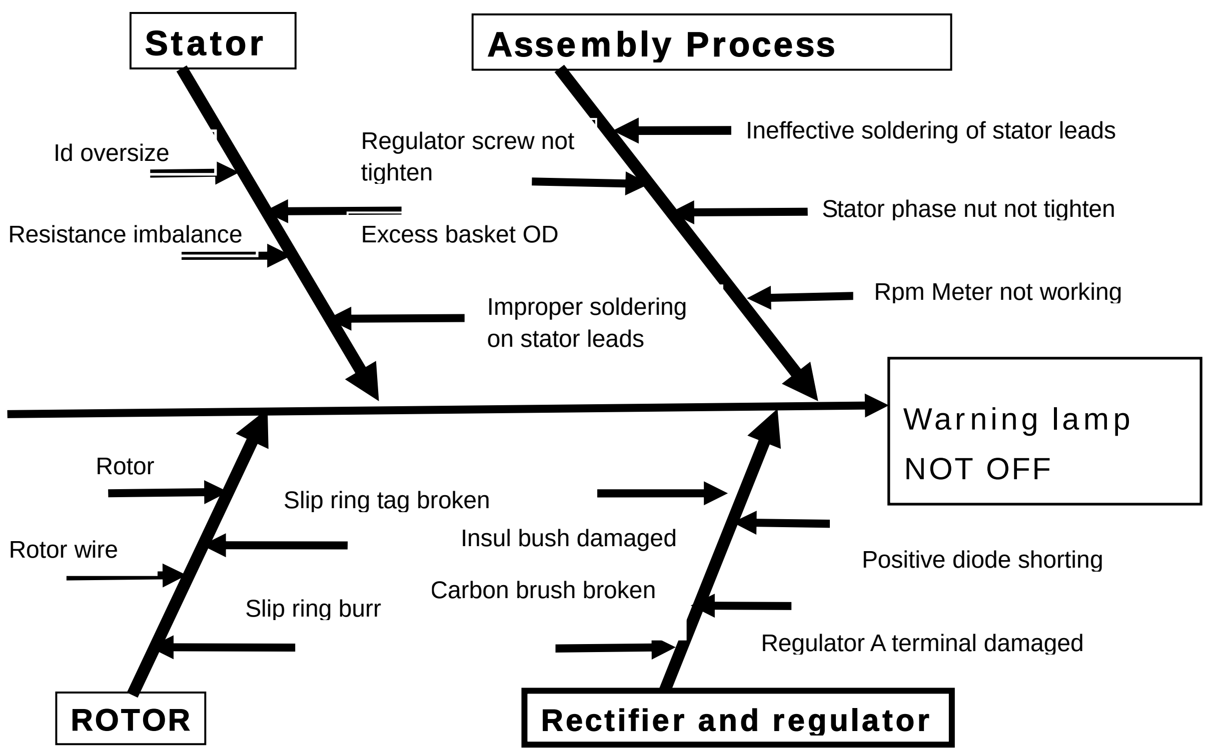


Fig 2: Cause & Effect Diagram

3.1 Identifying the Root Cause:

3.1.1 Shainin Component Search (Appendix 1)

This method is suitable for an assembled product to find out whether the defect in the product is due to the assembly process or one of its constituent parts [1]. The various steps are detailed in the Appendix. Initially one pair of Best of Best (BOB) and Worst of Worst (WOW) products are chosen for analysis. They are disassembled and reassembled twice to find out whether good remains good and bad remains bad consistently, through D/d Test. It is preferable to have a measurable response to do this D/d test. If the D/d ratio is greater than 1.25, it means the assembly process is consistent and the defect in the product is due to one of its constituent parts. To find out which is that part, the parts are interchanged between good and bad as predetermined and the part which totally reverses the performance of the product from good to bad and vice versa is termed the culprit

As detailed in Appendix 1, the search is conducted. The defect is found to be due to one of the sub-assembly and not the assembly process as evidenced from the initial D/d Test. Then through swapping of the sub assemblies as per the pre determined priority – it is observed the Stator is the culprit.

3.1.2 Shainin Paired Comparison (Appendix 2)

As a sequel to component search it is recommended that Paired comparison is done, as per Shainin. The principle of this method is that, when there is a good and bad component that is contributing to the defect, there must be something significantly different existing in that pair. If that difference could be identified the reason for the problem could be known [1]. Six pairs of SRE brackets from BOB and WOW are compared and the Tukey End Count Test is applied to find the significance as detailed in Appendix 2.

It is found that, the ID of the stator is contributing to the defect. Further it is observed that, the stators that are having ID near to the top specification limit are yielding bad alternators.

3.2 Validating the Root Cause:

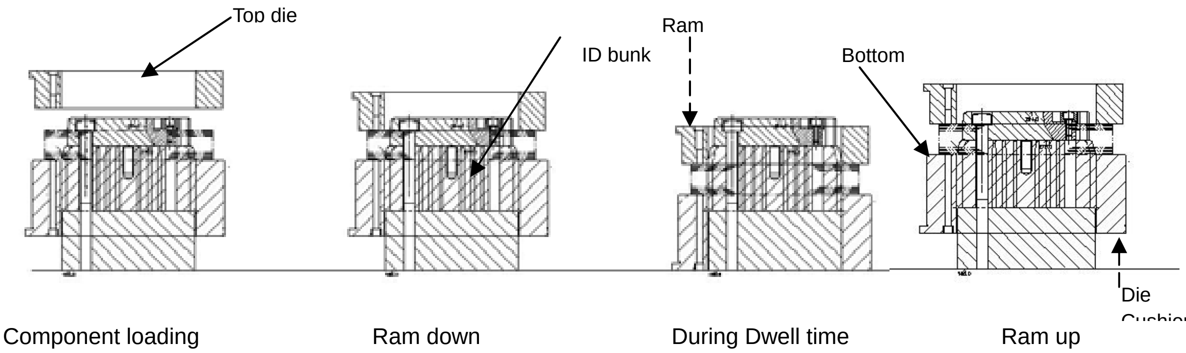
3.2.1 Shainin B vs C Test (Appendix 3)

In order to confirm the findings of Paired comparison, this validation test is done. In this six pairs of “assumed” good and bad stators are selected and assembled. If the output response behaves in accordance to the assumption – ie assumed good stators yield good alternators and assumed bad stators yield bad alternators – then the assumption is validated as correct [1]. This validation is done as detailed in Appendix 3, which confirms the finding. Hence the specification or tolerance band of the stator ID needs to be redefined.

4. Eliminating the Root Cause:

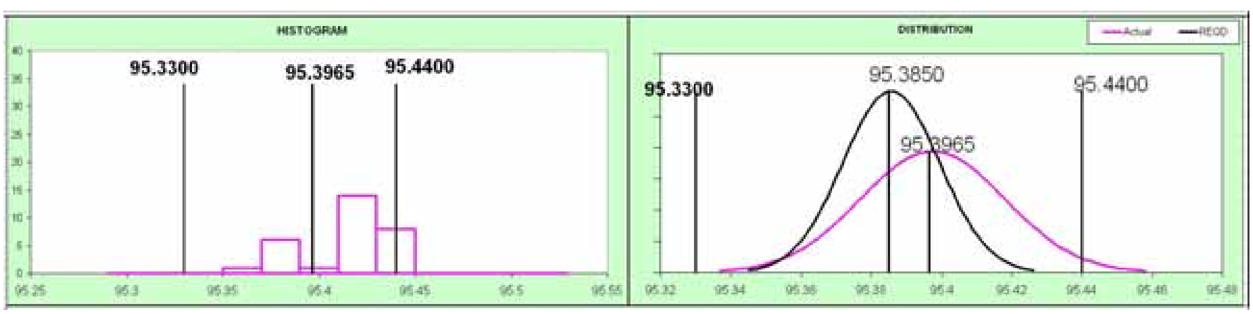
<u>4.1 Analysis of Stator core Manufacturing Process</u>:

The analysis of the stator manufacturing process indicates the stator ID is controlled during the stator Coining operation. This is a press operation wherein the stator core is squeezed in a tool under controlled pressure and time and then ejected out.(Fig 3)



<u>Fig 3: Stator Core Coining Operation</u>

The process capability study of the operation is as shown in (Fig 4} which indicates the variation in the operation need to be reduced to curtail the population near to the top limit of the specification. It is decided to conduct Analysis of Variance experiment to identify and optimize the significant parameters contributing to the Stator ID variation(Cp-1.44,Cpk-1.25).



<u>Fig 4: Stator ID Capability (Before Improvement)</u>

<u>4.2 Taguchi Orthogonal Array Experiment</u>: (Appendix 4)

The factors that can contribute to the variation in the Stator ID are identified and their levels that can yield reduced variation are decided based on engineering knowledge. The experiment is conducted as detailed in Appendix 4. Two responses are measured – ie. Stator ID and ovality in ID. From the ANOVA, it is found, the Dwell time is the only significant factor and the optimum level is decided from the response graph [2].

A confirmatory experiment with the optimum parameters has yielded the desired reduced variation as shown in the process capability study-Cp-2.02,Cpk-1.75 (Fig 5).

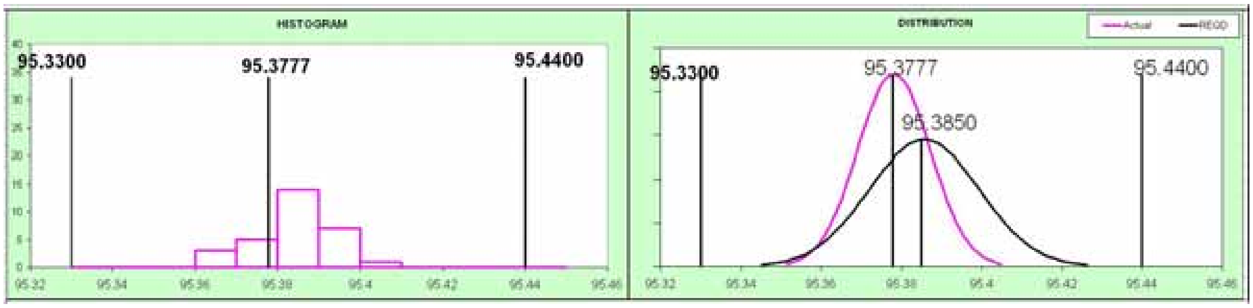


Fig 5 Stator ID Capability (After Improvement)

5. Validating and Standardizing the Improvement:

Checking Alternator Performance:& updating process standards:

Another Pilot production run of the new product is conducted with the modified process parameters of the stator manufacturing process. The result confirms the improvement has eliminated the rejection phenomenon of “Warning Lamp Not Off” Table 1 , Fig 6. Hence these process parameters are standardized in the control plan of the process.

Table 1: Process Yield Compared

	Before Improve-ment	After Improve-ment
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

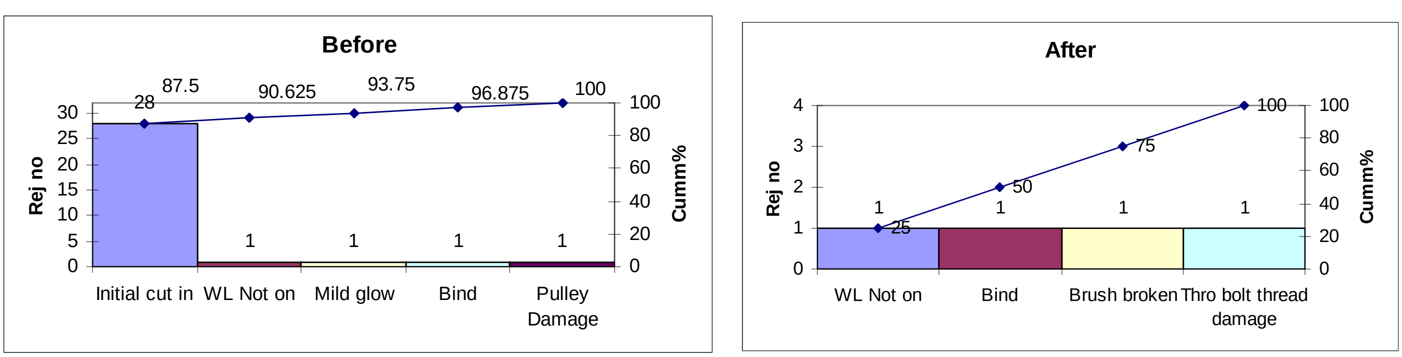


Fig 6. Rejection Pareto Compared

6. Conclusion:

Thus the cause of the problem identified during the pilot production trial run is understood and eliminated before PPAP, facilitating immediate ramp up of production. Initially, knowledge from the cause & effect diagram indicated various components and the assembly process as possible causes. Validation and elimination of these causes will normally require many experiments, but the use of Shainin Clue generating tools like Component search and paired comparison – enhanced the funneling down to the culprit. Shainin B vs C test is used to validate the finding / cause. It is observed nearly 15 % of the final product is not meeting the performance – even though the constituent components are conforming to the specification. The root cause is identified as the variation within the tolerance band. The variation which was acceptable to the earlier product is not matching the performance requirement of the new product introduced. Using the Taguchi OA experiment this variation is reduced leading to evolution of a more robust process. As a future improvement, it is proposed to conduct Taguchi Parameter Design considering the Noise Factors in Outer Array, to attain still more robust process. Thus a new product standard as required by the customer application, demands new process standards.

Thus the use of Shainin Clue Generating tools has elucidated the unknown cause, improving the Knowledge Bank. Once the cause is understood, the subsequent use of Taguchi OA leads to optimizing the process. Thus the integration of Shainin and Taguchi has lead to evolution of a more robust process.

References:

[1] **Keki R. Bhote et al** (2000) : " World Class Quality – Using Design of Experiments to Make it Happen" , AMACOM American Management Association, New York.

[2] Philip J. Ross, *Taguchi Techniques for Quality Engineering*, 1988, McGraw Hill Book company, New York

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Appendix 1

Shainin Component Search between Alternator Assembly Process and Alternator Product

1.0 **Ball park stage**

1.1 The Green Y is the WL Current measured at 1790 RPM

1.2 The least count of instrument is 0.01 A – acceptable

as per 5:1 rule of Product variation : Instrument variation

1.3 Two Best of Best (BOB) & Worst of Worst (WOW) alternator assembly were selected for analysis

1.4 Both the units were disassembled and reassembled twice -bad remained bad and good remained good.

Table A1.1 Ball Park Stage (Alternator)

	BOB WL Current	WOW WL Current
Initial assembly	0.31	0.08
After 1st re-assembly	0.32	0.06
After 2nd re-assembly	0.28	0.05
Median	0.33	0.065
Range	0.11	0.03

1.5 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

Since the D/d ratio is greater than 1.25, assembly process is stable and not the culprit.

1.6 **Control limits for WOW & BOB**:

Control limit = Median +/- (2.776/1.81)d

For BOB :- Min = 0.2227, Max = 0.4375;

For WOW - Min = -0.423, Max = 0.1723

2.0 Elimination stage

2.1 Components are ranked in the descending order of perceived importance to Green Y.

A : DE Bracket and Rotor Assy **B** :Rectifier assy **C**: Stator Sub assy

2.2 The above were interchanged and after interchange returned to original. The Experiment is stopped when total reversal occurs. In this case it happened when Stator sub assy is interchanged. Table A2.1

Table A2.1 - Component search Data -With in Alternator

Test No	Component switched over	Good assy control limits		Rejected Assy control		Results
		Max:0.4375A	Min:0.2227A	Max:0.1723A	Min:-0.423A	
		Assy	A	Assy	A	
1	Initial		0.31		0.08	
2	After Ist reassembly		0.32		0.06	
3	After IInd reassembly		0.28		0.05	
4	A:DE bracket & Rotor Assy	Ab Rest g	0.23	Ag Rest b	0.06	
	Return to original	All Good	0.25	All Bad	0.05	
5	B:Rectifier & Regulator Assy	Bb Rest g	0.29	Bg Rest b	0.08	
	Return to original	All Good	0.25	All Bad	0.05	
6	C:Stator sub Assy	Cb Rest g	0.06	Cg Rest b	0.32	Stator Sub assy is culprit
	Return to original	All Good	0.3	All Bad	0.07	
7	Capping run	Cb Rest g	0.05	Cg Rest b	0.31	Stator sub assy reconfirmed
	Return to original	All Good	0.29	All Bad	0.05	

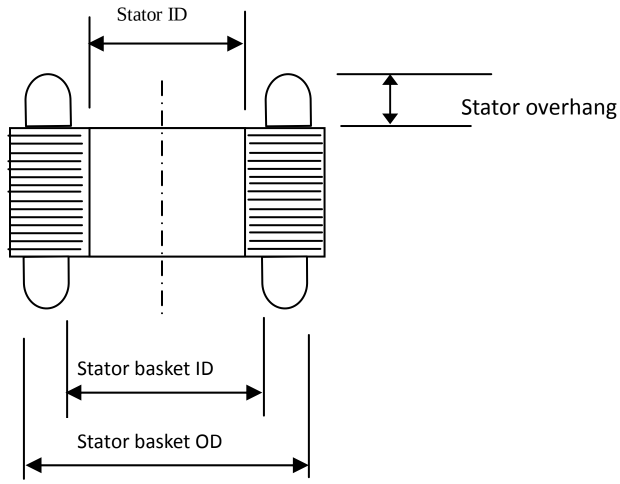
2.3 capping run stage:

The assembly is interchanged between the good and bad assemblies to reconfirm.

Appendix 2

Paired Comparison of Good and Bad

All the features of stator sub assy are to be checked – visual, dimensional, etc



SCHEMATIC DIAGRAM OF STATOR

Table: A2 .1 Paired Comparison

Sl no	Stator Basket OD	Stator Basket ID	Stator Overhang	Stator ID	ID Ovality
G1	119.10	99.2	15.24	95.39	0.07
G2	119.20	99.16	15.35	95.37	0.06
G3	118.95	99.17	15.39	95.38	0.065
G4	119.18	99.21	15.49	95.37	0.055
G5	119.14	99.36	15.65	95.39	0.06
G6	118.98	99.24	15.47	95.38	0.065
B1	118.93	99.14	15.45	95.44	0.05
B2	118.99	99.2	15.33	95.43	0.065
B3	119.1	99.18	15.21	95.44	0.06
B4	119.13	99.32	15.31	95.43	0.07
B5	119.17	99.22	15.27	95.425	0.065
B6	119.08	99.29	15.55	95.44	0.065

Tukey Test:

It is used to find the significant difference in the characteristics of good & bad – by End count method.

The end count determines the confident level of determining the significance. The method of calculating End count is as below.

- Each column is arranged in ascending / descending order.
- If the top & bottom entries belong to same good or bad then the end count is Zero
- If top & bottom are from different families then – the continuous entries of a family (good or bad) at top is top end count; similarly for bottom end count.
- Sum of top & bottom end counts is Total End count
- Depending on the total end count of that particular feature compared, the difference between good and bad is decided with the following confidence level:

Total End count is		
	6	Then Confidence level = 90%
	7	= 95%
	10	= 99%
	12	= 99.98%

Table: A2 .2 Tukey Test

	Sample	Stator basket OD		Stator basket ID		Stator Over hang		Stator ID		ID Ovality
	B1	118.93	B1	99.14	B3	15.21	G2	95.37	B1	0.05
	G3	118.95	G2	99.16	G1	15.24	G4	95.37	G4	0.055
	G6	118.98	G3	99.17	B5	15.27	G3	95.38	G2	0.06
	B2	118.99	B3	99.18	B4	15.31	G6	95.38	G5	0.06
	B6	119.08	G1	99.2	B2	15.33	G1	95.39	B3	0.06
	G1	119.1	B2	99.2	G2	15.35	G5	95.39	G3	0.065
	B3	119.1	G4	99.21	G3	15.39	B5	95.425	G6	0.065
	B4	119.13	B5	99.22	B1	15.45	B2	95.43	B2	0.065
	G5	119.14	G6	99.24	G6	15.47	B4	95.43	B5	0.065
	B5	119.17	B6	99.29	G4	15.49	B1	95.44	B6	0.065
	G4	119.18	B4	99.32	B6	15.55	B3	95.44	G1	0.07
	G2	119.2	G5	99.36	G5	15.65	B6	95.44	B4	0.07
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	

Appendix 3

B Vs C Test of Stator ID

Table: A3 .1 Random Experiment

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

Table: A3 .2 Tukey Test

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

Appendix 4

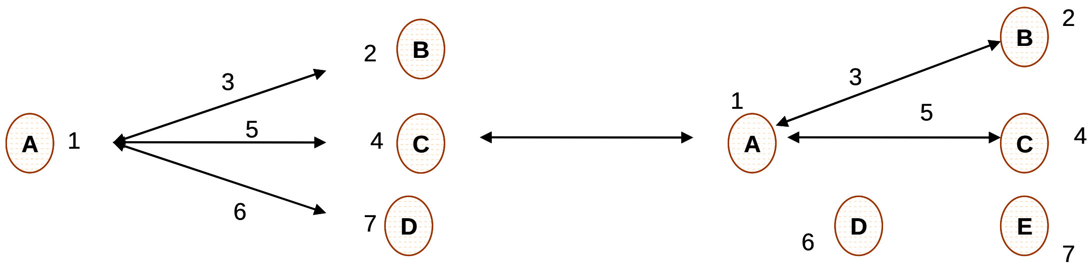
Taguchi Orthogonal Array Experiment

A4 .1 Identifying Factors and Levels:

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		

A4 .2 Experiment Formulations:

L8 OA is chosen for experiment and the standard linear graph is modified as required to assign the columns of the OA to the factors and interactions as shown:



STANDARD LINEAR GRAPH

MODIFIED LINEAR GRAPH

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

A4.3 Response Table & ANOVA for Stator ID:

	Ram Pr	Dwell time	1*2	Hardness	1*4	Die cusion	Initial pack	Core ID		Total
Column	1	2	3	4	5	6	7	A	B	
Exp 1	1	1	1	1	1	1	1	95.3	95.2	190.5
Exp 2	1	1	1	2	2	2	2	95.29	95.38	190.67
Exp 3	1	2	2	1	1	2	2	95.38	95.325	190.705
Exp 4	1	2	2	2	2	1	1	95.4	95.39	190.79
Exp 5	2	1	2	1	2	1	2	95.33	95.29	190.62
Exp 6	2	1	2	2	1	2	1	95	95.315	190.315
Exp 7	2	2	1	1	2	2	1	95.385	95.38	190.765
Exp 8	2	2	1	2	1	1	2	95.325	95.34	190.665
									Target Total	1525.03

Column	1	2	3	4	5	6	7
Level 1	762.665	762.105	762.6	762.59	762.185	762.575	762.37
Level 2	762.365	762.925	762.43	762.44	762.845	762.455	762.66
Range	0.3	0.82	0.17	0.15	0.66	0.12	0.29

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

Hence Dwell Time is the only significant factor.

A4.4 Response table and ANOVA for Stator ID ovality:

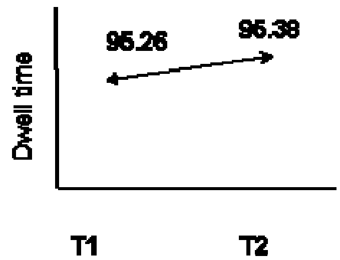
	Ram Pr	Dwell time	1*2	Hardness	1*4	Die cusion	initial pack	Ovality		Total
column	1	2	3	4	5	6	7	A	B	
Exp 1	1	1	1	1	1	1	1	0.075	0.04	0.115
Exp 2	1	1	1	2	2	2	2	0.07	0.025	0.095
Exp 3	1	2	2	1	1	2	2	0.035	0.05	0.085
Exp 4	1	2	2	2	2	1	1	0.055	0.045	0.1
Exp 5	2	1	2	1	2	1	2	0.065	0.065	0.13
Exp 6	2	1	2	2	1	2	1	0.045	0.05	0.095
Exp 7	2	2	1	1	2	2	1	0.04	0.045	0.085
Exp 8	2	2	1	2	1	1	2	0.04	0.04	0.08
									Target total	0.735

Column	1	2	3	4	5	6	7
Level 1	0.049375	0.054375	0.046875	0.051875	0.046875	0.053125	0.049375
Level 2	0.04875	0.04375	0.05125	0.04625	0.05125	0.045	0.04875
Range	-0.000625	0.010625	-0.00438	-0.00563	-0.00438	0.008125	-0.00063

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

No factor is having significant effect on ovality.

A4.5 Selecting Optimum Level:



From the response graph, level 2 of the Dwell time is giving the better response. To decide the levels of the other factors, the experiment that is yielding the best response nearer to the design target is chosen, It is found to be experiment no. 7.

Hence the optimum levels of the factors are identified as:

Recommended levels of factors

Ram pressure = 160 kg/cm2

Dwell time = 5 sec

Die cushion pressure = 20 kg/ cm2

The other parameters are considered noise factors and it is proposed to do a Taguchi parameter Design to make the process more robust.