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A Paper On Plunge Grinding Cycle Time Optimization Without Hampering Surface Quality Of Deep Groove Ball Bearing's Outer Ring's Inner And Outer Races

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Abstract

This paper presents a detailed study as to how we can achieve optimum Cycle time without hampering Quality while performing grinding operations on the Deep Groove Ball Bearing (Inner and Outer Races). This work has demonstrated the application of Half Fraction Factorial Design method to achieve optimal production cycle time for 6203 Deep groove ball bearing. For study fifteen likely parameters were identified in their descending order of priority along with the process expert. Two operating levels, one Best of the Best (BOB) & other Worst of the Worst (WOW) were selected and three sets of runs were conducted. Then another three sets of runs were conducted with revised set of parameters.

Keywords— deep groove; plunge grinding; race; cycle time

1.INTRODUCTION

Demands of customer are raising day by day and are equally becoming sopisticated due to many alternatives and huge competition. The most important function of grinding process is to generate the specified functional characteristics for surfaces. Functional characteristics generated by grinding process include Good geometry (profile, radius, waviness, surface roughness), Good Capability (short spread, stable trend, robust process), Good visual aspect (no damage). But along with quality Cycle time reduction has become a key area of opportunity for organizations that are under increasing pressure to get more done with fewer resources in order to remain competitive. By reducing cycle time organizations can reduce cost, increase quality, and improve customer service. All too often in organizations, less than five percent of the total elapsed time performing a process has anything to do with real work.

The main reference on optimal cycle calculation in grinding processes is the work developed by Malkin. Based on this work, R. Bueno and San Sebastian has successfully developed the GrindSim software to set-up and optimizes cylindrical grinding processes. Two possible criteria can be used to design a grinding cycle: 1) Minimize the process cycle time or 2) Adjust the cycle to a previously established process time, minimizing wheel wear. The process parameters to be optimized include the feed for each stage of the infeed cycle, the stock removal in each stage and the spark-out time.

2. MATERIALS AND METHODS

2.1 Design of experiments

The design of experiments technique is a very powerful tool, which permits us to carry out the modeling and analysis of the effect of process variables on the response variables. The response variable is an unknown function of the process variables, which are known as design factors. In the present study, the design factors selected are: Gap eliminator safety position (μ), Sizematic Knockoff 1 Position (μ), Incremental retreat 1, initial (μ), Incremental retreat 2, initial (μ), Air Grinding Feed Rate (μ/sec), Rough 2 feed rated (μ/sec), Fine feed rate (μ/sec), Spark out feed rate (μ/sec), Gap eliminator setting (%),Grinding compensation (μ), Grinding compensation interval (cycles), Dress interval (cycles), Dress feed rate (μ/sec), Dress compensation (μ), Spark out time (sec).

The values of process parameters according to the experiment plan were varied within following limits, as shown in table below –

Table 1. Parameters selected

Parameter		Levels B	Levels M	Description
A	R 102	160	250	Gap eliminator safety position (μ)
B	R 104	60	90	Sizematic Knockoff 1 Position (μ)
C	R 110	3	10	Incremental retreat 1, initial (μ)
D	R 111	2	8	Incremental retreat 2, initial (μ)
E	R 127	200	1000	Air Grinding Feed Rate (μ/sec)
F	R 129	40	80	Rough 2 feed rated (μ/sec)
G	R 130	20	50	Fine feed rate (μ/sec)
H	R 131	1	4	Spark out feed rate (μ/sec)
I	R 133	1	5	Gap eliminator setting (%)
J	R 117	0.5	5	Grinding compensation (μ)
K	R 144	1	8	Grinding compensation interval (cycles)
L	R 143	8	15	Dress interval (cycles)
M	R 132	10	30	Dress feed rate (μ/sec)
N	R 115	5	10	Dress compensation (μ)
O	R 114	0.3	0.8	Spark out time (sec)

2.2 Response variables selected

Diameter is used as the response variable for the process. For selecting the most affecting parameter, we will first calculate decision Limits for all 15 selected parameters, and those parameters whose Standard Deviation exceed the respective decision limit values will be considered as most affecting parameters. It is useful for detecting general variations in the process and for monitoring an established manufacturing process. Hence, in present study diameter which describes the geometry and standard deviation have been selected as the response variable.

2.3 Machine Specifications

The machine used for grinding of 6203 Bearing type is SSB 200. The technical specifications of this machine are as follows: -

Table 2. Machine specification

Work piece dimension – OD	-	20 - 160 mm
Work piece dimension - loading width	-	100 mm
Work piece dimension – grinding width	-	100 mm
Machine weight	-	6850 kg

As the Deep grove ball bearing used in work is of 6203 grade whose OD is in between the range 20 – 160mm hence as per the specifications and technical data of SSB 200 it is the best choice for machining operations to be done on 6203 grade bearing.

Slides systems: -

Linear motor driven hydrostatic cross and length slides, repeatability accuracy 0.05 μm.

Dressing: - Two options of dressers available:
- Hydraulic motor driven full profile diamond roller dresser.
- Electro-spindle driven cup wheel dresser.

Both dressers are mounted on a hydraulic pivoting unit fixed on the cross slide.

Grinding spindles: -

A wide range of high-frequency spindles are available. Grinding wheel peripheral surface speeds up to 80 m/s.

Work head spindle: -

The hydrostatic work head spindle, made by KMT Precision Grinding is servo motor driven.

Gauging method: -

In-process 2-finger electronic gauging head. The gauging unit operates through the work head spindle.

Machine control: -

Graphical user interface provides user-friendly controls. Control System, Siemens 840D.

Chucking principle: -

Shoe centerless or centric chucking. In both cases, the work pieces are loaded/unloaded through chutes. A hydraulically driven V-type loader is handling the work pieces between the chuck and the chutes.

Grinding Operations: -

Internal grinding of bearing rings (or similar) of various types and dimensions.

2.4 Workpiece material

Material of Deep groove Ball Bearing (all parts including outer ring) is 52100 Chrome Steel having 60 – 64 Rc Hardness. Composition of AISI 52100 USA chrome steel is as follows: -

Carbon (C) = 0.95 – 1.1%, Silicon (Si) – 0.15 – 0.35%, Manganese (Mn) = 0.5% max., Phosphorous (P) = 0.0.12% max., Chromium (Cr) = 1.3 – 1.6%, Molybdenum (Mb) = 0.08% max., Nickel (Ni) = 0.25% max.and Sulphur (S) = 0.25% max.

Properties of 52100 Chrome Steel include high strength to resist cracking and it provides hard surface to resist subsurface rolling contact fatigue.

2.5 Measurement Technique used

Measurement technique used in this work involves only the deviation of grinded outer ring dimensions from original outer ring dimensions. For this purpose a Universal Deviation apparatus (UDA) is used. Thus UD Apparatus does not measure actual dimension but it measures deviation of ring dimension from actual dimension. Figure below shows the UD apparatus.

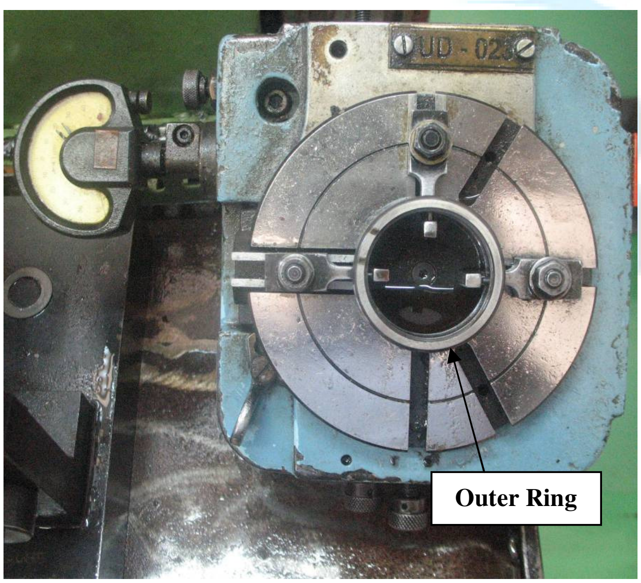

Fig. 1. Set-up for checking ring diameter

The results given by UD test are of patterns as shown in below figure

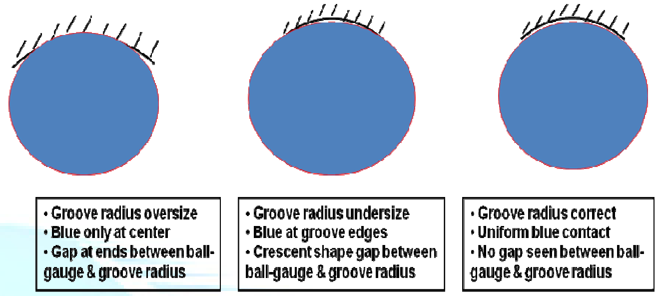

Fig. 2. Patterns of groove diameter given by UD test

2.6 Calculation of Decision Limits

Decision limits are those values that will establish a range for identifying the most influencing parameters. Statistical ways have been adopted to calculate the values of decision limits for both Driving as well as Clamping sides of the outer ring of the bearing.

A set of 90 outer rings have been taken to check for the inner race diameter, keeping in view that best machining results are obtained in the mid-process span, i.e., pre 30 rings and post 30 rings are not expected to go through fine grinding, and hence best grinding is observed on the mid 30 rings that are ground.

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Table 3. 90 Rings Trial

Sl. No.	Driving Side Ab	Driving Side Am	Clamping Side Ab	Clamping Side Am
1	8.5	10	10.5	16
2	10	21.5	14.5	26.5
3	11.5	19	18	26.5
4	9.5	16	18.5	20.5
5	8.5	13	18.5	24.5
6	8.5	14.5	14	16.5
7	10	10	13.5	13.5
8	8	16.5	13	22
9	7.5	12.5	9.5	17
10	6.5	5.5	8	12.5
11	8.5	15.5	7.5	18
12	8	13	8.5	15
13	6	8	8.5	12.5
14	9	15.5	8.5	20
15	7	10	8	15.5
16	5	5.5	8	12
17	5.5	15	7.5	17.5
18	5.5	13	8	15.5
19	5.5	13.5	5	19.5
20	5.5	14.5	6	14.5
21	5.5	9.5	6.5	14
22	3	7	4.5	12.5
23	6.5	17	6	9.5
24	7.5	11	8	14
25	4	8	5	11
26	5	9.5	6.5	14.5
27	3.5	15	8.5	17.5
28	4.5	8.5	6.5	10.5
29	5.5	6.5	6.5	11.5
30	4.5	8.5	6	14
Stdev	2.128	4.079	4.019	4.476

Table 4. Decision Limits Calculation

Driving Side

	Median
Ab	2.1282
Am	4.0791
	Range
Ab	0.6764
Am	1.9377

d	1.3071
D	1.9510

D / d	1.4927

Calculation of decision limits

Formula Used	median ± 2.776(d/1.81)

	Decision Limits	
Ab	0.1235	4.1328
Am	2.0745	6.0838

Ab	All Best
Ab	All Marginal

Sl. No.	Driving Side Ab	Driving Side Am	Clamping Side Ab	Clamping Side Am
1	8.5	12.5	5.5	18
2	9.5	10	6.5	14
3	9.5	12.5	7.5	16.5
4	6.5	10.5	8.5	13.5
5	8.5	9.5	10	13.5
6	8.5	16.5	7	21
7	8.5	15	7	17
8	8.5	10	9.5	13.5
9	7	15	4	18
10	4.5	4.5	5.5	10.5
11	10	11	8.5	13
12	9	9	4.5	12.5
13	8	14	5.5	19.5
14	8.5	10.5	5.5	16.5
15	10.5	12.5	6.5	14.5
16	10	11.5	6	14.5
17	7	17.5	3	8.5
18	5.5	10	8.5	14.5
19	7	13.5	9	16.5
20	6.5	4	5	9
21	9	13.5	6.5	15.5
22	9	5	10.5	9.5
23	7.5	13.5	8.5	14
24	6.5	12	4	14.5
25	7.5	9.5	5	9.5
26	6	5.5	3.5	12.5
27	5.5	11	5	13.5
28	4.5	14.5	3.5	16
29	8.5	8	1.5	12.5
30	13.5	11.5	10.5	14
Stdev	1.903	3.378	2.344	3.005

	Median
Ab	2.3440
Am	4.4763

	Range
Ab	1.7402
Am	1.7630

d	1.7516
D	2.1322

D / d	1.2173

Clamping Side

Formula Used		median ± 2.776(d/1.81)

	Decision Limits		
Ab	-0.3424		5.0305
Am	1.7899		7.1627

Ab	All Best
Ab	All Marginal

2.7 Selecting the most affecting parameters

For selecting the most affecting parameter, we will first calculate decision Limits for all 15 selected parameters, and those parameters whose Standard Deviation exceed the respective decision limit values will be considered as most affecting parameters.

This is done by keeping one variable constant at a time (one best and rest marginal), i.e., one variable is set at its best value and other 14 are set at their marginal values.

	Driving Side		Clamping Side	
Sl. No.	Ab	Am	Ab	Am
1	10.5	11.5	10	13.5
2	12.5	3	7.5	8.5
3	10	15.5	11.5	22
4	9.5	13.5	9	19.5
5	10	13.5	8.5	13
6	10.5	10	11	10.5
7	10.5	14	10	13
8	12	13.5	12	16
9	12	12.5	13	14.5
10	11	6	13	11.5
11	11.5	12	11	12.5
12	10.5	8	12	11
13	10.5	20	12.5	20.5
14	10	23	12	22
15	11	10.5	10.5	12.5
16	8.5	5.5	11.5	9
17	5	4	6	7.5
18	7.5	10	8	15
19	8.5	8	9	12
20	6	14.5	7.5	24
21	5	6	6	8.5
22	5.5	4	6	7
23	4.5	0.5	8.5	6
24	6.5	5	9.5	11
25	6.5	0.5	8	7.5
26	9	8.5	9.5	11
27	7.5	6.5	5.5	10
28	5.5	13.5	7.5	16.5
29	5	10.5	8.5	14
30	4.5	5	6	9
Stdev	2.579	5.315	2.279	4.768

Following is the Table which gives the conclusions on the same for Driving Side.

Table 5. Most affecting parameter selection for driving side

Run	Stdev	Decision Limits		Conclusion
AbRm	45.1432	2.0745	6.0838	A-Siginificant
AmRb	3.2502	0.1235	4.1328	
BbRm	41.1972	2.0745	6.0838	B-Significant
BmRb	2.5146	0.1235	4.1328	
CbRm	41.5781	2.0745	6.0838	C-Significant
CmRb	1.8862	0.1235	4.1328	
DbRm	4.8419	2.0745	6.0838	D-Not Significant
DmRb	1.7564	0.1235	4.1328	
EbRm	3.5163	2.0745	6.0838	E-Not Significant
EmRb	2.2957	0.1235	4.1328	
FbRm	4.9366	2.0745	6.0838	F-Not Significant
FmRb	4.1118	0.1235	4.1328	
GbRm	4.3824	2.0745	6.0838	G-Significant
GmRb	6.3444	0.1235	4.1328	
HbRm	3.4560	2.0745	6.0838	H-Not Significant
HmRb	2.4946	0.1235	4.1328	
IbRm	3.0335	2.0745	6.0838	I-Not Significant
ImRb	2.3134	0.1235	4.1328	

JbRm	4.6478	2.0745	6.0838	J-Significant
JmRb	20.6275	0.1235	4.1328	
KbRm	40.6450	2.0745	6.0838	K-Significant
KmRb	4.1950	0.1235	4.1328	
LbRm	4.4016	2.0745	6.0838	L-Not Significant
LmRb	1.7473	0.1235	4.1328	
MbRm	3.8387	2.0745	6.0838	M-Not Significant
MmRb	1.8523	0.1235	4.1328	
NbRm	3.2816	2.0745	6.0838	N-Not Significant
NmRb	2.9816	0.1235	4.1328	
ObRm	3.0667	2.0745	6.0838	O-Not Significant
OmRb	2.2664	0.1235	4.1328	

Following is the Table which gives the conclusions on the same for Clamping Side.

Table 6. Most Affecting Parameter Selection For Clamping Side

Run	Stdev	Decision Limits		Conclusion
AbRm	46.0755	2.0745	6.0838	A-Siginificant
AmRb	2.7883	0.1235	4.1328	
BbRm	41.8699	2.0745	6.0838	B-Significant
BmRb	3.1195	0.1235	4.1328	
CbRm	42.5428	2.0745	6.0838	C-Significant
CmRb	2.2281	0.1235	4.1328	
DbRm	4.8220	2.0745	6.0838	D-Not Significant
DmRb	1.6078	0.1235	4.1328	
EbRm	4.9141	2.0745	6.0838	E-Not Significant
EmRb	3.8123	0.1235	4.1328	
FbRm	4.6723	2.0745	6.0838	F-Not Significant
FmRb	2.0996	0.1235	4.1328	
GbRm	6.6251	2.0745	6.0838	G-Significant
GmRb	2.3798	0.1235	4.1328	
HbRm	2.7697	2.0745	6.0838	H-Not Significant
HmRb	2.5984	0.1235	4.1328	
IbRm	2.9812	2.0745	6.0838	I-Not Significant
ImRb	2.4143	0.1235	4.1328	
JbRm	3.9474	2.0745	6.0838	J-Significant
JmRb	21.1641	0.1235	4.1328	
KbRm	40.6013	2.0745	6.0838	K-Significant
KmRb	3.3571	0.1235	4.1328	
LbRm	2.9016	2.0745	6.0838	L-Not Significant
LmRb	1.9552	0.1235	4.1328	
MbRm	3.5867	2.0745	6.0838	M-Not Significant
MmRb	2.0150	0.1235	4.1328	
NbRm	3.6255	2.0745	6.0838	N-Not Significant
NmRb	7.6628	0.1235	4.1328	
ObRm	3.0476	2.0745	6.0838	O-Not Significant
OmRb	2.6332	0.1235	4.1328	

Thus from Tables we conclude that the significant parameters affecting the grinding cycle time are: -

A - Gap eliminator safety position (μ),
B - Sizematic Knockoff 1 Position (μ),
C - Incremental retreat 1, initial (μ),
G - Fine feed rate (μ/sec),
J - Grinding compensation (μ), and
K - Grinding compensation interval (cycles)

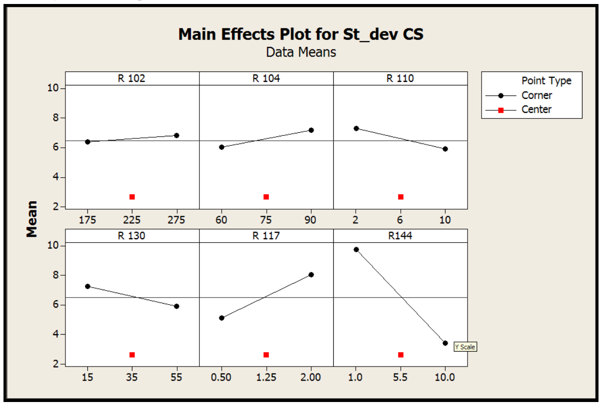
3. Results and Discussions

The influence of the process parameters on the response variables selected, viz., surface finish and cycle time, have been assessed for Inner race of outer ring of Deep groove ball bearing by conducting experiments as disused earlier. Half fractional factorial design was applied in planning and conducting the experiment. Each parameter was taken at two levels – Best Level and Marginal Level, only, thus considering that the response varies linearly with change in input conditions. The results of the screening experimentation thus showed that out of fifteen parameters considered, the 6 parameters, Gap eliminator safety position (μ), Sizematic Knockoff 1 Position (μ), Incremental retreat 1 initial (μ), Fine feed rate (μ/sec), Grinding compensation (μ) and Grinding compensation interval (cycles) were significant.

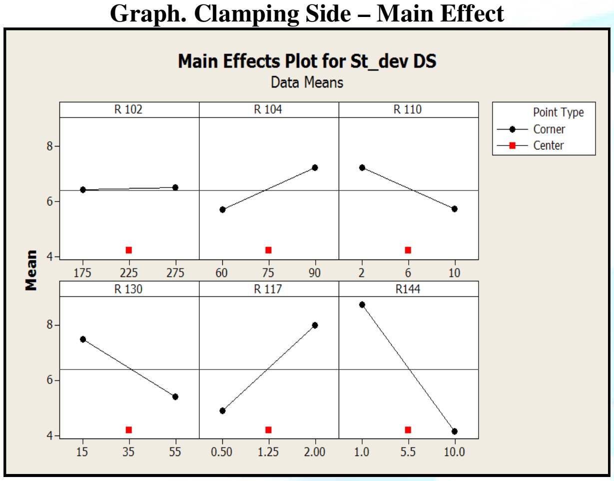
The results are then put into the Minitab software for further analysis.

Validation of the models: Graphical tools

It is usually necessary to check the fitted model to ensure it provides an adequate approximation to the real system. Unless the model shows an adequate fit, proceeding with investigation and optimization of the fitted response it is likely to give poor and misleading results. Graphical tools can be used to validate the models. The graphical method characterizes the nature of residual of the models. A residual is defined as the difference between an observed value and its fitted value.



Graph. Clamping Side – Main Effect

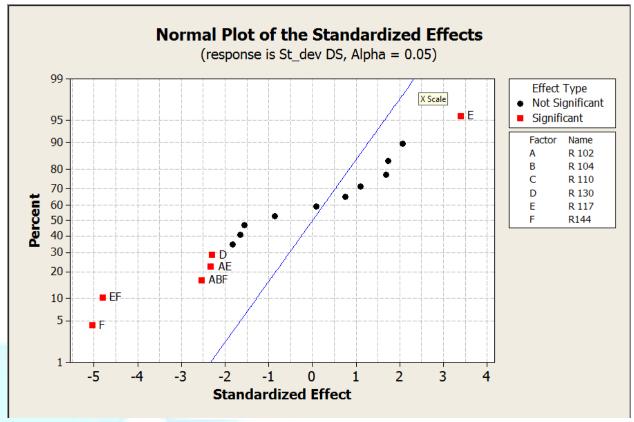


Graph. Driving Side – Main Effect

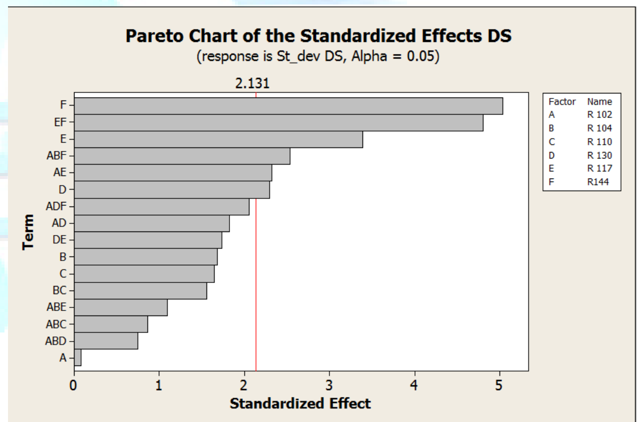
Normal Probability plot and Pareto Chart: -

Graphs below show the Normal probability plot of the standerdized effect for Driving side and clamping side respectively. The Pareto Chart shows that the effects A - Gap eliminator safety position (μ), B - Sizematic Knockoff 1 Position (μ), C - Incremental retreat 1, initial (μ), G - Fine feed rate (μ/sec), J - Grinding compensation (μ), and K - Grinding compensation interval (cycles) are most significant for the process to achieve optimum cycle time without affecting the surface finish quality, and therefore should be studied in greater depth.

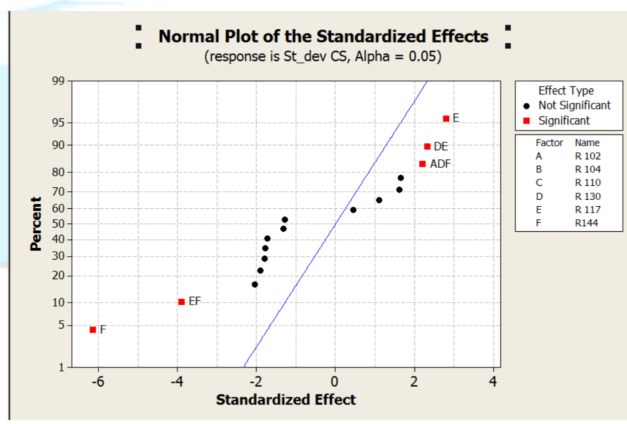
Also graphs ___ present a normal probability plot of the effects and it shows that the effects A - Gap eliminator safety position (μ), B - Sizematic Knockoff 1 Position (μ), C - Incremental retreat 1, initial (μ), G - Fine feed rate (μ/sec), J - Grinding compensation (μ), and K - Grinding compensation interval (cycles) fall away from the straight line which implies that they are statistically significant at 5 percent significant level.



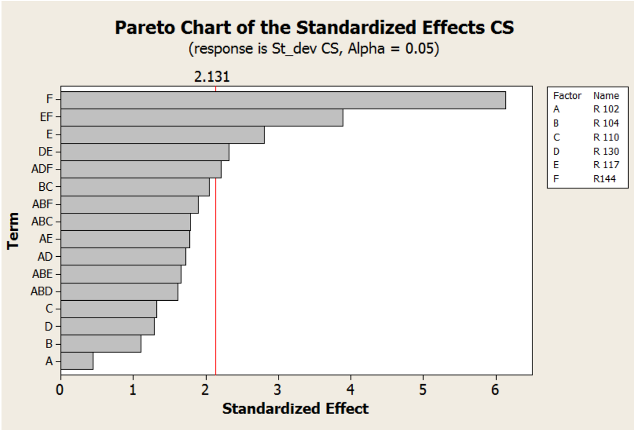
Driving Side – Normal Probability plot for Standardized Effects



Driving Side – pareto Chart for Standardized Effects



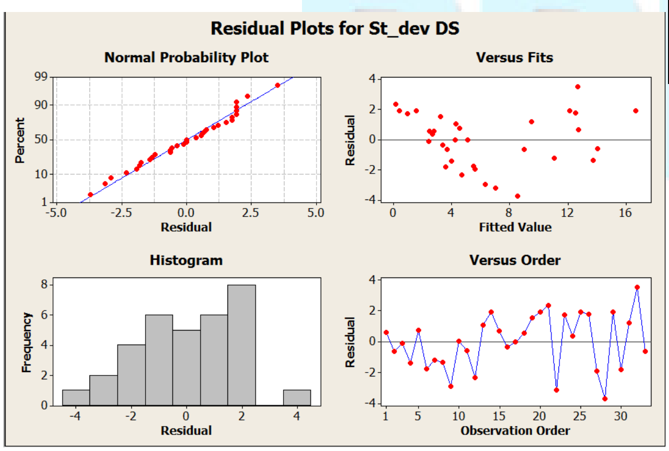
Clamping Side – Normal Probability plot for Standardized Effects



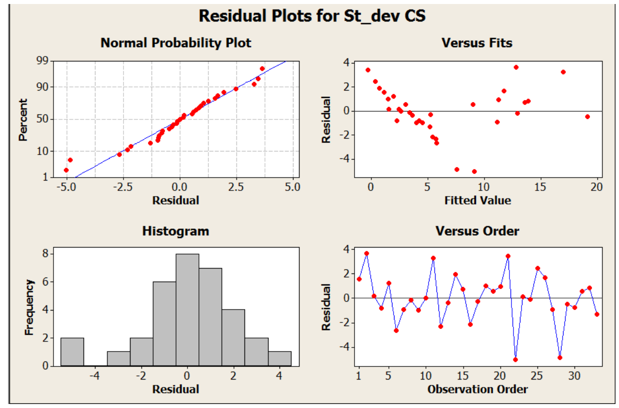
Clamping Side – Pareto Chart for Standardized Effects

Residual Plots: -

Graphs shows residual plots for Driving Side and clamping side respectively. In the normal probability plot of the residuals and histogram of the residuals as shown in figures above, the data were plotted against a theoritical normal distribution in such a way that the points should form an approximately straight line, and a departure from this straight line would indicate a departure from a normal distribution, which was used to check the normal normality distribution of the residuals. As shown in figure, it is reasonable that the assumptions of normality were satisfied for the data. The plots of residuals verses the fitted values and residuals versus the order of data indicated no obvious pattern, implying that residuals of the models were randomly distributed.



Graph. Driving Side – Residual Plots



Graph. Clamping Side – Residual Plots

4. CONCLUSIONS

1. From statistical analysis, it is clear that the six process setting parameters (A - Gap eliminator safety position (µ), B - Sizematic Knockoff 1 Position (µ), C - Incremental retreat 1, initial (µ), G - Fine feed rate (µ/sec), J - Grinding compensation (µ), and K - Grinding compensation interval (cycles)) amongst the fifteen selected for brainstorming have significant effects on the cycle time.
2. Global solution achieved for Grinding machine SSB is as follows: -

Sr.No.	Parameter	Value
1	R102 - Gap Elimination	275 µ
2	R104 - Sizematic Knock Off	60 µ
3	R110 - Incremental Retreat 1	2 µ
4	R130 - Fine Feed Rate	55 µ/sec
5	R117 - Grinding Compensation	1 µ
6	R144 - Compensation Interval	3cycle

3. Key advantages from Optimized Process Parameters are as follows: -

Description	Pre DOE	Post DOE
Air Feed Time	1.02 Sec	0.87 Sec
Rough Feed Time	3.24 Sec	2.76 Sec
Fine Feed Time	1.02 Sec	0.30 Sec
Spark Out Time	0.64 Sec	0.44 Sec
Non Prod. Time	0.98 Sec	0.87 Sec
Act. Dress Time	2.78 Sec	2.31 Sec
Total Cycle Time	7.09 Sec	5.48 Sec
Prod rate	1011 pcs/hr	1314 pcs/hr

Thus it is clear that the production rate is increased by 303 rings/hour.

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