December 2018

AUTOMATED PROCESS ADJUSTMENT TO IMPROVE PROCESS CAPABILITY

Applying Adjustment Calculator Using Predictive Statistics

SONA BLW
MORE TORQUE PER GRAM

Objective

- To improve Process Stability at Hard Turning Process.
- Incorporating Auto Inspection and Auto Tool Wear Offset (Adjustment) to eliminate Manual Intervention in the Process.

PROCESS FLOW CHART

- Raw Material
- Billet Cutting
- Forging
- Coining
- Soft Machining
- Heat Treatment
- **Hard Turning**
- Inspection
- Packing & Dispatch

Methodology

- Part Selection carried out by prioritizing the Critical Parameters being manufactured in Hard Turning Process and as Monthly Sales Volume.

Microsoft Excel Worksheet

CRITICAL PARAMETERS LIST				
Sr. No	**Part No.**	**Parameter**	**LSL**	**USL**
1	LI08A1 RIGHT	COUNTER BORE 1	33.402	33.426
		BOSS LENGTH	61.740	61.940
		COUNTER BORE 2	33.476	33.500
		BOSS DIA	43.930	43.950
		BORE DIA	34.920	34.960
2	TI02A1	BOSS DIA	55.000	55.025
3	TI02A1	BOSS DIA	55.000	55.025
4	TF07B1	BORE DIA	25.536	25.540
5	TF06A1	BOSS DIA	69.604	69.612
6	SP01A1	BOSS DIA	37.959	37.975
7	PT02B1	BORE DIA	22.215	22.242
8	MS02B1	BORE DIA	15.003	15.024
9	PT02B1	BORE DIA	22.215	22.242
10	PT02B1	BORE DIA	22.21[illegible]	[illegible]
11	MS08A1	BOSS DIA	[illegible]	[illegible]
12	MM16B1	BORE DIA	[illegible]	[illegible]
[illegible]	[illegible]M16A1	BOSS DI[illegible]	[illegible]	[illegible]

Background – Current Process Situation

- The Hard Machining is carried out on CNC Turning Machine with Auto Loading & Unloading of Parts through Robot Gantry System.
- 100% Parts are verified for the Parameter.
- Manually Tool Wear Offset (Adjustment) is carried out in CNC Turning Machine.

Adjustment Process

- The Tool Wear Offset is provided in CNC Machine for the compensation of the Insert Wear
- Tool Wear Offset are provided for maintaining the Parts at the Mean Value.
- Operator is taking the Tool Offset (Adjustment) based on his skill / best of his knowledge and no statistical tools are applied to know the Adjustment amount.

Manual Intervention

Machine Operator is operating CNC Turning Machine with 2 Spindles (Machining 2 Different or Same Parts running).

- Process requires the Machine Operator to be present on the Machine at all times:
  - To Inspect the Part
  - To Provide Tool Wear Offset based on Needs.
  - To record the Observed Values in Periodic Inspection Reports and Pre Control Charts.
- For a normal process Machine Operator has to take 14 to 18 Offset per Machine Spindle.

Target

- Auto Inspection to be initiated with facility of Auto Adjustment (Tool Offset). Proposed Benefits:
  - Elimination of Manual Inspection & Adjustment.
  - Reduction of Manpower one Machine Operator can operate up to 3 Machines (with 2 Spindle each).
  - Auto Recording of the Observations (Inspection Values).
  - Continuous Run Charts to observe Trends.

Trial Plan

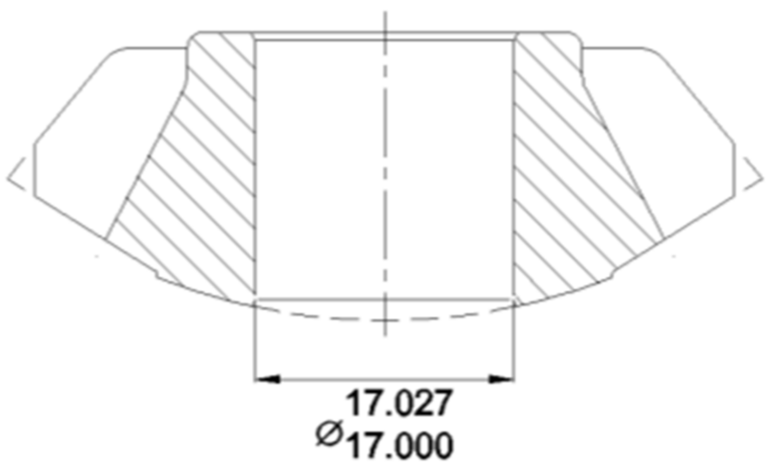
- Selecting Parts for conducting Trials.
- Capturing the Tool Wear through Statistics.
- Generating Tool Wear offset Calculator
- Trials with Calculator.
- Establishing the Auto Adjustment Mechanism.
- Monitoring the Auto Adjustment and taking Improvement Actions.

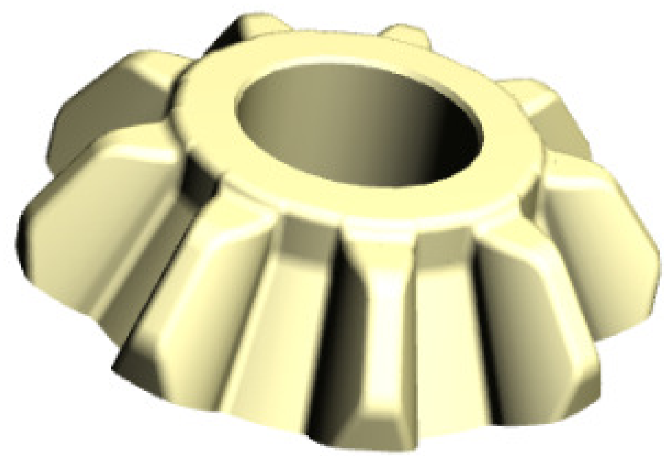
Part Selection

- Parameters : Bore Diameter
- Specification : 17H8 (17.000 ~17.027 mm)
- Machine : M 71 (Muratec Machine 2 Spindle)

SP01B1

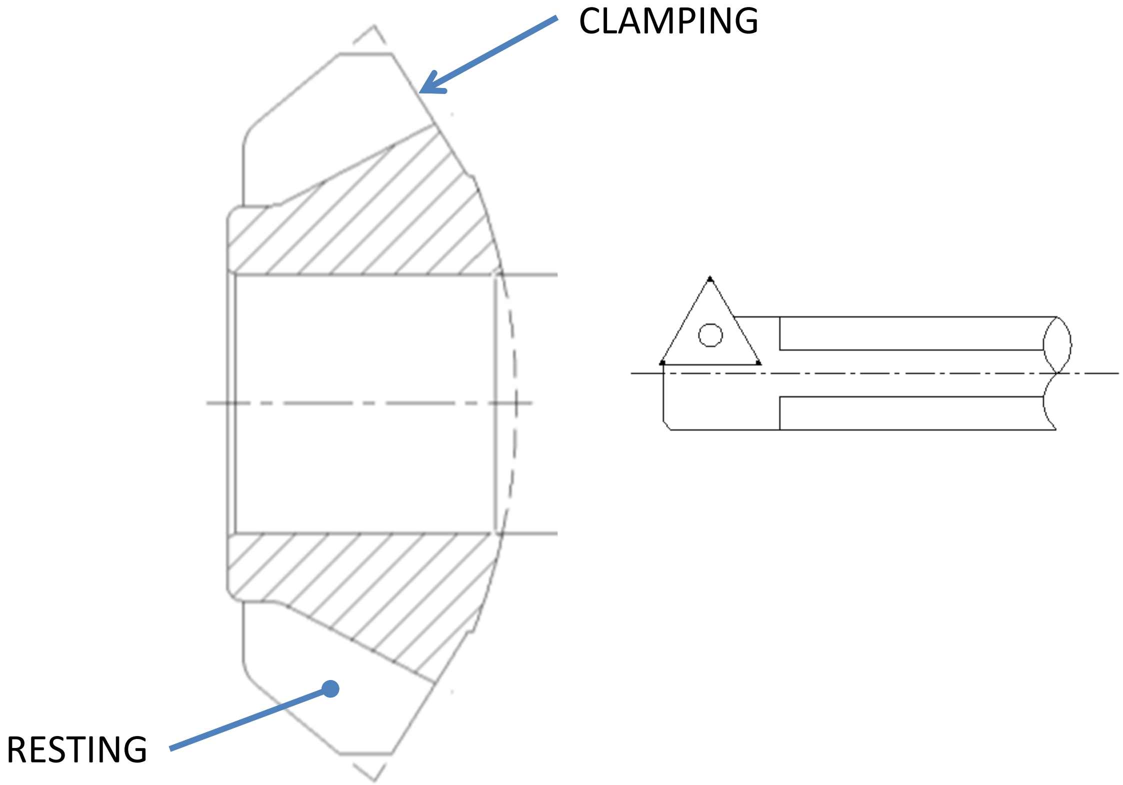
Differential Bevel Pinion





Note: Measurement done by an air-gauge, across the length of the bore, and the minimum of the measured value taken while making sure that the ovality and taper are below 3 μ, each.

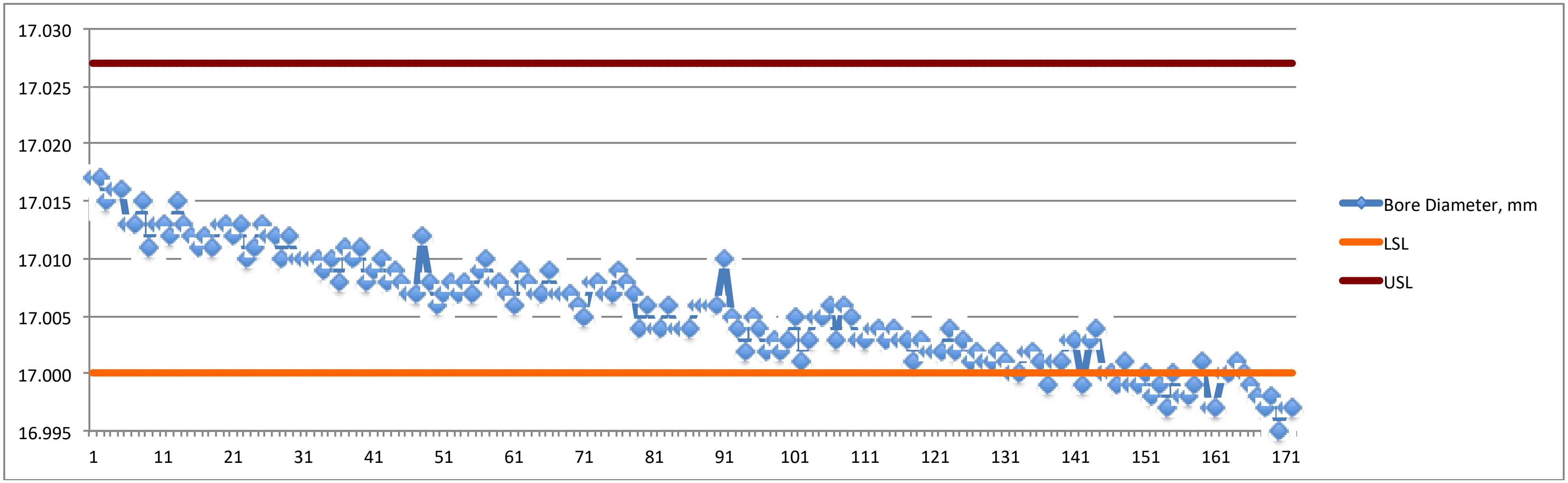
Hard Turning Process



First Step

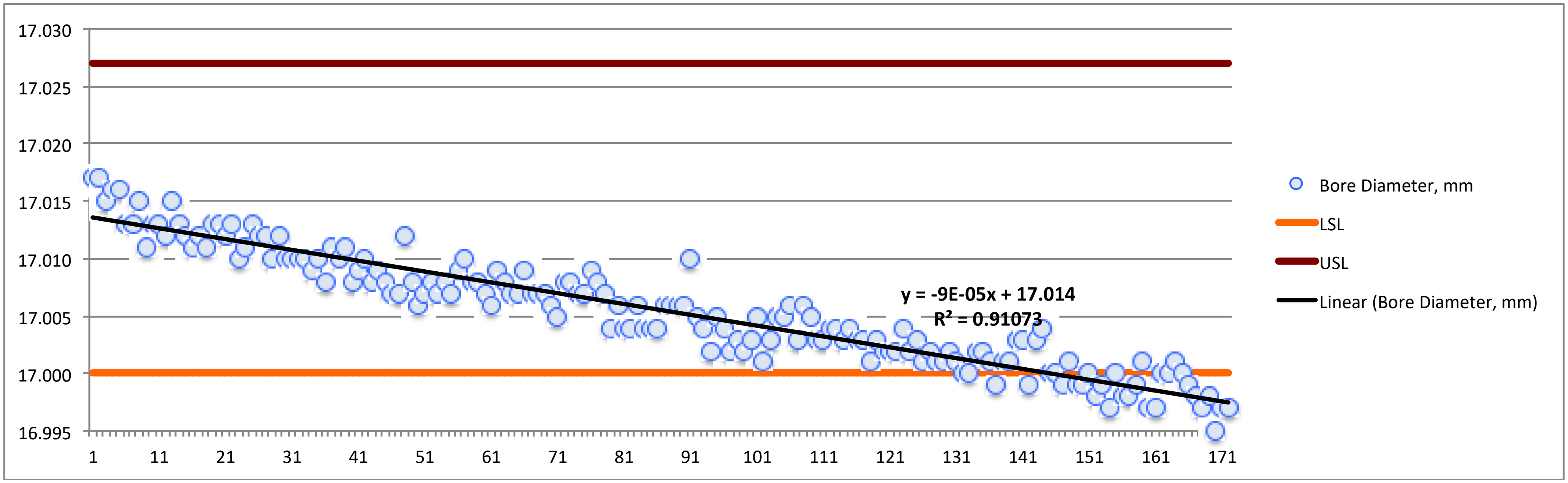
- In order to understand the behavior of the process, an experiment was conducted in which parts were manufactured…
  - Without giving an offset.
  - Till sufficient number of Rejections (Defects) were produced.

Experimental Data



OBSERVATIONS of Parts manufactured at Hard Machining without taking Tool Wear Offset

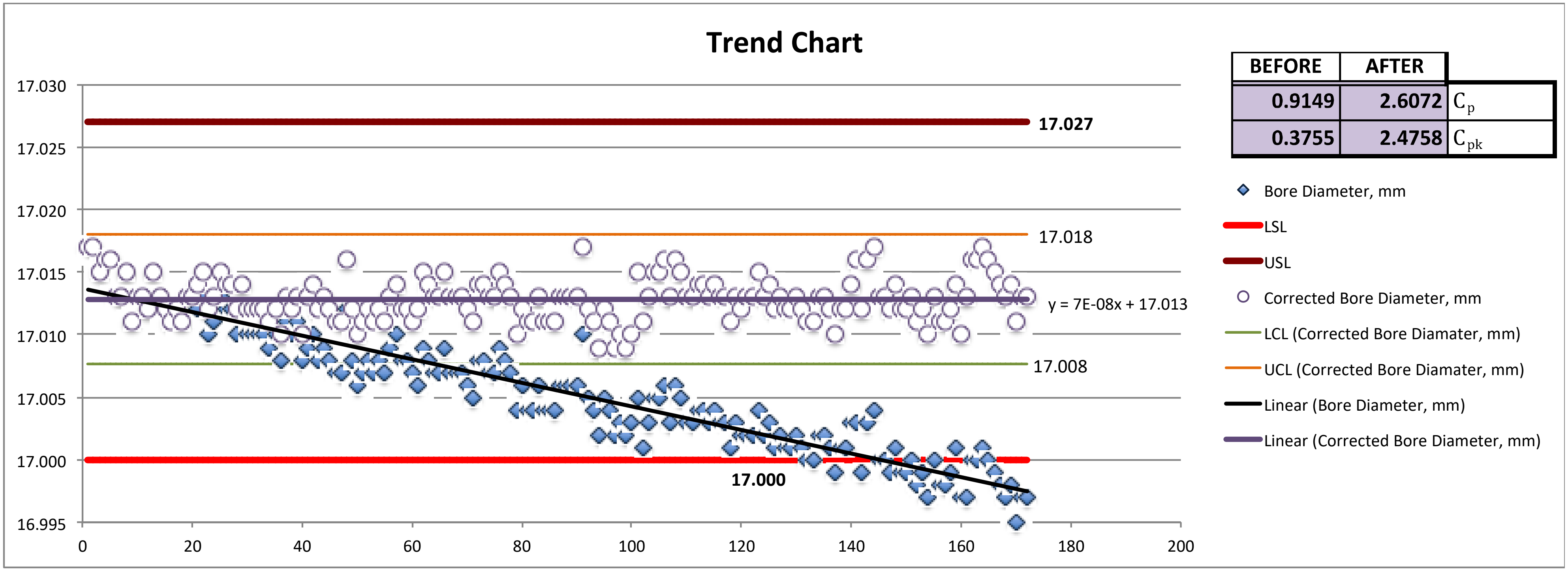
Understanding the Data



Best Fit Line for the Observations.

Fitted Line: y = α + β*x

Simulation



BEFORE	AFTER	
0.9149	2.6072	C_p
0.3755	2.4758	C_{pk}

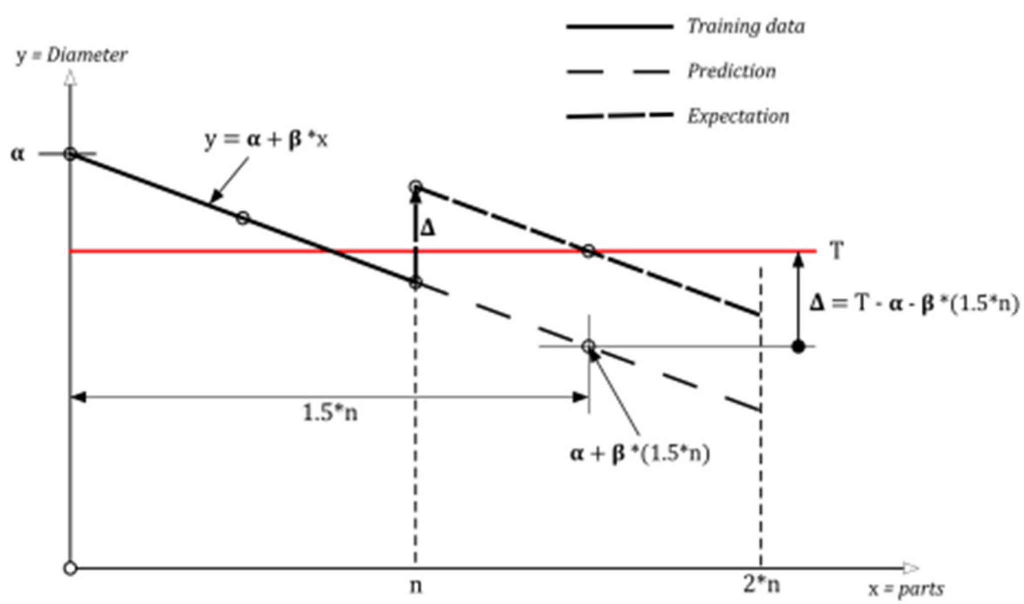
Simulation : Correction Factor (Offset) taken at every part based on the Gain (β) and the Bias (α).

Conclusion of the Simulation

- If the offset is taken based on the α and β of the fitted line from the previous data, Process Capability can be improved significantly.
- Based on the trend of the tool wear, it was decided that the offset will be taken after every 20 parts based on the process performance of the previous 20 parts.

Scheme of the Calculator

- OFFSET CALCULATOR developed based on Linear Regression to calculate the Offset Values after every 20th Part.



Formulas:

$\mu_x = \Sigma x_i/n = \Sigma i/n = (n+1)/2$

$\mu y = \Sigma yi/n$

$s(xx) = \Sigma(x_i - \mu_x)^2 = \Sigma x_i^2 - (\Sigma x_i)^2/n = \Sigma i^2 - (\Sigma i)^2/n = [n*(n+1)*(2*n+1)/6] - [n*(n+1)/2]^2/n = n*(n-1)*(n+1)/12$

$s(xy) = \Sigma(x_i - \mu_x)*(y_i - \mu_y) = \Sigma x_i*y_i - (\Sigma x_i)*(\Sigma y_i)/n = \Sigma i*y_i - (\Sigma i)*(\Sigma y_i)/n = \Sigma i*y_i - (n+1)*(\Sigma y_i)/2$

$\boldsymbol{\beta} = s(xy)/s(xx)$

$\boldsymbol{\alpha} = \mu_y - \boldsymbol{\beta}*\mu_x$

Fitted Line: $y = \boldsymbol{\alpha} + \boldsymbol{\beta}*x$.

Let Target, $T = (USL+LSL)/2$

Since our aim is $\mu_y = T$,

Offset (in microns), $\boldsymbol{\Delta} = 1000*[T - \boldsymbol{\alpha} - \boldsymbol{\beta}*(1.5*n)]$; rounded off.

The Calculator

	RIGHT	LEFT	
Unit			Select "mm" or "μ" (If blank, then the default is μ).
Parameter			Enter the parameter to measure and control (for example, 'Bore Diamter').
LSL			Enter Lower Specification Limit.
USL			Enter Upper Specification Limit.
Default Target			
Target			Enter Target Value (Keep blank for default).

① Settings

② Running the Calculator

	RIGHT μ		LEFT μ	
S. No.		Offset, μ		Offset, μ
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				

③ Overall Results

	RIGHT	LEFT
Unit	μ	μ
Cum Offset, μ	0	0
Mean		
Target	0.000	0.000
LCL		
UCL		
C_p		
C_{pk}		

An Example – Settings

	RIGHT	LEFT	
Unit	mm	mm	Select "mm" or "μ" (If blank, then the default is μ).
Parameter	Bore Diameter	Bore Diameter	Enter the parameter to measure and control (for example, 'Bore Diamter').
LSL	17.000	17.000	Enter Lower Specification Limit.
USL	17.027	17.027	Enter Upper Specification Limit.
Default Target	17.014	17.014	
Target			Enter Target Value (Keep blank for default).

Calculator 1_1.mp4

calculator 2_@.mp4

Offset Calculator and the Results of an Experiment

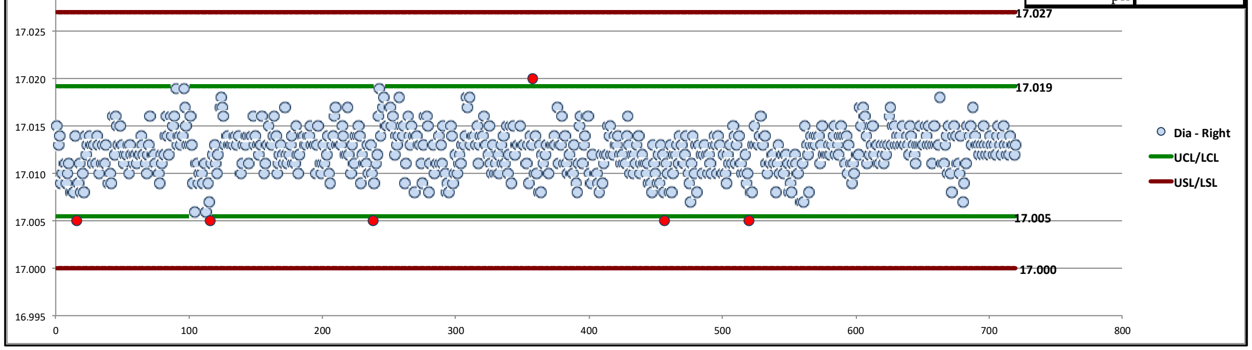
	RIGHT (mm)		LEFT (mm)	
S. No.	Bore Diameter	Offset, μ	Bore Diameter	Offset, μ
1	17.015		17.013	
2	17.013		17.012	
3	17.014		17.010	
4	17.009		17.009	
5	17.010		17.013	
6	17.011		17.016	
7	17.011		17.017	
8	17.009		17.013	
9	17.010		17.013	
10	17.011		17.015	
11	17.008		17.014	
12	17.008		17.013	
13	17.008		17.013	
14	17.008		17.013	
15	17.014		17.014	
16	17.005		17.013	
17	17.009		17.014	
18	17.011		17.013	
19	17.008		17.013	
20	17.010	8	17.013	-1
21	17.008		17.013	
22	17.014		17.012	
23	17.012		17.013	
24	17.013		17.013	
25	17.014		[illegible]	
26	17.013		[illegible]	
27	17.013		[illegible]	
28	17.011		[illegible]	
29	[illegible]		[illegible]	
30	[illegible]		17.011	
31	[illegible]		17.010	
32	[illegible]		17.013	
33	[illegible]		17.011	
34	17.011		17.013	
35	17.013		17.011	
36	17.011		17.009	
37	17.011		17.013	
38	17.013		17.009	
39	17.009		17.010	
40	17.010	3	17.009	5
41	17.010		17.009	

n = 720 + 720

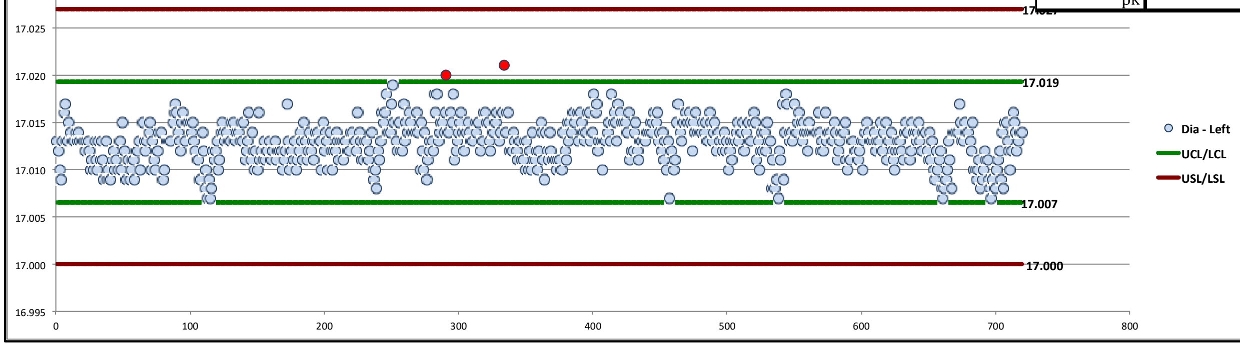
	RIGHT	LEFT
Unit	mm	mm
Cum Offset, μ	62	48
Mean	17.012	17.013
Target	17.014	17.014
LCL	17.0054	17.0065
UCL	17.0192	17.0193
C_p	1.9593	2.1105
C_{pk}	1.7881	2.0189

Stability of the Process

C_p	1.9593
C_{pk}	1.7881



C_p	2.1105
C_{pk}	2.0189



- The method of Offset Calculator has resulted in a significant increase in process capability.
- However, unstable points are noticed on the control charts.
- Can we improve it further?

Microsoft Excel Worksheet

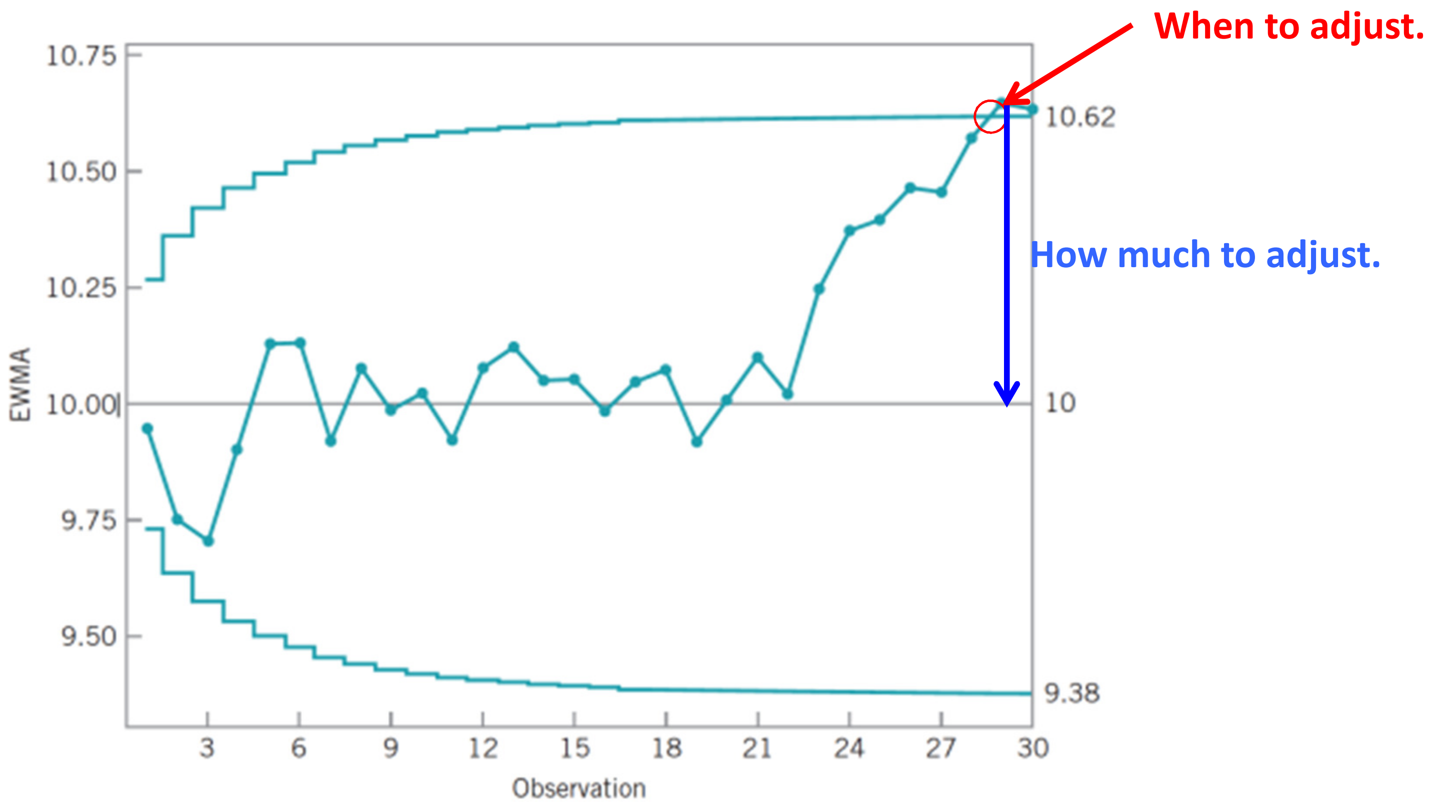
Concerns with the Linear Regression Based Offset Calculator

- Offset is calculated at a fixed interval (say, after every 20 parts).
  - ➢ Does not consider tool wear pattern (fast or slow).
- No action is taken for the first 20 parts.
  - ➢ Danger of scrapping up to 20 parts in case the original set-up was flawed.
- Assumes normality of the data.
  - ➢ Assumption is wrong if the actual data is not normally distributed.

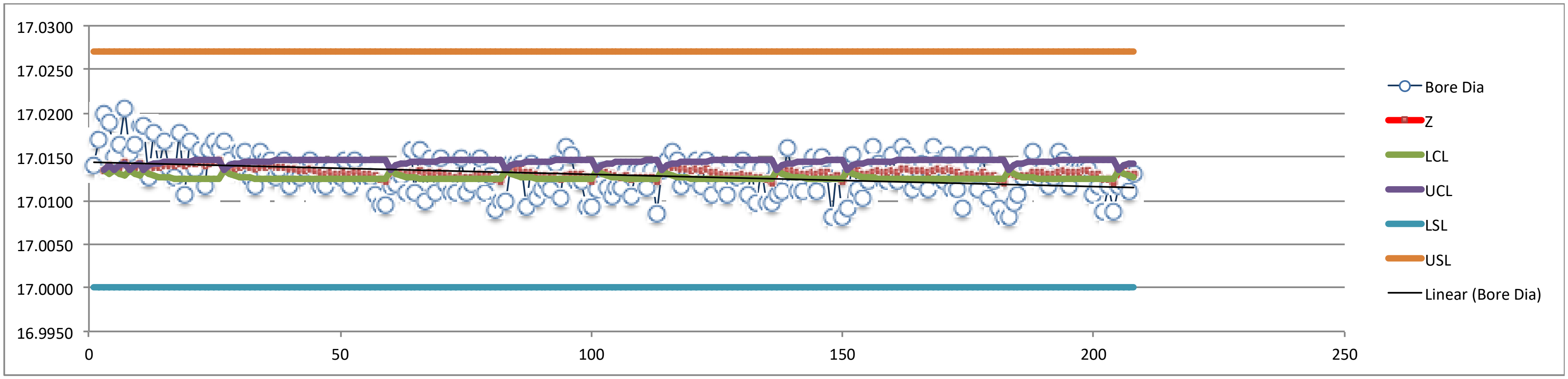
Alternative: The Exponentially Weighted Moving Average (EWMA) Method

- Can quickly detect a small shift in the process mean.
- Robust to non-normality of the data.
- Provides a forecast where the process mean will move.
  - Control limits used to decide <u>*when*</u> to make an adjustment.
  - The difference between the target and the forecast of the mean used to determine <u>*how much*</u> adjustment is necessary.

Application of the EWMA Control Chart



Simulation of Applying EWMA Method



sigma	0.0023747
Cp	1.89496251
Cpk	1.81157221

Min	17.008	17.000	LSL
mu	17.013	17.014	Target
Max	17.020	17.027	USL

Scheme of the Calculator

The EWMA OFFSET CALCULATOR

Exponentially Weighted Moving Average Control Chart

$$z_i = \lambda x_i + (1-\lambda) z_{i-1}$$

$$0 < \lambda \le 1$$

$$z_0 = \mu_0 = Process\ Target$$

If the observations x_i are independent random variables with variance σ^2, then the variance of z_i is:

$$\sigma_{z_i}^2 = \sigma^2 \left(\frac{\lambda}{2-\lambda}\right)\left[1-(1-\lambda)^{2i}\right]$$

And the EWMA Control Chart:

$$UCL = \mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]}$$

$$Center\ line = \mu_0$$

$$LCL = \mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]}$$

The OFFSET CALCULATOR:

$$z_0 = \mu_0 = Process\ Target \qquad (1)$$

$$z_i = \lambda x_i + (1-\lambda) z_{i-1} \qquad (2)$$

If $z_i > UCL$, or $z_i < LCL$, then:

$$Offset = z_0 - z_i \qquad (3)$$

Set $i = 0$, and continue with (1).

Note:

$0 < \lambda \le 1 = 0.1$, Default.

L = 2.7, Default.

σ = (USL – LSL)/(6*C_p’) where C_p’ is target Process Capability = 1.667, Default.

The EWMA Calculator

	RIGHT	LEFT	
Parameter			Enter the parameter to measure and control (for example, 'Bore Diamter').
LSL			Enter Lower Specification Limit.*
USL			Enter Upper Specification Limit.*
Default Target			
Target			Enter Target Value (Keep blank for default).
Constants for EWMA			
λ			Enter the lambda Value $0 < \lambda \leq 1$ (Keep blank for default=0.1).
L			Enter the L Value $2 \leq L \leq 3$ (Keep blank for default=2.7).
Target Cp			Enter the target Cp Value (Keep blank for default=1.667).

* Mandatory input.

If any of the cells is ***like this,*** *then there is an error in the input, or it is an incomplete input.*

① Settings

② Running the Calculator

	RIGHT		RIGHT	
n		Offset		Offset
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				

③ Overall Results

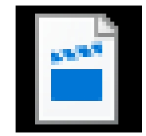
	RIGHT	LEFT
Cum Offset	0.000	0.000
Mean		
Target	0.000	0.000
C_p	#DIV/0!	#DIV/0!
C_{pk}	#DIV/0!	#DIV/0!
Min	0.0000	0.0000
Max	0.0000	0.0000
LSL	0.0000	0.0000
USL	0.0000	0.0000

An Example – Settings

Parameter	Bore Diameter	Bore Diameter	Enter the parameter to measure and control (for example, 'Bore Diamter').
LSL	0.000	0.000	Enter Lower Specification Limit.*
USL	27.000	27.000	Enter Upper Specification Limit.*
Default Target	13.500	13.500	
Target	13.500	13.500	Enter Target Value (Keep blank for default).
Constants for EWMA			
λ			Enter the lambda Value $0 < \lambda \leq 1$ (Keep blank for default=0.1).
L			Enter the L Value $2 \leq L \leq 3$ (Keep blank for default=2.7).
Target Cp	2.000	2.000	Enter the target Cp Value (Keep blank for default=1.667).

* Mandatory input.

If any of the cells is ***like this,*** ***then there is an error in the input, or it is an incomplete input.***



EWMA.mp4

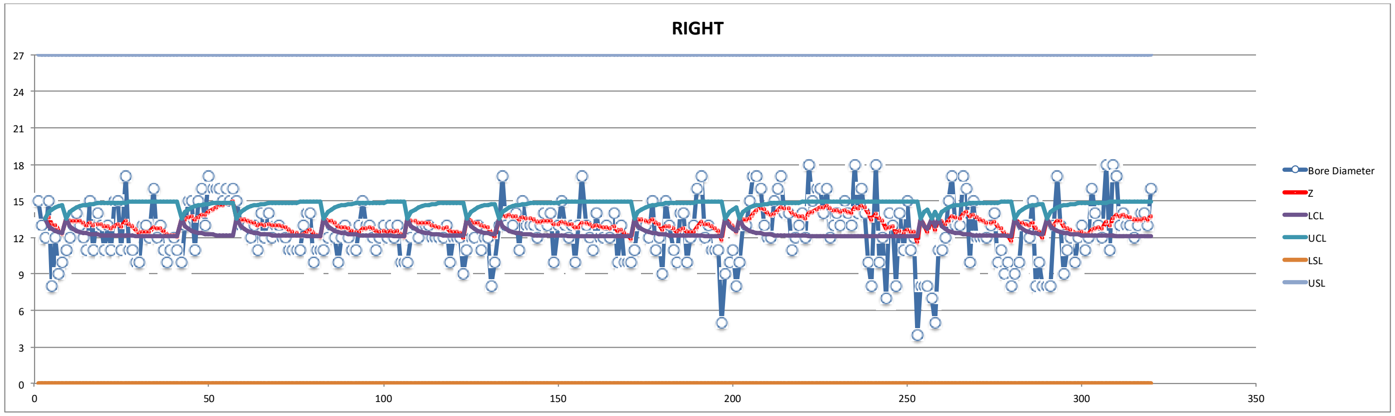
EWMA Offset Calculator and the Results of an Experiment

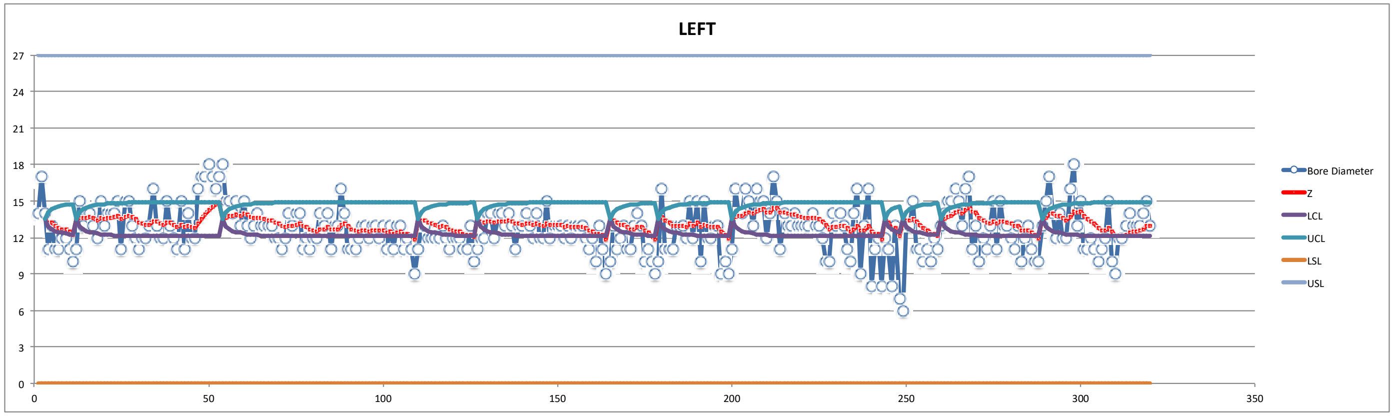
n	RIGHT Bore Diameter	RIGHT Offset	LEFT Bore Diameter	LEFT Offset
1	15.0000		14.0000	
2	13.0000		17.0000	
3	12.0000		14.0000	
4	15.0000		11.0000	
5	8.0000		13.0000	
6	12.0000		11.0000	
7	9.0000		11.0000	
8	10.0000	1.179035	12.0000	
9	11.0000		12.0000	
10	12.0000		11.0000	
11	13.0000		10.0000	1.263644
12	14.0000		11.0000	
13	13.0000		15.0000	
14	12.0000		13.0000	
15	11.0000		14.0000	
16	15.0000		14.0000	
17	11.0000		13.0000	
18	14.0000		12.0000	
19	13.0000		15.0000	
20	11.0000		13.0000	
21	13.0000		14.0000	
22	11.0000		14.0000	
23	15.0000		14.0000	
24	15.0000		15.0000	
25	11.0000		11.0000	
26	17.0000		15.0000	
27	11.0000		15.0000	
28	11.0000		13.0000	
29	10.0000		12.0000	
30	10.0000		11.0000	
31	13.0000		12.0000	
32	13.0000		12.0000	
33	12.0000		13.0000	
34	16.0000		16.0000	
35	12.0000		13.0000	
36	13.0000		12.0000	
37	11.0000		12.0000	
38	10.0000		15.0000	
39	11.0000		13.0000	
40	12.0000		12.0000	
41	11.0000	1.463722	11.0000	
42	10.0000		15.0000	
43	13.0000		11.0000	
44	15.0000		14.0000	
45	15.0000		12.0000	
46	11.0000		12.0000	
47	15.0000		16.0000	
48	16.0000		17.0000	
49	12.0000		17.0000	

n=320+320

	RIGHT	LEFT
Cum Offset	18.474	13.540
Mean	12.481	12.684
Target	13.500	13.500
C_p	1.9324	2.3526
C_{pk}	1.7866	2.2105
Min	4.0000	6.0000
Max	18.0000	18.0000
LSL	0.0000	0.0000
USL	27.0000	27.0000

How the Calculator Worked



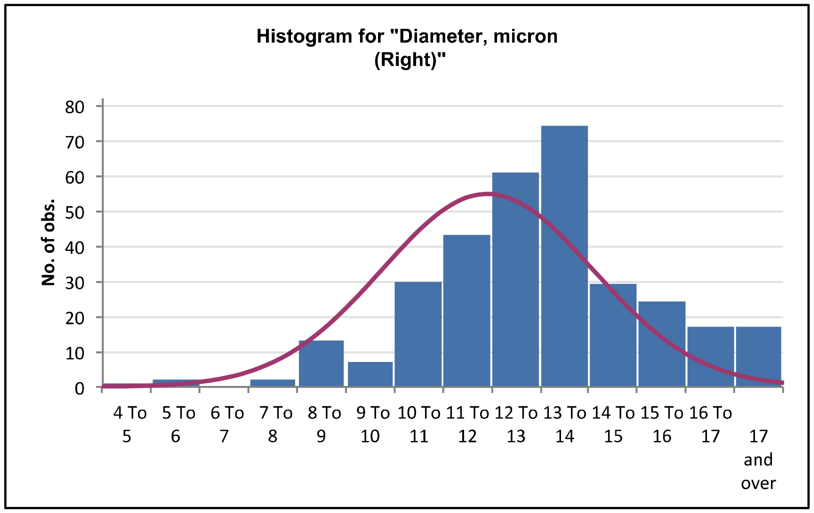


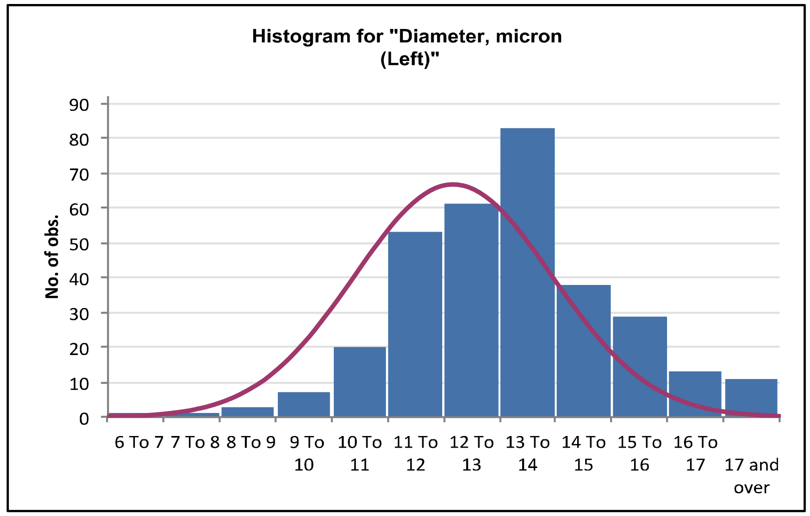
Trials with EWMA

SUMMARY SHEET FOR TRIALS CONDUCTED WITH EWMA CONTROL CHART																	
S.No.	Machine No	Date	Part No	Parameter	LSL	USL	Qty	Offset Frequency		Cummulative Offset		Cp		Cpk		Duration	Remarks
								Right	Left	Right	Left	Right	Left	Right	Left		
1	M 71	20-06-2018	SP01B1	Bore Dia	0.000	27.000	240	0	8	0.00	-5.51	2.49	1.77	2.4106	1.7320	1.5 hrs	Ewma v0
2	M 71	22-06-2018	SP01B1	Bore Dia	0.000	27.000	120	3	2	4.35	-2.49	3.12	2.42	2.8019	2.2207	1 hrs	Ewma v0_1
3	M 71	23-06-2018	SP01B1	Bore Dia	0.000	27.000	640	15	11	18.47	13.54	1.93	2.35	1.7866	2.2105	5 hrs	Ewma v0_1
4	M 84	24-07-2018	LI08A1	Boss Dia	43.925	43.945	120	17	20	-14.44	-15.06	1.11	1.45	0.6898	0.8034	2 hrs	Ewma v0_1
5	M 84	31-07-2018	LI08A1	Boss Dia	43.925	43.945	120	16	16	-12.83	-12.79	1.17	1.39	0.739	0.8902	2.5 hrs	Ewma v0_1
6	M 84	01-08-2018	LI08A1	Boss Dia	43.925	43.945	120	11	4	-9.06	-4.07	1.63	1.50	1.2375	1.2864	2.5 hrs	Ewma v0_1
7	M 84	09-08-2018	LI08A1	Boss Dia	43.925	43.945	300	45	28	-35.18	-22.69	1.58	1.57	0.9836	1.2193	4 hrs	Ewma v0_1
8	M 84	11-08-2018	LI08A1	Bore Dia	34.920	34.960	154	10	10	-17.54	-17.54	3.05	2.82	2.4607	2.2698	3.5 hrs	Ewma v0_1
9	M 84	11-08-2018	LI08A1	Bore Dia	34.930	34.960	150	0	1	0.00	1.64	2.80	2.55	2.7382	2.4651	3 hrs	Ewma v0_1
10	M 84	16-08-2018	LI08A1	Counter Bore Dia 1	33.402	33.426	350	33	-	31.47	-	2.04	-	1.7544	-	7.5 hrs	Ewma v0_1
11	M 84	17-08-2018	LI08A1	Counter Bore Dia 1	33.402	33.426	400	10	-	13.46	-	2.66	-	2.4907	-	8 hrs	Ewma v0_1
12	M 84	18-08-2018	LI08A1	Counter Bore Dia 2	33.476	33.500	350	80	-	-8.00	-	2.30	-	2.2423	-	7.5 hrs	Ewma v0_1
13	M 58	27-08-2018	LI05B2	Bore Dia	18.160	18.200	200	14	-	-27.51	-	2.23	-	1.9495	-	2.5 hrs	Ewma v0_1
14	M 61	29-08-2018	PT02B1	Bore Dia	22.215	22.242	200	41	-	-47.42	-	1.69	-	1.1930	-	3 hrs	Ewma v0_1
15	M 62	04-09-2018	PT02B1	Bore Dia	22.215	22.242	180	3	-	4.80	-	2.46	-	1.4318	-	2.5 hrs	Ewmav1_0
16	M 84	06-09-2018	LI08A1	Boss Dia	43.925	43.945	110	8	4	-7.98	-4.12	1.71	[illegible]				
17	M 84	07-09-2018	LI08A1	Boss Dia	43.925	43.945	300	27	22	-26.77							
18	M 84	10-09-2018	LI08A1	Boss Dia	43.928	43.945	100	14	[illegible]								
		[illegible]	LI08A1	Boss Dia	43.925	43.945											

Microsoft Excel Worksheet

Normality of the Resulting Diameter Values





	Diameter, micron (Right)	Diameter, micron (Left)
Alpha (for confidence interval)	5.%	5.%
Count	320	320
Mean	12.48125	12.68438
Variance	5.42284	3.65869
Standard Deviation	2.3287	1.91277
Mean Standard Error	0.13018	0.10693
Coefficient of Variation	0.18658	0.1508
Minimum	4.	6.
Maximum	18.	18.
Range	14.	12.
Median	13.	13.
Median Error	0.00912	0.00749
Percentile 25% (Q1)	11.	11.
Percentile 75% (Q3)	14.	14.
IQR	3.	3.
MAD (Median Absolute Deviation)	1.5	2.
Coefficient of Dispersion (COD)	0.13654	0.11178
Skewness	-0.16489	0.09699
Skewness Standard Error	0.13587	0.13587
Kurtosis	3.66094	3.51042
Kurtosis Standard Error	0.26921	0.26921
Skewness (Fisher's)	-0.16566	0.09744
Kurtosis (Fisher's)	0.69037	0.53748

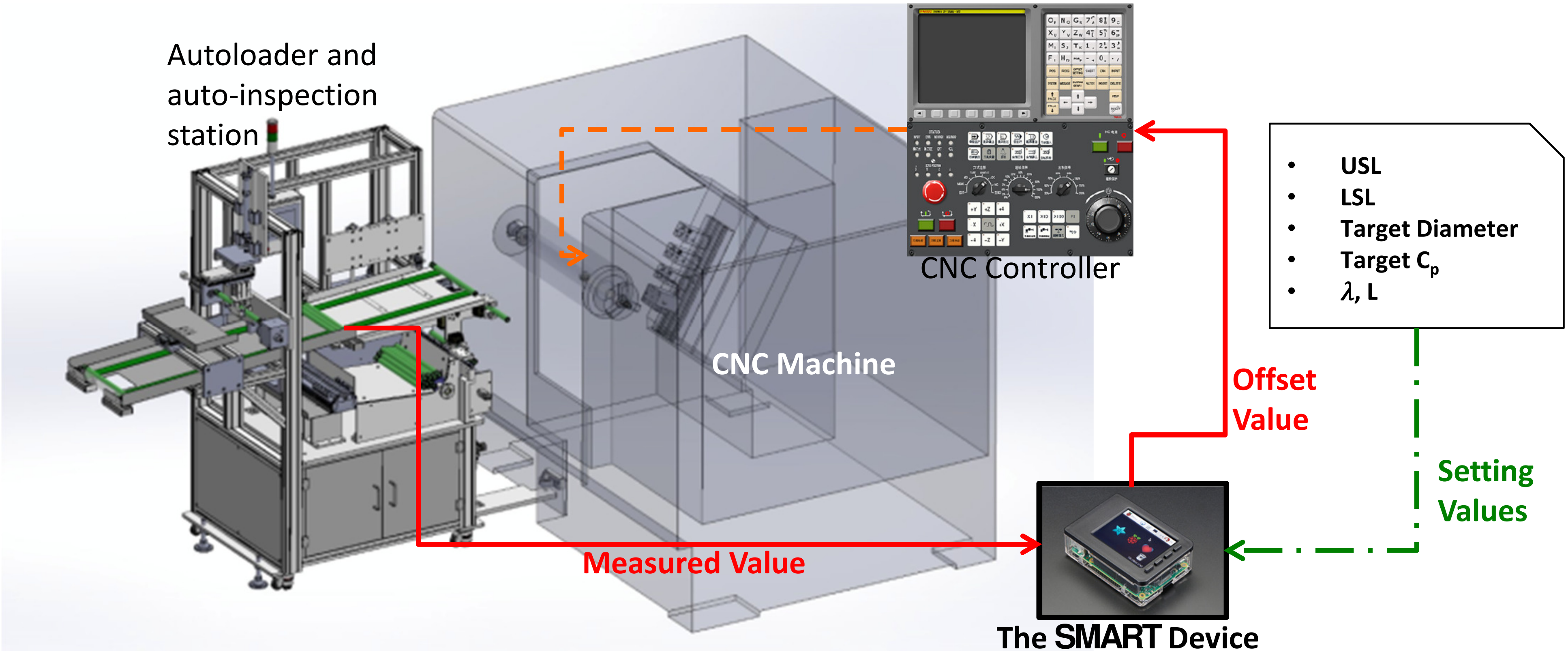
Normality Tests

	Variable #1 (Diameter, micron (Right))			Variable #1 (Diameter, micron (Left))		
	Test Statistics	**p-level**	**Conclusion: (5%)**	**Test Statistics**	**p-level**	**Conclusion: (5%)**
Kolmogorov-Smirnov/Lilliefor Test	0.	1.	*No evidence against normality*	0.	1.	*No evidence against normality*
D'Agostino Skewness	1.22324	0.22124	*Accept Normality*	0.72246	0.47001	*Accept Normality*
D'Agostino Omnibus	5.96484	0.05067	*Accept Normality*	3.60351	0.16501	*Accept Normality*

Advantages of the EWMA Method

- Gives controlled results; provides high process capability.
- Resulting data is nearly normally distributed.
- The calculated offset is:
  - Not drastic, so does not tamper with the process.
  - Need-based, so is appropriate and at the right time.
- The Calculator is in action immediately after three parts are made.
- Continuously learns the process behavior and acts.

The SMART (SONA Machine Adjustment Reckoning Tool) Device – An Image



Next Steps

- The **SMART** Device to be monitored and developed horizontally on other CNC Machines.

THANK YOU