Process Capability Studies with Respect to Grammage and Caliper - A Case Study

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ABSTRACT

Process capability studies carried out with respect to grammage and caliper for the out put of a Paper Machine is reported here. Statistical techniques have been used to evaluate the data to come to meaningful conclusions. Sufficient details are given so that such studies can be carried out by others who are interested in such studies for their machine out puts.

From this study it is found out that the machine understudy is not capable of meeting the required specifications of grammage namely Nominal ± 5% for individuals and Nominal ±2.5% for average of ten test values. The process capability values respectively are 0.588 and 0.770 as against required value of 1.33.

Also, it is found that the process is capable to achieve caliper at levels of Average ± 10% for individuals and Average ± 5% for average of 10 test results as the process capabilities are 1.278 and 1.475 respectively. However, the present consumer is demanding specifications of Average ± 5% for individuals and Average ± 2.5% for average of ten test results for many varieties. This specification cannot be met for the out put of the machine under study as the process capability values are 0.639 and 0.737 respectively.

This study indicates that revamping of machine is necessary to improve process capability.

INTRODUCTION

Good statistical tools are available to handle industrial data to get meaningful conclusions (1) Among them, process capability can be used effectively to ascertain the performance of Paper Machines with respect to grammage and caliper. These procedures can be used in many other areas also in the Paper Mill.

As the process capability study depends on correct assessment of 'Standard Deviation', it is necessary that the process from which samples are drawn are in 'Statistical Control', This simply means that the variations in the process are because of random causes only and assignable causes are absent.

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Some of the data which may be because of assignable causes are discarded during homigenization of data, one of the simplest methods to ascertain whether the data are homogeneous (i.e. only random causes are in operation) is to plot the data on a Normal-probability graph. If the data are homogeneous (i.e. if process is in statistical control) the data generally fall on a line. A simpler method is to plot the frequency distribution (Fig. 1), If the shape approximates the normal bell shaped curve, it can be inferred that the process is under statistical control.Control chart technique can also be used to ascertain whether the process is in statistical control or not.

When once the process is in statistical control, sufficient data are collected to study the process capability.

TESTING PROCEDURE

Full Roll-width samples were collected for each Roll, cut to 25 cm X 40 cm size samples using template, conditioned in Environment Conditioned Room (65 ± 5% RH & 27 ± 2°C temp.) and then tested for grammage and caliper. Total of 25 Rolls from consecutive out put were sampled. For grammage testing, calibrated electronic balance (ANAMED make, sensivity 0.01g) capable of weighing correct to 2nd decimal place was used. For caliper testing caliper testing instrument (L & W make) with least count of 5 μm was used. Caliper was tested at the centre of each spacimen, 4 layers thick. The caliper value of single sheet was calculated by dividing the caliper of 4 layers by four.

The frequency distribution of data is given in Fig. 1 which has a bell shaped appearance indicating homogeneity of data. (For caliper data, homogeneity is achieved after homogenization process only).

STATISTICAL ANALYSIS

Variability across CD: The average grammage and caliper for each roll (average of 7 samples) is given in Table 1. From average data for each roll, Grand average and average standard deviation are computed.

HOMOGENIZATION FOR DISPERSION OF GRAMMAGE DATA

From statistical Tables Appendix IX (A), Ref. (1) for n = 7, B4 = 1.882. Therefore B4 x $\bar{S}_G$ = 1.882 x 1.511 = 2.84 By comparing (B4 x $\bar{S}_G$) with S_G values given in Table-1, it is observed that all S_G values are below 2.843. Hence it is concluded that the data are homogeneous as no data is discarded.

HOMOGENIZATION FOR DISPERSION OF CALIPER DATA

Again similar to the homogenization of grammage data, B4 x $\bar{S}_C$ = 1.882 x 1.597 = 3.005. Here also, all S_C values given in Table-1 are below 3.005 and hence are homogeneous.

HOMOGENIZATION FOR CENTRAL TENDENCY — GRAMMAGE DATA

From statistical Tables (Ref. 1) for n = 7, A 1 = 1.277. Therefore, A1 x $\bar{S}_G$ = 1.277 x 1.511 = 1.929. Now $\bar{X}_G$ ± A1 $\bar{S}_G$ = 59.40 ± 1.929 or 57.47 to 61.33. By inspection of data in Table-1, all average grammage data are within 57.47 to 61.33. Hence, they are homogeneous with respect to central tendency also.

HOMOGENIZATION FOR CENTRAL TENDENCY - CALIPER DATA

A1 x $\bar{S}_C$ = 1.277 x 1.597 = 2.039 $\bar{\bar{X}}_C$ ± A1 $\bar{S}_C$ = 69.31 ± 2.039 or 67.27 to 71.35 . By inspection of data in Table-1, average caliper data for roll No. 5, 10 and 11 are beyond the limits of 67.27 to 71.35 and hence are disarded.

Therefore the revised $\bar{\bar{X}}_C$ = 68.93 - (1st revision) with the revised $\bar{\bar{X}}_C$, the limits would be 68.93 ± 2.039 or 66.891 to 70.969.

Again inspection of data in Table-1 indicates that data of Roll No. 6 and 17 has to be disarded. Again, the revised $\bar{\bar{X}}_C$ = 68.95 - (2nd revision) with this revised $\bar{\bar{X}}_C$, the limits would be 66.911 to 70.989. With this 2nd revision, all remaining data are found to be homogeneous.

(Note: If two many data are discarded, say more than 25%, the whole sampling and testing has to be carried out again).

PROCESS CAPABILITY CALCULATIONS

Grammage

Process capability is given by $\frac{USL - LSL}{6 \times S_G / C_2}$ where USL = upper specification limit, LSL = Lower

TABLE -I

Analysis of Data w.r.t. variability in CD

Quality: White Maplitho (SS) Nominal Grammage: 60.0 g/m²

Sample tested across CD for each roll : 7

Roll No.	Grammage, g/m²		Caliper, µm	
	Average ($\bar{X}_G$)	Standard Deviation (S_G)	Average ($\bar{X}_C$)	Standard Deviation (S_C)
1.	59.17	1.582	67.50	1.768
2.	58.70	0.997	67.86	1.391
3.	59.96	1.451	68.57	2.440
4.	58.71	1.330	68.04	2.782
5.	61.08	1.859	71.79*	1.220
6.	60.73	1.561	71.07*	0.863
7.	59.76	1.110	69.71	0.994
8.	58.67	0.778	70.54	0.987
9.	58.46	1.040	69.11	1.391
10.	60.39	1.330	72.50*	1.443
11.	60.27	1.270	71.96*	0.983
12.	61.00	1.337	70.18	1.519
13.	60.67	1.154	68.04	1.220
14.	61.24	0.785	69.29	2.266
15.	59.29	2.065	67.68	2.095
16.	57.80	1.268	67.50	1.614
17.	57.86	1.719	66.43*	2.216
18.	58.43	1.957	68.75	1.768
19.	58.39	1.667	67.86	0.945
20.	59.19	2.308	68.75	1.614
21.	59.99	1.802	70.70	1.747
22.	58.80	1.247	69.46	2.148
23.	58.54	2.046	69.82	1.356
24.	58.26	1.989	69.29	1.591
25.	59.63	2.120	70.36	1.567
Grand Avg.	**59.40**	**1.511**	**69.31**	**1.597**
	($\bar{X}_G$)	($\bar{S}_G$)	($\bar{X}_C$)	($\bar{S}_C$)
			68.95 (Revised)	

* *Values discarded during homogenization.*

specification limit, $\bar{S}_G$ = Average standard deviation for grammage after homogenization and C_2 = a statistic depending on n to be taken from statistical Tables (In our Example n = 7, C_2 = 0.8882 ∴ Process capability

$$= \frac{63.0 - 57.0}{6 \times 1.511/0.8882} = 0.588$$

(Note : The acceptable tolerance limit is ± 5% nominal which would be ± 3g/m² for nominal grammage of 60 g/m². Hence, USL = (60 + 3) and LSL = (60—3).

CALIPER

Process capability is given by $\frac{USL - LSL}{6 \times \bar{S}_c / C_2}$ with usual notations. Here, $\bar{S}_c$ = Average standard deviation for caliper after homogenization.

HERE TWO CASES ARISE

(i) If the required specification is taken as average ± 10% as per IS 1848 –1991, writing and printing papers.

(ii) If the required specification is taken as Average ± 5% as per IS 14490:1997, plain copier paper

$$\text{Case (i) Process capability} = \frac{6.895 \times 2}{6 \times 1.597/0.8882} = 1.278$$

$$\text{Case (ii) Process capability} = \frac{6.895}{6 \times 1.597/0.8882} = 0.639$$

It is, therefore clear that for writing and ptg. papers the process capability is almost acceptable but not for plain copier paper.

PROCESS CAPABILITY WITH RESPECT TO AVERAGE

Grammage:

From Table-II it is seen that the natural tolerance (the limit within which 99.7% values lie) achieved for average grammage is 59.40 ± 2.322 g/m²

$$\text{Process capability} = \frac{USL - LSL}{2.322 \times 2} = \frac{3.58}{4.644} = 0.770$$

Note : The specification of tolerance for an average of 10 values is Nominal ± 2.5%. However, as the average in this case is for 7 values across the machine, the USL – LSL value is widened equal to

$$\frac{60 \times 0.025 \times 2 \times \sqrt{10}}{\sqrt{7}} = 3.58 \text{ g/m}^2.$$

CALIPER:

From Table II, it is seen that natural tolerance achieved for caliper (after homogenization and discarding data of 5 rolls) is 68.95 ± 2.793

$$\therefore \text{ Process capability} = \frac{USL - LSL}{2.792 \times 2}$$

Here again, two cases arise:

Case (i) Specification of Average ± 5.0%

Case (ii) Specification of Average ± 2.5%

$$\text{Case (i) Process capability} = \frac{6.895\sqrt{10}/\sqrt{7}}{2.793 \times 2} = 1.475$$

Case (ii) Process capability

$$= \frac{6.895\sqrt{10}/\sqrt{7}}{2.793 \times 2} = 0.737$$

DISCUSSIONS & CONCLUSIONS

1. The process capability of grammage across the machine, i.e. grammage profile is poor for achieving the required specified tolerance of Nominal ± 5%. The process capability achieved is 0.588 as against a bare minimum of 1.0 for a well-centered process but generally required value of 1.33. This clearly indicates that a large amount of out put would be beyond specification limits.

The problem can be solved only by revamping the head box or changing it.

2. The process capability of caliper across the machine, i.e. caliper profile is assessed at two levels of specified tolerance.

a) If the specified tolerance is Average ± 10% then

TABLE -II

Analysis of Data with respect to variability in M.D.

Roll No.	Grammage, g/m²		Caliper, µm		
	Average $(\bar{X}_G)$	Moving Range (R_G)	Average $(\bar{X}_C)$	Moving Range (R_C)	Moving Range (R_C) (revised)
1.	59.17	0.47	67.50	0.36	0.36
2.	58.70	1.26	67.86	0.71	0.71
3.	59.96	1.25	68.57	0.53	0.53
4.	58.71	2.37	68.04	3.75	1.67
5.	61.08	0.35	71.79*	0.72	*
6.	60.73	0.97	71.07*	1.36	*
7.	59.76	1.30	69.71	0.83	0.83
8.	58.67	0.21	70.54	1.43	1.43
9.	58.46	1.93	69.11	3.39	1.07
10.	60.39	0.12	73.50*	0.54	*
11.	60.27	0.73	71.96*	1.78	*
12.	61.00	0.33	70.18	2.14	2.14
13.	60.67	0.57	68.04	1.25	1.25
14.	61.24	1.95	69.29	1.61	1.61
15.	59.29	1.49	67.68	0.18	0.18
16.	57.80	0.06	67.50	1.07	1.25
17.	57.86	0.57	66.43*	2.32	*
18.	58.43	0.04	68.75	0.89	0.89
19.	58.39	0.80	67.86	0.89	0.89
20.	59.19	0.80	68.75	1.95	1.95
21.	59.99	1.47	70.70	1.24	1.24
22.	58.80	0.26	69.46	0.36	0.36
23.	58.54	0.28	69.82	0.53	0.53
24.	58.26	1.37	69.29	1.07	1.07
25.	59.63		70.36		
Grand Avg.	**59.40** $(\bar{\bar{X}}_G)$	**0.873** $(\bar{R}_G)$	**69.31 (68.95)** $(\bar{\bar{X}}_C)$ Revised	**1.287** $(\bar{R}_C)$	**1.05 (Revised)** $(\bar{R}_C)$

Natural Tolerance Achieved

$(\bar{\bar{X}}_G) \pm 2.66 (\bar{R}_G)$ or 59.40 ± 2.322

$(\bar{\bar{X}}_C) \pm 2.66 (\bar{R}_C)$ or $68.95 \pm 2.66 \times 7.05$ or 68.95 ± 2.793

* *Values discarded during homogenization.*

GRAMMAGE AND CALIPER DISTRIBUTION

Grammage - g/m^2 Fig. 1

Total Values - 25 x 7 = 175

g/m^2 Range	No. of Values	
55.90 - 57.15	17	
57.16 - 58.40	34	
58.41 - 59.65	51	
59.66 - 60.90	34	
60.91 - 62.15	29	
62.16 - 63.40	9	
63.41 - 64.65	1	

Caliper - μ m

Total Values - 25 x 7 = 175

Caliper Range	No. of Values	Before Homogenization
62.50 - 64.11	3	
64.12 - 65.72	6	
65.73 - 67.33	16	
67.34 - 68.94	60	
68.95 - 70.55	41	
70.56 - 72.16	28	
72.17 - 73.77	21	

Caliper - μ m

Total Values - 20 x 7 = 140

Caliper Range	No. of Values	After Homogenization
63.75 - 65.00	7	
65.01 - 66.26	14	
66.27 - 67.51	22	
67.52 - 68.77	35	
68.78 - 70.03	33	
70.04 - 71.29	21	
71.30 - 72.55	8	

the process capability is 1.278 which is very near to 1.300 and hence is quite good.

b) If the specified tolerance is Average ± 5%, then the process capability is 0.639, which is very poor.

This indicates that specified tolerance as per IS 1849-1991 for writing and printing papers is achievable white the specified tolerance as per IS 14490-1997, for plain copier paper is not achievable. Hence, it is clear that good quality paper cannot be made with present capability level.

This problem can be solved by improving calenders. Also improving Head box would also be beneficial which is required for grammage profile.

3. The process capability of average grammage from roll to roll is 0.770 (grammage variation in time-regime). This is again inadequate to meet the specifications of nominal ± 2.5%.

The wider variation for average grammage may be becuase of both poor profile and also variation overtime (poor process stability). However, as indicated earlier, improvement in Head box is to be considered first and after improving Head box, if the variation from roll to roll persists, then, steps should be taken to improve process stability.

This necessitates steps to be taken to improve stuff consistency uniformity, retention uniformity etc.

4. The process capability of Average caliper from Roll to Roll is 1.475 for caliper specification of Average ± 5.0% and it is 0.735 for caliper specification of Average ± 2.5%. This indicates that where higher tolerances are acceptable, the process can turn out acceptable product but if the specification is stringent it is not capable.

5. The study reported here can be carried out for other parameters also, as the basic features are same and such studies help in exposing the deficiencies so that corrective steps can be taken. The other parameter for which this method can be used are brightness, tensile strength, Burst Factor, Tear Factor, Stiffness and other strength properties.

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REFERENCES

1. Methods for statistical Quality Control during production, Part-I control chart for variables, IS:397 (Part-I)-1972.

2. Alfred H. Jaehn, Quality Improvement Team Hand Book, TAPPI PRESS, 1997.

APPENDIX - 1

Legend

X : Individual data

$\bar{X}$: Arithmetic mean data

$\bar{X}_G$: Arithmetic mean of Grammage Data

$\bar{X}_C$: Arithmetic mean of caliper data

S_G : Standard deviation of Grammage data

S_C : Standard deviation of caliper data

$\bar{\bar{X}}_G$: Grand arithmetic mean of Grammage data

$\bar{\bar{X}}_C$: Grand arithmetic mean of caliper data

$\bar{S}_G$: Arithmetic mean of standard deviation for Grammage

$\bar{S}_C$: Arithmetic mean of standard deviation for caliper

R_G : Moving range of Grammage data

R_C : Moving range of Caliper Data

$\bar{R}_G$: Arithmetic mean of moving range of Grammage

$\bar{R}_C$: Arithmetic mean of moving range of caliper

USL : Upper specification limit

LSL : Lower specification limit

C_2 : Value from standard statistical Tables (Ref. 1)

B4 : Value from standard statistical Tables

A1 : Value from standard statistical Tables

n : Number of samples tested across machine.