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Statistical Process Control (SPC) Tools for Minimizing the Moulding Defects in Spun Pre-stressed Concrete Electric Pole Production

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Abstract

Statistical process control tools are used to monitor production process over time to detect changes and to decrease mistakes for better capture and conversion of customer's needs. The aim of this paper is to identify and minimize various types of defects in spun pre-stressed concrete pole manufacturing. SPC tools like check sheet, histogram, Pareto chart, process flow chart, cause-effect diagram, control chart (p-chart and np-chart) are used and it is found that the thickness uniformity problem is the vital few problem and responsible for 90% of the total results of the problems. Operating characteristics curve is drawn to find out type-I error and type-II error. It is found that the average run length is 319 when the process is in control. Finally, the major causes of nonconformities of the quality problem are specified and possible remedies are proposed.

Keywords: Check Sheet, Histogram, Pareto Chart, Cause-Effect Diagram, Operating Characteristics Curve.

1. Introduction

Statistical process control tools are basic quantitative techniques for total quality management (TQM) and have widely been used to monitor process performance and to detect abnormal situations of the process behavior. The role of statistical process control (SPC) is to make a process stable by reducing process variability [1]. TQM tools are check sheet, Pareto chart, process flow chart, stratification analysis, scatter diagram, histogram, cause-effect diagram and control charts. Enormous steel rod manufacturing companies and some other manufacturing companies are using various methods to optimize their production and process failures. Paul and Azeem [2] used Pareto chart and cause-effect analysis for identifying and analyzing the defects of a pharmaceutical product. Joshi and Kadam [3] have also used Pareto chart and cause-effect analysis in manual casting process to know correct cause and remedial factors in order to increase productivity and to improve customer satisfaction. Sultana, Razive and Azeem [4] used statistical process control tools to increase total output and for identifying major loss times from various machine breakdowns using hourly data system. Mohana Rao et al. [5] used univariate control chart for monitoring hot metal making process in a blast furnace of a steel industry for continuous quality improvement. They also concluded that large number of process parameters combined with lower penetration of manufacturing automation and shortage of skilled workers are the main causes for which foundry industry suffers from poor quality and productivity. Kumar, Mantha and Kumar [6] analyzed the reasons for increasing scrap in manufacturing industries by using quality management tools. Fouad and Mukattash [7] used statistical process control tools in order to identify the major and root causes of quality problem and possible remedies of them. Applying the tools they have found that the steel tensile strength is the vital few problem and account for 72% of the total results of the problems. Raghavendra et al. [8] used statistical process control technique on liners manufacturing industry that improve process capabilities by reducing rejection rate from 6.52% to 4.62%. Cause effect diagrams, design of experiments, if-then rules (expert systems) and artificial neural networks are used to identify, analyze and rectify casting defects by Mane, Sata and Khire [9]. A comparison of the univariate out-of-control signals with the multivariate out-of-control signals was done by El-Din, Rashed and El-Khabeery [10]. They conduct a case study on steel making where average run length was used to analyze performance for charting method. Samanta and Bhattacherjee [11] used Shewart control chart in order to analyze quality characteristics for mining applications. Statistical process control tools may be used in any industry and service center in order to find out the main causes and sub-causes of any problem of the system. In this paper, statistical process control tools are used in spun pre-stressed concrete (SPC) pole manufacturing industry for identifying and minimizing defects and finally some remedies are proposed to increase productivity and customer satisfaction.

2. Methodology

At first, process flow chart is used to examine various processes for the production of SPC electric pole. A check sheet is used to record data of various types of defects for further processing. A histogram is used that represents the frequencies of defects by classes of data that helps to access the current production situation. Then Pareto chart is used to rank the causes from most significant to least significant. To broken down the main causes to sub-causes; cause-effect diagram is used where the causes are broken down into the main categories of man, machine, material, method, management and environment. To monitor the proportion of nonconforming in a sample p-chart is used and np-chart is used to monitor the number of nonconforming units in a sample. Then the operating characteristic (OC) curve has drawn for displaying and investigating probability of accepting the lot with fraction of nonconforming. Finally, recommendations are given based on the findings.

3. Analysis

To examine potential sources of moulding defects of spun pre-stress concrete pole production and to identify steps for improving, process flow chart is done.

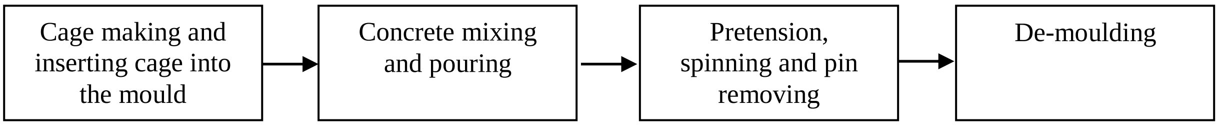

Fig. 1. Process flow chart for spun pre-stressed concrete production

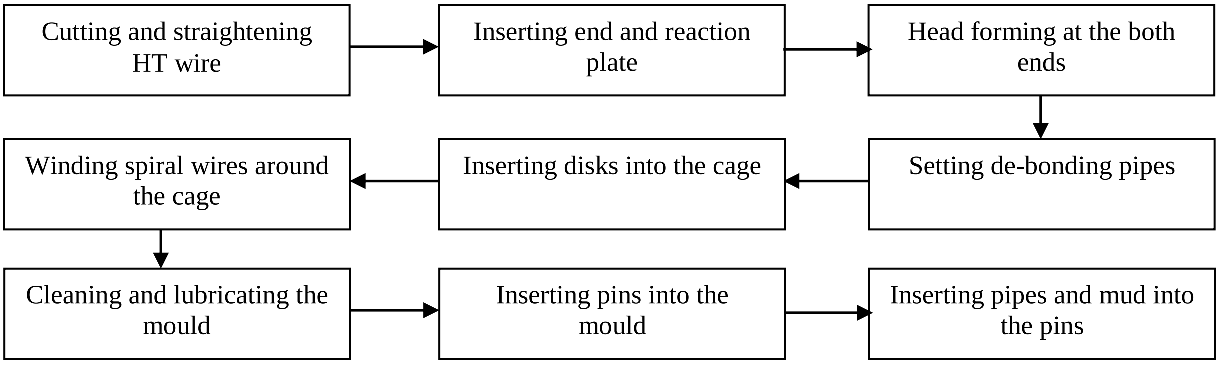

Fig. 2. Process flow chart of cage making and inserting the cage into the mould

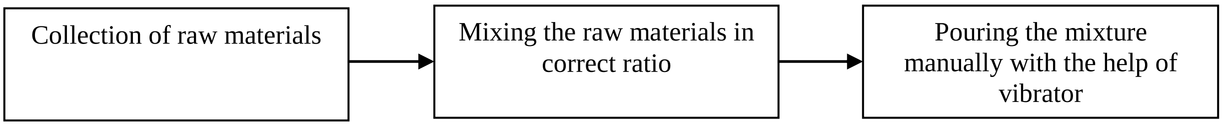

Fig. 3. Process flow chart of concrete mixing and pouring the mixture into the mould

Fig. 4. Process flow chart of pretension, spinning and pin removing

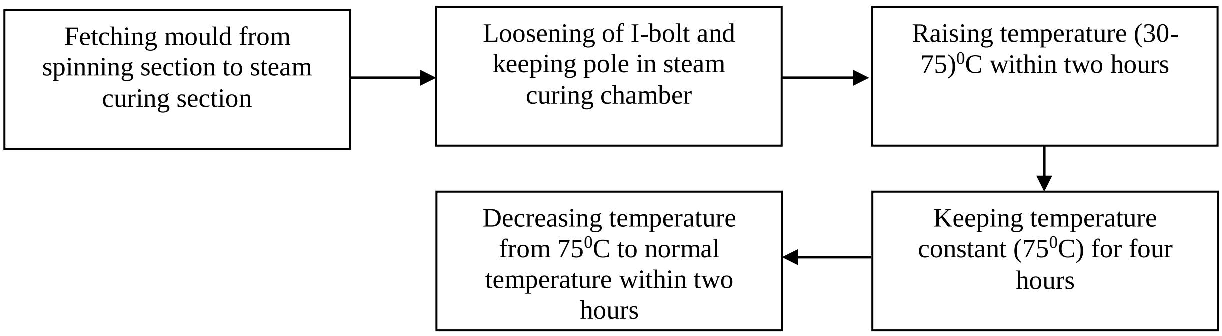

Fig. 5. Process flow chart of de-moulding

After analyzing the process, check sheet is used to collect and organized data of moulding defects. The check sheet, also called a ‘defect concentration diagram’, is a simple tool used to record data for further processing.

Table 1. Check sheet for various defects of spun pre-stressed concrete poll production

Type of defects	Talley	Frequency	Frequency (%)	Cumulative frequency (%)
Thickness problem	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 ll	72	90.00	90.00
Honey comb problem	𝍸	5	6.25	96.25
Collar distance problem	ll	2	2.50	98.75
Minor crack at the top	l	1	1.25	100
Total		80	100	

Histogram determines the statistical nature of the collected data sets and the frequency distribution shows how often each different value in a set of data occurs. Fig. 6. Shows the histogram of the defects found in moulding of SPC pole production. The Pareto chart ranks the causes from most significant to least significant. It depicts a series of vertical bars lined up in a descending order– from high to low– to reflect frequency, importance or priority. In Pareto chart the number indicated sequentially as: (i) thickness uniformity problem, (ii) honey comb problem, (iii) collar distance problem and (iv) minor crack at the top. It is seen that the thickness uniformity problem is the vital few and responsible for 90% of total defects.

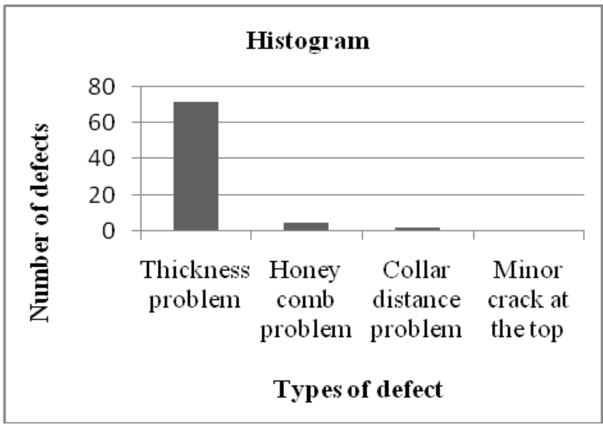

Fig. 6. Histogram for various defects of spun pre-stressed concrete poll production

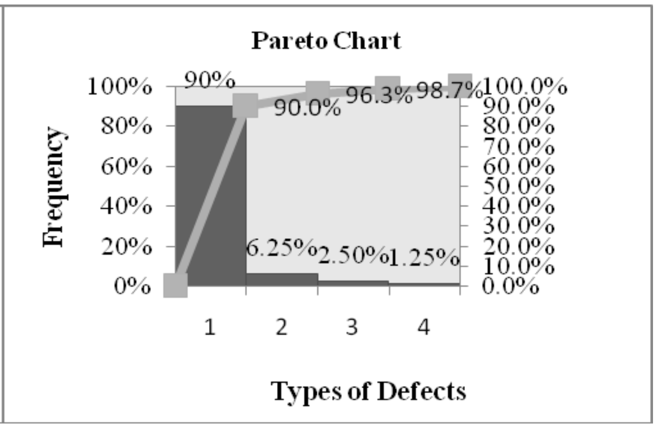

Fig. 7. Pareto chart for various defects of spun pre-stressed concrete poll production

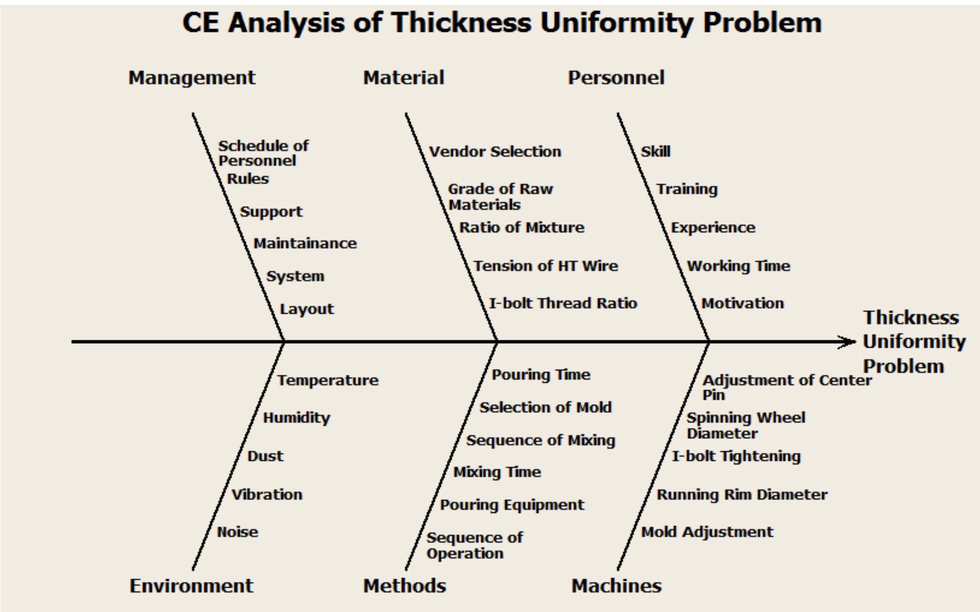

Figure 8: Cause-effect diagram for thickness uniformity problem

Since, the thickness uniformity problem is the major problem; therefore, the cause-effect diagram is used to identify possible causes for thickness uniformity problem by broken down the main causes into sub-causes. It is also known as ‘fishbone diagram’ which combines brainstorming that helps to consider all possible causes of thickness uniformity problem for spun pre-stressed concrete electric pole production. Control chart have used to monitor quality and to see how the process chances over time.

<u>p-chart for fraction non-conforming of average sample size</u>

d = Non-conforming (defective) poles, n = average sample size =180 and m = number of periods =27

$\bar{p} = \frac{\sum_{i=1}^{m} p_i}{m}$ = 0.0105

Therefore, Control limit,CL = $\bar{p}$ =.0105

Upper control limit, UCL = $\bar{p} + z_{\alpha/2}\sqrt{\{\bar{p}(1-\bar{p})/n\}}$ and Lower control limit, LCL = $\bar{p} - z_{\alpha/2}\sqrt{\{\bar{p}(1-\bar{p})/n\}}$

For 3σ quality, $z_{\alpha/2}$= 3

Here, UCL = 0.0333 and LCL = - 0.0115. As the fraction non-conforming can’t be negative. So, LCL = 0

<u>np-chart for fraction non-conforming of average sample size</u>

UCL_{np} = np +3√{np(1-p)} = 5.99, CL_{np}= np = 1.89, LCL_{np}= np - 3√{np(1-p)} = -2.2.

As the fraction non-conforming can’t be negative. ∴ LCL = 0

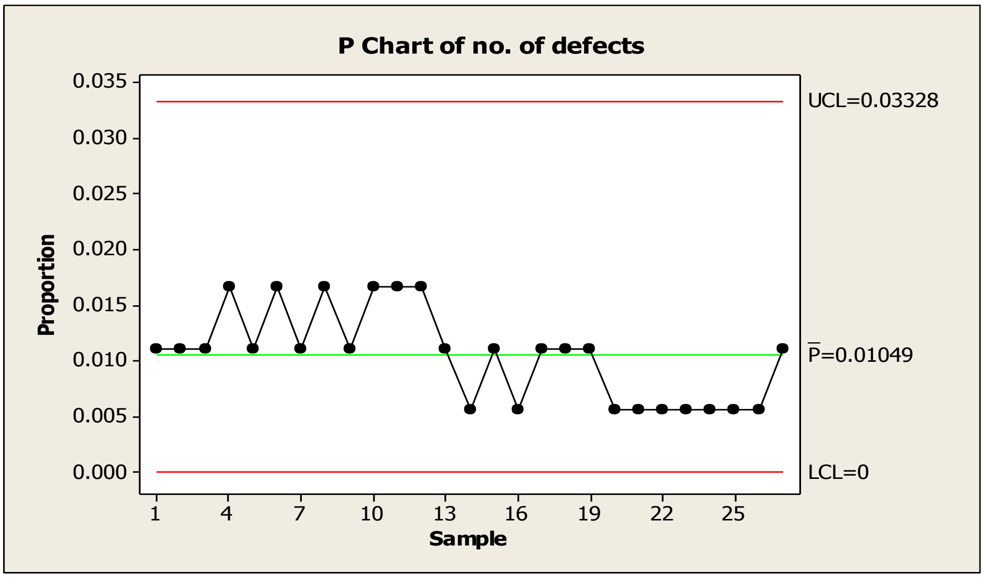

Fig. 9. p-chart for average Sample Size

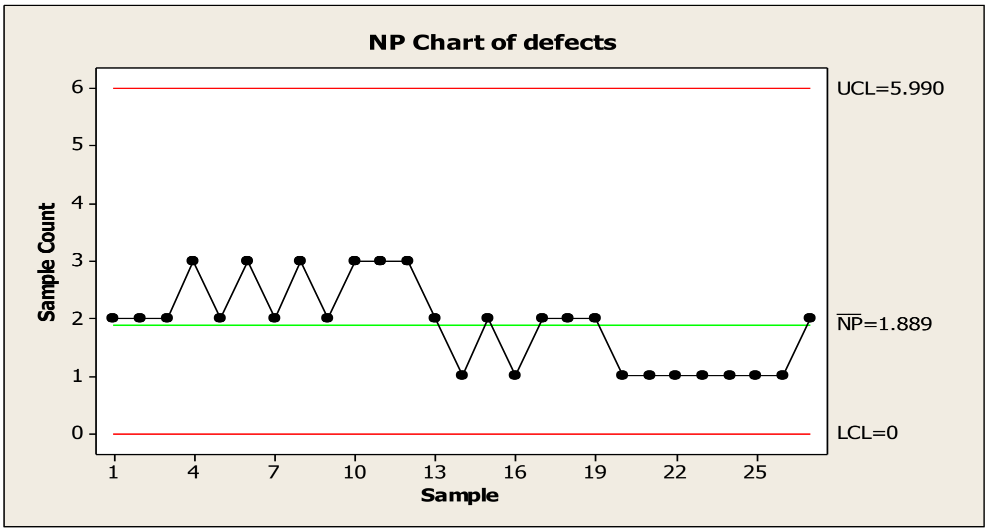

Fig. 10. np-chart for average Sample Size

The control chart shows that the process is in control. Therefore, operating characteristics curve has used to investigate the probability of accepting the lot with fraction of nonconforming.

The Operating Characteristics Function and Average Run Length
Let, α = Type-I error = Producer's risk, and, β = Type-II error = Customer's risk.
$\beta = P(D < n.UCL) - P(D \leq n.LCL)$
Here, UCL = 0.03310, $\bar{p}$ = 0.01044 and LCL = 0.
$\beta = P(D<181*0.03310) - P(D\leq 0*0.3310) = P(D<6) - P(D\leq 0) = 0.996$
$\alpha = 1 - \beta = 1 - 0.996 = 0.004$
If we vary the value of $\bar{p}$,then the value of β also changes which is shown below:

Table 2: Sensitivity analysis of β

$\bar{p}$	P(D<6)	P(D≤ 0)	β=P(D<6)− P(D≤ 0)
0.005	0.999	0	0.999
0.010	0.997	0	0.997
0.01044	0.996	0	0.996
0.015	0.979	0	0.979
0.020	0.927	0	0.927
0.025	0.830	0	0.830
0.030	0.698	0	0.698
0.035	0.552	0	0.552
0.040	0.411	0	0.411
0.045	0.290	0	0.290
0.050	0.195	0	0.195
0.055	0.125	0	0.125
0.060	0.078	0	0.078

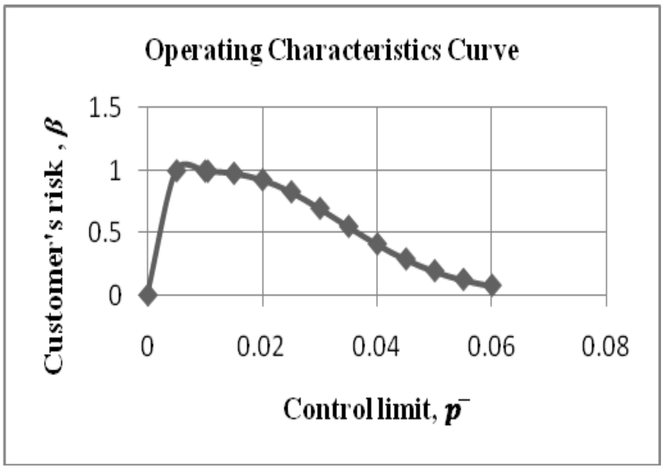

Fig. 11. Operating characteristics curve

ARL = $\frac{1}{\alpha}$, as the process is in control. Thus ARL is 319. This indicates that we have to take the sample size as large as 319 to detect a non-conforming product when process is in control.

4. Discussion and Recommendation

We have recognized that the main cause of quality problem is thickness uniformity problem. So, here are some remedies of this problem:

1. Changing the design or one of the designing parameters of the mould, such that introducing an extra sheet metal section in the joining sections of the mould or changing the edge parts of the mould for leakage control of concrete mixture into the mould during spinning may minimize the defects. This research proposes a new edge design of the mould.

Figure 12: Existing mould

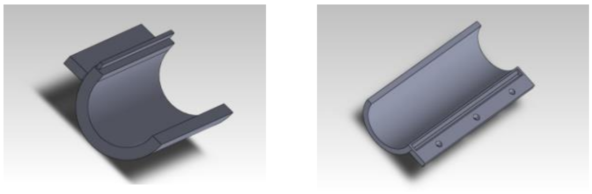

Figure 13: Proposed design mould

2. Check center pins and tightening the bolt before starting the operation of molding.
3. Optimize the r.p.m. of existing spinning machine.
4. Create groups for Fixed Area Network (GFAN) to minimize problems of scheduling and inter-relationship between the quality control team, junior engineers and workers.
5. The diameter of the spinning machine and the mould should check regularly to ensure the peripheral uniformity of both mould and spinner to avoid the mould hammering.
6. Check the wet of the raw materials before stating the production and keep checking the wet after a certain interval as the quality largely depends on the raw materials.
7. Change the metals used for manufacturing the mould. Metals of light weight and of high tensile and compressive strength should be chosen for manufacturing the mould.
8. Improved I-bolts should be attached with the mould for tightening the mould properly. Moreover, existing I-bolts should be re-grinded regularly for effective use of the threads of the bolt.

5. Conclusions

Statistical process control tools detect the major problems for manufacturing spun pre-stress concrete poles. The thickness uniformity problem is the major problem and it should be minimized at first. Operating characteristics curve and calculations of type-I error and type-II error helps to identify customer and consumer risks. The average run length is 319 for this in control process. This research and proposed recommendations is helpful for any spun pre-stressed concrete electric pole production company to minimize the problems and to increase productivity and customer satisfaction.

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