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Application of Statistical Quality Control for Investigating Process Stability and Control in an Electric Wire Industry

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ABSTRACT

This paper employed statistical quality control approach to investigate process stability in an electric wire manufacturing industry. Quality control tools such as Xbar and S charts as well as process capability charts were applied to measurements obtained from the electric wire manufacturing industry on important features of wire product. This was done to determine if the processes are in or out of control, and to determine the capability of the processes towards the production of a particular product to meet preset specifications. Results showed that the production process was in statistical process control in respects of the product diameter and electrical resistance, with no assignable cause of variation. It was further revealed that, though the wire production process used has high capability of effectively meeting the preset specification limits in respect of the product electrical resistance, nevertheless, it has low capability of meeting the preset specification limits in respect of the product diameter, hence incurring some losses as scraps.

Keywords: *Quality control, process stability, process control, control chart.*

1. INTRODUCTION

Every production process displays a certain amount of variation. While some processes display common and naturally occurring variation others display assignable causes of variation in addition. Control charts and their limits are very important decision aids as they provide information about the process behaviour and have no intrinsic relationship with any specification targets.

Control charts are a proven technique for improving productivity. A successful control chart program will reduce scrap and rework, which are the primary productivity killers in *any* operation. If scrap and rework are reduced, then productivity increases, cost decreases, and production capacity (measured in the number of *good* parts produced per hour) increases.

Quality has become one of the most important consumer decision factors in making a choice among competing products and services. The phenomenon is widespread, regardless of whether the consumer is an individual, an industrial organization, a retail store, a bank or financial institution, or a military defence program. Consequently, understanding and improving quality are key factors leading to business success, growth, and enhanced competitiveness. A well implemented quality control scheme provides adequate protection for the consumers, in one hand, in terms of production of quality product, and for the producer, in other hand, in terms of waste reduction (Montgomery, 1991).

Statistical quality control combines various dimensions to describe and evaluate the quality of a product. These dimensions include features, reliability, performance, conformance to standard, serviceability, maintainability, durability, availability, aesthetics, security and tolerance of the product (Banks, 1989). Also, the quality dimension being inspected may possess attribute or variable characteristics. Hence, control charts could be for variables (e.g. Xbar chart, R chart) or for attributes (P chart, nP chart, C chart, U chart) (Montgomery, 2009). The quality control analysis of an industry product is measured from the perceptive of any of these dimensions. Data related to such dimension being investigated will be collected and analysed at various stages of production of the product. The out-of-control samples of the product that fall short of the standard specification of the dimension will be determined and investigated. These out-of-control samples are usually due to assignable causes which after thorough investigation can be eliminated (Ogunlade and Fadakinni, 1996).

Many researchers have applied different quality control tools to measure, monitor and improve the quality of production process (Page, 1961; Woodall and Adam, 1993; Ott *et al.*, 2005). Page (1961) and Woodall & Adam (1993) designed and applied the Cumulative Sum (Cu-Sum) control chart in monitoring a change in the parameter of the distribution of quality characteristics. Ewan (1963) and Ott *et al.* (2005) discussed how and when to use the Cu-Sum charts with special emphasis on practical problems. Saniga (1989) established a procedure for economic selection of control chart parameters on a rigorous basis and with flexibility of choice. The Weibull distribution was employed as a failure mechanism in Chung and Lin (1993) to develop a dynamic control chart parameters which may change over time. An exponentially weighted average control chart was established in Steiner (1998) to monitor a grouped data for processed shifts.

In electric wire manufacturing, the different stages of production the wire passes through have a great impact on the quality of the final product. The processes include loading, wire drawing and annealing processes. Each of these processes has various quality variables. According to Changsun and Naksoo (2012), the major variables in the drawing process are the reduction ratio, die angle, friction at the interface of wire and die, and drawing velocity. Noonai et al. (2011) concedes that increasing of the degree of reduction ratio will increase the tensile strength and yield stress but the percentage elongation after heat treatment will be decreased. Cetinarslan (2012) investigated the influences of reduction ratio and drawing speed on cold drawing of ferrous and copper wires and prove that the drawing speed has a remarkable effect on tensile strength of wires as tensile strength values increased with increasing drawing speed. Olokode et al. (2008) also investigated the effects of process annealing on the mechanical properties of cold worked copper wires and concludes that the hardness of copper during cold drawing increases with degree of deformation due to strain hardening, and that the hardness reduces remarkably after annealing is done. However, prior to investigating effect of process parameters, it is essential to first establish whether a production process is in control or out of control. Consequently, this paper considers the application of quality control as a tool for investigating process stability and control using a case study of an electric wire manufacturing industry in Lagos, Nigeria.

2. METHODOLOGY

Data related to quality control in the wire manufacturing industry was acquired by working directly with the company's quality control team for a period of twenty consecutive days. The data collected include the diameter and electrical resistance of size 15 AWG annealed stranded copper conductors. These were done using micrometer screw gauge and wheat stone bridge meter respectively. The data were collected on four samples of the product being investigated in each of the twenty days. The collected data were analyzed using Xbar chart and S chart to estimate the control limits and determine the samples that are out-of-control from the standard specifications. The standard specifications of the parameters being considered are presented in Table 1. The Xbar chart measures shift in central tendency of the process and the S chart monitors the dispersion or variability of the process.

Table 1: Standard specifications for diameter and electrical resistance

Product	Diameter (mm)	Electrical resistance (Ω)
Size 15 AWG Stranded Copper Conductor	5.10±0.20	10.78±0.25

2.1. Xbar Chart and S Chart for Variable

Control charts for variables monitor characteristics that can be measured and have a continuous scale, such as the diameter and electrical resistance of a conductor wire being considered. Xbar Chart and S Chart are examples of such charts. They monitor both the central tendency of the data (the mean) and the variability of the data (either the standard deviation or the range). To construct the Xbar chart, the control line is constructed by taking the mean ($\bar{x}$) of the four samples of each product considered in each day and the center line of the chart is then computed as the mean of all days means (Montgomery, 2009).

$$\bar{x}_i = \frac{\sum_{k=1}^{k} x_{ik}}{k} \qquad (\forall i,\ i = 1, 2, \dots\dots n)$$

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \cdots \bar{x}_n}{n}$$

Where, for each of the parameters considered (i.e. diameter and electrical resistance);

$\bar{x}_i$ = mean of the samples considered in each day

x_{ik} = diameter or electrical resistance of the wire sample

i = day's index

k = number of samples considered in each day

$\bar{\bar{x}}$ = mean of all the days' samples means

n = number of days

For the s-chart, process standard deviation for each day, s_i, is computed as

$$s_i = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}}{n-1}} \qquad (\forall i,\ i = 1, 2, \dots\dots n)$$

The center line, $\bar{s}$, of the s-chart is computed as the average of all the days' standard deviations as:

$$\bar{s} = \frac{s_1 + s_2 + \cdots s_n}{n}$$

The upper and lower control limits of the charts are computed as:

For the Xbar chart;

Upper control limit (UCL) = $\bar{\bar{x}} + z\sigma_{\bar{x}}$

Lower control limit (LCL) = $\bar{\bar{x}} - z\sigma_{\bar{x}}$

And for the s-chart;

Upper control limit (UCL) = $\bar{s} + z\sigma_s$

Lower control limit (LCL) = $\bar{s} - z\sigma_s$

where:

z = standard normal variable ($z = 3$ for 99.74% level of confidence)

$\sigma_{\bar{x}}$ = standard deviation of the distribution of sample means.

σ_s = standard deviation of the distribution of sample standard deviations.

2.2. Process Capability Analysis

Process capability is a measure that estimates ability of a production process to meet preset specifications. It is determined by using the process capability index c_{pk} which is computed as the ratio of the specification width to the width of the process variability (Montgomery, 2009).

$$c_p = \frac{\text{specification width}}{\text{process width}} = \frac{\text{USL} - \text{LSL}}{6\sigma_{\text{within}}}$$

Where:

USL = upper specification limit

LSL = lower specification limit

σ_{within} = standard deviation of the samples that fall within the specification limits

However, to address a possible lack of centering of the process over the specification range, the process capability of each half of the normal distribution is computed and the minimum of the two is used. That is;

c_{pk} = min {CPU, CPL}

Where:

$$\text{CPU} = \frac{\text{USL} - \bar{\bar{x}}}{3 \times \sigma_{\text{within}}}$$

$$\text{CPL} = \frac{\bar{\bar{x}} - \text{LSL}}{3 \times \sigma_{\text{within}}}$$

CPL is a capability index defined as the ratio of the interval formed by the process mean and LSL and one-sided spread of the potential process. CPU is a capability index defined as the ratio of the interval formed by the process mean and USL and one-sided spread of the potential process.

Hence,

$$c_{pk} = \min\left(\frac{\text{USL} - \bar{\bar{x}}}{3\sigma_{\text{within}}}, \frac{\bar{\bar{x}} - \text{LSL}}{3\sigma_{\text{within}}}\right)$$

Generally, if

$c_{pk} = 1$: The process variability just meets specification.

$c_{pk} \leq 1$: The process variability is outside the range of specification and not capable of producing within specification.

$c_{pk} \geq 1$: The process variability is tighter than specification and exceeds minimal capability.

The percentage of samples that have measurements less or greater than the preset lower or upper specification limit are determined respectively as thus:

$$\% < \text{LSL} = \left[1 - \left(\frac{\bar{\bar{x}} - \text{LSL}}{\sigma_{within}}\right)\right] \times 100\%$$

$$\% > \text{USL} = \left[1 - \left(\frac{\text{USL} - \bar{\bar{x}}}{\sigma_{\text{within}}}\right)\right] \times 100\%$$

2.2.1 Overall Capability Analysis Indices

The capability analysis indices considered thus far estimates the performance of the samples that are within the specification limits. However, in order to estimate the performance of all the samples, overall capability indices are defined. P_p, PPL, PPU and P_{pk} are overall capability indices respectively defined in the same manner as in c_p, CPL, CPU and c_{pk}, but with a little difference in their computation. Within standard deviation is used while computing c_p, CPL, CPU and c_{pk}, whereas overall standard deviation is used while computing P_p, PPL, PPU *and* P_{pk}. Overall standard deviation is defined as the standard deviation of all the samples considered over the twenty days (which is equal to eighty at four samples per day over a period of twenty days). C_{pm} is a capability index that is the ratio of the specification spread (USL - LSL) to the square root of the mean squared deviation from the target. Hence, the higher the C_{pm} index, the better the process.

3. RESULT AND DISCUSSION

The mean and standard deviations of the diameter and electrical resistance data, of the wire product collected were estimated and are as presented in Tables 2 and 3 respectively.

Table 2: Samples Diameter for Size 15 AWG Stranded Annealed Copper Conductor

Day	Sample (x_i) (mm)				$\bar{x}_i$	s_i
	1	2	3	4		
1	5.10	5.02	5.06	5.20	5.10	0.08
2	4.83	4.79	5.09	4.98	4.92	0.14
3	5.00	5.10	5.20	5.10	5.10	0.08
4	5.10	5.30	5.08	5.33	5.20	0.13
5	5.05	5.34	5.31	5.05	5.19	0.16
6	5.16	5.11	5.06	5.17	5.13	0.05
7	5.00	5.22	5.03	4.92	5.04	0.13
8	5.10	5.20	4.95	5.00	5.06	0.11
9	5.00	5.14	5.15	5.25	5.14	0.10
10	5.20	5.28	5.20	5.09	5.19	0.08
11	4.90	5.25	5.23	5.40	5.20	0.21
12	5.30	5.31	5.17	4.88	5.17	0.20
13	5.21	5.21	5.37	5.21	5.25	0.08
14	5.07	5.16	5.06	5.36	5.16	0.14
15	5.14	5.00	5.14	5.19	5.12	0.08
16	5.21	4.92	5.00	4.81	4.99	0.17
17	4.80	5.10	4.90	5.10	4.98	0.15
18	5.45	5.15	5.00	5.26	5.22	0.19
19	5.11	5.15	5.05	5.09	5.10	0.04
20	5.24	5.10	4.97	5.34	5.16	0.16
					$\bar{\bar{x}} =$ 5.1196	$\bar{s} =$ 0.124
					$\sigma_{\bar{x}} =$ 0.0673	$\sigma_s =$ 0.0413

Table 3: Samples Resistance for Size 15 AWG Stranded Annealed Copper Conductor

Day	Sample (x_i) (mΩ/m)				$\bar{x}_i$	s_i
	1	2	3	4		
1	10.79	10.86	10.86	10.79	10.83	0.04
2	10.83	10.84	10.84	10.73	10.81	0.05
3	10.78	10.85	10.73	10.73	10.77	0.06
4	10.83	10.72	10.73	10.86	10.79	0.07
5	10.88	10.78	10.9	10.69	10.81	0.10
6	10.75	10.71	10.78	10.84	10.77	0.05
7	10.71	10.72	10.88	10.79	10.78	0.08
8	10.74	10.84	10.86	10.78	10.81	0.06
9	10.88	10.76	10.75	10.89	10.82	0.08
10	10.71	10.74	10.71	10.87	10.76	0.08
11	10.73	10.89	10.72	10.88	10.81	0.09
12	10.88	10.76	10.89	10.77	10.83	0.07
13	10.72	10.79	10.69	10.76	10.74	0.04
14	10.76	10.86	10.78	10.85	10.81	0.05
15	10.73	10.81	10.84	10.71	10.77	0.06
16	10.74	10.75	10.83	10.85	10.79	0.06
17	10.88	10.74	10.75	10.89	10.82	0.08
18	10.86	10.77	10.82	10.86	10.83	0.04
19	10.78	10.87	10.87	10.75	10.82	0.06
20	10.69	10.86	10.85	10.71	10.78	0.09
					$\bar{\bar{x}} =$ 10.7959	$\bar{s} =$ 0.065
					$\sigma_{\bar{x}} =$ 0.02543	$\sigma_s =$ 0.0217

Figs. 1 and 2 show the Xbar and S charts of the product's samples in respects of the diameter (Fig. 1) and electrical resistance (Fig. 2) of the electric wire product. It could be observed, from the charts, that all the days' averages fall within the lower and upper control limits (which are respectively three-sigma below and above the mean with 99.74% level of confidence). Consequently, it can be inferred that there is a 99.74% probability that the quality characteristic (diameter and electrical resistance) values obtained from the processes fall within the control limits, with only 0.26% outside a 3- sigma control limits. This shows statistically that the wire drawing process for the product is stable. It also shows that there is no assignable cause of variation in the production processes. Therefore, there is a very low chance of unprecedented level of process variation as inherent level of variation are only normal and common causes of variation such as inadequate working condition. Furthermore, it is interesting to note that the process centers from the control charts fall in the range of the real target specifications which signify very low naturally occurring level of variation in the processes.

Figs. 3 and 4 show the process capability analyses of the wire products' diameter and electrical resistance respectively. In Fig. 3, it could be observed that there are low process capability indices in respect of the product diameter. Since each of these capability indices are less than one (< 1), then it is highly possible that the process may not be capable of meeting the preset specification limits in respect of the product diameter. It is also worth noticing from Fig. 3 that the normal distribution curve is not centered relative to the preset specification because its capability index is less than one. Though, it has earlier been established that there are no assignable variation in the process, yet, the fact that the capability index is less than one may result in a substantial percentage of the products not within the preset specification limits in respect of diameter of the product.

In Fig. 4, it can be observed that there are high process capability indices in respect of the electrical resistance of the product. All the capability indices are greater than unity (> 1), meaning that the process of producing the products has a very high capability of meeting the preset specification limits in respect of the product electrical resistance. Also in Figure 4, the normal distribution curve of the process is centered exactly relative to the preset specifications which resulted into a very low 0.03% percentage of the products to be defective. Also, since the capability index is greater than one, hence, the process variability is tighter than specifications and the process exceeds minimal capability.

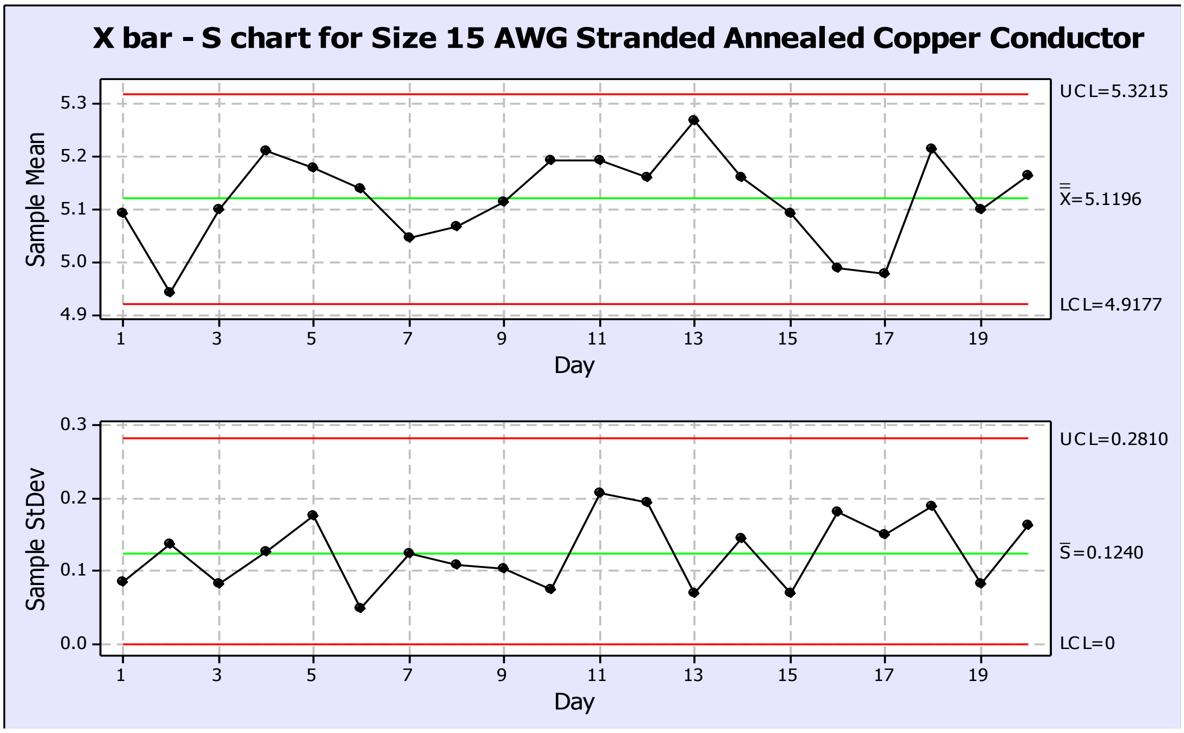

Fig. 1. Xbar and S Charts for the product samples' diameter in mm

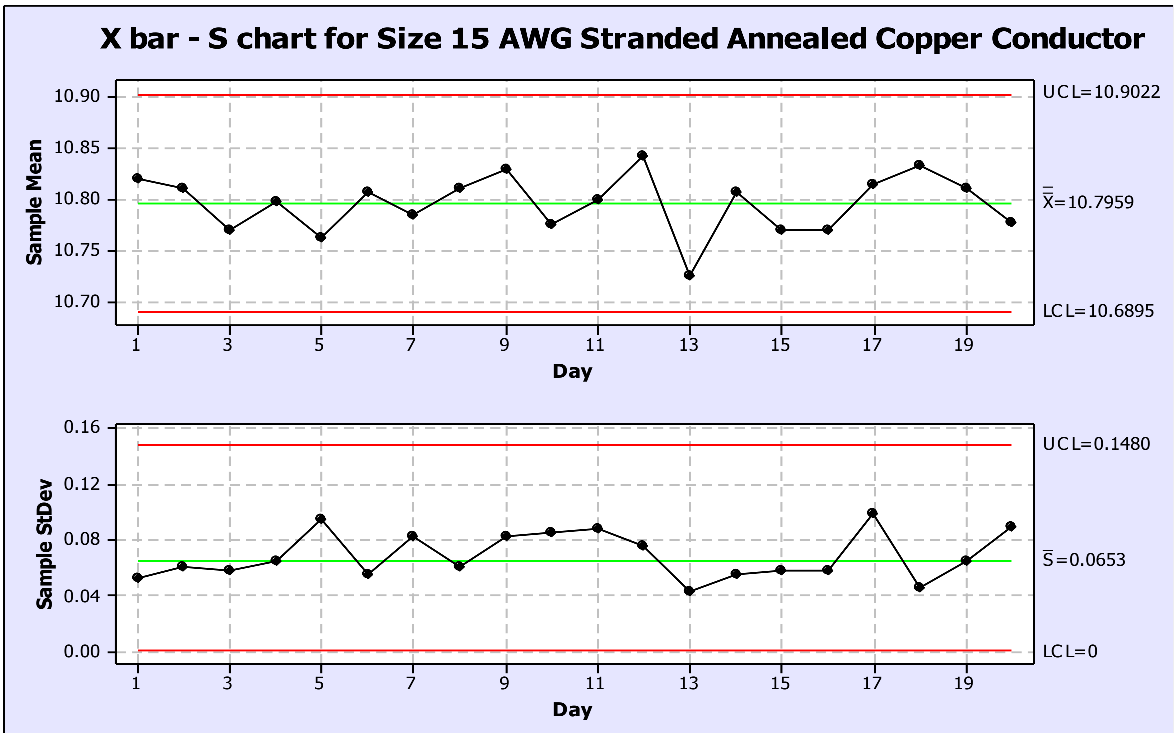

Fig. 2. Xbar and S Charts for the product samples' electrical resistance in mΩ/m

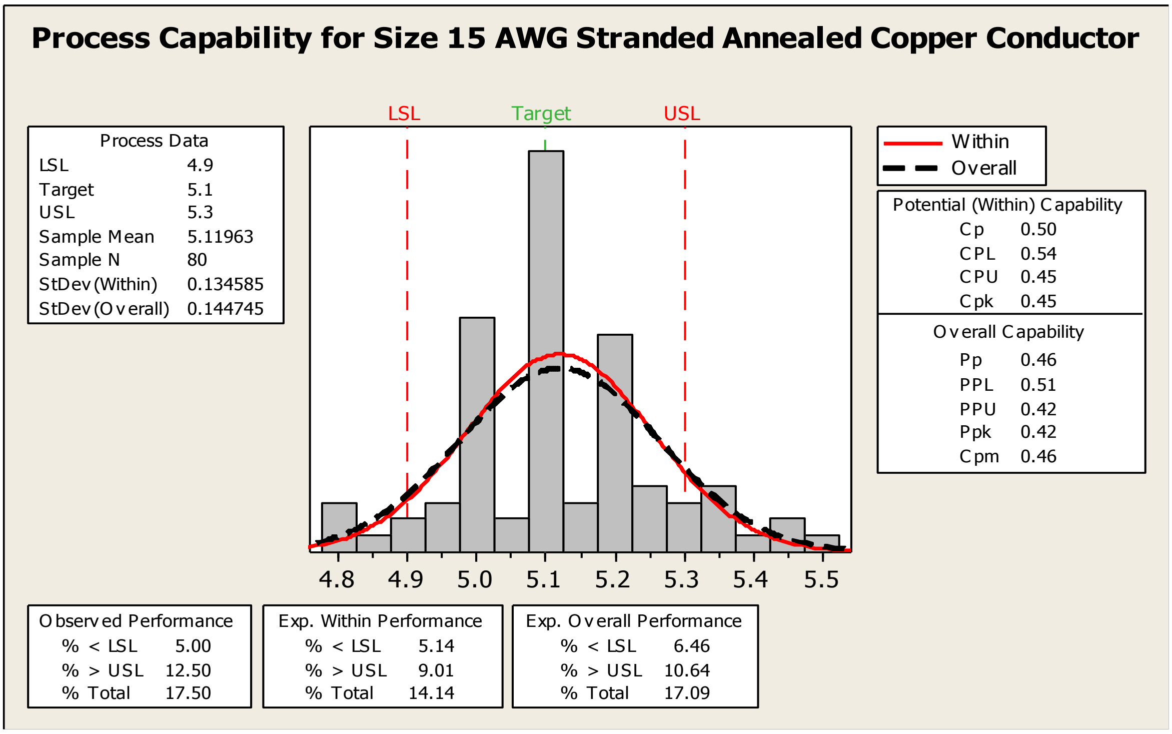

Fig. 3. Process capability analysis for the product samples' diameter

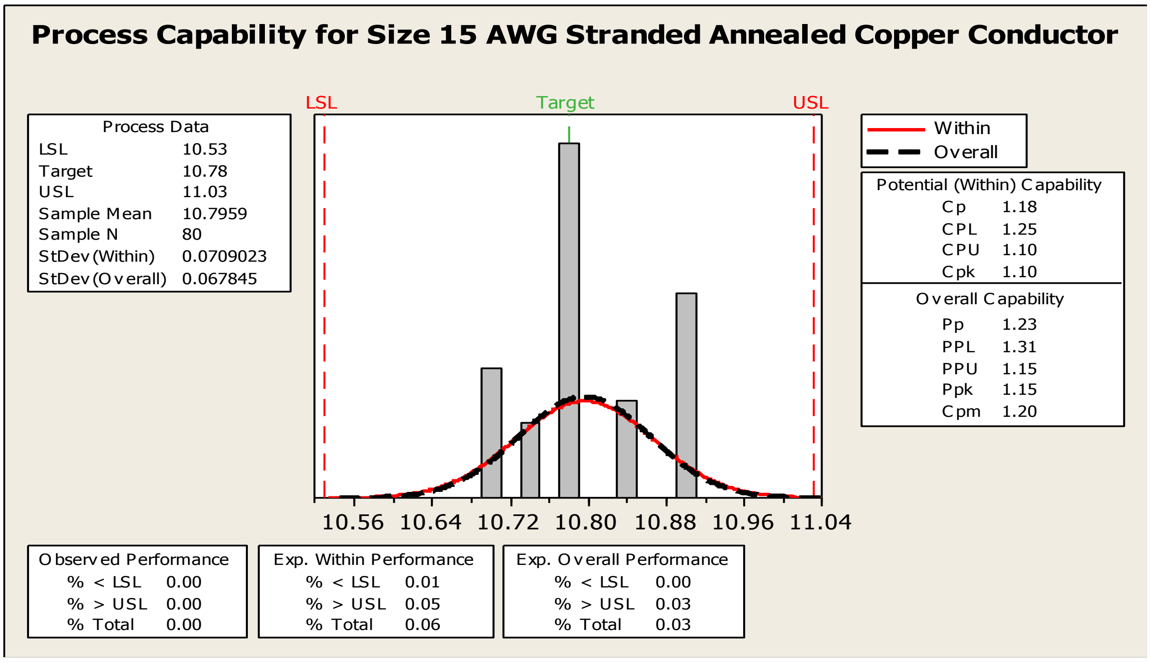

Fig. 4: Process capability analysis for the product samples' electrical resistance

4. CONCLUSION

The statistical quality control Xbar and S charts have been successfully applied to the production process of Nigeria Wire Industry Limited with respects to diameter and electrical resistance of the product as quality characteristics. The Xbar and S charts constructed revealed that the data obtained on the quality characteristics are uniformly distributed and that the data are all within the control limits with only 0.26% outside a 3- sigma control limits, which is equivalent to a 99.74% level of confidence. Consequently, this shows that there is no assignable cause of variation in the production processes, which means that the production process is stable. Therefore, there is a very low chance of unprecedented level of process variation, with normal inherent level of variation as the only common source variation which may arise as a result of inadequate working condition. However, if a system falls within the control limits does not guarantee that the preset specification limits will be met. Hence, the process capability to meeting the preset specification limits was conducted in respects of the quality characteristics. In respect of the product diameter, the capability analysis revealed low values for all the capability indices. This corresponds to low capability of the production process in effectively meeting the preset specification limits. Nevertheless, in respect of the product electrical resistance, the capability analysis revealed high values for all the capability indices, which corresponds to high capability of the production process in effectively meeting the preset specification limits of the product electrical resistance.

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