# ADJUSTING OFF – CENTERING PROCESS FOR A BLOW MOLDED PLASTIC PRODUCT BY USE OF WINQSB SOFTWARE

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**ABSTRACT**

In most manufacturing processes, and in spite of statistical control, several process capability indices refer to non conformance of the true mean ( $\mu_c$ ) from the target mean ( $\mu_T$ ), and the variation is also high. In this paper, data have been analyzed and studied for a blow molded plastic product (Zahi Bottle) (ZB).

WinQSB software was used to facilitate the statistical process control, and process capability analysis and some of capability indices. The relationship between different process capability indices and the true mean of the process were represented, and then with the standard deviation ( $\sigma$ ), of achievement of process capability value that can reduce the standard deviation value and improve production out of theoretical control limitations and cost reduction.

The study exhibits that when adjusting the center to the target value by adjusting the mold to the machine, the capability index ( $C_p$ ) enhanced by (14.56 %), capability index ( $C_{pk}$ ) is enhanced by (14.48 %), capability index ( $C_{pm}$ ) is enhanced by (12.5 %) and accuracy index ( $C_a$ ) is enhanced by (14.49 %). The percentage of the specification band used up by the process ( P ) is reduced by (12.8 %) and the degree of variation increases.

# ضبط عدم تمركز العملية لمنتج بلاستيكي مصنع بماكنة نفخ باستخدام برامجيات (WinQSB)

**الملخص**

في أغلب العمليات الانتاجية، وبالرغم من حالة الضبط الاحصائي فان مؤشرات المقدرة المختلفة تشير الى حالة عدم المطابقة للمتوسط الحقيقي عن المتوسط المستهدف، وكذلك مقدار التشتت يكون كبير. في هذا البحث تم دراسة وتحليل البيانات لمنتج بلاستيكي مصنع بطريقة النفخ (علبة زاهي).

استخدمت برامجيات (WinQSB) لتسهيل عملية الضبط الاحصائي وكذلك تحليل مقدرة العملية وبعض مؤشرات المقدرة. رسمت العلاقة بين مؤشرات المقدرة المختلفة مع متوسط العملية الفعلي ومن ثم مع مقدار التشتت لغرض الوصول الى مقدار مؤشر مقدرة الغاية منه تقليل قيمة التشتت وتحسين الانتاج خارج حدود الضبط النظري وتقليل الكلفة.

نتائج البحث بينت انه عند تعديل التمركز الى القيمة المستهدفة من خلال تضبيط القالب على الماكنة تحسن مؤشر المقدرة ( $C_p$ ) بمقدار (14.56 %) و مؤشر المقدرة ( $C_{pk}$ ) بمقدار (14.48 %) و مؤشر المقدرة ( $C_{pm}$ ) بمقدار (12.5 %) ومؤشر الدقة ( $C_a$ ) بمقدار (14.49 %) وقلت نسبة الاستفادة من حدود المواصفة ( P ) بمقدار (12.8 %) واصبحت حرية التشتت اعلى.

**KEYWORDS: Process Capability, Process Capability Analysis, WinQSB Software, Process Capability Index, Control Charts, Mean Shift, Off – Center.**

## INTRODUCTION

In any manufacturing operation [**Groover, 10**], variability exists in the processes output, the operated parts may appear to be identical, but close inspection reveals dimensional differences from one part to the next. Manufacturing variations can be divided into two types: random and assignable. There are four factors [**Besterfield, 09**] that contribute to these variation (processes, materials, operators and miscellaneous). As long as these four factors fluctuated in a normal or expected manner, a stable pattern of many random or chance cause of variation develops. They are inevitable, very small in magnitude, and difficult to identify. Those causes of variation which are large in magnitude and therefore readily identified, are classified as assignable causes. As long as [**Arnold, Chapman, 07**] only chance variation exists, the process is said to be in statistically controlled. If there is an assignable cause of variation, the process is not in control and is unlikely to produce a good product. The objective of Statistical Process Control (SPC) is to detect the presence of assignable causes of variation. SPC has two objectives: first is to help select processes capable of producing the required quality with minimum defects. Second is to monitor process to be sure it continues to produce the required quality and no assignable cause of variation exists. The output of every process has a unique pattern that can be described by its shape, center, and spread. A histogram is [**Geng, 04**] a frequency distribution that graphically displays the measurements taken from a process and shows how those data points are distributed and centered over a measurement scale. Histograms give a picture of what the process is producing over a specified period of time, although not sequentially. A clear picture of the process variation for the specified time frame become evident and comparisons can be made against the expected process output vs. the actual production. Taguchi looked for [**Waters, 96**] both high quality and low costs. He gets this by defining target performance in key areas. When the process aims not just to be within specified quality limits – in which being just inside the limits is good enough – but to be near the target value (the center). The organization can then use statistical methods to find the most important factors that set product quality. Taguchi's advice is to aim for a target performance rather than get within some limits. But the random variations in all processes mean that it can't always hit the target. When the variations are too large it produce defect. Whenever a defective unit is produced, it is a sign that something has gone wrong with the process. The organization should find the cause of the defect and correct it before any more defects are made.

## CONTROL CHART

A control chart [**Stapenhurst, 05**] was developed specifically to determine whether process outputs exhibit common cause variation only, or whether, and when, special cause variation is occurring. When samples are taken **[Schilling, Neubauer, 08]** periodically on a process, the average of the samples will tend to cluster about some overall average, or process level. The control chart consists of three parallel lines: two outside lines, called Upper Control Limit (UCL) and Lower Control Limit (LCL), and a Center Line (CL). The CL reflects the average of the data, while the control limits are calculated to have a high probability of the sample data being contained between them if the process is stable. If the process level shifts, however, points will plot outside the limits, indicating the need for corrective action on the process.

A control chart, in control for 20 or 30 samples have been collected on the chart [**Kulkarni, Bewoor, 09**], the UCL and LCL of the process may already be computed. Control limits define the boundaries of the normal behavior of the process. Their values depend only on the output data generated by the process in the immediate past. Control limits are therefore independent of specification limits. However, both sets of limits are used in the practice of SPC, although in different ways. The UCL and the LCL may be calculated from the mean and standard deviation for all samples (or σ) of the plotted data as follows:

$$\text{UCL} = \text{Grand Mean} + (3 \times \sigma) \quad (1)$$

$$\text{LCL} = \text{Grand Mean} - (3 \times \sigma) \quad (2)$$

The $\bar{\bar{X}}$ - R chart, which it is one of the control charts for variables consists [**Stapenhurst, 05**] of two parts, the $\bar{\bar{X}}$ chart and the R chart. The $\bar{\bar{X}}$ chart is conventionally drawn above the R chart. The S (standard deviation) chart can be used in place of the R chart when sample sizes (n) rise above about 9 or if calculations are automated or particularly if the sample size varies from group to group. Whereas $\bar{\bar{X}}$ is the mean of the sample and calculated us summation of the data and divided by the sample size, R is the range of the

data which is the deference between maximum and minimum value, and s is standard deviation of the sample. Two considerations [**Allen, 10**] for sample size selection First, the larger the sample size, the closer the control limits and more sensitive the chart will be to assignable causes. Second, n should ideally be large enough that the sample averages of the value follow a specific pattern. The pattern in question relates to the so-called "normal" distribution. In many situations, this pattern happens automatically if $n \geq 4$. The grand mean $\overline{\overline{X}}$ and $\overline{R}$ and $\sigma$ calculated as follows:

$$\overline{\overline{X}} = \frac{\sum_{i=1}^{m} \overline{X}}{m} \quad (3)$$

$$\overline{R} = \frac{\sum_{i=1}^{m} R}{m} \quad (4)$$

$$\sigma = \frac{\overline{R}}{d_2} \quad (5)$$

Whereas, $d_2$ is a constant depends on the sample size n.

## PROCESS CAPABILITY

Capability indices that [**Pearn, Kotz, 06**] qualify process potential and process performance are practical tools for successful quality improvement activities and quality program implementation. Apparently, the first Process Capability Index (PCI) to appear in the literature is the precision index $C_p$, defined as:

$$C_p = \frac{USL - LSL}{6 \times \sigma} \quad (6)$$

While the precision index $C_p$ measures the magnitude of the process variation, the index *k*, to be defined below, describes the process capability in terms of departure of the process mean μ from the center (midpoint or Target) *T* and provides a quantified measure of the extent that a process is off-center. The index *k* is one of the original Japanese indices and is defined as:

$$k = \frac{|\mu - T|}{\frac{USL - LSL}{2}} = \frac{|\mu - T|}{d} \quad (7)$$

Where μ is the process mean, d = (USL – LSL) / 2 is the half specification width, and *T* is the midpoint between the upper and lower specification limits (*T* = (USL + LSL) / 2). This index measures the departure of process mean from the midpoint of specifications.

The complementary index $C_a = 1 - k$ , referred to as the accuracy index, is defined to measure the degree of process centering relative to the manufacturing tolerance. The index is expressed as:

$$C_a = 1 - \frac{|\mu_c - T|}{d} \quad (8)$$

It measures the degrees of process centering, and alerts the user if the process mean deviates from the center *T* (which is often the target value). Whereas $C_a = 1$ when $\mu = T$, and $0 < C_a < 1$ when the process center is shifted, and $C_a = 0$ when $\mu = LSL$ or $\mu = USL$, and $C_a < 0$ when $\mu < LSL$ or $\mu > USL$.

The PCI in equation (6) has [**Montgomery, 05**] a useful practical interpretation (P) namely, is the percentage of the specification band used up by the process.

$$P = \left( \frac{1}{C_p} \right) \times 100 \quad (9)$$

Equation (6) assumes that the process has both upper and lower specification limits. For Upper Specification only ($C_{pu}$) and Lower Specification only ($C_{pl}$), one sided PCIs defined as follows:

$$C_{pu} = \frac{USL - \mu}{3\sigma} \quad (10)$$

$$C_{pl} = \frac{\mu - LSL}{3\sigma} \quad (11)$$

The process capability ratio $C_p$ does not take into account where the process mean is located relative to the specifications. $C_p$ simply measures the spread of the specifications relative to the six sigma spread in the process. It may be more accurately reflected by defining a new process capability ratio that takes process centering into account. This quantity is:

$$C_{pk} = \min(C_{pu}, C_{pl}) \quad (12)$$

If $C_{pk} = C_p$, the process is centered at the midpoint of the specifications, and when $C_{pk} < C_p$ the process is off – center. Thus, $C_p$ measures potential capability in the process, whereas $C_{pk}$ measures actual capability.

For any fixed value of $\mu$ in the interval from LSL to USL, $C_{pk}$ depends on $\sigma$ and becomes large as $\sigma$ approaches zero. That large value of $C_{pk}$ does not really tell us anything about the location of the mean in the interval from LSL to USL. One way to address this difficulty is to use a process capability ratio that is a better indicator of centering $C_{pm}$ as follows:

$$C_{pm} = \frac{\text{USL - LSL}}{6 \times \tau} \qquad (13)$$

$$\tau = \sqrt{\sigma^2 + (\mu - \text{T})^2} \qquad (14)$$

When both $C_{pk}$ and $C_{pm}$ coincide with $C_p$ when $\mu = T$ and decrease as $\mu$ moves away from $T$. However $C_{pk} < 0$ for $\mu > USL$ or $\mu < LSL$, Whereas $C_{pm}$ approaches zero asymptotically as $|\mu - T| \to \infty$.

An important assumption [**Montgomery, 05**] underlying this discussion of process capability and the ratios $C_p$ and $C_{pk}$ is that their usual interpretation is based on a normal distribution of process output. If the underlying distribution is non normal, then the statements about expected process fallout attributed to a particular value of $C_p$ or $C_{pk}$ may be in error. However,

For large values [**Spiegel, Stephens, 08**] of samples $N\,(N \geq 30)$, the sampling distribution of means is approximately a normal distribution with mean $\mu_{\bar{x}}$ and standard deviation $\sigma_{\bar{x}}$ irrespective of the population (so long as the population mean and variance are finite and the population size is at least twice the sample size). This result for an infinite population is a special case of the central limit theorem of advanced probability theory, which shows that the accuracy of the approximation improves as N gets larger. This is sometimes indicated by saying that the sampling distribution is asymptotically normal.

It is a good approximation that **[Booker, Raines, Swift, 01]** if the number of components in the stack is greater than 5, then the final assembly characteristic will form a normal distribution regardless of the individual component distributions due to the "Central Limit Theorm".

## OBJECTIVES OF AN ANALYSIS OF PROCESS CAPABILIT

The basic [**Grant, Leavenworth, 96**] statistical problem in process quality control is that of establishing a state of control over the manufacturing process, which is, eliminating special causes of variation and then maintaining that state of control through time. Once a state of control has been established, attention turns to the question, "Is the output meeting specifications, and if not, can the process be adjusted to a level where it will?" Actions that result in change or adjustment in a process, directed at eliminating common causes, are frequently the result of some form of capability study. The comparison of natural tolerance limits with the specification range may lead to any of the following possible courses of action: (1) No action: If the natural tolerance limits fall well within the specification limits, usually no action will be required. (2) Action to adjust centering: When the natural tolerance range is about the same as specification range, a relatively simple adjustment to the centering of the process may be all that is necessary to bring virtually all products within specifications. (3) Action to reduce variability: This is usually the most complex action. In those cases where several product streams merge into one line prior to inspection, action may involve the relatively uncomplicated task of bringing the several streams under control separately at some standard $\overline{X}$. In other cases, a complex analysis of the sources of variation may be required resulting in changes of methods, tooling materials, and/or equipment. (4) Actions to change specifications: This is a design decision but one that should not be ignored by quality control personnel. Simply because specifications are stipulated in writing does not necessarily mean they are inviolate. On the other hand, quality control and manufacturing personnel cannot callously ignore them without running the risk of causing real trouble.

## USES OF PROCESS CAPABILITY INFORMATION

Process capability information [**Juran, Godfrey, 99**] serves multiple purposes: (1) Predicting the extent of variability that processes will exhibit. Such capability information, when provided to designers, provides important information in setting realistic specification limits. (2) Choosing, from among competing processes or equipment, that which is best to meet the specifications. (3)

Planning the interrelationship of sequential processes. One process may distort the precision achieved by a predecessor process. Quantifying the respective process capabilities often points the way to a solution. (4) Providing a quantified basis for establishing a schedule of periodic process control checks and readjustments. (5) Testing theories of causes of defects during quality improvement programs. (6) Serving as a basis of quality performance requirements for purchased product or equipment. In certifying suppliers, some organization use a capability index as one element of certification criteria. In these applications, the value of the capability index desired from suppliers can be a function of the type of commodity being purchased.

## THE WINQSB SOFTWARE

The Quantitative Systems for Business (QSB) [**Ionica, Edelhauser, 08**] software package contains the most widely used problem-solving algorithms in Operations Research and Management Science (OR/MS). The WinQSB is the Windows version of the QSB software package. The computer product WinQSB is intended [**Ciobanica, 11**] to solve quantitative problems in management, and it was realized in the Georgia Institute of Technology, Atlanta, USA by Y. L. Chang and presented in 1997 in the paper WinQSB Decision Support Software. The WinQSB software [**Ionica, Edelhauser, 08**] is one of the most important events in decision making process. Operations Research and Management Science (OR/MS) software systems are used to construct examples, to understand the existing concepts, and to discover useful managerial concepts. On the other hand, new developments in decision making process often motivate developments of new solution algorithms and revision of the existing software systems. OR/MS software systems rely on a cooperation of OR/MS practitioners, designers of algorithms, and software developers.

## THE PRACTICAL WORK

Blow molding is used to produce plastic refills for different kinds of detergents. Zahi Bottle (ZB) was chosen as a case study in this research; to study the capability of the process for the machine which manufactures this type of bottle as shown in **figure (1)**, **figure (2)** shows the bottle mold.

**Table (1)** shows the collected data for Zahi Bottle Neck (ZBN) which is the critical character for this product. Thirty Samples (m = 30) were measured and five sample size (n = 5) were taken every one hour for five days. The measurements were taken by Vernier caliper, which was calibrated before use, and all measurements were gauged by the same inspector. The tolerance of the ZBN was (28 ± 0.5 mm).

After that the data in table (1) was entered by WinQSB software version (2), which is the updated version of the program. **Figures (3), (4) and (5)** show the control charts for ($\overline{\mathrm{X}}$ - chart), (R – chart) and (s – chart) which were used to control the process under study. All charts clarified that the process was under control for all points; the first condition for the study process capability was realized.

**Figure (6)** shows the histogram for the data under study which was analyzed and displayed by the WinQSB software program, the second condition for studying the process capability was realized too.

**Figure (7)** shows the window for the process capability analysis by WinQSB software for the data entered, by analyzing Process Capability Ratios (PCRs). The result appears that the process is incapable and the mean shifted – off.

## RESULTS AND CONCLUSIONS

The histogram in **figure (6)** and $\overline{\mathrm{X}}$ - chart in **figure (3)** represent high magnitude dispersion for means for the data value. PCRs ($C_{pk}, C_{pm}$) and the process accuracy ($C_a$) were calculated by **equations (2), (3)** and **(8).**

This indicates that, with manufacturing continuity under similar conditions in the long run, some parts of the products will lay out of tolerance limits, mainly adjusting centering is highly recommended in such situations.

**Table (2)** shows the hypothetical values of the mean and graduating slightly above and below the target mean until the tolerance limits ($\mu_{c\ \mathrm{hypo}}$) which were calculated for assessment for process capability without shifting off. **Equations (12), (13) and (8)** PCIs and process accuracy index $C_{pk}$, $C_{pm}$ and $C_a$ were calculated. **Figure (8)** exhibits the relationship, drawn by excel software, between the different process capability ratios and $\mu_{c\ \mathrm{hypo}}$. **Figure (9)** magnified the upper area of **figure (8)** to show the value of PCIs when $\mu_c = 28$, which were $C_{pk} = C_{pm} = 0.969$ and $C_a = 1$.

By the same way different values were assumed for of the standard division $\sigma$ to calculate different PCRs, the results were shown in **table (3)**. **Figure (10)** exhibits the results for $C_p, C_{pk}$

and $C_{pm}$ calculated by different values of the variation $\sigma$. **Figure (11)** magnify the middle area of **figure (10)** to show the value of $\sigma$, which was 0.15 when $C_{pk} = 0.969$.

**Figures (8) and (9)** were cumulative to give a wide area to ($\mu$) and ($\sigma$) against PCRs, to help the quality control engineers and designers by knowing the real limits of tolerance in conformity with different process variability.

**Table (4)** calculated the original and estimated data for the studied characteristic, the Percentage of Enhancements (PE) and Percentage of Utilization (PU) from new values. The values of PE and PU were calculated as follows:

$$\text{PE} = \frac{\text{Original values}}{\text{Hypothetical values}} \times 100\% \qquad (15)$$

$$\text{PU} = \left|100 - \text{PE}\right| \times 100\% \qquad (16)$$

Decreasing the standard deviation amount by (0.02) and increasing the process capability to (1.11) leads to the decrease of the percentage of product defects.

Improving a process by re-centering it is easier than changing the sources of variation. In most of manufacturing processes, the shifting between true mean and the target mean is caused mostly by the machine or by the fixtures on the machine. Re setup for the machine, for mold, raw material temperature, amount of injected raw material and the time before opening the mold improves the mean value. The cooling operation of the mold from times to time is important to gain products with high quality.

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## ABBREVIATION

| | |
|---|---|
| $\mu_c$ | True Mean (Non Conforming Mean) |
| CL | Center Line |
| LCL | Lower Control Limit |
| OR/MS | Operations Research and Management Science |
| PCI | Process Capability Index |
| PCRs | Process Capability Ratios |
| PE | Percentage of Enhancements |
| PU | Percentage of Utilization |
| QSB | Quantitative Systems for Business |
| SPC | Statistical Process Control |
| UCL | Upper Control Limit |
| ZB | Zahi Bottle |

**Figure (1) Zahi bottle refill product**

**Figure (2) Zahi bottle mold**

**Table (1) The collected data for ZBN**

| Date | Time | No. | X1 | X2 | X3 | X4 | X5 | $\overline{X}$ | R | s |
|---|---|---|---|---|---|---|---|---|---|---|
| 1st day | 9 | **1** | 27.7 | 27.9 | 28 | 28.1 | 28 | 27.94 | 0.4 | 0.151658 |
| | 10 | **2** | 28 | 28.1 | 28.2 | 28 | 27.9 | 28.04 | 0.3 | 0.114018 |
| | 11 | **3** | 28.1 | 27.9 | 27.8 | 28 | 28.4 | 28.04 | 0.6 | 0.230217 |
| | 12 | **4** | 28.3 | 28.1 | 28 | 27.9 | 28.2 | 28.1 | 0.4 | 0.158114 |
| | 1 | **5** | 28.3 | 28.4 | 28 | 28.2 | 28.1 | 28.2 | 0.4 | 0.158114 |
| | 2 | **6** | 28.1 | 28.2 | 28.4 | 28 | 28 | 28.14 | 0.4 | 0.167332 |
| 2nd day | 9 | **7** | 27.7 | 28 | 27.9 | 28.1 | 27.9 | 27.92 | 0.4 | 0.148324 |
| | 10 | **8** | 28.2 | 27.7 | 27.9 | 28 | 28.1 | 27.98 | 0.5 | 0.192354 |
| | 11 | **9** | 28 | 28.4 | 28.3 | 27.9 | 28 | 28.12 | 0.5 | 0.216795 |
| | 12 | **10** | 28 | 28.1 | 28.3 | 28.1 | 27.9 | 28.08 | 0.4 | 0.148324 |
| | 1 | **11** | 28.4 | 28.1 | 28.4 | 28 | 28 | 28.18 | 0.4 | 0.204939 |
| | 2 | **12** | 28.1 | 28.2 | 28 | 28.3 | 27.8 | 28.08 | 0.5 | 0.192354 |
| 3rd day | 9 | **13** | 27.9 | 28.1 | 28.1 | 27.8 | 27.9 | 27.96 | 0.3 | 0.134164 |
| | 10 | **14** | 27.6 | 27.8 | 28 | 28 | 27.9 | 27.86 | 0.4 | 0.167332 |
| | 11 | **15** | 28 | 28.2 | 28.3 | 28 | 28.4 | 28.18 | 0.4 | 0.178885 |
| | 12 | **16** | 28.1 | 28.2 | 28.2 | 28.4 | 27.9 | 28.16 | 0.5 | 0.181659 |
| | 1 | **17** | 28.3 | 28.2 | 28 | 28.4 | 28 | 28.18 | 0.4 | 0.178885 |
| | 2 | **18** | 28 | 28.4 | 28.1 | 27.9 | 28.2 | 28.12 | 0.5 | 0.192354 |
| 4th day | 9 | **19** | 27.9 | 28 | 28.2 | 27.8 | 28 | 27.98 | 0.4 | 0.148324 |
| | 10 | **20** | 27.8 | 28 | 28.1 | 27.9 | 28 | 27.96 | 0.3 | 0.114018 |
| | 11 | **21** | 28.1 | 28.4 | 28 | 28.1 | 28.2 | 28.16 | 0.4 | 0.151658 |
| | 12 | **22** | 28 | 28 | 28.2 | 28.1 | 27.9 | 28.04 | 0.3 | 0.114018 |
| | 1 | **23** | 27.8 | 27.9 | 28 | 28.1 | 28 | 27.96 | 0.3 | 0.114018 |
| | 2 | **24** | 28.2 | 28.3 | 28.1 | 28 | 28.4 | 28.2 | 0.4 | 0.158114 |
| 5th day | 9 | **25** | 28 | 27.9 | 27.6 | 27.8 | 27.9 | 27.84 | 0.4 | 0.151658 |
| | 10 | **26** | 28.1 | 28.2 | 27.8 | 28 | 27.9 | 28 | 0.4 | 0.158114 |
| | 11 | **27** | 28.3 | 28.4 | 28 | 28.1 | 28 | 28.16 | 0.4 | 0.181659 |
| | 12 | **28** | 27.9 | 28.2 | 27.9 | 28 | 28.1 | 28.02 | 0.3 | 0.130384 |
| | 1 | **29** | 28 | 28.3 | 28.1 | 28 | 28.1 | 28.1 | 0.3 | 0.122474 |
| | 2 | **30** | 28.4 | 28.2 | 28 | 28.3 | 28.1 | 28.2 | 0.4 | 0.158114 |

**Remark (1):** All dimensions in mm
**Remark (2):** All diagrams draw in excel


**Figure (3) WinQSB ($\overline{X}$ - chart) for ZBN**

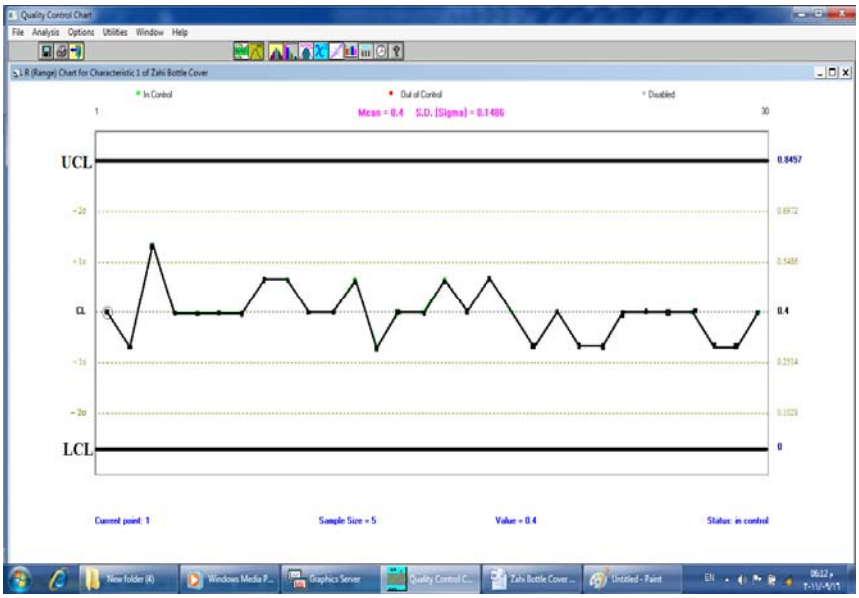



**Figure (4) WinQSB (R- chart) for ZBN**

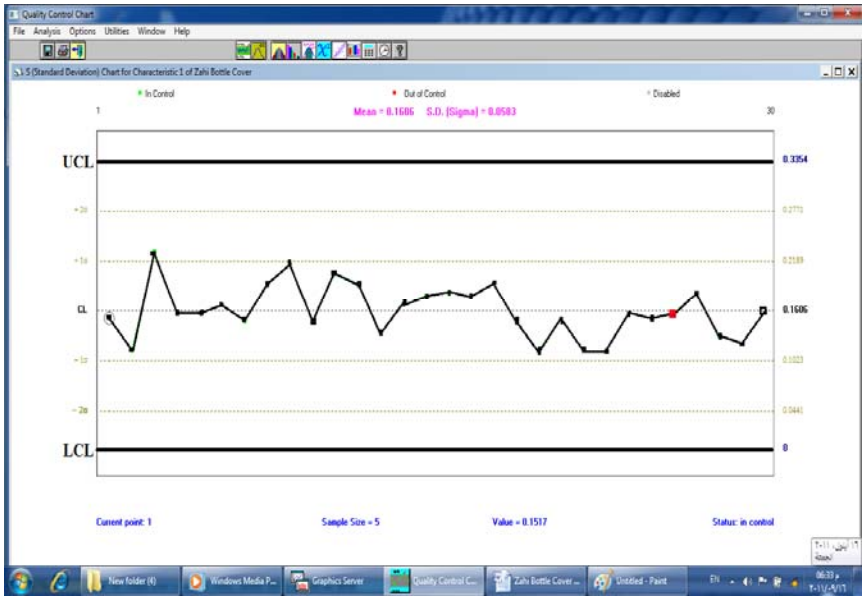



**Figure (5) WinQSB (S - chart) for ZBN**

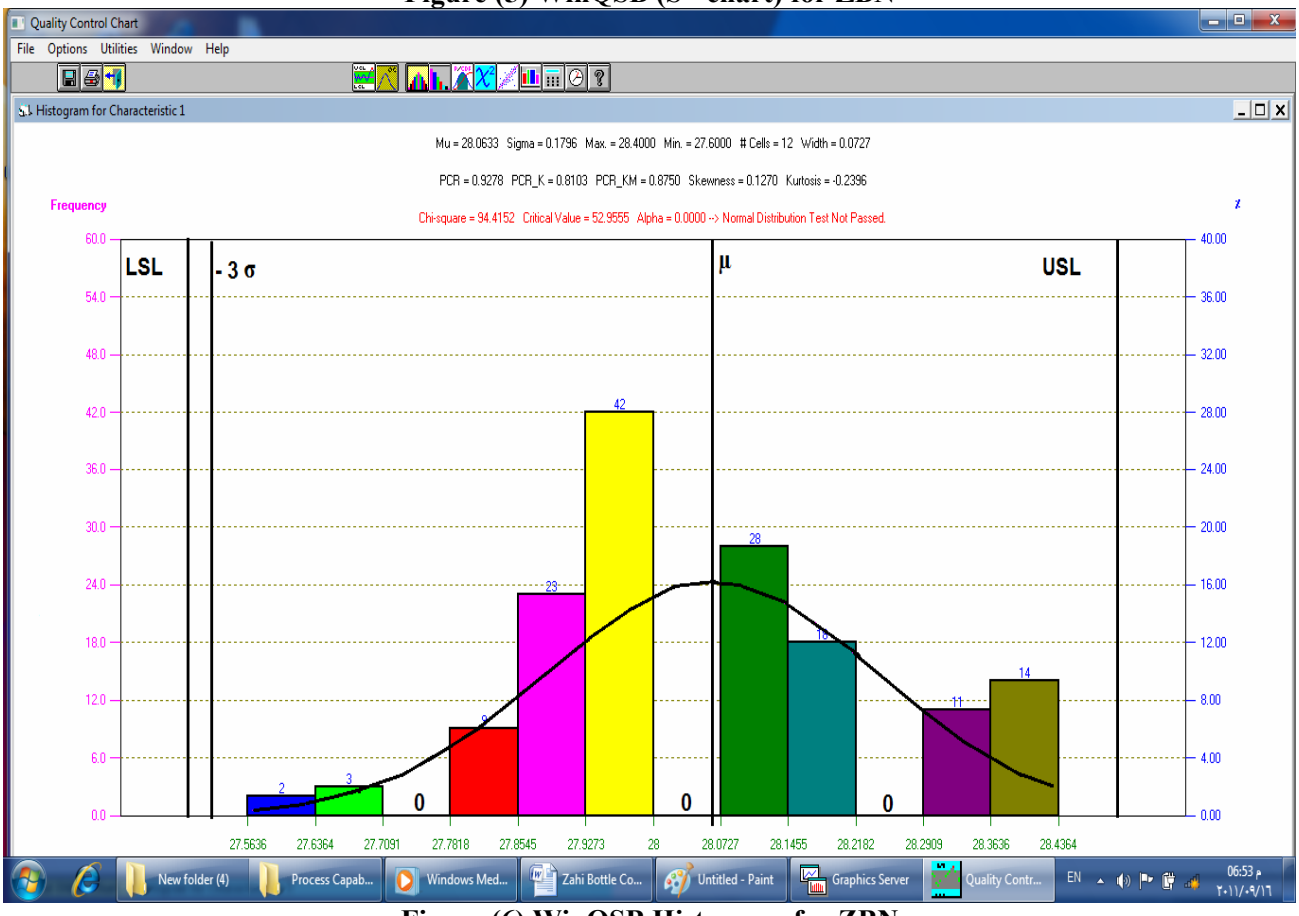
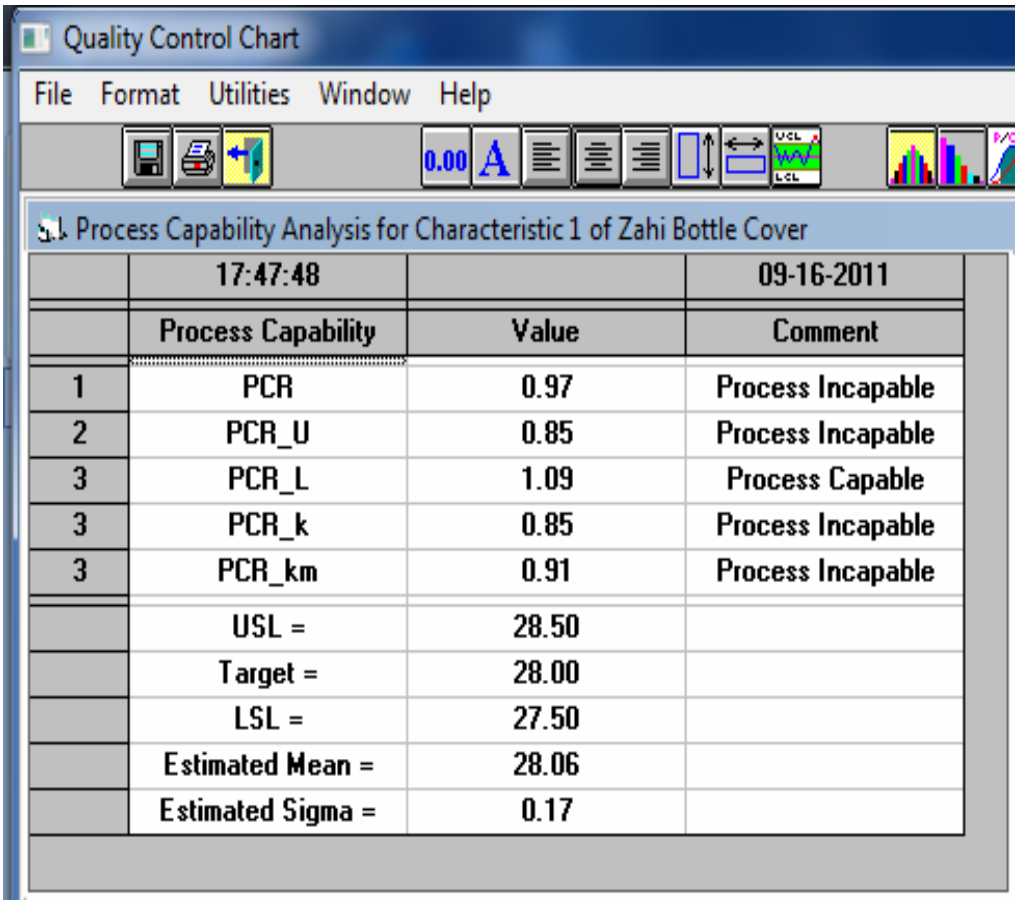



**Figure (6) WinQSB Histogram for ZBN**




| | 17:47:48 | | 09-16-2011 |
|---|---|---|---|
| | Process Capability | Value | Comment |
| 1 | PCR | 0.97 | Process Incapable |
| 2 | PCR_U | 0.85 | Process Incapable |
| 3 | PCR_L | 1.09 | Process Capable |
| 3 | PCR_k | 0.85 | Process Incapable |
| 3 | PCR_km | 0.91 | Process Incapable |
| | USL = | 28.50 | |
| | Target = | 28.00 | |
| | LSL = | 27.50 | |
| | Estimated Mean = | 28.06 | |
| | Estimated Sigma = | 0.17 | |

**Figure (7) WinQSB for the PCRs**

**Table (2) The result for $C_{pk}$, $C_{pm}$ and $C_a$ calculated by hypothetical values of the calculated mean without shifting $\mu_{c\ \text{hypo}}$**

| μc | Cpk | Cpm | Ca |
|---|---|---|---|
| 27.50 | 0.0000 | 0.3152 | 0 |
| 27.55 | 0.0969 | 0.3460 | 0.1 |
| 27.60 | 0.1938 | 0.3828 | 0.2 |
| 27.65 | 0.2907 | 0.4274 | 0.3 |
| 27.70 | 0.3877 | 0.4820 | 0.4 |
| 27.75 | 0.4846 | 0.5493 | 0.5 |
| 27.80 | 0.5815 | 0.6319 | 0.6 |
| 27.85 | 0.6784 | 0.7304 | 0.7 |
| 27.90 | 0.7753 | 0.8378 | 0.8 |
| 27.95 | 0.8722 | 0.9306 | 0.9 |
| 28.00 | 0.9692 | 0.9692 | 1 |
| 28.05 | 0.8722 | 0.9306 | 0.9 |
| 28.10 | 0.7753 | 0.8378 | 0.8 |
| 28.15 | 0.6784 | 0.7304 | 0.7 |
| 28.20 | 0.5815 | 0.6319 | 0.6 |
| 28.25 | 0.4846 | 0.5493 | 0.5 |
| 28.30 | 0.3877 | 0.4820 | 0.4 |
| 28.35 | 0.2907 | 0.4274 | 0.3 |
| 28.40 | 0.1938 | 0.3828 | 0.2 |
| 28.45 | 0.0969 | 0.3460 | 0.1 |
| 28.50 | 0.0000 | 0.3152 | 0 |

**Table (3) The result for $C_p$, $C_{pk}$ and $C_{pm}$ calculated by hypothetical values of the variation $\sigma$**

| σ | Cp | Cpk | Cpm |
|---|---|---|---|
| 0.01 | 16.6667 | 14.5567 | 2.6007 |
| 0.02 | 8.3333 | 7.2783 | 2.5106 |
| 0.03 | 5.5556 | 4.8522 | 2.3793 |
| 0.04 | 4.1667 | 3.6392 | 2.2258 |
| 0.05 | 3.3333 | 2.9113 | 2.0662 |
| 0.06 | 2.7778 | 2.4261 | 1.9109 |
| 0.07 | 2.3810 | 2.0795 | 1.7660 |
| 0.08 | 2.0833 | 1.8196 | 1.6338 |
| 0.09 | 1.8519 | 1.6174 | 1.5147 |
| 0.10 | 1.6667 | 1.4557 | 1.4082 |
| 0.11 | 1.5152 | 1.3233 | 1.3132 |
| 0.12 | 1.3889 | 1.2131 | 1.2285 |
| 0.13 | 1.2821 | 1.1197 | 1.1527 |
| 0.14 | 1.1905 | 1.0398 | 1.0847 |
| 0.15 | 1.1111 | 0.9704 | 1.0237 |
| 0.16 | 1.0417 | 0.9098 | 0.9686 |
| 0.17 | 0.9804 | 0.8563 | 0.9188 |
| 0.18 | 0.9259 | 0.8087 | 0.8735 |
| 0.19 | 0.8772 | 0.7661 | 0.8322 |
| 0.20 | 0.8333 | 0.7278 | 0.7945 |
| 0.21 | 0.7937 | 0.6932 | 0.7599 |
| 0.22 | 0.7576 | 0.6617 | 0.7280 |
| 0.23 | 0.7246 | 0.6329 | 0.6987 |
| 0.24 | 0.6944 | 0.6065 | 0.6715 |
| 0.25 | 0.6667 | 0.5823 | 0.6463 |
| 0.26 | 0.6410 | 0.5599 | 0.6228 |
| 0.27 | 0.6173 | 0.5391 | 0.6010 |
| 0.28 | 0.5952 | 0.5199 | 0.5806 |
| 0.29 | 0.5747 | 0.5020 | 0.5615 |
| 0.30 | 0.5556 | 0.4852 | 0.5436 |

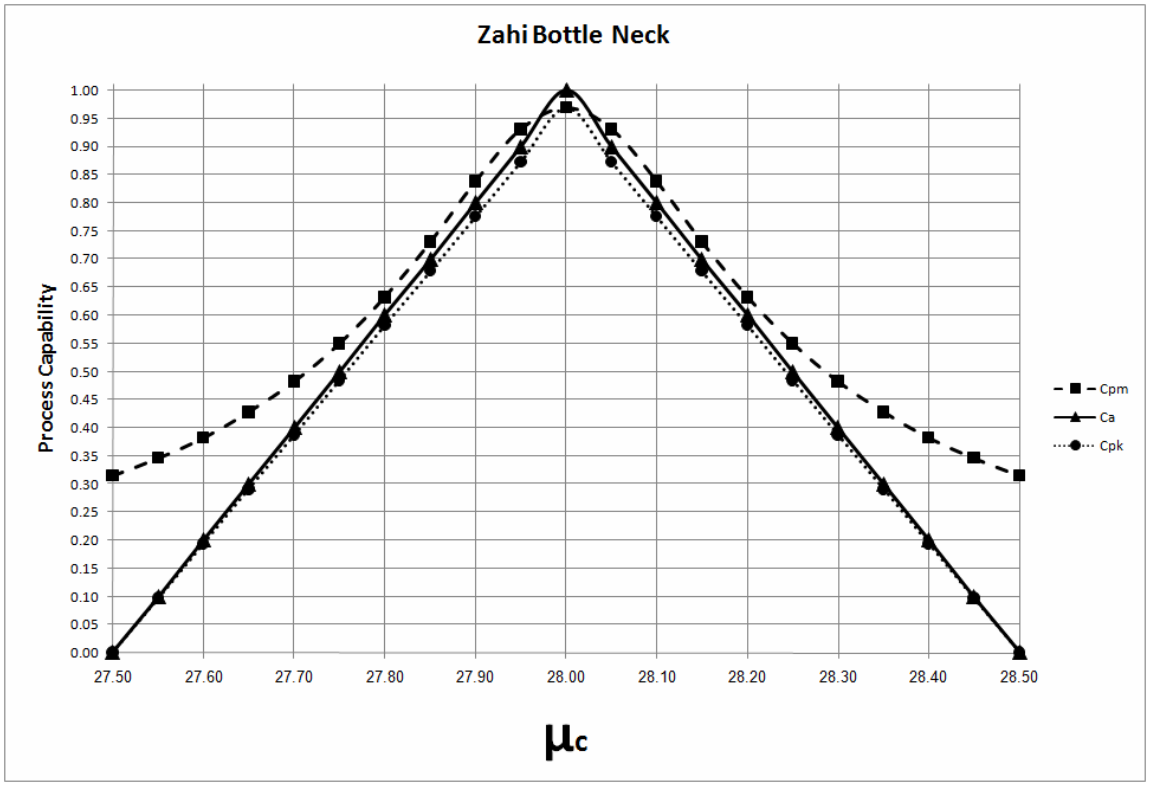



**Figure (8)** $C_{pk}$, $C_{pm}$ **and** $C_a$ **calculated by hypothetical value of the calculated mean without shifting** $\mu_{c\ \text{hypo}}$

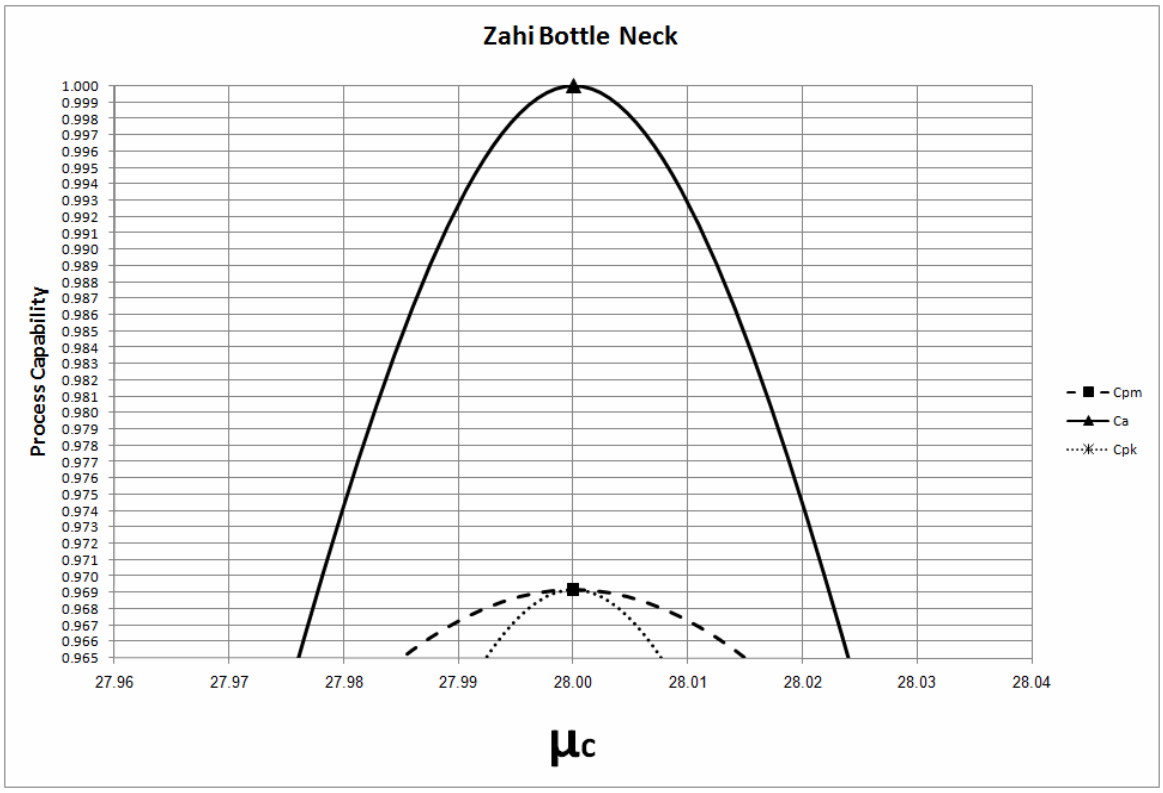



**Figure (9) the upper area of figure (8) magnified to show the value of PCIs when** $\mu_c = 28$

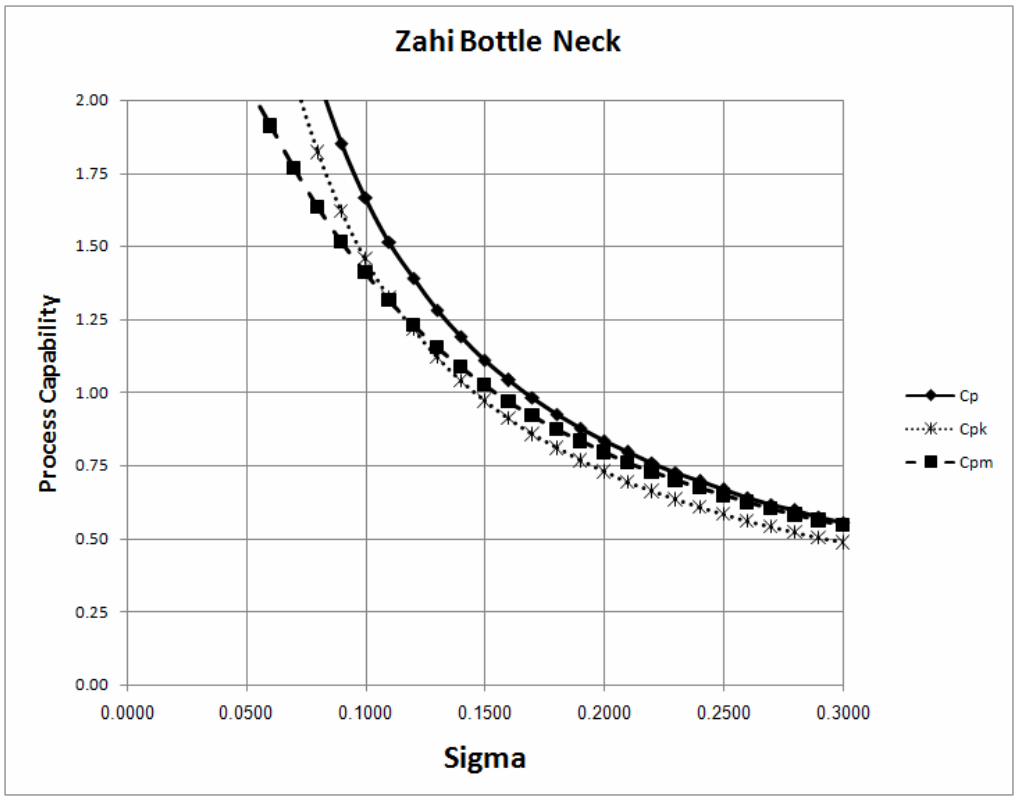



**Figure (10) The result for $C_p, C_{pk}$ and $C_{pm}$ calculated by hypothetical values of the variation $\sigma$**

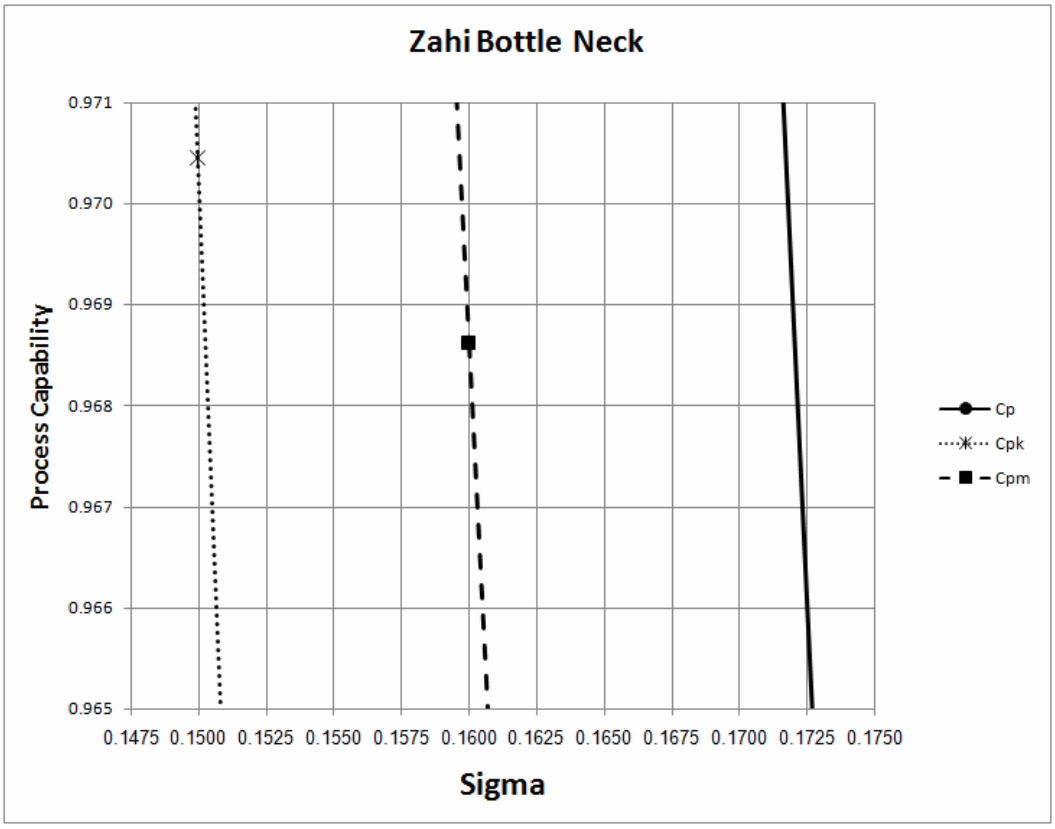



**Figure (11) the middle area of figure (10) magnified to show the value of $\sigma$ when $C_{pk} = 0.969$**

**Table (4) original and estimated data for the studied characteristic, the percentage of enhancements, percentage of utilization from new values.**

| Equation | Zahi Bottle Neck Original | Zahi Bottle Neck Hypothetical | Percentage of Enhancement | Percentage of Utilization |
|---|---|---|---|---|
| $\mu_C = \overline{\overline{X}}$ | 28.0633 | 28 | 99.77 % | 0.23 % |
| $\overline{R} = \frac{\sum R}{N}$ | 0.40000 | 0.3489 | 87.22 % | 12.78 % |
| $\sigma = \frac{\overline{R}}{d_2} = \frac{\overline{R}}{2.326}$ | 0.1720 | 0.15 | 87.20 % | 12.8 % |
| $C_p = \frac{USL - LSL}{6 \times \sigma}$ | 0.9689 | 1.11 | 114.56 % | 14.56 % |
| $P = (\frac{1}{C_p}) \times 100$ | 103.2 % | 90 % | 87.20 % | 12.8 % |
| $C_{pk} = \min C_{pu}, C_{pl}$ | 0.8463 | 0.9689 | 114.48 % | 14.48 % |
| $C_{pm} = \frac{USL - LSL}{6 \times \sqrt{\sigma^2 + (\mu_C - T)^2}}$ | 0.9093 | 1.023 | 112.5 % | 12.5 % |
| $C_a = 1 - \frac{\lvert \mu_C - T \rvert}{d}$ | 0.8734 | 1 | 114.49 % | 14.49 % |