# A Study on Estimating Measurement Error in the Measurement of Earing of Pilfer-Proof Caps

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## ABSTRACT

The present study was carried out in a reputed Indian integrated aluminum industry. Closure stock, a premiere product of this company, is used as pilfer-proof caps. One important output characteristic was earing percentage, which was basically an undulated edge that emerged during deep drawing due to nonuniformity of metal flow. Earing was defined as the difference between hills and valleys on the cup ring after deep drawing of a circular blank. Plant management was interested in implementing statistical process control (SPC) to control earing. There was a discrepancy in the test results of earing percentage of the product tested in their laboratory and in their customer's laboratory. They were also apprehensive about the presence of considerable error in the measurement system, which might creep into the study and spoil the SPC effort. Before implementation of the SPC, management decided to ascertain the measurement system and have an estimate of measurement error. Therefore, the present study was initiated. Three lots and all three operators were taken into the purview of study. Two cups (closed sample) were drawn from each lot by each of the operators, with 30 cups being drawn. Each cup was measured twice by each operator. Thus, a set of 180 observations was obtained. The data were analyzed using five-stage nested analysis of variance (ANOVA). Error due to repeatability and reproducibility were estimated from ANOVA. Estimate of error of the measurement system was obtained by combining these two components. This error was compared with the international standard. It was recommended to consider this error while reporting the test results to the customer. As a result of implementation, the discrepancy problem of test results of earing percentage was substantially reduced.

*Key Words*: Repeatability; Reproducibility; Measurement error; Nested ANOVA.

## INTRODUCTION

The management of the company decided to implement SPC for a few of their major products produced in their different plants. In the Belur plant, the closure stock was used for implementing SPC throughout the production line. The main output characteristic of the product is percentage earing. The plant management was interested in implementing SPC to control earing.

There was discrepancy in the test result of earing percentage of the product tested in their laboratory and in their customer's laboratory.

Before implementation of the SPC, management decided to ascertain the measurement system and have an estimate of measurement error. They were also apprehensive about the presence of considerable error in the measurement system, which might creep into the study and spoil the SPC effort.

The closure stock coil is used to punch bottle caps. During deep drawing of the cup, the metal may not flow uniformly in all directions. As a result, an undulated edge instead of a straight edge emerges. This phenomenon is known as earing. It can be either 90° or 45° depending whether the ears appear perpendicular or along the line of rolling or 45° to the direction of rolling. Earing is defined as the difference between hills and valleys on the cup ring after deep drawing of a circular blank. Mathematically, percentage earing is given by

$$\text{earing} = \left[\frac{2(h_{\max} - h_{\min})}{h_{\max} + h_{\min}}\right] * 100$$

where $h_{\max}$ is the maximum height of the ear and $h_{\min}$ is the minimum height of the ear.

## OBJECTIVE

To assess the measurement error involved in the measurement of earing of closure stock.

## APPROACH

1. Identify the contributing factors affecting the measurement process of measuring earing.
2. Ascertain the contribution of the major factors in the measurement error.
3. Ascertain the total measurement error and its percentage in the total variation.

## DATA COLLECTION

Three lots and all three operators were taken into the purview of study. Two cups (closed sample) were drawn from each lot by each of the operators, with 30 cups being drawn. Each cup was measured twice by each operator. Thus, a set of 180 observations was obtained.

For measurement of earing, cylindrical cups are drawn from circular blanks cut out from the sheet. The cups will show either 45° or 90° earing. The operator marks the ears formed under visual examination.

Then the earing value is obtained by holding the inverted cups onto the measuring instrument along the marked lines. The direction of the ear, i.e., the degree, is obtained by visual examination by the operator.

## DEFINITIONS AND TERMINOLOGY

*Measurement error* is defined as the variation in observations when the same item or piece is measured twice by a fixed measurement system. Two components of measurement error are error due to *repeatability* and *reproducibility*. *Reproducibility* arises due to different operators using the same measurement system and *repeatability* is the basic inherent precision of the measuring instrument, i.e., the variation in measurement of the same item inspected by the same operator.

***Table 1.*** ANOVA table.

| Sources of variation | df | SS | MS | Calculated F | Tab F(0.05) |
|---|---|---|---|---|---|
| Between lots | 2 | 3.1854 | 1.5927 | 17.6574 | |
| Between cup drawing operators within lot | 6 | 2.2095 | 0.3683 | 4.0831 | $F(6,9) = 4.10$ |
| Between cup within cup drawing operators within lot* | 9 | 0.8118 | 0.0902 | 3.1873 | $F(9,54) = 2.79$ |
| Between measurement operators within cups within cup drawing operator within lot* | 36 | 3.4148 | 0.0949 | 3.3534 | $F(36,54) = 1.64$ |
| Error | 54 | 1.5277 | 0.0283 | | |
| Total | 107 | 11.1492 | | | |

*Note:* * means that the corresponding effects are significant.

***Table 2.*** Average value for each cup drawn by different cup-drawing operators.

| Operator | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Lot/cup | 1 | 2 | 1 | 2 | 1 | 2 |
| 1 | 0.7117 | 0.9 | 1.0333 | 1.225 | 1.3533 | 1.2567 |
| 2 | 1.5117 | 1.31 | 1.3267 | 1.375 | 1.6933 | 1.4567 |
| 3 | 1.3633 | 1.3117 | 1.7116 | 1.4367 | 1.4717 | 1.3633 |

## ANALYSIS AND RESULT

The disputed lots (where + and − earing were mixed up) were not considered for analysis. Nested ANOVA was performed on the three lots that showed 45° earing.

Nested ANOVA

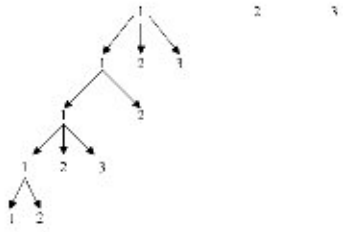
Lots

Cup drawing operator

Samples

Measurement operator

Measurements



## CONCLUSIONS

1. There was no significant difference between cup-drawing operators.
2. There was significant difference between cups within cup-drawing operator. From Table 2 it can be concluded that each operator shows inconsistency in drawing the cup.
3. There was significant difference between measurement operators for a single cup. From Table 3 it can be concluded that operator 1 has a tendency to give lower value, while operator 2 has a tendency to give a higher value.
4. From analysis:

   Variation in the average of the measurements made by the different operators $(\sigma_{\text{measurementoperator}}) = 0.1670$

   Variation in the measurement due to the measuring gauge $(\sigma_{\text{repeatability}}) = 0.1680$

   Variation between cups within cup-drawing operator within lot $(\sigma_{\text{cupdrawingoperator}}) = 0.1015$

   Hence $\sigma_{\text{reproducibility}}$

   $$= (\sigma^2_{\text{measurementoperator}} + \sigma^2_{\text{cupdrawingoperator}})^{1/2}$$

   $$= 0.1954$$

   Measurement error

   $$= (\sigma^2_{\text{repeatability}} + \sigma^2_{\text{reproducibility}})^{1/2}$$

   $$= 0.2579$$

   Measurement error as a percentage of the total variation = 63.82

***Table 3.*** Average value for each cup by different operators.

| Cup/operator | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 0.545 | 0.955 | 0.635 |
| 2 | 0.71 | 1.02 | 0.97 |
| 3 | 0.825 | 1.285 | 0.99 |
| 4 | 1.245 | 1.26 | 1.17 |
| 5 | 1.065 | 1.565 | 1.43 |
| 6 | 1.07 | 1.415 | 1.285 |
| 7 | 1.365 | 1.575 | 1.595 |
| 8 | 1.055 | 1.525 | 1.35 |
| 9 | 1.125 | 1.41 | 1.445 |
| 10 | 1.035 | 1.59 | 1.5 |
| 11 | 1.425 | 1.88 | 1.775 |
| 12 | 1.015 | 1.73 | 1.625 |
| 13 | 1.35 | 1.165 | 1.575 |
| 14 | 1.02 | 1.53 | 1.385 |
| 15 | 1.5 | 1.95 | 1.685 |
| 16 | 1.36 | 1.455 | 1.495 |
| 17 | 1.315 | 1.53 | 1.57 |
| 18 | 1.285 | 1.21 | 1.595 |

## RECOMMENDATIONS

1. Since the operators made mistakes in ascertaining the degree (or direction) of the ear, proper visual examination must be initiated and encouraged.
2. The operators must be trained regarding the cup-drawing operation.

3. The operators must be trained regarding the measurement of earing.
4. The estimated error in the measurement system must be taken into consideration while reporting test results to the customer.

## IMPLEMENTATION

The operators were given training regarding cup-drawing operation to reduce inconsistency in drawing the cups. Operators 1 and 2 were given special training on measurement of earing to reduce their bias. These steps resulted in reduction of measurement error from 0.2579 to 0.1965. The test result was reported to the customer along with the estimated error of earing measurement. This resulted in reduced discrepancies between the test result obtained from their own laboratory and that from their customers' laboratory.

## ABOUT THE AUTHORS

Nandini Das is presently working on the faculty in the Statistical Quality Control and Operations Research (Training and Promotional) Unit of the Indian Statistical Institute (Kolkata), India. She received her M. Stat. and M. Tech. (Quality, Reliability, and Operations Research) degree from the Indian Statistical Institute. Presently she is engaged in teaching and consultancy on behalf of ISI.

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