Measurement system performance analysis using MINITAB

Shao Jun[1],Qian Ting[1]

[1]China Tobacco Zhejiang Industrial Co.,Ltd., Hangzhou 310024, China

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Abstract. This article introduces the principle of mathematical statistics such as R&R (Repeatability and Reproducibility), variation ratio (%P/TV), tolerance ratio (% P/T) and number of distinct category in the measurement system. The article takes infrared moisture analyser the InfraLab 710 e-Series as a measurement system and uses hierarchical nested analysis method to perform destructive experimental moisture equilibrium. Taking moisture in shredded leaves during tobacco primary process as example, we setup up three conditions of cut tobacco leaves moisture at 11%, 15% and 20%, and analyse the results generated by MINITAB tools to identify the source of fluctuations, the extent and root cause in the measurement process which will be used to evaluate the measuring performance of infrared moisture meter. Then the analysis will be carried out to see if the measurement system meets the criteria of acceptable requirements, which will be a reliable tool for applications of cut tobacco leaves moisture measurement.

Introduction

The moisture level in cut tobacco leaves is an important physical property during tobacco processing, which directly affects the product quality in later process. However, the moisture within cut tobacco leaves can easily change due to environmental temperature and humidity, as a result, it is very difficult to work and control the moisture level as a quality index[1]. Currently the moisture is majorly measured by infrared moisture meter for cut tobacco processing application. The measurement system detects the reflected light after the material absorbs infrared light, but only the moisture on the surface to cut tobacco leaves can be measured. So we evaluate the performance of this the moisture meter (InfraLab 710 e-series) by analysing the R&R (Repeatability and Reproducibility), %P/TV and %P/T of the infrared moisture meter system. MINITAB is used as a tool to evaluate the cut tobacco moisture measurement performance of this device [2].

Principle

The measurement system includes Variables Data (for both destructive and non-destructive test) and Attributes Data. The repeatability and reproducibility are used to assess the fluctuation of the system. Repetitive fluctuation σ_{RPT}^2 reflects the change of the parameter itself, reproducibility fluctuation σ_{RPD}^2 reflects the influence from different operators. The measurement system fluctuation σ_{ms}^2 is $\sigma_{ms}^2 = \sigma_{RPT}^2 + \sigma_{RPD}^2$. Repetitive fluctuation σ_{RPT}^2 includes the measurement equipment fluctuation σ_e^2, reproducibility fluctuation σ_{RPD}^2 includes the change of operators σ_o^2 and the interaction between operator and the equipment σ_{op}^2 .

During the process, the total fluctuation includes the system fluctuation and measurement system fluctuation. The total fluctuation of data σ_{T}^2 includes the fluctuation between measurement targets σ_p^2 and measurement system fluctuation σ_{ms}^2 , so the total fluctuation is $\sigma_{\mathrm{T}}^2 = \sigma_p^2 + \sigma_{ms}^2$ or $\sigma_{\mathrm{T}}^2 = \sigma_p^2 + \sigma_o^2 + \sigma_{op}^2 + \sigma_e^2$. [3]

For calculating ends multiplied by the square of 6 times:

$$(TV)^2 = (PV)^2 + (AV)^2 + (EV)^2 \quad (1)$$

In the formula: TV——Total Variation; PV——Part Variation; AV——Appraiser Variation; EV——Equipment Variation.[4]

It is crucial for the measurement system to accurately and reliably reflect the parameters fluctuation from the target. There are two methods to evaluate the measurement system:

i)The ratio between R&R (fluctuation from the measurement system) and TV (total variation), i.e. P/TV:

$$P/TV = \frac{R\&R}{TV} \times 100\% \tag{2}$$

ii) The ratio between measurement system fluctuation (R&R) and the tolerance of the target. [5] i.e. P/T:

$$P/T = \frac{R\&R}{USL - LSL} \times 100\% = \frac{6\sigma_{ms}}{USL - LSL} \times 100\% \tag{3}$$

Table 1:Benchmark of measurement system performance

Measurement system performance	Note
（P/TV and P/T）≤10%	Good performance
10%<（P/TV or P/T）≤30%	Acceptable performance
（P/TV or P/T）>30%	Unqualified performance

The standard deviation of target fluctuation and system fluctuation leads to the number of distinctcategories among the analysis, which is used to determine if the system has enough resolving power.

$$\text{Number of distinctcategories} = \left\lfloor \frac{\sigma_p}{\sigma_{ms}} \times 1.41 \right\rfloor \geq 5 \tag{4}$$

Generally if the number of distinctcategories is smaller than 2, the measurement system cannot provide meaningfulresult. The number of distinctcategories should be larger than 5 to provide enough resolving power, so the data can be used in analysis and controlling process.

Application analysis

Under certain circumstances, the sample may bedamaged during the measurement, so multiple measurements arenot possible. The moisture measurement for cut leaves is a typical example. The conventional method ignores the difference between samples in the same batch, where the difference is solittlethat it is all right to take multiple samples in a batch as the same result from a single sample, to evaluate the fluctuation of the system[6]. After some experiments, we found that above methodology is not suitable for moisture measurement. The difference between online samples from the same batch is too big to ignore. We use improved temperature and humidity balancing method via environmental experiments box, and nesting R&R analysis option in MINITAB to conduct the measurement process.

Step1: The equipment should be stable after some running time, and the calibration with oven is necessary.

Step2: The cut leave moisture should be tested to check repeatability and reproducibility.

Step3: The moisture level of cut leaves should be decided by the environmental experimental box, and it should be balanced for 48 hours. The samples should be distributed evenly inside the box, among top, middle and bottom layers.

Step4: The same operator should take out 9 samples from each layer, and put on a metal lid for each sample. For each metal box, the sample should be transferred into the sample tray provided along with the moisture analyzer.

Step5: The sample should be spread evenly acrossthe tray, and 2 readings should be made quickly.

Step6: After the first operator, a second operate should do the same again just like previous operator.

Such design aims to lower the environmental and sample differentiation influence when the samples are taken online. The equilibrium creates three batches of samples and two quick measurements are made for each sample. In a very short time, thedifference betweenmoisture levels is small, so they can be treated as a single sample fromthis batch. The shortcoming is that the second measurement can be slightly lower than the first one, by 0.10% approximately. And this value of difference increases at higher moisture level.

Here are the three conditions to evaluate the moisture analyzer performance (number of distinct categories and R&R).

Table 2:Designed Experiments

Temperature/℃	Humidity/%RH	Moisture/%	Balance time/h
22	55	11	48
22	65	15	48
22	75	20	48

Measurement application

1.1 Analysis for cut leaves moisture around 11%.

Figure 1 is the output from MINITAB. As shown in A, the variation is not only from the target, but also from the measurement, which is mainly from repetition. Part B shows that each operator measures the sample well, where all the data points are within the range, with good repetition. Part C shows most of the mean values are out of the control range. The actual fluctuation is large and the measurement system is good. Part D shows the result by group of parts. [7] The variation is large and the process fluctuates. Part E shows the result of group by operators, the mean value change is small and reproducibility is small.

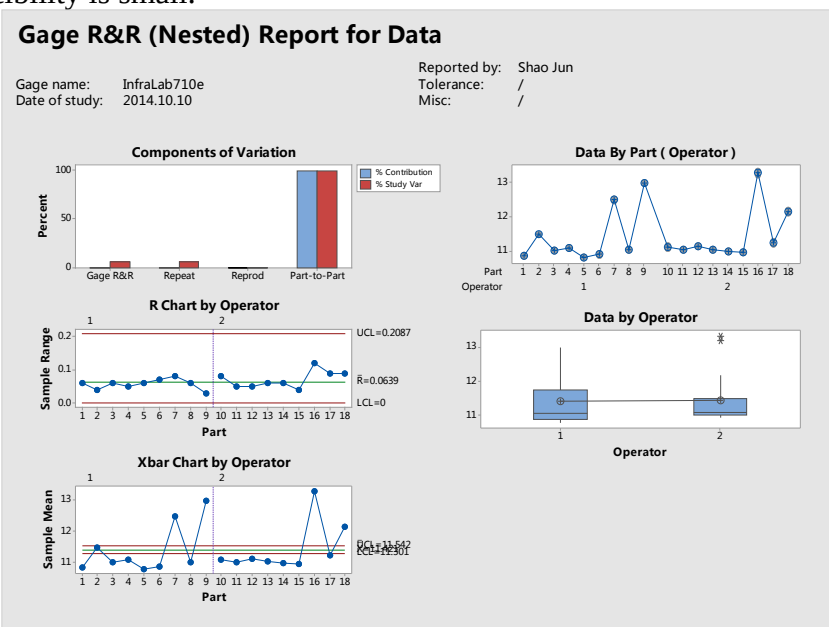

Fig.1: Destructive experiment R&R (Nested) analysis

The measurement system performance result: variance component contribution rate of 0.36, study variation (%SV) 6.04% % < 10%, the measurement system performance is good, and the number of distinct categories[8] [9] for NDC = 23.

1.2 Analysis for cut leaves moisture around 15%.

Figure 2 shows the result from MINITAB output, which is basically the same as figure 1. Part E shows the result grouped by operator, which shows some difference between operators.

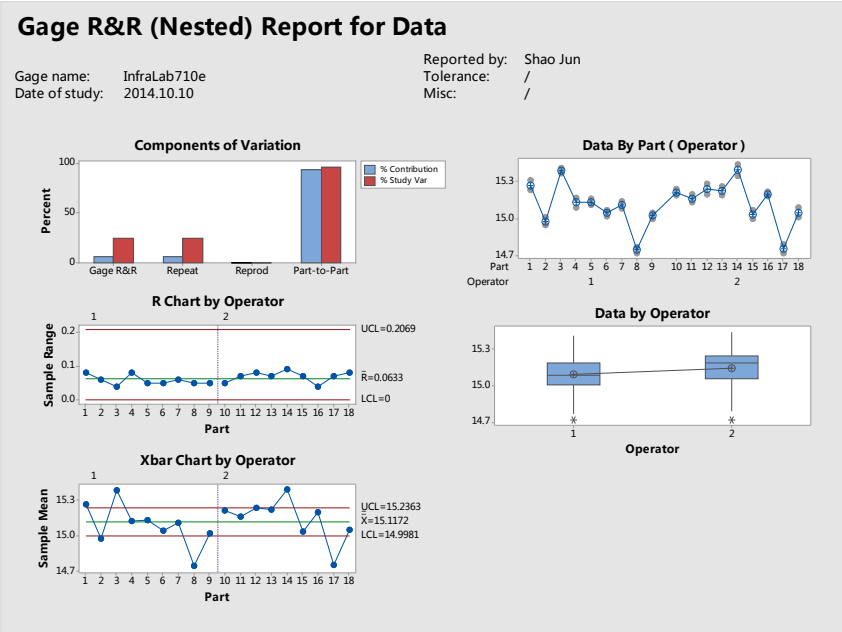

Fig. 2:Destructive experiment R&R (Nested) analysis

The measurement system performance result: variance component contribution rate of 6.27, study variation (%SV) 25.04% % <30%, the measurement system performance is acceptable, and the number of distinct categoriesfor NDC = 5.

1.3 Analysis for cut leaves moisture around 20%.

Figure 3 shows the output from MINITAB, which is basically same as Figure 1, but the difference between two quick measurements is obviously larger than the difference under 11% and 15% conditions.

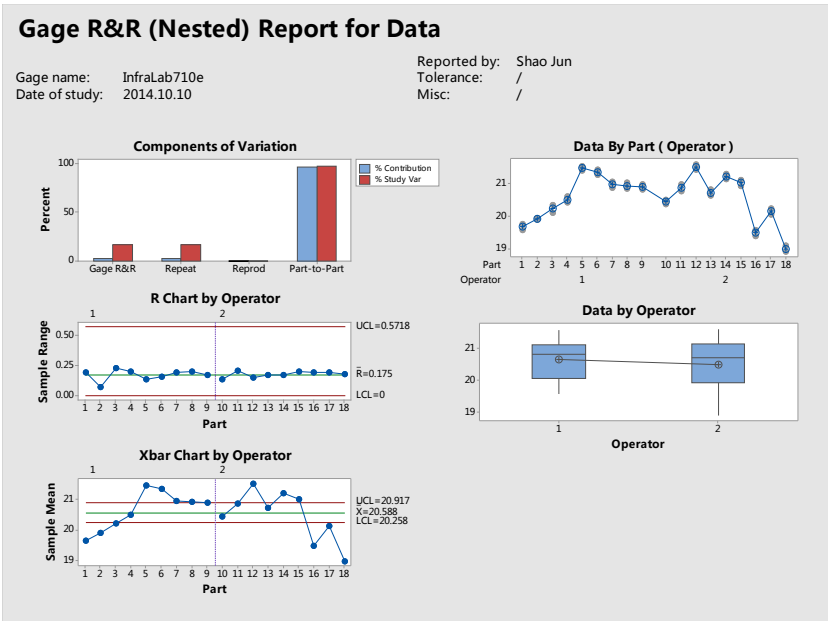

Fig. 3:Destructive experiment R&R (Nested) analysis

The measurement system performance result: variance component contribution rate of 2.87, study variation (%SV) 16.95% % <30%, the measurement system performance is acceptable, and the number of distinct categoriesfor NDC = 8.

Based on above analysis, the measurement system for cut leave moisture [10] is acceptable.

Conclusions

This analysis is an improved version of traditional measurement system analysis (destructive experiment). We use nesting method to implement R&R analysis. We used layered temperature/humidity equilibrium method for Infrared Analyzer measurement system analysis. Each layer is sampled respectively, and the result is completely acceptable for cut leave moisture measurement system analysis.

While the measurement device improves, and the process quality gets better, the analysis provides effective methodology and important scientific basis for lab instrument evaluation using MSA.

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