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Statistical Process Control (SPC) Method to Improve the Capability Process of Drop Impact Resistance: A Case Study at Aluminum Cans Manufacturing Industry in Indonesia

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ABSTRACT

The purposes of this study are, first, analyzing why the Capability Process (Cpk) index of Drop Impact Resistance (DIR) does not meet the customer requirement or below 1.33, second, finding out what improvements should be made to make it meet the specifications. Statistical Process Control (SPC) is a method used in this research with supporting other tools such as Cause and Effect Diagrams (CED), Nominal Group Techniques (NGT) and why, what, where, when, and how (5W1H) method. After improvement was made, the results of the study were satisfactory, the average of DIR test was increased by 26.21% i.e. from 20.41 cm to 25.76 cm, standard deviations reduced from 1.80 to 1.48, and the potential Cpk increased significantly from 0.48 to 1.79. The SPC supported by other statistical tools was effective and efficient to improve quality, so the process statistically can be categorized as in control. At the end of this research, the further discussion is still needed to maintain what has been achieved and also to make the research even better. It is recommended for further researchers to examine the chemical composition of aluminum M_1 alloy 3104 influence on the strength of the drop impact resistance and to analyze data. It is recommended to integrate or combine SPC with Six Sigma or Engineering Process Control (EPC).

1. Introduction

Recently, many the packaging industry were growing up in the world with the great opportunities, one of them is the aluminum cans packaging industry. The global demand for aluminum packaging in 2019 was predicted 335 billion cans as reported by Can Maker Magazine. In Indonesia, as stated by the Minister of Industry on www.Tempo.co.id edition 20 April, 2019, that investment in the food and beverage industry sector was increased by 11% in year 2019 compared to the previous year. In order to be able to capture those good market opportunities, the quality and price are the essential thing needs to be prepared. For getting it, the effort made by one of the aluminum cans packaging industry in Indonesia was doing innovation the aluminum raw material from type M_o to M_1 with minor changing on the process to get the finished good cans quality both for visual and strength performance that are still on the specification. The constraint was noticed that the Cpk index for DIR does not meet the customer requirement or below 1.33. *Fig. 1* is showing up of DIR test schematic for aluminum beverages

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cans, the test basically to give assurance if the aluminum cans after filling are safe during the transportation process.

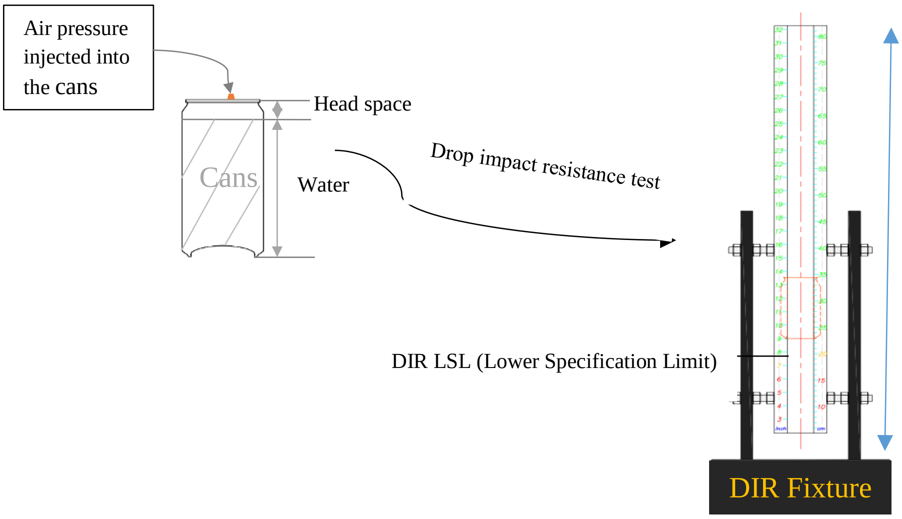


Fig. 1. *DIR test schematic.*

The test result of nine quality parameters are as in *Table 2* below, it is describing the achievement of the Cpk with $M_{1.}$

Table 1*. The 5 hours capability study data of aluminum cans Slk 330 mL with material M_1.*

Quality Parameters (unit)	Sample (n)	Ave.	Min	Max.	Std dev.	Cp	Cpk
1.Finish can height (mm)	*180*	*146.02*	*145.87*	*146.15*	*0.05*	*3.04*	*2.24*
2. Flange width (mm)	*180*	*2.09*	*1.99*	*2.19*	*0.04*	*2.06*	*1.96*
3. Plug diameter (mm)	*60*	*50.05*	*50.01*	*50.10*	*0.002*	*3.40*	*2.50*
4. Axial load (Lbs)	*150*	*227.8*	*224*	*232*	*1.37*	*NA*	*12.60*
5. Buckle strength (Psi)	*150*	*96.12*	*94.4*	*98.3*	*0.86*	*NA*	*2.35*
6. Thin wall thickness (mm)	*200*	*0.092*	*0.09*	*0.095*	*0.001*	*NA*	*2.01*
7. Dome depth (mm)	*300*	*10.41*	*10.35*	*10.46*	*0.02*	*3.94*	*1.96*
8. Reform diameter (mm)	*300*	*44.78*	*44.76*	*44.82*	*0.01*	*3.92*	*3.24*
9. DIR (mm)	*150*	*20.41*	*17.28*	*22.86*	*1.80*	*NA*	*0.48*

This study emphasizes the area of future research SPC with other tools to analyze and streamline process capability. Hence, this research is considered to advance and embrace high valued methodologies to help the industry to become more competitive in the global.

The aim of this study first is to analyze what are the causative factors which were causing the index Cpk could not meet the requirement or below 1.33; second, to knowing what the improvement should be made on the production process to make it meet the requirement by utilizing SPC with supporting other statistical tools.

2. Literature Review

SPC is a good method to measure and control the product quality during the process. As well as, aluminum cans packaging industry which produced beverages and beer cans needs to be controlled well in terms of the quality to give assurance that the product filled inside the cans is safe. The visual aspect of the body of the cans is very important for the quality and it may conduct a serious defect that can affect the innocuity of the filled beverage [1]. If the packaging quality like aluminum cans categorized as good quality if it can be able to retain the carbon dioxide dissolved into the product for certain periods [2]. The packaging with good in form and design combining with proper material selection will be able to attract the customer to buying [3]. Page et al. [4] mentioned that the packaging functions must continue to be performed satisfactorily until well after the end of the stated shelf-life period.

Making sure the product quality is good or meeting the customer requirement its needs to be controlled well in every step of the production operation. SPC method can be implemented to maintain the process variations. Serious implementation of SPC to monitor process stability and capability through the identification of the root cause will create a positive result for the company [5]. As succeed implemented at molding plastic industry, SPC gave a significant improvement on the Cpk with increasing from 0.63 to 1.59 [6]. By supporting others' methods in determining the cause of process variation, SPC becoming more useful in the operation. As mentioned by Harpreet et al. [7] that SPC beside to control variation also proven as a technique for determining a process is called “under control” when process capability and predicting are yielded from a process.

To evaluate and analyze the production process, SPC can be used [8, 9]. SPC method improve the quality in mass production, and the process capability index is tool for continuous improvement [10]. Implementing SPC method with using fish born and process monitoring chart Cpk can be improved [11]. Cp and Cpk value beside to control process variation also can be used to monitor the quality control inter company or organization like studies conducted by Chen et al. [12]. To determining the root cause of the faulty in the process, Pareto chart, fish bone diagram and 5 whys can be utilized [13]. SPC have the power in ability to examine a process and sources variation in the process with only beneficiary two of seven quality tools were used as succeed implemented in automotive industry [14]. SPC method with applied $\bar{X}$-R chart in monitor process stability that the significant result was achieved as study done by Ucurum et al. [15] at Cast Iron Part Production. Brainstorming with technical member in manufacture is effective for gather the idea for improvement the NGT method can be used as tools [16]. Brainstorming collected in NGT method; idea improvement based on the customer demand of Kaizen concept is be able to make it happen [17]. For reducing the losses on the process of Plan-Do-Check and Action (PDCA) with combining others method can be applied [18]. Kaizen concept with 8 steps of PDCA was success gratefully to reduce defect in automotive battery manufacturing [19]. To maintain the Cpk keeping on the track $\bar{X}$-R chart can be applied [20] .

3. Research Methodology

Potential capability index improvement process needs to go through several steps. Our study was organized over the beverage cans manufacturing industry. *Table 1* is representing as an initial capability study data achieved after changing input aluminum material to M_1.

Steps in overall Cpk improvement are as follows:

Step 1: Data collection.
Step 2: Data analysis [X-R chart & potential Cpk].
Step 3: Determine main root cause and dominant root cause (CED and NGT).
Step 4: Determine improvement with 5W1H.
Step 5: Standardization.

For detail, the steps of improvement process to improve potential Cpk are shown in *Fig. 4*.

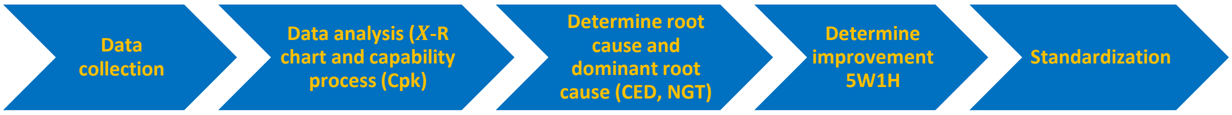


Fig. 2. *Process capability improvement steps.*

4. Findings and Data Analysis

As described in *Table 1*, the drop impact resistance is as one of critical parameter; after changing input material to material M_1, the capability index does not meet the customer requirement as plotted to the run chart of the capability index achievement (*Fig. 3*).

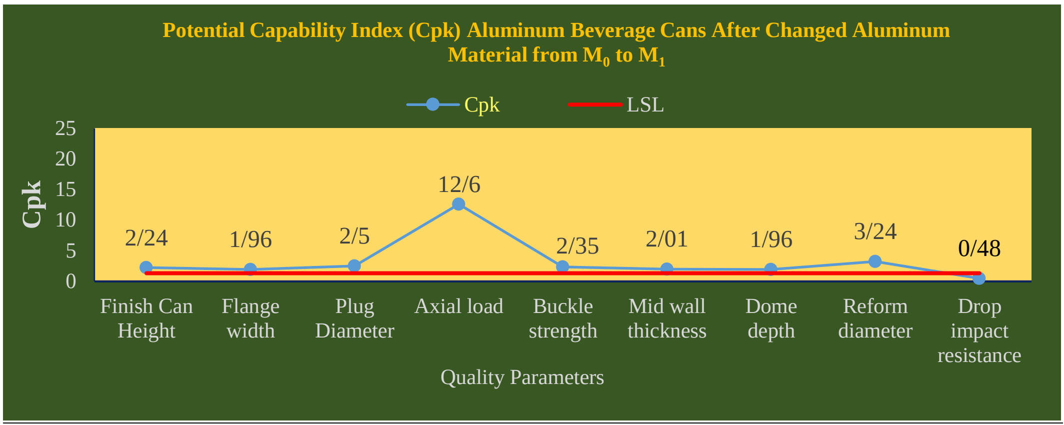


Fig. 3. *Run chart of capability index achievement with material M_1.*

4.1. Data Analysis (X-R Chart and Cpk)

The quality parameter of DIR with index Cpk achievement was 0.48. Details of the control chart and histogram for DIR are shown in *Fig. 4* and *Fig. 5* in below.

With refer to *Fig. 4* and *Fig. 5*, DIR with material M_1 both for stability and Cpk are does not meet the customer requirement. In term of stability process, on the $\bar{X}$-chart, there were 4 points out of the control limits and on R-chart, there was one point touched the lower control limit, and the potential Cpk was 0.48 with mean the process was not capable. With these achievements, the research is needed; the aim of the research is to analyze the factors are causing the faulty of achievement for the Cpk index and to determining the steps of correction to improve the Cpk index to a minimum 1.33. To achieve all these objectives, each stage of the process needs to be controlled well; to control the quality at each stage of the process of aluminum cans forming, the method can be used is SPC, with supporting other methods and tools like CED, NGT, and 5W1H that will result positive improvement in term of the stability and capability of the process.

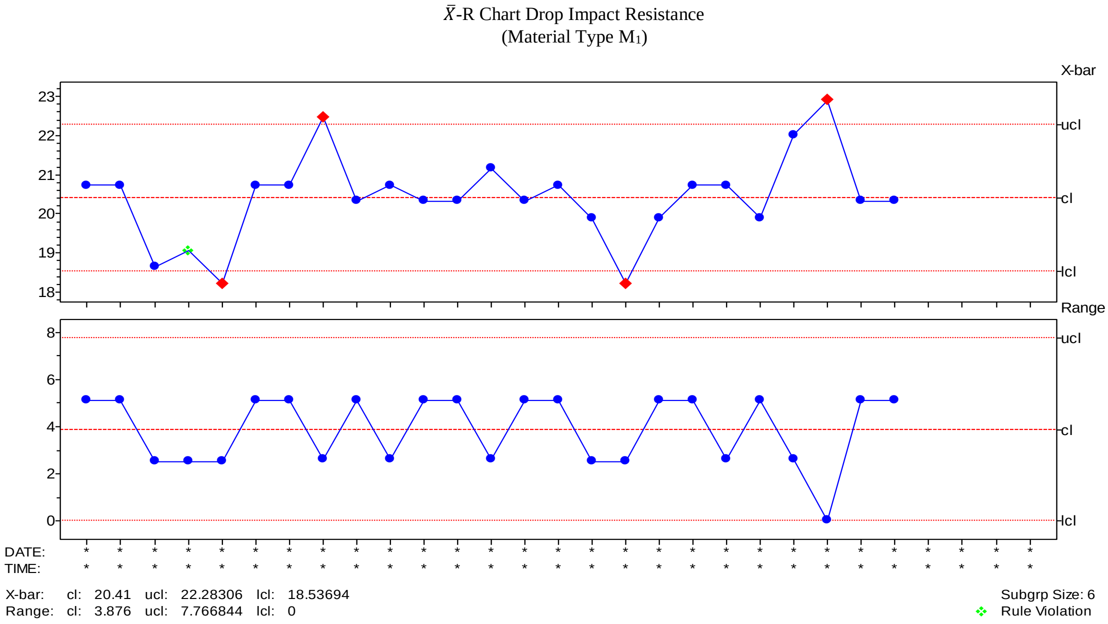


Fig. 4. *Control chart drop impact resistance aluminum cans with material M_1.*

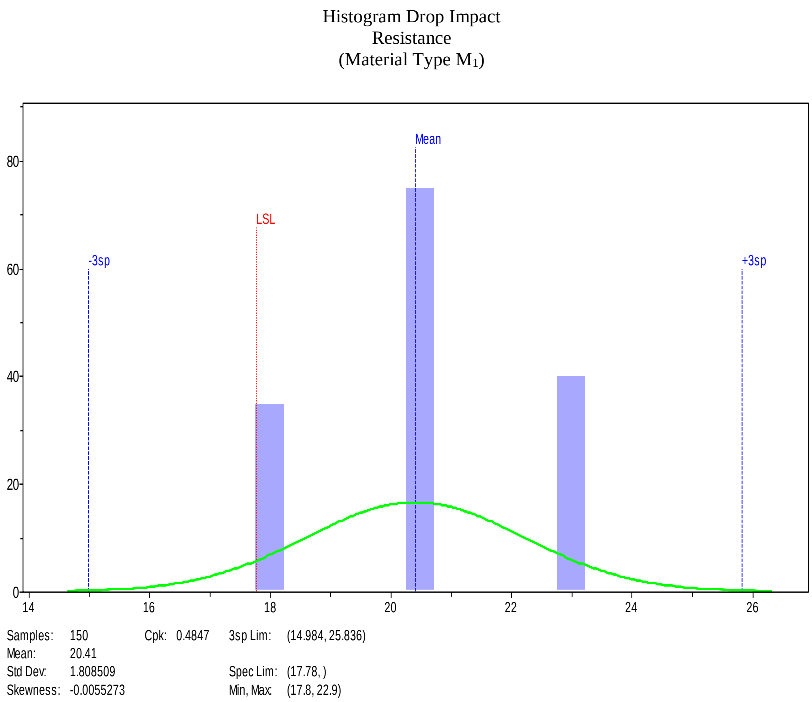


Fig. 5. *Histogram of DIR for aluminum cans with material M_1.*

4.2. Determine Root Cause and Dominant Root Cause (CED and NGT)

Before making CED, brainstorming has conducted with production, QA, Engineering, and Corporate production team to determine the main root cause, the brainstorming result as shown in *Table 2*.

Table 2. *Brainstorming data to find the possible root cause of drop impact resistance faulty in the achievement of the Cpk index.*

No	Causes	Causes Factor	Code
1	*Annealing or softening (yield strength) of material aluminum.*	*Material*	*F1*
2	*Aluminum material thickness.*	*Material*	*F1*
3	*Washer oven dryer temperature.*	*Machine*	*F2*
4	*Temperature feco oven decorator.*	*Machine*	*F2*
5	*Temperature oven Inner Bake Oven (IBO).*	*Machine*	*F2*
6	*Mat conveyor jam with full cans inside oven dryer (Washer, Feco Deco or IBO) with duration > 5 minutes.*	*Machine*	*F2*
7	*The dimension of dome depth.*	*Machine*	*F2*
8	*The aluminum thickness dome area.*	*Tooling*	*F3*
9	*Profile/Geometry tooling: punch sleeve & dome die.*	*Tooling*	*F3*
10	*Dimension reform diameter.*	*Machine*	*F2*
11	*Air pressure that injected to inside the cans during testing DIR.*	*Method*	*F4*
12	*Base plate thickness for testing drop impact resistance.*	*Method*	*F4*
13	*Operator less knowledge.*	*Man*	*F5*
14	*Mistake or wrong in measurement.*	*Man*	*F5*
15	*Lack of lighting.*	*Environment*	*F6*
16	*Unstable speed of body maker machine.*	*Machine*	*F2*
17	*SOP not updated.*	*Method*	*F4*

From 17 items of possibilities were causing for DIR do not meet the customer specification in term of the Cpk achievement, for making clear and easier in analysis then next table will give the classification information in more specific and details as stratification.

Table 3. *The cause of the human (man) factor.*

	No.	Potential Cause	Causes Factor
F5		*Operator less knowledge.*	*Man*
		Wrong in measurement.	*Man*

The cause of the material factor is in *Table 4*.

Table 4. *Cause of material factor.*

	No.	Potential Cause	Cause Factor
F1	*1*	*Annealing or softening material aluminum deformation after washer dryer.*	*Material*
	2	*Thickness off aluminum material.*	*Material*

The cause of the method factor is shown in *Table 5*.

Table 5. *Cause of method factor.*

	No	Potential Cause	Cause Factor
F4		*Air pressure that injected to inside the cans fluctuated.*	*Method*
		Base plate fixture of drop impact resistance.	*Method*
		SOP not update.	*Method*

The cause of the machine factor is shown in *Table 6*.

Table 6. *Cause of machine factor.*

	No.	**Potential Cause**	**Cause Factor**
F2	*1*	*Body maker machine speed fluctuated.*	*Machine*
	2	*Temperature dryer washer.*	*Machine*
	3	*Temperature feco deco.*	*Machine*
	4	*Temperature IBO.*	*Machine*
	5	*Mat oven dyer washer, feco or IBO jam or stopped > 5 minutes.*	*Machine*
	6	*The dimension of dome depth.*	*Machine*
	7	*The dimension of reform diameter.*	*Machine*

The cause of the tooling geometry factor is shown in *Table 7*.

Table 7. *Cause of tooling factor.*

	No.	**Potential Factor**	**Cause Factor**
F3	*1*	*Punch sleeve tooling geometry.*	*Tooling*
	2	*The aluminum thickness dome area.*	*Tooling*

The cause of the environment factor is shown in *Table 8*.

Table 8. *Cause of environment factor.*

	No.	**Potential Factor**	**Cause Factor**
F6	*1*	*Lack of lighting*	*Environment*

4.2.1. CED

CED or fish born diagram for DIR is shown in *Fig. 6*.

There were ten possible root causes of the Cpk why do not meet the customer requirement as can be seen on the red rectangular box with dashed lines as shown in *Fig. 6*. Details description is as follows:

- Cause factor of man: The possibility of operator did wrong or a mistake in measurement and lack of knowledge.
- Cause factor of material: YS of aluminum after washer dryer, the variation between before and after drying process was too high and the thickness of aluminum raw material.
- Cause factor of method: Air pressure that injected inside the cans > 60 psi and Base plate fixture for DIR test the thickness > 31 mm.
- Cause factor of the machine: Temperature oven washer dryer; Mat conveyor washer dryer, Feco oven deco or IBO jam or stopped > 5 minutes.
- Cause factor of tooling: Punch sleeve tooling geometry and aluminum thickness at dome area.
- Environment: Lack of light sources.

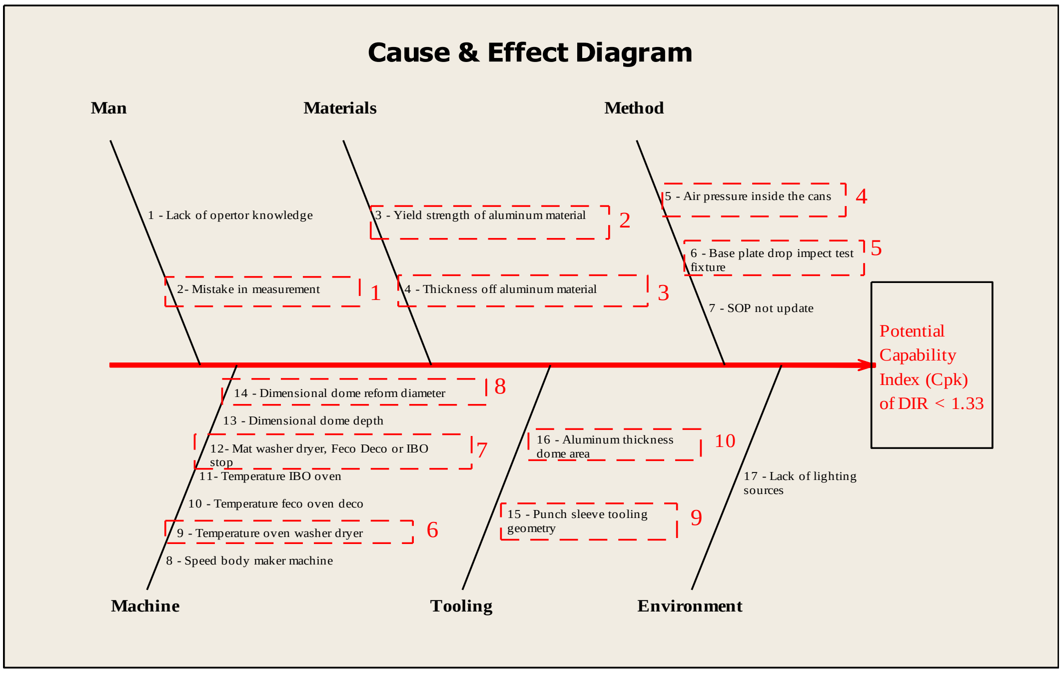


Fig. 6. *CED or fishbone diagram for DIR faulty in achieving Cpk index.*

4.2.2. Constructing NGT

From six factors with ten findings, then continuing to find out what the dominant cause is. NGT method is used, elaborating with 8 members of an expert at the plant with a different background as such education, age, year of service, and current expertise with these differences in the various background it will be resulted more accurate to give the information and finally correct decision is gotten. The concept of it is shown in *Table 9*.

Table 9. *Data NGT total score from 8 members.*

No.	Variable Causes	Scorer								Total Score
		Scorer 1	Scorer 2	Scorer 3	Scorer 4	Scorer 5	Scorer 6	Scorer 7	Scorer 8	
1	Vc_1	4	5	5	4	5	6	5	5	39
2	Vc_2	5	4	6	5	5	5	5	5	40
3	Vc_3	5	4	5	4	5	5	6	5	39
4	Vc_4	7	8	7	6	5	8	7	8	56
5	Vc_5	5	5	4	6	4	5	5	6	40
6	Vc_6	7	5	5	6	6	7	7	8	51
7	Vc_7	5	5	5	5	4	5	6	5	40
8	Vc_8	5	4	5	4	5	6	5	5	39
9	Vc_9	8	7	8	6	7	8	7	7	58
10	Vc_{10}	5	5	4	5	5	5	6	5	40

Vc_1: operator wrong measurement, Vc_2: aluminum yield strength, V_{C3}: Aluminum material thickness, Vc_4: air pressure that injected inside the cans for test DIR high fluctuations , Vc_5: baseplate fixture drop impact resistance > 31 mm, Vc6: temperature oven washer dryer too high > 420°F, Vc_7: Mat (oven dryer, IBO) and feco deco stopped for more than 5 minutes, Vc_8: reform diameter dimensional, Vc_9: tooling geometry of punch sleeve, and Vc_{10}: aluminum thickness dome area.

NGT calculation is based on the basic comment calculation with the following formula:

$$\text{NGT} \geq \frac{1}{2}\ (\text{Total number of scorer} * \text{Caused Variable}) + 1. \tag{1}$$

On this study, number of the scorers are 8 and variable causes are 10, so based on the formula *Eq. (1)* the NGT will be as follows:

$$\text{NGT} \geq \frac{1}{2}\ (8 * 10) + 1, \text{ so NGT} \geq\ 41.$$

Revert to *Table 9* linked to the NGT value, three potential variables having NGT value higher than 41, it becomes a dominant factor of the cause for the Cpk of DIR achievement, namely air pressure injected to inside the cans, temperature of oven dryer, and tooling geometry of punch sleeve.

5. Determining Improvement

5.1. Improvement Plan

Improvement plant for increasing the potential capability of DIR with 5W1H is shown in *Table 10*.

Table 10. *Sequence of Cpk improvement for DIR (Plan).*

No	Cause	Why	What	Where	When	Who	How
1	*Unstable air pressure which was injected into inside the cans some time more than 60 Psi was observed.*	*Pressure gauge indicator was broken.*	*The pointer scale has not precise.*	*Regulator drop test fixture.*	*Aug 2019*	*Hadi.P*	*Changed with a new one.*
2	*The temperature of washer oven dryer too hight > 420°F.*	*Only using one zone for drying the cans.*	*Reducing the temperature to below 420^{0}F.*	*Oven washer dryer.*	*July 2019*	*Farid*	*Activated oven zone 2 to getting temperature oven dryer below 420°F.*
3	*Profile or geometry tooling of Punch Sleeve.*	*The clearance needs to be adjusted in matching with new material.*	*Punch sleeve nose radius.*	*Punch Nose Radius R_1 dan R_2*	*Sept 2019*	*Anton*	*Modifying punch nose radius, R_1 punch nose radius was changed from 0.05 inch to 0.06 inch and R_2 punch nose was changed from 0.042 inches to 0.05 inch.*

After improvement plan as shown in *Table 10*, then we continue to implement improvement.

5.2. Implementation of Improvement (Do)

Table 11. *Implementation of quality improvement.*

No	Implementation of Improvement	Improvement Activity
1	*Air pressure is injected inside the cans before the test DIR.*	*To avoid air pressure that injected to inside the cans before test DIR, the pressure gauge indicator changed to the new one and doing a routine check for the function of pressure gauge with monthly bases and put on the calibration schedule.*
2	*Temperature oven washer dryer too high > 420°F.*	*When run production with material M_1 changed drying cans process from one zone to two zones with activated oven dryer zone 2, with set point temperature zone 1: 385oF and zone 2: 395°F.*
3	*Tooling geometry or profile punch sleeve.*	*Stretching aluminum at dome area point 3 (p3) as shown in Fig. 8 was reached 3.83% from the original thickness, it resulted in the drop impact resistance became weak.*

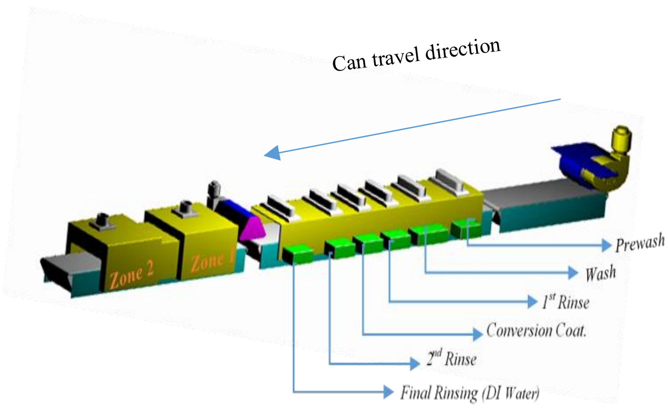


Fig. 7. *Oven washer dryer zone 1 and zone 2.*

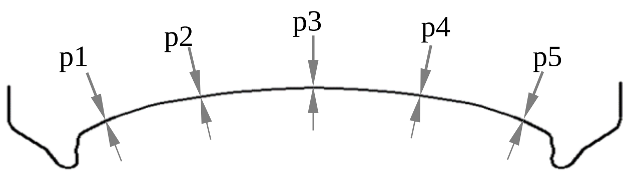


Fig. 8. *Measurement point for aluminum thickness dome area of aluminum beverage cans.*

To avoid stretching on the dome area p3, punch sleeve nose radius was modified, the modification area is shown in *Fig. 9* in below.

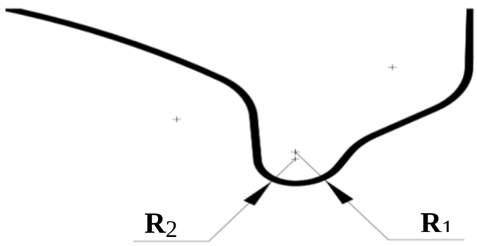


Fig. 9. *Schematic of dome formation for aluminum beverages cans: R_1: radius 1 and R_2: radius 2.*

Details for radius punch sleeve changing are as follows:

- Punch sleeve nose radius R_1 changed from 0.05 inch to 0,060 inch.
- Punch sleeve nose radius R_2 changed from 0.42 inch to 0,50 inch.

6. Evaluation (Check)

After some improvement were done then we follow the evaluation or controlling of improvement whether effective or not. The tools are used to do evaluation are $\bar{X}$-R chart and Cpk.

6.1. Constructing $\bar{X}$-R Chart of DIR after DID Some Improvements

Table 12 is DIR test data after some improvement done.

Table 12. *DIR test data.*

Date	Time	Machine	i	ii	iii	iv	v	vi	X	R
03 Oct, 2019	*8:15*	*1*	*27.94*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*26.25*	*2.54*
		2	*25.4*	*27.94*	*25.4*	*25.4*	*27.94*	*25.4*	*26.25*	*2.54*
		3	*27.94*	*25.4*	*22.86*	*25.4*	*25.4*	*25.4*	*25.4*	*5.08*
		4	*25.4*	*25.4*	*22.86*	*27.94*	*25.4*	*27.94*	*25.82*	*5.08*
		5	*25.4*	*25.4*	*25.4*	*25.4*	*27.94*	*27.94*	*26.25*	*2.54*
	9:15	*1*	*27.4*	*25.4*	*27.94*	*25.4*	*25.4*	*25.4*	*26.16*	*2.54*
		2	*25.4*	*25.4*	*22.86*	*25.4*	*27.94*	*25.4*	*25.4*	*5.08*
		3	*22.86*	*25.4*	*25.4*	*27.94*	*25.4*	*25.4*	*25.4*	*5.08*
		4	*27.94*	*25.4*	*25.4*	*22.86*	*27.94*	*25.4*	*25.82*	*5.08*
		5	*25.4*	*25.4*	*27.94*	*25.4*	*25.4*	*25.4*	*25.82*	*2.54*
	10:15	*1*	*25.4*	*27.4*	*25.4*	*27.94*	*25.4*	*25.4*	*26.16*	*2.54*
		2	*25.4*	*27.94*	*25.4*	*22.86*	*25.4*	*25.4*	*25.4*	*5.08*
		3	*25.4*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*25.82*	*2.54*
		4	*25.4*	*25.4*	*27.94*	*25.4*	*27.94*	*25.4*	*26.25*	*2.54*
		5	*22.86*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*25.4*	*5.08*
	11:15	*1*	*25.4*	*25.4*	*27.94*	*25.4*	*25.4*	*25.4*	*25.82*	*2.54*
		2	*25.4*	*27.94*	*22.86*	*25.4*	*25.4*	*25.4*	*25.4*	*5.08*
		3	*25.4*	*25.4*	*27.94*	*25.4*	*25.4*	*25.4*	*25.82*	*2.54*
		4	*25.4*	*25.4*	*25.4*	*27.94*	*22.86*	*25.4*	*25.4*	*5.08*
		5	*25.4*	*25.4*	*22.86*	*25.4*	*27.94*	*25.4*	*25.4*	*5.08*
	12:15	*1*	*27.94*	*25.4*	*25.4*	*25.4*	*25.4*	*25.4*	*25.82*	*2.54*
		2	*22.86*	*25.4*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*5.08*
		3	*25.4*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*25.82*	*2.54*
		4	*25.4*	*22.86*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*5.08*
		5	*27.94*	*25.4*	*25.4*	*25.4*	*27.94*	*25.4*	*26.25*	*2.54*
									$\bar{\bar{X}}$	$\bar{R}$
									25.77	*3.76*

Based on the customer information, stated to the manufacturing quality plan that DIR specification was 17.78 cm minimum average.

6.1.1. Determining Center Line (CL), upper control Limit (UCL), and lower control Limit (LCL) of $\bar{X}$-chart

With refer to *Table 12*, following are how to determine CL, UCL, and LCL of $\bar{X}$-Chart.

$$\text{CL} = \overline{\overline{\text{X}}} = 25.765. \quad (2)$$

$$\text{UCL} = \overline{\overline{\text{X}}} + A_2\overline{\text{R}} = 25.765 + 0.483(3.759) = 27.580. \quad (3)$$

$$\text{LCL} = \overline{\overline{\text{X}}} - A_2\overline{\text{R}} = 25.765 - 0.483(3.759) = 23.949. \quad (4)$$

A_2 is constant as shown in *Table 13*.

6.1.2. Determining CL, UCL, and LCL of R-chart

$$\text{CL} = \overline{\overline{\text{R}}} = 3.759. \quad (5)$$

$$\text{UCL} = D_4\overline{\text{R}} = 2.004(3.759) = 7.533. \quad (6)$$

$$\text{LCL} = D_3\overline{\text{R}} = 0(3.759) = 0. \quad (7)$$

D_3 and D_4 are constants as shown in *Table 13*.

Table 13. *The control chart constants.*

Sample Size = m	**A2**	**A3**	**d2**	**D3**	**D4**
2	*1.880*	*2.659*	*1.128*	*0*	*3.267*
3	*1.023*	*1.952*	*1.693*	*0*	*2.574*
4	*0.729*	*1.628*	*2.059*	*0*	*2.282*
5	*0.577*	*1.427*	*2.326*	*0*	*2.114*
6	*0.483*	*1.287*	*2.534*	*0*	*2.004*
7	*0.419*	*1.182*	*2.704*	*0*	*1.924*

Calculated results from points 6.1.1 and 6.1.2 plotted to the chart are shown in *Fig. 10*.

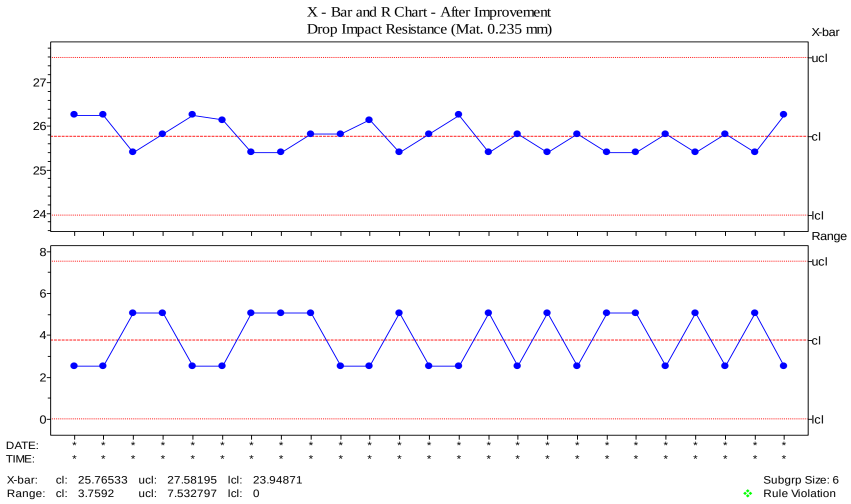


Fig. 10. *$\bar{X}$-R chart DIR after Improvement.*

6.2. Determining the Cpk → Check

After the stability of the process has reached then the second evaluation is process performance capability whether the process is stable or not. The method chosen for the index was Cpk. The Cpk calculation will use the estimation of standard deviations. To determine the estimated standard, deviations can be followed by the *Eq. (8)*, with d_2 refer to *Table 13*.

Determining the standard deviation (S).

$$S = \bar{R}/d_2 = 3.759/2.534 = 1.48. \tag{8}$$

Determining Cpk. DIR only has one side specification (minimum specification) and the Cpk = minimum (Cpu, Cpl); due to only one side specification, the Cpk will be the same with Cpl ($Cpk = Cpl$). To calculate the Cpk index the formula is:

$$Cpk = \frac{(\bar{\bar{X}} - LSL)}{3S} = \frac{(25.765 - 17.78)}{3\left(\frac{\bar{R}}{d2}\right)} = \frac{(25.765 - 17.78)}{3\left(\frac{3.759}{2.534}\right)} = \frac{7.985}{4.450} = 1.79. \tag{9}$$

The calculation results above plotted to the histogram by using NWA Quality Analyst v6.3 with the output is shown in *Fig. 11*.

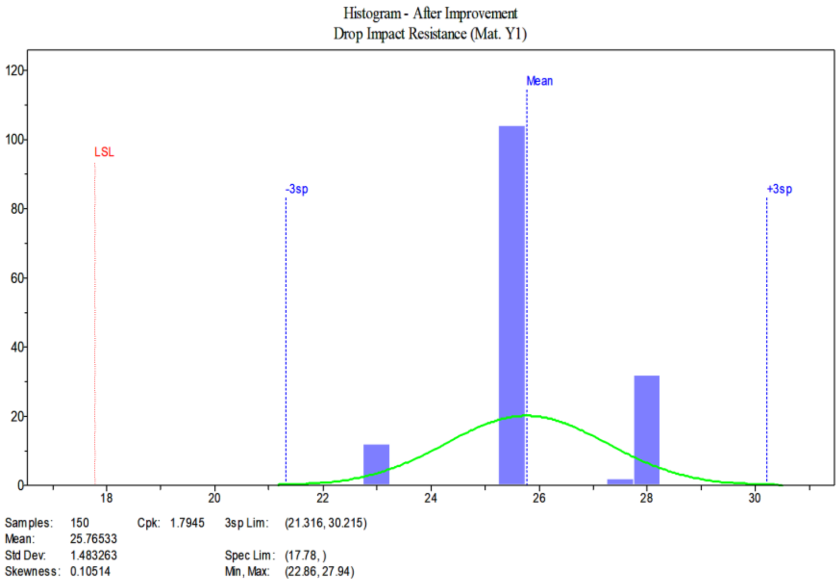


Fig. 11. *Histogram of DIR with material M_1 after improvement.*

Based on *Fig. 11*, the Cpk index has reached 1.73, it means the DIR has capable because of the index of Cpk > 1.33.

7. Standardizations (Action)

As described in the result and discussion above, the DIR after doing some improvement has already stable and capable if we plot on the distribution plot as shown in *Fig. 12*.

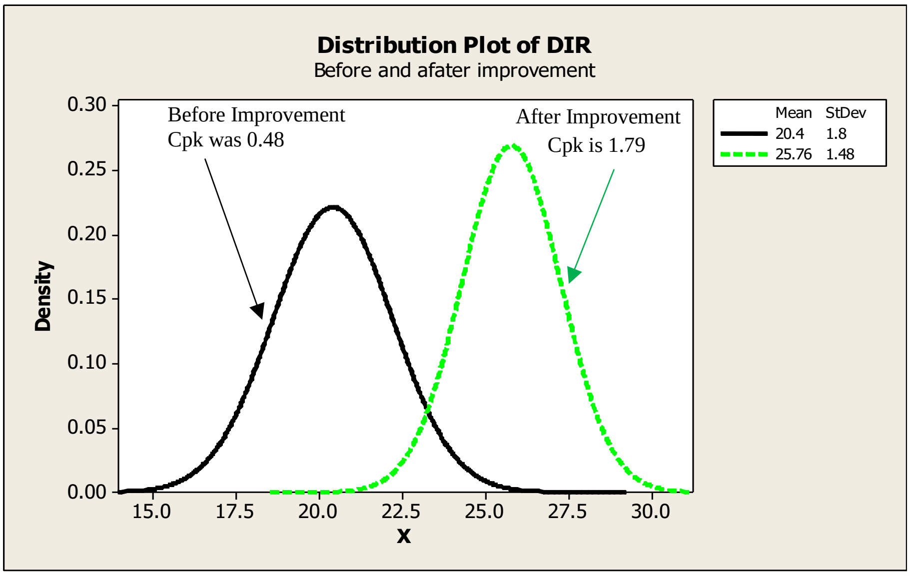
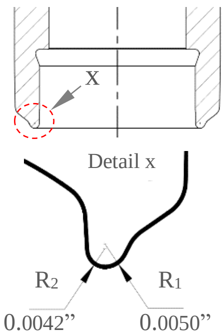
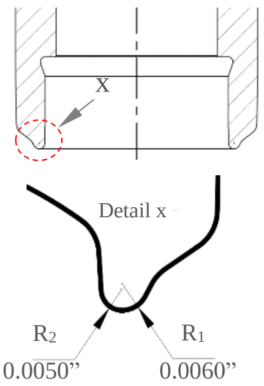


Fig. 12. *Distribution plot of DIR before and after improvement.*

With the above achievement, the next step is determining the standardization to maintain if the improvement has done, as guidelines in the future.

Table 14. *Standardization to maintain the Cpk of DIR with material M_1 (Cont's).*

Dominant Cause	**Remarks**	
Air pressure was injected into the cans has fluctuated with the range 4 psi so the DIR test results becoming unstable	*Before improvement*	*Unstable reading on the pressure gauge indicator.*
	After improvement	*Stable reading by changing the pressure gauge indicator and put on the permanent mounting.*
	Standardizations	*Pressure gauge indicator, put in calibration schedule to make well control.*
Temperature oven dryer washer setpoint over then 420°F.	*Before improvement*	*Cans drying process was using one oven zone with setpoint temperature 435°F with curing time 1 minute and 26 seconds.*
	After improvement	*Cans drying process was using two oven zones with setpoint zone 1: 385°F and zone 2: 395°F, with curing time 2 minutes and 52 seconds.*
	Standardizations	*Issue oven card, monthly bases, and verified by engineering Dan quality assurance manager.*
The tooling geometry of the punch sleeve does not match for new aluminum type M_1.	*Before improvement*	*Punch Nose Radius* *R1: 0.050 Inch* *R2: 0.042 Inch* 

Dominant Cause	Remarks	
	After improvement	*Punch Nose Radius* *R1: 0.060 Inch* *R2: 0.050 Inch* 
	Standardizations	*Revision Technical Drawing of Punch sleeve.* *Documents: 0106384, Rev 1 (29-07-19)*

8. Conclusion

The root cause of why the index Cpk does not meet the specification were due three dominant factors. The first, air pressure was injected inside the cans when doing DIR test is unstable or fluctuated with the range 4.0 psi; second, the set point oven temperature on the washer dryer was 435°F, it’s too high so the aluminum cans is easy for annealing or softening when machine stops for a while; third, the punch sleeve nose radius tooling geometries, the clearance does not match with dome die. The improvement has been done with changing the pressure gauge indicator with putting on the rigid mounting and to avoid annealing or softening of the aluminum cans the oven dryer washer was activated with two zones with set point zone #1 was 385°F and set point zone #2 was 395°F then the punch nose radius R_1 and R_2 were modified to make correct clearance between punch nose and dome die; punch nose radius R_1 was changed from 0.050 inch to o.060 inch and punch nose radius R_2 was changed from 0.042 inch to 0.050 inch. After improvement was done the DIR increased by 26.21%, from 20.41 cm to 25.76 cm; the standard deviation was reduced from 1.80 to 1.48 and then the index Cpk was increased from 0.48 to 1.79. Then, for the $\bar{X}$-R chart and R-chart, point is out of control limit and there was no trend, so, statistically the process is categorized in control and capable. At the end of this research, further discussion is still needed to maintain what has been achieved and also to make the research even better, it is recommended for further researchers to examine the chemical composition of aluminum M_1 alloy 3104 influence on the strength of the drop impact resistance and to analyze data it is recommended to integrate or combine SPC with Six Sigma or EPC.

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