Process parameter optimisation of a minster draw-redraw system

Yashwantraj Seechurn | Pankaj Ramlugun

Department of Mechanical and Production Engineering, University of Mauritius, Reduit, Mauritius

Correspondence
Yashwantraj Seechurn, Department of Mechanical and Production Engineering, University of Mauritius, 80837 Reduit, Mauritius.
Email: y.seechurn@uom.ac.mu

Non-conformance in Unit Depth Value (UDV) of expansion rings for metal cans makes them prone to major defects, such as swells and distortions, during the Drawing/Redrawing industrial process. In this paper, with the aim of improving the manufacturing process quality, the process parameters for the Minster Draw/Redraw machine at a generic company are optimised so as to obtain the desired UDV. The Taguchi method is used to determine the most influential process parameters. Nine experiments have been performed with four selected parameters, namely, Upper Blank Holder Pressure, Lower Blank Holder Pressure, Profile Pad Pressure, and Inner Ram Value. A multiple-linear regression analysis is also conducted to demonstrate the relationship between UDV and the considered parameters. The best settings for the respective process parameters are obtained via Analysis of Means (ANOM). Furthermore, Analysis of Variance (ANOVA) shows that the Inner Ram Value is the process parameter that most significantly affects the formation of expansion rings. The same methodology proposed in this study can easily be extended to find the optimum settings of process parameters for different can heights. Finally, an equation is formulated to predict the setting values of the most significant process parameters under user-specified UDVs.

KEYWORDS
design of experiment, process optimisation, Taguchi method, Unit Depth Value

1 | INTRODUCTION

At a generic manufacturer of metal cans, hereafter referred to as Company X Ltd, no compromises are made in terms of quality and safety production. All necessary measures as per different ISO standards are taken to ensure strict hygiene and high quality of the manufactured cans, since the latter are used to pack consumable goods. Quality is defined as the “degree to which a set of inherent characteristics fulfils requirement” (ISO 9000), and with respect to cans, quality is determined by integral features such as the depth of expansion rings. The latter are a series of rings pressed onto the metal that can be present on any part of the can body or at the integral end (Figure 1). Expansion rings are reinforcement features that provide cans with additional strength to withstand the stresses experienced during handling and sterilisation.1

In addition to a visual inspection, the quality control of cans is carried out by two quality inspection machines, namely, the Light Tester and the Camera Tester. Using the light tester, light is projected through the can and if detected by a light sensor on the other side of the can, presence of a small aperture is indicated. With the camera tester, an image analysis

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2019 The Authors. Engineering Reports published by John Wiley & Sons Ltd.

Engineering Reports. 2019;1:e212056.
https://doi.org/10.1002/eng2.12056
wileyonlinelibrary.com/journal/eng2 | 1 of 14
software detects any dents to the body or base of the can after a camera captures images of the can’s bottom panel, wall, and top edges. Process spoilage and Hold For Inspection (HFI) are two main types of defects detected on every production line. Process spoilage defects are serious defects in the form of crushed cans, sharp distortions, major swells, etc, which occur during production, whereas HFIs arise when suspicious defects such as abnormal marks and minor dents are spotted by the Camera Tester at the end of the production line. HFIs require further evaluation to determine the severity of the defect.

Despite all efforts of the Quality Control team at Company X Ltd, defects in cans are inevitable on all production lines of the company. Quality issues due to defects detected by the inspection equipment during quality testing are remedied by corrective maintenance carried out on the machines. However, the most complex type of defect, which is difficult to identify and detrimental to the quality of the manufactured cans, is “noncompliance of Unit Depth Value (UDV) to specification.” Noncompliance in UDV (the depth of expansion ring on the bottom panel of every can) represents a deviation in the optimum geometry of the can end. If the integral end profile obtained does not have the precise contour of the expansion rings, the can end is then likely to buckle under large amount of pressure during the handling or sterilising process. A conformity test using a quality control equipment known as a Can/End Buckling Test Station is usually performed to verify the structural integrity of the bottom panel of a can by determining the pressure at which it buckles. Figure 2 shows a peak formation, representing failure of the bottom panel of a can as air is gradually filled in the can to achieve the test pressure.

The catastrophic repercussions of this defect were experienced at Company X Ltd a few years ago when the bottom panel of a large number of cans of height 42.21 mm had blown up. A recall was effected by the quality department and the defective cans were traced back to a particular production line. Wrong settings of process parameters were identified as the major cause of this defect. Consequently, all the defective cans were scrapped and the company had to incur a huge cost for this production loss. The present study aims to reduce this particular defect on cans of height 42.21 mm by identifying the optimum settings of parameters affecting UDV and formulating a mathematical equation for prediction of parameter(s) setting.

Parameter optimisation is of major importance in Can manufacturing, given the variety of methods having been used to improve sheet forming processes by controlling design variables. Similar approaches applied to other processes such as tube rotary draw bending and wire drawing have shown that defects can be avoided by using optimum conditions of process variables. JingDong et al have highlighted the need to focus on improving part quality by determining
optimum process parameters using an alternative to the time-consuming “trial-and-error” procedure. However, this can be very complex, since part quality is also influenced by geometry, material, surface roughness, lubrication, and machine features. Hence, sheet forming remains a research topic of continuing interest given the necessity to determine the impact of these factors on product quality. The methodology adopted in this study would be very useful for other practitioners seeking to find the best settings of process parameters for different can heights. Furthermore, establishing a mathematical equation would enable companies to determine accurate and precise setting(s) of process parameter(s) in record time, with minimal effort and cost spent on several trials.

2 | LITERATURE REVIEW

In drawing and redrawing operations of steel or aluminium sheets to produce semifinished cans, a blank holder goes down first and grips the blank. Then, the draw punch descends to form the part. In order to achieve further reduction in sheet metal thickness in deep drawing, the partly formed cup is placed in an inverted position on the die and is redrawn, thus completing the reverse redrawing process (Figure 3).

A blank sheet experiences a large amount of plastic deformation upon interaction with forming tools to obtain a desired shape. The likelihood of a thin sheet to experience several types of defects is high if appropriate settings are not used for process parameters. Some of the most common defects are wrinkling in the flange, wrinkling in the side wall, tearing, earing, and surface scratches. Results from a deep drawing experiment on cylindrical cups have shown that height of wrinkles are significantly reduced by increasing blank holding force, decreasing friction coefficient, increasing radius of tool edge, and reducing deep drawing depth all together in one drawing operation.

Colgan and Monaghan have studied six parameters in the deep drawing process of steel sheets: punch radius, die radius, velocity of punch, clamping force, coefficient of friction, and draw depth. They have concluded that the smaller the die radius, the greater the drawing force induced and the greater is the overall thinning of the cup sidewall. In a study of deep drawing of a stainless steel blank, Padmanabhan et al have shown that die radius has a higher impact at a particular friction coefficient compared to the blank holder force parameter. The latter has been reported to vary linearly with coefficient of friction, such that an increase in coefficient of friction for a small range leads to a decrease in the blank holding force.

However, Winklhofer et al have demonstrated that velocity of the tool had more influence on formability of the output while assessing the impact of process parameters like drawing depth, drawing ratio, blank holder pressure, and punch velocity on forming of aluminium sheet metals at very high temperatures. Deep drawing and shallow drawing are vast fields of study and still remain an active area of research, although several experimental and research works on innumerable aspects of modelling, simulation methods with optimisation have been carried out during the past decades. Up to
this date, results obtained have been found to be accurate enough for use as a reference in theoretical treatment of cup drawing.10

Process optimisation is a common method usually adopted by industrial engineers to find the best result in a given system or process, within constraints. Optimisation of process parameters in obtaining the most favourable UDV would be crucial in minimising defects and increasing production efficiency at Company X Ltd. There are two types of parameters, namely, geometric parameters and physical/process parameters. The geometric parameters include thickness of metal sheet, die shoulder radius, radius of punch’s nose, and radial clearance between punch and die, whereas physical or process parameters include velocity of punch, blank holding force, force of punch, and coefficient of friction. A geometric parameter is more difficult to control than a physical parameter. Nevertheless, it is possible to eliminate or even reduce the occurrence of defects such as wrinkling, tearing, and formation of cracks in the drawing process by only controlling physical parameters.18

The parameter design phase in the application of Taguchi Robust Design method gives the optimum values for the control parameters in order to obtain the desired output.19 This method, which has been developed by Dr Genichi Taguchi, boosts up engineering productivity.20 Simpson21 has defined Robust Design method as “an engineering technique used in real life situation to improve productivity for a certain process by producing high quality products at a faster rate and at the lowest possible cost.” Taguchi Orthogonal Array (OA) is based on a design matrix that enables the consideration of a selected subset of combinations of multiple factors set at multiple levels. They are balanced in a way such that all levels of all factors are considered equally. In this type of design, only the main effects and two-factor interactions are considered. Other interactions such as the higher-order interactions are assumed to be nonexistent.22 Antony et al23 have successfully applied Taguchi OA in design of experiments in order to determine the optimum control parameters that would give the maximum pull-out strength in the hot forming process of a metal ring to be inserted in a plastic body. Periyanan and Natarajan24 have shown that Taguchi technique can also be used for optimisation of a process having two response variables. However, to find out the effect of any parameter on the quality characteristic, Analysis of Variance (ANOVA) is performed on the results obtained from the series of experiments performed.10 Using Taguchi design of experiment and ANOVA, Lodhi and Agarwal25 have been able to show that discharge current had the most significant effect on the surface roughness of AISI D3 steel that had undergone wire electric discharge machining.

3 | STATISTICAL PROCESS CONTROL

Statistical Process Control (SPC) is a quality tool used to monitor the behaviour of a process with data usually recorded and displayed on a control chart. In this study, SPC was used to monitor the behaviour of the draw/redraw process on five different days. UDV data collected during production were analysed and interpreted using control charts to extract maximum information about process stability. Determining the sampling method was a very important step to avoid bias during data collection for SPC. Systematic Random Sampling was selected as the best sampling method based on two crucial factors: a very large population (about 400 000 cans/day) and production around the clock. Using this technique, each unit had an equal chance of being selected within the population as a first item was randomly picked from the whole population and then the incoming ones were selected up to the sample size.

Mean chart, range chart, individual chart, run chart, and moving range chart are the different forms in which control charts can be expressed. Mean chart and range chart are generally used when subgroups of large samples are to be plotted while the other charts are used when individual samples are to be plotted. Control charts can verify both accuracy (central tendency) and precision (spread) of collected data for a particular process. For the purpose of this study, mean and range charts were used. The sample size chosen was 6, which is a reasonable size for calculation of the sample mean and for obtaining a good estimate of the standard deviation.26

From the mean and range charts, no mean UDVs of any sample could be seen above the Upper Action Line or below the Lower Action Line. In addition, all the points for the sample mean appeared within specifications. It could be said that the process was in SPC. However, these analyses were not enough to give a credible interpretation. Additionally, the Process Capability Indices (Cp and Cpk) for each day had to be calculated and analysed.

Cp is a simple comparison of the total variation with tolerances. It can only be calculated when there are two specification limits, namely, Lower Specification Limit (LSL) and Upper Specification Limit (USL). A value of Cp less than 1 indicates that process variation is greater than the specified tolerance band, and hence, the process is incapable. As Cp value increases, capability of the process also increases. Same applies for the Cpk, which is a measure of process variation and also the centring of the process on the target value. A difference of zero between Cp and Cpk values suggests
that the process is centred on the target specification. A process that is centred is one whose process mean and mid specification/target coincide.\textsuperscript{26} The values of Cp and Cpk were calculated using Equations (1) and (2) as follows:

\[
Cp = \frac{USL - LSL}{6\sigma}
\]

\[
Cpk = \frac{USL - \mu}{3\sigma} \text{ or } \frac{\mu - LSL}{3\sigma}, \text{ whichever gives a lower value}
\]

where $\sigma$ is the standard deviation of the process and $\mu$ is the process mean. The results are shown in Table 1.

The Cp values obtained are much greater than one meaning that the process is highly capable of producing cans within specifications. However, Cp values are not equal to Cpk values implying that the process is not centred.

4 | EXPERIMENTAL

4.1 | Product specification

The can, commonly used to pack tuna and seafood, is made of Tin Free Steel, which is an electrolytic chrome plated steel. The base steel is of Type MR, having the composition shown in Table 2. The dimensions of the end product, shown in a full sectional front view (Figure 4), include a target value of 3.10 mm for UDV.

4.2 | Description of machine

The Minster Press machine has 16 different machine parameters that ensure its effective functioning. Among them, some are not set, some are always kept constant and the remaining parameters are varied. However, some variables may not affect the formation of the bottom panel of cans in terms of unit depth. The parameters are listed accordingly in Table 3, and relevant variables are illustrated in Figure 5.

Lubrication level is the amount of coating (epoxy or vinyl) being applied on the top and bottom of the metal sheet to assist the operations by reducing friction between the toolings and the metal sheet. Feeder distance is the distance along which the feed fingers move the sheet to the dies after every stroke of the press machine.

The Minster machine consists of a double action draw die, with the blank holder connected to the outer ram of the machine and the draw punch fixed to the inner ram. The Inner Ram Value (IRV) and Outer Ram Value are the heights at which the Inner Ram and Outer Ram are to the metal blank when the machine is at rest. It is noteworthy that cans of different heights vary in IRVs.

| Material composition |
|----------------------|
| C  | Mn  | P   | S   | Si  | Cu  | Ni  | Cr  | Mo  |
| 0.13% | 0.6% | 0.02% | 0.05% | 0.02% | 0.2% | 0.15% | 0.1% | 0.05% |

TABLE 2  Material composition

![Section view of can showing key dimensions](image)
TABLE 3  Machine parameters

| Parameter                              | Setting  | Meaning                                                                 |
|----------------------------------------|----------|--------------------------------------------------------------------------|
| Lubrication                            | Not set  | Punch and die clearance                                                  |
| Punch corner radius                    | Kept constant | Upper Blank Holder Pressure                                              |
| Die radius                             | Vary     | Lower Blank Holder Pressure                                              |
| Shut height                            |          | Profile Pad Pressure                                                     |
| Top Dead Centre                        |          | Scrap Ejector/Kicker Pressure                                            |
| Bottom Dead Centre                     |          | Feeder Distance                                                         |
| Outer Ram Value                        |          | Inner Ram Value                                                          |
| Press Speed                            |          |                                                                           |

FIGURE 5  Draw-redraw machine showing variables

Punch corner radius and die radius are the radiiuses of the nose of the upper tooling (punch) and die, respectively. Having the correct punch corner radius or die radius is crucial as it brings a change in the distribution of forces and also allows the metal to flow smoothly through the die cavity. Punch and die clearance is the gap between the side of the punch and the side of the die when they are engaged during production. It enables the punch to draw on the sheet metal without causing any tears. Different amount of clearance is set for different can sizes. The amount of clearance is generally around 7% to 15% greater than the thickness of the sheet. However, if clearance between the punch and die is too small, the metal sheet is likely to tear up even though both the punch and die have the correct radius.

As the machine operates with an electro-pneumatic system, many pressure parameters are used at different settings. Upper Blank Holder Pressure (UBHP) and Lower Blank Holder Pressure (LBHP) are the pressures at which the upper blank holder and lower blank holder hold the blank prior to start of drawing operation. It is desirable to have a higher blank holder force to eliminate wrinkling defects in drawn cup-shaped products. Profile Pad Pressure (PPP) is the pressure at which the profile pad (Figure 6) is pushed to the cup during the redrawing operation to form the final diameter and expansion rings on the bottom panel of the can. Can Ejector Pressure is the pressure at which the cans are ejected to a cross-over conveyor after the redrawing operation and Scrap Ejector Pressure is the pressure at which scrap metal skeletons are ejected from the side of the press machine to the bin. According to Singh and Agnihotri, one of the process parameters affecting the drawing process output is Press Speed, which is the speed at which the tools move during operation of the machine. The Press Speed is controlled by a limit switch for speed adjustments. Another process parameter is
Shut Height, which is the distance from the face of the ram, at the bottom of its stroke, to the bed of the press. Top Dead Centre and Bottom Dead Centre relate to the topmost and bottommost positions of the ram.

4.3 Identification of control parameters and their levels

Among the eight parameters that can be varied on the machine (Table 3), Scrap Ejector Pressure, Can Ejector/Kicker Pressure, and Feeder Distance do not have any effect on UDV. The Feeder Distance parameter is used prior to the drawing operation while both the Scrap Ejector Pressure and Can Ejector/Kicker Pressure parameters are set after the drawing operation. Although the Press Speed can be varied, it is kept constant for the production of different types of cans. The setting for the Press Speed parameter is determined by the production engineers as per instructions in the machine manual and based on experience. A brainstorming session was carried out with the Production Engineering and Quality Control crews, and consequently, the following four key parameters were selected: UBHP, LBHP, PPP, and IRV.

The settings of the parameters were set at three equally spaced levels as shown in Table 4. The range of values for each parameter were selected based on the user manual of the Minster machine and as per usual practice at Company X. Operating the machine above or below these parameter settings would cause machine jamming and major defective products such as torn cans.

4.4 Orthogonal array design

The method used for design of experiment in this project was Orthogonal Array (OA) since it enables the experimentation of various main parameters set at different levels, at a medium cost and moderate accuracy, within a reasonable time frame. Nine experiments were performed using the L9 OA according to Table 5.

| Parameters                        | Levels | Level 1  | Level 2  | Level 3  |
|-----------------------------------|--------|----------|----------|----------|
| A: Upper Blank Holder Pressure    |        | 120 Psi  | 140 Psi  | 160 Psi  |
| B: Lower Blank Holder Pressure    |        | 120 Psi  | 140 Psi  | 160 Psi  |
| C: Profile Pad Pressure           |        | 4 Psi    | 8 Psi    | 12 Psi   |
| D: Inner Ram Value                |        | 333 mm   | 335 mm   | 337 mm   |

**TABLE 4** Levels for parameters

| Expt no. | Parameter levels | UDV (mm) | Avg UDV (mm) |
|----------|------------------|----------|--------------|
|          | A B C D | Trial 1 | Trial 2 | Trial 3 | |
| 1        | 1 1 1 1 | 3.24    | 3.25    | 3.23    | 3.24 |
| 2        | 1 2 2 2 | 3.10    | 3.11    | 3.10    | 3.10 |
| 3        | 1 3 3 3 | 2.95    | 2.96    | 2.97    | 2.96 |
| 4        | 2 2 3 1 | 3.29    | 3.28    | 3.29    | 3.29 |
| 5        | 2 1 2 3 | 2.93    | 2.95    | 2.94    | 2.94 |
| 6        | 2 3 1 2 | 3.13    | 3.14    | 3.13    | 3.13 |
| 7        | 3 3 2 1 | 3.26    | 3.27    | 3.26    | 3.26 |
| 8        | 3 2 1 3 | 2.91    | 2.92    | 2.93    | 2.92 |
| 9        | 3 1 3 2 | 3.08    | 3.09    | 3.09    | 3.09 |

**TABLE 5** Results of experiments

Abbreviation: UDV, Unit Depth Value.
For each experiment, three trials were carried out and the average value of UDV (Avg UDV) was determined. The unit depth of the expansion rings was measured using an Absolute Digimatic Indicator (ADI), as per the ISO/IEC 17025:2005 standard. The height of the instrument with respect to the product was calibrated using a gage of 42.21 mm. The height of the ADI was adjusted such that the pointer of the plunger was resting on the surface of the gage. The can was then placed beneath the instrument and the dial was adjusted to touch the depth of the expansion ring (Figure 7). The ADI was set to zero again. The dial was readjusted and placed on the upper surface of the expansion ring (Figure 8). The displayed value indicating the depth of the expansion ring was recorded.

All the parameters used for the experiments were independent parameters, meaning there was no correlation between the four selected parameters. Correlation coefficient matrix within independent variables was generated using E-Views software and the results are shown in Table 6. The values obtained confirm the absence of multi-collinearity within the four selected parameters. Regarding the other parameters, they were set and kept constant for all the experiments.

**FIGURE 7** Absolute Digimatic Indicator set to zero

**FIGURE 8** Absolute Digimatic Indicator showing depth

**TABLE 6** Correlation coefficient matrix

|       | UBHP  | LBHP  | PPP   | IRV   |
|-------|-------|-------|-------|-------|
| UBHP  | 1.0000| 0.0000| 0.0000| 0.0000|
| LBHP  | 0.0000| 1.0000| 0.0000| 0.0000|
| PPP   | 0.0000| 0.0000| 1.0000| 0.0000|
| IRV   | 0.0000| 0.0000| 0.0000| 1.0000|

Abbreviations: IRV, Inner Ram Value; LBHP, Lower Blank Holder Pressure; PPP, Profile Pad Pressure; UBHP, Upper Blank Holder Pressure.
### 4.5 Signal-to-noise ratio

Signal-to-noise (S/N) ratio identifies and measures the noise factors that affect the response of a particular signal. For a system to be robust and responsive, S/N ratio should be maximised such that unwanted noise factors do not affect the system. There exist three main types of responses for signal to noise (S/N) ratio, namely, Smaller the better, Larger the better, and Nominal the best. Taking into consideration the type of system under study, it was concluded that the best response would be a nominal UDV lying within specifications, i.e., Nominal the best. Moreover, the system is of a static nature, i.e., no external factor has a direct linear impact on the output of the results. The desired nominal value within specification is 3.10 mm. To calculate the S/N ratio for each experiment in dB^2, the decimal logarithm of the square of Avg UDV divided by the variance was multiplied by 10. The S/N ratios for experiments 1 to 9 are listed in Table 7.

### 5 RESULTS AND DISCUSSION

#### 5.1 Analysis of Mean

In Analysis of Means (ANOM), all experiments having the same level set for a specific parameter were identified, and for all levels, the mean S/N ratio was calculated. For example, since the IRV parameter set at level 1 was used in experiments 1, 5, and 9, the S/N ratios for these three concerned experiments were considered and a mean was calculated. The results are shown in Table 8.

The highest value of the S/N ratios for each factor was identified since it minimises the effects of the noise factors. The corresponding factor levels for the selected S/N ratio values are the best parameter settings to yield the nominal UDV of the expansion ring.

From Table 8, the best parameter settings as obtained from ANOM are therefore UBHP at level 2, LBHP at level 1, PPP at level 2, and IRV at level 2.

#### 5.2 Effect of parameters

To determine the main effects, a mean of the 3 Avg UDV values from Table 5 for each factor level (for, e.g., values of experiments 1, 2, and 3 for factor A level 1) was calculated and graphs of mean response against factor level were plotted for all 4 parameters as shown in Figure 9. Since the response is considered better if it is closer to the target value of 3.10 mm, from the plots, it appears that the optimum mix would be to set UBHP at level 1, LBHP at level 2, PPP at level 2 and IRV at level 2. This corresponds to trial number 2 but that would not always be the case. Furthermore, the difference between the highest and lowest response value, which is sometimes called the main effect, is highest for IRV, which could be considered to have the greatest impact on Average UDV.
From the main effect plots, it is also observed that IRV is the only factor that causes an almost constant decrease in the response. For UBHP, changing between the 3 levels does not have a significant effect on the response as is also observed when moving from level 1 to level 2 for LBHP. Only LBHP at level 3 shows a sharp rise in the average UDV, which may be due to an experimental error.

5.3 Regression analysis

For regression modelling, results obtained from Taguchi design of experiments (Table 5) were used to analyse whether the independent variables (UBHP, LBHP, PPP, and IRV) explained the variation in the dependent variable UDV. Microsoft Excel and E-views software were used for the analysis and the AVOVA results are shown in Table 9.

Since the sample size was small, the Shapiro-Wilk test was carried out using Analyse-it software to check whether the distribution of data is normal or not:

Null Hypothesis (H₀): The distribution of the population is normal.
Alternative Hypothesis (Hₐ): The distribution of the population is not normal.

The p-value obtained was 0.079, which is greater than 0.05, implying that the null hypothesis is not rejected at the 5% significance level, i.e., the data are normal.

Based on the ANOVA results, the estimated regression equation is

\[ UDV = 30.1075 - 0.000250UBHP + 0.000667LBHP + 0.002083PPP - 0.080833IRV + \epsilon \]  

(3)

From Table 10, the R² value of the regression is 0.9916 showing that 99.16% of the total variations of UDV are explained by the independent variables of the model. The adjusted R² value is 0.983104 (98.31%), which is lower than the R² value, meaning that not all independent variables in the model are significant.

An F-test was also carried out to verify the significance of the regression as a whole, i.e., to test whether the independent variables as a group explained the dependent variable. The hypothesis was set as shown below.

| TABLE 9 | Analysis of Variance results for regression analysis |
|---------|----------------------------------------|
| **Coefficients** | **P-value** |
| Intercept | 30.1075 | 1.81087E-05 |
| UBHP | -0.00025 | 0.541469739 |
| LBHP | 0.000666667 | 0.150072468 |
| Profile pad pressure | 0.002083333 | 0.328804817 |
| Inner ram value | -0.080833333 | 2.73974E-05 |

Abbreviations: LBHP, Lower Blank Holder Pressure; UBHP, Upper Blank Holder Pressure.

| TABLE 10 | Regression statistics |
|---------|---------------------|
| **Regression statistics** |
| Multiple R | 0.995767011 |
| R Square | 0.99155194 |
| Adjusted R Square | 0.98310388 |
| Standard Error | 0.018371173 |
| Observations | 9 |
Null Hypothesis (H₀): None of the independent variables explains the dependent one, ie, all coefficients are equal to zero.

Alternative Hypothesis (Hₐ): At least one of the independent variable explains the dependent one, ie, at least one slope coefficient is not equal to zero.

From Table 11, the F probability value is 0.000213 (0.0213%), which is less than 5%. Thus, the Null Hypothesis is rejected in favour of the Alternative Hypothesis at 5% level of significance. Even at one 1% level of significance, the Null Hypothesis would be rejected. Hence, at least one of the independent variable explains the dependent one.

A two-tail hypothesis testing (using P-value) was also carried out to determine the statistical significance of each coefficients:

- Null Hypothesis (H₀): The coefficient of the independent variable is equal to zero.
- Alternative Hypothesis (Hₐ): The coefficient of the independent variable is different from zero.

H₀ is rejected if P-value is less than 5%, else H₀ is accepted if P-value is greater than 5%. Comparing the P-values for each coefficient (Table 12) with the critical value, only the coefficient of IRV was deemed significant at 5% level of significance. Therefore, we conclude that IRV is the main determinant of UDV in our model and the remaining regressors (UBHP, LBHP, and PPP) are dropped. UBHP and LBHP control the flow of metal into the die cavity and prevent wrinkling occurring on the wall rather than on the bottom panel of the part, which explains why the depth of expansion ring at the bottom of the can is not affected by blank holder pressure. The profile pad helps to give the desired shape of the bottom panel of the can during the redraw operation as the cylindrical punch presses the cup through the redraw die. PPP does not have any impact on the UDV due to its very low pressure, which is only required to push the profile pad to the cup and the drawing force actually comes from the punch.

The new regression equation is as follows:

\[ UDV_i = \beta_0 + \beta_1 IRV_i + \epsilon_i. \quad (4) \]

The regression was run again using only IRV as independent variable and the estimated equation is

\[ UDV_i = 30.1825 - 0.08083IRV_i + \epsilon_i. \quad (5) \]

The mean of the residuals was calculated and it was found that the value obtained could be approximated to zero. Hence, \( \epsilon_i \) was assumed to be zero and the final equation sums up to

\[ UDV_i = 30.1825 - 0.08083IRV_i. \quad (6) \]

The Jarque-Bera test was used to test whether the residuals follow a standard normal distribution or not according to the following hypothesis.

H₀: Residuals are normally distributed.
Hₐ: Residuals are not normally distributed.

| P value | UBHP | LBHP | PPP   | IRV   |
|---------|------|------|-------|-------|
| (54.15%)| 0.5415 | 0.1501 | 0.3288 | 0.00002740 |

**Decision rule**
- Fail to reject H₀
- Fail to reject H₀
- Reject H₀ in favour of Hₐ

Abbreviations: IRV, Inner Ram Value; LBHP, Lower Blank Holder Pressure; PPP, Profile Pad Pressure; UBHP, Upper Blank Holder Pressure.
TABLE 13  Jarque-Bera test results

|             |          |
|-------------|----------|
| Series: residuals |          |
| Mean        | $-3.94e^{-16}$ |
| Median      | $-0.008333$ |
| Maximum     | $0.021667$  |
| Minimum     | $-0.013333$ |
| Std. Dev.   | $0.012990$  |
| Skewness    | $0.705614$  |
| Kurtosis    | $1.812757$  |
| Jarque-Bera | $1.275417$  |
| Probability | $0.528502$  |

FIGURE 10  Normality graph

TABLE 14  Predicting IRV values

| UDV Specification | IRV setting |
|-------------------|-------------|
| 2.95              | 337         |
| 3.00              | 336         |
| 3.10              | 335         |
| 3.15              | 334         |
| 3.20              | 333         |
| 3.25              | 333         |

Abbreviations: UDV, Unit Depth Value; IRV, Inner Ram Value.

The residuals analysis details in Table 13 and Figure 10 show the distribution of the residuals and depict that the trend of the residuals approximates the Standard Normal Distribution. When generated on the E-views software, the P-value was 0.5286 (52.86%), which is greater than 5%. Thus, the Null Hypothesis cannot be rejected and it is concluded that the residuals are normally distributed.

Using Equation (6), different UDV values that lie within the actual available client specifications were used to generate IRV values as shown in Table 14. It is observed that to obtain a nominal UDV value of 3.10 mm for cans of 42.21 mm, IRV setting should be 335 mm.

The closer the punch is to the blank when it is at rest, ie, the lower the IRV, the more effective is the stretch forming process that occurs as the punch moves downwards and forms out the bottom. This explains the increase in UDV from Table 14.

6 | CONCLUSION

In this paper, an efficient methodology was devised to counteract the defect of non-conformance to specification of UDV in the drawing process of metal cans. Taguchi design of experiment method was used to design and conduct real time experiments based on the L9 OA, using four selected process parameters set at three different levels. The results obtained were reliable since repeated measurements of the results were made as per the ISO/IEC 17025:2005 standard to ensure precision and accuracy. From results of ANOM, the optimum settings for the selected parameters were UBHP = 120 Psi, LBHP = 140 Psi, PPP = 8 Psi, and IRV = 335 mm.
Using regression analysis, a mathematical model was developed to define the relationship between the dependent parameter (UDV) and the independent parameters (UBHP, LBHP, PPP, and IRV). From results of ANOVA, IRV was found to be the process parameter that most significantly affects UDV. An equation of UDV in terms of IRV was obtained, which could be used to predict the setting for the most significant process parameter using available client’s specification values. Obtaining the desired UDV would ensure satisfactory structural performance of the can bottom panel under the action of forces during the later stages of the food can manufacturing process.

The new set of parameter settings would definitely have a significant positive impact at Company X Ltd since it would reduce the number of bottlenecks due to this particular defect, minimise loss of money due to scrap metal, and increase inventory level by reducing a significant amount of defects per year. Currently, the company is only able to produce 400,000 cans albeit a production capacity of 432,000 cans per day. The recommended solution is expected to bring a gain in terms of an additional production of 8000 cans per day, leading to a marked improvement in machine utilisation.

CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

ORCID
Yashwantraj Seechurn https://orcid.org/0000-0002-1733-0642

REFERENCES
1. Canadian Food Inspection Agency website. http://www.inspection.gc.ca/food/fish-and-seafood/manuals/metal-can-defects/eng/1348848316976/1348849127902?chap=0. Accessed November 19, 2015.
2. Robertson GL. Metal packaging materials. In: Food Packaging: Principles and Practice. 3rd ed. Boca Raton, FL: CRC Press; 2016:197-198.
3. Lim Y, Venugopal R, Ulsoy AG. Process Control for Sheet-Metal Stamping. London, UK: Springer; 2014.
4. Simonetto E, Ghiotti A, Bruschi S, Gemignani R. Dynamic detection of instability defects in tube rotary draw bending. Procedia Manufacturing. 2017;10:319-328.
5. Karabay S, Erturk AT, Zeren M, Yamanoglu R, Karakulak E. Failure analysis of wire-breaks in aluminium conductor production and investigation of early failure reasons for transmission lines. Eng Fail Anal. 2018;83:47-56. https://doi.org/10.1016/j.engfailanal.2017.09.007
6. JingDong L, Li H, HongBo Z. Forming defects analysis for sheet metal forming using Gaussian process regression. In: Proceedings of the 29th Chinese Control and Decision Conference (CCDC); 2017; Chongqing, China.
7. Ahmetoglu MA, Altan T, Kinzel GL. Improvement of part quality in stamping by controlling blank-holder force and pressure. J Mater Process Technol. 1992;33:195-214.
8. Sah S, Mahayotsanun N, Peshkin M, Cao J, Gao RX. Pressure and draw-in maps for stamping process monitoring. J Manuf Sci Eng. 2016;138(9):091005. https://doi.org/10.1115/1.4033039
9. Machine Parts website. http://newmachineparts.blogspot.com/search/label/What%20is%20double%20action%20draw%20die%3F. Accessed November 12, 2015.
10. Kumar JP, Tanveer MB, Makwana AS, Sivakumar R. Experimental investigation and optimization of process parameters on the deep drawing of AISI202 stainless steel. Int J Eng Res Technol. 2013;2(4):8.
11. Singh CP, Agnihotri G. Study of deep drawing process parameters: a review. Int J Sci Res Publ. 2015;5(2):1-15.
12. Reddy VR, Reddy JT, Reddy G. Effect of various parameters in the wrinkling in deep drawing cylindrical cups. Int J Eng Trends Technol. 2012;3(1):53-58.
13. Colgan M, Monaghan J. Deep drawing process: analysis and experiment. J Mater Process Technol. 2003;132(1-3):35-41. https://doi.org/10.1016/S0924-0136(02)00253-4
14. Padmanabhan R, Oliveira MC, Alves JL, Menezes LF. Influence of process parameters on the deep drawing of stainless steel. Finite Elem Anal Des. 2007;43(14):1062-1067. https://doi.org/10.1016/j.finel.2007.06.011
15. Gyadary R, Reddy GCM. Analysis of optimization of blank holding force in deep drawing by using LS DYNA. Int J Eng Res Appl. 2013;3(3):1975-1995.
16. Winklhofer J, Trattning G, Lind C, Sommitsch C, Feuerhuber H. Process simulation of aluminium sheet metal deep drawing at elevated temperatures. AIP Conf Proc. 2010;1252:927-934.
17. Volk M, Nardin B, Dolsak B. Application of numerical solutions in the deep-drawing process and the holding system with segments' inserts. J Mech Eng. 2011;57(9):7. https://doi.org/10.5545/sv-jme.2010.258
18. Patel ND, Patel BC, Thakkar KJ. A review of deep drawing process and interdependency of its parameters. Int J Eng Dev Res. 2014;2(3):3218.
19. Sukthomya W, Tannock JDT. Taguchi experimental design for manufacturing process optimisation using historical data and a neural network process model. Int J Qual Reliab Manag. 2005;22(5):485-502. https://doi.org/10.1108/02656710510598393
20. iSixSigma website. http://www.isixsigma.com/methodology/robust-design-taguchi-method/introduction-robust-design-taguchi-method/. Accessed January 27, 2016.
21. Simpson TW. *Manufacturing Processes: Integrated Product and Process Design*. New York, NY: McGraw Hill; 2000.
22. ReliaSoft Corporation website. http://www.weibull.com/hotwire/issue131/hottopics131.htm. Accessed February 1, 2016.
23. Antony J, Warwood S, Fernandes K, Rowlands H. Process optimisation using Taguchi methods of experimental design. *Work Study*. 2001;50(2):51-58. https://doi.org/10.1108/00438020110366330
24. Periyanan PR, Natarajan U. Optimization of multiple-quality characteristics in micro-WEDG process using Taguchi technique. *Int J Qual Reliab Manag*. 2014;31(2):205-219. https://doi.org/10.1108/IJQRM-12-2011-0158
25. Lodhi BK, Agarwal S. Optimization of machining parameters in WEDM of AISI D3 steel using Taguchi technique. *Procedia CIRP*. 2014;14:194-199. https://doi.org/10.1016/j.procir.2014.03.080
26. Oakland JS. Process capability. In: *Statistical Process Control*. 6th ed. Oxford, UK: Butterworth-Heinemann; 2008:257-268.
27. The Library of Manufacturing website. http://thelibraryofmanufacturing.com/deep_drawing.html. Accessed September 20, 2015.
28. Minitab Inc. website. http://support.minitab.com/en-us/minitab/17/topic-library/modeling-statistics/doe/taguchi-designs/what-is-the-signal-to-noise-ratio/. Accessed February 8, 2016.
29. TIBCO Software Inc. website. http://documentation.statsoft.com/STATISTICAHelp.aspx?path=Experimental/Doc/Overview/TaguchiMethodsSignaltoNoiseSNRatios. Accessed February 8, 2016.
30. Prakash R. Apte’s web-page. https://www.ee.iitb.ac.in/~apte/CV_PRA_TAGUCHI_INTRO.htm. Accessed February 1, 2016.

**How to cite this article:** Seechurn Y, Ramlugun P. Process parameter optimisation of a minster draw-redraw system. *Engineering Reports*. 2019;1:e12056. [https://doi.org/10.1002/eng2.12056](https://doi.org/10.1002/eng2.12056)