Evaluation of forming parameters affecting the grooving process for automotive connecting rod: an experimental and statistical approach

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Abstract: Forming industries are trying to reduce the cost of product without affecting its quality by minimising the defects to get-up the globalisation, competition and increase demand in the manufacturing domain. Present investigation is focused on identifying and minimising the various defects occurs in the grooving operation for connecting rod used to connect recliners of automobile seat. The cumulative approach of Pareto, AHP and Taguchi analysis has been applied to overcome the defects and to improve the productivity. Pareto analysis is used to find out the major intensity of defects, AHP techniques is applied for selection of most appropriate operational parameters. Finally, Taguchi analysis is carried out for optimisation of process parameters and selection of the best range of each parameter. From ANOVA the optimised value of each process parameter for minimisation of defects are evaluated and validated by conducting experiments in the industrial unit and found huge reduction in the percent rejection of component.

Keywords: metal forming; defects; quality; Pareto analysis; analytical hierarchy process; AHP; design of experiment; DOE; ANOVA; forming parameters; optimisation; productivity improvement.

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1 Introduction

Metal forming in modern engineering deals with numerous forming operations performed on component to achieve final desired geometry. The process parameters and sequence of operations are designed according to final shape of the component. Even a minor deviation in the process parameters can result in defects. To produce defect free components with negligible material loss and minimum tool cost are the prime objectives of metal forming (Lee et al., 2012). Any concern related to quality leads to fitment issue in the final stage, repeat operation in the field and customer dissatisfaction, which is expensive to the firm. An inspection is carried out after manufacturing for the component dimensions and associated mechanical and electrical properties. The routine practice is to stop the production line and investigate the root cause, if the part is out of specification which results increase in lead time. Hence, it is important to improve quality by minimising the defects occur during manufacturing (Chauhan and Agrawal, 2014). Various sources of manufacturing defects were studied and sorted by Pareto analysis. Among the available defects major concern is selected for experimentation (Segala and Wettergren, 2016). The process design is used to get the finest set of process parameters. The main objective of the proposed research is to find the defects occur in the grooving operation to manufacture a connecting rod of required shape and size. The analytical hierarchy process (AHP) approach is used to find the process parameters like force, cam angle, tool radius, time and cost which affects the result of the process. The rank is given to each parameter by their weightage through pairwise comparison (Pandey et al., 2018).

A Scientific methodology to design the experiments is essential for effective conduction of experiments. Statistical methodology approach is used to analyse the experimental data. Optimisation of critical process parameters is carried out by using Taguchi technique, as it requires least numbers of experiments (Akella et al., 2013; Majumder, 2017). In this statistical method L_9 orthogonal array (OA) is selected and results obtained from analysis of variance (ANOVA), influence of the forming parameters are investigated (Hussain et al., 2015). Taguchi method experiments process parameters combination, instead of testing all possible parameters. Most significant process parameter which affect the quality of the component can be found out with minimum experimentation (Periyanan et al., 2013).

2 Literature review

Many researchers had taken efforts at the design stage to produce defect free components. The process design tends to find the best set of process parameters. Shi et al. (2004) and Venkateswarlu et al. (2010) explained the need for minimising the cost involved in process control and mass inspection, if one optimises the product and process design to insure product robustness. Nataraj and Ismail (2017) used Pareto analysis and fishbone analysis from the obtained collective data to find and minimise root causes of defect occurred at inner tubes used in motorbikes. Jablonsky (2015) proposed a method using AHP model which can work practically without any support of decision makers to generate ranking. Bhushan and Rai (2004) confirmed that among the available alternatives, the preferences decided based on the criteria, known as multiple criteria decision-making (MCDM). Singaravel and Selvaraj (2017) proposed the application of AHP through calculation of weight criteria to obtain optimum machining parameters in turning operation. The results found that by using optimum machining parameters the performance of operation can be improved. Balakrishnan et al. (2017) described total five process parameters for laser welding process selected through AHP by decision-making techniques. Finally three significant process parameters were selected for further investigation to find their effect on laser welding process. Alkaabneh et al. (2012) suggested a combine approach using AHP, Taguchi method and finite element method for injection moulding process to select optimised process parameters. The optimal settings of the parameters is determined by ANOVA process. The proposed approach was successfully applied to obtained different optimal levels of parameters. Raju and Narayanan (2016) used a combined optimisation method by merging response surface methodology (RSM) and Taguchi grey relational analysis method (TGRA) to summarise the set of process parameters, such as spindle speed, feed rate, tool diameter, vertical step depth, etc. necessary to find constructive responses. With the help of combined optimisation method, superior results were obtained and validated through experimental trials. Tiwari et al. (2016) explained Taguchi parameter design as the most preferable tool compared to traditional method which is time consuming and require lengthy experimentation. Quality of the product considerably increases with reduction in defect through setting of optimal process parameters. Selvam et al. (2018) focused on optimisation of the weld spots along with the improvement in productivity through experimentation in an industry. Optimum spot quantity was designed by using Taguchi L_{27} OA. Data was analysed by recording the samples in two stages for different assembly formations. Mondal and Kumar (2016) presented an analysis of the optimal cutting parameters for crane-hook-pin in a radial drilling machine using Box-Behnken design. The effect of the input process parameters and their interactions on responses were studied using response surface modelling. ANOVA was used to study the effect of important parameters and analysis of model. Kumaravadivel (2015) proposed a method using process window approach to optimise the parameters by considering their interaction between each other for sand casting process. Optimisation was carried out by using Taguchi’s method and parameters were analysed by RSM to supplement the results. Reduction in percentage rejection was obtained by using optimised value of the significant parameters. Gantar et al. (2002) highlighted on the important issues related to sheet metal forming. Determination of optimal product shape, optimal primary blank geometry, prediction of fracture, final sheet thickness, wrinkling, loads acting on the active tool surfaces, spring back and residual stresses in the product were discussed. For designing a complicated 3D automotive stamping operation CAE method, integrated RSM, simulations and Pareto finest probable solutions search method were applied to solve the related problem (Ingarao and Di Lorenzo, 2010).

From the literature survey it is that the effective application of quality tools such as Pareto analysis, AHP and optimisation methods can considerably decrease the rejection rate and increase productivity by identifying the defects. Application of these tools can be used effectively to overcome the associate defects in grooving and forming operations.

3 Problem identification and description

Considering the efforts put into the growth of lightweight components and structures in automotive applications (Gantar et al., 2002), current process was studied and defects were identified.

3.1 Current process

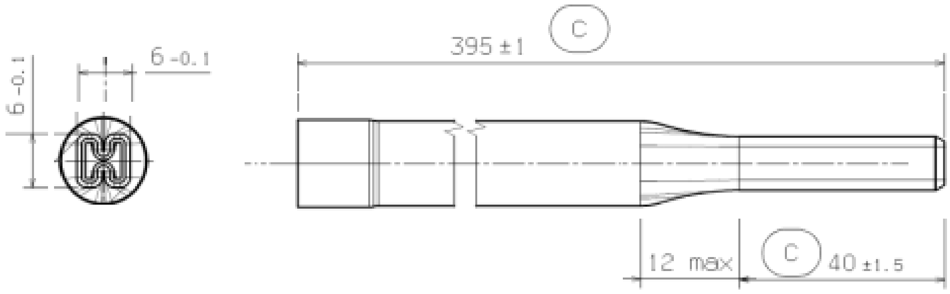
Connecting rod used to connect two recliners of automobile seat for driver and co-driver adjustment is shown in Figure 1(a) and 1(b).

The specification of the rod:

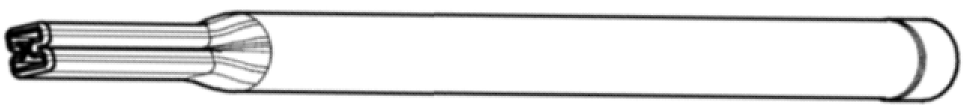
- Material: SAE 1010-1020.
- Diameter: 9.48 +/– 0.1 mm.
- Thickness: 0.9 mm +/– 0.1 mm.
- Yield strength: Min 365 N/mm^2.
- Tensile strength: Min 405 N/mm^2.
- Elongation: Min 31%.

The process sequence carried out for manufacturing of connecting rod is shown in Figure 2. It consists of total five operations in sequence i.e., grooving, flatting, serration, crimping and internal diameter (ID) enlargement.

Figure 1 (a) Connecting rod drawing (b) Connecting rod 3D drawing



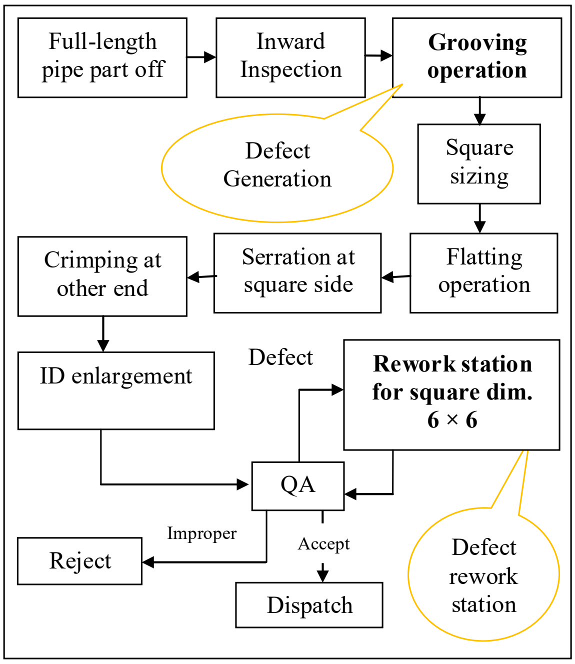
(a)



(b)

Full-length pipe cut into required length of 395 +/– 1 mm and inspection was carried out through tensile test. Grooving is the first operation performed up to 40 mm length from one end of the rod on the 30-ton capacity mechanical press followed by flatting and serration operation. In current operation, grooving is made on the rod by converting the circular cross-section into a square cross-section. The flatting process is used to make rod surface perfectly flat (square section) with required dimensions from all four sides. Serration marks (40 nos.) are protruded on the flat surface for gripping and positioning purpose. Crimping is carried out on the other end of the rod up to 10 mm followed by ID enlargement by 0.3 mm up to crimping mark. After completion of the above required operations, component is checked for quality and defective parts are sent to rework station according to defect observed.

Figure 2 Process sequence for connecting rod (see online version for colours)



3.2 Defect observed

After a quality check, monthly about 20% component found defective which causes rework and after rework also, nearly half of the defected components are rejected. The cost of poor quality due to rework is around USD 6,000 per year. Based on the available data Pareto analysis was performed to identify various defects in the connecting rod which causes rework after immediate containment action (ICA). The types of defects observed in the rod are shown in Figure 3.

- Inaccurate diagonal shape

  Formation of diagonal size was not as per the desired dimension (7.6 mm) after grooving operation.

- Operation missing

  Operations missed by the operator due to improper location of the part.

- Improper square shape (6 × 6 mm) and crack

The square shape of required dimensions was improper and cracks were observed after grooving operation.

- Damage and crack after enlargement

  Cracks were observed in the rod at opposite end after ID enlargement.

- Enlarging length excess

  ID enlargement length was more than the required i.e., 8 mm +/– 0.1 mm.

- Enlarging length undersize

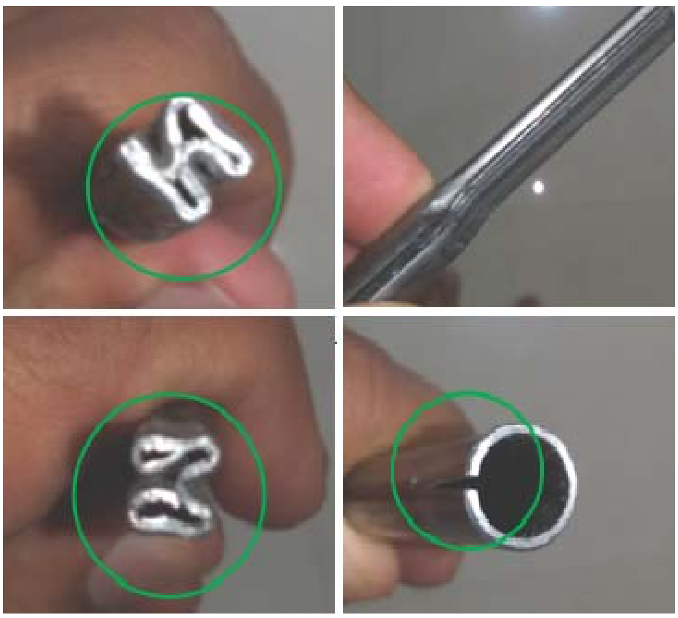
  ID enlargement length was less than the requirement.

- Serration marks missing

  Serration marks were missing after completion of the third operation.

The above-mentioned defects were plotted graphically to find the major intensity of defect. Figure 4 represents major intensity of defect observed at square forming in the grooving operation. This was the major concern among the entire available defects. This concern was repetitively reported in finished goods (FG) inspection area. It was one of the top three concerns in FG inspection area causes fitment problem at customer end which leads to operator's fatigue at rework station with customer dissatisfaction. Ishikawa diagram represented in Figure 5 was established to identify possible reasons that cause defect of square forming and occurrence of the crack in grooving operation.

Figure 3 Variety of defects observed (see online version for colours)



The causes were clustered into the set; each cause considered as a base of variation in the final geometry of the work piece. Various possible causes were found out and tested.

Figure 4 Intensity of defects (see online version for colours)

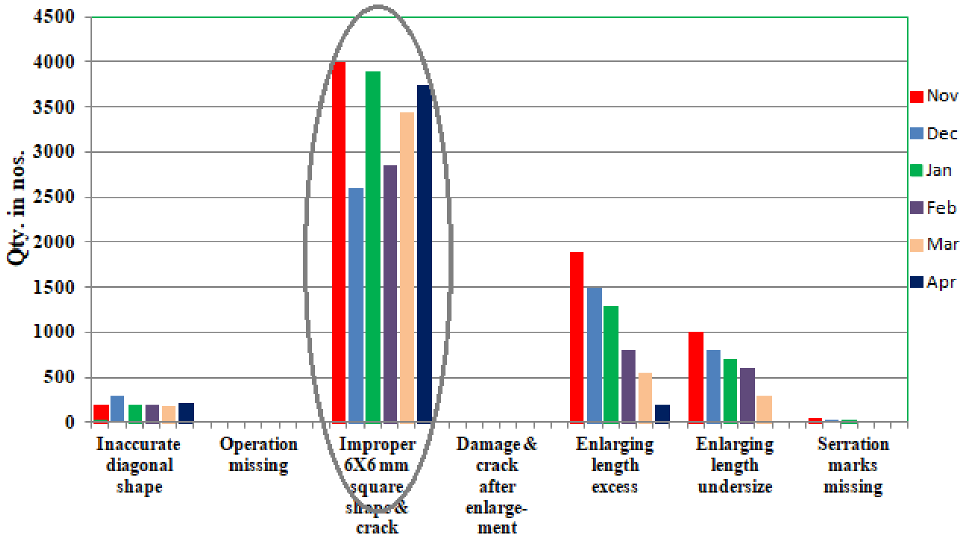
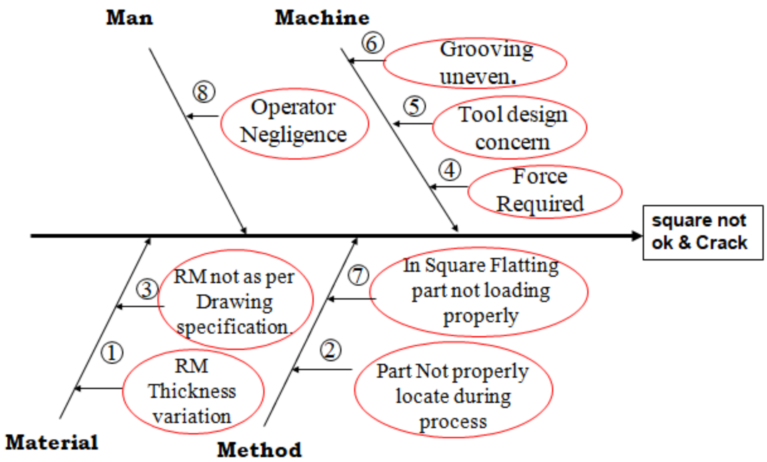


Figure 5 Possible defect causes (see online version for colours)



Possible defects categorised under 4Ms.

- Man

  The defects may arise due to operator's negligence or dislocation of the part from the desired position. The operator's awareness about standard operation sheet (SOS) and process sequence to be followed is checked.

- Machine

  Die is checked for the proper fitting of the grooving insert in the slot and area of contact with the work piece from both sides. The grooving insert radius is checked whether it is according to the requirement or not. The angle of the cam (which is responsible for actuation of horizontal motion of follower) is checked according to necessity. The amount of force exerted on the component is measured and checked as per the operation requirement.

- Material

  The raw material (RM) of the rod is checked for dimensions as per the drawing and the material properties along with chemical compositions are tested in accredited laboratories.

- Method

  For accurate manufacturing of the rod, all the methods as mentioned in standard operating procedure are observed.

Every factor in accordance of the defect has been tested by systematic inspection. After careful supervision, the conclusions were made based on the testing and observations as mentioned in Table 1. Based on the conclusions, action was taken for finding out the parameters, which are responsible for the variation in the desired result (final shape of the connecting rod). As seen from the conclusion, some parameters need to be focused.

Table 1 Testing and conclusion for the probable cause

Sr. no.	*Probable cause*	*Testing and observations*	*Conclusion*
1	RM thickness variation	Defected parts were checked for thickness and found acceptable.	Not valid
2	Part not locate correctly during the process	Problem regarding dislocation of work piece was not observed throughout the process	Not valid
3	RM not as per drawing specification	After checking defected parts for chemical and mechanical properties, RM was found as per specification.	Not valid
4	Force required	Force exerted is not as per the requirement and found more than the desired value	Valid
5	Tool design concern	Grooving insert radius was not as per the requirement of the part.	Valid
		Cam angle does not transmit the required force for proper groove formation	Valid
6	Grooving uneven	At grooving stage, part profile was found non uniform	Valid
7	In square flatting part not load properly.	After observation for process, it was found that there was no problem of loading	Not valid

4 Conceptual framework

Cutthroat competition was observed in automobile sector as a result of globalisation. Every original equipment manufacturer (OEM) is trying to reduce the cost without affecting the quality. Most of the OEMs are getting their job done by their suppliers.

After carrying out the systematic survey of some OEMs, it was found that one of the industry was facing the problem of rejection for connecting rod up to 10% per month, which is quite high. Identified problem need to be further analysed for finding the root cause of failure. As explained earlier, the possible causes of failure may include man/machine/material/method (4Ms).

The focus is on establishing conceptual framework to mitigate the failure or rejection of component in order to increase the productivity. It's well established that Pareto analysis is suitable for finding the main root cause of defects. The following aspects are considered for the proposed work,

- Study the process at an industrial unit to find all possible causes of defects.
- While performing the operation, effect of numerous parameters are to be considered. It is very difficult to find out the exact influence of every parameter. Based on the expertise, it is necessary to find the effective process parameters by using AHP.
- Optimise the significant parameters through design of experiments and ANOVA.
- Carryout the actual experimentation by considering the optimised value of parameters.
- Compare the results obtained and suggest the suitable solution.

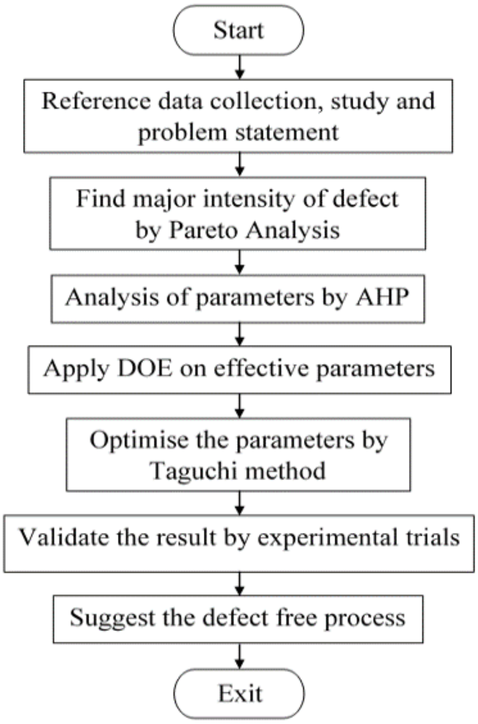
Based on this frame work a methodology has been planned to suit the stated problems and to overcome the defects. This detailed methodology is explained further to motivate the future research.

5 Methodology

Present study is carried out in the industrial unit involved in manufacturing of various automobile components using sheet metal forming process. The industry was facing the problem of increase in overall lead time of the process due to component rejection which causes customer dissatisfaction. Main objective of the current work is to find the root cause of the various defects observed in the component and suggest the suitable solution to overcome the defects. Previously, best possible process parameters were set by a trial and error method based on the know-how of the engineer. The flowchart of the methodology adopted for the study is shown in Figure 6.

Various aspects are considered to find out the defects. Data related to specific component is collected through study of metal forming process in industrial unit. As various defects are observed on the component, Pareto analysis is used to identify the major defect responsible for rejection. According to cause and effect diagram root cause of defect generation is studied. Effective parameters which causes various defects are found out by AHP technique using past experience. Pairwise comparison criteria is developed to find the weightage of each selected parameter (Majumder, 2017). Experimental design is carried out by using three most significant parameters obtained by AHP. Taguchi method is adopted for analysis and optimisation using design of experiments. Total 9 numbers of experiments are conducted using L_9 OA. Preparation of the manufacturing unit for the conduction of trials is done by using the set of optimised parameters. The optimised parameters are validated by experimental trials in the same industrial unit. Experimentations are conducted in the same working environment with same operator as used previously. Finally, the suggestions are recommended to the industry for defect free product and process.

Figure 6 Flowchart of methodology



6 Critical analysis of parameters Using AHP

Complication of parameter optimisation for multiple performance characteristics is too much difficult than single performance characteristic. AHP technique is used for translating multiple criteria parameter optimisation characteristics into single performance optimisation of the characteristic by building hierarchy. Lots of investigators performed optimisation by using various methods (Triantaphyllou, 2000);

- Analytical network process (ANP)

  ANP uses a network, not including hierarchical levels. It is very useful where various decision problems cannot be structured by hierarchical levels because of dependencies of parameters.

- ELECTRE

  It is divided into two parts as several outranking relations, which aim to compare each pair of actions followed by utilisation procedure that detailed the recommendations.

- Technique for order preference by similarity to ideal solution (TOPSIS)

  TOPSIS select the alternative that is nearby to the best attribute value and furthermost from the worst. Set of alternatives compared by identifying weights and normalising scores for each criterion. The best score is selected by calculating the geometric distance between each alternative and best alternative.

- Weighted product model (WPM)

  Rather than calculating sub-scores, every alternative evaluated with remaining by multiplying the number of recital scores, individually for each criterion. Each recital scores is raised to the power matching to the virtual weight of the related criterion.

- Weighted sum model (WSM)

  This method calculates the estimate on an alternative for a user by calculating the user's addition of the ratings specified by the equivalent alternatives. The equivalent match between alternatives been weighted by every rating.

- Analytical hierarchy process

  The vital benefit of using AHP method is that it permits the decision makers to highlight on comparisons of objects and the study can made free from irrelevant concern (Sarkar et al., 2014).

Figure 7 Die used for grooving operation (see online version for colours)

While performing the operation many parameters may correlate to distract the output (Saaty, 2013). Those parameters are very difficult to control; also, the exact contribution of each parameter is very difficult to find out (Naceur et al., 2001). This work requires greater proficiency and leads to a time-consuming affair. When their contribution and weights are found out, one can focus on them to resolve the issues of defects arising in the product and prevent the loss incurred due to those defects (Tahriri et al., 2008; Kusumawardani and Agintiara, 2015). Figure 7 shows the die used for the grooving operation with the considered parameters.

6.1 Working with AHP

In AHP, the best conclusion is obtained by considering set of assessment criteria and a set of substitute options (Triantaphyllou and Mann, 1995; Greco et al., 2005). The weightage for each assessment criterion being generated based on the assessor's pair wise comparisons of the criterion (Vaidya and Kumar, 2006). The higher weightage value decides the importance of a criterion. A score to every alternative assigns according to the assessor's comparisons of the options based on criterion. More is the score; superior is the performance of the alternative regarding the measured criterion. Weighted sum of all scores obtained concerning all the criteria is the total score for a given alternative (Saaty, 2008).

6.2 Implementation

The AHP can implement in following steps (Saaty, 2013, 2008):

- Criteria weights will be found out by calculating the vector (Bunruamkaew 2012).
- Option scores matrix will be calculated.
- Options will be rank according to weightage.

Numbers of options '*n*' will be evaluated by taking into account '*m*' evaluations. A functional practice for checking the consistency of the results will also be introduced (AHP Tutorial, 2016). The matrix shown below gives the qualitative important terms in the form of quantitative numbers. Fuzzy logic technique is used to form the matrix (Rao, 2013). Taking '*M*' attributes, the pair wise assessment of attribute '*i*' with attribute '*j*' yields a square matrix $B_{M\times M}$ where a_{ij} shows the relative importance of attribute '*i*' regarding attribute '*j*'. In the matrix, $b_{ij} = 1$ when $i = j$ and $b_{ji} = 1/b_{ij}$ (Rao, 2013; Saaty, 2008).

$$\left\{ B_{M\times M} = \begin{bmatrix} 1 & b_{12} & b_{13} & \dots & \dots & b_{1M} \\ b_{21} & 1 & b_{23} & \dots & \dots & b_{2M} \\ b_{31} & b_{32} & 1 & \dots & \dots & b_{3M} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ b_{M1} & b_{M2} & b_{M3} & \dots & \dots & 1 \end{bmatrix} \right\} \tag{1}$$

According to the fundamental scale of absolute numbers (Saaty, 2013, 2008) pairwise comparison matrix prepared for the observed parameters in Table 2.

a The geometric mean (GM) of the i^{th} row is considered and normalising the GMs of rows in the comparison matrix (Rao, 2013).This can be represented as;

$$GM_j = \left[\prod_{j=1}^{M} b_{ij} \right]^{1/M} \tag{2}$$

b To find out the relative normalised weights of the attributes, a GM method is used. Due to simplicity and easiness to find out the maximum eigenvalue and to decrease the discrepancy in judgments said method is used.

$$W_j = GM_j \Big/ \sum_{j=1}^{M} GM_j \tag{3}$$

Table 3 indicates the comparative normalised weightage (w_j) of all attribute.

After preparing the matrix, the weightage of the each criterion is calculated and rounded as mentioned in Table 4 (Rao, 2013; Saaty, 2008).

Table 2 Pair wise comparison matrix

	Force (kN)	*Cam angle (deg.)*	*Tool radius (mm)*	*Time (sec.)*	*Cost (USD)*
Force	1	4	7	9	9
Cam angle	1/4	1	3	4	6
Tool radius	1/7	1/3	1	5	3
Time	1/9	1/4	1/5	1	2
Cost	1/9	1/6	1/3	1/2	1

Source: Saaty (2008)

Table 3 Relative normalised weightage

Sr. no.	*Criteria*	GM_j
1	Force	4.68
2	Cam angle	1.78
3	Tool radius	0.93
4	Time	0.40
5	Cost	0.31

Table 4 Relative rounded weightage

Sr. no.	*Parameters*	*Weightage*	*Rounded weightage*
1	Force (kN)	57.69	58%
2	Cam angle (deg)	21.93	22%
3	Tool radius (mm)	11.50	12%
4	Time (sec)	5.00	5%
5	Cost (USD)	3.87	3%

7 Experimental design

A technical move towards preparation or planning of the experiments is essential for proficient conduction of experiments (Wei and Yuying, 2008). The process of planning the experiment is carried out by the statistical design of experiments, such that suitable data will be composed and evaluate by a statistical technique. Statistical analysis is used for the experimental errors if any (Ponthot and Kleinermann, 2005). Hence, there are a couple of aspects for an experimental problem: the design of the experiments and the statistical technique. These two aspects are directly linked to the process of study depends directly on the design of experiments in use.

7.1 Design of experiment

DOE is the direct evaluation of two or more parameters for their capacity to influence the resulting average or unpredictability of particular process or product. To achieve this in an efficient and statistical way, the levels of the effective factors are changed in a tactical manner. Significant factors for the process are determined by analysing the entire set of the result obtained by particular experiment combinations. Increase in the level further causes lead to improvement in the result (Chinnaiyan and Jeevanantham, 2014).

Table 5 Design of experiments

Experiment no.	*Force (kN)*	*Cam angle (deg.)*	*Tool radius (mm)*
1	40	35	1.2
2	40	36	1.3
3	40	37	1.4
4	45	35	1.3
5	45	36	1.4
6	45	37	1.2
7	50	35	1.4
8	50	36	1.2
9	50	37	1.3

According to DOE for three variables i.e., force, cam angle and groove insert radius L_9 OA is selected. Previously the operation was carried out at 45 kN, so the range of applied force 45 +/– 5 kN (i.e., 40 kN, 45 kN and 50 kN) is considered. With reference to Figure 8, cam angle used is calculated by equation (4) considering the coefficient of friction between hard steel as 0.4. Where 'a' represent horizontal stroke and 'b' represent vertical stroke.

$$\begin{aligned} &\varphi = \tan^{-1}(\mu) \\ &\varphi = \tan^{-1}(0.4) = 21.80^\circ \\ &\therefore \lambda = \left(45 - \frac{21.80}{2}\right) = 34.09^\circ \approx 35^\circ \end{aligned} \tag{4}$$

In the old design, cam angle considered was 37°, so the range is selected from 35° to 37°. The former tool radius of 1.5 mm leads to development of crack therefore to obtain the proper depth in formed tool three groove inserts were examined from 1.2 to 1.4 mm radius. Experiments were carried out for three parameters at three levels to find out optimal set of parameters for the said operation. By considering L_9 OA, nine numbers of experiments were carried out by taking the set of respective values. Design of experiment for selected combination of parameters is appended in Table 5. The depth of rod measured while performing the experiments is shown in Figure 9. Throughout the experimentation, grooving depth of each formed part was measured with digital vernier calliper having a resolution up to 0.01 mm.

Figure 8 Angle of cam

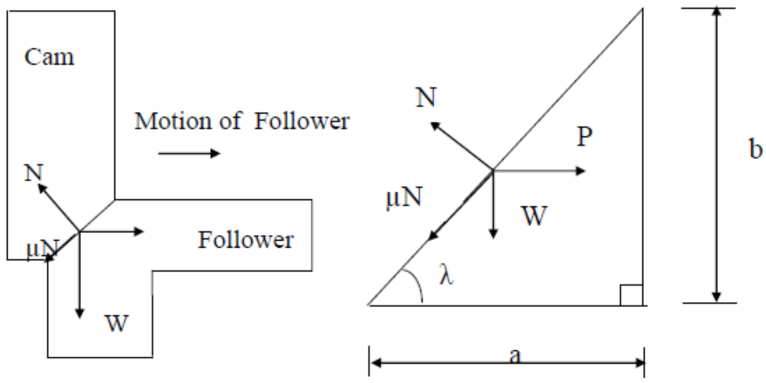
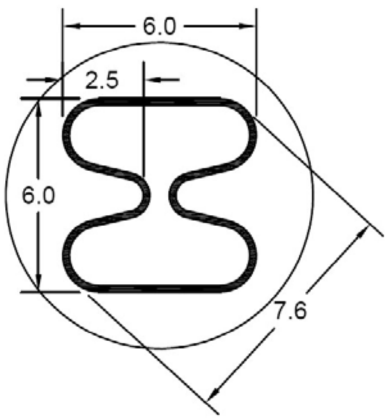


Figure 9 Depth measured for connecting rod



The depth of the rod should be kept close to the designed dimensions, as it is one of the most vital parameters to be maintained for the final assembly. More depth causes crack after grooving operation and less depth causes improper fitting. This variation in the depth causes rejection of the work piece.

7.2 Experimental setup

Trials were carried out on FMT make 'FMC 30' C type press having 30-ton capacity as shown in Figure 10. The selected press machine has motor capacity of 3 HP (22,371 watts) and performs 40 strokes per minute (SPM). Lubrication plays a very significant role in any type of forming operation. Material properties, as well as lubrication system used, are equally important for the metal formability. Therefore, to avoid crack formation, draw cut oil i.e., Smoothpress 9020 lubricating oil was used for lubricating the work piece during operation. All the moving parts of the press were regularly lubricated through oil cups by EP0 oil for maintaining the constant working condition throughout the experimentation. All the trails were conducted at room temperature. A load cell as surface strain gauge sensor (9,232 A) was used to measure the applied force proportional to strain. The experimental results are mentioned in Table 6.

Figure 10 FMC 30 mechanical press (see online version for colours)

Table 6 Measurement values of design of experiments

Experiment no.	*Force (kN)*	*Cam angle (deg.)*	*Tool radius (mm)*	*Depths (mm)*
1	40	35	1.2	2.42
2	40	36	1.3	2.48
3	40	37	1.4	2.45
4	45	35	1.3	2.48
5	45	36	1.4	2.49
6	45	37	1.2	2.51
7	50	35	1.4	2.49
8	50	36	1.2	2.52
9	50	37	1.3	2.52

The signal to noise (S/N) data analysis is performed in the present study. The effects of the grooving process parameters on the depth characteristics were investigated through the graphs of the main effects obtained in the analysis of data. The best situation for every quality concern is recognised through S/N data examination supported by the data analysis (Sivakumar et al., 2015).

8 Statistical analysis

Statistical techniques used for the optimisation and computation of metal forming and machining processes are (Markopoulos et al., 2016):

- Factorial design method

  In this method, every factor generally considered as an independent variable and considered at various discrete levels where discrete values lie inside a predefined array. A range of factors on single or other response variables can be successfully investigated when trials are performed by the factorial design process. In this method, large amount of experiments should be conducted which results in extra cost.

- Response surface methodology

  The least square method is used to resolve the parameters in the estimated models. The term response surface describes the output of a method when input parameter values differ within specified array. The relationship between input and output variable is used to determine a suitable function. Suitable DOE method applied to predict the accurate evaluation of parameters.

- Grey relational analysis

  The relation between calculated variables and optimum parameters can be determined by grey relational grade graphs by grouping the grades for all factors. Various responses are converted in one and the optimisation of various criteria abridged to the single quantity.

- Statistical regression methods

  The interaction between the available parameters for a particular process represent statically in the statistical regression model. It shows the change in dependable parameter based on a change in undependable parameters. It also used when experimental data is not available.

- Taguchi method

  Time and cost can abridge by performing the minimal number of experimentation based on OA by means of Taguchi technique. It develops a particular design of OAs to study the whole parameters space with the minimum experiments only. Taguchi technique employs the S/N ratio to recognise the quality character applied for engineering design problems.

The current part gives the relevance of the Taguchi's experimental design process. The method of carrying out experiments and levels of experiments are selected. Experiments were performed to inspect the effect of process parameters on the output parameters. In present work response output is the depth of formed part (connecting rod) in grooving operation.

Minitab served as a perfectly adequate tool for many statistical problems, which are time-consuming to solve analytically.

8.1 Analysis of S/N ratio

In the Taguchi technique, the term signal represents the essential value (mean) for the output characteristic and the term noise represents the adverse value (standard deviation) for the output characteristic. S/N ratio is used to measure the quality characteristic deviating from the required value and simple to execute. Usually there are three main quality objectives in the analysis of the signal to noise ratio; larger is better, nominal is best and smaller is better (Wei and Lin, 2011). In this study, the S/N ratio analysis is carried out by considering 'smaller is better' quality characteristic. The quality attributes conflicting from the required value calculated by S/N ratio are described in Table 7.

Table 7 Analysis of signal to noise ratio

Experiment no.	*Force (kN)*	*Cam angle (deg.)*	*Tool radius (mm)*	*Depths (mm)*	*S/N ratio*
1	40	35	1.2	2.42	–7.676
2	40	36	1.3	2.48	–7.889
3	40	37	1.4	2.45	–7.783
4	45	35	1.3	2.48	–7.888
5	45	36	1.4	2.49	–7.923
6	45	37	1.2	2.51	–7.993
7	50	35	1.4	2.50	–7.958
8	50	36	1.2	2.52	–8.028
9	50	37	1.3	2.52	–8.029

The S/N ratio is defined as [$n = -10 \log (MSD)$] (mean square deviation). Response table for S/N ratio is prepared by using 'smaller is better' objective as appended in Table 8. It is observed that force proved to be the most significant parameter followed by cam angle and tool radius.

Table 8 Response table for signal to noise ratio (smaller is better)

Level	*Force*	*Cam angle*	*Tool radius*
1	–7.783	–7.841	–7.899
2	–7.935	–7.947	–7.935
3	–8.005	–7.935	–7.899
Delta	0.222	0.106	0.047
Rank	1	2	3

8.2 Find ANOVA

In ANOVA, variations of the parameters were found out, which affect considerably on the output of the process. Variance and the sum of squares were calculated in the analysis. 95% confidence level is used in F-test value to decide the important factors, which affect the method and fraction contribution as mentioned in Table 9.

DF degree of freedom

SS sum of squares

MS mean squares

F fisher ratio

P probability value.

$$Sum\ of\ square(SS) = \sum_{i=0}^{n} (y_i - y)^2 \tag{5}$$

$$Mean\ square\ (MS) = \frac{Sum\ of\ square}{Degree\ of\ freedom} \tag{6}$$

$$F\ ratio = \frac{MS\ effect}{MS\ error} \tag{7}$$

The P-value is the probability that the tests statistics will take on a value that is at least extreme as that of the observed value of the statistic when null hypothesis H_o is true.

Table 9 Analysis of variance

Source	*DF*	*SS*	*MS*	*F*	*P*	*% contribution*
Force	2	0.0065	0.00325	7.81	0.021	78.423
Cam angle	2	0.0016	0.00081	0.66	0.551	19.527
Tool radius	2	0.0001	0.00009	0.06	0.944	02.049
Error	2	0.0018	0.00311			
Total	8	0.0082	0.00727			

8.3 Effect of various process parameters

The S/N ratio shows the expected performance of a product or procedure in the existence of noise factors. Process parameter settings with the least S/N ratio every time yields the best possible quality with least variance. The response calculated for all level of every parameter like force, cam angle and tool radius as graph of main effects plot for signal to noise ratio is shown in Figure 11. The optimal values were obtained where the S/N ratio was maximum.

8.4 Regression analysis

It emphasises on the conditions that only provide the best depth value among the conditions tested. The ANOVA shows the importance of various factors and their relations at 95% assurance or confidence level. ANOVA shows the ‘model’ as ‘significant’ which is desirable from a model point of examination. The probability values < 0.05 in the ‘P’ column indicates the significant factors and interactions. The major factors and their relations were included in the final depth model while the insignificant interactions were rejected from the depth model. It shows that the main important parameter is force followed by cam angle and tool radius. Piecewise linear regression with breakpoint was used as the statistical method to develop the mathematical model of the depth means of both control factors and noise factors. Based on the experimental dataset, the depth empirical model was developed and the coefficients of regression were determined and appended in Table 10. The mathematical model was useful in predicting the depth during the forming process.

$S = 0.0185 \qquad R - Sq = 80.48\%$

$R - Sq_{(adj)} = 68.77\% \qquad R - Sq_{(Pred)} = 20.13\%$

A proper selection of forming process parameters can be developed to refer in useful works for industries (Kim et al., 2001; Pereira et al., 2013; Golovashchenko et al., 2011).

Figure 11 Main effects plot for S/N ratio (see online version for colours)

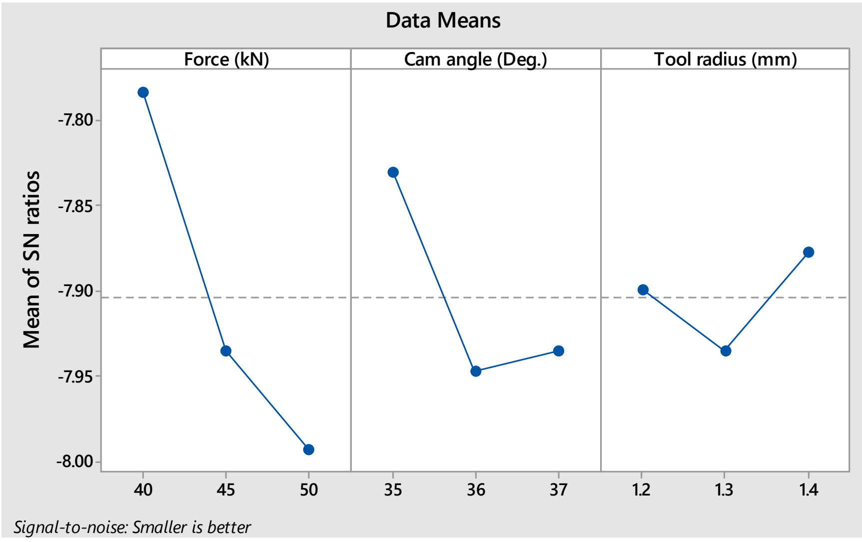


Table 10 Coefficients of regression

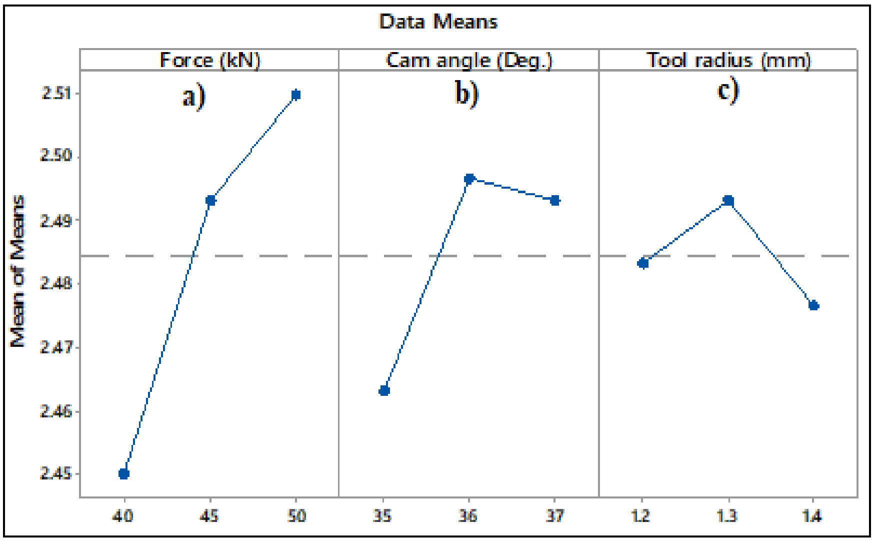
Predictor	*Coef*	*SE coef*	*T*	*P*
Constant	1.726	0.282	6.12	0.002
Force	0.006	0.001	4.18	0.009
Cam angle	0.013	0.007	1.76	0.139
Tool radius	–0.016	0.075	–0.22	0.835

As seen from the above analysis force, cam angle and tool radius are the vital process parameters, which have the greatest influence on the process. If the force increases compared to its optimal value, the depth of the component also increases which leads to the development of crack. Conversely, optimal cam angle causes translation of force from vertical to horizontal direction also plays the vital role for increasing the efficiency of the process and maintaining the required depth. Tool radius also concerns with a change in depth and formation of a crack. Variation of the said parameter may cause the deviation from the defined geometry of the rod.

9 Result and discussions

As per Taguchi analysis L_9 OA, the measured result (quality characteristics i.e., depth) is converted in to S/N ratio for each experimental conditions. The effect of each operating parameter is predicted based on S/N ratio analysis (Raj and Radhika, 2017). The standard S/N ratio for each factor level shows the relative effect of the various factors on quality characteristics (depth) during the forming process. Minitab-17 software is used to analyse the process by Taguchi method based on 'smaller is better' approach. Smaller depth is suitable to avoid the crack generation during grooving operation of the stated component. As per this approach, the optimum parameters for the grooving process are suggested based on mean of S/N ratio. Figure 12 shows the main effects plot for means where minimum value shows the optimum value of parameters for the respective process. From the S/N analysis and main effects plot of means the effect of process parameters are investigated and explained.

Figure 12 Main effects plot for means (see online version for colours)



9.1 *Effect of force*

The applied force for grooving operation plays a vital role for developing the exact depth of groove. The force must be accurate to avoid any deviation in shape and size of component. In present investigation prominent effect of force was observed on depth of groove. The effect can be well predicted based on mean effects plot obtained by Taguchi analysis as shown in Figure 12. It can be seen from Figure 12(a), if the force increases, depth of groove also increases linearly. This is attributed due to the fact that increase in force resulted extra insertion of punch in the slot of the component. Moreover, applied force must be greater than the spring force which is provided for the reversal of the follower (punch holder) and due to more deformation crack may initiate in the component.

9.2 Effect of cam angle

Cam angle is important parameter in converting vertical stroke of cam in to horizontal stroke of follower. From the main effects plot of means as shown in Figure 12(b) a trend is observed in which depth increases initially due to rise in the cam angle and decreases with further rise in cam angle. This change in cam angle causes due to change in friction angle which is responsible for transferring the force.

9.3 Effect of tool radius

Tool makes direct contact with the component during operation, which tends to deform the required shape of the component by means of applied force. Tool radius or tool thickness is responsible for obtaining the required depth of groove, which is according to force transferred from cam to follower. From the main effects plot of means as shown in Figure 12(c) a trend is observed, where depth increases initially with tool radius and decreases later by increase the same. This is due to the fact that as the radius of tool increases, corresponding arc of tool contact with the component also increases which offers more frictional resistance to insertion thus, reduces the depth.

9.4 ANOVA and significance of parameters

The ANOVA for the S/N ratio of the depth reflects the difference in average performance of each experiment. The ANOVA shows the significance of considered factors and their interactions at 95% confidence level. Therefore, based on the average S/N ratio for each factor level as illustrated earlier, the optimum forming performance for depth is obtained at level 1st for force and cam angle, level 3rd for tool radius. The optimised values of process parameters are mentioned in Table 11.

Table 11 Optimise values of process parameters

Sr. no.	*Parameter*	*Value*
1	Force (kN)	40
2	Cam angle (deg.)	35
3	Tool radius (mm)	1.4

The mathematical relationship is established for correlating the grooving depth of connecting rod and the forming parameters with the help of regression analysis and the developed model is given below.

$$\textbf{Depth} = 1.726 + 0.00633\ Force + 0.01333\ Cam\ angle - 0.0167\ Tool\ radius$$

This model will be useful for predicting the performance of process for upcoming researcher in the field. Also, the obtained results clearly indicate that the force parameter has the utmost influence followed by cam angle and tool radius on the defect formation. Variation of these parameters causes crack in work piece and improper geometry during grooving operations.

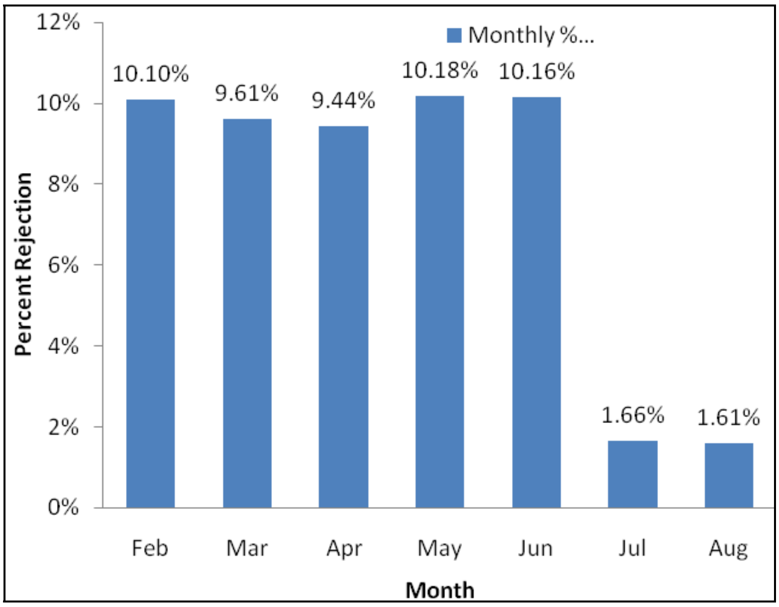
9.5 Implement the corrective measures

On the basis of above analysis the optimal parameters are found and shown in Table 11. The optimum setting (i.e., force 40 kN is adjusted through change in stroke length, Cam Angle is maintained at 35° to transfer vertical force of cam to horizontal force of follower and tool insert radius 1.4 mm instead of 1.5 mm) were implemented on the same setup and the experimentation is carried out and the corrective measures are shown in Table 12. After implementing the optimum process parameters, the rejection rate of components before and after is analysed and explained in next section.

Table 12 Corrective measures

Sr. no.	*Probable cause*	*Action plan*
1	Force required	The applied force is required to change as 40 kN instead of 45 kN by the adjustment in stroke length.
2	Tool design concern	Grooving insert radius is required to change as 1.4 mm instead of 1.5 mm.
		Cam angle is required to change by 35° instead of 37°.
		New tool is required to be made for increase the part productivity and to eliminate the quality concerns.

Figure 13 Monthly % rejection (see online version for colours)



9.6 Monthly percentage rejection

The main objective of this investigation was to increase the productivity by the same setup through decrease the number of defects observed in the component which causes the rejection. The optimised values of the parameters were validated by conducting the experiments on the same tool and rejection rate per month was calculated. The defects rate of components drastically reduces due to the use of optimum setting of process parameters obtained in the investigations. Figure 13 clearly indicates the rejection rate of incorrect setting was higher (nearly 10%) and after optimum setting it is reduced up to 1.66% i.e., around 8% reduction in rejection of components is achieved. This also leads to reduction in cycle time, which improves the productivity. These optimum values are implemented to minimise various defects observed in the component. This also reduces operator's fatigue at rework station. In future same procedure can be adopted for the similar kind of operation carried out on the identical set up, so that upcoming researcher and industrial people can be benefited further.

10 Conclusions

A good quality forming with minimum cost and time is prime concern in modern forming industries. Considering this aspect, present investigation is focused on minimising the various forming defects occurred on the hollow rod (connecting rod) used to connect recliners of the automotive seat. Work is carried out in one of the metal forming industry which was facing the problem of high rejection rate due to various defects observed in the component. This study is carried out by considering four major steps as,

1. Pareto analysis for finding the root cause of problems.
2. AHP techniques for selection of most appropriate operational parameters.
3. Taguchi analysis for optimisation of process parameters and selecting the best ranges of each parameter.
4. Validating the obtained results with actual process.

From the above analysis the major conclusions are drawn which are summarised as follows,

- As per the number of defects observed in connecting rod, the major intensity of defect i.e., inaccurate square forming was selected from the Pareto analysis.
- Critical analysis of the various effective parameters is carried out using AHP technique and three parameters (force, grooving tool insert radius and cam angle) are selected for further optimisation.
- The significant process parameters are optimised using Taguchi analysis.
- From ANOVA and S/N ratio analysis the optimised value of each process parameters for minimisation of defects are, force = 40 kN, grooving insert radius = 1.4 mm and cam angle = 35°.

By using these optimised values the total percentage rejection was reduced up to 1.66%. The solution for defect free process and change in setup is suggested to reduce the cost of rework. The same course of action can be followed for the identical set up by the similar type of methodology to overcome the problems of rejections by defects, ultimately the productivity of the firm increases.

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