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Research paper

Design Process Optimization of Lower Arm Assembly Suspension

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Abstract

Metal stamping process is a process that converts blank sheet metal into complex shapes of component and parts with high dimensional accuracy at very short cycle time. Sheet metal stamping process involves upper and lower die. The upper part, or 'ram', uses gravity to fall upon the lower part, or 'base', of the press. A press operator loads a sheet metal blank into the press machine while the press is in the open position. Today, most factories require the press operator to ensure everything and everybody is clear of the press. Once safety has been considered, the operator simply presses a button and the ram falls upon the base. At the final process, the product will form into parts needed. Lower arm parts were identified to study the defect that contributes to the problem in the line production. In order to achieve the required shape at the final process, the best lower design and optimal condition of the stamping process needs to be achieved. This can be done experimentally by manipulating the operating conditions, machine set-up and tooling modifications. Therefore, this study focuses on optimization of the process parameter and introduction of a new lower arm design.

Keywords: *Lower arm; Metal stamping; Optimization.*

1. Introduction

The lower arm assembly suspension part of a vehicle or also called control arm is shown in Fig. 1. It is a part of a vehicle's suspension system that improves the safety of the driver when driving as well as making the driving process more contented and comfortable on the road. Lower arm contributes in safeguarding and ensuring the driving process to be smoother and to control the vehicle as well.

Fig. 1: Lower Arm Assembly Suspension Part

This control arm is the main part of the independent suspension system where it is a system that connects the chassis of a vehicle to its wheel hub. The system controls the position of the outboard end in a single degree of freedom and to maintain its radial distance requires the inboard or known as chassis. Chassis is usually attached by a single pivot and is typically via a rubber bushing. The single bushing job does not control the arm from moving back and forth and it is not moving at its will due to the limitation of the separate link or radius rod. It is for the upper and lower arm to support the springs and the shock absorbers. This arrangement helps preventing the lateral movements of the spring.

The role of control arms is to govern the motion of the wheels to make it move coordinately with the body of the vehicle. The role of the control arm is absorbing the impact on the road in line with the role of shock that is to get a grip of everything. This control arm is very important, especially to balance and reduce the impact of the car if it is going to go through a bump. This is due to the fact that the control arm is able to move up and down when it hits something to reduce its weight. This helps in making sure that the bottom of the tire to be in its place during the impact. The act of allowing a vehicle to turn its pivot and wheel is closely related to the control arms. This is because of the character of the control arms that link the suspension of a car to its actual frame. Both of it are linked by the help of a component named as brushings that attach the suspension through a part known as the ball joint. As a result, the suspension of the car, the actual frame and the tire are connected [1].

Sheet metal stamping is one of the most important metalworking processes in aviation, aerospace and automobile. This process is widely used to produce structural stamping parts, such as motor vehicle bumpers. Sheet metal stamping is a much-preferred process in automotive industry as complex shapes of automotive components could be produced with precise dimensional accuracy at a very short period of time [2,3].

The word "die" is a term used to determine the tooling used to produce the stamped parts. A set of die usually consists of a male and female part in order to produce shaped stamping. The male and female components work in opposition to both punch holes in the stock. The upper half of the set of die, which may either be male or female, is mounted and pressed, delivering the stroke action. The lower half is attached to an intermediate bolster plate that in turn is secured to the press bed. The use of guide pins in the set is to ensure alignment of the upper and lower halves of the die set [4].

The automotive industry demands high productivity, improvements and unit cost reduction in order to compete with the other players. The days of 'a simple washer to a very complicated fender, in all plant stamping faculty' are gone. In-house manufacturing facilities preferably produce only limited number of major car panels [5]. The introduction of advanced materials also plays important role in stamping process. The industrial demand has led to an increase in the use of advanced materials, among those being high strength steel (SPFH590). However, the greater strength achieved is at the expense of reduced formability as well as an increase in defect rate. This 'deviation' from the desired shape is associated with longer time consummation and operational cost. To achieve a favored outcome in the component production, the most optimal stamping process has to be attained. This can be done experimentally by manipulating the operating conditions, machine set-up and tool modifications. However, this trial and error approach can prove to be costly, as production would also be interrupted in the process.

Major defects could happen during sheet metal stamping [2,3]. Producing a high-quality automotive body is challenging, as they are comprised of one or more components, each having its features that have their very own dimensions. The quality of the final product in the manufacturing industry, especially in the sheet metal forming process depends on parameters such as blank material used, blank holder force, tool design, lubrication and material properties [6]. One of the typical defects in the sheet metal stamping process is when the material parameters influence the stress and strain fields directly, and then further influence the springback after unloading [7,8].

Springback is the geometric change made to a part at the end of the forming process when the part has been released from the forces of the forming tool. Upon completion of sheet metal forming, deep-drawn and stretch-drawn parts spring back and thereby affect the dimensional accuracy of a finished part. The final form of a part is changed by the springback, which makes it difficult to produce the part. As a result, the manufacturing industry is faced with some practical problems [4].

Springback, also known as elastic recovery, is the result of metal that tends to return to its original shape after undergoing compression and tension (stretching). All metals have what is called an elastic limit. All metals are like elastic bands, in that it can be bend or roll to a certain point, but the metals will return to their original shape. In rolling a work piece, the inside radius is squeezed together or forced into compression and the outside bend radius is forced into tension or stretched. When the pinch roll tension is released, the work piece relaxes and opens up slightly [9].

Design of Experiments is the design of any task that aims to describe the variation information under conditions that can be concluded through hypothesis. DOE aims to predict the outcome values or parameters. It can be also said as the "predictor variables". A slight change in one or more values can result in changes of the outcome variables that are termed as "output variables". DOE can create multiple variables at one condition of such surface body. But not all the variables are a useable factor when conducting experiments. It can be said DOE is a platform for which to determine factors or values for the surface body but does not necessarily mean all the factors are useable. In order to avoid such matter, a research surface method is needed to be used and, in this project, the selected method is the Box-Behnken design method.

Response surface methodology (RSM) is usually used for empirical model building, which is a collection of mathematical and statistical techniques. The design of experiments was done carefully with one aim in mind that is to optimize a response (output variable). The response was influenced by several variables (input variables). A series of tests which is also known as runs, was aimed to identify the motives for changes in the output response in where the input variables were tempered beforehand. This is what an experiment is. The use of RSM is to optimize the design and is focused at reducing the cost of expensive analysis methods such as finite element method or CFD analysis and their associated numerical noise.

To help visualize the shape of the response surface, graphical representation were used, either in three dimensional space or contour plots. Curves of constant response drawn in the xi, xj plane are also known as Contours. A specific height of the response surfaces tallies with each of the contour.

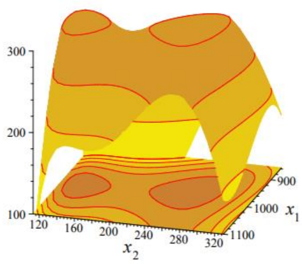


Fig. 2: Example of 3-D Response Surface Methodology

The Box-Behnken design does not cover an embedded factorial or fractional factorial design, which is a stand-alone quadratic design. At the midpoints of the edges of the process space and at the centre, the treatment combinations were made in this design. 3 levels are required from each factor and the designs can be used over and over again (or near rotatable). When being compared to central composite designs, the design has restricted capability for orthogonal blocking.

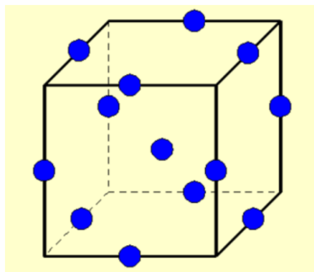


Fig. 3: Example of a Box-Behnken Design for Three Factors

Box-Behnken design was incomplete at three-levels of factorial designs by merging into two-levels of factorial designs with unfinished block designs in an exact style. Box-Behnken design was introduced because as the parameters grows, there will be a lot of wastage. The design is aimed to limit the sample size as the number of parameters grows. The sample size is kept to a value that is sufficient for the estimation of the coefficients in a second degree least squares approximating polynomial. A block of samples conforming to two levels of factorial design was repeated over different sets of parameters that are focused in this design. The parameters that are not used in the factorial designs stays at their average level throughout the block. The rotatability criteria were chosen depending on the number of parameters that the design meets either exactly or the type (full or fractional), the size of the factorial, and the number of blocks that are assessed and evaluated. To recognize if an experimental design is rotatable, the predicted response at any point is a function of the distance from the central point alone that varies.

2. Box-Behnken Design

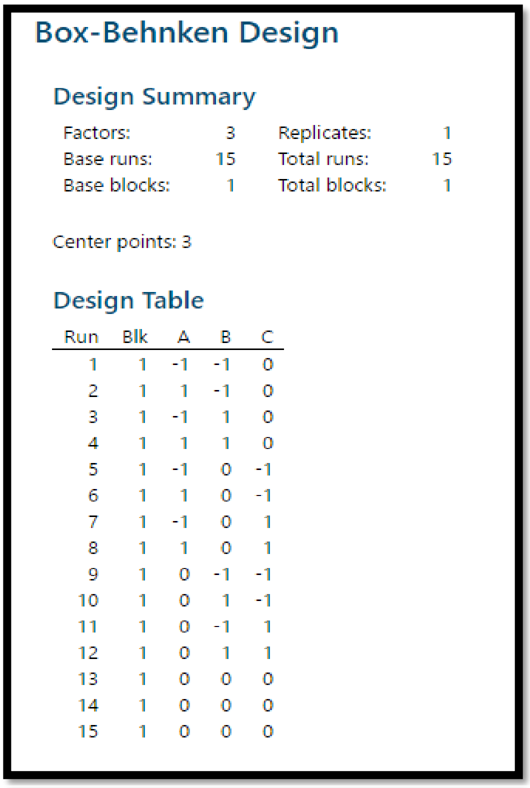
The parameters used for the projects are shown in Table 1.

Table 1: Material for the lower arm: High Strength Steel (SPFH590)

Die radius of the punch (mm)		
58.5	58.6	58.7
Spring's Elasticity (Nm)		
3100	3150	3200
Height of the die punch (mm)		
120	170	255

These parameters are determined by using the Design of Experiments (DOE) where there can be a full factor that exist which means so many parameters involved but may not be significant for or be a waste factor. Thus, the parameters are filtered by the Box-Behnken design to determine which factors can be used instead of using the full factor. Then, it would select only 3 factors that can be used and measured.

Box-Behnken design as shown in Fig. 4 which can be found from the Minitab software. From the result of the experiment, the data will be analyzed with Box-Behnken design in order to determine the best process parameter for reduction of springback effect. Every data will be evaluated precisely in order to achieve the most accurate result. There will be a total of 3 factors that will be used with three values under each factor. DOE will identify the most significant parameters to optimize springback that include any single factor or the interaction or combination of process parameters.


Box-Behnken Design

Design Summary

Factors:	3	Replicates:	1
Base runs:	15	Total runs:	15
Base blocks:	1	Total blocks:	1

Center points: 3

Design Table

Run	Blk	A	B	C
1	1	-1	-1	0
2	1	1	-1	0
3	1	-1	1	0
4	1	1	1	0
5	1	-1	0	-1
6	1	1	0	-1
7	1	-1	0	1
8	1	1	0	1
9	1	0	-1	-1
10	1	0	1	-1
11	1	0	-1	1
12	1	0	1	1
13	1	0	0	0
14	1	0	0	0
15	1	0	0	0

Fig. 4: Design table of Box-Behnken Design

3. Results and Discussion

The example of experimental data collected is listed below. The test consists of parameters of spring elasticity, die radius and height of the punch.

Die radius: 5.6mm
Spring elasticity: 3200Nm
Height of the punch: 120mm

Fig. 5: Experimental Lower Arm Assembly Suspension Part

Table 1 shows the diameter of the lower arm and corresponding height of springback based on three parameters previously mentioned. Box-Behnken Design analysis of data in Table 1 was performed using Minitab.

Table 1: Diameter of the lower arm after punched under specific parameters

Test 1 (mm)			
Trial	Inside Diameter	Outside Diameter	Height of the springback
A	57.04	58.64	14.80
B	56.68	58.68	14.15
C	56.68	58.60	14.91
D	57.04	58.63	15.85
Test 2 (mm)			
A	58.26	58.83	14.90
B	58.10	58.62	14.30
C	57.83	58.66	14.89
D	58.08	58.82	15.72
Test 3 (mm)			
A	58.12	58.87	15.01
B	58.10	58.70	14.32
C	57.36	58.65	14.93
D	58.14	58.77	15.84

Fig 6, 7 and 8 show Box-Behnken in response to surface design, available surface design and options for randomize runs respectively. Based on the Fig 6, 7 and 8, the analysis began by choosing the Stat tab and DOE menu. The number of available surface design response helps to create a non-randomize run which means that all the runs are kept in the same sequence throughout all the experiments.
All the result was plotted on the worksheet on the Minitab under the Box-Behnken Design. The analyses were performed between the experimental and the theoretical value of the project. The theoretical value would be at an absolute value to make the comparison. Thus, it can ensure the result of the project can achieve the standard burring punch force under such specific parameters.

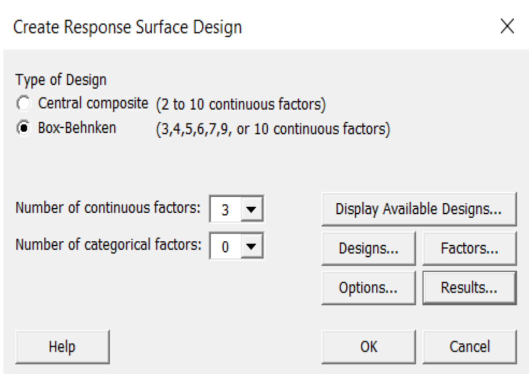


Fig. 6: Box-Behnken in Response Surface Design

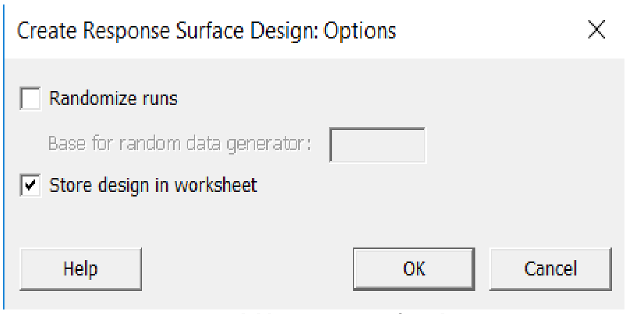
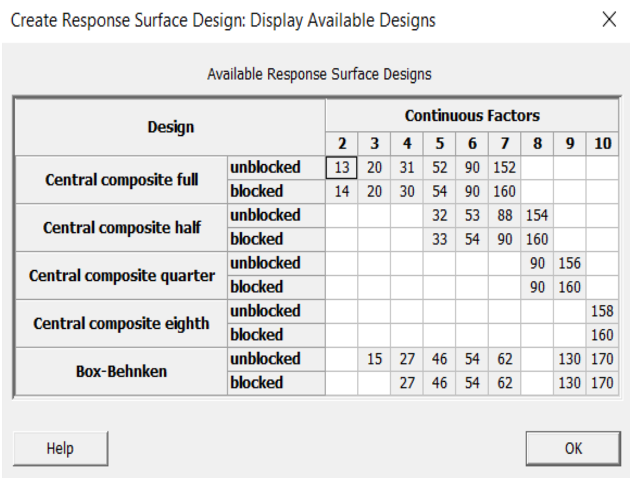


Fig. 7: Available response surface design



Design		Continuous Factors								
		2	3	4	5	6	7	8	9	10
Central composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

Fig. 8: Options for Randomize Runs

Based on the results Box-Behnken Design method optimized the process of designing of the lower arm assembly suspension part.

4. Conclusion

This paper discusses on how to use the Box-Behnken Design in designing a lower arm assembly suspension part. Many parameters were considered in order to meet its standard, which is 5kN force on the burring hole of the lower arm by adjusting the parameters of the burring punch. In addition, the spring elasticity also affects the burring hole that could be related to the springback that exists after the punch. With the Box-Behnken Design, the optimization process in the lower arm assembly suspension part could be determined.

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