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Formulation of a Model and Analysis of Mechanical Timer Parameters by Using Response Surface Method in MINITAB

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Abstract :- Aim of this paper is to development methodology in MINITAB for design parameter analysis of mechanical timer unit which will give us required time delay, by forming mathematical model .Design parameters analysis was carried out in MINITAB using RSM to identify critical design parameters. It is effective to use the orthogonal arrays in fractional factorial designs. MINITAB offers four types of designed experiments: factorial, response surface, mixture, and Taguchi (robust). The steps follow in MINITAB to create, analyze, and graph an experimental design are similar for all design types. After conducting the experiment and enter the results, MINITAB provides several analytical and graphing tools to help to understand the results. While this paper demonstrates the typical steps for creating and analyzing a factorial design, These steps can be apply to any design which created in MINITAB to identify critical design parameters.

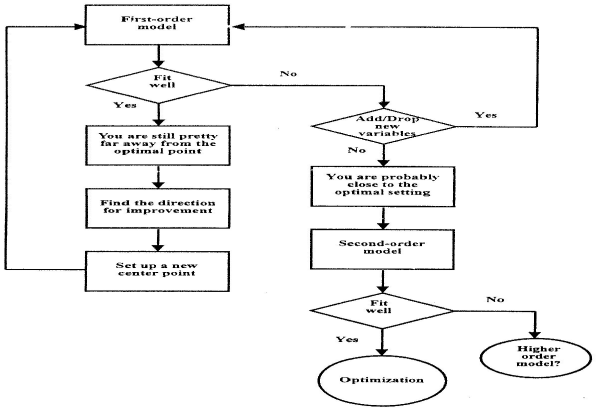
Keywords :- Response surface methodology, Orthogonal array, Taguchi Array, MINITAB

I. INTRODUCTION

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process. An easy way to estimate a first-degree polynomial model is to use a factorial experiment or a fractional factorial design. This is sufficient to determine which explanatory variables have an impact on the response variable(s) of interest. Once it is suspected that only significant explanatory variables are left, then a more complicated design, such as a central composite design can be implemented to estimate a second-degree polynomial model, which is still only an approximation at best. However, the second-degree model can be used to optimize (maximize, minimize, or attain a specific target for).Practical concerns.Response surface methodology uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality. In practice, both the models and the parameter values are unknown, and subject to uncertainty on top of ignorance. Of course, an estimated optimum point need not be optimum in reality, because of the errors of the estimates and of the inadequacies of the model. Nonetheless, response surface methodology has an effective track-record of helping researchers improve products and services: For example, Box's original response-surface modelling enabled chemical engineers to improve a process that had been stuck at a saddle-point for years. The engineers had not been able to afford to fit a cubic three-level design to estimate a quadratic model, and their biased linear-models estimated the gradient to be zero. Box's design reduced the costs of experimentation so that a quadratic model could be fit, which led to a (long-sought) ascent direction.[1][2]

Fig- 1 Flow chart of RSM

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II EXPERIMENTAL

a) Identifying important parameters

From the literature and the previous work [6] done , among many independently controllable primary and secondary process parameters affecting the time delay, the primary process parameters viz Angle(*A*), Gear ratio(*B*), and Pallet weight (C) were selected as process parameters for this study. Angle(*A*), Gear ratio(*B*), and Pallet weight (C) are the primary parameters contributing to the required time delay

b) Orthogonal arrays Experiment

A lot of factors are often taken up at the same time at the early stage of the problem solving. The experiment frequency increases in the factorial experiment on which it experiments by all the level combinations when the number of factors taken up in the experiment increases. Then, the obtaining necessary information can be done by an experiment frequency that is less than the factorial experiment by providing experimental conditions by using the table that is called an orthogonal array. The experimental design is widely used in various fields including industry, medicine and psychology. The fractional factorial designs are effective when the number of factors considered is large and when it is difficult to experiment all the combinations. It is effective to use the orthogonal arrays in fractional factorial designs. The orthogonal arrays which will be used changes according to the number of factors and the number of levels considered. Two-level orthogonal arrays such as L_8 and L_{16} are used when factors of two levels are considered. Three-level orthogonal arrays such as L_9 and L_{27} are used when factors of three levels are considered. Their use and subsequent analysis are almost the same, but there is great difference in degrees of freedom. In three-level orthogonal arrays, the degree of freedom a two factor interaction is four. Two factor interactions will appear across two columns. Due to this reason, the number of factors that can be considered is limited. Actually, there are only two prepared linear graphs for L_{27}.

L_{27} orthogonal array

In the factorial experiment, it is necessary to experiment by combining the levels of the factor taken up all. The total experiment frequency increases rapidly when the number of factors increases, and the inconvenience in the experiment is caused.. When the levels of all the factor taken up are three, the three-level orthogonal array is used.

C) Development of mathematical model.

1. Response surface methodology

Response surface methodology(RSM) is a collection of mathematical and statistical technique useful for analyzing problems in which several independent variables influence a dependent variable or response and the goal is to optimize the response[14]. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Eq.(1). Then these factors can be thought of as having a functional relationship or response as follows:

$Y=\Phi(x1, x2, \ldots, xk)\pm er$ (1)

Between the response Y and $x1, x2, \ldots, xk$ of k quantitative factors, the function Φ is called response surface or response function. The residual er measures the experimental errors. For a given set of independent variables, a characteristic surface is responded. When the mathematical form of Φ is not known, it can be approximate satisfactorily within the experimental region by polynomial. In the present investigation, RSM has been applied for developing the mathematical model In applying the response surface methodology, the independent variable was viewed as a surface to which a mathematical model is fitted. The second order polynomial (regression) equation used to represent the response surface Y is given by[15]

$Y = b0 + \Sigma bi\, xi + \Sigma bii\, xi + \Sigma bij\, xi\, x\, j + e$ (2)

and for three factors, the selected polynomial could be expressed as

$\sigma = b0 + b1(N) + b2(S) + b3(F) + b11(N2) + b22(S2) + b33(F2) + b12(NS) + b13(NF) + b23(SF)$ (3)

In order to estimate the regression coefficients, a number of experimental design techniques are available. In this work,

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central composite face centred design surfaces very accurately

d) Formulation of Response Surface Model by MINITAB16 software

1. *Response Surface Regression: T (Time) versus A (angle), B (gear ratio), C (P Wt)*

Before you use MINITAB, you need to determine what design is most appropriate for your experiment. Choosing your design correctly will ensure that the response surface is fit in the most efficient manner. MINITAB provides central composite and Box-Behnken designs. When choosing a design you need to identify the number of factors that are of interest. determine the number of runs you can perform ensure adequate coverage of the region of interest on the response surface. The next step is to fit the quadratic model. The quadratic model allows detection of curvature in the response surface.

The following terms cannot be estimated, and were removed.
B (gear ratio)*C (P Wt)
The analysis was done using uncoded units.
Estimated Regression Coefficients for T (Time)

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Sr.No	A (angle)	B (gear ratio)	C (P Wt)	T (Time)	StdOrder	RunOrder	Blocks	PtType
1	313.5	3807.4	0.47	62.8	1	1	1	1
2	313.5	3807.4	0.47	62.8	2	2	1	1
3	313.5	3807.4	0.47	62.8	3	3	1	1
4	313.5	4007.8	0.42	58	4	4	1	1
5	313.5	4007.8	0.42	58	5	5	1	1
6	313.5	4007.8	0.42	58	6	6	1	1
7	313.5	4208.19	0.45	61.2	7	7	1	1
8	313.5	4208.19	0.45	61.2	8	8	1	1
9	313.5	4208.19	0.45	61.2	9	9	1	1
10	330	3807.4	0.42	59.5	10	10	1	1
11	330	3807.4	0.42	59.5	11	11	1	1
12	330	3807.4	0.42	59.5	12	12	1	1
13	330	4007.8	0.45	60	13	13	1	1
14	330	4007.8	0.45	60	14	14	1	1
15	330	4007.8	0.45	60	15	15	1	1
16	330	4208.19	0.47	65.8	16	16	1	1
17	330	4208.19	0.47	65.8	17	17	1	1
18	330	4208.19	0.47	65.8	18	18	1	1
19	346.5	3807.4	0.45	63	19	19	1	1
20	346.5	3807.4	0.45	63	20	20	1	1
21	346.5	3807.4	0.45	63	21	21	1	1
22	346.5	4007.8	0.47	64.7	22	22	1	1
23	346.5	4007.8	0.47	64.7	23	23	1	1
24	346.5	4007.8	0.47	64.7	24	24	1	1
25	346.5	4208.19	0.42	52	25	25	1	1
26	346.5	4208.19	0.42	52	26	26	1	1
27	346.5	4208.19	0.42	52	27	27	1	1

Table I shows the L_{27} orthogonal array

Term Coef SE Coef T P
Constant 1931.63 0.000000 * *
A (angle) 0.11 0.000000 * *
B (gear ratio) -0.64 0.000000 * *
C (P Wt) -2829.25 0.000000 * *
A (angle)*A (angle) -0.01 0.000000 * * B (gear ratio)*B (gear ratio) 0.00 0.000000 * *
C (P Wt)*C (P Wt) 211.17 0.000000 * *
A (angle)*B (gear ratio) -0.00 0.000000 * *
A (angle)*C (P Wt) 8.48 0.000000 * *

S = 0 PRESS = 0
R-Sq = 100.00% R-Sq(pred) = 100.00% R-Sq(adj) = 100.00%
The equation form from above analysis is given as below,

Equ.: $T = 1931.63 + 0.11A - 0.64B - 2829.25C - 0.01A^2 + 211C^2 + 8.48AC$ ----------[Eq 1]

2*) Collecting and Entering Data*

After you create your design, you need to perform the experiment and collect the response (measurement) data.

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To print a data collection form, follow the instructions below. After you collect the response data, enter the data in any worksheet column not used for the design.

Analysis of Variance for T (Time)

Source	DF	Seq SS	Adj SS	AdjMSF	P
Regression	8	410.447	410.447	51.3058	* *
Linear	3	310.821	37.877	12.6257	* *
A (angle)	1	2.645	0.000	0.0002	* *
B (gear ratio)	1	19.845	0.363	0.3629	* *
C (P Wt)	1	288.331	1.217	1.2174	* *
Square	3	13.519	37.184	12.3947	* *
A (angle)*A (angle)	1	13.202	13.202	13.2017	* *
B (gear ratio)*B (gear ratio)	1	0.202	0.868	0.8682	* *
C (P Wt)*C (P Wt)	1	0.116	0.001	0.0013	* *
Interaction	2	86.107	86.107	43.0533	* *
A (angle)*B (gear ratio)	1	85.127	0.006	0.0056	* *
A (angle)*C (P Wt)	1	0.980	0.980	0.9797	* *
Residual Error	18	0.000	0.000	0.0000	
Pure Error	18	0.000	0.000	0.0000	
Total	26	410.447			

Obs	StdOrder	T (Time)	Fit	SE Fit	Residual	Resid
1	1	62.800	62.800	0.000	0.000	*
2	2	62.800	62.800	0.000	0.000	*
3	3	62.800	62.800	0.000	0.000	*
4	4	58.000	58.000	0.000	0.000	*
5	5	58.000	58.000	0.000	0.000	*
6	6	58.000	58.000	0.000	0.000	*
7	7	61.200	61.200	0.000	0.000	*
8	8	61.200	61.200	0.000	0.000	*
9	9	61.200	61.200	0.000	0.000	*
10	10	59.500	59.500	0.000	-0.000	*
11	11	59.500	59.500	0.000	-0.000	*
12	12	59.500	59.500	0.000	-0.000	*
13	13	60.000	60.000	0.000	0.000	*
14	14	60.000	60.000	0.000	0.000	*
15	15	60.000	60.000	0.000	0.000	*
16	16	65.800	65.800	0.000	0.000	*
17	17	65.800	65.800	0.000	0.000	*
18	18	65.800	65.800	0.000	0.000	*
19	19	63.000	63.000	0.000	0.000	*
20	20	63.000	63.000	0.000	0.000	*
21	21	63.000	63.000	0.000	0.000	*
22	22	64.700	64.700	0.000	-0.000	*
23	23	64.700	64.700	0.000	-0.000	*
24	24	64.700	64.700	0.000	-0.000	*
25	25	52.000	52.000	0.000	0.000	*
26	26	52.000	52.000	0.000	0.000	*
27	27	52.000	52.000	0.000	0.000	*

Predicted Response for New Design Points Using Model for T (Time)

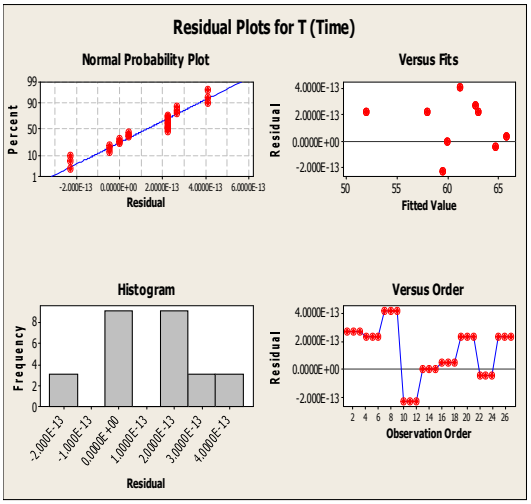
Point	Fit	SE Fit	95% CI	95% PI
1	62.8	0	(62.8, 62.8)	(62.8, 62.8)
2	62.8	0	(62.8, 62.8)	(62.8, 62.8)
3	62.8	0	(62.8, 62.8)	(62.8, 62.8)
4	58.0	0	(58.0, 58.0)	(58.0, 58.0)
5	58.0	0	(58.0, 58.0)	(58.0, 58.0)
6	58.0	0	(58.0, 58.0)	(58.0, 58.0)
7	61.2	0	(61.2, 61.2)	(61.2, 61.2)
8	61.2	0	(61.2, 61.2)	(61.2, 61.2)
9	61.2	0	(61.2, 61.2)	(61.2, 61.2)
10	59.5	0	(59.5, 59.5)	(59.5, 59.5)
11	59.5	0	(59.5, 59.5)	(59.5, 59.5)
12	59.5	0	(59.5, 59.5)	(59.5, 59.5)
13	60.0	0	(60.0, 60.0)	(60.0, 60.0)
14	60.0	0	(60.0, 60.0)	(60.0, 60.0)
15	60.0	0	(60.0, 60.0)	(60.0, 60.0)
16	65.8	0	(65.8, 65.8)	(65.8, 65.8)
17	65.8	0	(65.8, 65.8)	(65.8, 65.8)
18	65.8	0	(65.8, 65.8)	(65.8, 65.8)
19	63.0	0	(63.0, 63.0)	(63.0, 63.0)
20	63.0	0	(63.0, 63.0)	(63.0, 63.0)
21	63.0	0	(63.0, 63.0)	(63.0, 63.0)
22	64.7	0	(64.7, 64.7)	(64.7, 64.7)
23	64.7	0	(64.7, 64.7)	(64.7, 64.7)
24	64.7	0	(64.7, 64.7)	(64.7, 64.7)
25	52.0	0	(52.0, 52.0)	(52.0, 52.0)
26	52.0	0	(52.0, 52.0)	(52.0, 52.0)
27	52.0	0	(52.0, 52.0)	(52.0, 52.0)

III. GRAPH WINDOW OUTPUT:-

a) Residual Plots

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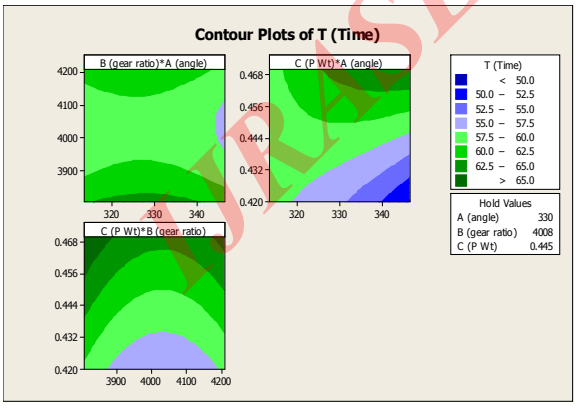
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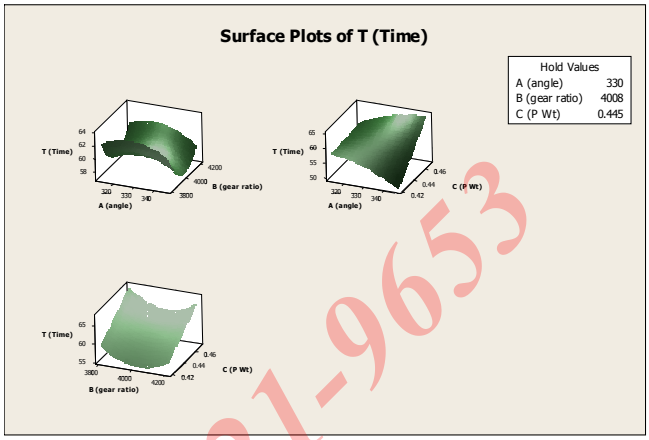
b) Plotting the Response Surface.

You can use Contour/Surface (Wireframe) Plots to display two types of response surface plots: contour plots and surface plots (also called wireframe). These plots show how are response variable relates to two factors based on a model equation .Contour and surface plots are useful for establishing desirable response values and operating conditions. In a contour plot, the response surface is viewed as a two-dimensional plane where all points that have the same response are connected to produce contour lines of constant responses surface plot displays a three-dimensional view that may provide a clearer picture of the response surface. The illustrations below compare these two types of plots.

C) Contour Plot.



d) Surface Plot



IV. OPTIMIZATION OF MODEL

a) Optimising parameters

Contour plots show distinctive circular shape indicative of possible independence of factors with response. A contour plot is produced to visually display the region of optimal factor settings. For second order response surfaces, such a plot can be more complex than the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point by identifying whether the stationary point found is a maximum response or minimum response or a saddle point. To classify this, the most straightforward way is to examine through a contour plot. Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. If a contour patterning of circular shaped contours occurs, it tends to suggest independence of factor effects while elliptical contours as may indicate factor interactions.

Response surfaces have been developed for both the models, taking two parameters in the middle level and two parameters in the *X* and *Y* axis and response in *Z* axis. The response surfaces clearly reveal the optimal response point. RSM is used to find the optimal set of process parameters that produce a maximum or minimum value of the response. In the present investigation the process parameters corresponding to the maximum tensile strength are considered as optimum (analyzing the contour graphs and by solving Eq.(4)). Hence, when these optimized process parameters are used, then it will be possible to attain the maximum tensile strength.

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b) *Response Optimization*

Parameters	Goal	Lower	Target	Upper	Weight	Import
T (Time)	Target	59	60	61	1	1

Global Solution

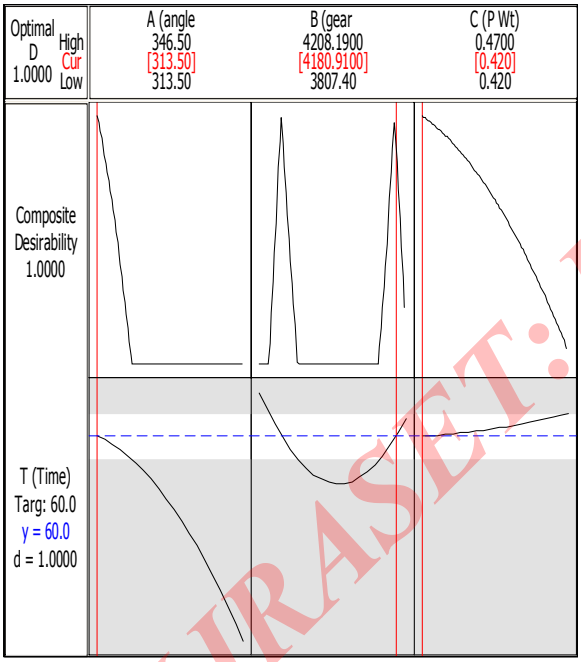
A (angle) = 313.5
B (gear rati = 4180.91
C (P Wt) = 0.42

Predicted Responses

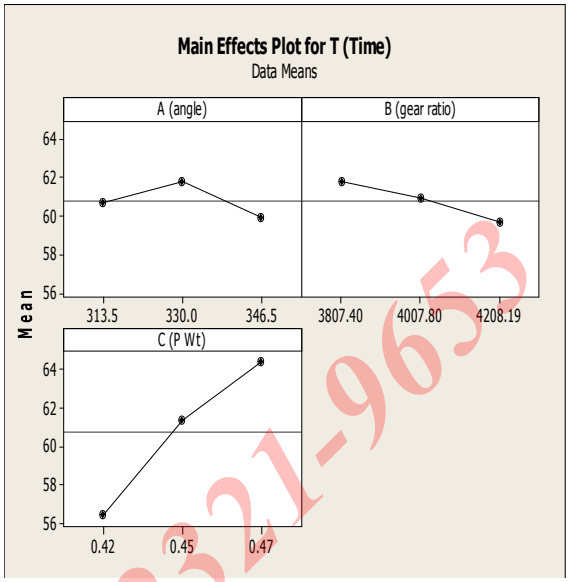
T (Time) = 60, desirability = 1.000000

Composite Desirability = 1.000000

C) *Optimization Plot*



Main Effects Plot



The same steps are followed for another six design parameters in two sets. The other two equations and main effects plot for these two sets of parameters are given below.

Readings for Other Two Sets

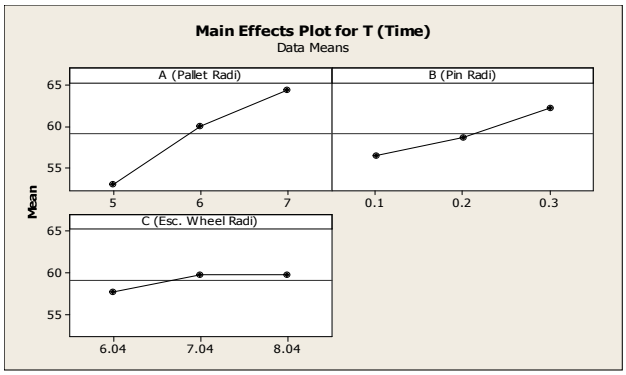
Parameter Set 2:

A: Pallet Radius
B: Pin Radius
C: Escarpment Wheel Radius

The equation form for above parameter is given below

$T = -69.6938 + 21.6833A + 20.6667B + 11.240C - 1.283A^2 + 66.6667B^2 - 0.7167C^2 - 3.1667AB$

Main effects plot for these parameters is give below,



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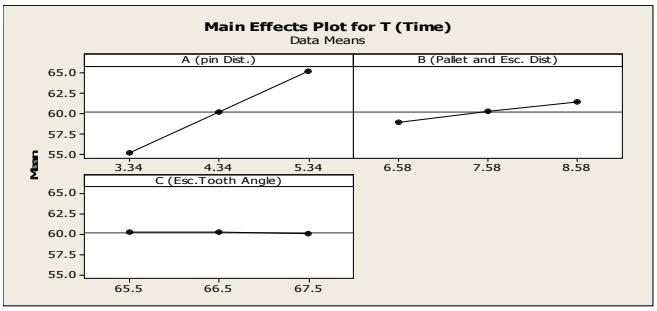
Parameter Set 3:

A: Pallet to pin distance
B: Distance between pallet and escapement wheel
C: Tooth angle for escapement wheel

The equation form for above parameter is given below

$T = 1638.62 + 8.45A + 4.12B - 48.87C - 0.02A^2 - 0.07B^2 + 0.37C^2 - 0.43AB$

Main effects plot for these parameters is give below,



V) RESULT & CONCLUSION:-

The response surface methodology analysis has been reviewed. RSM can be used for the approximation of both experimental and numerical responses. Two steps are necessary, the definition of an approximation function and the design of the plan of experiments .From the experimentation we got the global value (60 min) of time by using various parameters i.e. angle, gear ratio, pallet weight, pallet radius, pin radius, escarpment wheel radius, pallet to pin distance, distance between pallet and escapement wheel and tooth angle for escapement wheel. The most effecting parameter are find out from the main effects plots for all nine parameters against Time (T).

The main effecting parameters are as follows,

A:Pallet weight
B: Pallet radius
C: Pin Radius
D: Pin Dist.

In above parameters pallet weight and pallet radius are directly proportional to each other, hence we consider next parameter for our further design study. Those parameters are

A:Pallet weight, B: Pin Radius and C: Pin Dist.

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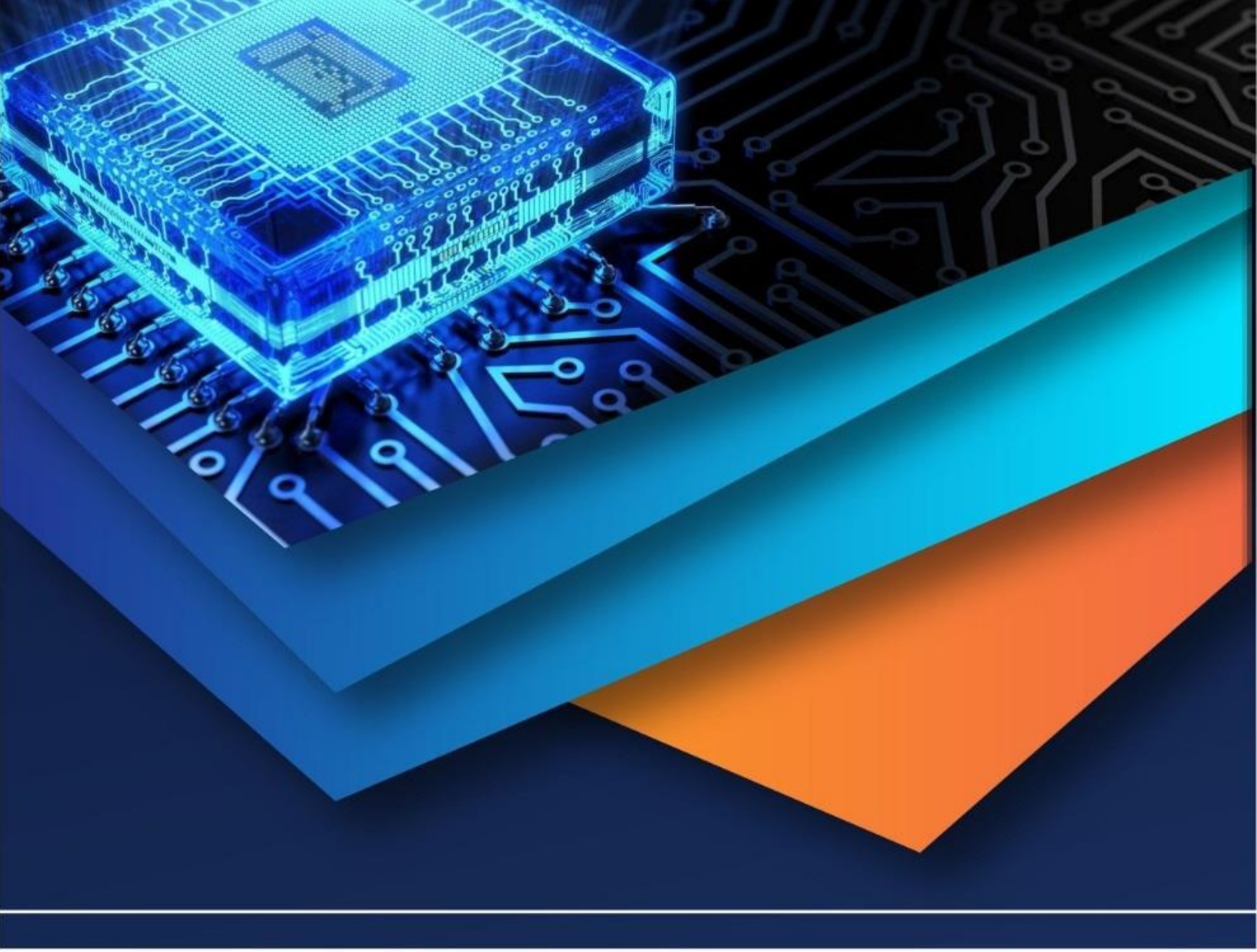
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