Analysis of Spray Gun Body using Design of Experiments

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Abstract— The optimization design of components is always one of the top concerns in industry. In this paper, we analyses the parameters of spray gun body with the application of DOE methodology, a full factorial DOE is conducted to estimate the regression model and identify the statistical significant factors. And then, with the selection of additional experimental points, response surface methodology RSM is introduced to construct the precise regression model between input variables and performance indexes. Based on that, an optimum solution that can satisfy both performance requirements are brought forward and testified.

Key words: Design of Experiments, Response Surface Methodology, p-Diagram, Transfer Functions

I. Introduction

The development of products or processes is a complex, expensive and risky multistage process, and special requirements should be considered in this process, such as consumer demands, price, operational conditions and legislation background. To develop or to optimize processes, many companies use statistical approaches, such as response surface methodology (RSM), in their research department in order to achieve the best combination of factors that will render the best characteristic of a product and or process response.

It is widely accepted that RSM is a useful tool to analyse results from many different experimental responses. In this Paper, the objectives of this review are to provide some useful information regarding mathematical modelling by using design of experiments (DOE) followed by response surface methodology, and to discuss some recent published Mathematical and Statistical Methods in design.

By using of P-Diagram to classify the variables associated with the product into inputs (M), noise factors (Z), error,design parameters (x) and output (Y).This control factors (X) will influence the output(Y) and both (X&Y) can be adjusted and controlled. However, noise factors (Z) will also influence output (Y) and cannot be significantly controlled. [1]

In case of spray gun body following diagram can be produced according to factors: [fig1]

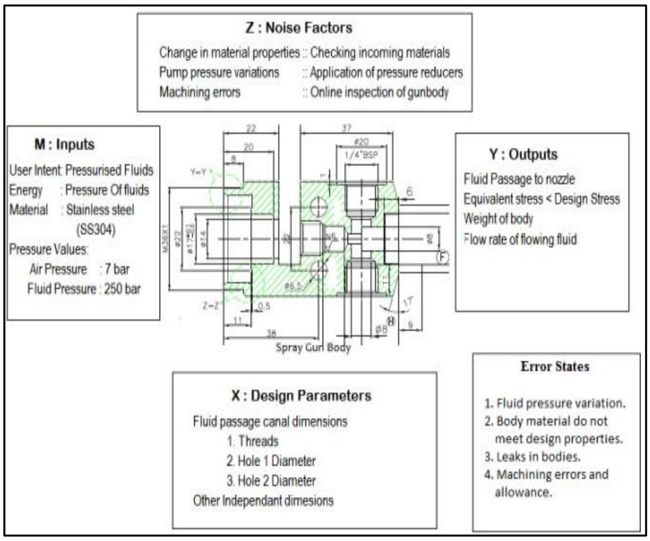

Fig. 1: P Diagram of spray gun body

II. Full Factorial DOE and ANOVA Analysis

A. *Design of Full Factorial Experiment*

In this work, Our objective is to the equivalent stress induced in body is to be limit within design stress is considered as Critical-to-Quality and Weight of the component is to optimize for targeted stress hence it is also considered s CTQ. The first step of experiment design for spray gun body is to set the values for input variables.[2,3 Considering the realistic value intervals, we assign two levels for each factor as Table 1.

Factor	Name	Lower limit	Upper limit
1	Thread	1/4"BSP	3/8" BSP
2	Vertical hole	6mm	10mm
3	Horizontal Hole	6mm	11mm

Table 1: Control factors

For the purpose of experimentation, a randomized dual-replicate orthogonal matrix, as shown in Table 1 was created in MINITAB® 18. According to orthogonal experimental design, a two-level full factorial DOE with three factors needs equal to 15 experimental runs and Simulation results are as Table 2 (randomized when conducting experiments).

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StdOrder	RunOrder	PtType	Blocks	Thread	Hole_H	Hole_V
1	1	2	1	13.1572	6	8
2	2	2	1	16.6624	6	8
3	3	2	1	13.1572	11	8
4	4	2	1	16.6624	11	8
5	5	2	1	13.1572	8.5	6
6	6	2	1	16.6624	8.5	6
7	7	2	1	13.1572	8.5	10
8	8	2	1	16.6624	8.5	10
9	9	2	1	14.9098	6	6
10	10	2	1	14.9098	11	6
11	11	2	1	14.9098	6	10
12	12	2	1	14.9098	11	10
13	**13**	**0**	**1**	**14.9098**	**8.5**	**8**
14	**14**	**0**	**1**	**14.9098**	**8.5**	**8**
15	**15**	**0**	**1**	**14.9098**	**8.5**	**8**

Table 2: Minitab for Internal Parameter

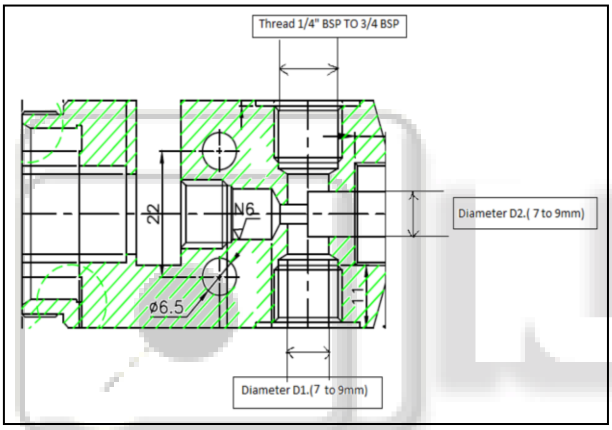


Fig. 2: For Internal Parameter

III. Finite Element Analysis for Generated Combinations

StdOrder	RunOrder	Thread	Hole_H	Hole_V	Equivalent Stress (mpa)	Weight (gm)
1	1	13.1572	6	8	143.89	442.39
2	2	16.6624	6	8	165.7	430.6685
3	3	13.1572	11	8	142.57	438.7787
4	4	16.6624	11	8	168.84	427.0535
5	5	13.1572	8.5	6	106.12	444.0575
6	6	16.6624	8.5	6	123.74	433.6553
7	7	13.1572	8.5	10	160.53	437.6563
8	8	16.6624	8.5	10	197.7	424.6072
9	9	14.9098	6	6	97.72	440.6156
10	10	14.9098	11	6	149.74	436.3974
11	11	14.9098	6	10	171.57	432.3224
12	12	14.9098	11	10	162.4	429.46268
13	**13**	**14.9098**	**8.5**	**8**	**119.92**	**435.1797**
14	**14**	**14.9098**	**8.5**	**8**	**119.92**	**435.1797**
15	**15**	**14.9098**	**8.5**	**8**	**119.92**	**435.1797**

Table 3: Eq. Stress Values using FEA

Possible combinations obtained from Minitab box-behnken design are modelled in design software i.e. creo parametric according variations in dimensions.[4] Designed models are analyzed in "ansys" and finite element analysis is performed for each combination.(table3).

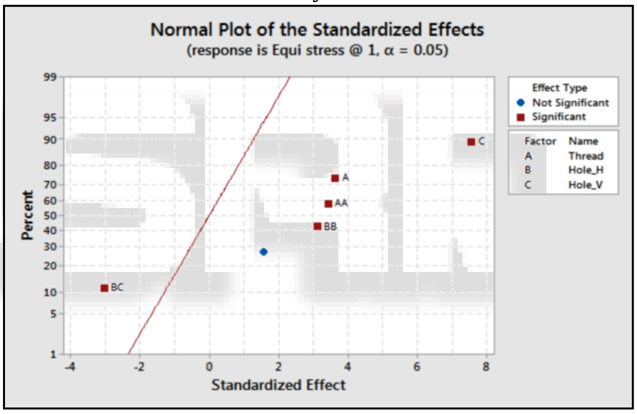
IV. Response Surface Regression Analysis

The Results of Response Surface Regression are as Table 4.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	10289.9	1714.99	16.96	0.000
Linear	3	7343.9	2447.96	24.21	0.000
Thread	1	1322.8	1322.78	13.08	0.007
Hole_H	1	249.4	249.43	2.47	0.155
Hole_V	1	5771.7	5771.68	57.07	0.000
Square	2	2010.0	1005.00	9.94	0.007
Thread*Thread	1	1181.5	1181.54	11.68	0.009
Hole_H*Hole_H	1	971.2	971.24	9.60	0.015
2-Way Interaction	1	936.1	936.05	9.26	0.016
Hole_H*Hole_V	1	936.1	936.05	9.26	0.016
Error	8	809.0	101.13		
Lack-of-Fit	6	809.0	134.84	*	*
Pure Error	2	0.0	0.00		
Total	14	11099.0			

Table 4: Analysis of Variance



A. *Constant Variance*

According to the response surface regression results, are shown in table 4 and 5. The p value in factors shows the degree of effectiveness of each term. Each factor with a p value less than 0.05 is considered as an effective factor and those with p values larger than 0.05 are regarded as ineffective ones.

V. The Optimization of the Regression Model

The regression model can be optimized with the deletion of insignificant factors. The comparison between original and optimized model is showed in Table 6.

The model is analyzed to determine the conformity of these assumptions to avoid any model inadequacies. The assumptions of normality and homoscedasticity are conformed by generating the estimated effects on Table 2.

After removal of insignificant factors from the model and comparing the parameter we obtain the transfer function which will get accurate stress value of component and minimize the weight of component. From model summary R-SQ(adj) 87.24% which predict the error is 10%.

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Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
10.0562	92.71%	87.24%	59.33%

Table 5: Model Summary

Once, all the assumptions were verified and consolidated, an experimental model explaining the behavioural relationship between all the selected geometry variables are shown in Eq. (1) and Eq. (2)

A. Transfer Function:

1) Weight:

476.68 - 1.046 Thread - 0.2365 Hole_H + 0.738 Hole_V 0.02645 Thread*Thread - 0.06013 Hole_H*Hole_H 0.02610 Hole_V*Hole_V - 0.18878 Thread*Hole_V

2) Equivalent Stress:

1159 - 165.8 Thread - 17.3 Hole_H + 39.44 Hole_V + 5.81 Thread*Thread + 2.587 Hole_H*Hole_H - 3.06 Hole_H*Hole_V

VI. The Transfer Function Using Excel

Equivalent stress values are obtained by using transfer function. This theoretical stress value is compared with stress value obtained from finite element analysis. Following table shows error.table7

StdOrder	RunOrder	Thread	Hole_H	Hole_V	Equivalent Stress (mpa)	Weight (gm)	EQ STRESS USING T/F	ERROR
1	1	13.1572	6	8	143.89	442.39	141.2884	2.6015
2	2	16.6624	6	8	165.7	430.66	167.4087	-1.7087
3	3	13.1572	11	8	142.57	438.77	152.2834	-9.7134
4	4	16.6624	11	8	168.84	427.05	178.4037	-9.5637
5	5	13.1572	8.5	6	106.12	444.05	103.7571	2.3628
6	6	16.6624	8.5	6	123.74	433.65	129.8775	-6.1375
7	7	13.1572	8.5	10	160.53	437.65	157.4771	3.0528
8	8	16.6624	8.5	10	197.7	424.60	183.5975	14.1024
9	9	14.9098	6	6	97.72	440.61	94.3425	3.3774
10	10	14.9098	11	6	149.74	436.39	135.9375	13.8024
11	11	14.9098	6	10	171.57	432.32	178.6625	-7.0925
12	12	14.9098	11	10	162.4	429.46	159.0575	3.3424
13	**13**	**14.9098**	**8.5**	**8**	**119.92**	**435.17**	125.8313	-5.9113
14	**14**	**14.9098**	**8.5**	**8**	**119.92**	**435.17**	125.8313	-5.9113
15	**15**	**14.9098**	**8.5**	**8**	**119.92**	**435.17**	125.831	-5.9113

Table 7: Comparison between T/F and FEA

VII. Optimization of Weight Using Solver Command in Excel

After verification of transfer function, stress is targeted for value of design stress i.e. 154 mpa and dimensions of inlet port thread, diameters of fluid flow passage canals are obtained. These dimensions give optimum weight of gun body for design stress

Thread	16.6624	Weight	430.3046091
Hole_H	7.531616		
Hole_V	7.814921	Equivalent Stress	153.9999999

Table 8:

Hence it is found that for equivalent stress 164mpa,thread is 3/8"BSP,diameter of vertical hole is assumed to be 8mm and diameter of horizontal hole assumed to be 7.5mm approximately.

By using above dimensions following stress and weight value is obtained by using transfer function.

Thread	16.6624	Weight	429.8961832
Hole_H	7.5		
Hole_V	8	Equivalent Stress	157.1255135

Table 9: Solver Result

After determination of final dimensions, Model is designed and finite element analysis is performed. And equivalent stress values are obtained. Figure shows finite element analysis of final design

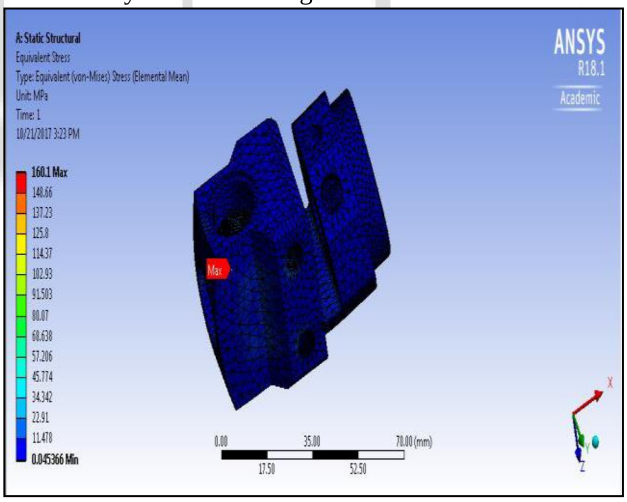

Fig. 3: Final ANSYS Model

Results							
Minimum	0. mm	4.5366e-002 MPa	-29.206 MPa	-6.935e-003 mm	-1.8067e-003 mm	-5.3674e-003 mm	1.1345 MPa
Maximum	8.4104e-003 mm	160.1 MPa	158.47 MPa	1.5247e-003 mm	1.8075e-003 mm	9.5973e-004 mm	160.1 MPa

Table 8: Result

VIII. Conclusion

In this study, the effect of three parameters namely, hole h, hole v, threads on stress and weight was investigated. To minimize weight of spray gun body without hampering flow rate & stress induced in body in order to ensure safety of product. According to the obtained results, all the above-mentioned parameters we conclude that stress was not exceeds 157 and weight of spray gun body reduced 5% . By means of analysis of variance, which shows the relationship

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between stress and weight of three parameters was obtained, that was statistically confirmed.

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