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Experimental Analysis of Vibrations in Ceiling Fan

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ABSTRACT

Vibration in ceiling fan is an important parameter for study. Total vibration is dependent on fan rotation frequency. As vibrations contribute to more power consumption, and also causes excess wear and tear resulting in bearing failure, hence it is important to reduce the vibrations. Every vibration reduction process starts with identification of vibration sources [1]. Ceiling fans are extensively used to create an indoor breeze, improve the space air distribution and hence enhance the feeling of comfort. The fan speed, diameter, number of blades, blade angle and vibrations all play an important role in deciding the vibrations. Few previous studies have investigated fan induced flow and its characteristics under different geometric and operating conditions. In this study, response surface methodology is used to predict vibration characteristics. The experiments were conducted based on the three different fans having three different blades, three room size, three different ceiling fan rod lengths three regulator knob positions and mathematical model was developed.

Key words: Response Surface Method, Ceiling Fan vibration, Optimization, MINTAB 16, L81 Array

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1. INTRODUCTION

People feel discomfort when they get sweat in a space with a stagnant air. Therefore people try to create air breeze around their bodies either naturally or mechanically to enhance body convective heat transfer .Air motion helps sweat evaporation and accordingly brings body comfort feeling. Ceiling fans are used in offices; residences as an alternative in summer for comfort. The flow pattern features induced by ceiling fans are very helpful for people having interest working in this field. So knowing flow characteristics, as a result of ceiling fan rotation would help improving the fan design in addition to selecting its optimum placement to save energy [2]. Therefore it is very important to select and control the input parameters for power saving. Various prediction methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. The response surface methodology (RSM) is helpful in developing a suitable approximation for the true function relationship between the independent variables and the response variable that may characterize the power level for ceiling fan [7]. It has been proved by several researchers that efficient use of statistical design of experimental techniques; allow development of an empirical methodology, to incorporate a scientific approach in analysis of ceiling fan vibration. Even though sufficient literature is available on analysis of ceiling fan vibration, no systematic study has been reported so far to correlate the process parameters and vibration. Hence, in this investigation, the design was used to conduct experiments for exploring the interdependence of the process parameters and second order mathematical model for vibration was developed from the data obtained by conducting the experiments.

2. EXPERIMENTAL IDENTIFICATION OF IMPORTANT PARAMETERS

From the literature and previous work done among many independently controllable parameters affecting vibrations, the parameters viz. Fan Blades (A), Room volume (B), Downrod length (C), Fan speed (D) were selected as primary parameters for the study. These parameters are contributing to the vibration in the ceiling fan. Different combinations of parameters were used to carry out the trial runs. This was carried out by varying one of the factors while keeping the rest of them at constant values.

CONDUCTING EXPERIMENTS

For conducting experiments three different fans of various blades mainly (2, 3, 4), three different room size, three different rod length, and three different fan speed position were selected. Using FFT, vibrations in m/s^2 were recorded. Rod length for fan was measured. Reading in different room, using different rod at different regulator knob position were recorded as in observation table, [Table 1]

Table1. Parameters Level selected for the Experimentation properties

Parameters	**Levels**		
	Low (1)	**Medium (2)**	**High (3)**
Fan (A)	2	3	4
Room Size (m^3) (B)	66.56	167.19	355.84
Rod Length (Inch) (C)	6.5	10.25	12
Speed Knob Position (D)	2	3	4

3. DEVELOPMENT OF MATHEMATICAL MODEL

3.1.RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is a collection of mathematical and statistical technique useful for analyzing problems in which several independent variables or responses are considered to optimize the desired output. 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:

$Y = \Phi(x_1, x_2, \ldots, x_k)$……………………………………………………………………………. Eq.(1).
Between the response Y and $x_1, x_2, \ldots, x_k$ of k quantitative factors , the function Φ is called response surface or response function. For a given set of independent variables, a characteristic surface is responded. In the present investigation, RSM has been applied for developing the mathematical model for characteristics of power. In applying the response surface methodology, the independent variable was viewed as surface to which a mathematical model is fitted.

Table2. Observation Table

Run Order	Fan blades Level	Room Volume Level	Downrod Length Level	Fan Speed Level	Vibration (m/s)
1	1	1	1	1	1.9
2	1	1	1	2	2.58
3	1	1	1	3	3.66
4	1	1	2	1	1.64
5	1	1	2	2	2.09
6	1	1	2	3	3.84
7	1	1	3	1	2.26
8	1	1	3	2	2.63
9	1	1	3	3	3.41
10	1	2	1	1	1.62
11	1	2	1	2	1.82
12	1	2	1	3	2.32
13	1	2	2	1	1.96
14	1	2	2	2	2.05
15	1	2	2	3	2.77
16	1	2	3	1	2.21
17	1	2	3	2	2.57
18	1	2	3	3	3.46
19	1	3	1	1	3.5
20	1	3	1	2	2.69
21	1	3	1	3	2.19
22	1	3	2	1	1.86
23	1	3	2	2	2.13
24	1	3	2	3	2.68
25	1	3	3	1	2.49
26	1	3	3	2	2.5
27	1	3	3	3	3.2
28	2	1	1	1	4.69
29	2	1	1	2	6.46
30	2	1	1	3	6.33
31	2	1	2	1	5.38
32	2	1	2	2	5.6
33	2	1	2	3	6.55
34	2	1	3	1	5.82

35	2	1	3	2	4.89
36	2	1	3	3	7.83
37	2	2	1	1	4.95
38	2	2	1	2	5.19
39	2	2	1	3	6.19
40	2	2	2	1	4.77
41	2	2	2	2	4.9
42	2	2	2	3	5.16
43	2	2	3	1	4.29
44	2	2	3	2	4.25
45	2	2	3	3	6
46	2	3	1	1	5.42
47	2	3	1	2	6.03
48	2	3	1	3	6.32
49	2	3	2	1	5.51
50	2	3	2	2	4.69
51	2	3	2	3	5.79
52	2	3	3	1	3.37
53	2	3	3	2	3.74
54	2	3	3	3	5.27
55	3	1	1	1	1.49
56	3	1	1	2	2.39
57	3	1	1	3	2.5
58	3	1	2	1	1.73
59	3	1	2	2	3.05
60	3	1	2	3	2.84
61	3	1	3	1	1.91
62	3	1	3	2	4.32
63	3	1	3	3	4.04
64	3	2	1	1	1.56
65	3	2	1	2	3.18
66	3	2	1	3	2.79
67	3	2	2	1	1.52
68	3	2	2	2	3.53
69	3	2	2	3	2.54
70	3	2	3	1	1.74
71	3	2	3	2	3.6
72	3	2	3	3	3.09
73	3	3	1	1	1.18
74	3	3	1	2	2.81
75	3	3	1	3	2.65
76	3	3	2	1	1.58
77	3	3	2	2	3.9
78	3	3	2	3	2.58

79	3	3	3	1	1.75
80	3	3	3	2	3.09
81	3	3	3	3	2.66

The mathematical equations for vibration by using response surface method (RSM) is

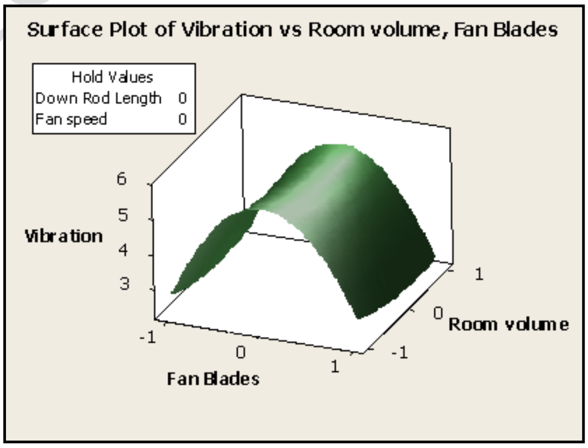
Vibrations (Y_1) =
3.4993+0.0369*A- 0.1898*B+0.0367*C+0.5659*D- 0.0361*AB+0.0889*AC+0.0872*AD-0.2731*BC-0.2083*BD-0.1244*CD-0.1117*ABC+0.1675*ABD-0.0533*ACD+0.0658*BCD-0.2694*ABCD

3.2 OPTIMIZING PARAMETERS

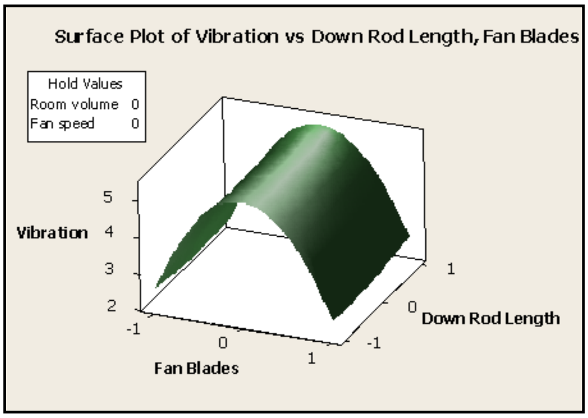
Contour plots show distinctive circular shape indicative of possible independence of factors with response. Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy 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 [4]. 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 vibrations are considered as optimum. Hence, when these optimized process parameters are used, then it will be possible to attain the minimum vibration. Figure 1.presents three dimensional response surface plots for the vibration. The surface plots generated are almost circular which reveals that there is lest dependency of the parameters on the vibration.

Where,
A=Fan blades level
B=Room Volume
C=Down rod length
D=Fan speed

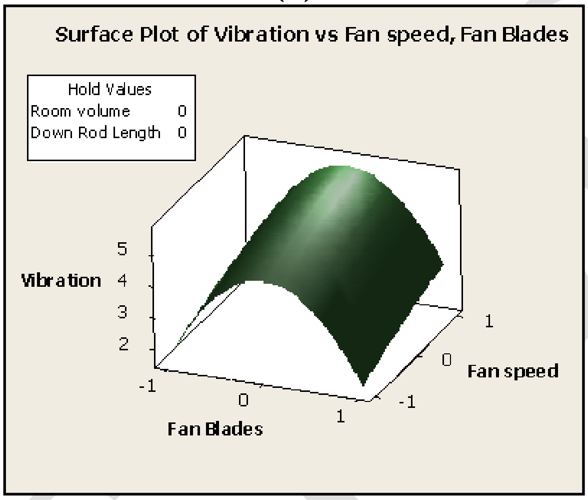
3.3 SURFACE PLOTS



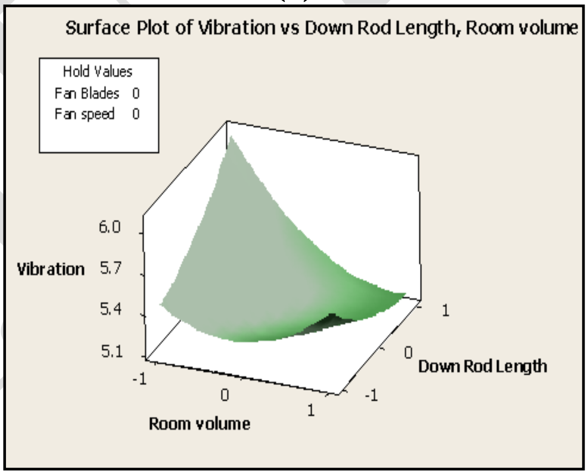
(a)


Surface Plot of Vibration vs Down Rod Length, Fan Blades
Hold Values
Room volume 0
Fan speed 0
Vibration
5
4
3
2
-1
0
1
Fan Blades
1
0
-1
Down Rod Length

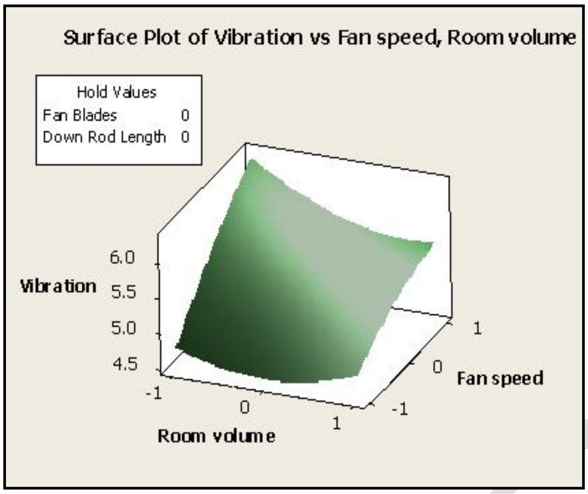
(b)


Surface Plot of Vibration vs Fan speed, Fan Blades
Hold Values
Room volume 0
Down Rod Length 0
Vibration
5
4
3
2
-1
0
1
Fan Blades
1
0
-1
Fan speed

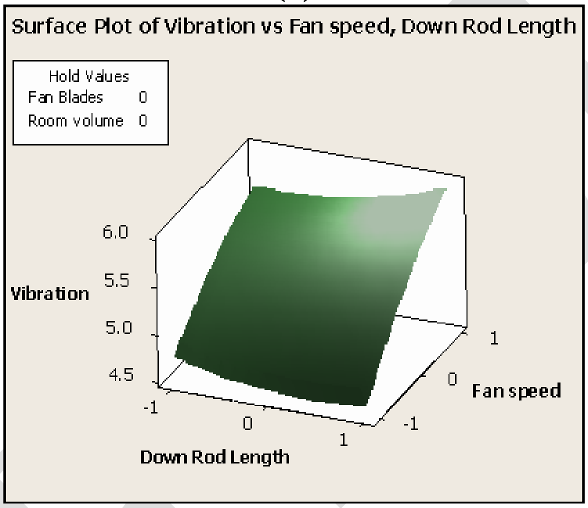
(c)


Surface Plot of Vibration vs Down Rod Length, Room volume
Hold Values
Fan Blades 0
Fan speed 0
Vibration
6.0
5.7
5.4
5.1
-1
0
1
Room volume
1
0
-1
Down Rod Length

(d)



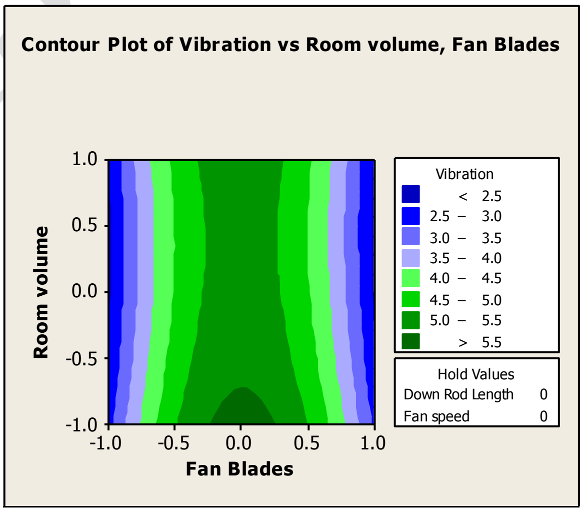
(e)



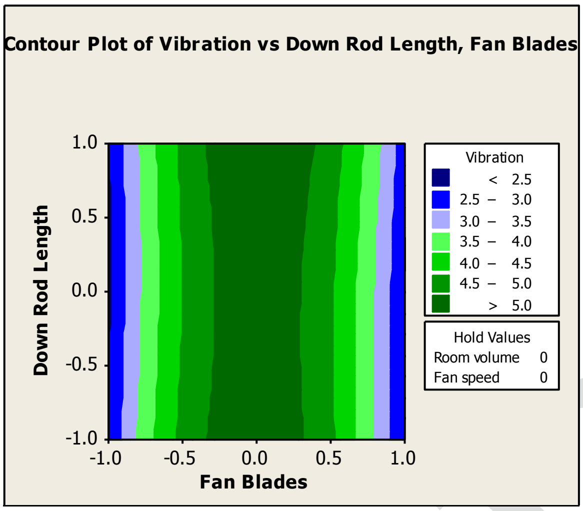
(f)

Fig 1: Surface Plots for Vibration

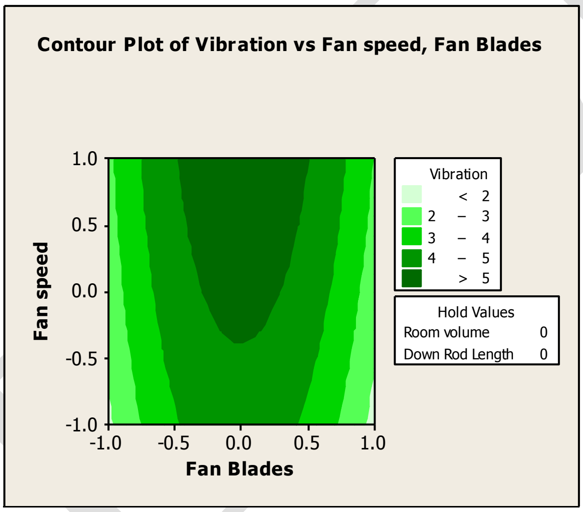
3.4 CONTOUR PLOTS



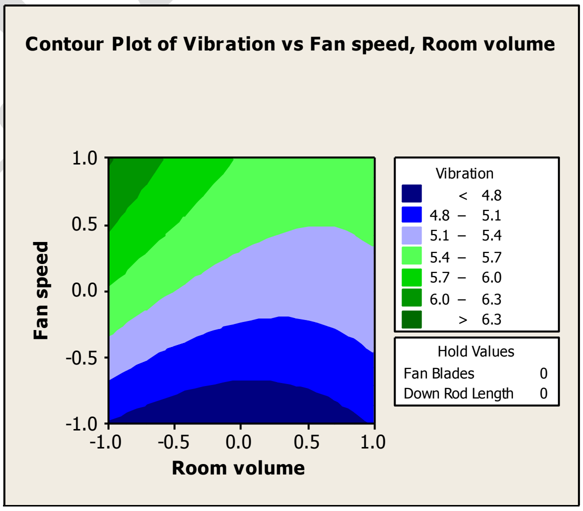
(a)


Contour Plot of Vibration vs Down Rod Length, Fan Blades
Down Rod Length
Fan Blades
1.0
0.5
0.0
-0.5
-1.0
Vibration
< 2.5
2.5 – 3.0
3.0 – 3.5
3.5 – 4.0
4.0 – 4.5
4.5 – 5.0
> 5.0
Hold Values
Room volume 0
Fan speed 0

(b)


Contour Plot of Vibration vs Fan speed, Fan Blades
Fan speed
Fan Blades
1.0
0.5
0.0
-0.5
-1.0
Vibration
< 2
2 – 3
3 – 4
4 – 5
> 5
Hold Values
Room volume 0
Down Rod Length 0

(c)


Contour Plot of Vibration vs Fan speed, Room volume
Fan speed
Room volume
1.0
0.5
0.0
-0.5
-1.0
Vibration
< 4.8
4.8 – 5.1
5.1 – 5.4
5.4 – 5.7
5.7 – 6.0
6.0 – 6.3
> 6.3
Hold Values
Fan Blades 0
Down Rod Length 0

(d)

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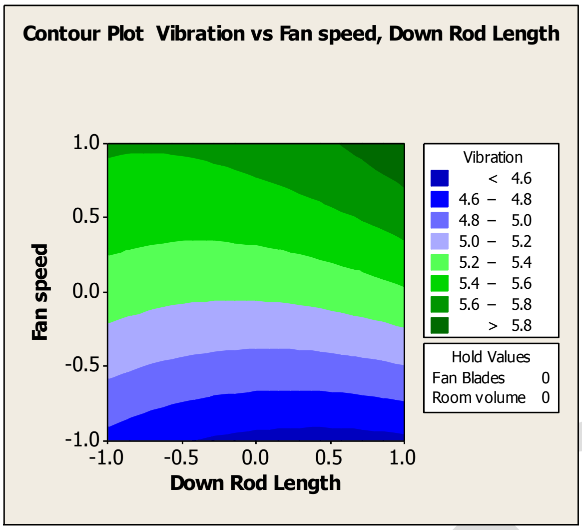


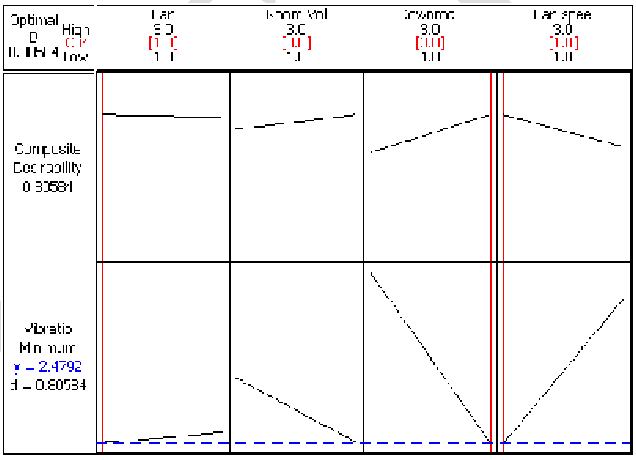
(e)

Fig 2: Contour Plots for vibration

3.5 RESPONSE OPTIMIZATION

Table3. Parameters for Optimization

Parameter	Goal	Lower	Target	Upper	Weight	Import
Energy Consumption	Minimum	0.315	0.315	0.53	1	1 1



3.6 GLOBAL SOLUTION

Fan Blades Level = 3
Room Volume Level = 3
Downrod Length Level = 1
Fan Speed Level = 1

Vibration = 1.190 m/s^2
Desirability = 0.79198
Composite Desirability = 0.79198

CONCLUSION

From the experimentation we got the global value of vibration 1.190 m/s^2 with the set up of Fan having four blades, 355.84 m^3 Room Volume, 12 inch Downrod length and Desirability function of 0.79198 which is the Probability of achieving vibrations.

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