Experimental Analysis of Air Delivery in Ceiling Fan

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Abstract— Ceiling fans are one of the mostly used comfort device in domestic use. Air delivery produced from fan is multiple of the rotational frequency of the fan. Air delivery is one of the most important parameter. To analyze the air delivered from the fan was important to identify the parameters affecting it. 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, room size, number of blades and downrod length all play an important role in deciding the induced flow pattern features in space. Few previous studies have investigated fan induced flow and its characteristics under different geometric and operating conditions. In this study, response surface methodology was used to predict air delivery from the fan. The experiments were conducted based on three different Fan Blade, three different room volume, three different downrod lengths, three different fan speeds and mathematical model was developed. For targeted air delivery optimum levels of input parameters were selected using optimization analysis.

Keywords— Response Surface Method, Ceiling Fan, Air delivery.

I. 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 [1]. Air motion helps sweat evaporation and accordingly brings body comfort feeling. Ceiling fans are used in offices, residences as an alternative in summer comfort. The flow pattern features induced by ceiling fans are very helpful for people of interest working in the 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 maximize Air Delivery. Therefore it was very important to select and control the input parameters for obtaining air delivery. 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 [2].

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 nature of the air delivery. 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 air delivery [4]. Even though sufficient literature is available on analysis of ceiling fan air delivery, no systematic study has been reported so far to correlate the process parameters and air delivery. Hence, in this investigation, the design was used to conduct experiments for exploring the interdependence of the process parameters and model for air delivery was developed from the data obtained by conducting the experiments.

II. EXPERIMENTAL IDENTIFYING IMPORTANT PARAMETERS

A. Identifying Important Parameters

From the literature and previous work done among many independently controllable parameters affecting air delivery, the parameters viz. Fan (A), Room volume (B), down rod length (C) and Fan speed (D) were selected as primary parameters for the study [3]. These parameters are contributing to the air delivery of 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.

Table I

<table>
<thead>
<tr>
<th>Parameters Level Selected For The Experimentation</th>
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<tbody>
<tr>
<td>Parameters</td>
</tr>
<tr>
<td>Fan Blade (A)</td>
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<tr>
<td>Room Size (m³) (B)</td>
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<tr>
<td>Rod Length (Inch) (C)</td>
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<td>Speed Knob Position (D)</td>
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B. Conducting Experiments

For conducting experiments three different number of fan blade, three different room size, three different Downrod length, and three different fan speeds were selected. Using Anemometer, air delivery in (m/s) for fan were recorded. The reading in different room, using different Downrod at different fan speeds recorded as follows.

III. DEVELOPMENT OF MATHEMATICAL MODEL

A. 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 response and the goal is to optimize the response. 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:

\[ Y = \Phi(x_1, x_2, \ldots, x_k) + \epsilon \]  

(1)

Between the response \( Y \) and \( x_1, x_2, \ldots, x_k \) of \( k \) quantitative factors, the function \( \Phi \) is called response surface or response function. The residual error measures the experimental errors. For a given set of independent variables, a characteristic surface is responded [5]. When the mathematical form of \( \Phi \) 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 the form of multiple regression equations for quality characteristics of air delivery. In applying the response surface methodology, the independent variable was viewed as surface to which a mathematical model is fitted.

### Table II

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<th>Downrod Length (C)</th>
<th>Fan speed (D)</th>
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</table>

**Table II Observation Table**
The mathematical equations for air delivery by using response surface method (RSM) is

\[
\text{Air Delivery} = 0.05432 + 0.248148A + 0.300000B + 0.603704C + 0.475926D - 0.138889AB - 0.175000AC - 0.191667AD - 0.111111BC - 0.069444BD - 0.066667CD + 0.041667ABC + 0.091667ABD + 0.100000ACD - 0.008333BCD - 0.0312500ABCD
\]

Where,

- A = Fan,
- B = Room Volume
- C = Down rod length
- D = Fan speed

B. 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 [7]. 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 was 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 power consumption were considered as optimum. Hence, when these optimized process parameters were used, then it was possible to attain the maximum air delivery [6]. Figure presents three dimensional response surface plots for the air delivery obtained from the regression model. The surface plots generated are almost planer which reveals that there is lest dependency of the parameters on the air delivery.
C. Surface Plots

![Surface Plot of Air Delivery vs Room Volume, Fan]

![Surface Plot of Air Delivery vs Downraed Length, Fan]

![Surface Plot of Air Delivery vs Fan speed, Fan]

![Surface Plot of Air Delivery vs Room Volume, Fan]

D. Contour Plots

![Contour Plot of Air Delivery vs Room Volume, Fan]

![Contour Plot of Air Delivery vs Fan speed, Fan]

![Contour Plot of Air Delivery vs Downraed Length, Room Volume]

![Contour Plot of Air Delivery vs Downraed Length, Fan]
E. Response Optimization

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F. Global Solution

- Fan Blade = 3
- Room Volume = 3
- Down rod Length = 1
- Fan speed = 1
- Air Delivery = 2.4
- Desirability = 1.0000

Composite Desirability = 1.0000

IV. CONCLUSIONS

From the experimentation we got the global value of Air Delivery 2.4 with the set up of Fan having three blades, 66.56 m³ Room Volume, 12 inch Down rod length & Fan knob position 4 and Desirability function of 1.000 which is the Probability of achieving power consumption.

REFERENCES


