

Optimum Design of a Heat-Exchanger-Fan Casing of Clothes Dryer Using the Taguchi Method

Jang-Kweon Kim*

(Received March 3, 1999)

This study is carried out to get the high flowrate of a heat-exchanger (HE) fan through an optimum condition of a fan casing. The control factors in the present study are the orifice inlet diameter, the orifice inlet clearance, the cut-off angle, and the cut-off clearance. The goal of this study is to select the best combination of each control factor of the HE fan casing with a minimum variability and to obtain a linear relationship between the flowrate and the number of revolution. Thus, the parameter design of the Taguchi method is adopted for robust design by a dynamic characteristic analysis using orthogonal arrays and S/N ratios. The flowrate measurements are conducted by using a small-sized fan tester according to the orthogonal array L9(3⁴). In the present study, the flowrate under an optimum condition having a set of <A2 B3 C3 D1> satisfies with the linear equation $y=0.0039 \cdot M$ as to the number of revolution, and the flowrate is improved by about 44.4 (%) as compared with the current condition.

Key Words : Analysis of Variance (ANOVA), Taguchi Method, Control Factor, Noise Factor, Optimum Condition, Parameter Design, Signal Factor, Signal-to-Noise (S/N) Ratio, Heat-Exchanger (HE) Fan, Clothes Dryer

Nomenclature —————		S'	: Pure sum of square
ANOVA	: Analysis of variance	S_E	: Error sum of square
A	: Control factor of orifice inlet diameter (mm)	S_m	: Sensitivity of measured data (dB)
B	: Control factor of orifice inlet clearance (mm)	S_T	: Total sum of square
C	: Control factor of cut-off angle (°)	S_β	: Variation of linear effect of signal factor
D	: Control factor of cut-off clearance (mm)	V	: Variance
D_f	: Degree of freedom	V_E	: Error variance
(e)	: Pooled error term	$y_{i,1}$: Measuring value of (i, 1) array
F	: F-distribution	β	: Proportional constant
N1, N2	: Noise factors	η	: Signal-to-noise (S/N) ratio (dB)
k	: Number of signal level (k=3)	$\Delta\eta$: Difference of S/N ratio between optimum condition and current condition (dB)
M	: Signal factor	$\Delta\eta_1$: Difference of estimated S/N ratio between optimum condition (Z) and current condition (Y) (dB)
r	: Effective number of replication	$\Delta\eta_2$: Difference of S/N ratio of measured data between optimum condition (X) and current condition (W) (dB)
r_0	: Number of response data for each signal level ($r_0=2$)	ρ	: Contribution percentage of source (%)
S	: Sum of square		

* Department of Marine Engineering, Kunsan National University, 1044-2, Soryong Dong, Kunsan 573-702, Chonbuk, Korea /Website: <http://flowkim.kunsan.ac.kr> /E-mail: flowkim@kunsan.ac.kr.

1. Introduction

Nowadays, there are two kinds of clothes dryers in both domestic and foreign markets. One is a duct-exhausting type clothes dryer which extracts a hot-humid air including evaporating water in clothes by heaters through a duct from clothes dryer, and the other is a condensation-type clothes dryer which extracts water formed by a heat-exchanger (HE) fan in a hot-humid air including evaporating water in clothes by heaters from clothes dryer. In the present study, the condensation-type clothes dryer is adopted. Especially, the condensation-type clothes dryer has a merit that it does not wet a wall when it is used in the house because it does not extract the hot-humid air of clothes dryer outside. The HE fan which is adopted in the condensation-type clothes dryer has three functions such as heat-exchange, circulation and cooling but it is composed of only one fan made of plastic material.

Kadoya et al (1984) developed a new condensation-type clothes dryer using such a HE fan. They showed that this condensation-type clothes dryer had an over-70 (%) rate of recovery which is the percentage of water volume that the HE fan can extract water in clothes and also this dryer had made possible a reduction of weight, number of parts and cost as compared with their conventional condensation-type clothes dryer.

In the present study, the Taguchi method (Phadke, 1989; LG, 1993; ANOVA-TM, 1993; Wilkins, 1993; Fowlkes et al, 1995; Kim, 1998; Kim, 1999) is introduced to determine the major design factors of the HE fan casing by experiment and to get a maximum flowrate in the condition of the lowest number of revolution according to the increase of heating capacity in the process of a newly developed condensation-type clothes dryer. This new clothes dryer will realize low noise performance in spite of the increase of heating capacity with the same cabinet size as a conventional clothes dryer.

Though the studies related with the fan design using the Taguchi method are rarely conducted. Kim (1998; 1999) developed a high flowrate

sirocco fan installed in an indoor package air-conditioner using the Taguchi method. He applied the dynamic characteristic of the Taguchi method to the sirocco impeller in order to get optimum condition of the inner to outer diameter ratio, the width to outer diameter ratio, the number of blade and the setting angle of blade respectively which could affect the flowrate performance severely.

In the present study, the orifice inlet diameter, the orifice inlet clearance, the cut-off angle and the cut-off clearance of the HE fan casing which can affect the flowrate performance greatly are investigated to obtain their effects on the optimum design using the dynamic characteristic of the Taguchi method.

2. Structure of Clothes Dryer and the HE Fan

Figure 1 shows a schematic diagram of the structure elements in a condensation-type clothes dryer. Clothes dryer used in the present study is largely composed of the front door, the heaters, the drum which accepts clothes, the HE fan and the motor that operates the HE fan. Moreover, the HE fan is composed of an impeller and a casing.

Figure 2 shows the details of the HE fan. Figure 2(a) shows the assembling parts of the HE fan and Fig. 2(b) shows the detail specification of

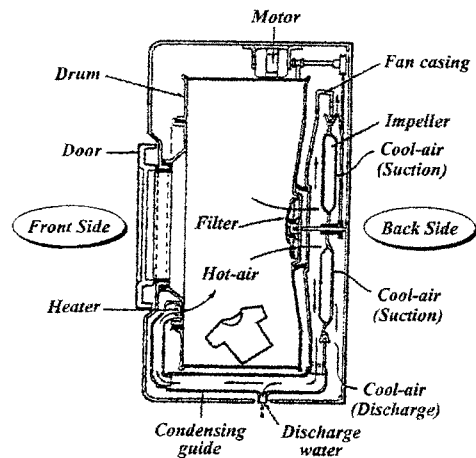


Fig. 1 Schematic diagram of structure elements in the clothes dryer.

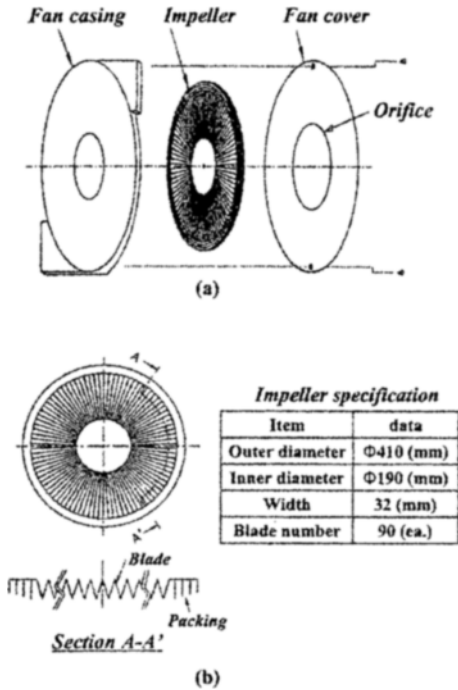


Fig. 2 Details of heat-exchanger-fan.

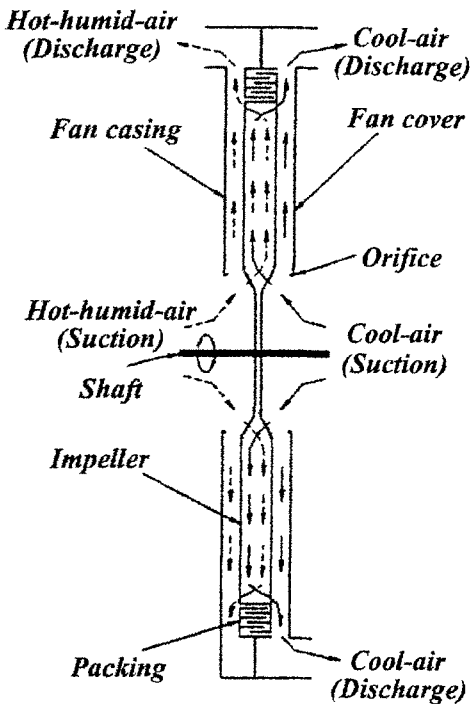


Fig. 3 Diagram of heat transfer concept of heat-exchanger-fan.

the HE fan impeller. The HE fan impeller is composed of ninety blades per each side with a thickness 1 mm of corrugated shape radially, the main plate having a triangle shaped side plate which closes the tip side of the inner circumference of the blade and the side plate having a triangle shaped side plate which closes the tip side of the outer circumference of the blade. And the HE fan impeller is assembled as an injection-molded plastic made of polypropylene material. The fan casing is installed separately in the inner and the outer side of the HE fan impeller.

Figure 3 shows a diagram of heat transfer concept of the HE fan. According to the rotation of an impeller, the HE fan operates like a radial type centrifugal fan. Thus, the HE fan sucks relatively cool air from the outside of clothes dryer and hot-humid air from wet clothes in the drum respectively. At the same time, the HE fan ventilates respective air outwards through the fan casing. Therefore, the HE fan has a role of two fans. While cool air and hot-humid air meet the blade surface of impeller respectively in the fan casing, they exchange heat mutually as heat convection and conduction at the blade surfaces. At this time, condensed water forms at the blade surface and is collected in the fan casing by a centrifugal force and is discharged to the outside of clothes dryer. Therefore, the HE fan does not only have a role of two fans, but also a role of heat exchanger.

3. Application of the Taguchi Method

The Taguchi method is a tool which optimizes the condition of design parameters in order to get the robust performance of goods and the process of work under any user environments.

In product development, the goal of the designer is to identify settings of product design parameters that make the product's performance less sensitive to the effects of environmental variables. deterioration and manufacturing variation (Lee et al., 1996). A cost-effective method for counteracting these undesirable variations is by reducing the influence of the sources of variation rather than by controlling them (Bounou et al.,

1995). This strategy is adopted by G. Taguchi for improving robustness and product quality over uncontrollable variability (so called noise).

The means of the Taguchi method is to demonstrate the large scale effect which is obtainable as a lower cost, a higher quality, a quick delivery and a desired function through a small scale execution (or experiment) as a basis of function characteristics and noises using an orthogonal array and a signal-to-noise (S/N) ratio (LG, 1993).

3.1 Parameter design

The parameter design of the Taguchi method is well known as a method for finding an optimum condition of design factors in order to assure the reproducibility of the downstream (so called customer's quality) and to get a stability by minimizing the influences of noise environments without avoiding and controlling noise factors which cause the variation of functions (Pardkes, 1989; Chen et al., 1996).

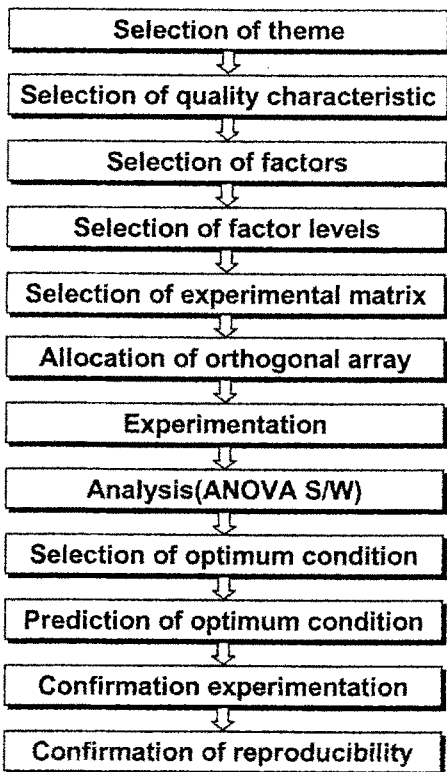


Fig. 4 Application procedure of parameter design.

Figure 4 shows a diagram representing an application procedure of the parameter design of the Taguchi method used in the present study (Wilkins, 1993). Firstly, we select a theme, and then determine the quality characteristic which is the most suitable to the theme. Also, we select the factors and their levels. Secondly, after selecting the experimental matrix, we allocate the factors and their levels to an orthogonal array and execute the experiment according to the order of each experimental combination located in that orthogonal array, and then obtain the experimental response data of a target value. Thus, we input this response data into the ANOVA software suitably. After analysing the S/N ratio, the sensitivity and the proportional constant using the ANOVA software, we select their optimum condition and also obtain the estimated result of the optimum condition. Thirdly, we execute a confirmation experiment in order to confirm if the selected optimum condition agrees with the result of the confirmation experiment. Fourthly, we input the response data of the confirmation experiment into the ANOVA software once more, and analyse them, and then obtain the S/N ratio and the proportional constant. Next, we consider a condition used generally by experience as a current condition, and also execute its experiment, and then obtain the S/N ratio and the proportional constant both of experiment and of estimation through the analysis of the ANOVA software. Finally, in order to execute the confirmation procedure of reproducibility, we obtain the difference of the S/N ratio between the optimum condition and the current condition in relation to estimation, and also obtain the difference of the S/N ratio between the optimum condition and the current condition in relation to experiment. From the above S/N ratio differences, we judge the optimum condition suitably according to the decision condition of reproducibility.

Figure 5 shows a diagram representing the classification of design parameters adopted by the optimization technique of the HE fan that satisfies the high flowrate clothes dryer in the present study. We selected three numbers of revolution as a signal factor in order to analyse the HE fan

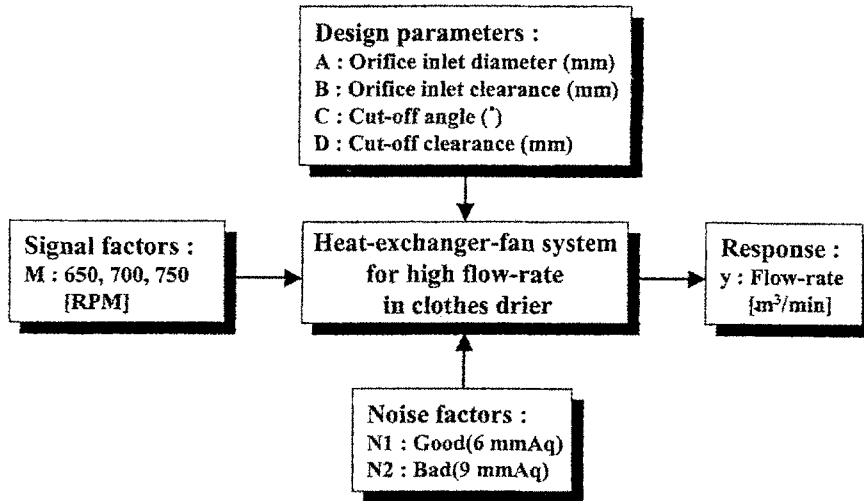


Fig. 5 Classification of design parameters.

system using the dynamic characteristic of the Taguchi method. And also we selected four kinds of the design parameters of the fan casing as a control factor. Finally, we selected two kinds of system resistances, which are coincident with a pressure loss in clothes dryer, having a good condition and a bad one respectively as a noise factor. Thus, we could obtain the flowrate as a system response by executing the experiment from the combination results of these factors. Therefore, the mathematical expression of functional relation between the output and the input parameters can be given by

$$y = f(M, A, B, C, D, N1, N2) \quad (1)$$

In case that the output y changes according to the signal factor M , Eq. (1) can be expressed as Eq. (2) again by introducing the error factor e and the proportional constant β as a controllable factor.

$$y = \beta M + [f(M, A, B, C, D, N1, N2) - \beta M] = \beta M + e \quad (2)$$

In this case, in order to minimize the influence of error factor e , Eq. (2) can be expressed as Eq. (3) representing an ideal linear relation by controlling optimally the values of the internal parameters of the HE fan system using the S/N ratio and the sensitivity S_m .

$$y \approx \beta M \quad (3)$$

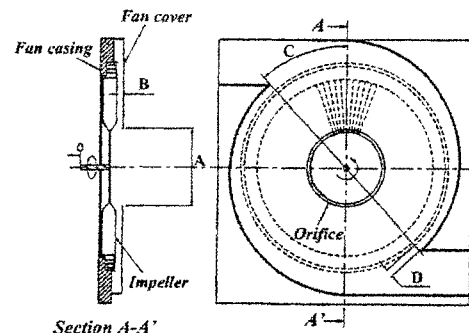


Fig. 6 Geometry configuration of heat-exchanger fan.

3.2 Allocation background of factors and their levels into an orthogonal array

Figure 6 shows a diagram representing the geometry configuration of the HE fan used in the present study. As we could see in Fig. 6, we selected four kinds of control factors for the present study as follows; the orifice inlet diameter (A), the orifice inlet clearance (B), the cut-off angle (C) and the cut-off clearance (D) respectively, and then expressed their results as Table 1. Table 1 represents the inner array of an orthogonal array. In order to determine the levels of each control factor A, B, C and D, we used the data of a conventional clothes dryer and regarded them as level 2. Thus, we arranged the levels of each control factor as three kinds of levels by changing the value from the level 2 respectively.

Table 1 Inner array

	Factor description	Level 1	Level 2	Level 3
Control factors	A : Orifice inlet diameter (mm)	156	175	192
	B : Orifice inlet clearance(mm)	5	8	11
	C : Cut-off angle (°)	45	50	55
	D : Cut-off clearance(mm)	14	19	24

Table 2 Outer array

Factors	Level 1	Level 2	Level 3
Signal factor: N : Number of revolution [RPM]	650	700	750
Noise factor: N : System resistance (mmAq)	Good 6	Bad 9	— —

Table 3 Experimental results of orthogonal array L9 (3⁴).

Set no.	Estimate characteristic value: Flow rate[m ³ /min] Estimate characteristic type : Dynamic									
	Inner array				Outer array					
	Control factor				M1		M2		M3	
	A	B	C	D	N1	N2	N1	N2	N1	N2
1	1	1	1	1	1.23	0.99	1.40	1.19	1.56	1.38
2	1	2	2	2	1.80	1.48	2.05	1.76	2.28	2.03
3	1	3	3	3	2.31	1.89	2.61	2.23	2.90	2.57
4	2	1	2	3	1.29	1.02	1.47	1.24	1.65	1.44
5	2	2	3	1	2.02	1.66	2.29	1.97	2.55	2.26
6	2	3	1	2	2.09	1.73	2.35	2.04	2.61	2.33
7	3	1	3	2	1.49	1.19	1.70	1.44	1.90	1.67
8	3	2	1	3	1.61	1.31	1.79	1.54	1.99	1.77
9	3	3	2	1	2.26	1.87	2.55	2.20	2.83	2.52

Table 2 represents the external array of the orthogonal array and shows two kinds of levels of noise factor and three kinds of levels of signal factor. In the present study, we regarded the noise factor as the system resistance coincident with the pressure loss caused by each part installed in the clothes dryer until a desired flowrate was reached within the flow passage. Thus, we selected the system resistance 6 (mmAq) obtained when the clothes are not wholly filled in the drum as a good condition and the system resistance 9 (mmAq) obtained when they are completely filled in the drum as a bad condition respectively. Especially, because the signal factor (M) is the input factor of signal at the dynamic characteristic of the Taguchi method, we selected three numbers of revolution such as 650, 700 and 750 (RPM) respectively as a signal factor in the present study.

4. Experimental Method

In order to measure the flowrate of the HE fan exactly in the present study because the HE fan requires a small flowrate, we used a small-sized fan tester. The small-sized fan tester having a suction function using only one nozzle in the chamber was made by referring KSB6311 and AMCA STANDARD210-85. The method of the flowrate measurement was given by Kim (1995). And the HE fan casing was made from nine kinds of samples according to the combination of each control factor having three kinds of levels respectively in order to use the Taguchi method in the present study. As a result of experiment, Table 3 shows the experimental results of the flowrate of the HE fan measured by using the combination order of orthogonal array L9(3⁴) related with nine kinds of samples of the HE fan casing according to the three numbers of revolution divided with the noise factor of good condition and bad one. And we used the commercial software ANOVA-TM Ver. 2.5 (1993) for the variance analysis of experimental data.

5. Results and Discussion

5.1 Analysis of contribution percentage of source

Table 4 shows the result of the ANOVA analysis of the S/N ratio in order to know the contribution percentage of source having the influence on the optimum condition of the control factors. From the S/N ratio of Table 4, because both sum of square S and variance V of the control factor A (the orifice inlet diameter) show the smallest value respectively among each control factor, we can neglect the control factor A. Therefore, we executed a pooling after regarding the control factor A as an error factor in the ANOVA software in order to confirm the contribution percentage of source (Corson et al., 1993). As a result, we can see that the contribution percentage of

source of each control factor shows the highest value of 85.32 (%) in the case of B (the orifice inlet clearance), 7.24 (%) in the case of C (the cut-off angle) and 3.51 (%) in the case of D (the cut-off clearance) respectively.

5.2 ANOVA of S/N ratio and Sensitivity

Generally, the parameter design concept of the Taguchi method is well known to adopt the two-step optimization procedure. Step 1 is to find the most stable condition minimizing variations in performance caused by variations in noise factors by selecting the control factor having the highest S/N ratio. Step 2 is to finely tune the mean to a target value by controlling the sensitivity defined as an adjustment factor (Wilkins, 1993). In the dynamic characteristic analysis, because the sensitivity has a similar slope to the proportional constant β , we can select β as an adjustment factor in step 2.

Table 5 shows a data conversion for the S/N ratio (η), the sensitivity (S_m), the proportional constant (β), etc. calculated from the flowrate result of Table 3 in order to find out which level of each control factor affects much more to the flowrate performance. The S/N ratio and β shown in Table 5 can be also obtained from the ANOVA software. Especially, β is satisfied with Eq. (3) as a slope affected the performance if the design is completed without any error factors.

Table 4 ANOVA analysis of S/N ratio.

Source	D_r	S	V	F	S'	ρ (%)
A	2	0.03	0.02	pooled	pooled	pooled
B	2	2.72	1.36	87.92	2.69	85.32
C	2	0.26	0.13	8.38	0.23	7.24
D	2	0.14	0.07	4.57	0.11	3.51
(e)	2	0.03	0.02	—	0.12	3.93
Total	8	3.15	1.58	—	—	100

Table 5 Data conversion for η , S_m and β of each set experiment.

Set no.	Control factor				S_r	S_β	S_E	V_E	η	S_m	β
	A	B	C	D							
1	1	1	1	1	10.2071	10.11	0.0978	0.0196	-37.5718	-54.6594	0.0019
2	1	2	2	2	22.0498	21.87	0.1837	0.0367	-36.9592	-51.3078	0.0027
3	1	3	3	3	35.7081	35.41	0.2984	0.0597	-36.9726	-49.2143	0.0035
4	2	1	2	3	11.1991	11.08	0.1236	0.0247	-38.1956	-54.2643	0.0019
5	2	2	3	1	27.5711	27.34	0.2262	0.0452	-36.8926	-50.3367	0.0030
6	2	3	1	2	29.2861	29.07	0.2128	0.0426	-36.3605	-50.0696	0.0031
7	3	1	3	2	14.9987	14.84	0.1542	0.0308	-37.8824	-52.9916	0.0022
8	3	2	1	3	16.9769	16.84	0.1334	0.0267	-36.7018	-52.4408	0.0024
9	3	3	2	1	34.3063	34.05	0.2587	0.0517	-36.5219	-49.3840	0.0034

Here, S_T is the total sum of square of the flowrate obtained according to each combination experiment in the condition of three signal factors, S_β is the variation of linear effect of the signal factor, S_E is the error sum of square of the error parts deviated from the center of non-linearity and V_E is the error variance of the S/N ratio, namely noise component. Here, the S/N ratio used in the present study is the ratio of useful energy to non useful energy and is defined as a zero point proportional dynamic characteristic related with the special equation group using in optimizing level of each control factor about experimental design. It is used when the ideal function passes through the origin and the output is linear with respect to the input and when the signal factor changes over a range. Thus, the relationships of each variable shown in Table 5 can be expressed as follows; (Pack et al., 1993)

Total sum of square (S_T):

$$S_T = \sum_{i=1}^k y_{i,1}^2 \tag{4}$$

Effective number of replication (r):

$$r = r_0 \sum_{i=1}^k M_i^2 \tag{5}$$

Variation of linear effect of signal factor (S_β):

$$S_\beta = \frac{1}{r} \left(\sum_{i=1}^k M_i Y_i \right)^2 \tag{6}$$

Error sum of square (S_E):

$$S_E = S_T - S_\beta \tag{7}$$

Error variance (V_E):

$$V_E = \frac{S_E}{kr_0 - 1} \tag{8}$$

S/N ratio (η):

$$\eta = 10 \log \left[\frac{\frac{1}{r} (S_\beta - V_E)}{V_E} \right] \tag{9}$$

Sensitivity (S_m):

$$S_m = 10 \log \left[\frac{1}{r} (S_\beta - V_E) \right] \tag{10}$$

Proportional constant (β):

$$\beta = \frac{1}{r} \sum_{i=1}^k M_i Y_i \tag{11}$$

where, with respect to the number 1 of combination experiment, Y_i of Eq. (6) and Eq. (11) is defined as Eq. (12) respectively

$$Y_1 = \sum_{i=1}^2 y_{i,1}, \quad Y_2 = \sum_{i=3}^4 y_{i,1}, \quad Y_3 = \sum_{i=5}^6 y_{i,1} \tag{12}$$

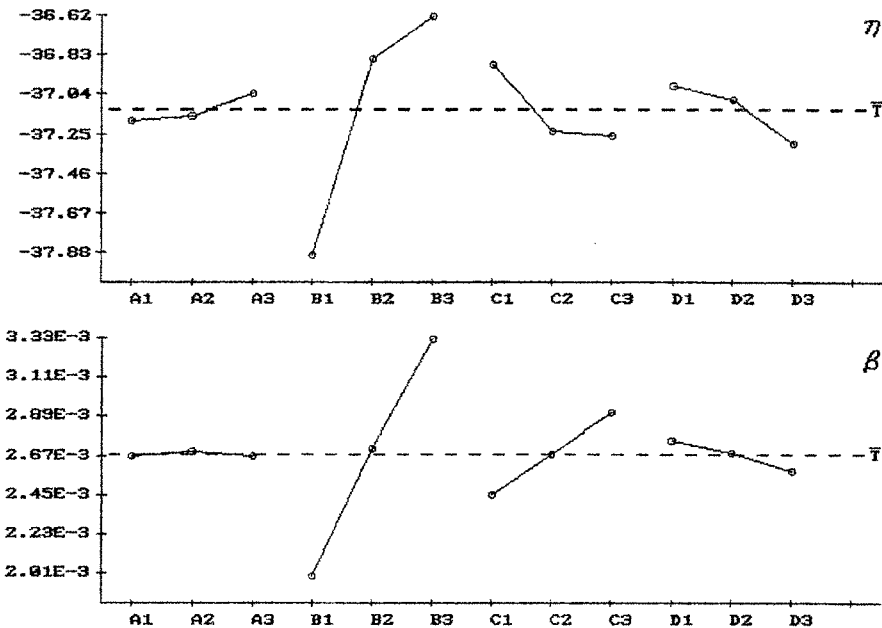


Fig. 7 Factorial effect chart of η and β .

Figure 7 shows a factorial effect chart of η and β calculated again as a mean of η and β respectively after collecting three kinds of same levels with respect to the level of each control factor defined as orthogonal array L9 using η and β of Table 5. Here, because the sensitivity S_m of Table 5 as well as the mean of S_m has similar trends with β and the mean of β , we omitted the sensitivity in Fig. 7. In the light of the S/N ratio only shown in Fig. 7, the optimum condition of each control factor is proved to be a set $\langle A3 B3 C1 D1 \rangle$ because the selection of the largest S/N ratio minimizes variations in performance caused by variations in noise factors. And in the light of β shown in Fig. 7, the optimum condition of each control factor is proved to be a set $\langle A2 B3 C3 D1 \rangle$ because the biggest of β increases a flowrate, namely a slope of performance curve given by Eq. (3) largely in spite of the same number of revolution.

5.3 Selection of optimum condition

In comparison with the optimum level of each control factor obtained from the analysis results of the S/N ratio (η) and β , the level factor satisfying the optimum condition with respect to the orifice inlet diameter (A) of the fan casing shows A3 in the case of the S/N ratio and A2 in the case of β respectively from Figure 7. But because the difference of the S/N ratio according to each level of A shows a comparatively small value each other, we selected A2 as the optimum level of the control factor A which contributes to the flowrate performance somewhat largely in spite of a small growth of variation. And because the optimum level factor with respect to the orifice inlet clearance (B) shows B3 having a large value commonly at the same time in the case of the S/N ratio and β , we could expect that B3 do not only increase the flowrate performance largely, but also it decrease the variation of error. Moreover, while the level factor satisfying the optimum condition with respect to the cut-off angle (C) shows C1 in the case of the S/N ratio, it shows C3 in the case of β . Therefore, in the present study, we selected C3 having an excellent flowrate as the optimum level of the control factor

C in consideration of the flowrate performance preferentially in spite of a small growth of variation in performance. Since the optimum level with respect to the cut-off clearance (D) shows D1 having a somewhat large value commonly at the same time in the case of the S/N ratio and β , we could also expect that D1 increases the flowrate performance largely in addition to decrease the variation of error. Therefore, if we summarize the above results, we can expect that the optimum condition satisfied with the S/N ratio and β at the same time is a set $\langle A2 B3 C3 D1 \rangle$. On the other hand, in order to compare with the above optimum condition given by a set $\langle A2 B3 C3 D1 \rangle$, we selected a set $\langle A2 B2 C2 D2 \rangle$ as a current condition by referring each design data of a conventional fan casing.

6. Confirmation Experimentation and Assessment of Reproducibility

In order to confirm the reproducibility (or robustness) experimentally of the optimum condition obtained by the ANOVA software from the experimental results of the orthogonal array L9, we measured the flowrate of the HE fan after making the fan casing by the optimum condition set $\langle A2 B3 C3 D1 \rangle$ of each control factor. Moreover, we also experimented the flowrate of the HE fan made by the fan casing satisfied with the current condition set $\langle A2 B2 C2 D2 \rangle$. We presented those flowrate results in Table 6. Here, because the increase rate of flowrate with respect to the optimum condition shows about 42~46 (%) at a good condition and a bad one respectively according to the total signal factors as compared with the current condition, we can see that the

Table 6 Confirmation experiment result.

Condition	Set of factor	Estimate characteristic: Flow rate [m ³ /min]					
		M1		M2		M3	
		N1	N2	N1	N2	N1	N2
Optimum	A2 B3 C3 D1	2.62	2.15	2.95	2.54	3.27	2.89
Current	A2 B2 C2 D2	1.80	1.48	2.05	1.76	2.28	2.03

Table 7 Confirmation result of reproducibility.

Condition	Set of factor	Estimation		Experiment		Gain ($\Delta\eta$)	
		η	β	η	β	$\Delta\eta_1$	$\Delta\eta_2$
Optimum	A2 B3 C3 D1	-36.66 (Z)	0.0037	-36.70 (X)	0.0039	0.28	0.26
Current	A2 B2 C2 D2	-36.94 (Y)	0.0028	-36.96 (W)	0.0027		

performance improvement at the optimum condition is accomplished largely.

Table 7 shows a confirmation result of reproducibility. The experimental values of the optimum condition and the current one shown in Table 7 were calculated by Eq. (9) and Eq. (11) respectively from the flowrate data shown in Table 6. And the estimated values of the optimum condition and the current one shown in Table 7 were obtained by the ANOVA software from the flowrate results shown in Table 3. Here, we can see that the optimum condition is more profitable in the performance improvement of flowrate because η and β of the optimum condition respectively with respect to the values of estimation and experiment are larger than those of the current condition. On the other hand, the yardstick for judgment of reproducibility for the optimum condition is generally given by a gain relation of ($\Delta\eta_1 \times 0.7 < \Delta\eta_2 < \Delta\eta_1 \times 1.3$) (LG, 1993). Therefore, we can see that the reproducibility of the optimum condition is realized because the gain relation is satisfied with a condition of [$0.196 (= 0.28 \times 0.7) < 0.26 (= \Delta\eta_2) < 0.364 (= 0.28 \times 1.3)$]. Here, we can judge that all procedures for determining the optimum condition shown in the present study are completed well. Since the proportional constant β in Eq. (3) is given by $\beta = 0.0039$ through the experimental values, we can see that the flowrate performance improvement of the optimum condition is achieved about 44.4 (%) more largely as compared with the current condition.

7. Conclusions

In the present study, the Taguchi method was introduced to find the optimum condition of the HE fan casing with respect to the orifice inlet

diameter, the orifice inlet clearance, the cut-off angle and the cut-off clearance which can affect more largely to the flowrate performance among lots of the design parameters of the HE fan casing. Here, the results of this study can be summarized as follows;

(1) The combination of the control factor satisfying the optimum condition is a set (A2 B3 C3 D1), and its reproducibility is confirmed through the experiment.

(2) The flowrate at the optimum condition is a linearly dependent on the number of revolution of the HE fan as $y = 0.0039 \cdot M$, and the flowrate performance at the optimum condition is increased about 44.4 (%) larger than that of the current condition.

(3) The contribution percentage of source as to the performance variation of flowrate confirms that B, C and D are major factors through the ANOVA analysis of the S/N ratio, and their order of magnitude is B[85.32 (%)], C[7.24 (%)], and D[3.51 (%)] in turn.

Finally, we confirmed that the Taguchi method was a very useful tool for finding the optimum condition at a comparatively cheap cost because it does not require a lot of experiment.

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