Improvement of a tool for the easy determination of control factor interaction in the Design of Experiments and the Taguchi Methods

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***Abstract*—**In recent years, the Design of Experiments (hereafter, DOE) have been widely used to decide optimum processing conditions. However, when large interactions between several control factors are present, since they behave as confounding variables, the estimation accuracy is significantly reduced and making the practical use of the DOE extremely difficult in some cases. As a common countermeasure, calculation accuracy is confirmed by comparing, through the final results, the best and worst results. This can be of great harm in terms of time and labor and, if the difference between the best and worst results is large, could result in the DOE estimations being ignored. Therefore, in previous studies, a usable tool for the easy determination of control factor interactions in the DOE was developed; here, said tool was able to determine control factor interactions in the DOE through several mathematical models. This research presented an improvement to the previous tool through an improved algorithm and more detailed mathematical models to evaluate complex control factor interactions. It was concluded that, (1) an improved tool for the determination of control factor interactions in the DOE and the Taguchi Methods was developed, (2) the tool was able to detect previously indistinguishable complex control factor interactions in the DOE or the Taguchi Methods, (3) a new algorithm was able to determine complex control factor interactions in models between control factors and functions.

***Keywords*—**Experimental design, innovation, innovative tool, algorithm, optimum condition, control factor interactions

I. INTRODUCTION

In recent years, the Design of Experiments (hereafter, DOE) and the Taguchi Methods have been widely used to decide optimum processing conditions [1], [2], [3]. Usually, the DOE procedure first defines the design parameters to be used. Second, the design parameters are used as control factors and all possible control factor combinations are compressed in an orthogonal table. Third, experimentation or CAE simulations are done according to the aforementioned orthogonal table. Finally, the obtained data is summarized and the optimum control factors are selected. Here, experiments or CAE simulations are performed in the orthogonal table. However, when large interactions between control factors are present, since interactions behave as confounding variables, the estimation accuracy is significantly reduced and making the practical use of the DOE extremely difficult in some cases.

As a common countermeasure, the calculation accuracy is confirmed by comparing, through the final results, the best and worst results. This can be of great harm in terms of time and labor and, if the difference between the best and worst results is large, could result in the DOE estimations being ignored. In previous studies [4], a tool for the easy determination of control factor interactions in the DOE and the Taguchi Methods was developed and evaluated. Specifically, the Level 1 of each control factor was intentionally set to be zero (0) in the orthogonal table in order to obtain functions that are not influenced by control factor interactions. The comparison between the aforementioned functions and conventional DOE orthogonal table functions was then used as an assessment criterion, under several mathematical models, to prove the presence of control factor interaction as well as to determine interacting control factors. This research presented an improvement to the previous tool through an improved algorithm and more detailed mathematical models to evaluate complex control factor interactions. It was thought that this method was necessary in order to clarify the control factor interaction ambiguity present in the DOE and the Taguchi Methods [5], [6], [7], [8].

II. DETERMINATION OF CONTROL FACTOR INTERACTIONS

A. Previous Control Factor Interaction Detection Algorithm

In this section, the previous algorithm for the easy determination of control factor interaction in DOE is shown [4]. Here, the developed algorithm consisted in setting a level value of 0 (Zero) in each control factor in order to observe that the final function did not present any influence due to control factor

Table 1 Orthogonal table in experimental

L4	Control factors A	Control factors B	Control factors C	Function F
No.1	A_1	B_1	C_1	F_1
No.2	A_1	B_2	C_2	F_2
No.3	A_2	B_1	C_2	F_3
No.4	A_2	B_2	C_1	F_4

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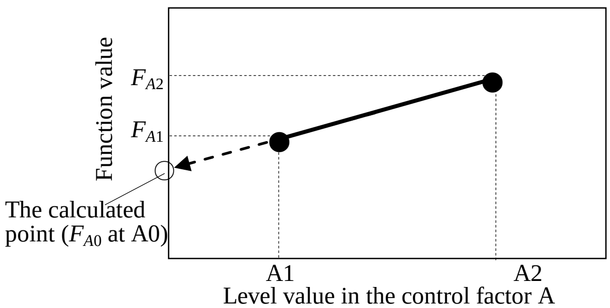

Fig. 1 Effective figure of the control factor (control factor A)

Table 2 Trial data without control factor interaction

Particularity of the trial set	Trial No.	Control factors A	B	C	Function F
Trial data without interaction from control factor A	No.1'	**0**	B_1	C_1	F_{A01}’
	No.2'	**0**	B_2	C_2	F_{A02}’
Trial data without interaction from control factor B	No.3'	A_1	**0**	C_1	F_{B01}’
	No.4'	A_2	**0**	C_2	F_{B02}’
Trial data without interaction from control factor C	No.5'	A_1	B_1	**0**	F_{C01}’
	No.6'	A_2	B_2	**0**	F_{C02}’

Table 3 Function F_{A0}’, F_{B0}’ and F_{C0}’ without control factor interaction effects at level value = 0

Equation (4)	Control factors without interaction effects
F_{A0}’	A (A and B or A and C)
F_{B0}’	B (A and B or B and C)
F_{C0}’	C (A and C or B and C)

Notes:
F_{A0}’and F_{B0}’ are not influenced in the presence of control factor interaction between control factors A and B.
F_{B0}’and F_{C0}’ are not influenced in the presence of control factor interaction between control factors B and C.
F_{A0}’and F_{C0}’ are not influenced in the presence of control factor interaction between control factors A and C.

interaction. For this, the algorithm used the properties present in the orthogonal array. For instance, in Table 1, control factors *A*, *B* and *C* were defined and two levels for each factor were defined as A_1, A_2, B_1, B_2, C_1 and C_2 respectively. The L4 orthogonal table shown uses the control factors and those levels for DOE. The function *F* is the final result of the experiment or the CAE simulations in DOE and is included in the orthogonal table. The mathematical model in equation (1) defined function *F* as,

$$F_L = 5A_S + 2B_T + 3C_M - 0.1\, A_S\, B_T \qquad (1)$$

In this case the equation is set so that A_S and B_T are the control factors with control factor interaction of a certain magnitude (0.1). The terms *S*, *T*, *M* could take a value of 1 or 2 and the term *L* could take values from 1 to 4. The relationship between the control factors and the final function was “$F_L = 5A_S + 2B_T + 3C_M$”. However, this relationship is affected by the control factor interaction, described as “$-\ 0.1\, A_S\, B_T$” in equation (1). This equation is supposed to yield the most desirable conditions when the final function *F* is obtained. Therefore the minus value “$-$” is used for the control factor interaction calculation. Final functions F_{A1}, F_{A2}, F_{B1}, F_{B2}, F_{C1} and F_{C2} for levels A_1, A_2, B_1, B_2, C_1 and C_2 was calculated by equations (2) due to the orthogonal table properties.

$$\left.\begin{aligned} F_{A1} &= (F_1 + F_2)/2 \\ F_{A2} &= (F_3 + F_4)/2 \\ F_{B1} &= (F_1 + F_3)/2 \\ F_{B2} &= (F_2 + F_4)/2 \\ F_{C1} &= (F_1 + F_4)/2 \\ F_{C2} &= (F_2 + F_3)/2 \end{aligned}\right\} \qquad (2)$$

When each level value for the control factors *A*, *B* and *C* is set to be zero “0”, the final functions F_{A0}, F_{B0} and F_{C0} can be approximated by equation (3) as depicted in Fig. 1.

$$\left.\begin{aligned} F_{A0} &= F_{A1} - \frac{F_{A2} - F_{A1}}{A_2 - A_1}\ A_1 \\ F_{B0} &= F_{B1} - \frac{F_{B2} - F_{B1}}{B_2 - B_1}\ B_1 \\ F_{C0} &= F_{C1} - \frac{F_{C2} - F_{C1}}{C_2 - C_1}\ C_1 \end{aligned}\right\} \qquad (3)$$

Even though the number of each level was only two and poses a simple calculation, when the number becomes larger an array setup would be more convenient. From here, six trials, as shown in Table 2, to define control interaction cases were performed. On the other hand, except for the level value = 0, the other levels kept the orthogonal property when looking for control factor interaction as shown in Table 2. Here, when the control factor level in *A*, *B* and *C* was set as zero “0”, the resultant final functions were denominated as $F_{A0'}$, $F_{B0'}$ and $F_{C0'}$ and were calculated by the equation (4) on the new trials.

$$\left.\begin{aligned} F_{A0}' &= (F_{A01}' + F_{A02}')/2 \\ F_{B0}' &= (F_{B01}' + F_{B02}')/2 \\ F_{C0}' &= (F_{C01}' + F_{C02}')/2 \end{aligned}\right\} \qquad (4)$$

In Table 3, it can be observed that, as zero values were set in Table 2, F_{A0}’and F_{B0}’ have no control factor interaction with *A*

Table 4 Control factor interaction assessment criteria

Conditions	Control factor interaction
$F_{A0}' = F_{A0}$, $F_{B0}' = F_{B0}$ and $F_{C0}' = F_{C0}$	No interaction
$F_{A0}' = F_{A0}$, $F_{B0}' = F_{B0}$ and $\boldsymbol{F_{C0}' \neq F_{C0}}$	Control factor interaction between control factors A and B.
$\boldsymbol{F_{A0}' \neq F_{A0}}$, $F_{B0}' = F_{B0}$ and $F_{C0}' = F_{C0}$	Control factor interaction between control factors B and C.
$F_{A0}' = F_{A0}$, $\boldsymbol{F_{B0}' \neq F_{B0}}$ and $F_{C0}' = F_{C0}$	Control factor interaction between control factors A and C.

and *B*; F_{B0}'and F_{C0}' have no control factor interaction with *B* and *C*; and F_{A0}'and F_{C0}' have no control factor interaction with control factors A and C.

Finally, the calculated final functions F_{A0}, F_{B0} and F_{C0} were compared with the trial final functions $F_{A0'}$, $F_{B0'}$ and $F_{C0'}$ respectively. Here, the control factor interaction and the control factors under reciprocal interaction can be determined under the criteria shown in Table 4.

B. Final Stage Evaluation Through Defined Mathematical Models

In the previous algorithm for control factor interaction determination was evaluated by using several simple mathematical models such as equation (1). The tool was able to determine control factor interactions in DOE [4], and the defined assessment criteria allowed the relationship between the influence magnitude and the control factor interaction estimation to be handled to a certain degree [4].

III. Evaluation Through More Detailed Models

A. Evaluation Through A Cubic Equation Model

Here, a more complex model was used for evaluation of the algorithm. The mathematical model using equation (5) was then used.

$$F_L = 0.05A_S{}^3 + 0.02B_T{}^3 + 0.03C_M{}^3 - 0.1\,A_S\,B_T$$
(Where L= A, B or C. S, T and M = 1, 2, 3 or 4.) (5)

Table 5 Control factors

Control factor	Level 1	Level 2	Level 3	Level 4
A	1	5	9	13
B	20	30	40	50
C	3	9	15	21

Table 6 Orthogonal array and functions

L16	Control factor			Function *F*
	A	B	C	
No.1	1	20	3	158.9
No.2	1	30	9	558.9
No.3	1	40	15	1377.3
No.4	1	50	21	2772.9
No.5	5	20	9	178.1
No.6	5	30	3	532.1
No.7	5	40	21	1544.1
No.8	5	50	15	2582.5
No.9	9	20	15	279.7
No.10	9	30	21	827.3
No.11	9	40	3	1281.3
No.12	9	50	9	2513.3
No.13	13	20	21	521.7
No.14	13	30	15	712.1
No.15	13	40	9	1359.7
No.16	13	50	3	2545.7

This cubic equation consists of the control factors *A*, *B* and *C*. Here, the control factors *A* and *B* influence to the control factor interaction final function. The control factors, levels and each level value are shown in Table 5. As 4 sets of the combination between the control factors and the final function are required for solution of the cubic equation, the control factors used 4 levels. The final result functions *F* were calculated using the equation (5) and (Orthogonal L_{16}) Table 5 (See Table 6).

Then the calculated final functions F_{A0}, F_{B0} and F_{C0} can be calculated by equations (2), (3) and Table 6, and the final functions $F_{A0'}$, $F_{B0'}$ and $F_{C0'}$ can be calculated by equation (4), Tables 2 and Table 3 with a new set of trials. Then, the calculated final functions F_{A0}, F_{B0} and F_{C0} were compared with the final functions $F_{A0'}$, $F_{B0'}$ and F_{C0} as shown in Table 7. It was concluded from Table 7 that control factors *A* and *B* had a control factor interaction and that the algorithm can determine it, as well as the involved control factors (*A* and *B)*.

Then two additional mathematical models were used for evaluation. In the two models, the control factors *A* and *C*, or the control factors *B* and *C* influence to the control factor interaction final function, and the coefficients of the involved control factor interactions were changed. Those results were shown in Tables 8 and 9. It was concluded from those tables that

Table 7 Evaluation results using eq. (5) (Control factor interactionbetween the control factors A and B)

The used model: $F_L = 0.05As^3 + 0.02B_T{}^3 + 0.03C_M{}^3 - 0.1A_SB_T$ (Where L=A,B or C S,T and M=1,2,3 or 4)			
F_{A0}= 1220.4	F_{A0}'= 1220.4	Equal	Assessment: **Control factors A and B have control factor interactions (see Table 4)**
F_{B0}= 138.6	F_{B0}'= 138.6	Equal	
F_{C0}= 1131.7	F_{C0}'= 1128.7	Not Equal	

Table 8 Evaluation results using new model (Control factor interaction between the control factors A and C)

The used model: $F_L = 0.05As^3 + 0.02B_T{}^3 + 0.03C_M{}^3$ $-0.2A_SC_M$ (Where L=A,B or C S,T and M=1,2,3 or 4)			
F_{A0}= 1220.4	F_{A0}'= 1220.4	Equal	Assessment: **Control factors A and C have control factor interactions (see Table 4)**
F_{B0}= 163.8	F_{B0}'= 115.8	Not Equal	
F_{C0}= 1158.2	F_{C0}'= 1158.2	Equal	

Table 9 Evaluation results using new model (Control factor interaction between the control factors B and C)

The used model: $F_L = 0.05As^3 + 0.02B_T{}^3 + 0.03C_M{}^3$ $-0.3B_TC_M$ (Where L=A,B or C S,T and M=1,2,3 or 4)			
F_{A0}= 1076.7	F_{A0}'= 1071.9	Not Equal	Assessment: **Control factors B and C have control factor interactions (see Table 4)**
F_{B0}= 138.6	F_{B0}'= 138.6	Equal	
F_{C0}= 1158.2	F_{C0}'= 1158.2	Equal	

the control factors *A* and *C*, or the control factors *B* and *C* had control factor interactions.

In addition, the control factor interactions were confirmed in the several cases as follows; when the mathematical models were quadratic equations, and when the mathematical models were cubic equations with a quadratic and a linear terms, the coefficients of the control factor were changed and level numbers of the control factor were increased for evaluation.

B. Evaluation Through Mathematical Models With One Control Factor Interaction Between Three Control Factors

As previously developed, a complex model of cubic nature was used for the evaluation of the algorithm. The mathematical model using equation (6) was then used.

$$F_L = 0.395A_S^3 + 0.941B_T^3 + 0.013C_M^3 + 0.509\,D_N^3 + 0.981\,E_O^3 - B_T C_M D_N \qquad (6)$$

(Where L= A, B, C, D or E. S, T, M, N and O = 1, 2, 3 or 4.)

Table 10 Control factors

Control factors	Level 1	Level 2		Level 3	Level 4
A	2.36	4.72		7.08	9.44
B	1.18	2.36		3.54	4.72
C	4.08	8.16		12.24	16.32
D	5.49	10.98		16.47	21.96
E	6.03	12.06		18.09	24.12

Table 11 Orthogonal array and functions

L16	Control factors					Functions
	A	B	C	D	E	*F*
No.1	2.36	1.18	4.08	5.49	6.03	280.50
No.2	2.36	2.36	8.16	10.98	12.06	2207.69
No.3	2.36	3.54	12.24	16.47	18.09	7438.62
No.4	2.36	4.72	16.32	21.96	24.12	17625.17
No.5	4.72	1.18	8.16	16.47	24.12	15931.38
No.6	4.72	2.36	4.08	21.96	18.09	11041.10
No.7	4.72	3.54	16.32	5.49	12.06	1627.56
No.8	4.72	4.72	12.24	10.98	6.03	418.86
No.9	7.08	1.18	12.24	21.96	12.06	6959.44
No.10	7.08	2.36	16.32	16.47	6.03	2063.85
No.11	7.08	3.54	4.08	10.98	24.12	14463.80
No.12	7.08	4.72	8.16	5.49	18.09	5926.41
No.13	9.44	1.18	16.32	10.98	18.09	6660.12
No.14	9.44	2.36	12.24	5.49	24.12	14059.91
No.15	9.44	3.54	8.16	21.96	6.03	5352.16
No.16	9.44	4.72	4.08	16.47	12.06	4109.71

Table 12 Evaluation results using eq.(6) (Control factor interaction between the control factors B, C and D)

The used model : $F_L = 0.395A_S^3 + 0.941B_T^3 + 0.013C_M^3 + 0.509\,D_N^3 + 0.981\,E_O^3 - B_T C_M D_N$ (Where L= A, B, C, D or E. S, T, M, N and O = 1, 2, 3 or 4.)			
F_{A0}= 5891.6	F_{A0}'= 6882.8	Not equal	Assessment: **Control factors B, C and D have control factor interactions.**
F_{B0}= 7634.7	F_{B0}'= 7634.7	Equal	
F_{C0}= 7651.3	F_{C0}'= 7651.3	Equal	
F_{D0}= 5567.8	F_{D0}'= 5567.8	Equal	
F_{E0}= 1305.0	F_{E0}'= 1813.8	Not equal	

As shown, the mathematical model has one control factor interaction between three control factors. This cubic equation utilized control factors *A*, *B*, *C*, *D* and *E*. Here, the control factors *B*, C and *D* influence to the control factor interaction final function. The control factors, levels and each level value are shown in Table 10. As 4 sets of the combination between the control factors and the final function are required for solution of the cubic equation, the control factors were used 4 levels. The final result functions *F* were calculated using the equation (6) and (Orthogonal L_{16}) Table 10 (See Table 11).

Then the calculated final functions F_{A0}, F_{B0}, F_{C0}, F_{D0} and F_{E0} were calculated by equations (2), (3) and Table 11, and the final functions F_{A0}', F_{B0}', F_{C0}', F_{D0}' and F_{E0}' were calculated by equation (4), Tables 2 and Table 3 with a new set of trials. Then, the calculated final functions F_{A0}, F_{B0}, F_{C0}, F_{D0} and F_{E0} were compared with the final functions F_{A0}', F_{B0}', F_{C0}', F_{D0}' and F_{E0}' as shown in Table 12. It was concluded from Table 12 that the control factors *B*, *C* and *D* had a control factor interaction and that the algorithm was able to determine the interaction and the involved control factors (*B*, *C* and *D*).

However, it was observed that when the control factor interaction $B_T C_M D_N$ in the equation (6) was changed to $A_S B_T C_M$ or $A_S B_T E_O$, in equations (7) or (8), the final results became indistinguishable as shown in Tables 13 and 14.

$$F_L = 0.395A_S^3 + 0.941B_T^3 + 0.013C_M^3 + 0.509\,D_N^3 + 0.981\,E_O^3 - A_S B_T C_M \qquad (7)$$

$$F_L = 0.395A_S^3 + 0.941B_T^3 + 0.013C_M^3 + 0.509\,D_N^3 + 0.981\,E_O^3 - A_S B_T E_O \qquad (8)$$

(Where L= A, B, C, D or E. S, T, M, N and O = 1, 2, 3 or 4.)

Table 13 Evaluation results using other model (Control factor interaction between the control factors A, B and C)

The used model : $F_L = 0.395A_S^3 + 0.941B_T^3 + 0.013C_M^3 + 0.509\,D_N^3 + 0.981\,E_O^3 - A_S B_T C_M$ (Where *L*= A, B, C, D or E. *S*, *T*, *M*, *N* and *O* = 1, 2, 3 or 4.)			
F_{A0}= 7634.5	F_{A0}'= 7543.6	Not equal	Assessment: **Indistinguishable**
F_{B0}= 7725.6	F_{B0}'= 7634.7	Not equal	
F_{C0}= 7742.2	F_{C0}'= 7651.3	Not equal	
F_{D0}= 5190.0	F_{D0}'= 5360.4	Not equal	
F_{E0}= 1918.3	F_{E0}'= 2088.8	Not equal	

Table 14 Evaluation results using other model (Control factor interaction between the control factors A, B and E)

The used model : $F_L = 0.395A_S^3 + 0.941B_T^3 + 0.013C_M^3 + 0.509\,D_N^3 + 0.981\,E_O^3 - A_S B_T E_O$ (Where *L*= A, B, C, D or E. *S*, *T*, *M*, *N* and *O* = 1, 2, 3 or 4.)			
F_{A0}= 7006.2	F_{A0}'= 7543.6	Not equal	Assessment: **Indistinguishable**
F_{B0}= 7769.1	F_{B0}'= 7634.7	Not equal	
F_{C0}= 7072.0	F_{C0}'= 7311.3	Not equal	
F_{D0}= 4988.4	F_{D0}'= 5227.7	Not equal	
F_{E0}= 2430.5	F_{E0}'= 2296.1	Not equal	

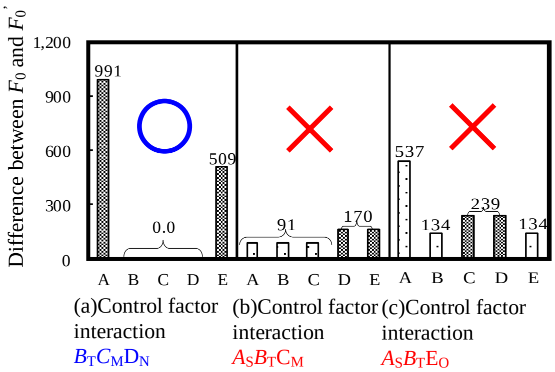

Fig.2 Difference between the function F_0 at level value = 0 using the approximate equation and the function F_0' by new trial using the value of level 1= 0.

As a result, it was decided to use the mathematical models shown in equations (6), (7) and (8) for the evaluation of the previous algorithm. The results of said evaluation are shown in Fig. 2. It was concluded that the interaction with control factors *B*, *C* and *D* in equation (6) was determined by the previous algorithm, but the interaction with of control factors *A*, *B* and *C* in equation (7) and the interaction of control factors *A*, *B* and *E* in equation (8) were not identifiable. This, since in equations (7) and (8), set at level value = zero "0", the final functions F_{A0}, F_{B0} and F_{C0} were calculated by equation (3) a comparison with final functions $F_{A0'}$, $F_{B0'}$ and $F_{C0'}$ calculated by equation (4) was not possible.

IV. Improvement of The Algorithm and Its Evaluatio

As the presented limitation of the algorithm needs to be addressed the following must be observed. The control factor A in the presented orthogonal array (Table 11) could not calculate with precision the final function at the level value = 0, and the difference between F_0 and $F_0{}'$ on the control factors A, B and C in Fig. 2 (b) and on the control factors A, B and E in Fig. 2 (c) were not 0. This can be asserted because, in this case, the angle of the approximation curve was not 0. Therefore, it was concluded that both the control factor interaction with the control factors *A*, *B* and *C* in equation (7) and the control factor interaction with the control factors *A*, *B* and *E* in equation (8) were not possible to detect with the previous algorithm. Here, in order to corroborate the previous results two orthogonal arrays were devised as shown in Table 16. The first orthogonal array, located in the left, was set to have control factor level values that were selected in a random fashion and zero "0" values were located in a way similar as in the previous algorithm. The second orthogonal array, located in the right, was systematically set to have control factor level values in ascending order (1 to 4). Then, the mathematical models using equations (6), (7) and (8) were used for the evaluation of the improved algorithm. Here, the values and functions *F* shown in Table 11 were used. Subsequently, the final functions F_0 (=F_{A0}, F_{B0}, F_{C0}, F_{D0} and F_{E0}) can be calculated by equations (2) and (3).

In order to compare the new orthogonal arrays as the difference between F_0 and $F_0{}'$, F_0 was described by Table 15, $F_{0\text{-}1}$' (= $F_{A0\text{-}1}$', $F_{B0\text{-}1}$', $F_{C0\text{-}1}$', $F_{D0\text{-}1}$' and $F_{E0\text{-}1}$') described the left orthogonal array in Table 16 and $F_{0\text{-}2}$' (= $F_{A0\text{-}2}$', $F_{B0\text{-}2}$', $F_{C0\text{-}2}$', $F_{D0\text{-}2}$' and $F_{E0\text{-}2}$') described the right orthogonal array in Table 16. The final functions $F_{0\text{-}1}$' and $F_{0\text{-}2}$' were can be calculated by equation (4) with a new set of trials. Upon comparison it was observed that independently, the differences between F_0 and $F_{0\text{-}1}$', the differences between F_0 and $F_{0\text{-}2}$', shown in Fig. 3, still offered an undistinguishable control factor interaction assessment. However, it was also observed that the results of said differences were the same. Here, it was considered that a subtraction between both orthogonal array differences could lead to a final assessment of control factor interaction in complex control factor arrangements as represented by the

Table 15 Basic orthogonal arrays with L16

No.	Factor				
	A	B	C	D	E
No.1	1	1	1	1	1
No.2	1	2	2	2	2
No.3	1	3	3	3	3
No.4	1	4	4	4	4
No.5	2	1	2	3	4
No.6	2	2	1	4	3
No.7	2	3	4	1	2
No.8	2	4	3	2	1
No.9	3	1	3	4	2
No.10	3	2	4	3	1
No.11	3	3	1	2	4
No.12	3	4	2	1	3
No.13	4	1	4	2	3
No.14	4	2	3	1	4
No.15	4	3	2	4	1
No.16	4	4	1	3	2

Table 16 Confirmation run orthogonal arrays

Random level value OA (**$F_{0\text{-}1}$'**)						Ascending level value OA (**$F_{0\text{-}2}$'**)					
No.	Factor					No.	Factor				
	A	B	C	D	E		A	B	C	D	E
No.1	0	1	1	1	1	No.1	0	1	1	1	1
No.2	0	2	2	2	2	No.2	0	2	2	2	2
No.3	0	3	3	3	3	No.3	0	3	3	3	3
No.4	0	4	4	4	4	No.4	0	4	4	4	4
No.5	1	0	1	1	1	No.5	1	0	1	1	1
No.6	2	0	2	3	4	No.6	2	0	2	2	2
No.7	3	0	3	4	2	No.7	3	0	3	3	3
No.8	4	0	4	2	3	No.8	4	0	4	4	4
No.9	1	1	0	1	1	No.9	1	1	0	1	1
No.10	2	2	0	4	3	No.10	2	2	0	2	2
No.11	3	3	0	2	4	No.11	3	3	0	3	3
No.12	4	4	0	3	2	No.12	4	4	0	4	4
No.13	1	1	1	0	1	No.13	1	1	1	0	1
No.14	2	3	4	0	2	No.14	2	2	2	0	2
No.15	3	4	2	0	3	No.15	3	3	3	0	3
No.16	4	2	3	0	4	No.16	4	4	4	0	4
No.17	1	1	1	1	0	No.17	1	1	1	1	0
No.18	2	4	3	2	0	No.18	2	2	2	2	0
No.19	3	2	4	3	0	No.19	3	3	3	3	0
No.20	4	3	2	4	0	No.20	4	4	4	4	0

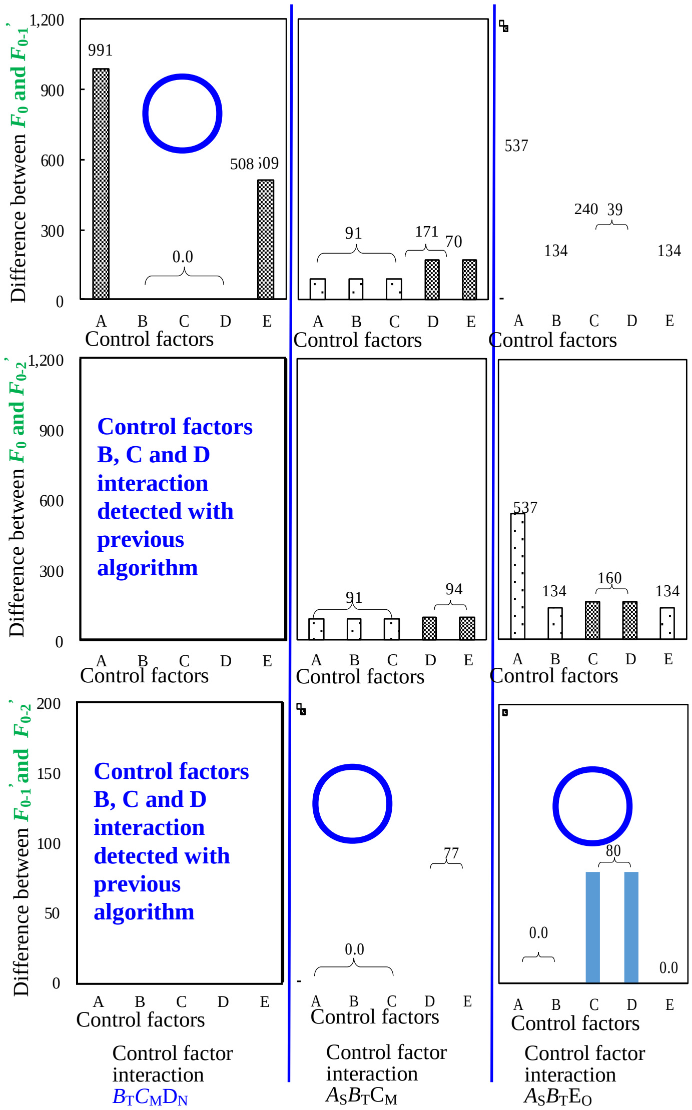

Fig.3 Results for the assessment of the control factor interactions using an improved algorithm for equations (6), (7) and (8)

difference between F_{0-1}' and F_{0-2}' in Fig. 3. Consequently, it was concluded that control factors B, C and D had an interaction in equation (6), control factors A, B and C had an interaction in equation (7), control factors A, B and E had an interaction in equation (8) and that the improved algorithm can determine the interactions and the involved factors $B_TC_MD_N$ in equation (6), $A_SB_TC_M$ in equation (7) or $A_SB_TE_O$ in equation (8).

V. Conclusion

It was concluded that,

(1) An improved tool for the determination of control factor interactions in the DOE and the Taguchi Method was developed.

(2) The tool was able to detect previously indistinguishable complex control factor interactions present in the DOE or the Taguchi Methods.

(3) A new algorithm was able to determine complex control factor interactions in models between control factors and functions.

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