

A Case Study to Setup Optimum Process Parameters in Thermal Deburring for Removing the Burr in Barrel of Fuel Injector Pump Using Taguchi Approach.

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Abstract— Deburring is the finishing technique that is very essential for the manufacturing of precise components. Deburring process with greater efficiency and full automation is an extremely difficult task. Thermal deburring offers a potential solution to such problems. For successful utilization of thermal deburring, more intensive research including parameters analysis of the process is still required. The parameters which affect the performance of thermal deburring are mixture ratio of oxygen & hydrogen gas, pressure of oxygen & hydrogen gas mixture, Impulse of the chamber and size of the burr. A case study is conducted to find the optimum process parameters for thermal deburring using taguchi approach..

Key words— Deburring, Thermal deburring, Optimization, Taguchi approach

I. INTRODUCTION

Burr is the undesirable projection of material formed as the result of plastic flow from a cutting or shearing operation (Ko and Dornfeld, 1991)[1]. Although burrs were considered a secondary operation within the machine processes, several aspects have been modifying the way burrs are handled during the machine processes. Deburring processes have been identified as the bottleneck in many machine industries (Balasubramaniam et al, 1998)[2]. The burr removal methods can induce dimensioning errors to the work piece if improperly executed (Dornfeld and Lisiewicz,1992)[3]. Finally, burrs may cause problems in further processes, such as handling and assembling operations. There is no standard procedure to remove burrs having different shape and dimensions. For removing burrs of different sizes and shapes, there are number of conventional processes available. Conventional deburring processes necessitate time, labour and other associated costs. Thermal deburring is found to offer the potential solution to these problems(ASM Handbook Volume 16, Machining 1990)[4].

Thermal Deburr (TD), as the name implies, is a manufacturing process utilizing heat energy to remove burrs. They are placed inside a very thick walled steel chamber. The sealed chamber is pressurized with a mixture of combustible gas. The gaseous mixture is ignited with an electric ignition device creating a powerful explosion. The explosion creates a very intense heat approaching several thousand degrees Fahrenheit within fractions of a second. This intense heat energy will attack anything with a high surface area to mass ratio.

Thermal deburring machine is the best solution for removing all internal and external burrs simultaneously in a single operation(Kennametal Extrude Hone,GmbH)[5]. Thermal deburring is unique among material removal processes primarily because it removes burrs and flash simultaneously throughout the work piece, including internal and external locations. (WWW.EXTRUDEHONE.COM)[6].

Thermal Deburring will not change any dimensions, surface finishes, or material properties of the parent part when performed properly with adequate fixtures.(John Halladay, 2011)[7].However it is important to find out the optimal process parameters that are capable of removing high amount of burr.

A case study has been conducted at M/s Bosch Ltd. Bangalore to reduce the rejection of barrel by using the thermal deburring method and to setup optimum process parameters using Taguchi approach.

The high pressure fuel injector pump performs its function through pumping elements consisting of a number plunger/barrel assemblies corresponding to a number of cylinders in a given engine. Fuel delivered by the supply pump flows through a fuel gallery along the length of high pressure pump and is introduced into plunger or barrel assembly via one or two fill ports. Fuel delivered by the supply pump flows through a fuel gallery along the length of high pressure pump and is introduced into plunger or barrel assembly via one or two fill ports.

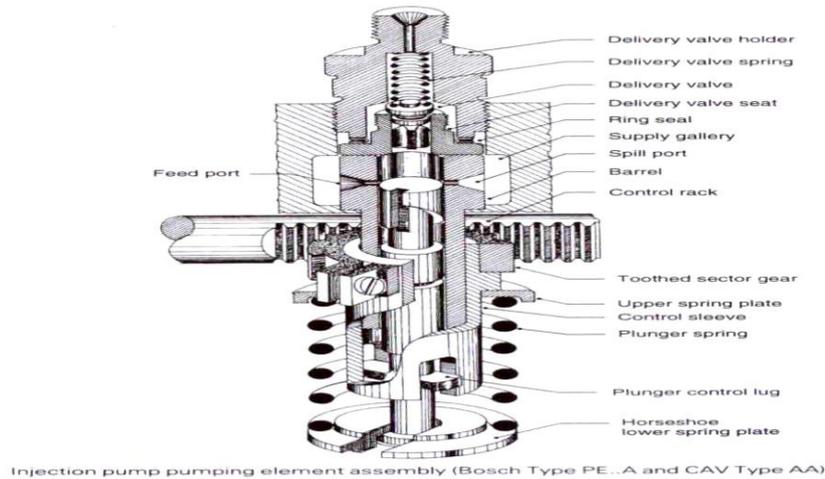


Fig. 1 Fuel injector pump

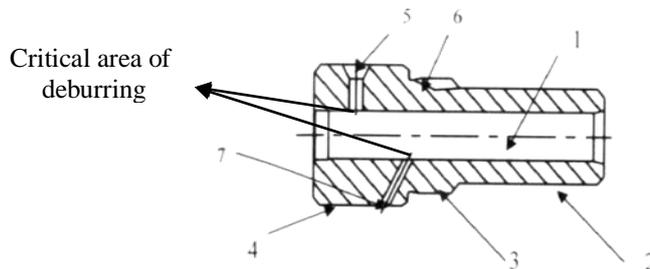


Fig. 2 Barrel

1. Barrel

The parts of Barrel are,

1. Main Bore.
2. Shaft
3. Step
4. Collar
5. Inlet hole
6. Fixing slot
7. Leak oil hole/excess oil vent

It is a component inside which plunger reciprocates. The barrel consists of two parts one is head portion and another is shaft portion. It has an inlet port and a bypass port (spill port). When the plunger is at BDC, fuel enters into the barrel through inlet port and excess fuel leaks out through spill port.

In this research, thermal deburring of the cross holes of component Barrel is performed. Efforts are taken to optimize the process parameters with considering characteristics like mixture ratio of oxygen & hydrogen gas, pressure of oxygen & hydrogen gas mixture, Impulse of the chamber and size of the burr. Verification experiment is carried out additionally to verify the predicted results at optimum level.

II. LITERATURE REVIEW

Deburring is considered to be very integral part of any machining or manufacturing process. Any process where there is a shearing or cutting or machining operation, burrs are automatically formed due to these process. There are many ways of deburring to remove the burr, they are conventional deburring process namely manual deburring, hand deburring etc and non-conventional deburring process like thermal deburring, electrochemical deburring, abrasive jet deburring etc. Now let us consider few of them,

2.1 Magnetic abrasive finishing method (MAF):

MAF is based on the magnetization property of ferromagnetic iron and the machining property of abrasives, the limitations of this process is that it Leaves behind abrasion marks on the surface of the deburred part. [9]

2.2 Thermal energy method (TEM):

TEM also known as thermal deburring, it deburrs multiple surfaces at the same time.. It is the fastest burr removal process, requiring only 20 milliseconds to remove a burr. Its limitations are Initial investment is high.[10]

2.3 Cryogenic deburring:

Cryogenic deburring is a cryogenic process work at low temperatures (approximately -195 C (-319.0 °F)) is achieved using liquid nitrogen, liquid carbon dioxide, or dry ice. Its are Brittleness property of the material increase and micro cracks are formed on the surface [11].

2.4 Manual deburring:

Manual deburring results in inconsistent quality. Repeatability is hard to achieve as it is done manually [12].

2.5 Electro-chemical deburring (ECD):

ECD can be used to deburr on a particular area , while the rest of the work piece is unaffected. It has its Limitations; Operation time is high compared to other methods. Higher burr height means more deburring time.[13]

2.6 Design of Experiments (DOE):

DOE ,Taguchi (1991) method is a widely used approach for robust design, which utilizes an orthogonal array (OA) to obtain dependable information about the design parameter with minimum time and resources, and adopts signal-to-noise (S/N) ratio to interpret experimental data and optimize performance. [14]

III. PROBLEM DEFINITION

The present reamer tool deburring operation of the cross holes of the barrels causes lines/patches on the inside of the bore which is a major causes for rejection in about nearly 13% rejection of the barrels. There is a scope for improvement for reducing rejection by changing the deburring process to thermal deburring and finding the optimal process parameters for conducting thermal deburring operation.

IV. METHODOLOGY

Conducting an experimentation to find out the optimal process parameters for Thermal deburring process.

The experiment is conducted by varying different controllable parameters such as mixture ratio of oxygen & hydrogen gas (O₂+H), pressure of oxygen & hydrogen gas(O₂+H), mixture, Impulse of the chamber and size of the burr.

4.1 Design of Experiments:

Table 1 Control factors and their levels

Symbol	Factors	Levels		
		Level 1	Level 2	Level 3
A	Mixture ratio of O ₂ +H gas	50 + 50 (O ₂ + H)	40 + 60 (O ₂ + H)	30 + 70 (O ₂ + H)
B	Pressure of O ₂ +H gas mixture	20 bar	24 bar	28bar
C	Impulse of the chamber	100mm	150mm	200mm
D	Size of the burr	Light burr	Medium burr	Heavy burr

A. Mixture ratio of Oxygen and Hydrogen gas is taken from the knowledge of the operator and the supervisor of the thermal deburring machine.

B. The pressure of oxygen and hydrogen gas mixture is taken from 20 bar, 24 bar and 28 bar.

20 bar is the minimum pressure that is available in the machine.
 24 bar is the middle value of the upper and lower pressure.
 28 bar is the maximum pressure that is available in the machine.

C. Impulse of the chamber can be taken from the 100 mm to 200 mm.
 100 mm is the minimum length of the chamber.
 150 mm is the middle value of the chamber length.
 200 mm is the maximum length of the chamber.

D. Size of the burr



Fig 3(a) Heavy burr



Fig 3(b) Medium burr



Fig 3(c) Light burr

4.2 Selecting an Orthogonal Array:

For 3 levels and 4 factors (3^4), L9 orthogonal array is selected which consists 9 set of experiments. Table 2 shows the L9OA(Orthogonal array)

Table 2 L9OA for 3 levels and 4 factors

Exp no	column			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1
factors	A	B	C	D

A=Mixture ratio of O₂+H, **B**=Pressure of O₂+H gas mixture(bar), **C**=Impulse of the chamber(mm), **D**=size of the burr.

The experiment is conducted as per ANOVA table. In each trial 300 barrels are deburred. For each experiment 2 trials were conducted. The number of components accepted after the thermal deburring is noted down.

Table 3 Experimental trial

Exp no.	Factors				No. Of components accepted for a batch of 300		Average of trials
	A	B	C	D	Trial 1	Trial 2	
1	A1	B1	C1	D1	251	253	252
2	A1	B2	C2	D2	253	257	255
3	A1	B3	C3	D3	233	241	237
4	A2	B1	C2	D3	241	245	243
5	A2	B2	C3	D1	258	264	261
6	A2	B3	C1	D2	252	258	255
7	A3	B1	C3	D2	247	251	249
8	A3	B2	C1	D3	250	254	252
9	A3	B3	C2	D1	272	274	273

4.3 Analysis:

ANOVA table is used for analysis which consists of sum of squares, mean of sum of squares variance and percent contribution i.e., SS, MS, F&P.

Table 4: sum of trials

Experiment no.	Trial 1	Trial 2	Sum of trials
1	251	253	504
2	253	257	510
3	233	241	474
4	241	245	486
5	258	264	522
6	252	258	510
7	247	251	498
8	250	254	504
9	272	274	546

Total sum of observations, T = 4554

Number of experiments, N = 18

Average of total sum of observation $\bar{T} = \frac{T}{N}$ (4.1)

$\bar{T} = 4554/18 = \bar{T} = 253$

4.4 Sum of square:

The sum of squares is a measure of the deviation of the experimental data from the mean value of the data. Summing each squared deviation emphasizes the total deviation. The sum of squares (SS_A) analysis for the factors and total variation is determined in table 5.

Total sum of squares, $SS_T = [\sum_{i=1}^n Y_i^2] - T^2/N$ (4.2)

$SS_T = 251^2 + 253^2 + 253^2 + 257^2 + 233^2 \dots - \frac{(4554)^2}{18}$

$SS_T = 1796$

Table 5 Sum of squares

Factors	Levels			Number of experiments	Sum of Squares
	1	2	3		
A	1488	1518	1548	6	$SS_A = [\sum_{i=1}^{ka} \left(\frac{A_i^2}{nA_i}\right)] - \frac{T^2}{N} = \frac{A1^2}{nA1} + \frac{A2^2}{nA2} + \frac{A3^2}{nA3} - \frac{T^2}{N} = 300$
B	1488	1536	1530	6	$SS_B = [\sum_{i=1}^{kb} \left(\frac{B_i^2}{nB_i}\right)] - \frac{T^2}{N} = \frac{B1^2}{nB1} + \frac{B2^2}{nB2} + \frac{B3^2}{nB3} - \frac{T^2}{N} = 228$
C	1518	1542	1494	6	$SS_C = [\sum_{i=1}^{kc} \left(\frac{C_i^2}{nC_i}\right)] - \frac{T^2}{N} = \frac{C1^2}{nC1} + \frac{C2^2}{nC2} + \frac{C3^2}{nC3} - \frac{T^2}{N} = 192$
D	1572	1518	1464	6	$SS_D = [\sum_{i=1}^{kd} \left(\frac{D_i^2}{nD_i}\right)] - \frac{T^2}{N} = \frac{D1^2}{nD1} + \frac{D2^2}{nD2} + \frac{D3^2}{nD3} - \frac{T^2}{N} = 972$

Error,

Since, $SS_T = SS_A + SS_B + SS_C + SS_D + SSe$ (4.3)

$SSe = SS_T - SS_A - SS_B - SS_C - SS_D$

$SSe = 1796 - 300 - 228 - 192 - 972$

$SSe = 104.$

4.5 Degree of freedom (DOF):

Total degree of freedom, $V_T = N - 1$ (4.4)

$V_T = 18 - 1 = 17$

Table 6: Degree of Freedom

Factors	DOF
A (V_A)	2
B (V_B)	2
C (V_C)	2
D (V_D)	2

For error, V_e

$V_e = V_T - V_A - V_B - V_C - V_D = 9$ (4.5)

4.6 Mean square deviation (MS):

Mean square deviation is the ratio of sum of squares to the degrees of freedom of the respective data.

Table 7: Mean square deviation

Factors	Mean square deviation
A	$MS_A = \frac{SS_A}{V_A} = 150$
B	$MS_B = \frac{SS_B}{V_B} = 114$
C	$MS_C = \frac{SS_C}{V_C} = 96$
D	$MS_D = \frac{SS_D}{V_D} = 486$
Error	$MSe = \frac{SS_e}{V_e} = 11.55$

4.7 F-test/ Variance ratio:

F-test/ variance is used to measure the significance of the factor under investigation with respect to the mean square of all the factors included in the error term.

Table 8: F-test/ Variance ratio

Factors	F-test/ variance ratio
A	$F_A = \frac{MS_A}{MSe} = 13.04$
B	$F_B = \frac{MS_B}{MSe} = 9.9$
C	$F_C = \frac{MS_C}{MSe} = 8.34$
D	$F_D = \frac{MS_D}{MSe} = 42.27$

4.8 Pure sum of squares:

Factor i , $SS'_i = SS_i - (MSe \times V_i)$, where $i=A,B,C,D$ (4.6)

Table 9: Pure sum of squares

Factors	Pure sum of squares
A	277
B	205
C	169
D	949

$$\begin{aligned} \text{Error, } ss'e &= SSe + [MSe(VA+VB+VC+VD)] & (4.7) \\ &= 104 + [11.5 \times (2+2+2+2)] \\ SS'e &= 196 \end{aligned}$$

4.9 Percentage contribution:

The percentage contribution for any factor is obtained by dividing the pure sum of squares for that factor by Total Sum of Squares and multiplying the result by 100. The percentage contribution is denoted by P and can be calculated using the following equations.

Table 10: Percentage contribution

Factor	Percentage contribution
A	$P_A = \frac{SS'A}{SS'T} \times 100 = 15.42\%$
B	$P_B = \frac{SS'B}{SS'T} \times 100 = 11.41\%$
C	$P_C = \frac{SS'C}{SS'T} \times 100 = 9.4\%$
D	$P_D = \frac{SS'D}{SS'T} \times 100 = 52.8\%$
Error	$P_e = \frac{SS'e}{SS'T} \times 100 = 10.91\%$

Table 11: ANOVA

Factors	Degree of freedom	Sum of Squares	Mean Square (MS)	F	Pure sum SS'	Percentage contribution (%)
A	2	300	150	13.04	277	15.42
B	2	228	114	9.9	205	11.41
C	2	192	96	8.34	169	9.4
D	2	972	486	42.26	949	52.8
Err	9	104	11.5	-	196	10.91
Tot	17	1796	857.5	73.54	1796	99.94

4.10 Signal to Noise ratio(S/N ratio):

Taguchi has created a transformation of the repetition data to another value that reflects the amount of variation present. The transformation is the signal to noise ratio. The higher value of S/N ratio is always desirable because greater S/N ratio will result in smaller product variance around the target value.

For Larger the better-type
 $S/N = -10 \log_{10} (\text{MSD})$
 Mean Square Deviation,

$$\text{MSD} = 1/n \sum_{i=1}^n \frac{1}{(y_i)^2} + \frac{1}{(y_2)^2} + \frac{1}{(y_3)^2} \quad (4.8)$$

$$\text{Sum of Squares, SS} = \sum \left(\frac{1}{y^2} + \frac{1}{y_2^2} + \dots \right) \quad (4.9)$$

Where the n=number of repetition, y = value

Table 12: Signal to Noise ratio

Sl. no	Sum of square	Mean square deviation	S/N ratio
1	3.14×10^{-05}	1.57×10^{-05}	48.04
2	3.07×10^{-05}	1.53×10^{-05}	48.15
3	3.56×10^{-05}	1.78×10^{-05}	47.495
4	3.38×10^{-05}	1.69×10^{-05}	47.721
5	2.93×10^{-05}	1.465×10^{-05}	48.341
6	3.07×10^{-05}	1.535×10^{-05}	48.138
7	3.22×10^{-05}	1.61×10^{-05}	47.931
8	3.15×10^{-05}	1.575×10^{-05}	48.04
9	2.68×10^{-05}	1.34×10^{-05}	48.72

4.11 Factors and their individual levels affecting the thermal deburring process are calculated from the L9OA

Table 13: Factors and their levels affecting

Factors	Level 1	Level 2	Level 3
A	248	253	258
B	247	256	255
C	253	257	249
D	262	253	244

For factor A, level 1
 $(Ex1+Ex2+Ex3)/3= (252+255+237)/3=248$

Similarly

For factor A, level 2
 $(Ex4+Ex5+Ex6)/3= (243+261+255)/3= 253$

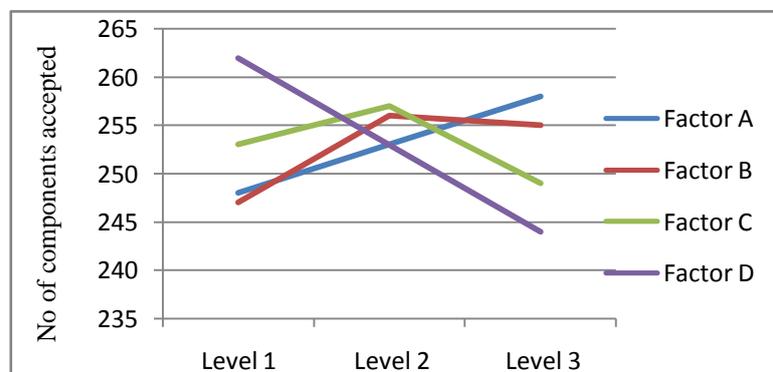


Fig. 4 showing number of components accepted in thermal deburring Vs Factors values as per calculation. From the above graph we the result that A3 B2 C2 D1 are the optimum process parameters for thermal deburring.

4.12 Verification experiment:

After determining the optimum conditions and predicting the response under these conditions, there is an experiment conducted with the optimum parameters and that results are compared with the predictions.

Table 14: Verification experiment

Exp. no.	Factors				No. Of components accepted for a batch of 300 numbers		Average of trials
	A	B	C	D	Trial 1	Trial 2	
1	A3	B2	C2	D1	275	277	276

V. RESULTS AND DISCUSSION

Thermal deburring process in thermal deburring machine, the varying controllable factors are Mixture ratio of Oxygen & Hydrogen gas, Pressure of Oxygen & Hydrogen gas mixture, Impulse of the chamber and Size of the burr. For the four factors and three levels 3^4 the Taguchi's L9 Orthogonal Array is selected and the experiment is conducted. Two sets of trials were conducted for each experiment and in each trial 300 components are deburred. The trials results are shown the table 3. Analysis is done through ANOVA procedure and tabulated in table 11. The parameters A3 B2 C2 D1 are found to be optimal process parameters. From table 11 it is evident that size of the burr contributes more in thermal deburring by 52.8%.

VI. CONCLUSION

The thermal deburring process with major factors affecting are selected as Mixture ratio of Oxygen & Hydrogen gas, Pressure of Oxygen & Hydrogen gas mixture, Impulse of the chamber and Size of the burr, at three different levels are used for conducting the experiment to obtain the optimum condition for thermal deburring process using DOE with Taguchi's method techniques and also the Analysis is carried out using the ANOVA procedure and also the S/N ratio is used for the larger the better type. From all these experiments, calculation and results it is known that out of the four major selected parameters the size of the burr will contribute more in the thermal deburring process. That is with ratio of 30+70 (O₂+H) gas mixture and then with 24 bar pressure of O₂+H gas mixture , with 150mm impulse of the chamber and with light burr the optimum thermal deburring process can be achieved on the thermal deburring machine.

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