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EXPERIMENTAL STUDY OF ELECTRO-CHEMICAL DEBURRING (ECD) PROCESS

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ABSTRACT

Deburring is the finishing technique required for manufacturing of precise components. Deburring process with high efficiency and full automation is an extremely difficult task. Electrochemical deburring (ECD) offers a potential solution to such problems. For successful utilization of ECD in present day manufacturing more intensive research including parametric analysis of the process is still required. In the present research an electrochemical deburring system with its various sub-systems have been successfully developed and a planned 3x3 full factorial experimental design was used to study the effects of the main influencing process parameters on deburring rate and change in burr height. Analysis of variance was carried out to test the effect of the variables at a significance level of 99%. The analysis of the experimental results made in the present research can act as a guide in selecting the best combination of input parameters for a given deburring criteria of SS304 materials.

Keywords: ECD, Deburring rate, Burr height.

1. INTRODUCTION

From various manufacturing operations like machining, trimming, shearing of sheet materials, forging, casting, etc., thin ridges called burrs, usually triangular in shape, may develop along the edge of a workpiece. These burrs, if not eliminated, may prove to be disadvantageous in a number of ways which is not desirable. Noisy and unsafe operation in assembled machine parts may result from the presence of burrs. For the parts moving relative to one another, burrs may lead to deterioration of the edge quality by causing friction and wear and tear as well as may produce noise and vibration. Leakage in hydro-pneumatic systems and short circuits in electrical components may also be caused by existence of burrs. During heat treatment, an edge crack into the parts can lead to breakdown with increasing tensile stress, if burrs are present. Moreover burrs being commonly sharp, may be hazardous to personnel [1, 2]. For removing burrs of various sizes, shapes and properties, a number of conventional burr removal methods are available and generally manual burr removal procedures find application in the industries. Conventional deburring processes require time, labor and other associated costs. Automation is the best way through which efficiency can be realized. But is an extremely difficult problem to make a successful deburring process fully automated and thereby achieve high efficiency. In-Hyu Choi and Jeong-Du Kim [3,4] studied and described the mechanism of electrochemical deburring by using electroplated cubic boron nitride (CBN) wheels. The deburring efficiency and electrochemical performance for deburring of burrs present in an internal cross-hole were also examined.

D. K. Pramanik, R. K. Dasgupta and S. K. Basu [5] investigated the electrochemical deburring process with graphite balls using turned aluminium specimens. Three different types of electrolyte were compared for quality of deburring and metal dissolution rate. M. Abdel Mohsen Mahdy [6] investigated and found out the best combination of drilling , enlarging and chamfering prior to enlarging, which minimizes the obtained burr size. S. J. Ebeid A. M. Abdel Mahboud [7] stated that the non-equilibrium machining processes, where stationary electrodes are utilized, have important practical applications in the fields of deburring and embossing. A comparative study, between rotating and non-rotating electrodes for the enlargement of conventionally pre-drilled holes was presented. S. R. Ghabrial and S. J. Ebeid [8] made a comparative study of stationary electrochemical machining performance with and without pressurized air in the electrolyte under various working conditions. The mixture was shown to improve the accuracy and surface finish, while diminishing sparking and formation of striations and smuts.

It is observed that literature is lacking to say much about the use of ECD for deburring of external burrs on SS304 material and thus it has been realized that there is an immense need for studying and analyzing the effect of various influencing process parameters of ECD of SS304 material in order to achieve the best deburring results.

In the present research, a 3 x 3 full factorial design technique was used to study the effect of different main influencing process parameters such as, voltage, initial inter-electrode gap and deburring time on various deburring criteria such as change in burr height and deburring rate for achieving enhanced deburring characteristics.

2. WORKING PRINCIPLE AND FUNDAMENTAL FEATIRES OF ECD

The principle of electrochemical deburring is exhibited in Fig.1. The ECD process takes place due to anodic dissolution and the deburring rate is mainly governed by the Faraday's laws of electrolysis. In ECD, the machining rate can be kept constant irrespective of the hardness and toughness of the material and physical and chemical properties of the machined surface is not changed after the deburring process. Due to this particular feature of ECD, there is no heat affected zone or residual stress on the workpiece surface. The current density at the peak of the surface irregularities is higher than that is elsewhere. Burrs are therefore removed preferentially, and the workpiece become smoothed. The electrolyte, which is being pumped rapidly through the inter-electrode gap, sweeps away the waste products from the deburring zone. Electrochemical deburring is a very quick process. Due to its speed and simplicity of operation, electrochemical deburring can often be performed with a fixed, stationary tool which acts as the cathode and the work piece acts as the anode. The process finds manifold applications in today's industrial world.

3. EXPERIMENTAL SETUP AND EXPERIMENTAL PROCEDURE

$3NaNO_3 + 3H_2O + 3e + Fe^{3+} \longrightarrow Fe(OH)_3 + 3NaNO_3$

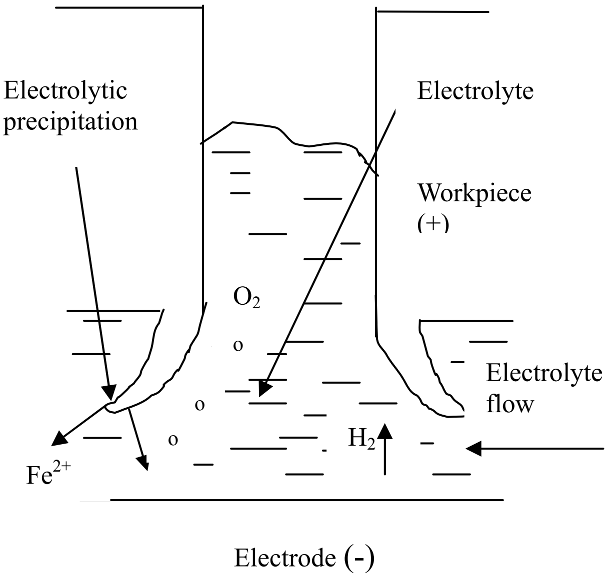

Fig 1. Mechanism of burr removal in ECD process

3.1 Design and Development of theExperimental Setup

The schematic diagram of the developed electrochemical deburring system used in the present research, is shown in Fig.2. Workpiece (SS304) and the deburring tool (copper) are being securely held by a three-jaw chuck and a collet chuck, respectively, with good accuracy. Both the tool and work holding devices are insulated from the main body in order to prevent the main machine body from electric shock and also to focus an electrochemical reaction between tool and workpiece only. In between the tool and the workpiece a sufficient electrolyte flow is necessary to carry away the heat and the products of machining and to assist the deburring process at the required rate by allowing adequate amount of electric current to flow. Both the tool and the workpiece are placed in the machining chamber to avoid the electrolyte splashing over other members of the ECD setup. The work holding device is made of titanium to avoid anodic attack. The metal in contact has been chosen in such a way that they do not differ much in their electrochemical behavior. The slide ways cannot be protected permanently, and so they are heavily coated with grease. The electrolyte flow system consists of a filter, corrosion resistant centrifugal pump, electrolyte storage tank, pressure gauge and flow-measuring device etc. The power supply system is equipped to supply different types of power like plain dc, pulse dc, etc. of different ranges.

3.2 Experimental Procedure

A total of twenty-seven pieces of workpiece were cut from a square bar of SS304 for conducting twenty-seven experimental runs. Burrs were created along the edge of each of these workpiece samples with the help of shaping operation. The initial height and the final height of the burr for each workpiece was measured using a digital micrometer having a least count of 0.0001. The deburring rate was calculated by dividing the change in burr height by the corresponding deburring time elapsed. The electrolyte was pumped into the inter-electrode gap with the help of a centrifugal pump. The deburring voltage and the frequency were adjusted by a DC power supply equipped with inbuilt ammeter, voltmeter and oscilloscope.

4. EXPERIMENTAL DESIGN

The effect of voltage(V), initial inter-electrode gap(G) and machining time(T) on the change in burr height, deburring rate and peak current during the ECD process of SS304 material were studied. Table 1 shows the operating conditions and their descriptions for the ECD process. The coded value and actual value of each parameter used in the present work are listed in Table 2. Table 3 exhibits the experimental design where columns 1, 2 and 3 contain the variable process parameters in coded form and columns 4 and 5 contain the values of the responses obtained from the experiments. For passage from the uncoded to the coded variables used in Tables 2 and 3, the following transformation equations (Eqns.1-4) were used [2].

Deburring voltage,

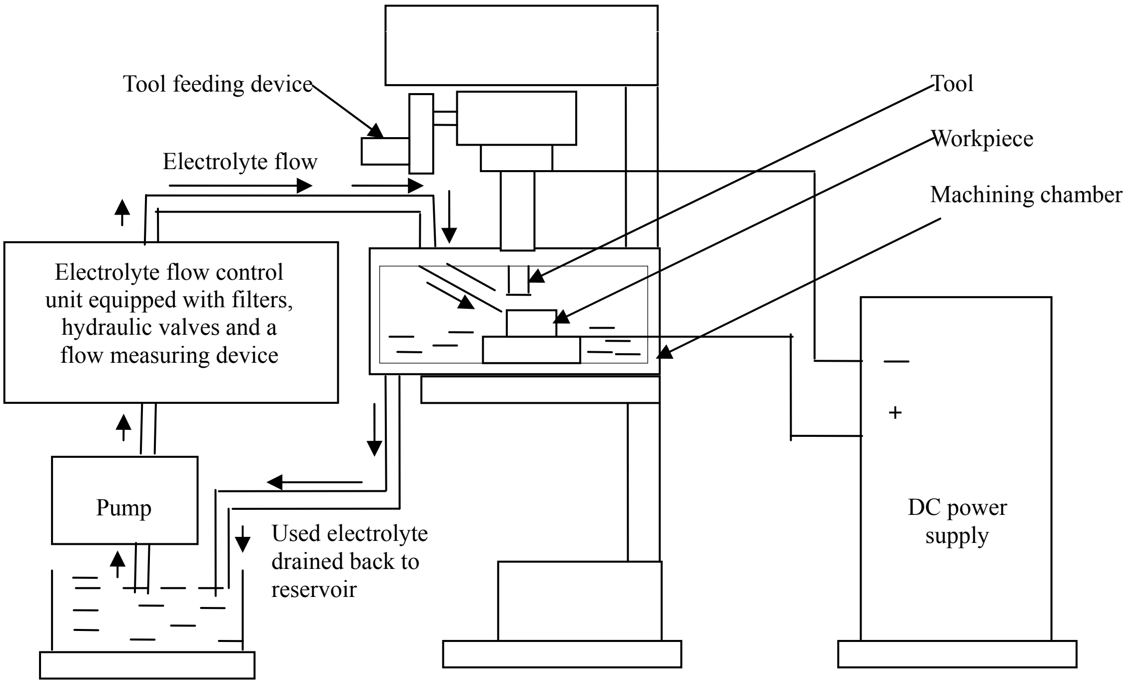

Fig 2. A schematic view of the ECD set up

$$x_1 = \frac{(V - V_0)}{\Delta V} \qquad (1)$$

Initial inter-electrode gap,

$$x_2 = \frac{(G - G_0)}{\Delta G} \qquad (2)$$

Deburring time,

$$x_3 = \frac{(T - T_0)}{\Delta T} \qquad (3)$$

where, x_1, x_2 and x_3 are the coded values of the variables V, G and T respectively. V_0, G_0 and T_0 are the values of voltage, initial inter-electrode gap and machining time at zero level (central level). ΔV, ΔG and ΔT are the intervals of variation in V, G and T respectively.

Table 1: Working conditions for the ECD process

Parameters (working conditions)	**Values / Descriptions**
Workpiece material	SS304
Electrolyte	$NaNO_3$
Electrolyte flow rate	4.5liter/min
Initial burr height	1 mm
Frequency	60 Hz
Pulse ON time	80%
Pulse OFF time	20%
Electrolyte concentration	25gm/liter
Deburring voltage	15 - 25volts
Initial inter-electrode gap	1.2 - 1.6mm
Deburring time	2 - 6minute

5. RESULTS AND DISCUSSION

5.1 Effect of the Working Parameters on the Change in Burr Height

In ECD change in burr height is an important criterion. The effect of initial inter-electrode gap on the change in burr height at various deburring times is represented through Fig. 3. It can be seen that an increase in the initial inter-electrode gap leads to a decrease in the change in burr height (removal height of the burr) at all deburring times and that the removal height of the burr is higher at higher deburring times. Increasing initial inter-electrode gap decreases the current density between the electrodes reducing the total change in burr height. In ECD, it is profitable to keep the inter- electrode gap small, but too small a gap should be avoided as this may cause electric sparks and shorts.

Table 2: Independent variables and their levels for the CCD used in the present study

Variable	**Symbol**	**Coded variable levels**		
		-1	0	1
Deburring voltage	x_1	15	20	25
Inter-electrode gap	x_2	1.2	1.4	1.6
Deburring time	x_3	2	4	6

Table 3: Arrangement of a 3x3 full factorial design used in the present study

Voltage (x_1)	Initial inter-electrode gap (x_2)	Time (x_3)	Change in burr height (mm)	De-burring Rate (mm/min)
0	1	-1	0.178	0.089
-1	0	-1	0.178	0.089
0	-1	-1	0.28	0.131
-1	1	0	0.301	0.075
1	0	0	0.462	0.115
1	-1	-1	0.251	0.126
-1	0	1	0.423	0.07
0	-1	1	0.66	0.11
1	-1	0	0.471	0.118
1	0	-1	0.249	0.125
1	-1	1	0.667	0.111
-1	-1	1	0.474	0.079
-1	-1	0	0.375	0.094
0	1	1	0.498	0.083
0	1	0	0.318	0.08
-1	-1	-1	0.229	0.124
0	0	-1	0.203	0.101
-1	0	0	0.339	0.085
-1	1	-1	0.16	0.08
0	-1	0	0.48	0.12
0	0	1	0.536	0.089
-1	1	1	0.39	0.065
1	1	-1	0.218	0.109
1	1	1	0.584	0.097
0	0	0	0.384	0.096
1	1	0	0.406	0.102
1	0	1	0.642	0.107

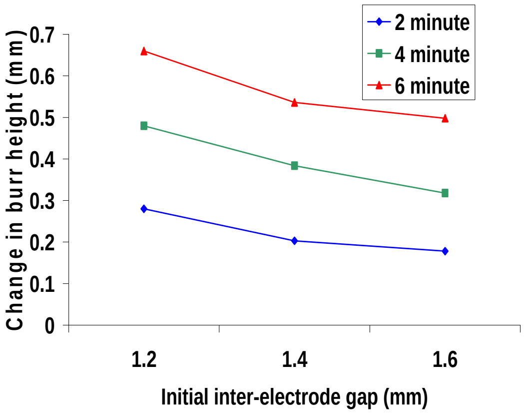

Fig 3. Effect of initial inter-electrode gap on the change in burr height at various deburring times when the voltage is set at 20 volts.

Fig. 4 shows the effect of initial inter-electrode gap on the change in burr height at various deburring voltages. This figure also exhibits similar pattern i.e. the change in burr height decreases with increase in the initial inter-electrode gap at all deburring voltages, the reason being the same as discussed in case of Fig. 3. From Fig. 4 it can also be seen that for a given initial inter-electrode gap, the change in burr height is more at higher voltages which is because of an increase in the current, flowing through the inter-electrode gap, due to increase in the voltage.

5.2 Effect of the Working Parameters on the Deburring Rate

Fig. 5 exhibits the effect of deburring time on the deburring rate at various initial inter-electrode gaps. It is found that the deburring rate decreases with time and that the deburring rate is higher at lower initial inter-electrode gaps. The increase in removal height of the burr with time is quite understandable because as machining is continued for longer duration, more amount of burr gets removed. However, the rate of burr removal (deburring rate) decreases with increase in the deburring time.

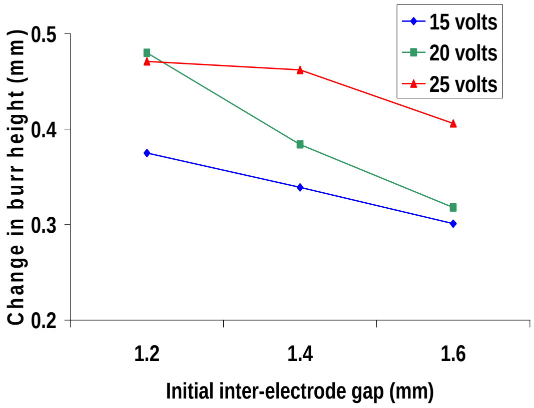

Fig 4. Effect of initial inter-electrode gap on the change in burr height at various deburring voltages when the deburring time is set at 4 minute.

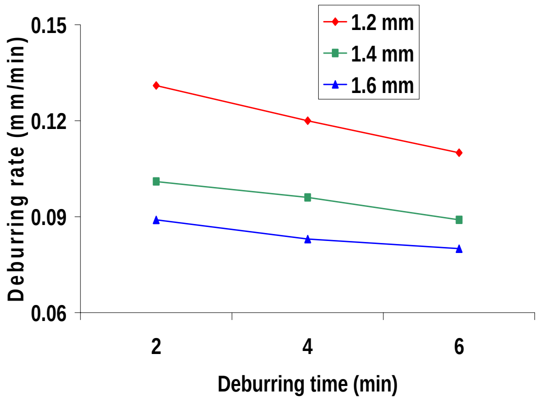

Fig 5. Effect of deburring time on the deburring rate at various initial inter-electrode gaps at 20 volts.

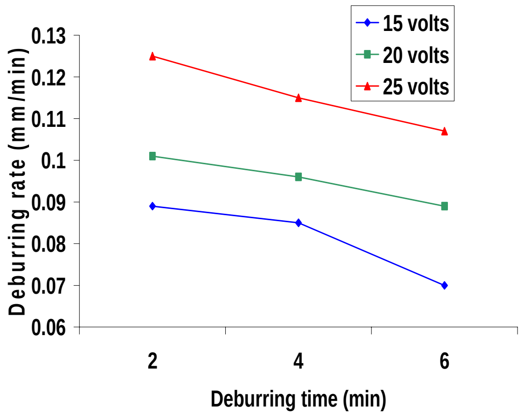

Fig 6. Effect of deburring time on the deburring rate atvarious deburring voltages with initial inter-electrode gap set at 1.4 mm.

This decrease in the deburring rate can be explained by the fact that the current flowing through between the tool and the workpiece, which is contributing to the electrochemical deburring, decreases with time as electrolytic dissolution proceeds, owing to the prevention of electrochemical reaction by the precipitation of sludge.

Fig. 6 presents the effect of deburring time on the deburring rate at various initial inter-electrode gaps. It is evident that the deburring rate is greater at higher voltages. This can be explained from the Ohm’s law i.e. at higher potential difference, the current is higher if the conductivity of the medium through which flowing remains unchanged. Here, since the flow rate of the electrolyte and its concentration were constant at 4.5 liter/min and 25gm/liter, therefore the conductivity of the electrolyte medium remained unaltered, leading to higher deburring current at higher voltages. As a result, it is seen that the removal rate of the burr increased with an increase in the deburring voltage. However, voltage cannot be raised beyond a certain value because it results in sparking which would damage both the tool and the workpiece.

5.3 Analysis of Variance (ANOVA)

An analysis of variance was performed on the experimental results. In the present study, the experiment comprised of three factors A (voltage), B (initial inter-electrode gap), C (deburring time) at *a, b* and *c* levels respectively where, $a = 3$, $b = 3$ and $c = 3$. A total of n observations (replications) were recorded for each of the abc treatment combinations where, $n = 1$. Outline significance tests for the three main effects and the interactions involved were performed. The effects model for the three-factor experiment is given by,

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkl} \tag{4}$$

where,

$i = 1, 2, \ldots\ldots\ldots\ldots, a$
$j = 1, 2, \ldots\ldots\ldots\ldots, b$
$k = 1, 2, \ldots\ldots\ldots\ldots, c$
$l = 1, 2, \ldots\ldots\ldots\ldots, n$

In Eqn.4, α_i, β_j and γ_k are the main effects, $(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$ and $(\beta\gamma)_{jk}$ are the two-factor interaction effects, $(\alpha\beta\gamma)_{ijk}$ is called the three-factor interaction effect, μ is a parameter common to all treatments (levels of the factors) called the overall mean and ε_{ijkl} is a random error component that incorporates all other sources of variability in the experiment [9, 10]. Now, in order that valid significance tests can be made, it must be assumed that the errors are values of independent and normally distributed random variables, each with zero mean and common variance σ^2. If the effects of any given factor or interaction are not all zero, then the mean square will estimate the error variance plus a component due to the schematic effect in question [10]. Analyses of variance (ANOVA) for the deburring rate and the change in burr height are shown in Table 4 and Table 5 respectively. [a]DF represents the degrees of freedom, [b]SS the sum of squares, [c]MS the mean squares and [d]F is defined as the ratio of mean square of the particular factor or interaction concerned to the mean square of error. One thing should be noted here that for a three-factor experiment with a single replicate, the sum of square for the ABC interaction is used for error sum of squares. In such cases, it is assumed that the ABC interaction is zero and that sum of square for the ABC interaction represents variation

Table 4: Analysis of variance (ANOVA) for deburring rate

Source	**[a]DF**	**[b]SS**	**[c]MS**	**[d]F**	**P**
A	2	0.0034	0.0017	73.14	0.000
B	2	0.0030	0.0015	64.39	0.000
C	2	0.0014	0.0007	31.31	0.000
AB	4	0.0004	0.0001	5.14	0.024
AC	4	0.0002	0.00004	1.68	0.246
BC	4	0.0002	0.00006	2.35	0.141
Error	8	0.0002	0.00002		
Total	26	0.0090			

Table 5: Analysis of variance (ANOVA) for change in burr height

Source	**[a]DF**	**[b]SS**	**[c]MS**	**[d]F**	**P**
A	2	0.0661	0.0330	437.27	0.000
B	2	0.0388	0.0194	256.96	0.000
C	2	0.4774	0.2387	3157.37	0.000
AB	4	0.0077	0.0019	25.78	0.000
AC	4	0.0188	0.0047	62.37	0.000
BC	4	0.0016	0.0004	5.6	0.019
Error	8	0.0006	0.0000		
Total	26	0.6114			

Only due to experimental error and thereby provides an estimate of the error variance [10]. From Table 4, it can be observed that only the three main factors like deburring voltage, initial inter-electrode gap and the deburring time has got significant effects on the deburring rate whereas none of the interaction effects are significant for the deburring rate. From Table 2, it can be seen that all the individual factors and all their interactions have got significant effects on the change in burr height.

6. CONCLUSIONS

For effective utilization of the electro-chemical deburring in modern manufacturing industry to achieve higher deburring rate with greater accuracy and surface finish specially for the hard to machine advanced materials such as stainless steel, die steel etc. there is need for proper design and development of the electrochemical deburring system with the provision of controlling the various process parameters. The developed electrochemical deburring system provides the scope of variation and control of a number of process parameters over a wide range of values. In the present paper, the effect of different main influencing process parameters of electrochemical deburring such as deburring voltage, initial inter-electrode gap and machining time on various deburring characteristics such as deburring rate and change in burr height were studied using a 3 x 3 full factorial experimental design. Analysis of the experimental result in the present study, revealed that it is desirable to keep the gap between the workpiece and the tool as small as possible because it increases both the removal height of the burr as well as the deburring rate. Higher voltage should be used to enhance the removal height of the burr and deburring rate too. Experimental investigations and analysis of the experimental results revealed that the individually the variable process parameters considered in the present set of research, i.e. voltage, initial inter-electrode gap and machining time at a constant flow rate and a constant concentration of electrolyte (25 gm/liter of Sodium Nitrate salt solution), have got dominant effects in controlling the change in burr height and the deburring rate as exhibited through various graphical representations. These representations can act as a guide in selecting the best combination of input parameters for given deburring criteria of SS304 materials. Analysis of variance showed that for the deburring rate, deburring voltage, initial inter-electrode gap and the deburring time has got significant effects whereas none of the interaction effects were significant and for the change in burr height, all the main effects and the interaction effects were significant.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T	Deburring Time	(minute)
V	Deburring Voltage	(volts)
G	Initial inter-electrode gap	(mm)
DF	Degrees of freedom	-
SS	Sum of Squares	-
MS	Mean Square	-
P	Probability	-