Stage and checking incoming and outgoing material in the form of inspections. The new approach, which is emerging, is based on analysis of variance (ANOVA) to investigate which design parameters significantly affect the quality characteristic. This approach is employed to analyze the influence of grinding parameters on material removal rate during grinding process. The purpose of the traditional definition of quality states that quality is good to the extent that it meets customer requirements. The next definition of quality is to discover innovative designs and ideas, extremely good quality related to aesthetics and functional aspects, etc. Quality is a good tool for competition. It is necessary for customer’s satisfaction and also for meeting societal obligations. To fulfill this goal, all these qualities have to be built in the product through systems approach and not just at the manufacturing process. An orthogonal array has used to plan the experiments. The raw data analysis and signal-to-noise ratio analysis have employed to analyze the influence of grinding parameters on material removal rate during grinding process. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This procedure eliminates the need for repeated experiments, saves time and conserves the material as opposed by the conventional procedure. Experimental results are provided to confirm the effectiveness of this approach.

1. Introduction

The Taguchi Technique for quality engineering is intended as a guide and reference source for Industrial practitioners (managers, engineers, and Scientists) involved in product or process experimentation and development. Dr. Genichi Taguchi, a Japanese engineer, was born on 15 Jan 1924. He was active in the improvement of Japan's industrial products and processes since the late 1940s. After the Second World War, the allied forces found that the quality of Japanese telephone system was extremely poor and totally unsuitable for long distance communication purpose. To improve the system the allied command recommended that Japan should establish research facilities similar to the Bell Laboratories in the United States in order to develop state-of-the-art communication systems. The Japanese founded the 'Electrical Communications Laboratories' (ECL) with Dr. Genichi Taguchi in charge of improving R&D productivity and enhancing product quality. He observed that a great deal of money and time was expended in engineering experimentation and testing. Dr. Taguchi started to develop new methods to optimize the process of engineering experimentations. He developed techniques, which are now known as 'Taguchi techniques'. Most of the engineers know how to set-up for a test intended to model actual field conditions and the various relationships involved to study design for performance compatibility. As the engineer gets exposure he deems that the approach is too costly and time consuming. Dr. Taguchi worked on this and espoused an excellent philosophy for quality control in the manufacturing industries. His philosophy has far reaching consequences, yet it is founded on three very simple and fundamental concepts.

2.1. Taguchi's definition of quality

The traditional definition of quality states that quality is conformance to specifications. Joseph M. Juran expanded this definition in 1974 and then the American Society for Quality Control (ASQC) in 1983. Juran observed, "Quality is fitness for use." The ASQC defined quality as "the totality of features and characteristics of a product or service that bear on its ability to satisfy given needs". Taguchi presented another definition of quality. His definition stressed the losses associated with a product. Taguchi stated "quality is the loss a product causes to society after being shipped, other than losses caused by its intrinsic functions." Taguchi asserted that losses in his definition "should be restricted to two categories: (a) loss caused by variability of function, and (b) loss caused by harmful side effects." Taguchi says that a product’s quality is fit for use if it "performs its intended functions without variability, and causes little loss through harmful side effects, including the cost of using it." It must be kept in mind here that "society" includes both the manufacturer and the customer. Loss associated with function variability includes, for example, energy and time (problem fixing), and money (replacement cost of parts). Losses associated with harmful side effects could be market shares for the manufacturer and/or the physical effects, such as of the drug thalidomide, for the consumer. Consequently, a company should provide products and services such that possible losses to society are minimized, or, "the purpose of quality improvement … is to discover innovative ways of designing products and processes that will save society more than they cost in the long run." The concept of reliability is appropriate here. The next section will clearly show that Taguchi's loss function yields an operational definition of the term "loss to society" in his definition of quality.

2.2. Goal Post Philosophy

According to the Goal Post Philosophy product is made in accordance with the blue print, within the permitted tolerance. This viewpoint embraces only the designers and makers. Thus the missing part of the philosophy is the customer requirement.
product may meet the print specifications but if the product does not meet the customer requirements then true value cannot be present. The Goal Post Philosophy is graphically shown in Fig 2.21.

![Fig. 2.21 Goal Post Philosophy](image)

2.3. Taguchi Philosophy
Taguchi espoused an excellent philosophy for quality control in the manufacturing industries. Indeed, his doctrine is creating an entirely different breed of Engineers who think, breathe and live quality. His philosophy has far-reaching consequences, yet it is founded on three simple and fundamental concepts.

- Quality should be designed into the product and not inspected in it. No amount of inspection can put quality back into the product.
- Quality is best achieved by minimizing the deviation from a target. The product should be so designed that it is immune to uncontrollable environmental factors.
- The cost of the quality should be measured as a function of deviation from the standard and the losses should be measured system wide.

The above three concepts are becoming the guiding principles of today’s quality control activities. Taguchi builds both his conceptual framework and specific methodology for implementation from these precepts. He recommended the following three-stage process.

**Concept Design:** It is the primary design stage in which engineering and scientific knowledge is used to produce the basic product or process design. It is very important stage but we cannot afford the research of all the concepts. Therefore, research is a very important stage but we cannot afford the research of all the concepts. Taguchi builds both his conceptual framework and specific methodology for implementation from these precepts. He recommended the following three-stage process.

**Parameter Design:** It is the secondary design stage in which an investigation is conducted to identify settings that minimize the performance variations.

**Tolerance Design:** It is the tertiary design stage in which the tolerances of the process conditions and the sources of the variability are set. This is a means of suppressing quality variations by directly removing its cause.

![Fig. 2.31 Taguchi Three Stage Design Process](image)

### 3. Factors Affecting MRR

The salient features of machining, affecting productivity, grinding costs, and work piece quality, are the Material Removal Rate (MRR), surface integrity and wheel wear. Optimal process parameters can be derived only if the relationships between these figures and the process parameters are known. In particular, the influence of the depth of cut (a) and the peripheral velocity of the work piece (vₘ) was investigated.

![Fig.3.1 grinding condition and process parameter](image)

### 4. Experimental Procedure:
A scientific approach to planning and conducting of experiments was incorporated in order to perform the experiments most effectively. Taguchi Technique was taken as the basis for planning the experiments so that the appropriate data is collected which may be analyzed to obtain valid and objective conclusions.

Planning of experiments was employed in order to fulfill the following requirement:
- To get the data uniformly distributed over the whole range of controllable factors to be investigated.
- To reduce the total number of experiments.
- To establish a relationship between different input variables.

The following are basic steps, which are followed during the experiment.
- **Selection of variable:** The variables selected are depth of cut and cutting speed.
- **Selection of the levels:** The levels selected are 3 for both the variables.
- **Selection of the Orthogonal Array:** As variables having three levels are being taken, so the degree of freedom associated with one variable is 2 (No. of levels–1). The DOF associated with the two variables is 4. An orthogonal array having at least 4 DOF is to be selected. In the present work, the OA selected is L₉.

During experimentation all the trials were repeated three times, so the total number of experiments performed is 27.

Then the raw data analysis and S/N data analysis have done.

The mild steel work pieces having 29.12 mm diameter and 50.5 cm length were grinded on the cylindrical grinding machine.

### 5. EXPERIMENTAL RESULTS

#### 5.1. Plan of experiment

The levels of the selected process variables were decided by the conducting experiments using one variable at-a-time approach. The process parameters,
their designation and three levels selected have given in Table 5.11.

Table 5.11 Process Parameters and their Levels

<table>
<thead>
<tr>
<th>Process Parameter</th>
<th>Parameter Designation</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed (m/min)</td>
<td>A</td>
<td>41.48</td>
<td>41.67</td>
<td>57.63</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
<td>B</td>
<td>0.019</td>
<td>0.015</td>
<td>0.020</td>
</tr>
</tbody>
</table>

5.2. Orthogonal Array

To define an orthogonal array, one must identify:
1. Number of factors to be studied
2. Levels for each factor
3. The specific 2-factor interactions to be estimated
4. The special difficulties that would be encountered in running the experiment

Table 5.21, L9 Orthogonal Array (with responses), shows experimental results of MRR obtained using the above-discussed procedure in previous section. The experiments were repeated thrice and R1, R2, R3 denote the repetitions. The S/N data (using MINITAB Software) for higher the better of the Material Removal Rate have also given in Table 5.21.

5.3. Effects of Process Parameters on MRR (S/N Ratio)

A greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest S/N value. The S/N ratio response graphs plotted in Figure 5.31(a,b). Based on the analysis of the S/N ratio graphs, the optimal machining performance for the metal removal rate was obtained at 41.07 m/min cutting speed (level 2) and 0.020 mm depth of cut (level 3).

Main Effects Plot for S/N Ratios

S/N Ratio: Higher the Better

5.4. Estimation of optimal value of the MRR

The optimal grinding conditions for the selected quality characteristic i.e., MRR are:
- Cutting Speed (A, Level 2): 41.07 m/min
- Depth of cut (B, Level 3): 0.020 mm
- Optimal value of the MRR: 19,906 mm³/s

5.5. Analysis of variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which parameters significantly affected the quality characteristics. The percentage contributions of the Grinding parameters have revealed that the influence of the Cutting Speed is significantly larger than that of Depth of Cut Shown in Table5.51

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DOF</th>
<th>Variance</th>
<th>F-Ratio</th>
<th>P-Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12.525</td>
<td>2</td>
<td>6.2627</td>
<td>0.91</td>
<td>0.473</td>
</tr>
<tr>
<td>B</td>
<td>103.188</td>
<td>2</td>
<td>51.5941</td>
<td>7.49</td>
<td>0.044</td>
</tr>
<tr>
<td>e</td>
<td>27.564</td>
<td>4</td>
<td>6.8909</td>
<td>0.439</td>
<td></td>
</tr>
</tbody>
</table>
| T      | 143.277 | 8   | 1.000    |         | 6. Confirmation Test

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters.

\[
\mu_{MRR} = \text{Predicted mean (optimal value) of MRR} = A(2) + B(3) - \frac{T}{27} = 14.597 + 18.372 - \frac{334.465}{27} = 20.581
\]

The confidence interval is a maximum and the minimum value between which the true average should fall at some stated percentage of confidence. From ANOVA: MRR,

\[
\eta_{eff} = \frac{\eta}{\eta + \frac{1}{R}}
\]

\[
\eta = \sqrt{\frac{\sum R_j j yR}{\sum R_j j yR^2}}
\]

\[
R: \text{ sample size for confirmation experiment}
\]

6. Confirmation Test

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters.
As \( R \to \infty \), \( \frac{1}{R} \to 0 \) and 

\[
C_{1\text{CE}} = C_{1\text{top}} \\
\frac{\text{CI}_{\text{CE}}}{\mu_{\text{MRR}}} = \sqrt{4.30 \times 6.727 \left(\frac{1}{5.4} + \frac{1}{3}\right)} = 3.875
\]

The predicted optimal range for the sample size of 3, of MRR is:

\[
(\mu_{\text{MRR}} - CL_{\text{CE}}) < \mu_{\text{MRR}} < (\mu_{\text{MRR}} + CL_{\text{CE}})
\]

\[
\]

\[
16.706 < \mu_{\text{MRR}} (\text{mm/s}) < 24.456
\]

\[
C_{1\text{top}} = \frac{F_{0.05} \times (A, f) \times V_{C}}{\eta_{\text{eff.}}}
\]

\[
= \frac{4.30 \times 6.727}{5.4} = 2.314
\]

The predicted optimal range for the entire population of MRR is:

\[
(\mu_{\text{MRR}} - CI) < \mu_{\text{MRR}} < (\mu_{\text{MRR}} + CI)
\]

\[
\]

\[
18.265 < \mu_{\text{MRR}} (\text{mm/s}) < 22.897
\]

From Table 5.3 L9 OA, the average response to three repetitions of optimal trial is 19.906 mm/s, optimal value of MRR. Thus the predicted range of the optimum MRR i.e. 18.265 < \( \mu_{\text{MRR}} \) (mm/s) < 22.897, for the entire population have satisfied. Hence the selected optimal values of Gridding Parameter for MRR have established/implemented.

7. CONCLUSION AND FUTURE SCOPE

The following sections give the conclusions as obtained from the results of the analysis of S/N Ratio and ANOVA obtained from experimentation using Taguchi Technique.

7.1 Conclusions

From above discussion, the optimal Grinding conditions for the selected quality Characteristic, MRR, are:

- Cutting Speed (A, Level 2) : 41.07 m/min
- Depth of Cut (B, Level 3) : 0.020 mm
- Optimal Material removal Rate : 19.906 mm³/s

The following are the percentage contributions of the parameters from Table 5.51:

- Cutting Speed : 47.30%
- Depth of Cut : 4.40%

The percentage contributions of the parameters have revealed that the influence of the Cutting Speed is significantly larger than that of Depth of Cut.

Traditional optimization techniques have very limited scope because of the complexity of the problems since they require a very large number of experiments. But Taguchi Technique requires very less number of experiments to optimize quality characteristics.

7.2 Scope for Future Work

The Taguchi methodology is best suited to optimize quality characteristics and hence can be well applied to optimize other responses of machining process e.g. surface roughness, tool wear, power consumption etc. The robust design methodology can also be applied for optimizing multiple responses in industrial experiments.

REFERENCES