Design of an Accuracy Control System in Ship Building Industry

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Abstract—Accuracy Control System (ACS) in shipbuilding industries is proven to improve quality of product along with reduction in rework, production time and performance of finished product. This concept had been implemented in many shipyards worldwide especially in USA, Japan, and Europe. The present study deals with one of the leading shipyards in India. A Pilot study on the initial implementation of accuracy Control System was carried out in this shipyard. To achieve this high degree of unit accuracy, a pilot dimensional control program was carried out in the plasma cutting machine used in the preparation stage of production process. Through the collection and analysis of data, we can identify the necessary steps to control the quality of process. Based on these findings, a detailed proposal was submitted on how ACS can be initiated. It is inferred that with this recommendation, the quality of products can be improved, thereby reducing production cost and increasing competitiveness.

Keywords—Accuracy Control, Control chart, Cause and Effect Diagram, Statistical process control, 5-why analysis.

I. INTRODUCTION

Ship production involves many stages of fabrication process namely preparation, subassembly, assembly, grant assembly, and erection. Throughout these processes it is expected that dimension variance could occur and if not managed properly it could cause dimensional problems which will lead to rework and delay. This problem can be controlled and minimized through good dimensional management practices like Accuracy Control. Accuracy control, which is based on statistical quality control, is defined as the reduction of variability in processes and products. In the shipbuilding industry, accuracy control means the use of statistical techniques to monitor, control and continuously improve shipbuilding design details and work methods so as to reduce variation and maximize productivity. [3] For successful implementation of an accuracy control program, it is necessary to verify that processes are under control or not. If processes are not under control, steps must be taken to eliminate identifiable influences. The steps include preparation of sampling plan, data collection and analysis of the data.

Once this data is collected and analyzed, shipyards can assess their own quality levels and initiate improvement actions where necessary. If industry averages for equivalent processes are known, shipyards can compare their process variations with these average or normal process variation levels to help judge the success of their accuracy control programs. [6]

II. PROBLEM DEFINITION

Ship building involves different stages. Interim products at each stage of construction are used for further work in the next stage. [2] During our preliminary study it was identified that in sub assembly stage most of the time is spent for non-productive adjustment and reworks. The main reason for this is the variation in accuracy of previous plasma cutting stage. This study aims to improve the accuracy of plasma cutting machine, thereby eliminating the non-productive works in the sub assembly stage of ship building.

III. LITERATURE REVIEW

In accuracy control theory, one of the most important technical tools is statistical process control (SPC). Instead of inspecting for quality after production, SPC focuses on online statistical quality control. In fact, SPC not only controls the process, but also has the capability to improve the process as well. Through analysing data from the process itself, SPC can be used as a powerful tool for reducing process variability and achieving process stability. Among all seven SPC tools, including Flowchart, Check Sheet, Pareto Diagram, Cause-and–Effect Diagram, Scatter Plot, Histogram and Control Chart, the Control Chart is considered as the most powerful one. Before exploring the different Control Chart’s it is necessary to review two basic types of factors that may affect the production process. [7]

Shewhart control charts are thought of as the most popular tool used in statistical quality control. Control charts are used to distinguish between common causes and special causes.
When the process is not running consistently, the existence of special causes of variation can be detected. Control charts have had a long history of use in industry.

A. Control Charts for Individuals

There are many situations in which the sample size used in monitoring the process has just one unit, n=1. Plate cutting in plasma machine is an example of this type of process. In these types of situations, the control chart for individual units is often extremely useful. In many instances when using this type of control chart, the moving range of two successive observations as the basis for estimating the process variability is used. The moving range is defined as,

\[ MR_i = |X_i - X_{i-1}| \]

After developing the moving range, a control chart can then be built from this.\(^{(7)}\)

B. Short-Run Control Chart

Standard control charts can be easily applied in manufacturing processes where a large number of identical parts are being produced. However, shipbuilding is often a one of a kind production industry, which means that batch sizes are very small, sometimes only one. For this situation, short run control charts were developed and are in common use today.

The difference between short run control charts and the standard control chart is, in the short run control chart, the measured quality characteristics values are replaced by deviation from nominal or target value. This can be expressed in the form of the following equation.\(^{(2)}\)

\[ X_{i,w} = M_{i,w} - N_w \]

Where,

\[ M_{i,w} = \text{ith actual sample measurement of the quality characteristic of w}, \]

\[ N_w = \text{Nominal value of the quality characteristic of w}, \]

\[ X_{i,w} = \text{Deviation of the actual measurement from nominal of the ith sample of quality characteristic w}. \]

Control charts are used to plot the values obtained by process sampling. Here X-bar – Moving Range (MR) charts are used because it involves plates with different dimensions and measurements are carried out at different time.

Historically control charts are applied in manufacturing where a large number of identical parts are being produced. With the general trend toward product customization, batch sizes are significantly reduced, sometimes even to one. Consequently, the short run control chart was developed and is in common use for these situations\(^{(2)}\).

Applying the principal of X-bar and R control charts to short run production, the measured quality characteristic is replaced by deviation from nominal. Variation between required and actual dimensions of the plate after cutting was collected and tabulated in the table 1.

The purpose of the control chart is to act as a visual aid whether the process is in control or out of control. If values fall outside the control limits, the cause must be determined, a decision on rework must be taken, and a correction should be made to eliminate the problem causing the variation.

So here two Control charts for variables are used;

• Individual short run control chart
• Moving average range chart

IV. METHODOLOGY

In order to find the out major factors in plasma cutting which results in rework in subassembly stage, a sample of cut plate is taken and the main parameters which affect the quality of cut plate are listed. These are,

• Cutting accuracy
• Cut edge roughness
• Cut edge squareness
• Dross

The data with regard to number of times these factors cause rework is plotted in the form of a Pareto chart, so as to identify the main causes of rework. It is found out that the variation in cutting accuracy of cut plate is the main reason for rework in subassembly stage.
A. Analysis of Cutting Accuracy

Steel plates required for ship building are mainly cut in CNC plasma cutting machine. Dimensions of plates cut by the machine using the process of plasma cutting is taken to analyze the cutting accuracy. Measurements were taken manually using a steel tape (837). The design and the measured dimensions were noted for the plasma cut components. The accuracy control check sheets are the medium on which all data are recorded. In this check sheet the different dimensions of the plate after cutting were noted, and it is compared with the required dimensions of the plate from design nesting diagram. The variation from the required dimension is also noted in the check sheet and tabulated (sample check sheet shown in Table 1). From the random sample of plate dimensions, control charts are prepared.

B. Calculation of Individuals Control Limits and Moving Range

The average of the individual values (variations) is calculated using this equation,

$$\bar{X} = \frac{\sum_{i=1}^{m} X_i}{m}$$

The difference between variation data points in table xi and its predecessor xi-1, is calculated as,

$$MR_i = |X_i - X_{i-1}|$$

For m individual values, there are m-1 ranges. Next, the arithmetic mean of these values is calculated as

$$\overline{MR} = \frac{\sum_{i=2}^{m} MR_i}{m-1}$$

On a graph, the calculated moving ranges (MRi) are plotted. A line is added for the average value $\overline{MR}$ and second line is plotted for the range upper control limit (UCLR) and lower control limit (LCLR). The plotted moving range and Individual Control chart shown in figure 1 and 2.

<table>
<thead>
<tr>
<th>Process</th>
<th>Instrument used</th>
<th>Dimensions</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma cutting</td>
<td>Steel Tape (837)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sl.no</th>
<th>Nesting No</th>
<th>Part No.</th>
<th>Measurement</th>
<th>Required, R(mm)</th>
<th>Actual, A(mm)</th>
<th>$X = A - R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5N8</td>
<td>05-TT1-W5-S</td>
<td>Length</td>
<td>7780</td>
<td>7780</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>5N8</td>
<td>05-TT1-W5-S</td>
<td>Width</td>
<td>2460</td>
<td>2453</td>
<td>-7</td>
</tr>
<tr>
<td>3</td>
<td>5N2 (N)</td>
<td>05-BS-W5-P</td>
<td>Length</td>
<td>3590</td>
<td>3588</td>
<td>-2</td>
</tr>
<tr>
<td>4</td>
<td>5N2 (N)</td>
<td>05-BS-W5-P</td>
<td>Width</td>
<td>1395</td>
<td>1395</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>5N18(M)</td>
<td>05-KNY1730-W1-S</td>
<td>Width</td>
<td>1040</td>
<td>1044</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>5N18(M)</td>
<td>05-KNY3082-W1-S</td>
<td>Length</td>
<td>1040</td>
<td>1043</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>5N04</td>
<td>05-991-W2-P</td>
<td>Width</td>
<td>873</td>
<td>868</td>
<td>-5</td>
</tr>
</tbody>
</table>
The control rules are violated and show assignable causes of variations at various regions of production process. The conclusions from the SPC study are:

- Process in plasma cutting machine are out of control because five sample points of individual X-bar chart of Plasma cutting process is outside the control limit.
- Six points of MR chart of Plasma cutting are out of control.

The above two conclusions from SPC study shows assignable causes of variations. These assignable causes are of larger in magnitude and are controllable in the cutting process of the plates. The assignable causes are to be eliminated from the production process to make the process efficient. For that collected the different causes which have the possibility on the effect of variation in accuracy of plasma cutting process using brainstorming session. The major causes are collected by detailed survey from operators, supervisors and managers those are directly involved in this process. Based on that cause and effect diagram is constructed with possible causes which affect the cutting accuracy and is shown in figure 3.

V. ANALYSIS OF ROOT CAUSES

Out of these possible causes the root cause which affects the cutting accuracy is found out by testing the significance of each cause on cutting dimensional variation. Table 2. Shows the tabulated results of each possible cause and there influence on cutting dimensional variations. From the results, it can be concluded that load variation of input power and variation in input design data are the two significant factors affecting the cutting accuracy of plasma cutting machine.

Exact root cause analysis is done using 5-why analysis. Processes like plasma cutting voltage regulation, supply frequency are important factors. In the shipyard 415 V, 50 Hz power supply is used as standard. Supply voltage fluctuated depending on the load as well as the nature of load. During peak working time it reduced to 370 V and at light load it was in the range of 440 V. There is sudden dip in voltage due to inductive loads like welding sets, coil heaters, hoisting applications of crane etc.
In shipyard rheostat type conventional Automatic voltage Regulators (AVR) are used with the machine and this device is not instantaneous type. Frequent variation in supply voltage also changes in the control voltage thereby affecting the performance of the equipments and the cutting accuracy. So by using 5-why analysis, one root cause was identified as the use of conventional rheostat type AVR is not capable to normalize the load output. Suggestion to rectify this problem is a recently developed equipment in power electronics with certain high efficient voltage regulators using IGBT (insulated gate bipolar transistor), SCR (Silicon controlled rectifier) etc. These devices are static as well as instantaneous type. This devices offers 0.5 per cent voltage regulation. These regulators also known as active regulators. Active regulators employ at least one active (amplifying) component such as a transistor or operational amplifier. Shunt regulators are often (but not always) passive and simple, but always inefficient because they (essentially) dump the excess current not needed by the load. When more power must be supplied, more sophisticated circuits are used. From the test results, the second influencing cause which affects the cutting accuracy of plasma machine is Variation in input design data.

In shipyard a software is used to design the ship structure. Using conversion software the hull structure design data is converted to G-code data which is plasma machine programming language. The conversion of design drawing of a plate to G-code is done without considering the capability of the machine. In shipyard, for cutting of plates of different thickness, same 80 ampere nozzle is used. The speed of cutting of the plate in programme text file sometimes exceeds the maximum speed that can be cut with 80 ampere nozzle. So Proper calibration of design data, and good fit of these with machine operating parameters, is required to minimize the variation related to input design data.

### Table II

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Test Conducted</th>
<th>Test result</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate parallelity to cutting table</td>
<td>Test 1: Trial taken 30 sample plate of 5 mm thick</td>
<td>Dimensional variation in 18 out of 30</td>
<td>Not Influencing</td>
</tr>
<tr>
<td></td>
<td>Test 2: Trial taken 30 sample plate of 25 mm thick</td>
<td>Dimensional variation in 20 out of 30</td>
<td></td>
</tr>
<tr>
<td>Slip of drive belts</td>
<td>Test 1: Trial taken 30 sample plate before maintenance</td>
<td>Dimensional variation in 17 out of 30</td>
<td>Not Influencing</td>
</tr>
<tr>
<td></td>
<td>Test 2: Trial taken 30 sample plate after maintenance</td>
<td>Dimensional variation in 18 out of 30</td>
<td></td>
</tr>
<tr>
<td>Current load variation</td>
<td>Test 1: Trial taken 30 sample plate during working time</td>
<td>Dimensional variation in 19 plates out of 30</td>
<td>Influencing</td>
</tr>
<tr>
<td></td>
<td>Test 2: Trial taken 30 sample plate during lunch time</td>
<td>Dimensional variation in 4 plates out of 30 plates</td>
<td></td>
</tr>
<tr>
<td>Use of damaged oval shape nozzle</td>
<td>Test 1: Trial taken 30 sample plate with damaged nozzle</td>
<td>Dimensional variation in 16 plates out of 30</td>
<td>Not Influencing</td>
</tr>
<tr>
<td></td>
<td>Test 2: Trial taken 30 sample plate with new nozzle</td>
<td>Dimensional variation in 18 plates out of 30</td>
<td></td>
</tr>
<tr>
<td>Variation in input design data</td>
<td>Test 1: Trial taken 30 sample plate with design data doesn’t match with machine operating condition</td>
<td>Dimensional variation in 10 plates out of 30</td>
<td>Influencing</td>
</tr>
<tr>
<td></td>
<td>Test 2: Trial taken 30 sample plate with design data match with machine operating condition</td>
<td>Dimensional variation in 2 plates out of 30</td>
<td></td>
</tr>
</tbody>
</table>
VI. CONCLUSIONS

For the implementation of accuracy control system in shipbuilding a pilot study of dimensional control program in plasma cutting machine was carried out. In order to analyse the cutting accuracy of the machine, statistical process control technique was used. Statistical process control study using control charts are done to check whether the process is controllable or not. Since the plate cutting is not batch production, short run control charts including individual control chart and moving range chart were used instead of standard R chart and X bar chart. Different samples went outside the control limit of both charts and therefore, it can be concluded that the process is out of control. It can be seen that assignable causes of variations occur in production which makes the process out of control.

Possible causes affecting the cutting accuracy are collected using brainstorming technique and cause and effect diagrams are drawn with these possible causes. The major causes are identified from these possible causes by testing each cause. From the test results it was concluded that, there are two major causes which affect the cutting accuracy. Load variation of input power and variation in input design data are the two significant factors affecting the cutting accuracy of plasma cutting machine.

Root cause for these major causes is found out using the 5-Why analysis. From the 5-Why analysis of input load variation, the major factor which affects the cutting accuracy is the inability of Automatic voltage Regulators to normalize the power load. The main reason for this is the AVR used in shipyard, which incidentally being an electro mechanical AVR.

Since the rheostat used does not respond instantaneously to fluctuation of loads, it is suggested to use recently developed high efficient voltage regulators using IGBT (insulated gate bipolar transistor) or SCR (Silicon controlled rectifier). These devices are static as well as instantaneous.

Second root cause was also found out using the 5-Why analysis. The conversion of design drawing of a plate to G-code is done without considering the capability of the machine. In shipyard, for cutting plates of different thickness, same 80 ampere nozzle is used. The speed of cutting the plate in programme text file sometimes exceeds the maximum speed that can be cut using 80 ampere nozzle. So it is recommended that a proper calibration of design data and good fit of these with machine operating parameters are to be carried out for minimizing the variation related to input design data.

REFERENCES