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# Vibration Analysis Of CNC Plasma Cutting Machine

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***Abstract:***
*This research investigates the vibration behavior of a CNC Plasma Cutting machine as part of a predictive maintenance approach. The study focuses on the influence of three process parameters: pressure, current, and cutting speed, with vibration RMS and acceleration (a(g)) as the measured responses. Vibration data were collected using a Vibration Analyzer and Bearing Defender. The results were analyzed through descriptive statistics, 3D surface plots, and multi-response optimization using the desirability function method. Findings indicate that pressure has the most significant impact on increasing vibration levels, while higher current tends to reduce fluctuations and stabilize the system. Cutting speed presents a non-linear effect, where excessive speed leads to increased vibration, and moderate speed results in lower vibration levels. Among 20 experimental combinations, the optimal configuration was found at 5.016 bar pressure, 72.838 A current, and 520.944 mm/min cutting speed. This combination yielded an RMS value of 0.282 mm/s and acceleration of 0.023 m/s², achieving a desirability score of 0.618. The study concludes that vibration analysis is a reliable method for monitoring CNC plasma cutting machine conditions, providing insight into early-stage mechanical failures and supporting data-driven maintenance decisions. By identifying the optimal process parameters, this research contributes to improving operational stability and efficiency in CNC cutting systems.*

***Keywords:*** *CNC Plasma Cutting, Vibration Analysis, RMS, Acceleration, Desirability Function, Predictive Maintenance.*

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## I. Introduction

CNC plasma cutting has replaced conventional thermal cutting due to its superior cutting quality, lower costs, and integration with computer control systems. The process uses an ionized (plasma) to transfer electrical energy to the material, enabling high-speed and precise cuts. Developed as a branch of Gas Tungsten Arc Welding in 1957, the method has evolved to offer improved reliability and durability of consumables [1].

The plasma torch plays a critical role in cutting efficiency by directing the plasma arc onto the material. It comprises several components such as electrodes, nozzles, gas rings, and shielding caps. Common gases include air, oxygen, and argon, while $CO_2$ and water are used as shielding agents. When these gases are energized, molecular collisions increase temperature significantly [2].

This technique allows for the cutting of various materials at different speeds, currents, and voltages. Its cost-effectiveness and flexibility make it highly attractive for industrial applications [3]. However, continued use of CNC machines can cause mechanical wear and generate vibrations, particularly along the rail tracks. These vibrations may reduce cutting accuracy and accelerate component degradation.

Vibration analysis (VA) is a widely used predictive maintenance method that enables the early detection of faults without requiring machine disassembly or downtime. It interprets vibration signals to assess machine condition and guide maintenance decisions [4]. VA has been effectively implemented across various industrial systems, including rotating and non-rotating machinery, continuous processes, and structural equipment [5].

Predictive maintenance programs based on VA can significantly reduce operational costs by minimizing downtime and optimizing repair schedules. The analysis of vibration data provides insight into mechanical degradation, supporting proactive decision-making [6]. By examining vibration amplitudes and frequencies, early signs of failure such as imbalance, misalignment, or looseness can be identified [7].

Modern vibration analyzers allow precise monitoring of machine health and have been applied successfully in CNC milling and cutting machines [8]. However, many current diagnostic models still neglect vibration data despite its importance in identifying mechanical anomalies. This study was therefore conducted to investigate vibration behavior in a CNC plasma cutting machine and evaluate its condition through vibration measurements.

## II. Material And Methods

This study involves observation and testing to analyze the cause-and-effect relationship in a machining process using a CNC plasma cutting machine, specifically the FLEXIGRAPH-Smart model equipped with the KOIKE D430 system. The main objective is to examine the effect of vibration on the frame of the CNC plasma cutting machine. Vibrations can significantly influence the stability of the machining process, reduce tool life, and affect the quality of the metal cutting results.

The process parameters investigated in this research include compressor pressure, cutting speed, and cutting depth, all of which are controlled through the programmable CNC system. Vibration signal measurements were carried out using a Vibration Analyzer to determine the magnitude of vibration that could potentially interfere with machining quality. These measurements serve as a basis for evaluating the impact of vibration on the overall performance and output quality of the cutting process.

This research utilizes the FLEXIGRAPH-Smart CNC Plasma Cutting machine equipped with the KOIKE D430 system. The test material used is SS400 carbon steel with dimensions of 500 mm × 500 mm × 5 mm. The supporting equipment used in this study includes the following:

**Figure 1 . Plasma CNC FLEXIGRAPH-Smart Sistem KOIKE D430**

The supporting equipment used in this study includes a Vibration Analyzer (FALCON – ACOEM), which functions to measure vibration signals on three axes, and a Bearing Defender (ACOEM), which is used to detect the condition of the machine bearings. In addition, a 10 HP Krisbow Compressor was used as the air supply source for the cutting process, while a Powermax 85 A Inverter served as the main power source for plasma cutting. A stopwatch and measuring tape were also used to measure processing time and material dimensions.

SS400 is a mild steel commonly used for general structural applications such as bridges, ship plates, and oil tanks. It contains key elements such as Carbon (0.17%), Manganese, Silicon, Sulfur, and Phosphorus. In this study, SS400 carbon steel was used as the test material, with dimensions of 500 mm × 500 mm × 5 mm and a melting point between 1494–1527 ℃.

**Figure 2 . SS400 Carbon Steel Plate**

This study was conducted using a FLEXIGRAPH-Smart CNC Plasma Cutting machine with the KOIKE D430 system. The material used was SS400 carbon steel with dimensions of 500 mm × 600 mm × 5 mm. The research aimed to investigate the effect of vibration on the machine frame during the cutting process.

The procedure began with the preparation of tools and materials. The steel plate was positioned, and the power supply and compressor were activated. Air pressure was regulated between 0.6 MPa and 1.0 MPa, ensuring consistent airflow to the cutting torch. A magnetic vibration sensor was placed on the machine frame, and a Vibration Analyzer (FALCON – ACOEM) was used to record three-axis vibration signals during operation.

The inverter was set to plasma torch mode with adjustable parameters such as current (Ampere), pressure (BAR), and PSI, depending on the test conditions. The CNC controller was initialized, and the cutting path was programmed using a square shape with dimensions 200 mm × 80 mm, including a 3 mm tolerance. A demo run was performed to simulate nozzle movement, followed by the actual plasma cutting process. Cutting speed was adjusted to 500 mm/min according to plate thickness. After cutting, surface imperfections were cleaned, and vibration data was collected for further analysis. The results were used to evaluate the impact of varying cutting parameters on machine vibration and cutting quality.

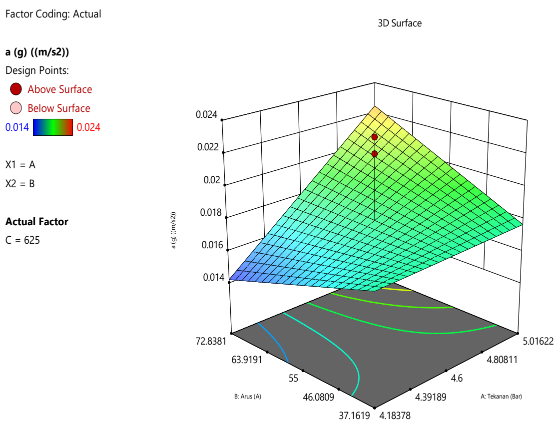
## III. Result

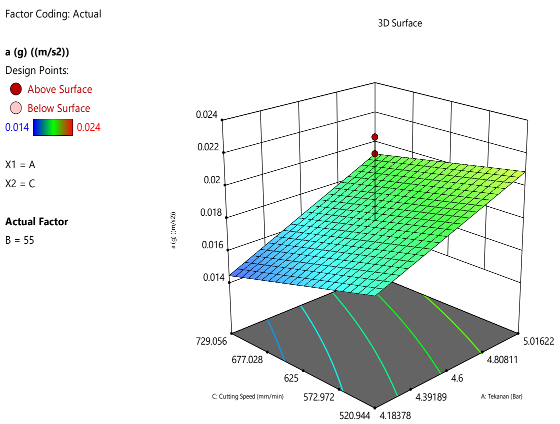
The experiment focused on analyzing vibration behavior in a CNC plasma cutting machine under the influence of three main process variables: pressure, electric current, and cutting speed. The experimental design followed a Central Composite Design (CCD) with a total of 20 treatment combinations. Each experiment was evaluated based on two response variables: vibration acceleration (measured in g) and RMS vibration velocity (measured in mm/s).

**Table 1 Vibration Test Result Data**

| Std | Run | Factor 1 A:Pressure Bar | Factor 2 B:Current A | Factor 3 C:Cutting Speed mm/min | Respone 1 V mm/s RMS | Respone 2 a (g) (m/s2) |
|---|---|---|---|---|---|---|
| 1 | 7 | 4.18378 | 37.1619 | 520.944 | 0.197 | 0.019 |
| 2 | 2 | 5.01622 | 37.1619 | 520.944 | 0.335 | 0.017 |
| 3 | 15 | 4.18378 | 72.8381 | 520.944 | 0.361 | 0.016 |
| 4 | 16 | 5.01622 | 72.8381 | 520.944 | 0.287 | 0.024 |
| 5 | 5 | 4.18378 | 37.1619 | 729.056 | 0.293 | 0.014 |
| 6 | 11 | 5.01622 | 37.1619 | 729.056 | 0.322 | 0.015 |
| 7 | 19 | 4.18378 | 72.8381 | 729.056 | 0.271 | 0.015 |
| 8 | 14 | 5.01622 | 72.8381 | 729.056 | 0.280 | 0.022 |
| 9 | 12 | 3.9 | 55 | 625 | 0.219 | 0.015 |
| 10 | 3 | 5.3 | 55 | 625 | 0.236 | 0.024 |
| 11 | 13 | 4.6 | 24.9999 | 625 | 0.456 | 0.020 |
| 12 | 17 | 4.6 | 85.0001 | 625 | 0.259 | 0.016 |
| 13 | 10 | 4.6 | 55 | 450 | 0.327 | 0.020 |
| 14 | 18 | 4.6 | 55 | 800 | 0.406 | 0.017 |
| 15 | 9 | 4.6 | 55 | 625 | 0.321 | 0.015 |
| 16 | 1 | 4.6 | 55 | 625 | 0.210 | 0.022 |
| 17 | 4 | 4.6 | 55 | 625 | 0.283 | 0.014 |
| 18 | 8 | 4.6 | 55 | 625 | 0.230 | 0.016 |
| 19 | 20 | 4.6 | 55 | 625 | 0.234 | 0.023 |
| 20 | 6 | 4.6 | 55 | 625 | 0.196 | 0.015 |

The measurement results showed that pressure had the most significant effect on vibration acceleration, where higher pressure levels led to increased vibration. In contrast, electric current exhibited a negative effect, contributing to a decrease in vibration acceleration. The response surface plots revealed a non-linear interaction between pressure and current, which supports the validity of the quadratic regression model used in this study.



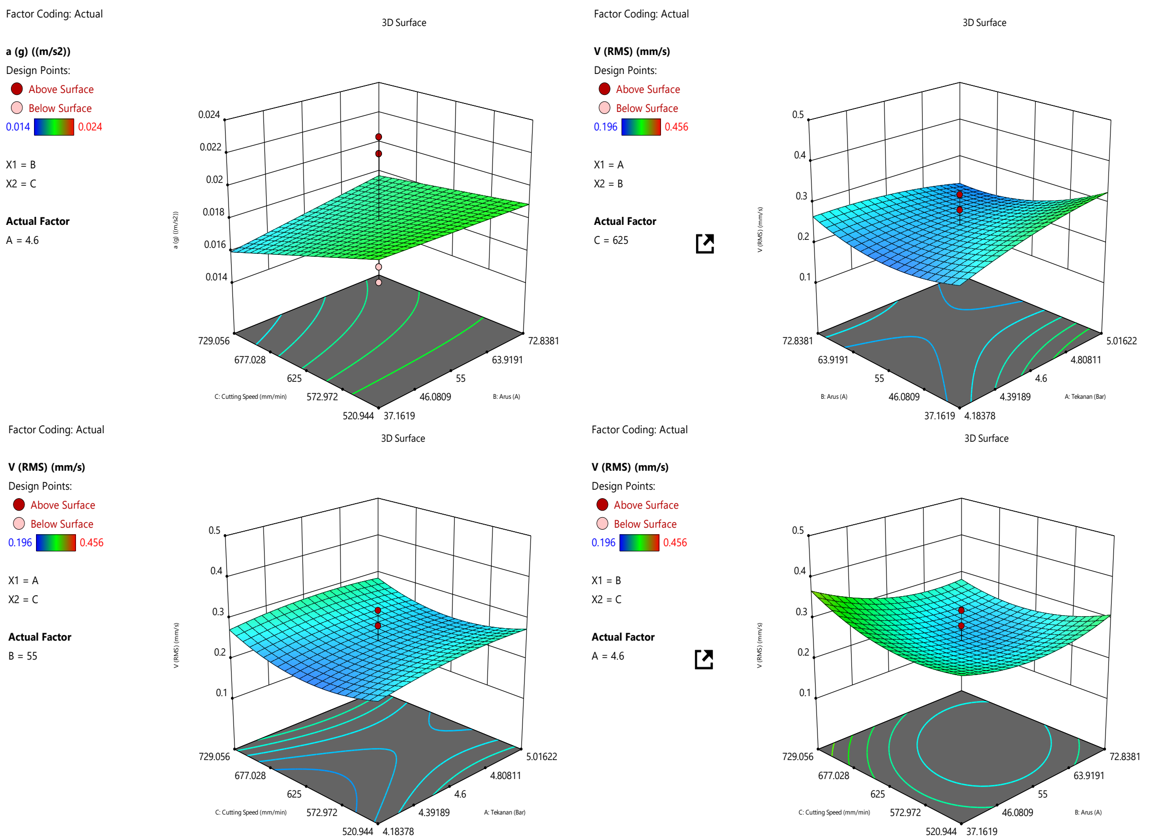



**Figure 3. Response Surface and Contour Plots of CNC Plasma Cutting Vibration Based on Pressure, Current, and Cutting Speed**

Plot (A) shows the combined effect of pressure and current on vibration acceleration, where a noticeable increase in acceleration is observed with higher pressure. Plot (B) depicts the interaction between pressure and cutting speed, also influencing the vibration acceleration. In plot (C), the combination of electric current and cutting speed shows a relatively lower impact on acceleration, indicating a more stable response. Plots (D), (E), and (F) focus on the response of RMS vibration velocity. Plot (D) reveals how pressure and current affect the RMS velocity, while plot (E) highlights the influence of pressure and cutting speed. Lastly, plot (F) displays the combined effect of current and cutting speed on RMS vibration velocity.

Each 3D surface plot illustrates the relationship between two input variables (pressure, electric current, and cutting speed) and the vibration response of the CNC plasma cutting machine, represented by either vibration acceleration (g) or RMS vibration velocity (mm/s). The color gradient on each surface indicates the magnitude of the response, where blue represents the minimum values and red or yellow represents the maximum values.

**Table 2 Limitations and Objectives of Process Variable Optimization on Vibration Response (RMS and Acceleration)**

| Name | Goal | Lower Limit | Upper Limit | Lower Weight | Upper Weight | Importance |
|---|---|---|---|---|---|---|
| A:Pressure | is in range | 4.18378 | 5.01622 | 1 | 1 | 3 |
| B:Current | is in range | 37.1619 | 72.8381 | 1 | 1 | 3 |
| C:Cutting Speed | is in range | 520.944 | 729.056 | 1 | 1 | 3 |
| V (RMS) | maximize | 0.196 | 0.456 | 1 | 1 | 3 |
| a (g) | maximize | 0.014 | 0.024 | 1 | 1 | 5 |

In this study, optimization was performed on the vibration response of a CNC plasma cutting machine, focusing on two main responses: vibration acceleration (a(g)) and RMS vibration velocity. The three process variables analyzed were pressure, electric current, and cutting speed, each with a defined operating range. The goal of the optimization was to maximize the vibration values in order to better understand the machine's dynamic behavior. Vibration acceleration was given the highest importance because it is the most sensitive indicator for detecting micro-vibrations, chatter, and sudden changes in machine conditions. This is especially important in high-speed machining, where acceleration provides faster insights compared to velocity or displacement.

**Optimization Solution Results**

The optimization results indicate that the best combination was achieved with the highest desirability value of 0.618. This parameter combination consists of a pressure of 5.015 bar, a current of 72.838 A, and a cutting speed of 520.944 mm/min, resulting in a vibration acceleration of 0.023 g and an RMS vibration velocity of 0.282 mm/s. The high desirability value suggests that this combination is the most suitable for achieving the optimization goal, which is to maximize the vibration response within safe limits. In general, the best-performing combinations feature high pressure and current values, indicating that increased energy input leads to greater vibration levels. This aligns with the principle that vibration acceleration is highly sensitive to rapid changes during the cutting process.

**Table 3 Statistical Analysis of Vibration Response**

| Response | Name | Units | Observations | Minimum | Maximum | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|
| R1 | V (RMS) | mm/s | 20.00 | 0.196 | 0.456 | 0.2862 | 0.0693 |
| R2 | a (g) | (m/s2) | 20.00 | 0.014 | 0.024 | 0.0180 | 0.0035 |

Table 3 summarizes the descriptive statistics for the two main responses: RMS vibration (R1) and acceleration a(g) (R2), based on 20 optimized parameter combinations. RMS values ranged from 0.196 to 0.456 mm/s, with an average of 0.2862 mm/s and a standard deviation of 0.0693, indicating considerable variation (max/min ratio: 2.33). This suggests RMS is highly sensitive to changes in process parameters. In contrast, acceleration a(g) ranged from 0.014 to 0.024 $m/s^2$, averaging 0.0180 $m/s^2$ with a lower deviation (0.0035) and ratio (1.71), showing more stable results across treatments. Overall, RMS is more responsive to parameter changes than acceleration, highlighting its importance in multi-response optimization.

## IV. Discussion

Based on vibration testing conducted on a CNC Plasma Cutting machine, 20 experimental combinations were generated by varying pressure, current, and cutting speed. Two primary response variables were observed: vibration acceleration (a(g)) and RMS vibration velocity (V RMS). The 3D surface analysis revealed that increasing pressure generally led to higher vibration responses, indicating elevated dynamic loads and system energy. Conversely, higher current levels tended to reduce both a(g) and V RMS, likely due to improved system stability. Cutting speed exhibited a more complex influence; higher speeds (>700 mm/min) often increased vibration, especially in RMS values.

Through multi-response optimization using the desirability function, the optimal parameter combination was identified at a pressure of 5.016 bar, current of 72.838 A, and cutting speed of 520.944 mm/min, yielding an acceleration of 0.023 g and RMS velocity of 0.282 mm/s, with the highest desirability value of 0.618. Statistical analysis indicated that V RMS had greater sensitivity to process parameter changes compared to a(g), suggesting its suitability as a responsive monitoring indicator, while a(g) is more appropriate for precision detection. Overall, pressure and current were found to be the most significant factors affecting vibration, and the optimal condition for maximizing vibration response was achieved using high pressure, high current, and low cutting speed.

## V. Conclusion

This study demonstrates that pressure, current, and cutting speed significantly affect vibrations in CNC Plasma Cutting machines. High pressure (up to 5.016 bar) increases vibration due to greater fluid force, while high current (72.838 A) tends to reduce vibration by creating a more stable cutting condition. Cutting speed shows a non-linear effect, with the lowest vibration occurring at moderate speeds (625 mm/min), whereas higher speeds (>700 mm/min) lead to increased vibration. RMS values are more sensitive to process changes than acceleration, making them suitable for general detection, while acceleration is better for identifying critical or micro-vibration conditions. The optimal parameter combination consists of 5.016 bar pressure, 72.838 A current, and 520.944 mm/min cutting speed, resulting in an RMS of 0.282 mm/s, acceleration of 0.023 $m/s^2$, and a desirability value of 0.618. The desirability method proved effective in identifying the best parameter combination to safely and efficiently maximize vibration response.

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