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Development of a Manufacturing Traceability and Multi-Surface Engraving Automation Platform Using Parametric CNC Macro Programming

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Abstract

This paper presents the development of a manufacturing traceability automation platform based on parametric Computer Numerical Control (CNC) macro programming. The proposed system integrates automated traceability generation, cylindrical engraving, and curved-surface engraving into a unified programming framework. Conventional engraving workflows typically require repeated Computer-Aided Manufacturing (CAM) modifications, toolpath regeneration, and CNC program release whenever production information changes. To overcome these limitations, a macro-based automation platform was developed to automatically generate production year, production week, serial number, and machine identification information directly at the machine controller level. The system also supports engraving operations on planar, cylindrical, and curved rotational surfaces through parameterized geometric calculations. Industrial implementation demonstrates improved manufacturing flexibility, simplified program management, and reduced repetitive engineering activities. The proposed approach provides an effective solution for manufacturing traceability management and intelligent production automation in CNC machining environments.

Keywords: Computer numerical control macro programming, Manufacturing traceability, Manufacturing automation, Computer-aided design, Computer-aided manufacturing, Curved surface engraving.

1 | Introduction

In modern manufacturing environments, product traceability has become a critical requirement for quality control, process management, and customer compliance. Components commonly require permanent marking of product information such as part numbers, revision levels, customer codes, production year, production week, serial numbers, and machine identification data [1]. Traditionally, engraving operations are performed using Computer-Aided Manufacturing (CAM)-generated toolpaths. Any change to marking content requires

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engineers to modify the engraving geometry, regenerate toolpaths, post-process the program, and release a new Computer Numerical Control (CNC) program [2].

As product diversity increases and traceability requirements become more complex, this workflow results in repetitive engineering effort, increased program management complexity, and a higher risk of human input errors [3].

To address these challenges, a manufacturing traceability and multi-surface engraving automation platform was developed based on parametric CNC macro programming, capable of automatically generating traceability information and supporting engraving operations on planar, cylindrical, and curved surfaces through a unified programming framework.

2 | Engineering Challenges

Before implementation of the automation platform, engraving operations faced several limitations. For each new product, engineers were required to create engraving programs through CAM software to generate:

I. Part numbers.
II. Revision levels.
III. Customer identification codes.
IV. Production year information.
V. Production week information.
VI. Serial numbers.
VII. Machine identification numbers.

Whenever any of this information changed, engineers were required to:

I. Modify engraving content in CAM software.
II. Regenerate engraving toolpaths.
III. Post-process the CNC program.
IV. Release a new machining program.
V. Manage multiple program versions.

In high-mix manufacturing environments, this resulted in:

I. Repetitive programming activities.
II. Increased engineering workload.
III. Complex program management.
IV. Higher probability of input errors.
V. Reduced manufacturing flexibility.

Additionally, cylindrical and curved surface engraving required dedicated CAM programming and verification for each geometry, further increasing preparation time.

The limitations of conventional engraving workflows have also been reported in previous manufacturing automation studies [4].

3 | Problem Statement

These challenges motivated the development of a unified engraving automation platform capable of supporting multiple surface geometries and automated traceability generation.

3.1|System Architecture

Input parameters

↓

Character library

↓

Traceability generator

↓

Surface calculation engine

↓

CNC macro output

The overall architecture of the proposed platform is illustrated in *Fig. 1*.

The developed automation platform utilizes parametric CNC macro programming techniques [5] to dynamically generate engraving information directly at the machine controller level.

The architecture consists of four primary modules.

3.2|Character Definition Module

A configurable character library was developed to support:

I. Numeric characters.

II. Alphabetic characters.

III. Customer-specific character formats.

The character structure allows rapid modification of character geometry without modification of the core engraving algorithm.

Supported font types include:

I. Standard industrial characters.

II. Customer-specific character formats.

This architecture provides a highly flexible platform for future expansion.

The proposed approach shares similarities with recent developments in intelligent manufacturing and adaptive machining systems while focusing specifically on engraving automation [6].

3.3|Automated Traceability Generation Module

The automation platform automatically generates variable production information, including:

I. Production year.

II. Production week.

III. Serial number.

IV. Machine identification number.

Unlike traditional methods, these values no longer require CAM programming or toolpath regeneration.

Once the initial product engraving program has been created, traceability information is generated automatically through parameterized macro logic.

3.4 | Cylindrical Surface Engraving Module

For cylindrical components, the automation platform automatically converts character coordinates into angular positions. This functionality enables:

I. Arc engraving.

II. Cylindrical text generation.

III. Circumferential identification marking.

IV. while maintaining consistent character spacing and alignment.

No additional CAM programming is required for routine traceability updates.

3.5 | Curved Surface Engraving Module

Conventional curved surface engraving typically requires dedicated CAM programming and separate toolpath generation for each component geometry. To eliminate repetitive programming activities, a parametric surface calculation algorithm was integrated into the macro framework.

Based on predefined surface parameters, the system automatically calculates:

I. Character positions.

II. Character spacing.

III. Surface projection coordinates.

IV. Character orientation.

This enables accurate engraving on curved rotational surfaces without generating a new CAM program for each traceability update.

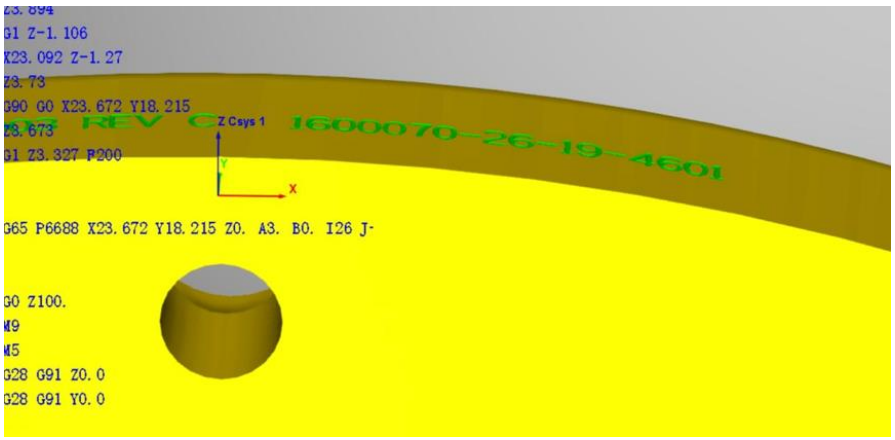


Fig. 1. VT verification of the curved-surface engraving module.

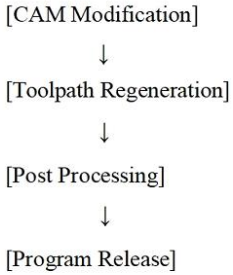


Fig. 2. Traditional engraving workflow.

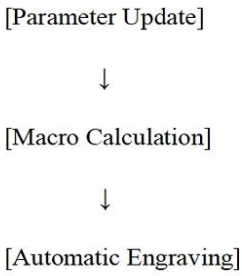


Fig. 3. Proposed automated engraving workflow.

Demonstrating automatic conversion of planar character trajectories into curved-surface toolpaths through real-time surface compensation calculations.

4 | Technical Innovations

Several innovative features were introduced during development. The proposed framework significantly improves production flexibility and supports digital manufacturing initiatives [7].

4.1 | Unified Multi-Surface Engraving Framework

The same macro architecture supports:

I. Planar engraving.

II. Cylindrical engraving.

III. Arc engraving.

IV. Curved surface engraving.

V. through a single programming framework.

4.1.1 | Automated traceability management

Variable production information is generated automatically without repeated CAM programming.

4.1.2 | Flexible font development

New character styles can be developed and integrated rapidly through parameterized definitions.

4.1.3 | Program reusability

Once a product engraving program is established, the same program can continue to be used throughout production without regeneration when only traceability information changes.

5 | Industrial Applications

The automation platform has been successfully applied in production environments for:

I. Product identification marking.

II. Serial number generation.

III. Production year marking.

IV. Production week marking.

V. Machine identification marking.

VI. Customer-specific traceability requirements.

The solution supports multiple product families while maintaining consistent engraving quality and reducing engineering intervention.

5.1|Benefits and Results

Prior to implementation, any change in production year, production week, serial number, or machine identification information required CAM modification and generation of a new engraving program. After implementation, only fixed product information such as part number, revision level, and customer code require initial CAM programming. Once the engraving program has been established, all variable traceability information is generated automatically by the automation platform.

As long as the product revision remains unchanged:

I. No additional CAM programming is required.

II. No new engraving toolpaths need to be generated.

III. No additional CNC programs need to be released.

This significantly reduces repetitive engineering activities while improving traceability consistency, program management efficiency, and manufacturing flexibility.

Table 1. Comparison of conventional and proposed automation systems.

Evaluation Item	Conventional Method	Proposed System
CAM modification	Required	Not required
Toolpath regeneration	Required	Not required
Program release	Required	Not required
Traceability update	Manual	Automatic
Program management	Multiple programs	Single program

Table 1 demonstrates the reduction of engineering activities achieved by the proposed automation platform.

6|Conclusion

The development of this manufacturing traceability and multi-surface engraving automation platform demonstrates how advanced CNC macro programming techniques can transform traditional engraving workflows into an automated traceability management solution.

By integrating customer-specific character generation, automated traceability information generation, cylindrical engraving, and curved surface engraving into a unified framework, the system reduces repetitive programming activities while improving manufacturing efficiency and operational consistency.

The project illustrates how CNC macro programming can be utilized not only for machining operations but also as a scalable platform for manufacturing automation and intelligent production support.

Authors' Contributions

All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

Data Availability

All data are included in the text.

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Conflict of Interest

No potential conflict of interest was reported by the authors.

Consent for Publication

All authors have provided their consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

This article does not involve studies with human participants or animals conducted by any authors.

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