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Simulation of Linear Interpolation Motion in CNC Machining

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Abstract – **This paper delves into the intricate realm of CNC machining by focusing on the simulation of linear interpolation motion. Through meticulous analysis and simulation, it offers a comprehensive understanding of the dynamics underlying linear interpolation in CNC machining processes. The incorporation of G-codes alongside a visualisation approach enhances both clarity and applicability, thereby facilitating innovation and optimisation in the field of CNC machining.**

Keywords – **Turning, Milling, Drilling, G-codes, Visualisation.**

I. INTRODUCTION

The simulation of the machining processes constitutes a methodological approach in simulation-driven design, facilitating the predictability of behaviour, performance, and outcomes across various machining processes, particularly in CNC machining. Distinguished by its reliance on computer-based product modelling and simulation, this methodology significantly enhances the quality and efficiency of machining processes [1].

Machining processes represent a fundamental aspect of the machining industry, pivotal for material removal from initial workparts to attain the desired final products. Classified as material removal processes, they encompass machining operations to shape metals into functional components. Turning, milling, and drilling stand out as the three most common machining operations, characterised by the precise separation of the material by the cutting tool, chip formations, and a new surface generation [2].

Machining processes are interconnected with the availability of compatible machine tools for their realisation. Over recent years, computer numerically controlled (CNC) machine tools have been prevalent in the manufacturing industry due to their enhanced reliability in comparison to traditional machine tools. Essential to the operation of CNC machine tools is the formulation of a precise sequence of instructions, commonly referred to as CNC programming [3].

CNC programming is a specialised field concerned with creating instructions to control CNC machine tools. Central to this field are G-codes, which exert control over the machine's tool moving parts, commonly associated with the functioning of an interpolator. This component, as a fundamental element of CNC systems, transforms the geometric toolpath into vectors of tool positions (Fig. 1a), enabling visualisation of the machine's motion and accurate orientation of its components in three-dimensional space (Fig. 1b) [4].

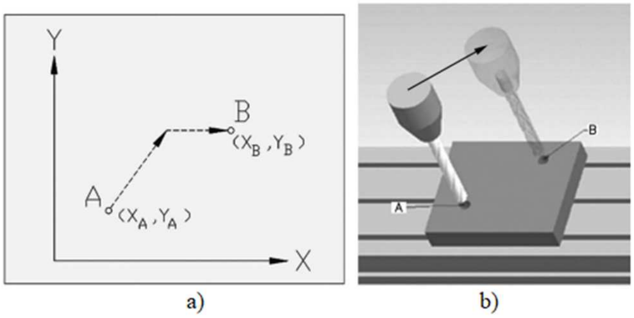

Fig. 1. a) Toolpath, b) Position of the cutting tool [5]

The toolpath closely aligns with the design specifications of the workpart, utilising information primarily from Computer-Aided Design (CAD). Complementary to CAD, Computer-Aided Manufacturing (CAM) software synchronises product design and machining processes, particularly in the realm of CNC machining. In correlation with CAD systems, CNC simulators represent advanced software solutions that imitate the behaviour and resultant outcomes of machining processes performed on sophisticated CNC machine tools [6].

The primary objective of this paper is to provide a comprehensive exposition of the machining process through CAD, alongside the creation of G-code-based programmes and subsequent simulation. Furthermore, the paper meticulously delineates the simulation procedure, a crucial aspect for verifying the efficacy and accuracy of the proposed machining operations. It aims to offer a thorough insight into linear interpolation motion within CNC machining, elucidating its multifaceted implications for industrial applications.

The simulation method contributes to a clear visualisation of the motion in CNC machining, including the understanding of the machining process performed on modern CNC machine tools and their functionalities, as extensively reviewed in relevant literature (e.g., [1]–[9]). Structurally, the paper comprises four sections: an introduction, a detailed research explanation, a discussion of the obtained results, and concluding remarks with potential applications.

II. RESEARCH

This research provides a comprehensive analysis of the design, programming, and simulation necessary for achieving linear interpolation motion in the CNC machining process of a clutch hub, with a particular focus on its outer contours.

To facilitate this analysis, precise 2D drawings are created using CAD systems, specifically AutoCAD software. These

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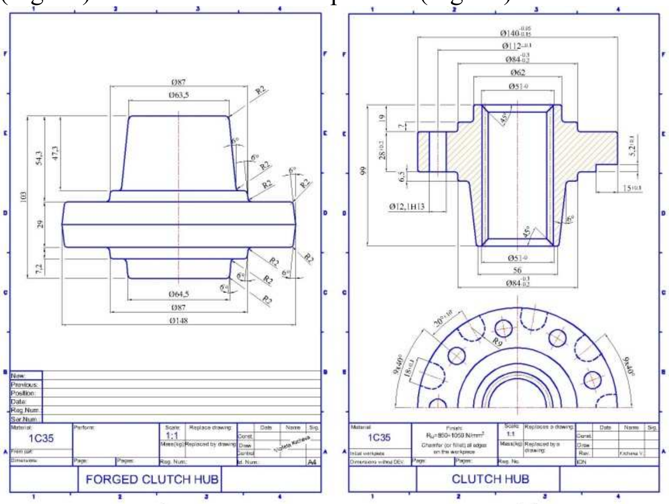
drawings accurately depict the machining operations involved, illustrating the progression from the initial forged clutch hub (Fig. 2a) to the final machined product (Fig. 2b).



a) b)

Fig. 2. a) Forged clutch hub, b) Clutch hub

The machining process comprises four machining operations.

The first operation is turning (Fig. 3), which refers to the shorter side of the workpart. The designated cutting tool for this operation is the PCLNR3232P19 external tool holder (Fig. 4a).

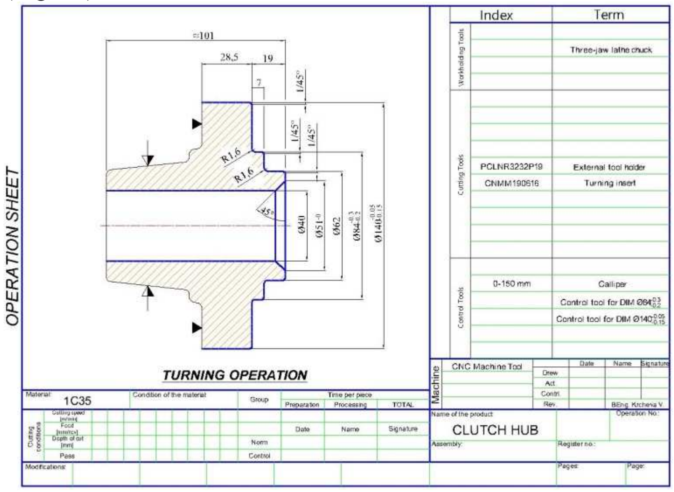


Fig. 3. First machining operation

This tool holder is joined by the CNMM190616 turning insert (Fig. 4a), both manufactured by ZCC-CT.

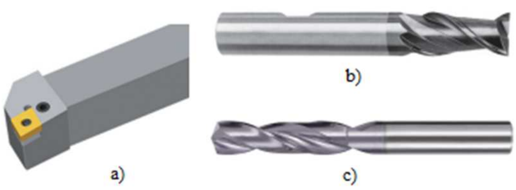


Fig. 4. Cutting tools

The second operation is turning (Fig. 5), which refers to the longer side of the workpart. The cutting tool designated for this operation remains consistent with the previous one.

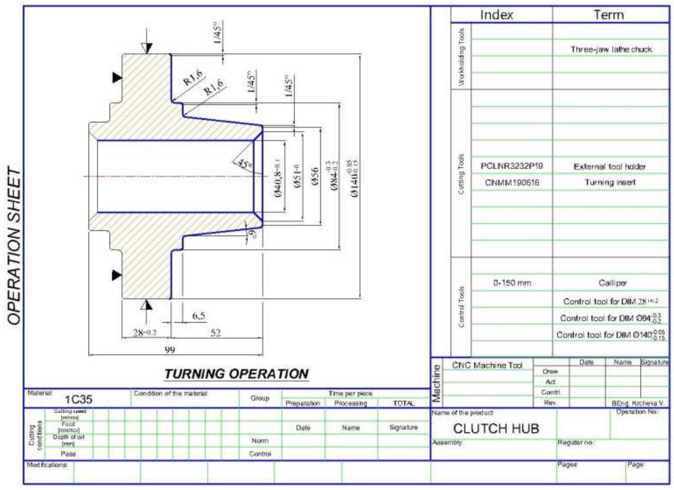


Fig. 5. Second machining operation

The third operation is milling (Fig. 6). The designated cutting tool for this operation is the 5602R302GM-1800 end mill (Fig. 4b), produced by ZCC-CT.

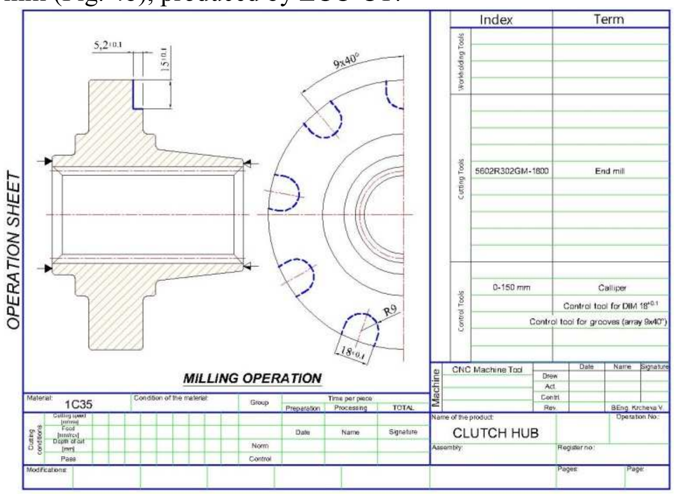


Fig. 6. Third machining operation

The fourth operation is drilling (Fig. 7). The designated cutting tool for this operation is the 1534SU03-1210 drill (Fig. 4c), produced by ZCC-CT.

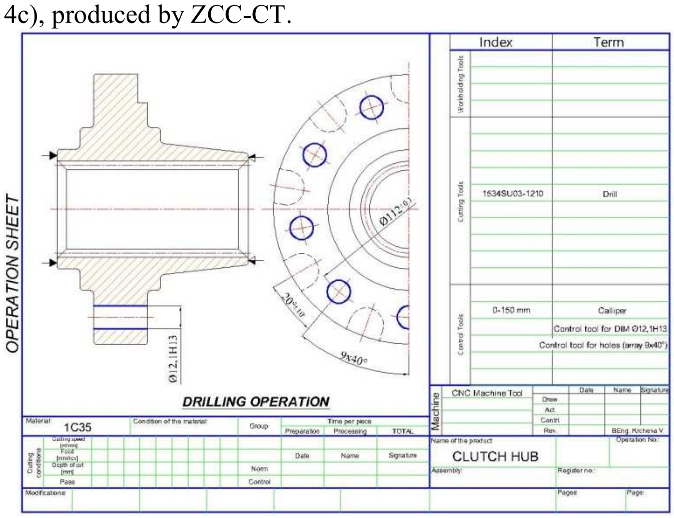


Fig. 7. Fourth machining operation

For each machining operation, a CNC programme is created (and is presented as a figure for space conservation and clarity). The programme of instructions for the first machining operation is depicted in Fig. 8.

```
%
O0001
N10 G21
N20 G17
N30 G40
N40 G90
N50 G94
N60 T0101
N70 M06
N80 G00 X0 Y0
N90 G01 Z-5 F0.2
N100 G01 X0 Y30
N110 G01 X-1 Y31
N120 G01 X-12 Y31
N130 G01 X-12 Y41
N140 G01 X-13 Y42
N150 G01 X-19 Y42
N160 G01 X-19 Y69
N170 G01 X-20 Y70
N180 G01 X-47.5 Y70
N190 G00 Z5
N200 M30
%
```

Fig. 8. First programme of instructions

The programme of instructions for the second machining operation is depicted in Fig. 9.

```
%
O0001
N10 G21 G17 G40 G50 G94
N20 G50 S1000
N30 T0101
N40 M06
N50 G00 X0. Y5. M08
N60 G01 X0. Y-28. F100.
N70 G01 X-1. Y-29.
N80 G01 X-45.5 Y-34.
N90 G01 X-45.5 Y-41.
N100 G01 X-46.5 Y-42.
N110 G01 X-52. Y-42.
N120 G01 X-52. Y-69.
N130 G01 X-53. Y-70.
N140 G00 X0. Y5. M09
N150 M30
%
```

Fig. 9. Second programme of instructions

The programme of instructions for the third machining operation is depicted in Fig. 10.

```
%
O0001
T1 M06
G17
G21
G90
G40
G49
G80
M03
G00 X68.9 Y12.2
G01 X54.2 Y9.6
G01 X68.9 Y12.2
G01 X45 Y53.6
G01 X35.4 Y42.1
G01 X45 Y53.6
G01 X0 Y70
G01 X0 Y55
G01 X0 Y70
G01 X-45 Y53.6
G01 X-35.4 Y42.1
G01 X-45 Y53.6
G01 X-68.9 Y12.2
G01 X-54.2 Y9.6
G01 X-68.9 Y12.2
G01 X-60.6 Y-35
G01 X-47.6 Y-27.5
G01 X-60.6 Y-35
G01 X-23.9 Y-65.8
G01 X-18.8 Y-51.7
G01 X-23.9 Y-65.8
G01 X23.9 Y-65.8
G01 X18.8 Y-51.7
G01 X23.9 Y-65.8
G01 X60.6 Y-35
G01 X47.6 Y-27.5
G01 X60.6 Y-35
M05
M30
%
```

Fig. 10. Third programme of instructions

The programme of instructions for the fourth machining operation is depicted in Fig. 11.

```
%
O0001
G17 G20 G40 G49 G80 G90
T01 M06
M03
G81 R0.1 Z-28 F0.2
X19.2 Y52.6
X-19.2 Y52.6
X-48.5 Y28
X-55.1 Y-9.7
X-36 Y-42.9
X0 Y-56
X36 Y-42.9
X55.2 Y-9.7
G80
M05
M30
%
```

Fig. 11. Fourth programme of instructions

These programmes of instructions are subsequently utilised in simulation software to predict and visualise the cutting tool's movement in practical conditions during the implementation of machining operations.

III. Results and Discussion

The following figures demonstrate the simulation of each toolpath aligned with the programmes of instructions composed of G-codes. These codes, also known as movement instructions, have defined the trajectory, direction, and precise positional movement of the cutting tool within a predetermined coordinate system. Additionally, incorporated M-codes in this programming language have controlled crucial machine tool operations such as main spindle speed, cutting tool feed rate, tool changes, coolant deployment, etc.

In the CIMCO Edit 2024 software programme, the toolpath for each machining operation is displayed, visually representing the sequential straight-line movements between coordinates defined in each programme. This visualisation offers a clear insight into the machining process, illustrating how these movements collectively shape the toolpath and interpolation motion in the CNC operations being analysed.

The simulation of programmes is intricately linked to the Cartesian coordinate system, a fundamental framework wherein every point on the workpiece corresponds to distinct X, Y, and Z coordinates. These coordinates define the programmed cutting tool's point in relation to the workpart and are derived from the diameters, lengths, and other dimensions specified in AutoCAD drawings for each machining operation.

The precise, straight-line movements achieved between meticulously defined coordinates within the simulation confirm the accuracy of the programmes and exemplify the foundational principle of linear motion in CNC machining. This motion predominantly occurs along one or more linear axes, typically X, Y, and Z, within three-dimensional space. It frequently necessitates interpolation, which involves the calculation and generation of intermediate points along the desired path, ensuring smooth and continuous movement.

The simulation of the first machining operation, as illustrated in Fig. 12, provides confirmation of its successful completion through the utilisation of linear interpolation motion. This motion entails the precise movement of the cutting tool along both the horizontal and vertical axes within the machining environment.

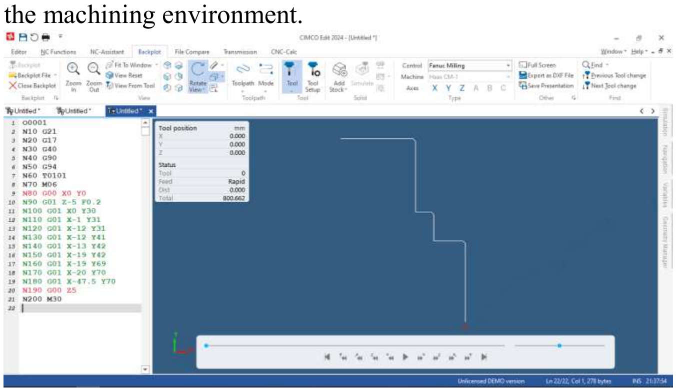


Fig. 12. Simulation of the first machining operation

During the realisation of the second machining operation, as depicted in Fig. 13, the cutting tool performs linear interpolation motions as it traverses along both axes. This process entails the precise calculation and generation of intermediate points along the desired path, facilitating smooth and continuous movement of the cutting tool.

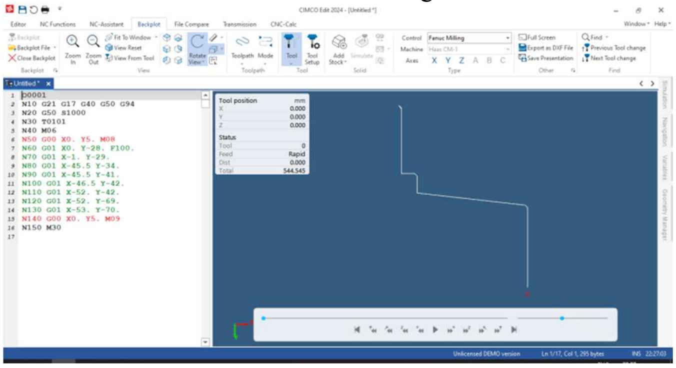


Fig. 13. Simulation of the second machining operation

The successful completion of the third machining operation, as illustrated in Fig. 14, is achieved through the implementation of linear interpolation motions along both the horizontal and vertical axes. Through precise calculation and control, the cutting tool traverses the workpart in a continuous motion, ensuring the accuracy and efficiency of the machining process.

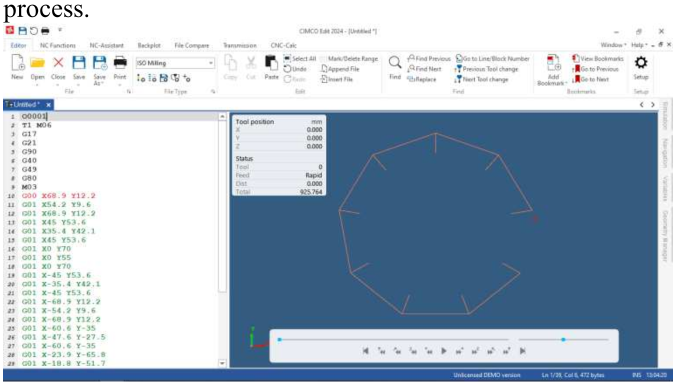


Fig. 14. Simulation of the third machining operation

The fourth machining operation is finalised with precise linear interpolation motion of the cutting tool along the horizontal and vertical axes, as depicted in Fig. 15. This motion ensures accurate machining of the workpart by directing the tool along predefined paths in the horizontal and vertical directions.

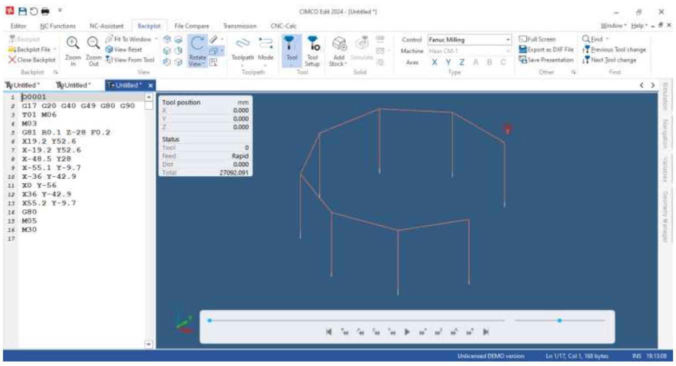


Fig. 15. Simulation of the fourth machining operation

IV. Conclusion

The simulation of the machining process is accomplished by a clear visualisation of the four machining operations, all involving linear interpolation motion.

The linear interpolation motion in CNC machining is crucial for achieving precision and accuracy in the production of final parts. By controlling the movement of the cutting tool along linear axes, CNC machines can machine components with tight tolerances and complex geometries, meeting the exact specifications of the design.

The linear interpolation motion in CNC machining is also fundamental to the automation capabilities of CNC machine tools. Through programmed instructions, the CNC controller controls the linear movement of the cutting tool, allowing for automated and repeatable machining processes without the need for manual intervention.

In conclusion, this study significantly advances the collective comprehension of linear interpolation motion within the realm of CNC machining. By prioritising practical applications, it emphasises the immediate relevance of simulation-driven methodologies in the manufacturing industry. Moreover, it facilitates optimisation of machining processes by rapidly examining manufacturing strategies without disturbance or waste, offering solutions for precision engineering, and enhancing efficiency and accuracy through sophisticated simulation methods.

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