Simulator "NC Virtual Simulator" to Support Manufacturing Digital Transformation

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1. Introduction

The manufacturing industry is quickly expanding the use of IoT, AI and other leading-edge technologies recently in addition to earnest efforts aiming to enhance productivity through a digital transformation of manufacturing processes and data links. Manufacturing businesses must pursue not only systems supporting variable-mix variable-volume production that can adapt to the rapid changes in supply and demand but also efforts to enhance the efficiency of prior inspections as well as quantify and standardize machining expertise due to a lack of skilled workers resulting from an aging society with a declining birthrate. The COVID-19 pandemic has made support for autonomous, automated and remote systems more imperative globally as the world struggled with restrictions in daily life at production plants.

In light of these circumstances, Mitsubishi Electric strives to model equipment design, production, operation, and maintenance processes in a virtual space and develop digital twin systems that support optimization of the entire value chain (1). The NC Virtual simulator was developed this time to replicate the real movements of NC machine tools in a virtual space to realize high-fidelity simulations under the same conditions as the actual machines.

2. Purpose and Features of the NC Virtual Simulator

The NC Virtual Simulator is an application that reduces the workload on machining sites and enhances operational efficiency and productivity by spearheading a greater digital transformation of processes in the engineering chain from product design through trial machining (Fig. 1).

The simulator is a Windows[1] application intended for use by design departments mainly in charge of creating process designs and machining programs for machine users. This software replicates the actual machining environment to make the hand off between design departments and machining sites go more smoothly. By using the same system data (machining conditions and parameters, calibrations, functional options, etc.) as the NC machine tool, the simulator achieves high-fidelity 3D simulations replicating not only the positional control but also the real Computerized Numerical Control (CNC) movements from smoothing, acceleration and deceleration to servo response delays. This level of fidelity has the distinct ability to detect various machining flaws that could only be discovered through trial machining in a virtual space (on a computer).
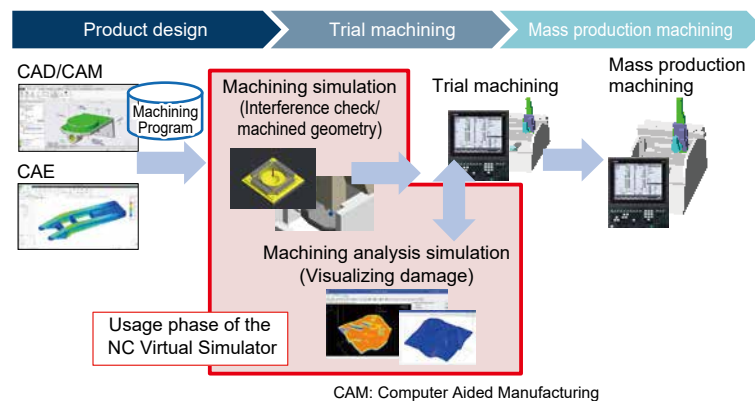

Fig. 1 Utilization phase of the NC Virtual Simulator

*Industrial Mechatronics Systems Works

The machine model simulations even support links to the NC Trainer2 plus, an existing Mitsubishi Electric product supporting customization development, which engineers can use as a tool to help improve the ease of machine design (machine model design using CAD) and ladder development by NC machine tool manufacturers.

*1 Windows is a registered trademark of the Microsoft Corporation.

2.1 Function to replicate NC machining tool movements in a virtual space

The NC Virtual Simulator runs in Windows on the same software as the real CNC machine and virtually models the feedback loop of the drive unit in the virtual space. It even has a function to synchronize the actual CNC system data to reproduce real CNC movements virtually (Fig. 2). These functions enable engineers to confirm authentic simulations tracking tool movements of the real CNC machine in addition to alarms and other alerts triggered on the actual CNC machine all in a virtual space.

The NC Virtual Simulator can even replicate the machining flaws that simulations at the CAD/CAM command level cannot as well as detect improper NC settings in advance. These capabilities help reduce rework sent back to the design departments from machining sites and workload on machining sites.

2.1.1 Simulation generating NC command positions

Unlike a block-level simulation in a CAD/CAM machining program, the NC Virtual Simulator utilizes the CNC software built into the actual CNC machine to enable a simulation that meticulously replicates the NC command position generation reflecting the acceleration, deceleration and other such parameters. More specifically, the emulation of real-time operations in the operating system running the CNC software at a CPU command level precisely reproduces periodic interrupt, task sequences, and other CNC software functions. By incorporating these functions, the simulator can simulate smoothing, acceleration, deceleration, and other processes generating command positions in a virtual space.

The combination of 3D machining and machining analysis simulation functions outlined later in this paper enables the NC Virtual Simulator to detect machining flaws not expressed by CAD/CAM simulations. These results let users make the detailed adjustments—such as fine tuning small level differences, acceleration, deceleration, and other parameter settings in the machine program—usually made by machining sites based on the results of trial runs but earlier in the design stage.

2.1.2 Drive response simulations

The NC Virtual Simulator provides a function to simulate the feedback loop process of drive units to reproduce the surface accuracy while taking into account the impact of response delays of the drive unit in addition to the CNC command positions. A simulation that includes the response delays in the feedback loop of drive units reproduces tiny deviations from the CNC command path, such as on the inner circumference.

These simulation results give users greater insight into up-front inspections at the design stage or prevent rework when issues arise on site in later phases after the design stage.

2.1.3 Links to NC machining tools

Users can reflect settings in simulations by simply importing system data exported from the real CNC machine such as machining conditions and parameters, calibrations, and functional options into the NC Virtual Simulator. This provides a function to easily match the
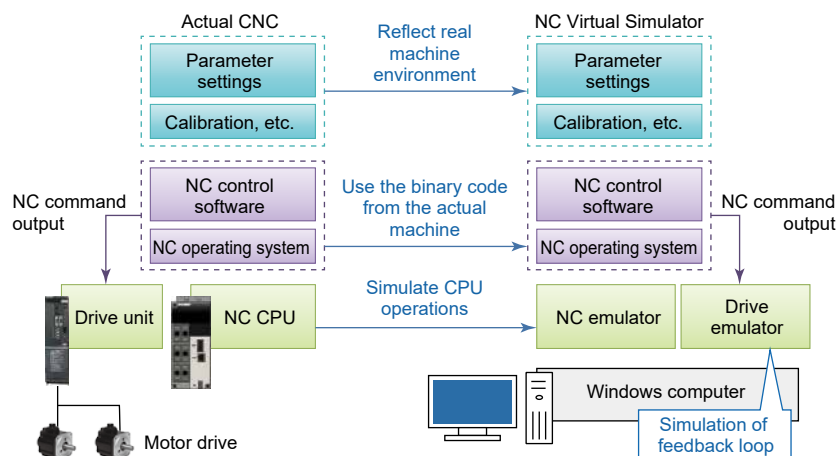

Fig. 2 Simulations of NC machine tool operations in a virtual space

various settings of the NC Virtual Simulator to those of the actual CNC machine without any manual settings, whether the machining program or NC parameters.

Mitsubishi Electric is also in development of a function to transfer data with the NC through a network. This function enables user to reflect any adjustments to the machining program or parameters made in the NC Virtual Simulator to the real CNC machine to resolve potential issues, such as mistaken or forgotten settings which can happen when reflecting these changes manually on the actual CNC machine.

2.2 3D machining simulations

The NC Virtual Simulator provides functions for two 3D machining simulations: a workpiece simulation that displays the geometry of a workpiece during machine and upon completion as a three-dimensional model as well as a machine simulation that displays the operation of machine parts and detects any interference between these parts.

Users can take advantage of the workpiece simulation (Fig. 3) to verify the machining of a workpiece as well as the geometry upon completion using a three-dimensional model. This simulation helps users estimate the time required for machining as well as confirm whether there are any burrs due to a missing machining process.
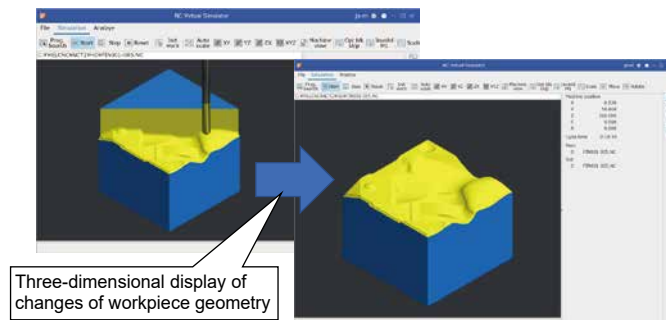
Users can take advantage of the machine simulation (Fig. 4) to verify the axial movement of machine parts using a three-dimensional model. This simulation helps users check for any machine interference between the parts, parts and tools, or tools and workpieces. The machine simulation even provides a warning and stop function in the event of any interference.

These simulations provide a tool for users to safely and quickly verify the machining program operations as well as check and correct the parameter settings virtually without every running the actual CNC machine.
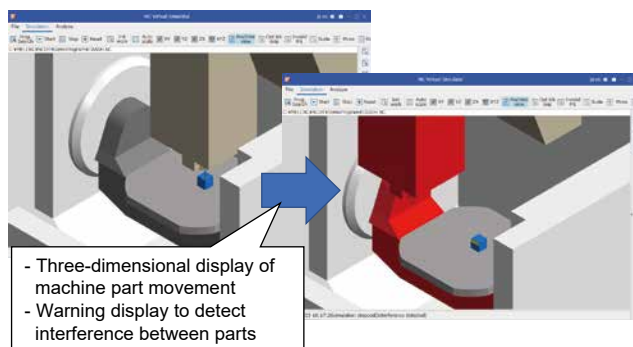
2.3 Machining analysis simulations

Machining analysis simulations displays a color map distinguishing differences in machining by color, whether the position and speed along small segments or the acceleration rate. These color maps make it easy for users to visually identify any sudden changes. The simulations also link each segment of geometry with the relevant program block so that users can identify which block of the machining program corresponds to a geometry path.

Users can take advantage of machining analysis simulation results to visually identify minute changes in geometry, analyze the cause of subtle surface damage in the machining, or revise machining programs.

Three-dimensional display of changes of workpiece geometry

Fig. 3 Workpiece simulation

- Three-dimensional display of machine part movement
- Warning display to detect interference between parts

Fig. 4 Machine simulation

2.3.1 Color map display

The color map from a machining analysis simulation (Fig. 5) isolates and displays the speed, acceleration rate, and other values using 256 different colors.

For example, users can use these color maps to easily identify neighboring paths with different acceleration rates. This provides visual results to check and correct any issues in the machining program for those corresponding areas (tiny level discrepancies, differences in neighboring machining paths, etc.)

Users can also highlight values within a specific range to check and modify the values of parameters for any speed or acceleration rate outside of the tolerance range.

2.3.2 Program link display

The NC Virtual Simulator can also add data to link the machining program blocks to the command position data generated by the NC to display the block corresponding to specific geometry by clicking the path displayed on the 3D model (Fig. 6).

This lets users easily check the corresponding block of problem paths found in the color map described in 2.3.1 to correct in the machining program.

2.4 Toggle function to prioritize speed or accuracy

As described in 2.3, the NC Virtual Simulator is unique for its ability to accurately reproduce operations of real CNC machines. However, in some cases, users may need an easy way to quickly check for any issues in the geometry of the completed workpiece (burrs due to missing machining processes) or for mechanical interference.

To do this, users can select a mode prioritizing simulation speed that does not replicate all of the command positions output by the NC but rather narrows down those that are within the tolerance range to enhance the simulation speed.

Users can take advantage of the mode prioritizing speed to first deal with missing machining processes, mechanical interference, and other major issues before using the mode prioritizing accuracy to eliminate tiny machining flaws.
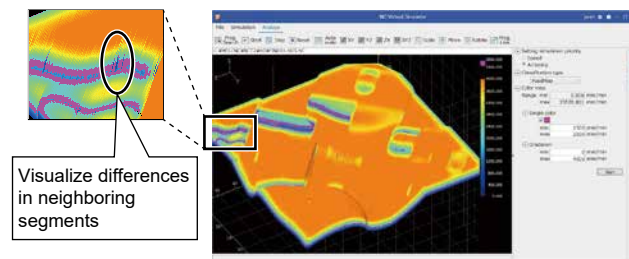

Visualize differences in neighboring segments

Fig. 5 Color map display

X16.7992Y23.7956Z-.0571
X17.5511Y24.5475Z-.2073
X18.1752Y25.1716Z-.3661

Click an arbitrary path

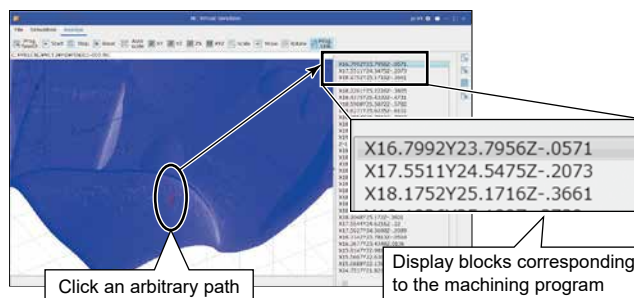Display blocks corresponding to the machining program

Fig. 6 Program link display

2.5 Links to NC Trainer2 plus

Mitsubishi Electric is in development of a function that will provide a link to the NC Trainer2 plus, which is an existing Mitsubishi Electric application used as a tool for machining operation training, the creation of ladder circuits of machine manufacturers, and development of customized screens (Fig. 7). This specific framework will enable users to run simulations by linking the operations executed in NC Trainer2 plus with the NC Virtual Simulator.

For example, this cross-software compatibility lets designers of machine manufacturers use NC Virtual Simulator to check for any interference while verifying the operation of a workpiece when developing a ladder circuit.

3. Conclusion

This paper has described the features of the NC Virtual Simulator developed as a tool to closely reproduce machining processes of NC machining tools in a virtual space to discover machining flaws and programming mistakes earlier in the design stage that are typically only found during a trial run. These simulations contribute to greater productivity on machining sites. Mitsubishi Electric will continue to consider various market needs and drive forward product development that provides even higher user value in a way that contributes to a better digital transformation of manufacturing businesses for a greater shift to smart factories.

Reference

(1) Fujita. T., et al. : Development of Machine Tool Digital Twin based on FA-IT Integrated Solution, Japan Society of Mechanical Engineers, Vol. 124, No. 1231, pp. 22-25, 2021
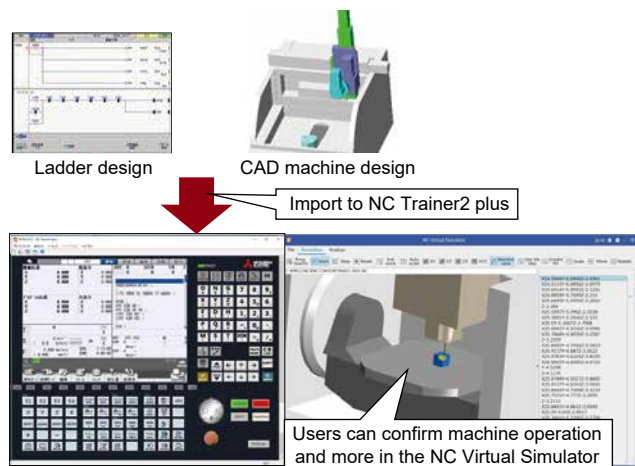

Fig. 7 Function to link to NC Trainer2 plus