Basic development of data sharing CNC system  
(Case study on high accuracy machining of characteristic lines)

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Received: 17 July 2019; Revised: 9 October 2019; Accepted: 20 December 2019

Abstract  
In this study, machining problems that can be solved by a numerical controller are considered, and a solution method is proposed. Regarding the data flow of machining process chains, product shape data created by computer-aided design (CAD) are converted into point sequence data by computer-aided manufacturing (CAM) to create a machining program in the machining process chain. Computer numerical control (CNC) faithfully interpolates a dedicated CNC program (ISO code) indicating a tool path and processing conditions, called G code, for machining a workpiece. However, there are no design shape data in the machining process. As the result, accurate measurement and correction with additional processing are required to obtain a high-precision product shape. In this study, as a mechanism that enables information flow belonging to CAD and CAM to be shared without losing it until CNC program execution, the implementation of an integrated CNC system with a shared database is addressed. Information in this database is described according to a predetermined format as data models. The data model that is the basis of information sharing and its practical use are described. Forming characteristic lines on a die were applied for confirmation of the effectiveness of the mechanism using data model. It was confirmed that actual machining realized high machining accuracy compared to the conventional technology.

Keywords : Integrated computerized numerical controllers (CNC) system, Shared database, Data model, Form accuracy, Characteristic line

1. Introduction

In comparison with the Numerical controllers (CNC) that was first computerized in the 1970s, the number of controllable axes by one unit, the program processing speed, the storage capacity, etc., have increased dramatically in recent years. This significant performance increase has made it possible not only to accelerate production but also to achieve complex operation of machine tool motion. Hence, machining of complex shapes without process division has become possible and mounting errors due to process division can now be eliminated. However, as machined shapes become more complex, factors influencing shape errors are more likely to occur, thereby increasing the machining difficulty.

There are various factors that affect the shape accuracy, each of which has multiple influences. An ideal solution to overcome the problem of shape inaccuracy would be obtained by accurately converting the shape data generated via computer-aided design (CAD) to the relative motion between the machine tool and the workpiece. Following the initial shape constructed by CAD, the NC program is eventually expressed as point-sequence data through computer-aided manufacturing (CAM). The NC program is merely a set of discrete position data and the original shape information no longer exists during machining. Generally, in the process chain, information is exchanged between processes using a general-purpose data format; however, there is almost no mechanism for mutual information use. Thus, the machining command is only converted into position data during machining because of the lack of interoperability of the processing information between processes.

The Standard for the Exchange of Product Model Data (STEP; ISO 10303) is a representative method of potential
open and standardized information exchange. STEP-NC (ISO 14649) has been developed as a standard format to improve system interoperability by integrating the CAD processing data into the machining command. In order to realize bidirectional information flows between CAD and CNC, Danjou et al. proposed a method of modeling and structuring knowledge acquired from manufacturing based on the STEP-NC standard (Danjou et al., 2013, 2017). Previously, Valilai and Houssmand developed a three-layered integrated and interoperable platform labeled the “INFELT STEP” platform, which enables interoperability between the CAD and simulation systems based on the STEP standard. This platform also allows the exchange of product data between different CAD and CAM (Valilai and Houssmand, 2010). Similarly, Wang et al. proposed an exchange mechanism to realize data exchange using a standard product data format (STEP/STEP-NC); hence, data can be exchanged between different CAD versions, systems, and file format products provided by different vendors (Wang and Xu, 2015). Thus, various studies for information sharing have been conducted based on the STEP-NC standard. The use of the STEP standard is recognized to realize information sharing and interoperability.

In this research, a mechanism was constructed that can always refer to information extracted from shape data in each process. In other words, a new process chain is proposed that can reflect shape information in machining commands. In this approach, the STEP-NC data format is used to exchange information between processes, and additionally, mechanisms that are not realized by the STEP standard such as characteristic extraction and feedback functions are achieved. As regards the machining program, the accuracy of shape produced by a machine tool is increased and the processing quality is improved by using a meaningful point group that reflects the design shape instead of the current point-sequence data.

2. Platform for sharing information from design to processing

As shown in Fig. 1, all the software tools and components: primarily CAD, CAM, and CNC, involved in the machining processes produce various types of information which are necessary in order to produce the optimum result from the input information. Nevertheless, there is no mechanism for mutually incorporating these various data during the processing the input and output information. Currently, the most commonly used CNC program is the ISO 6983 code, but the information contained is very limited, and it is difficult to inherit significant information and knowledge from upstream to downstream processes in the machining process chain. The current low interoperability of information due to the lack of an information reuse mechanism along with the one-way irreversible information flow is uncertainty factors influencing the CNC operation. If more information can be shared from the design stage to the machining execution, information loss between processes can be minimized, and information derived from the shape data can be maximized. For example, by using shape feature information, a highly accurate tool path could be generated. In addition, by storing and sharing machining and processing results, it becomes possible to construct an improvement cycle of the machining conditions and tool path data. Yamazaki et al. studied an architecture that extended the conventional CNC (Yamazaki et al., 1997). It created a database that made it possible to reuse work
procedures, NC programs, processing conditions, etc. Shinoki et al. proposed a machining operation planning system that generated machining NC programs by using past machining operation data proved as an achievement from the viewpoint of reusing programs (Shinoki et al., 2015). Although there are many experiments on the reusability of data, the effect of improving productivity was limited owing to difficulty of gathering sufficient data for evaluation.

The proposed approach is shown in Fig. 2. The system in this research consists of a platform and application software with the shared database and machining process as software components. The data stored in the shared database are structured and easy addition and reuse of data are possible. A growing system can be realized as an integrated CNC system. As the integrated CNC system including the above shared database corresponds to independent software, it is possible to implement the system according to the requirements of a given application and environment. One potential application is to realize high precision and high functionality for a specific machine tool by directly mounting the CNC as shown in Fig. 3. In another configuration, as shown in Fig. 4, the integrated CNC system behaves as a common base for the machine tools and the machining command generation engines in a case in which a plurality of machine tools are connected to the machining line via a network. It is also possible to install the system on the common factory platform and to directly transfer the machining commands to the CNC.

3. Mutual utilization of information and shared database

A common data model is provided to ensure information interoperability in all machining processes. In order to convey the intentions of the machining engineers, it is important to hierarchize the information from the view point of machining perspective and to construct structured data. Through data structuring, information on machining processes can be associated with the various stages from design to machining and measurement. In addition, it becomes possible to flexibly reference and inherit mutual data elements. For example, by structuring a tool path, machining command point sequences can be grouped and the attributes can be assigned to each of these groups. It is also possible to add characteristic information on a shape which is useful for compensating for the machining inaccuracy by grouping machined shapes.

3.1 Proposed data model

The proposed architecture is to realize data sharing in which meaningful information can be inherited by all the processes. Therefore, the STEP-NC data model, which is widely recognized in the interoperability of data, was applied. STEP-NC defined in ISO 14649 is an approach that brings in more information from design process to machine control. In this research, the STEP-NC data model was expanded in order to realize that information created by CAD can be inherited by subsequent processing as much as possible. For example, in the STEP-NC data model, it is possible to define a shape, but it does not consider creating a machining command to compensate for machining accuracy such as specifying a characteristic part. Therefore, additional information was typified by characteristics having an effect of improving machining accuracy and was added to the data model.
The information constituting the data model is shown in Table 1. Design information adopts the definition of STEP (ISO 10303). Information such as form features like edges, information indicating the actual state of cutting tools and machine tools, tool path attributes, etc. is defined and added to machined shape information, machining resource information, and machining command information as the extended ISO 14649. Machining technology information, machining execution information, machining result information and knowledge information of machining site are newly introduced. In Table 1, several data models and typical data items added to the original STEP NC data model for the purpose of extending the function to supplement the information defined by STEP are represented in italic letters. The added data model and data items are explained in detail as follows.

[Data models]

- **Machining technology information**: The STEP-NC data has shape information, but the design features of the product are not considered. The characteristic information on the shape extracted by CAD is defined as the machining technology information. As the result, information such as tolerance specified by CAM is retained. These pieces of information are reflected on the machining command.
- **Machining execution information**: The STEP-NC data does not consider the accumulation of information during processing execution. Operation history of the operator, sensor information, etc. are acquired via CNC and held as machining execution information.
- **Machining result information**: It can be used for analyzing and deducing by correlating with machining execution information and storing shape measurement data of the machining results. The Machining result information is currently unsupported. The construction of it will be future tasks.
- **Knowledge information of machining site**: Correlating the processing know-how of the operator with the change history of the machining process, and optimizes the machining command information. The knowledge information is currently unsupported. The construction of it will be future tasks.

[Data items]

- **Machine target**: It represents the objectives of individual machining such as targeting high dimensional precision or targeting shorter machining time.
- **Special characteristic**: It represents characteristic parts of a manufacturing feature such as ridgelines that should be clearly formed on the surface from the design point of view.
- **Machine tool state**: It represents the current state of a machine tool that differs from its original state such as the deflection of spindle column.
- **Actual tool state**: It represents the current state of a cutting tool that differs from its original state such as the wear of the tool.
- **Execution record**: It is the records of execution of a machining working steps: start time, finish time, and sampled data during the execution.
- **Machining environment**: It is a collection of the data sampled that represent the environment of machining such as coolant temperature.
- **Cutting state**: It is a collection of the data sampled during the execution such as spindle motor current.

| Data model | Contained information (data item) |
|------------|----------------------------------|
| Design information | CAD data (dimensional tolerance, geometric tolerance, surface roughness, characteristic data) |
| Machining technology information | Information on machining features, tools, choice of machining process etc. (machining_target) |
| Machined shape | Defined machining features (machined shape) information (special characteristic) |
| Machining resource information | Collected data of machine tool (machine tool state, cutting tool (actual tool state), pre-setter, measuring machine etc.) |
| Machining command information | Defined machining process (machining type), strategy information |
| Machining execution information | Execution log (execution record, machining environment, cutting state) |
| Machining result information | Information obtained as machining results such as inspection data |
| Knowledge of machining site | Machining process maintaining quality, machining optimization etc, machining operator’s know-how |

Table 1 Information included in proposed data model.
3.2 Sharing information on the sharing database

The interoperability of the information in this research is realized by a mechanism that can accumulate meaningful information among the information from the upstream and the downstream of the process chain and can use it mutually. As described above, by sharing data in each process, it becomes possible to reliably inherit the information necessary for processing to the next process. Figure 5 depicts a block diagram of a data model shared with software components constituting the integrated CNC system. Unimplemented data models and data flows are represented by dotted lines. The CAM used in this is not for commercial use but for testing with the function of creating processing command data for the integrated CNC system. The motor controller section uses existing CNC (FANUC Series 31i-B).

Focusing on the characteristic information, the data flow among processes is as follows.

(1) Characteristic information is extracted from the geometric information of CAD to obtain additional information of the integrated system.
(2) CAM refers to the processing technology information and creates machining commands.
(3) Machining command is decoded and executed by CNC. High precision machining that does not depend on mechanical properties can be processed based on characteristic information, etc.
(4) Machining execution information is recorded in association with the machining commands. It leads to improvement of machining conditions in the next machining.

Many research studies have been performed on automatic processes for the design and automatic generation of machining programs. Dwijayanti et al. developed a system that extracted machining features from the shape data created by CAD and automatically made the plans of the machining processes (Dwijayanti and Aoyama, 2014, 2015). Kiyooka et al. developed a system that automatically generates the NC program according to the process plan (Kiyooka, et al., 2017). However, there has never been any focus on the information interoperability that this research tries to realize.

One of the data included in the sharing database is machine resource information. This data model also includes NC data necessary for machining execution. The advantage of improving interoperability is that NC data is always used without time lag. This integrated CNC system uses the machine-specific NC data of the machine used for machining to generate tool paths and select machining conditions. Therefore, even when NC data is changed on site, a machining command is always generated from the latest machine information. Responding to dynamic changes in the shop floor always creates more accurate tool path.

4. Case study

As an example of improving product shape accuracy by sharing information from upstream processes, it is demonstrated that characteristic information specified by CAD can be effectively handed over to CNC using a shared database, even if it passes through CAM. In die/mold machining, the ability to accurately transfer characteristic information expressed in the design of a product determines the quality of the machined shape. It is possible to realize high-precision machining by the ability of CNC to understand and control the characteristic information extracted by
CAD. Generally, in conventional technology, to increase the shape accuracy, appropriate speed control during machining is important in addition to generating a highly accurate machining program. The inner deviation generated tool paths during machining largely depends on the command speed and the acceleration/deceleration time constant. The tool trajectory error is caused by the result of velocity control. On the other hand, for NC programs generated by CAM, CL data is generated from geometric information, then NC programs are generated by post processing in consideration of machine information and tool information. For optimal control of machine tools, it is important to generate NC programs utilizing machine information and NC controller parameters employed during actual machining. However, the NC data given to the CAM may not exactly match that of the machine tool to be executed. This is because various parameters necessary for machining are not fixed values because they are adjusted or changed by individual machine tools on site.

Therefore, an integrated CNC system is proposed in which the CNC controller can dynamically include the machine characteristics and CNC parameter information of the actual machine tool. To realize high accuracy machining, it is desirable to geometrically reproduce the designed shape as tool paths without depending on the mechanical characteristics. In the developed integrated CNC system, by utilizing the data of the shared database, machining command points on tool paths, can be accurately instructed on ridgelines which are one of the typical shape characteristics. In addition, regardless of the angle, the deceleration is determined with characteristic information described in the machined shape of the data model and the command speed at the corner described in the machining technology information of the data model as well. The integrated CNC system can accurately represent CAD-designed geometric information without relying on CNC and machine characteristics, as compared to conventional techniques.

As a specific example, as illustrated in Fig. 6, a shape in which an edge is expressed as a characteristic line traced in red line on the intersection line of two curved surfaces is examined. Figure 7 shows an example of the design of an automobile body that has characteristic lines as intersections of curved surfaces. In the integrated CNC system, this edge shape: the intersection line, is machined accurately using the extension of the data model which describes that the intersection line is a characteristic line with the attributes.

### 4.1 Machining shapes and conditions

In this case study, the intersection of two surfaces was applied for machining as an example of simplifying the above-mentioned mold shape. As the machining speed increases, the following accuracy of the servo system decreases, and the positional deviation increases. Also, CNC needs to control the machining speed to avoid mechanical impact. Even if the trajectory accuracy is good when the machining speed is low, the trajectory accuracy deteriorates as the velocity becomes high, and it becomes difficult to machine an accurate corner shape. According to the CNC control principle, high accuracy machining for intersection edges having an obtuse angle close to 180° is difficult than for edges having an acute triangle. Therefore, ridge shapes having an angle close to 180° was applied to confirm the effectiveness of the proposed method. The processing according to the prior art and the integrated CNC system is performed at high speed for machining ridge shapes having angles of 178°, 176°, and 172° shown in Fig. 8. The accuracy and machining time of the machined shape including the ridgeline which is a line of intersection of two planes are compared.

As described in Section 3.1, information (special characteristic) is added to the machined shape of the step form as extended data in the machined shape data model. A data model related to special characteristics is shown in Fig. 9.
characteristic line to be verified in this case study is described as BoundedCurve, which is one of the attributes of the class extended as SharpCurve. In actual machining, characteristic line information is used for shape analysis by machining strategies in Machining command information. The use of characteristic line information is described in detail in section 4.2.

As input data for the machining resource information, a small three-axis machining center was used for the machine tool, an aluminum alloy (A5052) was used for the work material, and the cutting tool was a ball end mill with a 4.0 mm radius. The machined shape data includes characteristic line information as an extended data in addition to the above-mentioned machined shape.

As an index of evaluation, an inner deviation of an edge apex measured by a laser microscope as trajectory accuracy and a processing time (cycle time) were selected.

4.2 Machining strategies

In the prior art, shape accuracy is acceptable if the command points of the machining program are within the specified tolerance. In that case, the command points on the ridgeline may scatter within the range of tolerance, and the ridgeline may not be machined accurately. Also, considering the ridgeline machining with crossing a tool path, to compensate for the accuracy as the edge shape, it is necessary to perform appropriate deceleration at the edge apex. In the prior art, a corner deceleration function is applied for machining an edge shape. But the necessity of corner deceleration is uniquely determined by the corner angle threshold value and the corner deceleration parameter set in the CNC, so that the accuracy of the edge shape is influenced by the setting of the CNC and the mechanical characteristics. As in this case of this processing object, under the condition where the edge angle is as close to 180° as possible, it is outside the threshold of the corner angle and is not recognized as the edge shape, and the deceleration is not considered. Furthermore, between the blocks of the machining program, since an inner deviation always occurs as the commanded speed increases, a difference in shape accuracy occurs depending on the commanded speed. Processing to clarify the line of intersection of planes with high shape accuracy becomes difficult as the command speed becomes higher.

In the integrated CNC system, because the shape information of the CAD data is taken over, the intersection line of two planes is recognized as a corner shape even if the edge angle is obtuse, and a machining program having a ridgeline as a corner vertex is generated independently of the edge angle. In this manner, the integrated CNC is enable to generate an accurate machining program that can accurately reproduce characteristic information geometrically. Furthermore, because the corner shape is designated, acceleration/deceleration processing can be performed in advance.
about the machining command point of the corner apex, so that speed control can be performed, which can reliably form the corner shape. In contrast to the prior art in which the shape accuracy is determined by the result of the speed control, the integrated CNC system geometrically determines the shape accuracy and performs the speed control resulting therefrom. This is an approach that guarantees accuracy.

As a strategy for machining in the evaluation test, the data model "Machining command information" is given machining conditions of the command feed speed 2000 mm/min (in the following F2000), the spindle rotational speed 10000 rpm, and one-way cutting. The speed F2000 is the maximum feed rate of the recommended cutting conditions of this cutting tool. The integrated CNC system can decelerate to a specified speed if the feature is an edge shape. The decelerating speed at the edge should be determined by the mechanical characteristics and the tool characteristics as a speed that can compensate for the accuracy. From the processing conditions in this case study, the command speed 500 mm/min (in the following F500) is specified as the deceleration speed at the edge, which makes the feed amount per cutting edge 0.025 mm/tooth for an aluminum work material. Under the above conditions, when a characteristic line is detected during motion control of linear interpolation with a speed F2000, the deceleration distance $d$ is obtained from the time constant to decelerate to the feed speed F500 in the vicinity of the characteristic line, and the deceleration start position is determined as shown in Fig. 10. In the conventional technology, the CAM generates a tool path with given NC data, NC parameters, tool information, etc., but it does not always match the NC data of the actual machine to be machined. The integrated CNC system uses machine specific NC data to generate a tool path. As a result, data that is determined depending on the NC parameters, such as specifying the deceleration start point, dynamically responds even when the parameters are changed, and a highly accurate tool path is always generated.

As described above, the shape accuracy is determined by two factors: the quality of a machining program and the speed control. In this case study, even in the prior art, the machining program is given the condition that the apex of the edge shape is explicitly instructed. Focusing on the speed control of the second factor, the tool path and machining time of the integrated CNC system and the prior art are compared by the following three patterns.

1. Integrated CNC system (command feed speed F2000)
2. Prior art F2000 (command feed speed F2000)
3. Prior art F500 (command feed speed F500)

4.3 Tool path accuracy

The machining accuracy is compared under the above three speed conditions for machining the ridge shape with an edge angle of 178 degrees, 176 degrees and 172 degrees. First, to verify the algorithm, position command values from the CNC to the motor are measured and compared. Next, actual machining is performed to compare the shape accuracy.

4.3.1 Calculated position command

The result of the CNC analyzing the machining program and controlling the speed after interpolation processing is output as a position command to the servo system. The characteristics of each algorithm can be clarified by comparing the position command values. As shown in Fig. 11, it is clarified that the actual tool trajectory is offset from the design shape by the tool diameter compensation. The measurement results are shown in Figs. 12, 13 and 14 as follows.
The algorithm of the integrated CNC system is applied in the vicinity of the edge shape vertex under the consideration of characteristic point information inheriting CAD data (blue line), which the feed speed is decelerated from F2000 to F500. The trajectory error at the edge vertex can hardly be recognized at any points. It was confirmed that, even with high-speed feed speed F2000 machining, for which it is difficult to maintain trajectory accuracy, it is possible to have a machining command that decelerates to an appropriate speed near the edge without depending on the edge angle.

In the prior art, the look ahead of the block in execution of the machining program is analyzed, and the movement command for each interpolation cycle is generated by calculating from the movement distance and speed. In this target shape, it is not considered to be a corner shape so that machining at the corner is processed without being decelerated at the corner. The edge with the angle 178 degrees is regarded as not edge shape, and the trajectory error due to internal tracks is small. However, as the edge angle becomes acute, the amount of trajectory error resulting from high-speed processing increases.

With the feed speed F500 constant-speed processing (green line), high-precision machining was performed in which the error at the edge apex cannot be substantially confirmed at any position. It is confirmed that the velocity F500 is sufficient to maintain trajectory accuracy.

The position command values according to the deceleration algorithm of characteristic points by the integrated CNC system are outputted to generate the theoretical servo command values.

### 4.3.2 Actual machining shape

Regarding the actual machining results by the small machining center, the measurement results achieved by the laser measuring device were superimposed on the command shape, as shown in Figs. 15, 16, and 17. The results are described as follows.

1. In the processing by the integrated CNC system for the feed speed F2000 shown by the blue line in Figs. 15, 16, 17, the inner turning deviation amount at the edge vertex is 1 µm, and the processing of feed speed F2000 is also suitable near the edge. It was confirmed that the tool passed by decelerating to speed.

2. In the prior art with the feed speed F2000, the corner shape is not identified. As the result, the control speed is not decelerated, and an error caused by the inner turning occurs at the corner. It is confirmed that the tool path error increases as the edge angle at the corner becomes acute.

3. In the prior art with constant low feed speed F500, the trajectory error due to the inner turning at the edge apex was within 1 µm. The feed speed F500 is sufficient to maintain trajectory accuracy independent of the angle.

In the integrated CNC system, it was proved that the shape accuracy does not depend on the command speed and that the shape information specified by CAD can be faithfully reproduced.
4.4 Processing time

Assuming that the cycle time 3.556 seconds of the constant feed speed F2000 in the current processing is 100%, the processing time of the feature point decelerating algorithm by the integrated CNC system recorded 4.323 seconds increased by 22%. It can be seen that the influence of deceleration at the characteristic points is very slight. The cycle time with constant speed F500 increased by 237% to 11.988 seconds. The results are shown in Table 2. Based on these results, applying the algorithm of the integrated CNC system realizes machining of equivalent precision to low feed speed with about 1/3 time.

In this case study, the algorithm that decelerates at the characteristic line obtained from shared data was applied. From the above results, in the integrated CNC system, it is apparent that highly accurate machining can be performed even at a higher command speed without intentionally adding special speed control to the machining command.

5. Conclusion

In order to compensate for inaccurate machining in CNC machine tools, a shared database and data model that can be interoperated in each stage of the process chain for CNC machining command generation were proposed in this study. The basic structures of the shared database and the data model of the design information and the machining information were discussed. Furthermore, a prototype data model of the machining technology information was created. In addition, a machining command was generated using the data model and implemented in a machining case study with a CNC machine tool. As the machining command was generated by recognizing the characteristic information of the shape, it was possible to confirm that the shape data was more faithfully transferred to the workpiece material compared to that yielded by a machining command generated using the conventional method.

| Command Speed          | Cycle time [s/line] | Inward turning amount [µm] |
|------------------------|---------------------|-----------------------------|
|                        |                     | 178° | 176° | 172° |
| F2000 constant speed   | 3.556 (100%)        | 2    | 4    | 6    |
| F500 constant speed    | 11.988 (337%)       | 1    | 1    | 1    |
| F2000 partially deceleration | 4.323 (122%)    | 1    | 1    | 1    |
References

Danjou, C., Le Duigou, J., Eynard, B., Integrated platform from CAD to CNC, A survey, IFIP Advances in Information and Communication Technology (2013), Vol. 409, pp.130-139.

Danjou, C., Le Duigou, J., Eynard, B., Closed-loop manufacturing process based on STEP-NC, International Journal on Interactive Design and Manufacturing (2017), Vol.11, Issue 2, pp.233-245.

Dwijayanti, K. and Aoyama, H., Basic study on process planning for turning-milling center based on machining feature recognition, Journal of Advanced Mechanical Design, Systems and Manufacturing, Vol.8, No. 4(2014), JAMDSM0058.

Dwijayanti, K. and Aoyama, H., Development of Automatic Process Planning for Turning –Milling center with 2 Turrets System, Journal of the Japan Society for Precision Engineering, Vol.81 No.5 (2015), pp.471-480.

Kiyooka, R., Dwijayanti, K. and Aoyama, H., Development of Automatic System on Process Planning and NC program Generation for Turning –Milling Machine Tool with Multi Turrets, Journal of the Japan Society for Precision Engineering, Vol.31 No.9 (2017), pp.878-882. (in Japanese)

Mazda Motor Corporation Official Home Page(on line), available from< https://www.mazda.co.jp/> , (accessed on May 24, 2019).

Shinoki, Y., Isnaini Mi’radj Mohammad, Sato, R. and Shirase, K., Machining operation planning system which utilize past machining operation data to generate new NC program, Journal of the Japan Society of Mechanical Engineers, Vol.81, No.832 (2015), p.15-00280. (in Japanese)

Valilai, O.F., Houshmand, M., INFELT STEP, An integrated and interoperable platform for collaborative CAD/CAPP/CAM/CNC machining systems based on STEP standard, International Journal of Computer Integrated Manufacturing (2010), Vol. 23, Issue 12, pp.1095-1117.

Wang, X.V., Xu, X.W., A collaborative product data exchange environment based on STEP, International Journal of Computer Integrated Manufacturing (2015), Vol. 28, Issue 1, pp.75-86.

Yamazaki, K., Hanaki, Y., Mori, M., and Tezuka, K., Autonomously Proficient CNC Controller for High-Performance Machine Tools Based on an Open Architecture Concept, Annals of the CIRP, 46-1(1997), pp.275-278.