Title: STEP-NC SYSTEM HAVING FUNCTION OF NON-LINEAR PROCESS PLAN

Abstract: A STEP(standard for the exchange of product data model)-NC(numerical control) system having a function of a non-linear process plan includes a non-linear process plan generator and a machine tool. The non-linear process plan generator produces a non-linear process plan including alternative machining process plans, and creates a part program including information of the non-linear process plan. The machine tool loads therein the part program created by the non-linear process plan generator and extracts the information of the non-linear process plan by analyzing the part program. The machine tool machines a workpiece based on the information of the non-linear process plan to manufacture a desired product.
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
STEP-NC SYSTEM HAVING FUNCTION OF NON-LINEAR PROCESS PLAN

FIELD of THE INVENTION

The present invention relates to STEP (standard for the exchange of product data model)-NC (numerical control) systems which machine workpieces under the control of numerical controllers to form final shapes of the workpieces according to designed shapes, thus manufacturing products; and, more particularly, to a STEP-NC system having a function of a non-linear process plan.

BACKGROUND OF THE INVENTION

Numerically-controlled machining techniques have been remarkably developed since a numerically-controlled milling machine was invented at MIT in 1952. Computer-aided numerically-controlled machining systems include CAD (computer aided design), CAPP (computer aided process planning), CAM (computer aided manufacturing), CNC (computer numerical control), and etc. In machining methods using the above-mentioned machining systems on shop floors, typically, part programs are created based on feature information of products designed by a CAD/CAM system so that the part programs are input into CNC machine tools with the numerical controllers to machine workpieces and manufacture the products.

The part program is an input to designate predetermined motions of a CNC machine tool. In the conventional part programming system, a user sets up a machining process plan through defining feature information, cut volume, machining procedures, tool information and machining conditions, based on hard copy drawings of a desired product or feature information of the product designed by a CAD system. Thereafter, the user expresses the desired motions of tools and the CNC machine tool in a
predetermined format (G&M code, hereinafter referred to simply as G-code) using a CAM system (or through a manual work in the case of simple motions), based on the machining process plan. A CNC controller controls the CNC machine tool by operating a motor or another actuator according to the part program created using the G-code. By the above-mentioned operation of the CNC controller, a final shape of the workpiece is formed to correspond to the desired shape of the product designed by the CAD system. The G-code is a machine language that refers the motions of the CNC machine tool to information about locations and velocities of tools or feed shafts. The G-code has been used for over fifty years since 1952.

However, the conventional part programming system expresses the machining process plan into the G-code, so that machining procedures of a CNC machine tool are linearly sequenced. The phrase “to be linearly sequenced” means that the G-code is linearly executed, and furthermore, the machining procedures are linearly determined in a step of setting up the machining process plan. For example, in case that a plurality of holes are formed on a workpiece according to the conventional part programming system using the G-code, machining procedures to manufacture the plurality of holes on the workpiece should be determined in the step of setting up a machining process plan. The determination of the machining procedures is to satisfy necessary conditions for the part program. Therefore, the conventional part programming system is problematic in that the determined machining procedures must be maintained even when an optimization of the machining procedures is required or a tool, such as a drill tip, is undesirably damaged or broken.

When a tool is damaged or broken during a machining process, it is required that the machining procedures be changed or the machining conditions be modified. However, the conventional part programming system cannot change the
machining procedures, because the numerical controller has information about only the axis motions of tools according to the fixed machining procedures. Furthermore, even when desired tools or jigs are not prepared, it is difficult to change the machining procedures or the part programs on the shop floor.

In the meantime, recently, a software language, which is a so-called "STEP-NC", is gathering strength. The STEP-NC language does not directly designate axis motions of tools but includes feature information, procedure information and the like which are used to create the axis motions. The axis motions of the tools are created by the CNC controller. As the demand for e-manufacturing intensified as a technology required for next generation production systems is increasing, it is expected that the above-mentioned language, STEP-NC, will have a great impact on the machining methods using CAD/CAM and CNC systems.

However, because the STEP-NC is mechanically neutral information, the STEP-NC information cannot be applied to every CNC system. Therefore, to manufacture a product by machining a workpiece using a specific CNC system based on STEP-NC information, the STEP-NC information needs to be modified to interface with the specific CNC system. In the process of modifying the STEP-NC information, various machining methods may be created according to intrinsic characteristics of the specific CNC system. That is, various alternative machining plans may be created in the process of modifying the STEP-NC information. Therefore, a new approach is required which can accommodate the alternative machining plans.

**SUMMARY OF THE INVENTION**

It is, therefore, an object of the present invention to provide a STEP-NC system having a function of a non-linear process plan, in which a non-linear process plan
including alternative machining process plans is recorded in a part program based on a STEP-NC data model, so that an optimum machining process plan is selected from the non-linear process plan by a CNC machine tool while considering shop floor conditions, thus machining a workpiece according to machining procedures of the optimum machining process plan to manufacture a desired product.

In accordance with an aspect of the present invention, there is provided a STEP-NC system having a function of a non-linear process plan, which machines a workpiece using a numerical controller to form a final shape of the workpiece according to a designed shape, thus manufacturing a product, the STEP-NC system including: a non-linear process plan generator for producing a non-linear process plan including alternative machining process plans, and creating a part program including information of the non-linear process plan; and a machine tool for loading therein the part program, extracting the information of the non-linear process plan by analyzing the part program, and machining the workpiece based on the information of the non-linear process plan.

**BRIEF DESCRIPTION OF THE INVENTION**

The above and other objects and features of the present invention will become apparent from the following description of preferred embodiments given in conjunction with the accompanying drawings, in which:

Fig. 1 is a block diagram of a STEP-NC system having a function of a non-linear process plan according to a preferred embodiment of the present invention;

Fig. 2 is a view showing a final shape of an example of products manufactured by the STEP-NC system of Fig. 1;

Fig. 3a is a view showing a plurality of cut regions of a workpiece for manufacturing the product of Fig. 2 in which the workpiece is sectioned into a plurality of parts
to define the cut regions;

Fig. 3b is a view showing a machining process plan alternative to cut the workpiece for manufacturing the product of Fig. 2 in which the workpiece is sectioned in another manner, different from that of Fig. 3a;

Fig. 4 is a representative example of NPSG (neutral process sequence graph) according to a machining process plan to form the final shape of the product of Fig. 2;

Fig. 5 is a representative example of HPSPG (hardware-incorporated process sequence graph) according to the machining process plan to form the final shape of the product of Fig. 2; and

Fig. 6 is a representative example of EPSG (executable process sequence graph) according to a practical CNC machining process to form the final shape of the product of Fig. 2.

**DESCRIPTION OF SPECIFIC EMBODIMENTS**

Hereinafter, embodiments of the present invention will be described in detail with reference to the attached drawings. Reference now should be made to the drawings, in which the same reference numerals are used throughout the different drawings to designate the same or similar components.

Fig. 1 is a block diagram of a STEP-NC system having a function of a non-linear process plan according to a preferred embodiment of the present invention.

Referring to Fig. 1, the STEP-NC system of the present invention includes a non-linear process plan generator 100. The non-linear process plan generator 100 takes a CAD file as an input through the Internet. Thereafter, a part program is created by a plurality of modules in the non-linear process plan generator 100, based on the CAD file input from the Internet. The part program created by the non-linear process plan generator 100 is, thereafter,
uploaded through the Internet. The non-linear process plan generator 100 includes a feature information analyzing and displaying module 102, a non-linear process plan producing module 104 and a part program producing module 106. The feature information analyzing and displaying module 102 takes a CAD information as an input to extract feature information of a product included in the CAD information, thus displaying the feature information of the product on a screen to provide the feature information to a user. The non-linear process plan producing module 104 determines machining regions of a workpiece based on the feature information, and, sets up a machining process plan therefor.

In case that the workpiece is machined by a lathe work, users may differently section the cut regions of the workpiece. For example, when a user sections the machining regions of the workpiece for manufacturing a product shown in Fig. 2 to form a final shape of the product, the user may section the cut regions of the workpiece in a manner shown in Fig. 3a wherein regions 5, 7 are respectively cut through a turning work and a grooving work. Otherwise, the user may also section the machining regions of the workpiece in a manner shown in Fig. 3b wherein the regions 5, 7 of Fig. 3a are replaced with regions 8, 9 that are cut through two turning works. Furthermore, when a region designated by the reference numeral 6 is cut to form a hole, the region 6 may be cut in a manner in that a drilling work is executed prior to a work of forming the final hole. Otherwise, the region designated by the reference numeral 6 may be cut through a boring work after the drilling work. As described above, in the lathe work, there may exist alternative machining process plans.

Therefore, the non-linear process plan producing module 104 includes modules for sectioning the alternative machining regions and for producing the alternative machining process plan. The non-linear process plan producing module 104 creates a non-linear process plan
including the alternative machining process plans. Thereafter, the part program producing module 106 sets up a part program including the non-linear process plan.

The STEP-NC system of the present invention further includes a machine tool 108 which receives the part program that was uploaded through the Internet by the non-linear process plan generator 100, thus practically machining the workpiece to manufacture the product. The machine tool 108 includes a part program analyzing module 110, a hardware information input module 112, an optimum process plan producing module 114, a machining path producing module 116, and an autonomous control module 118. The part program analyzing module 110 analyzes the part program input from the non-linear process plan generator 100 through the Internet, thus extracting the non-linear process plan information. The hardware information input module 112 generates a united non-linear process plan in which the non-linear process plan, taken in the hardware information input module 112 as an input, is united with a hardware information of the machine tool which practically machines the workpiece to manufacture the product. The optimum process plan producing module 114 sets up an optimum machining process plan, which is suitable to the machine tool, from various machining process plans included in the combined non-linear process plan. The machining path producing module 116 creates a machining path, along which the machine tool executes a desired machining process, based on the optimum machining process plan. The autonomous control module 116 practically executes the machining process through the machining path.

Figs. 4 through 6 are respectively representative examples of NPSG, HPSG and EPSG according to a machining process plan for a lathe work to form a final shape of the product of Fig. 2 by the STEP-NC system according to the preferred embodiment of the present invention. Fig. 2 is a view showing the final shape of an example of products. Fig.
3a is a view showing the cut regions of the workpiece to manufacture the product of Fig. 2 in which the workpiece is sectioned into a plurality of parts to define the cut regions. Fig. 3b is a view showing a machining process alternative to cut the workpiece to manufacture the product of Fig. 2 in which the workpiece is sectioned in another manner, different from that of Fig. 3a. As shown in Figs. 3a and 3b, the cut regions designated by the reference numerals 5 and 7 of Fig. 3a may be replaced with the cut regions designated by the reference numerals 8 and 9 of Fig. 3b.

As shown in Figs. 4 through 6, the non-linear machining process plan is expressed into process sequence graphs. Each of nodes in the process sequence graphs has a character (AND, OR, SYNCHRONOUS, PARALLEL and etc.) or information of a process unit (feature or delta volume of cut volume, machining conditions, tools and etc.). The character “AND” means that low-ranking nodes can be executed regardless of the sequence. The character “OR” represents that only one node of the low-ranking nodes can be selectively executed. The character “SYNCHRONOUS” represents that a plurality of resources of a hardware may simultaneously execute different low-ranking nodes. The character “PARALLEL” represents that a plurality of resources of the hardware may execute only one low-ranking node. For example, in a machine tool with two turrets, the character “SYNCHRONOUS” means that the two turrets simultaneously cut different regions of a workpiece, respectively. The character “PARALLEL” means that the two turrets cut one region of the workpiece with a predetermined interval. Furthermore, PSG is classified into the neutral process sequence graph (NPSG), the hardware-incorporated process sequence graph (HPSG) and the executable process sequence graph (EPSPG) according to its use (each of the terms NPSG, HPSG and EPSG has a functional meaning, and the terms are not used for a limitation purpose).
Fig. 4 is an NPSG of a machining process plan, which can be practiced regardless of machining tools or CNC machine tools, for machining the workpiece sectioned into delta volumes shown in Fig. 3a to form the final shape of the product shown in Fig. 2. Referring to Fig. 4, each of nodes represents information of a process unit, such as delta volume, machining processes, cutting conditions, used tools and etc., or characteristics of an executing sequence. Information of the NPSG may be expressed into a part program according to, e.g., STEP part 21 (clear text encoding rule), such that the information of the NPSG can be analyzed by any hardware based on a STEP-NC data model schema. Because the information of the NPSG must be neutral with respect to any hardware, the characters “SYNCHRONOUS” and “PARALLEL”, that dependent on the hardware information, cannot be used in the NPSG. At this time, information of the hardware used in a practical machining process is represented through the HPSG or the like.

Fig. 5 is a representative example of a non-linear process plan graph (HPSG) in case that a CNC lathe center with two turrets is used in the machining process according to the NPSG of Fig. 4. As described above, the information of the NPSG does not include any information of the hardware. Thus, the NPSG is required to be converted into information of the HPSG to utilize and reflect the function and performance of the machine tool to be used in the practical machining process. In the HPSG, each of nodes includes the information of the nodes of the NPSG and information of the hardware, such as the turrets and spindles. Furthermore, the characters “SYNCHRONOUS” and “PARALLEL” may be used in the HPSG to reflect the information of the hardware on the machining procedures during the practical machining process.

Fig. 6 is a machining process plan graph (ESPG) restructured from the HPSG of Fig. 5 which can be practically executed by a controller, such as NCK (numerical control kernel) or PLC (programmable logic controller). The
node with the character "AND" does not define any sequence thereof and the node with the character "OR" must select a sequence thereof, so that the controller is required to determine the sequences of the nodes with the characters "AND" and "OR". However, it is very important to ensure real time performance of the controller. In case the controller determines the sequences of the nodes with the characters "AND" and "OR" during the practical machining process, the real time performance of the controller may not be ensured. To ensure the real time performance of the controller, the controller determines in advance the sequences of the nodes with the characters "AND" and "OR" according to a previous set standard, while the HPSG is converted into the EPSG. Therefore, the information of the nodes of the EPSG is equal to the information of the nodes of the HPSG, but the EPSG does not have the nodes with the characters "AND" and "OR".

The HPSG is converted into the EPSG based on a selected performance standard for minimizing both the machining time and the exchanging number of the tools, thus increasing productivity of products. Furthermore, when an unexpected accident (for example, damage or breakage of the turrets or the tools) is caused during the machining process, the HPSG may be renovated. Thus, the renovated HPSG is converted into a new EPSG based on an alternative machining process plan.

As described above, the present invention provides a STEP-NC system having a function of a non-linear process plan, which proposes three methods (NPSG, HPSG and EPSG) of expressing a non-linear process plan based on a STEP-NC data model, so that information is transferred between CAD-CAM-CNC chain in the Internet environment without any obstacle, and which reflects information of a hardware on a shop floor, thus realizing an intelligence type autonomous control.

Furthermore, in the STEP-NC system of the present invention, because the information of the non-linear process
plan is reflected on the part program, various alternative machining process plan are provided on the shop floor. Therefore, a CNC machine tool is possible to execute an optimum machining process while considering the machining conditions of the shop floor. In addition, in case that an unexpected accident, such as damage to a tool or an operational error of the CNC machine tool, is undesirably caused, the STEP-NC system of the present invention autonomously deals with the problems without intervention of a person's selection. Therefore, the machining process is prevented from being delayed, and an unmanned machining and an artificial intelligence-type control are realized, thus increasing productivity of products.

Furthermore, to establish an e-manufacturing system, the STEP-NC system of the present invention realizes not only the interface of information of STEP-NC, but also the intelligent and autonomous control based on the information of the STEP-NC.

While the invention has been shown and described with respect to the preferred embodiments, it will be understood by those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention as defined in the following claims.
CLAIMS

1. A STEP (standard for the exchange of product data model) - NC (numerical control) system having a function of a non-linear process plan, which machines a workpiece under the control of a numerical controller to form a final shape of the workpiece according to a designed shape, thus manufacturing a product, the STEP-NC system comprising:

   a non-linear process plan generator for producing a non-linear process plan including alternative machining process plans, and creating a part program including information of the non-linear process plan; and
   a machine tool for loading therein the part program, extracting the information of the non-linear process plan by analyzing the part program, and machining the workpiece based on the information of the non-linear process plan.

2. The STEP-NC system of claim 1, wherein the non-linear process plan generator analyzes feature information of the product described by a STEP data model to represent executable machining methods for obtaining the product, and outputs the information of the non-linear process plan using a STEP-NC data model-based code.

3. The STEP-NC system of claim 2, wherein the executable machining methods include information about cut volume, machining procedures, machining conditions and tools.

4. The STEP-NC system of claim 1, wherein the non-linear process plan generator comprises:

   a feature information analyzing and displaying module for taking CAD (computer aided design) information as an input, extracting feature information of the product, and displaying the feature information of the product on a screen to provide the feature information to a user;
   a non-linear process plan producing module for
determining machining regions of the workpiece based on the feature information of the product, representing the alternative machining process plans respect to the workpiece, and setting up the non-linear process plan including the alternative machining process plans; and

a part program producing module for creating the part program including the information of the non-linear process plan.

5. The STEP-NC system of claim 1, wherein the machine tool analyzes the part program input from the non-linear process plan generator, extracts the information of the non-linear process plan, and practically machines the workpiece to manufacture the product along a machining path of an optimum machining process plan from the non-linear process plan.

6. The STEP-NC system of claim 1, wherein the machine tool comprises:

a part program analyzing module for analyzing the part program input from the non-linear process plan generator, and extracting the information of the non-linear process plan;

a hardware information input module for create a combined non-linear process plan, in which the non-linear process plan information, taken in the hardware information input module as an input, is combined with a hardware information of the machine tool which practically machines the workpiece to manufacture the product;

an optimum process plan producing module for setting up an optimum machining process plan, which is suitable to the machine tool, from the combined non-linear process plan;

a machining path producing module for creating a machining path, along which the machine tool executes a desired machining process, based on the optimum machining
process plan; and
an autonomous control module for executing the machining process along the machining path.

7. The STEP-NC system of claim 1, wherein the machine tool takes a code including the non-linear process plan information as an input regardless of types of hardwares, and converts the non-linear process plan to interface with a specific hardware used in the machining process.

8. The STEP-NC system of claim 1, wherein the non-linear process plan generator linearizes or converts the non-linear process plan to reflect machining conditions and shop floor conditions while the machine tool practically machines the workpiece to manufacture the product.
FIG. 4

- MACHINING FEATURE: 7
- PROCESS: ROUGH GROOVING
- MACHINING STRATEGY: GROOVING STRATEGY
- APPROACH/RETREAT STRATEGY: TOOL AXIS
- MACHINING CONDITIONS: FEED 50, SPINDLE 1000
- TOOL: GROOVING TOOL