STEP-NC – The STEP compliant NC Programming Interface

Evaluation and Improvement of the modern Interface

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Abstract

Conventional programming of numerical controlled machine tools is generally based on G-Codes (ISO 6983). This sequential programming language does contain simple commands for single movement and switching operations but cannot support more complex geometries or logical structures. Therefore it does no longer satisfy the requirements of modern NC technology. In the ISO standard 14649 (DIS) a new interface has thus been developed for the exchange of information between CAD/CAM systems and NC controllers. Its object-oriented design and the use of data elements of the widely disseminated STEP standard (ISO 10303) support comprehensive bi-directional data exchange whilst using common databases. Furthermore it facilitates the extension of modern NC controls' functionality and simplifies NC programming and modification by virtue of its feature-oriented data model. Mainly the separation of operation and geometry and the logical means for working step sequencing in the data model do support a more structured and task oriented NC programming.

Within an IMS project the European ESPRIT Project STEP-NC and the US Super Model Project do join in order to validate and to improve the existing data model of ISO 14649 for milling and to prepare models for additional technologies as there are turning, wood and glass cutting, rapid prototyping etc.

Keywords: STEP-NC, ISO 14649, NC technology, feature based NC programming

1 INTRODUCTION

In modern industrial production the exchange of product data assumes ever-greater significance. Companies that wish to react flexibly, quickly and inexpensively to a new market situation must make information available as soon as possible in all areas, and must ensure that it can also be processed. Data conversions, costly follow-up processing of incomplete data and misinterpretations mean loss of time and consequently of money. Furthermore product quality and productivity also depend on an optimised production. It is thus a common interest of all large companies who are manufacturing and developing on a global scale at various locations to have unified powerful data formats and data interfaces all the way down from the planning to the production.

While there are several new formats available for the exchange of geometry (IGES, STEP, etc.), the shop floor still deals with many paper drawings and poor NC programming interfaces, designed more than 40 years ago. Especially the part programming based on ISO 6983, also known as G and M Codes, is a bottleneck and forces the operator to often redo work already done in the planning department.

A part programme compliant to ISO 6983 does only contain a small subset of the information available in the CAD/CAM system. Its sequence of simple linear and circular movements and instructions is not sufficient to support more complex machine functionalities, a modern graphical work piece visualisation or the modification of a complex NC programme at shop floor level.

By improvements during the last years, a large number of extensions were generated to enable today's numeric controls (NC) to realise powerful advanced functionalities like tilted tools on freeform surfaces or online process control mechanisms. Some of these extensions have been standardised, others are control-, machine tool vendor or end-user specific. As a result the NC programme is not useful for information exchange between the process planning department and the shop floor, but a list of instructions specific to produce one part on one machine tool.

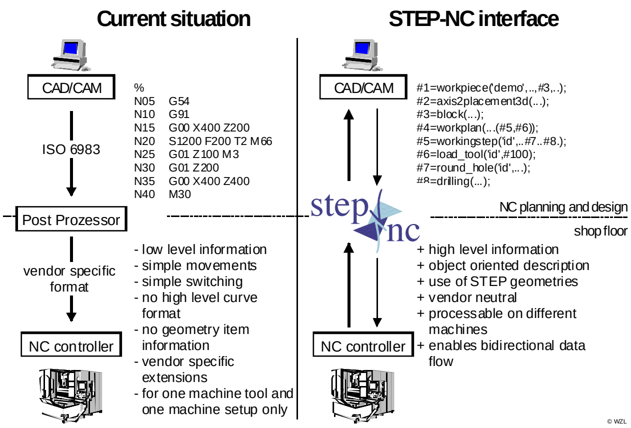

Figure 1: Deficits of current NC programming interfaces

Today the control as well as the CAM system has to be adapted to use the same specific codes and extensions. Otherwise the machine tool's functions cannot be addressed properly. Industries, using several different numerical controls, therefore are forced to use expensive post-processors, which generate control specific NC programmes that can only be used on particular machine tools. If the same NC programme should be executed on several basically identical machine tools, a common subset of programming codes and data formats having the same effect on each of these machines has to be used. Thus tool breakage control, collision avoidance or different kinematical abilities of the machine cannot be addressed in an optimised way.

Besides the limitations in part programming ISO 6983 and its extensions do not support bi-directional one-to-one exchange of NC programmes between different machine tools or computer aided systems (CAx). This means that any changes made directly in the NC code cannot automatically be fed back to upstream processes such as NC planning or design.

2 NEED FOR COMPREHENSIVE DATA IN THE NC

To realise complex functionalities like a collision avoidance or a tool path generation depending on the tools available at a machine tool comprehensive information is needed. First the geometries of the work piece, the machine tool and the tools are needed. In addition a set of technological information is necessary to decide which overlap, cutting depth, feed etc. can be chosen. As in today's production only CAD/CAM systems and not the machine's numerical control have access to this information, these functionalities can only be realised offline during the NC planning and not at runtime. Variations in the clamping position, the tolerances of the raw piece or the actual tool's shape cannot be considered directly. First the changes have to be noted, passed back to the planning, where they are inputted into the CAD/CAM system and then the tool paths and machining sequence have to be calculated once again. The new data then is reduced to simple linear and circular movements and switch operations, as only they can be stored in common part programmes based on ISO 6983. In a last step the part programme is adapted to a specific machine tool's control by a postprocessor. Because of all these data manipulations and data reductions, conventional part programmes can hardly be changed at the shop floor. Furthermore they are bound to single machines, and they cannot be exchanged between different machines nor be used for the bi-directional exchange of information within planning, work preparation and production.

Thus the NC programme – the interface between planning and numerically controlled production – on the other hand represents a very weak link in a company's information flow towards production.

This weak link in data exchange is now being stabilised by a new, modern programming interface called ISO 14649. The standard has been developed in close collaboration with international CAD/CAM manufacturers, end users, renowned control manufacturers such as Siemens and the chair for machine tools of WZL at the University of Technology Aachen. In contrast to conventional NC programmes it is based on exchanging and processing characteristics – so-called features (e.g. pockets, borings, grooves), technological data sets like operations, tools and the processing sequence. Based on a feature the machining process is defined step by step with processing tasks. Roughing and finishing operations are part of this. Through the combination of several features and their processing steps, all operations necessary for the manufacturing of a part, starting from the raw material, can be described. The feature description is based on a data model containing geometrical, technological and organisational data. Since the data model is compatible with ISO 10303 (STEP), which is considered to become one of the major data models for geometry data exchange between CAD/CAM systems, the new standard offers an interface for constant forwarding of product information to a machine tool's NC control, which was hitherto only present in planning [1].

4 STEP-NC DATA MODEL

To receive high level information in the NC a suitable data model for information exchange between CAM and NC is required. This demand is the basis for the work of ISO TC 184 / SC1 / WG7, the working group that is responsible for ISO 14649.

In order not to lose the information's context ISO 14649 is designed in an object-oriented way. Each item can thus be defined as an individual object containing not only descriptive attributes, but also an implicit meaning. For instance the geometric data element "SLOT" might geometrical be considered as a subtype of "POCKET", but in terms of mechanical engineering there are different requirements concerning manufacturing and functionality related to these items [1].

By strictly separating geometrical, operational and process sequence data the access and the storage of the information is simplified and exchange between highly specialised modules becomes possible. A system which cannot process technological information but can display or manipulate geometry, as for example a computer aided design system (CAD), thus might easily use the STEP-NC programme file for data in- or output. At the machine tool there might be data masks to adapt the technological parameters without displaying all complex 3D surfaces.

Figure 2 contains a simplified abstract of the core data-elements as defined in Part 10 – General Process Data – of ISO 14649. It shows how geometry, represented by features, and the operations are defined separately and then combined in a working step, which can be processed.

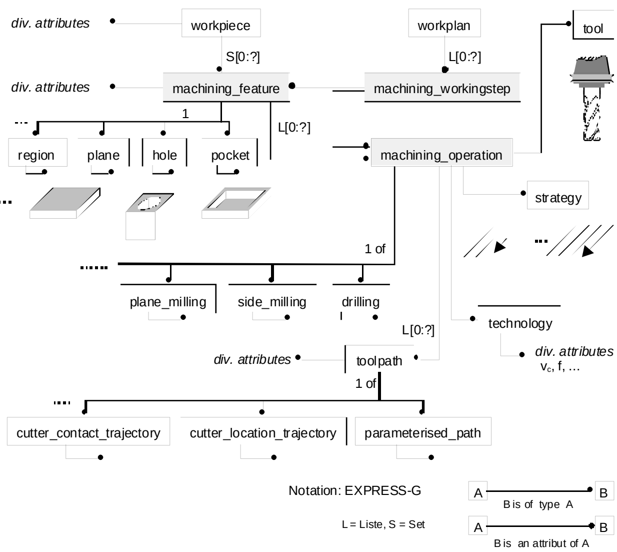

Figure 2 abstract of ISO 14649 Part 10

The logical structure and sequence of the NC programme is defined by a so-called EXECUTABLE. An executable can be a simple WORKING_STEP, a list of actions (WORKPLAN) or elements for logical structuring: IF_STATEMENT or WHILE_STATEMENT.

The manufacturing of a part is defined by a sequence of several working steps. A working step defines which operation has to be executed based on a geometrical item, such as a feature (e.g. hole, pocket, slot), a region or a freeform surface. The operation itself is one more object-oriented element of ISO 14649, which contains technological information, tool data, security planes or distances and the process strategy.

The control is expected to interpret this data and to generate the required switching and movement operations to machine the part. If the functionality of the NC control is not sufficient or a very specific tool path is required to influence or optimise the process, STEP-NC here also offers solutions, ensuring the benefits of the data model's object-oriented and context based structure. For instance the attribute its_tool_path of ISO 14649 allows an operation to overload the path generation based on the feature's geometry and explicitly make use of predefined cutter contact, cutter location and tool orientation curves. Still the geometry information is available for display purposes, process simulation etc.

5 INTELLIGENT AND FLEXIBLE MANUFACTURING

In contrast to conventional NC programmes, STEP-NC for the first time provides a model for the complete description of the processing task. Information formerly limited to CAD/CAM systems becomes available to the shop floor and at the machine tool. Any loss of information to abstract movements and switching information, as in the case of conventional programming interfaces, is avoided. Instead, comprehensible units like features and operations are comfortably and clearly programmed. At the shop floor during the setup of the machine tool and partly even at runtime the individual paths and switching commands are generated by the NC control. Since control is optimally adapted to the machine in question, not only the NC programming is simplified but complex processing tasks are also solved more efficiently than with CAD/CAM systems working offline and separately from machines. Controlled process data can be fed back into the control and there be used online for flexible path planning adapted to the processing situation. An example therefore is the active chatter avoidance. Whilst on the basis of conventional data interfaces such as ISO 6983 it was only possible to vary the technological parameters feed rate and rotational speed, the process can now be more efficiently regulated for instance by reducing the depth of cut. With conventional programming interfaces a change in the depth of cut could only have been performed offline in planning, since the necessary information on the volume to be machined has only been available at the CAD/CAM system. The data model of ISO 14649, on the other hand, embraces both raw-material and finished-part geometries, as in a CAD/CAM system. Volumes, tool paths or identations can be calculated by the numerical control.

One can imagine, that the machine tool is no longer only executing instructions, but also providing information and CAM functionalities. Production becomes more efficient and flexible.

6 FEEDBACK OF CHANGES AND KNOW-HOW

Changes in the NC programme are often necessary to improve the finished part and to optimise the production process. Today these changes cannot easily be fed back to the CAM system, as the context of single movement or switching instructions normally gets lost while generating conventional ISO 6983 NC programmes. That is why experiences of the shop floor are often not returned to the planning department and will not be available for the planning of future work pieces. The iterative improvement of the NC programme at the machine tool therefore becomes necessary even for similar parts.

At present sophisticated NC cycles or comments inside the part programme minimize the loss-of-context-problem. CAM and NC systems, which are able to re-interpret these user or vendor specific code extensions, can restore information and provide it through a data base to avoid redundant testing in the shop floor. But as the cycles are not standardised and as the included geometry model may vary, they are not suited to exchange information between different systems or companies.

Comparable to the NC cycles STEP-NC provides data elements for object oriented NC programming. But instead of defining single task, like a pocket cycle does, STEP-NC passes structured logical units (features, tools, working steps) and their internal relationships to the machine tool's control. Optimisations do not only result in changing single code lines, but in modifying the relevant attributes of an object. For example augmenting the depth of a drill hole does not simply mean to change “G01 Z100” to “G01 Z120” but the value of the attribute “its_depth” which is part of the feature's (object) “round_hole” description.

The modifications in an object oriented data model can be recognised and interpreted in NC planning or design. No information gets lost. Standardisation guarantees furthermore that this exchange is not limited to specific systems like the ones using vendor specific data element definition [2].

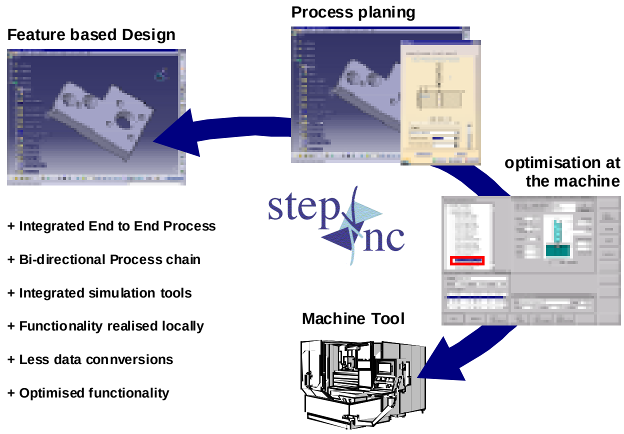

Figure 3: STEP-NC enables a bi-directional information exchange [Dassault Systèmes, Open Mind, Siemens]

7 STEP-NC CONSIDERS VARIABLE COMPONENTS

A NC programme is used to transfer the movement and switching instructions from the CAM system to the machine tool in order to achieve one specific result, the part. Whilst the geometry of this work piece can be considered as a static data element, the tool paths followed to generate the work piece geometry, operation data and the hardware are variable and might depend on each other:

As Volvo Cars (Sweden) stated, one single NC programme executed on two identical machine tools with equal control- and tool configuration produces two different results. This difference is caused by the machine tools' specific tolerances and abilities, the tools and the part setup.

Common NC programmes cannot consider all possible variations of these parameters. Therefore the programme always has to be tested and optimised at the machine tool it will be used on. The object oriented data model of STEP-NC treats geometry, technology or operations as single data. Only through a logical structure, the so-called MACHINING_WORKINGSTEP, the control gets the information which operation has to be processed on which geometrical item, e.g. a feature or a region. This allows the use of identical geometric descriptions on various machines while the more variable operation data is linked depending on the machine's characteristics and the actual machine setup.

If a slightly modified work piece has to be produced (e.g. a pocket's depth is reduced or the position of a hole has to be changed) only the description of the geometry is changed. The already optimised technological and operational elements remain unchanged. Production on all machines can directly restart without the conventional need of programme generation and iterative parameter optimisation for every machine tool.

8 PRACTICAL RESULTS

Both, the European STEP-NC and the American Super Model project set up scenarios for milling. These first prototypes proved the benefits and potential of STEP-NC [3].

The prototypes realised by the European STEP-NC consortium for milling are based on commercial systems from Siemens, Open Mind and Dassault Systèmes. CAM modules from Open Mind (HyperFact, SoloCAM) and Dassault Systèmes (Catia V5) generate the STEP-NC programmes including high level CAD geometry data, operation data and sequencing information. This programme file then is passed to the shop floor, where a Siemens Sinumerik 840D control and ShopMill, Siemens' shop floor oriented NC programming tool, were adapted to process ISO 14649 encoded NC programmes.

DaimlerChrysler and Volvo, participating as end-users in the STEP-NC project, use this prototype to gain experience with the new NC programming interface. As there are no more simple G- and M-codes passed to the machine, late changes in technology, programme sequence or even geometry can easily be realised and processed without the need of time consuming post processor runs and iterations with the planning department. Especially during the first test period some late changes in programme sequence and optimisation of technology had to be done. All these changes were visualised and simulated in ShopMill directly at the machine tool and stored back into the STEP-NC file to ensure, that no information got lost.

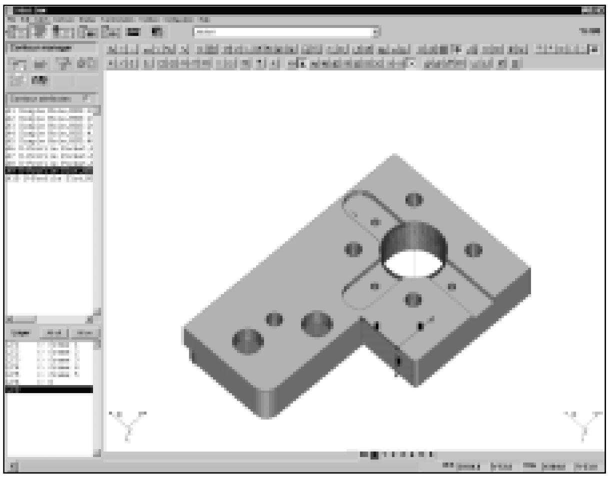

Figure 4 Complete manufacturing planning for the first STEP-NC work piece with Open Mind's SoloCAM

The next step within the European project will be the installation of a milling-scenario on machine tools with different kinematics and abilities (3 axis and 5 axis machines) in order to prove that STEP-NC supports exchangeability of programme files.

9 ISO 14649, THE INTERNATIONAL STANDARD

ISO 14649 is the result of the knowledge obtained in the European projects OPTIMAL and MATRAS, the input of users, suppliers and universities as well as the knowledge of experts for ISO 10303.

So far the Standard ISO 14649 contains today three parts:

Part 1	Overview and fundamental principles
Part 10	General process data
Part 11	Milling schema

Additional parts will follow, describing schemas for other manufacturing technologies such as turning, electronic discharge machining (EDM), grinding and wood & glass cutting.

This new interface uses a condensed CAD/CAM data set, which contains a geometry description through features (such as holes, pockets, profiles, surfaces etc.), the manufacturing technology, the tooling and the manufacturing sequence. The content and schemas of this standard is partially related to the STEP standardisation framework, especially the product description, which is standardised in ISO 10303 AP 203/204.

10 SUMMARY

Machine tools, their controls and additional components will always be installed depending on the end-users needs. Therefore every NC programming interface will be either too complex or much too simple depending on the required numerical control's functionalities.

While STEP-NC passes an object-oriented model to the control in order to enable NC controls to realise intelligent functionality in real-time and to integrate the shop floor not only as information recipient but also as an information supplier into modern industry's data exchange, there are other approaches that simply use the numerical control as a driver similar to a printer for a PC system. Here all information processing for axis-paths or PLC switch operations is generated offline directly by the CAM system. Real-time interaction as needed e.g. for process control cannot be realised.

The worldwide activities concerning STEP-NC are joined by the IMS STEP-NC project. The project focuses on several technologies in order to realise a complete and uniform up to date NC programming interface, ISO 14649. Further on this interface is tested in several different scenarios. On one side these scenarios are based on conventional CAD/CAM systems and NC controllers. They mainly evaluate the benefits of a more easy modification and exchange of NC programmes in the shop floor. For this purpose Open Mind integrated STEP-NC into their CAM module SoloCAM and Siemens implemented STEP-NC into their programming system ShopMill, which is running on a Sinumerik 840D. Volvo and DaimlerChrysler did already machine parts with drill holes, slots, pockets and contours, using this first industrial prototypes. During the next steps it is planned to extend the scenario using tool paths to manufacture and test more complex geometries. At the end of 2001 the Swiss partners will test the first STEP-NC prototype for EDM.

Besides more scientific scenarios are developed, where all CAD, CAM and NC data is stored in one database. Each CAx system or NC controller accesses the database to get or add information. There is no longer the need for several particular exchange files, which have to be archived and updated. Instead there is only one consistent STEP-NC data set, containing all relevant information to realise an intelligent and high productive production at the level of planning as well as in the shop floor.

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