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DEVELOPMENT OF A CNC ROUTER ADHERENT TO STANDARD STEP-NC BASED ON THE CONTROLLER ADVANCED MACHINE (EMC2)

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Abstract. *This paper describes the development and validation of a computer numerical controller architecture adherent to the standard STEP-NC Part-11 that is associated with the milling process. The STEP-NC controller development is based on the open source driver EMC (Enhanced Machine Controller or LinuxCNC) adherent to the standard RS-274 that originally works with the NC program using codes G/M (G-code). In order to validate the controller architecture was developed a NC machine tool topology type Router (portal structure) with three degrees of freedom as having the controller the LinuxCNC in x86 platform (personal computer) using the operating system Ubuntu/Linux with Kernel on Real time. The controller LinuxCNC has been integrated with the Data Model STEP-NC Part-10, 11 e 111, using an adapter, allowing the LinuxCNC to receive as input a numerical control program in format STEP-NC Part-21 also called STP. The format is based on the concept of workingsteps, machining features and machining operations, among others described by the standard, e.g., the STEP program focuses on a high-level description based on machining features and a more sophisticated data model but not the movement of the machine axes. This program numerical control with STEP-NC code is generated by the integrated design, process planning and computer-aided manufacturing (CAD / CAPP / CAM) called STEP Modeler (http://www.grima.ufsc.br/stepnc_project /), developed by GRIMA / UFSC, that allows the modeling of a prismatic part web-based machining features, having a data model adheres to the STEP project, enabling the integration of the life cycle of a piece, from design to manufacturing, via the Web. The LinuxCNC controller with adapter STEP-NC uses code generated by STEP Modeler and runs transparently to the operator of the CNC Router specially developed for validating the architecture conceived. This development allowed the validation of the concept of integration Lifecycle based on the data model of STEP-NC, from design to manufacturing using the concepts of design and machining features. The architecture is presented using models IDEFØ (Integration Definition for Function Modeling) and UML (Unified Modeling Language), showing the specification of integrated system CAD / CAPP / CAM, particularly the stage associated with CAM Execution, e.g., the controller/adapter STEP-NC developed based on LinuxCNC. The detailed project of the CNC Router is presented in a summarized manner. The results are shown through case study, process planning and manufacturing parts examples, its measurement and analysis. The ambience STEP-NC has been designed for Web context being also used in the disciplines of the Manufacturing Automation of graduate and postgraduate at UNB and UFSC, aiming at presentation of concepts and data models based on STEP, which will be the future of Automation Manufacturing, gets more mature every year.*

Keywords: *CAD, CAPP, CAM, CNC, STEP-NC, LinuxCNC*

1. INTRODUCTION

The rapid manufacturing, efficient and integrated has been a goal of researchers since the advent of machine CNC (Computer Numerical Control) during the 1980s (Rosso et al, 2003).

Data exchange between CAD, CAPP, CAM systems, is a problem that hinders the rapid manufacturing, efficient and integrated. To fix it, was developed by the international community the standard ISO10303 also called STandard for the Exchange of Product model data (STEP), (Kemmerer, 1999).

In the 1950s was developed in M.I.T. the first machine Numerical Control (NC), (MIT, 2011). These machines use the standard ISO6983 standard as NC programming (ISO6983, 1982). This pattern is known as G-code. They are based only on the description of the movements of the cutting tool (tool path) and some of the NC machine parameters. Since its development to date, these code have not changed significantly (Kramer et al., 2010). This creates a problem in the NC program portability and integration of manufacturing (Xu, 2009).

In 1990 was developed a new standard that solves the problem of the integration of CAD/CAPP/CAM. This new standard called STEP-NC or standard ISO14649 is based on the STEP standard. The STEP-NC standard is a new data interface high-level for NC programs. This paper uses the term STEP-NC as a synonym of the standard ISO14649.

This article presents a general review of the standards involved in the exchange of data between CAD/CAPP/CAM and CNC adherents of STEP-NC. Finally, the authors propose the development of a CNC Router adherent STEP-NC by means of an adapter part program in STEP-NC to program in G-code. This adapter uses the STEP Modeler system to create the part program in STEP-NC. This program will be the input file in the CNC controller (LinuxCNC) being converted to G-code transparently to the machine operator. A case study is done to validate the adherence of CNC Router to the standard ISO14649 and demonstrate the capability of the adapter.

2. REVIEW OF THE LITERATURE.

The exchange of information between CAD/CAPP/CAM and CNC has been, in the last decades, one of the biggest problems in the industry given the loss of information in the development cycle of a product (Xu et al., 2005). Currently there is a standard that allows this exchange, this standard known as STEP-NC (ISO14649). The following presents a literature review of the theory around the ISO 14649.

2.1 Integrated CAD/CAPP/CAM/CNC adherent STEP-NC

The international community's manufacturing industry supported by the International Organization for Standardization (ISO), made a great effort to introduce the STEP standard in a collaborative model that integrates CAD / CAPP / CAM / CNC. The STEP standard is recently being used in industry to improve the exchange of data between these systems. The default is informally known as STEP-Compatible Numeric Control (STEP-compliant Numerical Control) or STEP-NC so soon. STEP-NC is identified by the standard "ISO14649: Data Model for Computerized Numerical Controllers (ISO14649-1, 2003)." This standard defines the Reference Model Application STEP-NC. With STEP, begins to extend the information model manufacturing, emerging as a new paradigm for integrating CAD/CAPP/CAM/CNC (Xu, 2004b).

2.2 Standard ISO6389 – G-code

The ISO6983 standard describes the format of the program's instructions for NC machines. It is a generic format programming, i.e., is not a format for a specific type of machine (Ticona, 2011). The ISO6983 standard is not very flexible and, therefore, does not guarantee interoperability between machines NC, unless it these have the same interpreter NC (ISO6983, 1982). This standard mainly describes two types of codes: G and M.

2.3 The interpreter NIST RS274NGC

This interpreter reads the part program NC (ISO 6983 code or G / M) and produces calls to a set of canonical functions to carry out the machining. The output of the interpreter may be used to move machining centers from three to six axes. The input to the interpreter is RS274 code (review of the standard ISO6983) dialect defined by Next Generation Controller (NGC), which is a G-code with some modifications (Kramer et al, 2010). This interpreter is used by controller LinuxCNC.

2.4 Standard ISO14649 – STEP-NC

STEP-NC is an extension of STEP, thus, this standard takes advantage of the characteristic of the neutral format STEP data to digital information of a product, then that data can be shared and exchanged between various platforms, being the only way compatibility.

In this ISO14649 standard, it defaults to the way in which information about the CNC machining can be added to the parts represented in STEP product model (Mark, 2002).Therefore, this standard was developed in order to provide a data model for a new set of intelligent CNC controllers and consequently present an improved homologous of the old G-code.

This standard provides a data model object-oriented that incorporates the programming with features and contains a wide variety of information, such as their own features (complex areas, holes, canals or cavities) to be machined, the type of tool, machining parameters (cutting speed, feed rate, depth of cut), the processes of machining (drilling, milling, etc.) and order the execution of machining (Rosso et al, 2002).

This standard also uses topological definitions of STEP standard and provides the factory floor the possibility of changing manufacturing data and resubmit the sector projects preserving all data exchanged between CAD/CAM and CNC (Rosso et al, 2003). The information regarding a piece and its manufacture are stored in a file STEP-NC schematized in Figure 1.

The STEP-NC file can be basically divided into five items. The following are explains this items taking as reference the example 1 of part program STEP-NC, contained in part 11 of the standard STEP-NC.

- *Header*: This contains basic information about the author of the file, the name of the piece, the parts of the standard used in the file (schemas) and other information (ISO14649-10, 2003).
- *Part identification*: Contains basic information about the part to be machined, as the position of the work piece coordinate system for the machine, work piece material, and other configuration parameters of the machine. The part to be machined is described by the entity "*workpiece"* while the set of all machining operations is described by the entity "*workplan"*. The *workplan* defines the order of execution of each operation. This section always begins with the entity "*project"* that links the *workplan* to a *workpiece* and mark the beginning of the program (ISO14649-10, 2003). See an example illustrated in Figure 2.

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- *Workplan and executables*: The *workplan* consists of a set of named entities *executables* which are basically operations to machine performs. The *executables* can be of three types: *Workingsteps*, *NC Functions* and *Program Structures*. The *workingstep* executable is most important and most widely used because it is a function that associates the geometry to be machined in the form of features with the corresponding machining process (ISO14649-10, 2003).

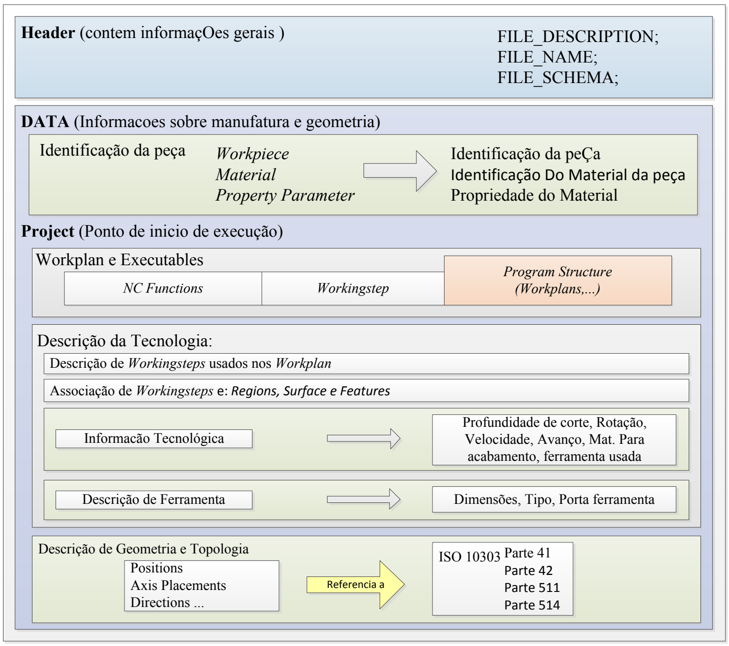

Figure 1. General structure of the organization of STEP-NC data (Adapted of Rosso, 2003).

```
DATA;
#1= PROJECT('EXECUTE EXAMPLE1',#2,(#4),$,$,$);
#2= WORKPLAN('MAIN WORKPLAN',(#10,#11,#12,#13,#14),$,#8,$);
#4= WORKPIECE('SIMPLE WORKPIECE',#6,0.010,$,$,$,(#66,#67,#68,#69));
```

Figure 2. Part identification (Adapted of ISO14649-11, 2003).

- *Technology descriptions*: This item covers the functions STEP-NC who write all machining processes and all the features used in the workingsteps. Also are described the data regarding the machine functions (refrigerant, chip removal, etc.), the used tools, strategies machining among other parameters, e.g. feed rate of tool (ISO14649-part 1, 10, 11 and 111, 2003).
- *Geometry descriptions*: All geometric data used by the various functions STEP-NC, as planes, axes and points are entities defined by ISO10303 part 1 (ISO10303-1, 1994).

3. RELATED WORK

There are several projects in which are construct, develop and work with standard ISO14649. Some of them are still currently active in conjunction with the development of other standards. Are presented below some of these projects.

3.1 Project Iso14649 ToolKit.

This project was started in December 2008 and completed in February 2009 by Mark Kramer and Thomas Pictor both programmers open manufacturing software (ISO-14649-toolkit, 2009). They created a set of tools (toolkit) for STEP-NC-based codes: sebnf2pars (sebnf2pars, 2008). The sebnf2pars is a tool for building analyzers of STEP Part 21 files and code from NIST [51] the standard ISO14649 parts 10, 11 and 111. There is also a tool for to interpret and to print NC code for 3-axis machining. The toolkit is programmed in C + + and allows the modification of its source code to couple it to the needs of any project with respect to NC controllers, as for example the controller LinuxCNC. In reviewing this project are identified some tools that mark the basis for the development of the architecture of the adapter of STEP-NC to G-code of this project. Is possible to use as example the structure of the program and the identification of data that are included in the physical file of STEP-NC, with the purpose of to make the modeled functional of adapter.

3.2 Project STEP Modeler UFSC/GRIMA

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This doctoral project was developed at the University Federal of Santa Catalina (UFSC) in conjunction with Manufacturing Group Integration (GRIMA) with the name: "UM SISTEMA PARA O PROJETO E FABRICAÇÃO DE PEÇAS MECÂNICAS A DISTÂNCIA VIA INTERNET ADERENTE À NORMA ISO 14649 (STEP-NC)", the end result was the software called" STEP Modeler " (Ticona, 2011).

STEP Modeler leverages the Internet technology by introducing the e-manufacturing. The e-manufacturing consists of a data stream compatible and without gaps in the chain CAD/CAPP/CAM/CNC. This software uses standard ISO14649 geared toward milling (parts 10, 11 and 111). The system automatically generates the physical file in p21 format.

Partially completed in December 2011, currently STEP Modeler undergoes changes in your source code, is constantly improving with respect to code generation in physical format or STEP Part 21. This project is using the standard ISO14649 2002. Importantly, the operation of this software because for their characteristics will be used in this project to generate the physical code part to be machined, using the output format STEP or "p21" (ISO 10303 Part 21, 2002).

4. MODELING OF CNC ADHERENT TO STEP-NC.

The literature reviewed thus far has shown the limitations of manufacturing integration between CAD/CAPP/CAM/ systems and CNC, thus as also the limitations of G-code. Presented itself the use of the STEP-NC standard, as the data model for NC programs, replacing the old standard ISO6983.

In this section present the methodology to model the functionality of CNC adherent to STEP-NC. This modeling is divided into two parts: modeling a functional prototype adapter part program in the STEP-NC code G / M and model which describes the inclusion of this latter (the adapter) in the NC controller, in this case LinuxCNC or EMC with the standard MTConnect.

The prototype adapter that converts part code in STEP-NC to G-code shall accomplish this function automatically to the CNC machine operator. This adapter will be included in the controller LinuxCNC. This allows the controller to read as input code piece in STEP-NC and create tool paths for machining related to the information contained in this code. The following is made the functional modeling of the prototype adapter of STEP-NC to G-code (in format RS274NGC).

4.1 Functional modelling of adapter

In Figure 3 is presented a general functional model (using IDEFØ diagram) of an integrated system CAD/CAPP/CAM/CNC adherent to standard STEP-NC. This system allows to display the lifecycle, the project, the planning, the CAPP with program generation STEP-NC (by STEP Modeler), and CAM execution by Controller NC (LinuxCNC) adherent to STEP-NC thanks to the adapter of STEP-NC to G-code

The functional model illustrated in Figure 5, is only implemented the STEP-NC adapter to G/M Code and the inclusion of adapter into LinuxCNC controller. There are two components which are not implemented. The first component is the software STEP Modeler that describes the integrated systems CAD/CAPP/CAM (Ticona, 2011) and generate the physical file p21 that is used as input in the CNC controller adherent to STEP-NC. The second component is the standard MTConnect (MTConnect, 2011) that is used for remote monitoring of CNC controller (Vijayaraghavan et al, 2008).

In Figure 4 can be observed them levels A1 and A2. On the level A1 is modeled the first part of the integrated system, referenced by the system STEP Modeler. The level A2 shows the modeling of CNC adherent to STEP-NC equipped with MTConnect, containing in his sub-levels the implementation of STEP-NC adapter to G-code (level A21).

The Figure 4 illustrates that the output of integrated system of CAD/CAPP/CAM adherent to STEP-NC (STEP Modeler) is the part program STEP-NC in P21 format. This program is taken as input in controller NC to convert it in a part program in G/M code through adapter included in the CNC.

The Figure 5 shows the interior of A2 level. This level present the functional modeling STEP-NC adapter to G code and the controller configuration LinuxCNC including the adapter and standard MTConnect.

The Figure 6 illustrates the internal functions of STEP-NC adapter to G-Code. At level A211 (Extract basic information) is taken as input the part program in STEP-NC and extracted the information regarding with the dimensions of the workpiece and XYZ coordinate point of security plane. This level also has the function to move the file STEP-NC original to NC controller. Later this file will be displayed in the GUI do LinuxCNC controller. The level A212 has the function of identifying the entity Machining_workingstep mapping the features, machining conditions, operations and tools (contained in the part program in STEP-NC) with the purpose of to obtain their characteristics and their information. The mapping of the information is done according to the type of machining feature according to the standard ISO14649. The level A213 has the function to generate a part program in G code from the extraction of information and individualization machining. These tasks are performed each data set of both basic and advanced information, e.g. a feature extracting and individualize their set of information and machining (machining conditions, operation, tools and security plan). The code generation of NC program contains the tool paths, feed rate, tool change manual, security plan among others. Also, this activity has the function to create a database with the tools used in machining, both for one as for various machining features.

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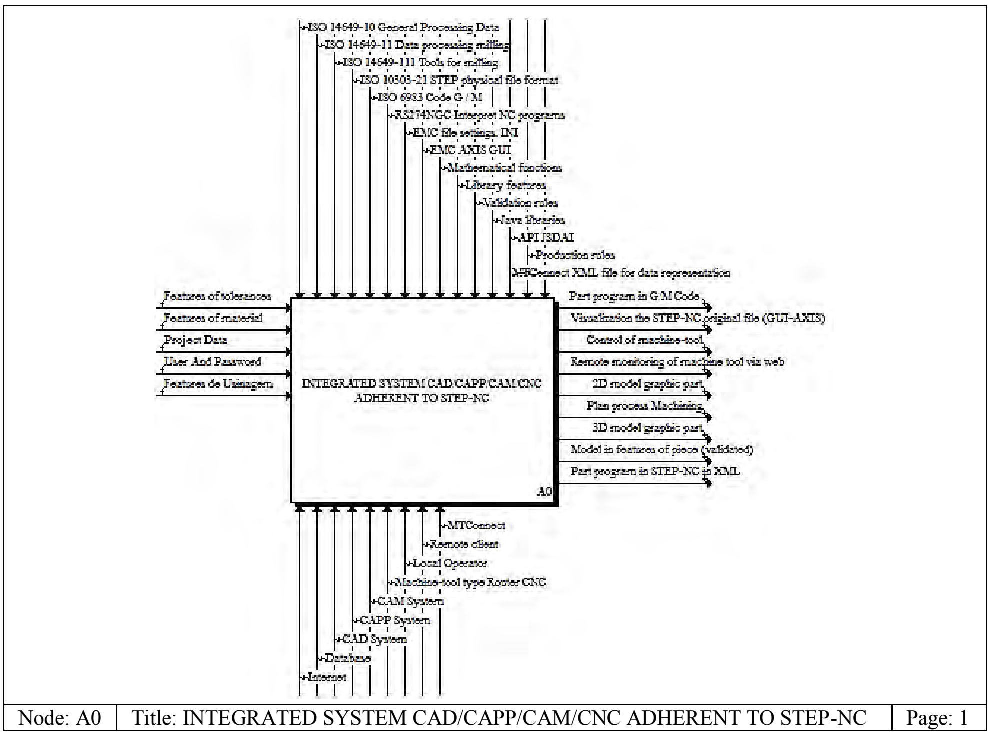

Figure 3. Overall diagram IDEFØ of integrated system, Node A0.

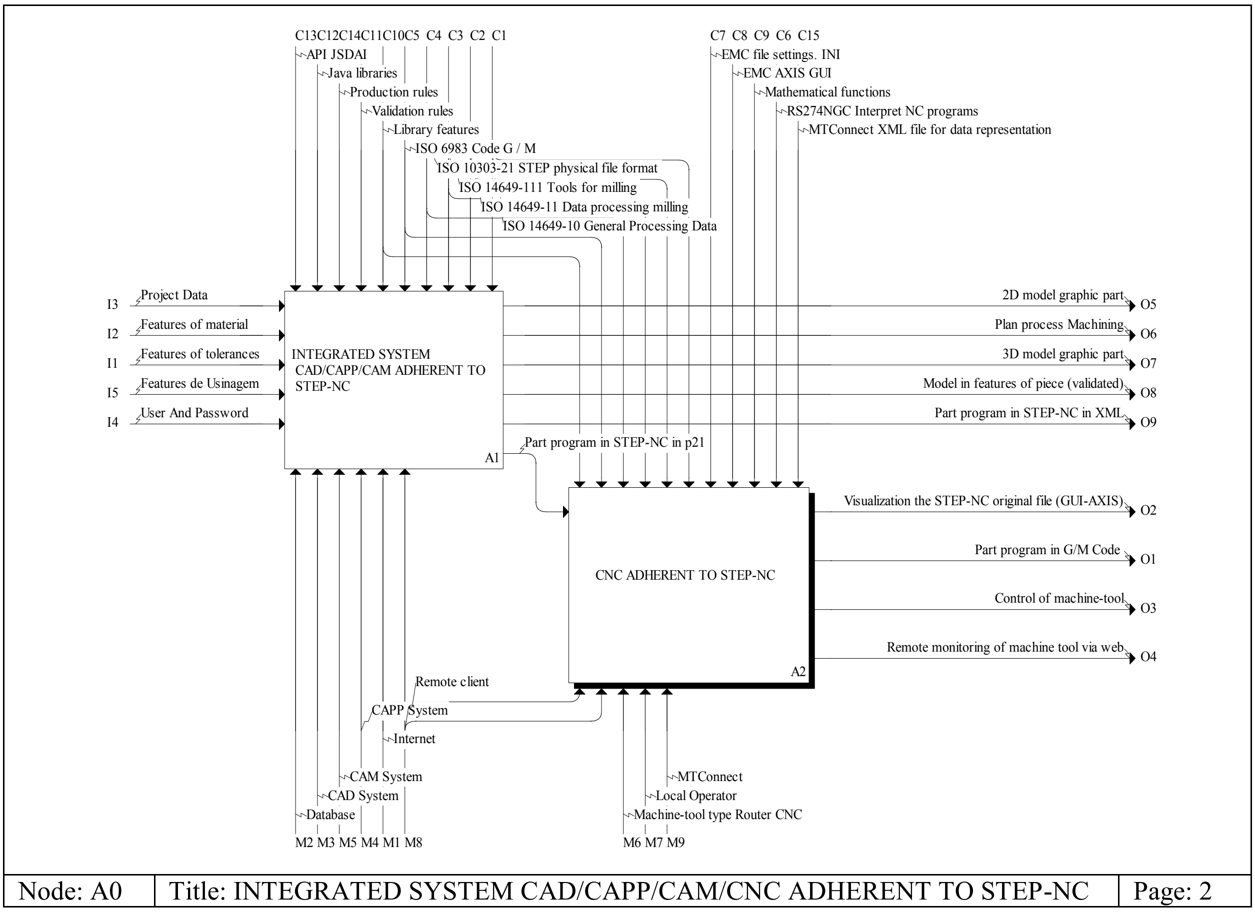

Figure 4. Diagram IDEFØ of integrated system, inside of node A0.

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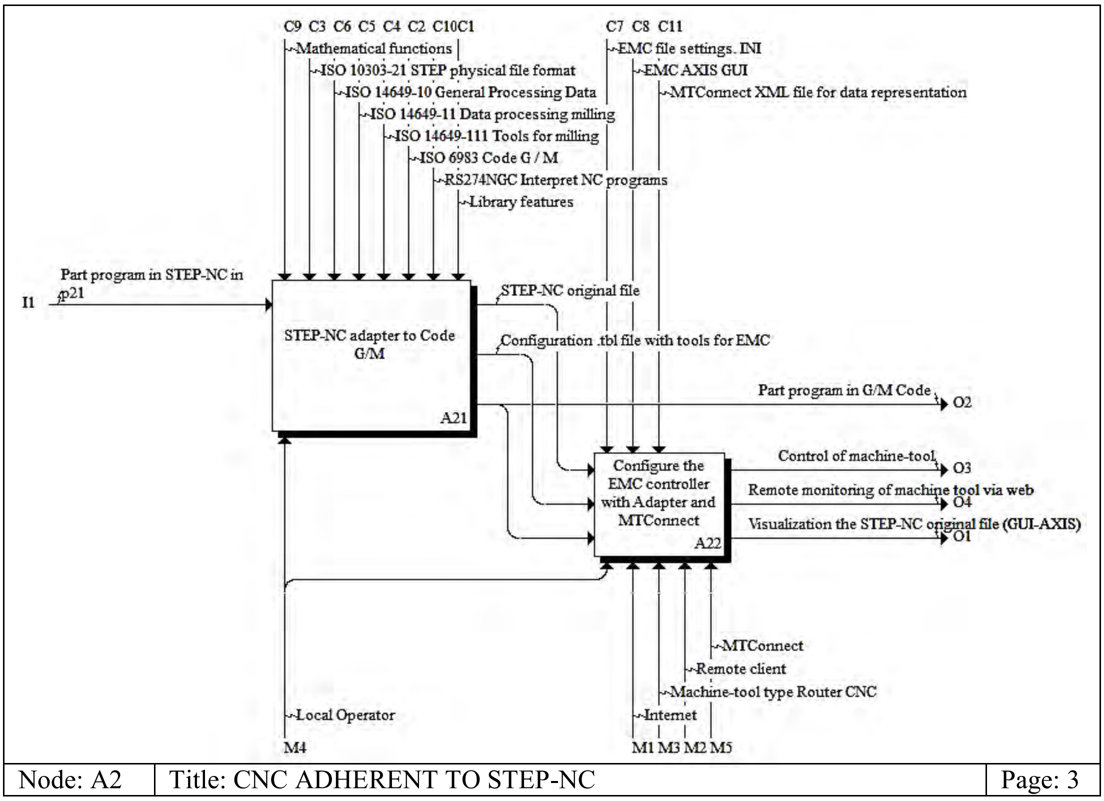

Figure 5. Diagram IDEFØ of CNC adherent to STEP-NC, inside of node A2.

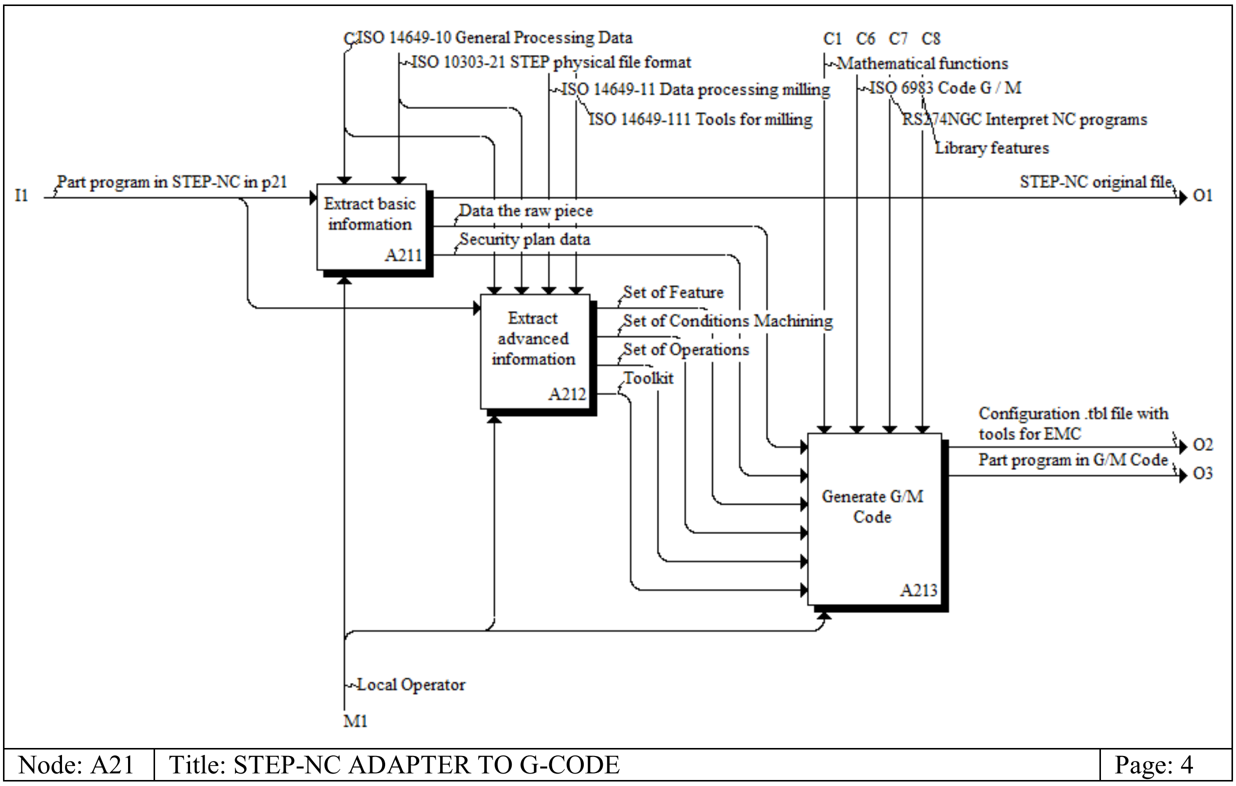

Figure 6. Diagram IDEFØ of STEP-NC adapter to G-code, inside of node A21.

The Figure 7 illustrates the UML model of level A211 and A212 respectively.

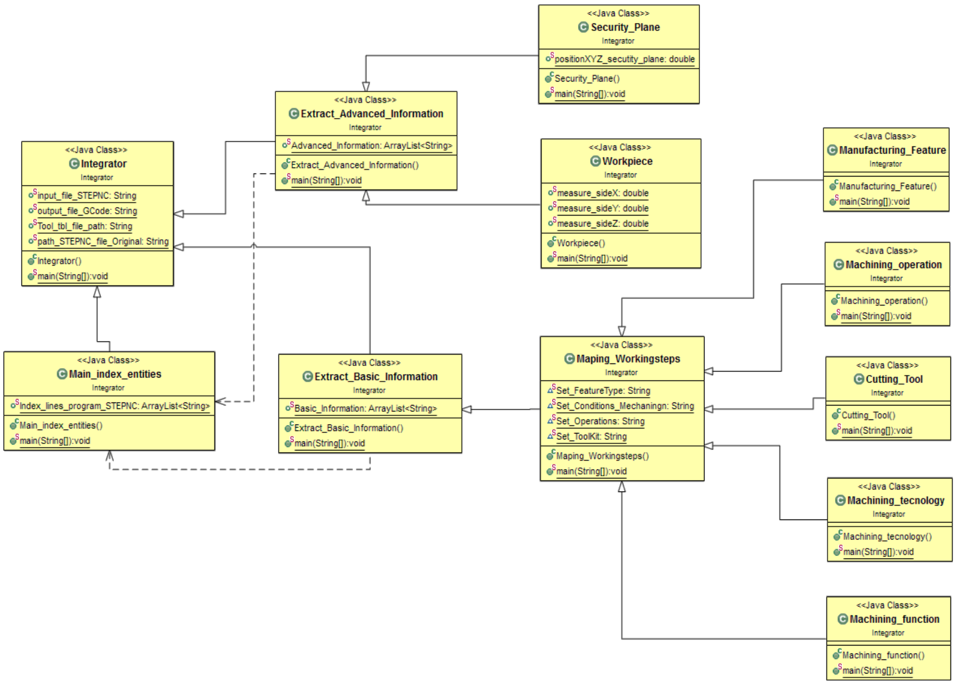

Figure 7. Model UML of level A211 and A212.

The following modeling, is the second part of CNC adherent to STEP-NC (Node A22). This model is related to the NC controller configuration concerning with the STEP-NC adapter to G Code and the MTConnect standard. Is only implemented the functional model of CNC configuration with the adapter linked. The Figure 8 show the Node A22.

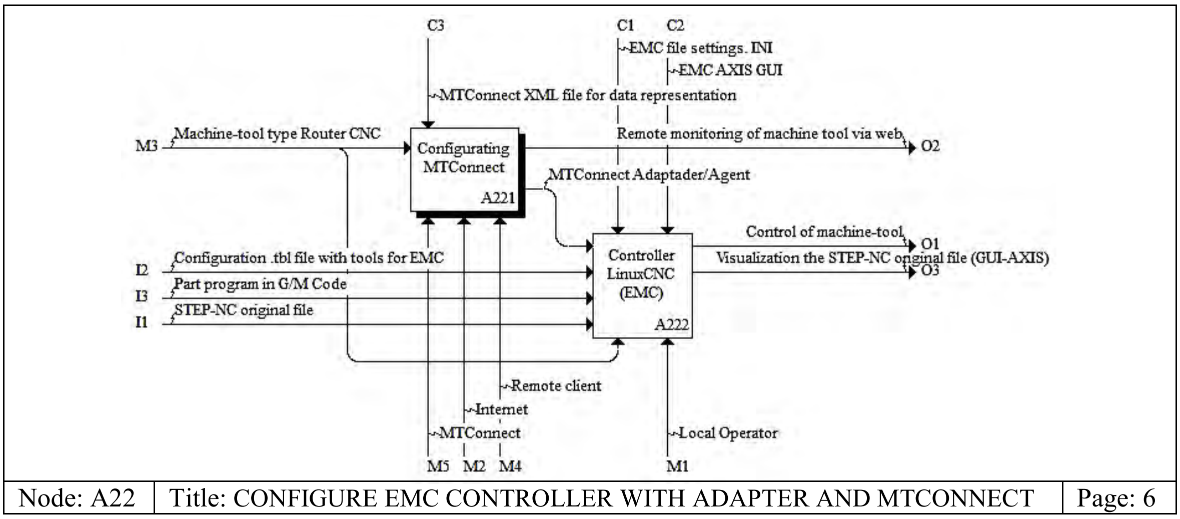

Figure 8. Diagram IDEFØ of STEP-NC adapter to G-code, inside of node A22.

5. IMPLEMENTATION OF NC CONTROLLER ADHERENT TO STEP-NC.

The implementation of CNC adherent to STEP-NC consists of two main steps. The first step is the implementation of STEP-NC adapter to G-Code, and the second step is the addition of the adapter in CNC (LinuxCNC). This section presents an implementation of the prototype adapter according to the functional modeling described in the previous chapter. According the IDEFØ diagrams (functional modeling regarding the adapter STEP-NC code to G), will be implemented several classes for programming the prototype adapter.

5.1 Implementation of the adapter STEP-NC code to G

The adapter consists of two main steps. The first step is the extraction basic and advanced information and the second step is the generation of G-code based on the information extracted.

5.1.1 Implementation of class for the extraction of information

Is important to remember that the data structure STEP-NC uses an object-oriented model to describe entities such as Workplan, Workingstep, as well as to identify Features, Operations, Tools and all geometric entities. Thus, each entity belongs to a class of objects and should be used as such. This is done by pointing to the parts of each object rather than a single physical record / line (see Figure 9). Parts of the information are also indexed and master index of entities that manage the location of each information (Rosso, 2005).The information are retrieved and mounted together for later use in generating of the code G.

Now, there are two types of classes for the extraction of information, the class for the extraction of basic information (e.g., dimensional characteristics of the raw piece, security plan) and the class for extraction of advanced information (e.g., type of feature, operation and tool), both use the main index of the part program in STEP-NC to perform their function.

The Figure 10 shows the machining information extracted from a part program in STEP-NC (generated by STEP Modeler) by means he classes implemented to extract of basic and advanced information.

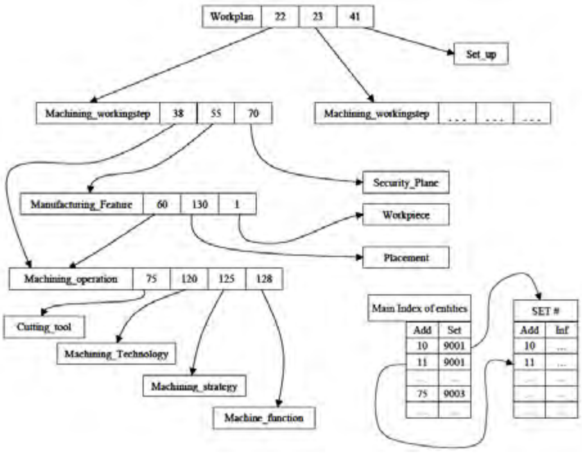

Figure 9. Entities index data structure of STEP-NC (Rosso et al, 2003).

```
(Quantity of features: 1)
(..::: Header ::: ..)
(..::: G Code generated by Adapter STEP-NC v1.0 R0.002 the G Code ::: ..)
(Input file: C:/Slot/SquaredUprofile/RanhuraParalela.STP)
(Basic Information)
(Data workpiece: CompX: 200, CompY: 150.0, CompZ: 30.0)
(Security plane: CompX: 0, CompY: 0, CompZ: 55.0)
(------------------------------------------------------------)
(Advanced Information)
(Feature - Slot1)
(T1: # 25, NameTool=SF20, TypeTool=FACEMILL, DiameterTool=10.0, TLO=40.0, BaseRadius=0.0;)
(T2: # 71 = NameTool=BallEndMill, TypeTool=BALL_ENDMILL, DiameterTool=4.0, TLO=60.0, BaseRadius=2.0;)
(LocationFeature: X=0.0, Y=15.0, Z=0.0;)
(Depth: Z=7.0;)
(TravelPath: type=LINEAR_PATH, lengthFeature=200.0, Direction=Hor;)
(OpenProfile Type: SQUARE_U_PROFILE, Surface Length = 10.0, Base Length = 10:00, Angulo Base = 2.0)
(End feature information)
```

Figure 10. Machining information from part program in STEP-NC (output data, from IDE Eclipse).

5.1.2 Implementation of class for generate G-code from machining information.

Order to generate an NC program or part program G code must be understood concepts such as, linear interpolation, circular interpolation, compensation radius of the cutting tool, coordinate systems, security plan, distance coordinates mode, manual tool change. All this to be able create the tool paths. These paths describe the movement of the cutting tool to remove material from the workpiece geometry and achieve the desired of the feature.

Many times a complex feature needs to be segmented into simpler parts to generate the trajectories of the cutting tool which describe its geometry, e.g., a hole with the flat base. According to the features contained in the standard ISO14649-10, is possible to machine this type of feature using from one to three types of tool following a specific order. Figure 11 shows an example of this feature and its segmentation into workingsteps (WS).

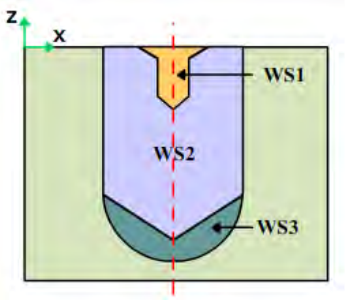

Figure 11. *Workingsteps* of a hole with spherical base (adapted from Ticona, 2011).

The implementation class to generate the trajectories of the cutting tool which are described in the code G, depend machining information, i.e. the type of machining feature, machining conditions, operations, tools, as well as the characteristics of the CNC machine.

There are several authors as Schützer et al. and Oliveira, who claim that the G code generation often requires manual adjustments because of the conditions and characteristics of the CNC machine. This task should be performed by the machine operator, which has enough experience to correct any errors in the NC program (Schützer, 2005 and Oliveira, 2003).

The proposed adapter generates G code not only from machining information also takes into account an additional configuration through a file that allows to modify the speed of advance of the machine, the maximum federate cut, maximum cutting depth between other options that can be supplied by the machine operator in order to generate an NC program suitable for the capabilities of the machine. In this case is the machine-tool type Router designed and manufactured to validate the CNC adherent STEP-NC through STEP-NC adapter to G-code.

Further on the authors present a case study of a program in STEP-NC containing various features. This study validates the CNC adherent to STEP-NC and consequently the capabilities of STEP-NC adapter to G/M Code.

5.2 Implementation of CNC adherent to STEP-NC

The controller used in this project is the LinuxCNC. The LinuxCNC, also called EMC (Enhanced Machine Controller) is a controller (software) FLOSS (Free/Open-Source Software) licenses with GNU/Linux that implements the ability to Numerical Control (NC) using any personal computer (PC) to control CNC machine-tool from 3 to 9 axis. The controller LinuxCNC uses the RS274D interpreter natively to process NC programs or part program in G-code. The open architecture of the NC controller allows to modify or add new features to EMC2. This project adds to the EMC2 two new features, they are:

a. Loading natively a part program in STEP-NC converting it into a part program in Code G/M to run by EMC.
b. Visualization of STEP-NC code loaded in a separate window next to the EMC GUI.

Is proposed a methodology to add the STEP-NC adapter G/M code in EMC. In the implementation adapter was used programming language JAVA. This language allows to create an executable ".jar" that can be called and run within the GUI LinuxCNC.

In the configuration of LinuxCNC is created a configuration file called "*file. INI*". In this file are all the configuration parameters for both of the machine as of the NC controller. The executable jar of the adapter is then added to this INI file. There is an option to achieve this, add the executable of adapter as a filter, that is, EMC will open part program in STEP-NC P21 or STP. This file type will be associated with the adapter and the adapter will be the one in charge of converting the part program in the STEP-NC to G-code and their output (G-code) will be loaded in the panel "sourceview" of GUI do EMC for their execution. Also the adapter generates a file ".tbl" which contains the tools used for machining. The original file of the tools is then replaced by the generated adapter. All these processes occur transparently to the operator of the machine.

The second feature that is added to the controller LinuxCNC is the possibility to view STEP-NC code that is uploaded. To achieve this was added to the AXIS GUI of EMC in the menu view an element called: "STEP-NC Viewer". By pressing this tab, runs a Python program with a GUI developed in Glade where is displayed in text form the file P21 or STP. Therefore, the operator of the machine has the option to display or hide the part program in STEP-NC related to the G code that was generated by the adapter.

In Figure 12 it can be seen the original INI file and modified INI file. In the modified file added the function of open part programs into STEP-NC (P21 and STP). This is made possible by the prototype adapter, which converts the input program P21 or STP to G code

In the Figure 13 to note the difference shown the original and the Modified AXIS GUI. In Figure 14 illustrates the final result of the modification of EMC AXIS-GUI, where was added the function of displaying the input file p21 or STP into an additional GUI.

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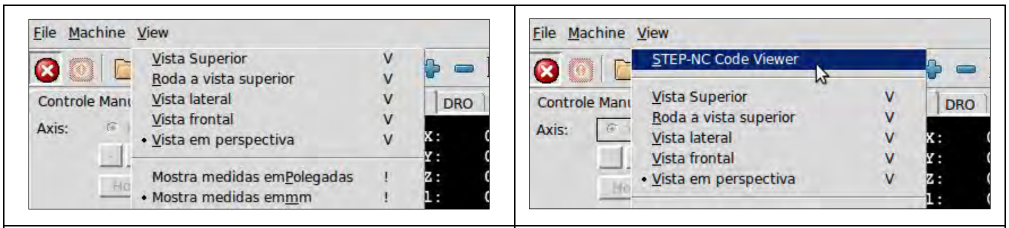
```
[FILTER]
PROGRAM_EXTENSION = .png,.gif,.jpg Greyscale Depth Image
PROGRAM_EXTENSION = .py Python Script
png = image-to-gcode
gif = image-to-gcode
jpg = image-to-gcode
py = python
```

a) Original INI file segment filter

```
[FILTER]
PROGRAM_EXTENSION = .png,.gif,.jpg Greyscale Depth Image
PROGRAM_EXTENSION = .py Python Script
PROGRAM_EXTENSION = .p21,.STP Iso14649 Ap21 to G-code
png = image-to-gcode
gif = image-to-gcode
jpg = image-to-gcode
py = python
p21 = java -jar "./AdapterSTEPNC_GCode.jar"
STP = java -jar "./AdapterSTEPNC_GCode.jar"
```

b) Modified INI file segment filter

Figure 12. INI file – segment filter.



a) Segment Original AXIS GUI b) Segment Modified AXIS GUI

Figure 13. GUI AXIS Original and Modified.

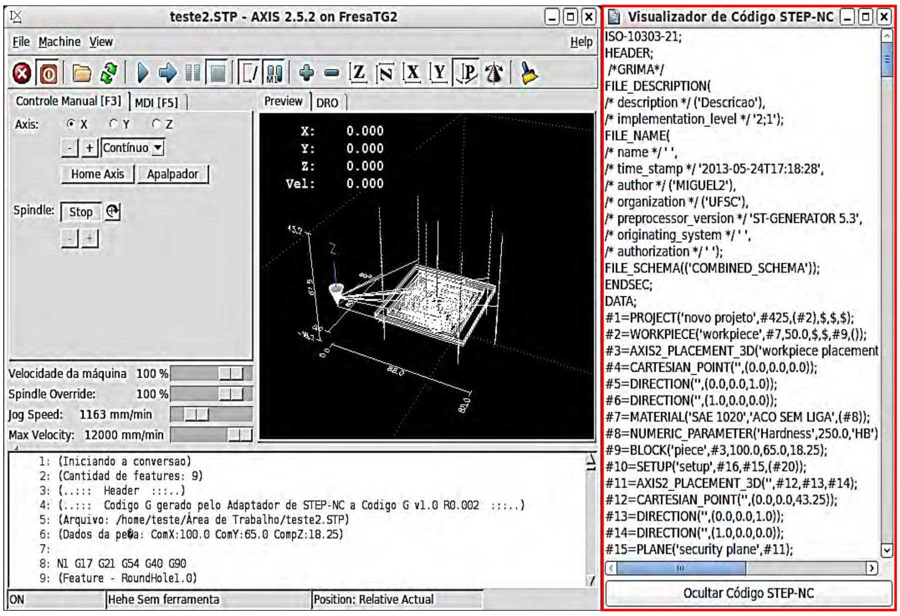


Figure 14. GUI AXIS whit GUI STEP-NC Code Viewer (Vizualizador de Código STEP-NC).

6. DESIGN, SIMULATION AND FABRICATION OF A MACHINE TOOL TYPE ROUTER

This section describes a summary of the development of a prototype machine-tool type CNC Router to validate the controller LinuxCNC adherent to STEP-NC. Are presented the design and manufacture of the Router. The parameter setting of mechanical machine (e.g. maximum federate of machine, limit of the axes XYZ, etc.) have been validated by means of testing adjustments.

6.1 Design and Manufacturing of the CNC Router

The design of the Router was performed at the CAD software, SolidWorks, in this software were projected all the pieces that make up the CNC Router. The design of the Router was based on industrial and didactic machines, found on the web. To facilitate assembly of components of Router, it was divided into several parts called: modules. In Figure 15 illustrates the complete CAD design of the CNC Router and in Figure 16 illustrates the complete CNC Router manufacturing.

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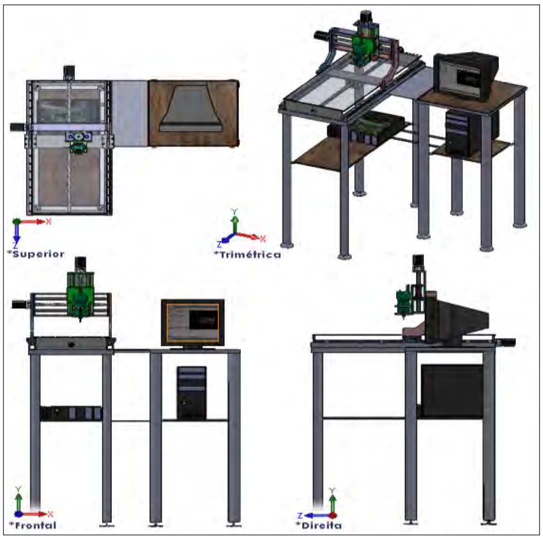

Figure 15. Complete design - CNC Router

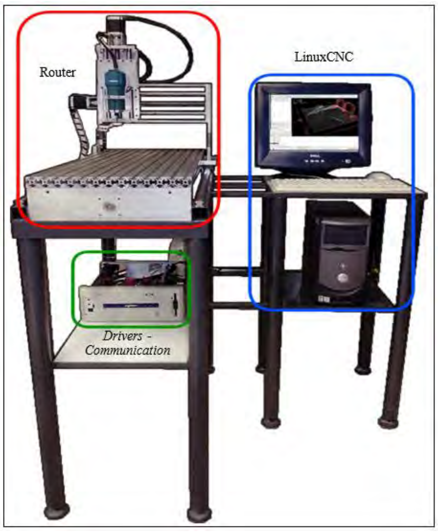

Figure 16. Manufacturing completed - CNC Router

7. CASE STUDY COMPONENT

To perform the case study was used as input to controller LinuxCNC a part program in STEP-NC generated by STEP Modeler software by UFSC / GRIMA. The machining operations for this case study component consist of drilling and milling.

The part program in STEP-NC P21 format was converted to G-code using the STEP-NC adapter to G-code. It was also generated file ".tbl" tools and was loaded in the controller GUI EMC axis. The following sequence of images show the results obtained.

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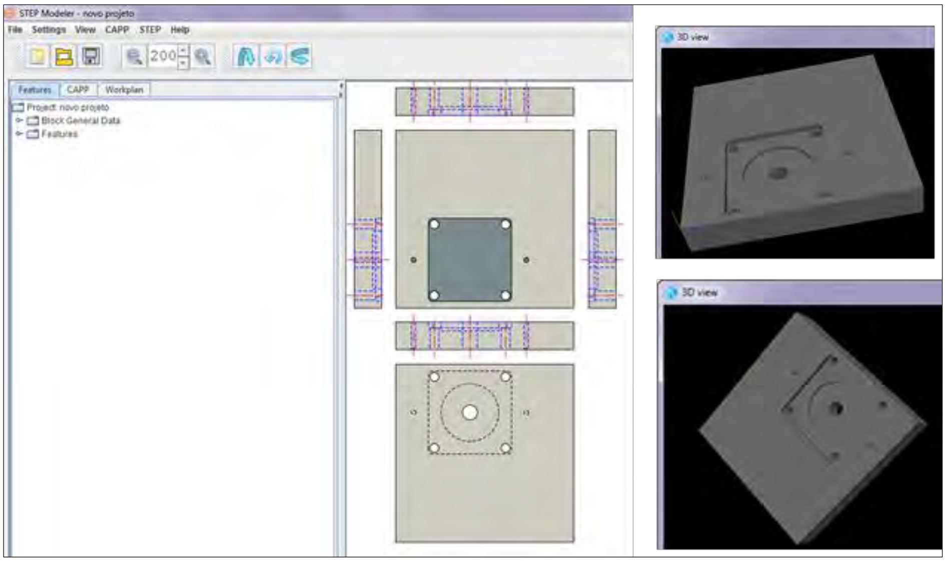

Figure 17. Part program STEP-NC generated by STEP Modeler.

```
ISO-10303-21;
HEADER;
 /*GRIMA*/
FILE_DESCRIPTION(
/* description */ ('Descricao'),'2;1');
FILE_NAME(
...
#31=MATERIAL('P','CARBIDE',());
#32=MILLING_TECHNOLOGY(0.175,.TCP.,11.0,-11.20450799366943,$,.F.,.F.,.F.,$);
#33=MILLING_MACHINE_FUNCTIONS(.T.,$,$,.F.,$,(),.T.,$,$,());
#34=ROUND_HOLE('Furo com base plana',#2,(#25,#48,#59),#35,#45,#39,$,#46);
#35=AXIS2_PLACEMENT_3D('Furo com base plana placement',#36,#37,#38);
...
#343=FACEMILL(#344,4,.RIGHT.,$,60.0);
#344=MILLING_TOOL_DIMENSION(6.0,0.0,0.0,40.0,0.0,0.0,0.0);
#345=CUTTING_COMPONENT(70.0,#346,$,$,$);
#346=MATERIAL('P','CARBIDE',());
#347=MILLING_TECHNOLOGY(0.011,.TCP.,14.5,-7.692488916108275,$,.F.,.F.,.F.,$);
#348=MILLING_MACHINE_FUNCTIONS(.T.,$,$,.F.,$,(),.T.,$,$,());
...
#423=MACHINING_WORKINGSTEP('ConicalBottomHole_RGH',#15,#399,#413,$);
#424=WORKPLAN('workplan setup plano: XY',(#47,#58,#73,#96,#107,#122,#159,#182,#193,
     #208,#231,#242,#257,#280,#291,#306,#329,#340,#355,#378,#389,#412,#423),$,#10,$);
#425=WORKPLAN('Main workplan',(#424),$,$,$);
ENDSEC;
END-ISO-10303-21;
```

Figure 18. Part program in STEP-NC, p21 format.

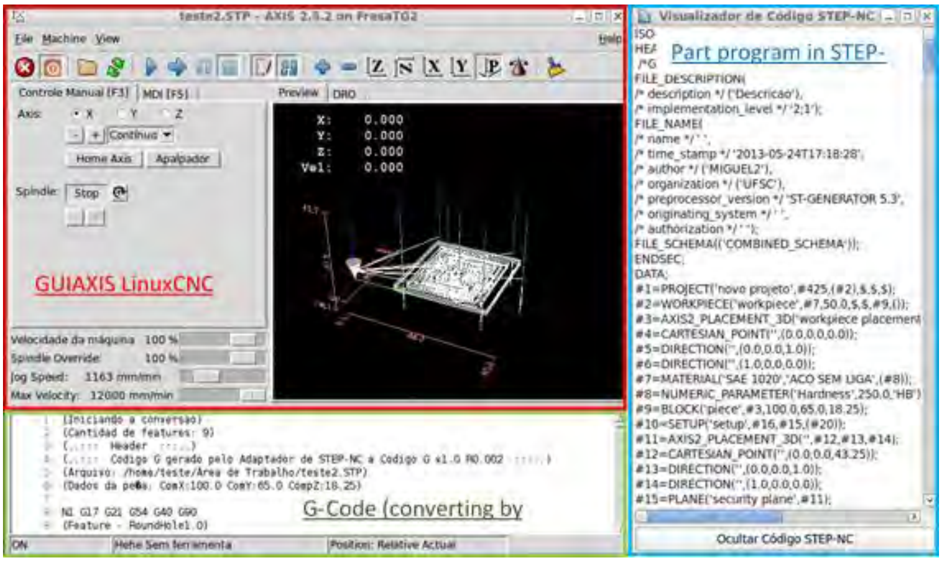

Figure 19. Controller: GUI AXIS LinuxCNC with G-Code and STEP-NC code Viewer.

Figure 20. Case study component.

8. CONCLUSION

This paper has exposed the importance of efficient and integrated manufacturing and the need for adequate exchange of information between CAD/CAPP/CAM and CNC. This exchange of information is related to the STEP-NC standard that, through him, it was possible to carry out the design, planning and manufacture of a part within a manufacturing environment. Therefore, STEP-NC creates a basis which satisfies the most recent requirements and demands with respect to a Bidirectional CAx process chain and CNC for machining.

Furthermore, the adapter that was developed allowed generate automatically G-code from a part program in STEP-NC, that is, the code was generated based on the machining features, machining conditions, machining operations and tools cutting in addition to parameters such as tool path, cutter radius compensation, feed rate, depth of cut, etc.

Already, in the union of all components of the a CNC Router (hardware and software) it was possible to create support for STEP-NC, i.e. was developed a CNC adherent to STEP-NC which allows carry out the process chain from a CAD design of a workpiece until their program execution in Code G.

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