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IMPLEMENTATION OF KINEMATIC MECHANISM DATA EXCHANGE BASED ON STEP

Yujiang Li
KTH Royal Institute of Technology,
Production Engineering
yujiang.li@iip.kth.se

Mikael Hedlind
KTH Royal Institute of Technology,
Production Engineering
mikael.hedlind@iip.kth.se

Torsten Kjellberg
KTH Royal Institute of Technology,
Production Engineering
torsten.kjellberg@iip.kth.se

ABSTRACT

In this paper, the first known valid implementation of kinematic mechanism based on STEP (ISO 10303, STandard for the Exchange of Product data) is presented. The result includes a general conceptual framework and two developed prototype applications. The framework is designed for integration of the STEP-based kinematic mechanism modeling with existing commercial CAx systems. The two applications are implemented for kinematic data exchange between Siemens NX and STEP-NC Machine via STEP AP214 (ISO 10303-214) files. Experiences of design and development of the applications are presented in this paper, and a valid example of data exchange using the developed applications is shown. As the first valid STEP implementation on kinematics, it demonstrates the feasibility of STEP-based data exchange for kinematic mechanism. The research result can also motivate deeper understanding and wider application of the STEP standard in the field of digital factory.

KEYWORDS

Kinematics, CADCAM, STEP, modeling

1. INTRODUCTION

Numerous commercial CAx software systems have been developed and applied in different fields of digital factory. Meanwhile, diverse partnerships have been built between IT software vendors, industrial practitioners, and academic researchers. And people have to face the problem on how to translate data formats among diverse software systems used by different partners. Therefore, the demand for a system neutral solution of product data exchange comes up in many perspectives: geometry, kinematics, tolerances, classification and so on.

Kinematic mechanism is one of the most important aspects in the field of industrial product data exchange and sharing. The basic conceptual technique to represent kinematic mechanism in CAD is common among majority applications: links and joints are combined to describe topology and geometry. And different types of motion constraints have been defined, e.g. revolution, translation, cylinder, etc. The need arises very often for the kinematic mechanism data exchange between miscellaneous information systems. Meanwhile, as a well-known standard for product data exchange, STEP addresses a solution for this demand with a particular integrated application resource, p105 (ISO 10303-105). However, applications for kinematic data exchange, based on a standard, are very rare.

The widely-used STEP application protocol AP214 (ISO 10303-214), integrating p105, offers a standardized data model schema for integration of the kinematics with geometry and assembly models. Several research projects, as mentioned in the next section, have tried to implement the kinematic model of AP214 as subtasks. But until now, no any known valid implementation for STEP-based data exchange of kinematic mechanism has been created.

STEP, as a system-independent neutral standard for product data exchanging, is introduced to provide a means for “the representation and unambiguous exchange of computer-interpretable product information" (stated in ISO 10303-1:1994). As the development of global market, companies collaborate in different forms, e.g. virtual enterprise, supply chain, or extended enterprise (Chryssolouris et al 2008). In this context, it is common that organizations in different locations using different software systems have to work together. Therefore, designers have to face the complex problem which is how to seamlessly exchange and share data with each other in a highly collaborative environment. Besides, designers and producers should exchange not only the product geometry data, but also information about processes and resources. Thus, standardized data exchange is often an intuitive solution. It is the comprehensive structure of the STEP standard and imperative needs for neutral product data format that make almost all major CAx software vendors support it more or less, especially in the representation of 3D geometry.

However, applications with the support for kinematic mechanism data are hardly implemented in industries. At present, most relevant companies have to use slides, fax, telephone, or paper-based documents to describe and exchange kinematic data. Skilled CAx operators' manual re-input usually is the only option to bridge the gap between different data formats. Such situation often makes huge waste of resources.

This research intends to help people with a feasible framework to automate and standardize the exchange of kinematic mechanism information in a most efficient way. The first known valid STEP-based implementation for kinematic mechanism will be presented with experiences from design and development processes. This will demonstrate how to use STEP models to facilitate the integrated data exchange with kinematics, geometry, and assembly.

2. LITERATURE REVIEW

STEP p105 is a member of the integrated application resources of STEP standard. It is a data model providing support for kinematic mechanism exchange and sharing for computer-aided kinematic design and analysis systems. This part of STEP standard was published in 1996 and then two technical corrigenda were published in 2000. At present, the second edition is under development and the first draft of its usage within an AP is planned in year 2011 by ISO.

The major features presented in p105 are structure, motion, and analysis related to kinematic mechanism. Typically, the kinematic structure is composed by links, joints, and pairs. As described in the standard document, links topologically represent the rigid parts in kinematic representation, pairs define the geometric aspect for the kinematic motion constraints and joints define the topology aspect of kinematic structure. These concepts are applied during the development in this research.

So far, there has been no known implementation for p105 valid modeling. Almost all found literatures regard it only as a conceptual model rather than an implementable integrated application resource. An important reason for such a blank is that there has been no guide or example on kinematics in any documents of STEP standard. Therefore the application of STEP-based kinematic modeling only has a simple history, as shown in Figure-1.

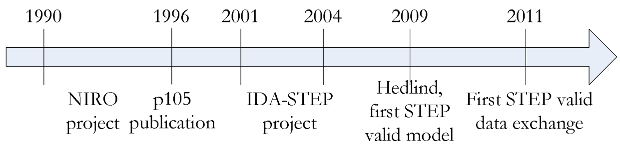

Figure 1 – Milestone of kinematic modeling using STEP

In the beginning of the ESPRIT Projects 2614/5109 NIRO (Neutral Interfaces for Robotics), the project partners developed a proposal for kinematics in STEP. This proposal was accepted by ISO as a basis for further STEP integration (Bey et al, 1994).

Two years later, the ESPRIT Project 6457 InterRob (Interoperability of Standards for Robotics in CIME) published the "Specification of a STEP Based Reference Model for Exchange of Robotics Models". The aim of this specification is very similar to application protocols of STEP: accurate exchange of manufacturing data between different systems. And its kinematic schemas were developed mostly based on ISO/DIS 10303-105:1994 (Haenisch et al, 1996). Nevertheless, there has been no any known application that uses this specification since it was published.

A research about machine control software in the context of industrial economy is an early attempt to involve the kinematic mechanism based on p105 (Birla and Kang, 1995). The STEP-based kinematic model is defined for the members of machining processes, in terms of fixtures, workpieces, and tools. But the result does not fully conform to STEP standard.

An expandable conceptual model for assembly information was proposed in a project held by National Institute of Standard and Technology (NIST) in USA, named Open Assembly Model (OAM) (Sudarsan et al., 2005, Rachuri et al., 2006). This model focuses on representations of geometry, kinematics, and tolerances, and it is claimed to use STEP as the underlying data structure. But it only adopts the concepts defined in p105, rather than the actual data model defined within its schema.

A small subset of p105 is used as a key part in a semantic-based machine tool modeling approach for 5-axis machining application by (Tanaka et al., 2008). The research extends the subset in its machine tool kinematic model. It is developed as a prototype system for ISO 14649 CNC data model.

An important attempt to implement kinematics of the STEP standard is the IDA-STEP project (Integrating Distributed Applications on the Basis of STEP Data Models, LKSoft, 2004). An outcome of the IDA-STEP project is a software prototype that can access, view, and edit STEP data which can be stored in a STEP database for internet-based exchange and sharing between multiple devices. This project succeeded to develop “an early prototype of a kinematic editor” and the result STEP file has a relatively complete description of the kinematic structure: joints, links, a limited number of pair types, and range values, although slight errors make it not valid to standard. A VRML file can also be produced and viewed in a web browser. According to the report, this is the first implementation attempt based on p105 since it was published.

Another implementation related to p105 that needs to be mentioned is the SKM (Space Kinematic Model) modular within the ongoing STEP-TAS (Thermal Analysis for Space) project which aims to build the thermal network and test environment for space missions (European Space Agency, 2007). The SKM module utilizes the kinematic structure of AP214 ARM (Application Reference Model) to describe the motion constraints of rigid bodies. But it is the AIM (Application Interpreted Model) schema that is intended for implementation and computer interpretation, rather than the ARM.

3. RESEARCH APPROACH

Two integrations are in focus during the development: integrating a kinematic mechanism with existing geometric model in a STEP AP214 file, and integrating kinematic data translation with existing commercial CAx systems.

At first, this research has to face challenges of exploring a way to merge kinematic mechanism representation to an existing STEP AP214 file that includes a 3D geometry model. To guide this part of the research, an AP214 valid kinematic model developed by (Hedlind et al., 2010) is used.

The research also focuses on the integration between STEP translators and existing commercial CAx systems. The STEP model, regarding the representations of geometric aspects, has been supported in lots of CAD systems, such as Siemens NX, Autodesk CAD, Pro/Engineer, and CATIA. Different ways are used in these systems, such as independent translators, command line, or even directly opening/saving, so that designers and researchers can use STEP files to exchange geometric data of their designs between different software systems. Hence, there is no need to develop a translator for geometric data model.

In order to demonstrate using STEP files to bridge kinematic mechanism between different systems, Siemens NX and STEP-NC Machine are selected. The reason why Siemens NX is chosen is that it provides a relatively open programming interface, NX Open, which enables the accesses to most of its functions including kinematic motion simulation. The choice of the STEP-NC Machine application was for its ability to simulate tool-paths described in AP238 (ISO 10303-238) together with AP214 machine tool geometry models. The machine tool kinematics is natively defined in XML format.

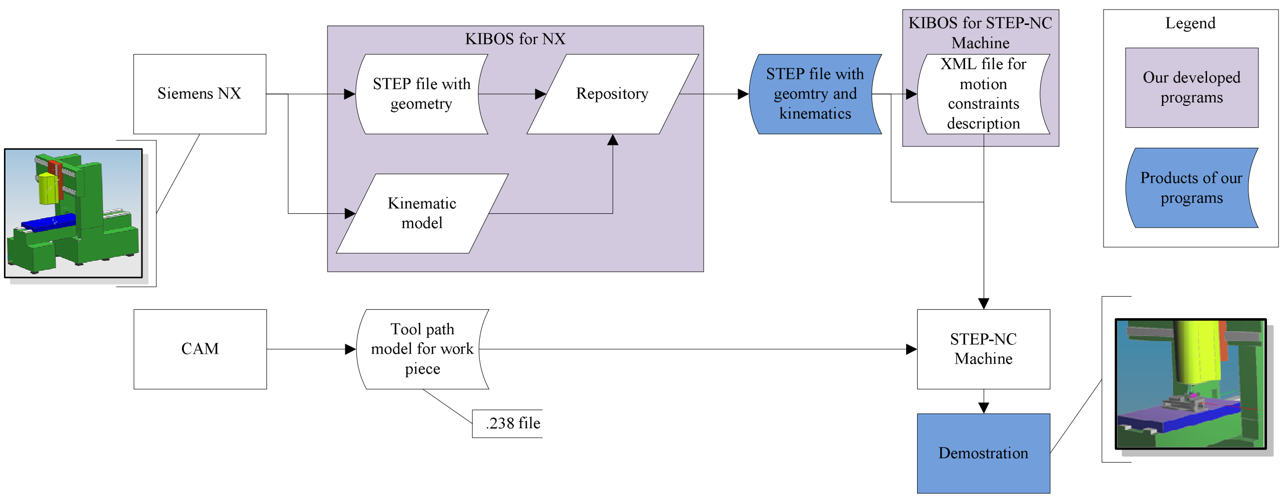

Figure 2 - Operation design

In this research, it is explored how AP214 can be utilized to exchange kinematic mechanism to support machine tool motion analysis and operation planning. The essential operations can be illustrated with the work flow diagram shown in Figure-2. The software developed in this research is named KIBOS (KTH Implementation Based On STEP). In this work flow, KIBOS for NX is executed within the session of Siemens NX 7.5. It acquires a STEP file, without kinematics, from the Siemens NX native STEP exporter. Meanwhile, it also collects kinematic data from the native NX model. Then, KIBOS for NX merges the kinematic data with the original STEP file in a data repository, and at last exports a new STEP AP214 file including both geometry and kinematics.

KIBOS for NX is designed to be firmly integrated with Siemens NX. It is able to be executed within NX and access NX functions. The aim of this integration is to make the user's operations as simple as possible. This solution can easily migrate to other CAx systems with the similar functionality, i.e. a built-in STEP exporter and an API (Application Program Interface) with necessary functions.

The conceptual framework, as illustrated in Figure-3, is applied here. Existing CAx software is used with limited STEP export functionality. Together with an external integration application to get the requested additional information, new possibilities for STEP-based data exchange is enabled with less effort compared with developing a completely new translator. This integration procedure requires that the chosen CAx software should have an accessible API or specified data format to get requested information and ability to export the first STEP file to be extended. These requirements can be fulfilled by many kinds of CAx software. Therefore this procedure can be applied in different contexts when implementing exporter from CAx to STEP.

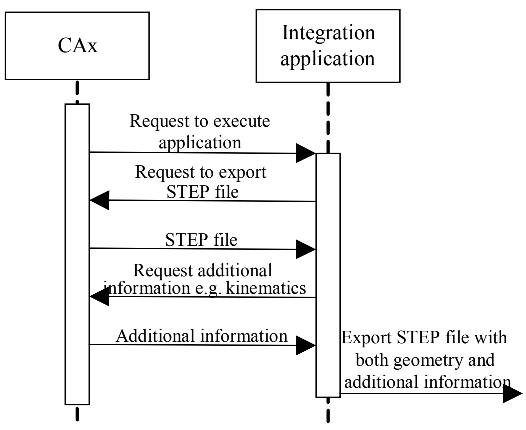

Figure 3 - An application integrated with CAx

On the other hand, KIBOS for STEP-NC Machine is an independent application to read the STEP file with geometry and kinematics, and to output an XML file describing kinematic information. The XML file conforms to the format defined by STEP-NC Machine. Together with the STEP file of a certain machine, it can be used to simulate motion of a machining operation in STEP-NC Machine.

4. SYSTEM DESIGN

This research includes development of two applications, KIBOS for NX and KIBOS for STEP-NC Machine. The two applications are similar in technical background and conceptual design. In this section they will be introduced in detail separately.

KIBOS is a STEP implementation based on AP214 AIM schema. It is developed with Java language, because both Siemens NX and STEP standard have powerful programming interfaces for Java. The API for Siemens NX, named NX Open for Java, enables access to all functions required in this implementation. Via NX Open, KIBOS for NX retrieves information from NX native model and executes STEP translation to produce the STEP file with geometry and assembly.

ISO 10303-22 SDAI (Standard Data Access Interface) specifies a programming interface to access data models based on EXPRESS (ISO 10303-11), the language describing STEP data model. ISO 10303-27 specifies a Java binding to SDAI and is implemented in JSDAI, an open source development package produced by LKSoftWare GmbH. Applications in this research are developed with JSDAI.

During system design, the integration of three layers is focused on: physical data, resources, and application. From the view of user demand, KIBOS is simple software with simple functionality: data format translation. But it needs to be seamlessly integrated with other resources, e.g. NX Open, STEP, and JSDAI. Hence, these resources are collected in a layer to link the application with physical data. Physical data is the data physically stored in the hard disk, mostly used as input and output. The application layer contains the developed program with data manipulation logic.

4.1 KIBOS FOR NX

The system architecture of KIBOS for NX is illustrated in Figure-4. At first, before development of the application it is needed to compile the AP214 AIM schema to an SDAI dictionary with JSDAI, so that necessary Java classes can be imported for early binding.

KIBOS for NX requires a native NX model with assembly, geometry and kinematics. Optionally, in order to make the output STEP file able to be used in KIBOS for STEP-NC Machine, the user also needs to label the faces where the cutting tool and the workpiece should be placed. In this implementation, the function of PMI (Product and Manufacturing Information) note in NX is used to label the surfaces.

4.2 KIBOS FOR STEP-NC MACHINE

The system architecture of KIBOS for STEP-NC Machine (see Figure-5) is similar to KIBOS for NX. The compiled library of AP214 AIM schema is also required to read and parse the STEP file by the developed STEP reader. Then, the XML creator generates the XML file according to the data of kinematic mechanism and general features. The XML file is created in a format defined and recognized by STEP-NC Machine. It stores kinematic information for a certain machine, e.g. kinematic chain definitions, axis definitions, axis placements, and motion ranges. It also includes placement data for cutting tool and fixture. KIBOS for STEP-NC Machine will automatically place both the STEP file and the XML file in the "machine" folder of the program folder of STEP-NC Machine.

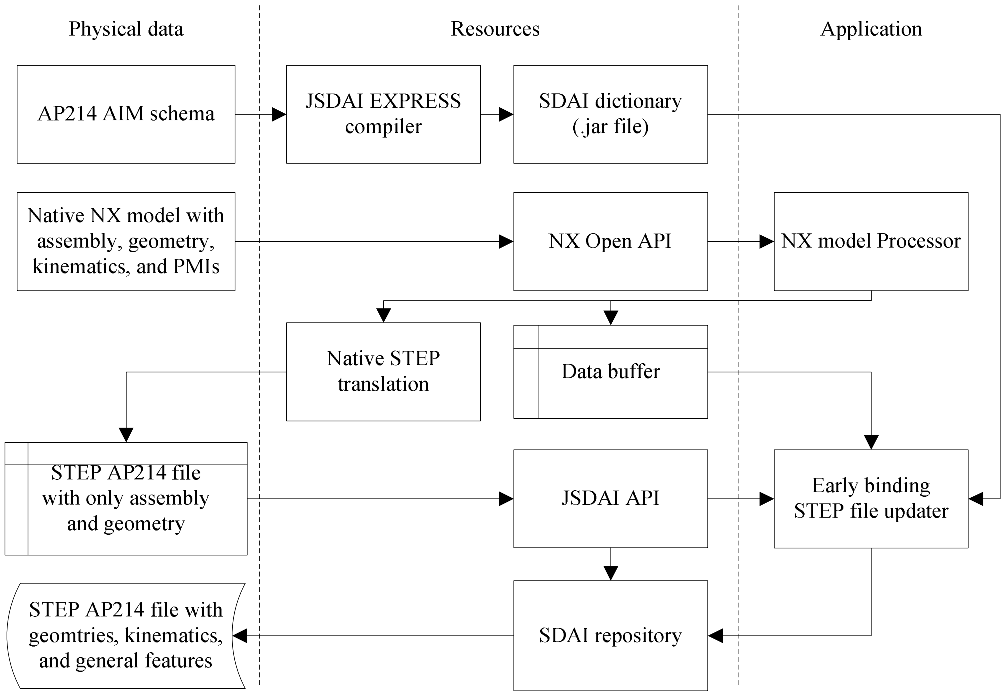

Figure 4 - System architecture of KIBOS for NX

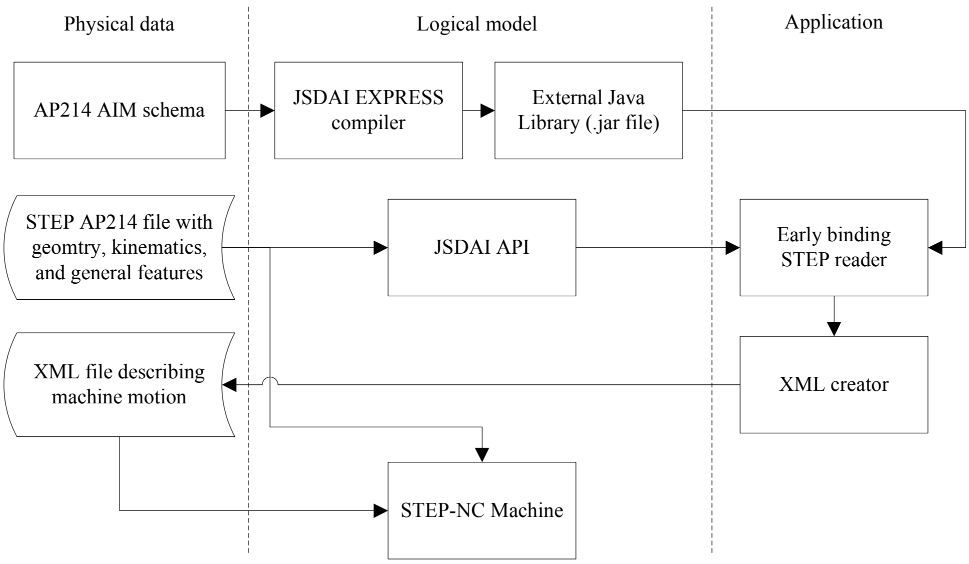

Figure 5 - System architecture of KIBOS for STEP-NC Machine

5. IMPLEMENTATION

Both KIBOS for NX and KIBOS for STEP-NC Machine are typical STEP implementations developed in the same development environment. JSDAI and the compiled dictionary of AP214 AIM provide full support for all the operations defined in SDAI and the data model of AP214 AIM. The GUI (graphical user interface) of KIBOS is developed with SWT (Standard Widget Toolkit), which is an open source library for platform-neutral GUI design and implementation. All the source codes of KIBOS are written and complied with Eclipse which is a well known open-source IDE (Integrated Development Environment).

KIBOS for NX is developed with the focus on high integration with existing design environment of Siemens NX. The implementation relies on NX Open for Java to interact with NX session and NX Open MenuScript to integrate the user operation. Thus, the application can be used to export the needed STEP file in the same way as other built-in exporters, as shown in Figure-6.

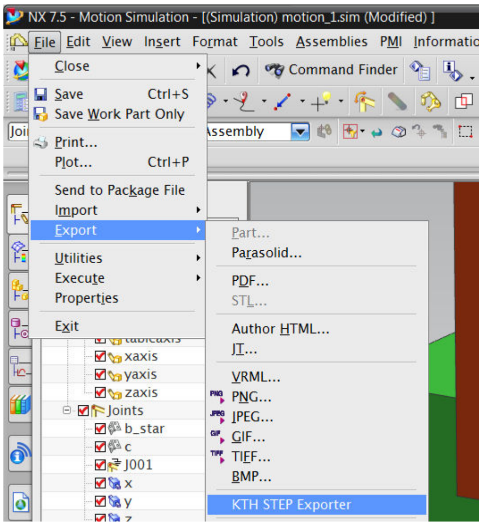

Figure 6 - The integrated menu button

The user interface of KIBOS for NX is shown in Figure-7. It is tailored similar to other common data format translators. The input model is the current working model in NX, and the file path and name of the output STEP file can be easily defined in the textboxes of the user interface, or selected from a file dialog by clicking the "Browse…" button.

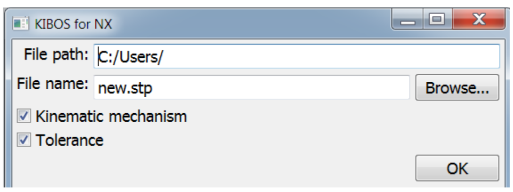

Figure 7 - Interface of KIBOS for NX

KIBOS for STEP-NC Machine is an independent application. The GUI is designed to finish all necessary configurations, as shown in Figure-8. The user can set the path of STEP-NC Machine, the input file, and the output XML file name. The actual orientation of the axis (Z axis) and the reference direction (X axis) of the machine is also able to be defined in case they are not set to the default orientation. The kinematic motion solver algorithm can be specified from a list of predefined variants defined by STEP-NC Machine. Note that, sometimes, the user would not like to repeat typing same values in the interface. Therefore, a text file is provided to pre-define the default values of all these configurations.

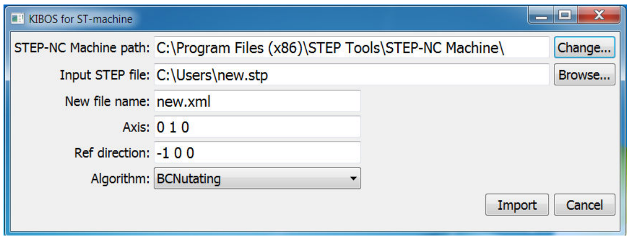

Figure 8 - Interface of KIBOS for STEP-NC Machine

6. CASE STUDY

This case study demonstrates and validates the presented system neutral solution for kinematic mechanism data exchange.

A CAD model of a DMG 5-axis machine tool is used in this sample, as shown in Figure-9. Although it is a simplified model, it still has full capability to demonstrate the motion of its 5 axes. This sample is used to perform the following tasks:

1. Creating a kinematic model in NX,
2. Exporting a STEP file with geometry and kinematics by KIBOS for NX,
3. Importing the information within the STEP file by KIBOS for STEP-NC Machine,
4. Simulating machining operation with the machine tool model in STEP-NC Machine.

The first task here is to create a complete kinematic model of this machine with special configuration such as axis definition and motion range. PMI notes are used to label the faces where the tool and the workpiece should be placed. In the component-based motion simulation module, six components/subassemblies are selected as the links to form the five kinematic joints to represent the five axes.

Then, using KIBOS for NX and KIBOS for STEP-NC Machine, the kinematic mechanism of the machine tool can be imported to STEP-NC Machine from Siemens NX via a STEP AP214 file.

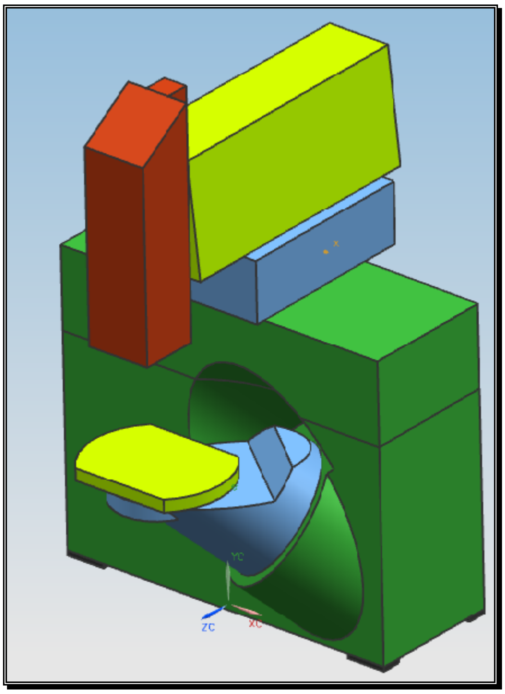

Figure 9 - CAD model of DMG machine in NX

The kinematic mechanism is displayed from a motion simulation in STEP-NC Machine. An AP238 file for machining of an impeller is used as a sample during this case study. This AP238 file is downloaded from the sample data set on the official website of STEP-NC Machine (STEP Tools Inc., 2011). The machining operations described in this file include fixture definition, tool paths, cutting tools, and operation sequence. During the motion simulation, the five-axis machining can be simulated and displayed in STEP-NC Machine, as shown in Figure-10.

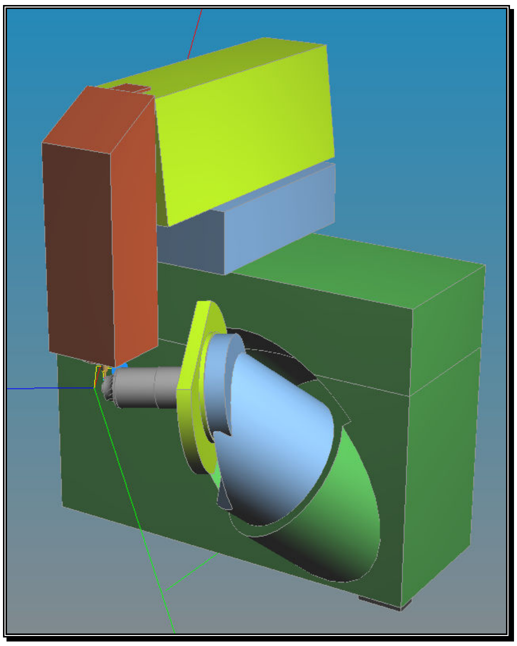

Figure 10 - Demonstration in STEP-NC Machine

7. CONCLUSIONS

This paper focuses on the strategy of STEP-based integration for kinematic mechanism exchange with existing commercial CAx software systems. The solution is presented with a general framework for system neutral integration. And two applications are developed to implement this framework. The major features of this solution include:

- Seamless linkage with existing CAx systems,
- Full integration with exported data on STEP using CAx native exporter,
- Valid standard data model with geometry, assembly, and kinematic mechanism,
- Standardized development environment.

As the first STEP valid implementation for kinematic modeling, KIBOS validates and demonstrates the capability of STEP AP214 AIM to represent and exchange kinematic mechanisms.

The industrial and academic significances are demonstrated in the result of this research. It provides the industrial practitioners an implementable framework for kinematic modeling exchange between different CAx systems. The IT vendors can be benefited by enhancing their products with STEP based kinematic modeling or data exchange in addition to their current support for standard geometric modeling. Besides, the developed application can assist academic researchers to create STEP files with valid kinematic mechanism. In addition to machine tool motion simulation (as shown in the case study), this result can be applied in other perspectives of digital factory, e.g. process planning, machine investment management, factory layout design, manufacturing configuration, ergonomics and so on.

8. ACKNOWLEDGMENTS

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