13th CIRP Conference on Computer Aided Tolerancing
May 11-14, 2014; Hangzhou, China
A Keynote Paper

A portrait of an ISO STEP tolerancing standard as an enabler of smart manufacturing systems

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Abstract

The International Organization for Standardization (ISO) has just completed (as of May, 2014) a major effort on a new standard ISO 10303-242 titled ‘Managed Model Based 3D Engineering.’ It belongs to a family of standards called STEP (STandard for the Exchange of Product model data). ISO 10303-242 is also called the STEP Application Protocol 242 (STEP AP 242, for short). The intent of STEP AP 242 is to support a manufacturing enterprise with a range of standardized information models that flow through a long and wide ‘digital thread’ that makes the manufacturing systems in the enterprise smart. One such standardized information model is that of tolerances specified on a product’s geometry so that the product can be manufactured according to the specifications. This paper describes the attributes of smart manufacturing systems, the capabilities of STEP AP 242 in handling tolerance information associated with product geometry, and how these capabilities enable the manufacturing systems to be smart.

Keywords: ISO; standards; STEP AP242; 3D models; PMI; tolerances; smart manufacturing; presentation; representation.

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1. Introduction

Progress in the field of computer aided tolerancing is strongly tied to the evolution of national and international dimensioning and tolerancing standards [1]. These standards lay down the rules for the specification of geometric information necessary to manufacture parts so that they can be assembled into properly functioning products. The task of developing such international standards has been shared by several Technical Committees (TC) – and their Sub-Committees (SC) – of the International Organization for Standardization (ISO). The works of three such committees are of interest to this paper.

The international standards for tolerancing symbols and their definitions (essentially, the syntax and semantics of dimensional and geometric tolerancing) are developed by ISO TC 213 *Dimensional and Geometrical Product Specifications and Verification*. Its standards are sometimes referred to as ISO GPS standards, which also include verification standards that deal with dimensional and coordinate metrology. The current status and future plans for ISO GPS standards were presented in the 12th CIRP Computer Aided Tolerancing conference [2] and so will not be repeated here.

Since three-dimensional (3D) models are rapidly replacing two-dimensional (2D) drawings as the master for product technical data in manufacturing industry [3], a need arose for standardized indications of dimensions and tolerances on 3D models. This need was met by ISO TC 10 *Technical Product Documentation* in its standard ISO 16792 [4]. Fig 1 illustrates an example of how to present the dimensioning, tolerancing, surface texture, and other similar information as ‘product manufacturing information’ (PMI) on a 3D model according to ISO 16792.

It is important to observe that ISO 16792 is mainly a *presentation* standard. A human being, trained in the field of engineering product documentation, can read Fig 1 and interpret it for further action. In fact, a model such as the one shown in Fig 1 can be zoomed, panned and rotated to view any detail. But the trend, as we will see in Section 2, is to make such information machine-readable. To accomplish this, there is an urgent need to have a computable *representation* of the type of information in Fig 1 so that an engineering information

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system (such as computer aided manufacturing) can process it automatically to take further action. The task of developing a standardized computable representation, in the form of standardized data models, rests with ISO TC 184/SC 4 *Industrial Data*.

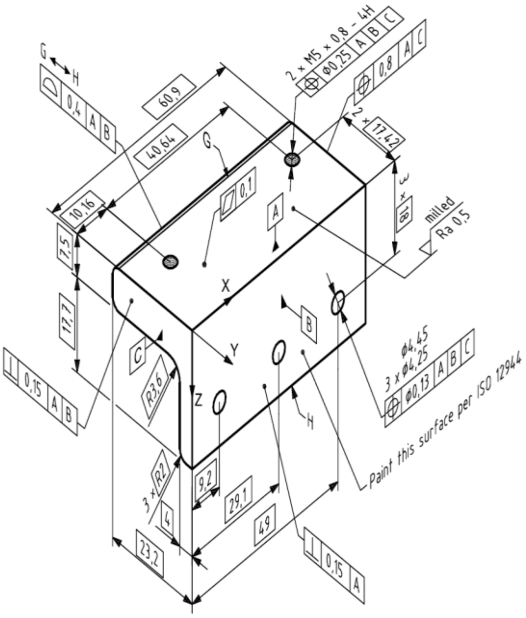

Fig. 1. An example of standardized presentation of product manufacturing information (PMI) on a 3D model [4].

ISO TC 184/SC 4 develops a family of standards, the most renowned of which is called STEP (STandard for the Exchange of Product model data) that describes standardized data models in several Application Protocols (AP). It has just completed (as of May, 2014) a major development of STEP AP 242 for ‘Managed Model Based 3D Engineering.’ STEP AP 242 contains computable representations for several types of 3D model data, including dimensional and geometric tolerances. Thus we are moving from mere *presentation* of PMI in 3D models to *representation* of such information that is machine-readable. And this is considered a major breakthrough that will enable several innovations in manufacturing.

This paper describes how STEP AP 242 PMI representation takes an important step towards making future manufacturing systems ‘smart.’ Section 2 gives a brief description of smart manufacturing systems and some of their enablers. This is followed in Section 3 by an introduction to the new ISO STEP AP 242. Section 4 then addresses PMI standardization covered by AP 242 and makes the case for its portrayal as an enabler of smart manufacturing systems. Some of the future plans and challenges are discussed in Section 5 and a summary is provided in Section 6.

2. Smart Manufacturing Systems

We live in a new manufacturing era that has been called the *Third Industrial Revolution* [5], which is characterized by the digitization of manufacturing. In this era of digitization of manufacturing, information will play an important role. How the product’s design and manufacturing information is authored, exchanged, and processed will determine who will succeed in this era. The metaphor ‘digital thread’ has been recently invoked to picture the flow of information along the product lifecycle and across the supply network [6].

Manufacturing systems in this new era will have to get ‘smart’. They need to be autonomous, self-aware, and self-correcting. In short, they should be able to function with as little human intervention as possible, while at the same time work harmoniously with human supervision and collaboration. Reaching this goal will be a daunting task, but research and development (R&D) is underway in several areas to pave the path towards this goal. Some of the R&D efforts relevant to this paper can be explained using a hierarchy of technical enablers shown Fig 2, in which only a few nodes along a path in the hierarchy are highlighted. A ‘smart manufacturing system’ in this diagram has many enablers, out of which only ‘model-based enterprise’ is highlighted immediately below that node as an enabler because that is the one relevant to this paper. Similarly, ‘model-based enterprise’ has many enablers including ‘3D model-based engineering,’ which has many enablers including ‘ISO STEP AP 242 standard,’ which contains many components including ‘PMI representation standard.’ We will explain each of the nodes highlighted in Fig 2 in some detail.

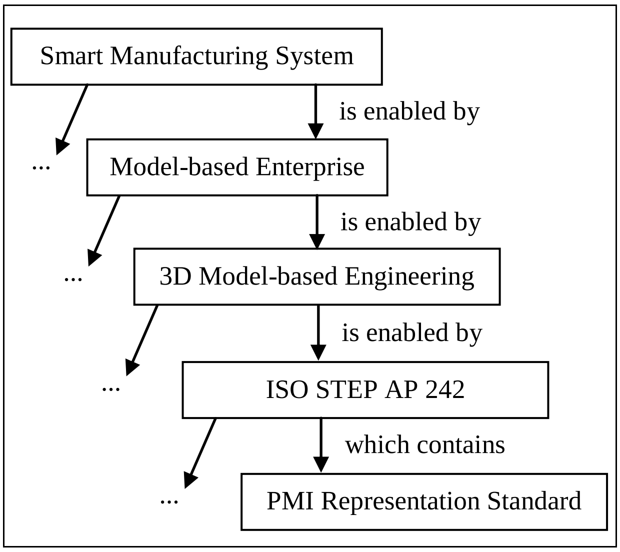

Fig. 2. A partial, hierarchical enabler diagram.

The enablers highlighted in Fig 2 have been selected after considerable discussion and debate with stakeholders. In each of the past five years the National Institute of Standards and Technology (NIST) has been hosting a summit of experts from government, industry, and academia on ‘model-based enterprise’ [7]. A common theme that has run through these annual summit meetings is that the world is moving (1) away from paper documentation and drawings, and (2) toward information models that are machine-readable. In short, what we envision as a smart manufacturing system is enabled, among other things, by a model-based enterprise that uses computable models both within a factory and across a supply network.

An important enabler of a model-based enterprise is the 3D model-based engineering, in which a digital 3D model serves as the authoritative information source for all activities in the product lifecycle and across the supply network. (It is important to point out that there are also several other important enablers of model-based enterprise, such as model-based systems engineering, but these are not covered in this paper.) The advantages of 3D model-based engineering, and the associated R&D challenges, are discussed and updated every year during the model-based enterprise summit at NIST. Many of the major findings of these summit meetings have remained relatively stable. For example, the conclusions from the fourth NIST summit held in December 2012 are [7]:

- Model-based methods and tools are increasing manufacturing productivity, but challenges remain in composite structure manufacturing, additive manufacturing, and process data sharing.
- Model-based inspection combined with optical measurement techniques is a potential game changer.
- Light-weight visualization formats are making model-based engineering feasible for small and medium sized companies.
- Systems engineering is an increasingly important component of model-based enterprise.
- Open standards and reference implementations are critical.

The last conclusion provides a strong justification for the presence of ISO STEP AP 242 standard in Fig 2 as an enabler of 3D model-based engineering, and a good segue to the next section.

3. ISO STEP AP 242

The most commonly implemented and used application protocols of the ISO STEP standards are AP 203 [8] and AP 214 [9], whose latest editions were published in 2011 and 2010, respectively. Both these APs address the same standardized 3D product models. It is generally perceived, however, that AP 203 was driven by the aerospace and defense industry, and AP 214 was driven by the (German) automotive industry. In 2009 a decision was made to merge these two APs into one called AP 242. This is the genesis of ISO 10303-242 ‘Managed Model Based 3D Engineering’ [10], which is currently (as of May, 2014) in the final stages of the ISO administrative process for publication as an International Standard.

Merging two popular APs into one has several advantages, including:

- Optimizing standards development and maintenance resources by eliminating duplication of efforts.
- Introducing new functionalities that are common to many industry sectors.
- Strengthening the acceptance and support by manufacturing industry by establishing a single universal brand.

Fig 3 illustrates the contents of ISO STEP AP 242.

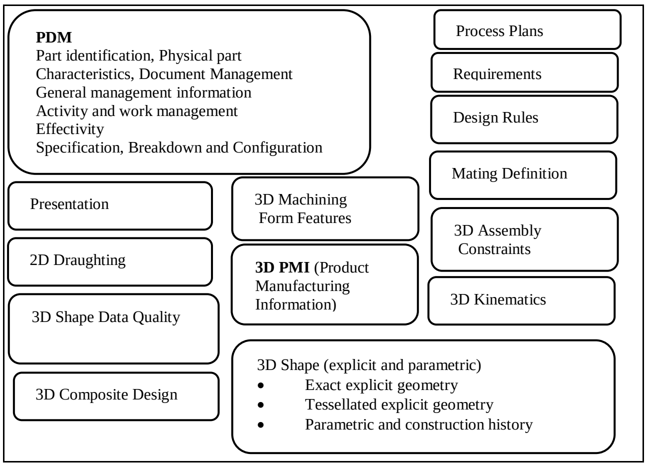

Fig. 3. An illustration of the contents of ISO STEP AP 242 (from [10]).

A quick study of Fig 3 reveals that ISO STEP AP 242 ‘Managed Model Based 3D Engineering’ contains several standardized information models that will enable 3D model-based engineering identified in Fig 2. Some elements of Fig 3 deal with ‘presentation’; these are graphical renderings that can be viewed and understood by human supervisors and collaborators. The rest of the contents in Fig 3 contain representations of the information that are machine-readable, thereby satisfying some of the key requirements for a model-based enterprise.

ISO STEP AP 242 is developed using a modular architecture [11]. Its modules use XML and EXPRESS schema languages, as appropriate for the intended applications, to define the data models [12].

One of the contents of STEP AP 242 illustrated in Fig 3 that is of interest to this paper is the 3D Product Manufacturing Information (sometimes referred to as

Product and Manufacturing Information), which is addressed next.

4. Product Manufacturing Information

Product Manufacturing Information (PMI) is a phrase used by the Computer Aided Design and Manufacturing (CAD/CAM) community to refer to Geometric Dimensioning and Tolerancing (GD&T), surface texture, finish requirements, process notes, material specifications, welding symbols, and other annotations. Some of this information is also referred to as Geometrical Product Specifications (GPS), especially in the ISO parlance. As mentioned earlier, PMI is also expanded as Product and Manufacturing Information, but the intent still remains the same.

4.1 PMI Standardization Processes

As noted in the introduction, three major ISO committees/subcommittees share the bulk of the responsibility for the development of what the CAD/CAM community calls PMI standards. There are dependencies, and hence time lags, in their standards development processes, as shown in Fig 4 and explained below.

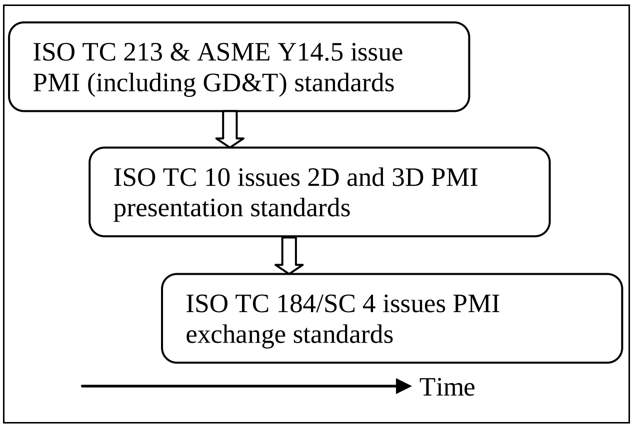

Fig. 4. A pictorial view of the roles, dependencies, and lags in the three PMI standards development processes.

ISO TC 213 and ASME Y14.5, which is a standardization body of the American Society of Mechanical Engineers, play the primary role of defining the syntax (symbols) and semantics (meaning of the symbols) of the PMI specifications using prose, graphics, and mathematical concepts [1-3]. They also define how these symbols should be presented on 2D drawings and, to a limited extent, on 3D models. ISO TC 10 then takes over the task of defining the precise graphical presentation of the symbols in 2D and in 3D [4] for human interpretation. It is also during this period that CAD/CAM software vendors implement PMI standards in their software and release them to the customers.

Taking input from these two ISO committees and from industry customers and CAD/CAM software vendors, ISO TC 184/SC 4 then defines the standardized information models for graphical *presentation* as well as *representation* of PMI in the STEP specifications. Then CAD/CAM software vendors develop import and export capabilities of the STEP standards-compliant data. The software vendor implementations are tested in an Implementors Forum [13, 14] to ensure that PMI have been correctly implemented and can be exchanged smoothly using the STEP standards. The process sequence shown in Fig 4 is repeated when ISO TC 213 develops and issues new and updated standards.

4.2 PMI Presentation vs Representation

3D graphical *presentation* – including zooming, panning, and rotating a model such as the one shown in Fig 1 – of PMI is an important capability that will enhance the human readability of complex data. Several efforts are underway to provide light-weight viewing of PMI (1) using the likes of 3DPDF and JT formats, and (2) on a variety of mobile devices. This capability will be critical in integrating humans as supervisors and collaborators in a smart manufacturing system. And, it will bring the benefits of smart manufacturing to the important segment of small- and medium-sized companies.

But 3D graphical presentation alone will not enable a manufacturing system to become smart. We also need PMI to be machine-readable. 3D PMI *representation* fulfills this need and it is one of the critical capabilities that ISO STEP AP 242 brings to industry as a major added value over the previous AP 203 and AP 214.

At the minimum, 3D PMI representation can transfer PMI data to various applications (for example, by automatically filling out an ‘electronic form’) without the need for re-entry by a human being. This will avoid a laborious and error prone process that is prevalent today. But, we can do a lot more. A computer aided manufacturing process planner, for example, can query the PMI representation to extract information about machining features, datums, tolerances and surface texture automatically. This can then be used to choose the machining fixtures, cutting tool, coolant, depth of cut, and feed rate automatically. A coordinate measuring system can also query for similar information to execute an inspection and quality control plan automatically. These measurements can be made (1) in-process during manufacturing for real time feedback control, or (2) off-line after the manufacturing to check for conformance to specifications. Such automation will be impossible without 3D PMI representation contained in the new ISO STEP AP 242.

5. Future Plans and Challenges

ISO is on track to publish the new standard ISO 10303-242 in 2014. Plans are already underway to develop Edition 2 of AP 242 [10]. Meanwhile, ISO TC 213 is actively planning and publishing new PMI standards [2, 15, 16]. With the appropriate time lag, as indicated in Fig 4, these PMI standards need to be included for standardization of their machine-readable representations in future editions of AP 242. If we label the PMI included in the current ISO STEP AP 242 as PMI 1.0, then we should get ready for PMI 2.0 that can be an order of magnitude more complex and more powerful than its predecessor PMI 1.0.

The major effect of ISO STEP AP 242 PMI will be felt in increased productivity by down-stream applications such as computer aided manufacturing process planning and inspection planning. Smooth interoperability and integration of these processes will test the belief that ISO STEP PMI representations can indeed enable smart manufacturing systems as envisioned in Fig 2.

6. Summary

We portrayed an upcoming ISO STEP PMI representation standard as an enabler of what makes a manufacturing system smart. Along the way, we described the roles and dependencies of three important ISO standards development committees and subcommittees involved in setting PMI standards. The computer aided tolerancing community can benefit immensely by paying close attention to the works of all these three standards bodies, thereby positioning itself to contribute to further digitization of manufacturing.

Acknowledgements and a Disclaimer

We want to thank our colleagues in the ISO STEP standards community for their contributions to the PMI standard, and its implementation and testing. Without their hard work, the progress reported in this paper would not have been possible.

Any mention of commercial products in this paper is for information only; it does not imply recommendation or endorsement by NIST.

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