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Development of a STEP-compliant inspection framework for discrete components

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Abstract: The measurement and inspection of manufactured parts play a vital role in manufacturing industry and is considered an integral part of the quality control. Though this is recognized, the state of the art in measurement and inspection of components is still recognized as a separate island of automation with no formal overall integration of standards and specifications. Although the introduction of probing has enabled automated inspection processes to become commonplace, the solutions for the in-process gauging at CNC machine tools and the programming of coordinate measuring machines is still vendor specific.

The introduction of new standards for data exchange, such as STEP, AP219, and STEP-NC, has influenced the future direction of the inspection process. In light of current research in this field, a STEP compliant inspection framework for a component is presented. This framework aims to provide a capability to establish standardized measuring and inspection across the total CAx chain. It will facilitate the use of information downstream in the chain, such as an inspection workplan, workingsteps, and a mechanism to close the loop and feedback of inspection results to component model design. In order to achieve this integration STEP-NC (ISO14649) along with AP219 has been used in this research to provide the basis of a STEP-compliant inspection framework.

Keywords: STEP-NC, DMIS, inspection, CNC, CMM

1 INTRODUCTION

Measurement and inspection of manufactured parts plays a vital role in manufacturing industry and is considered to be an integral part of quality control. Inspection planning and programming is an accepted part of the manufacturing process and today machined parts are inspected to much tighter tolerances in order to achieve quality finished products.

The inspection process of discrete components has been automated with time and has come a long way, from the early use of gauge blocks, dial indicators, and micrometers to today’s computer-controlled coordinate measuring machines (CMMs) with touch trigger probes.

The introduction of these CMMs has automated the inspection process by reducing the time and increasing the accuracy of the inspection results [1].

Today, inspection part programs for CMMs can be either based on DMIS [2] or a vendor-specific bespoke routine. Process control for online inspection of components at the CNC machine tool is achieved through bespoke inspection programs based on ISO6983 (G/M codes). Using a touch trigger probe on a CNC machining centre, the advantage is to provide first-off inspection in order to check the part dimensions and tolerances during the machining, before it goes to a CMM for final inspection.

Even though significant progress has been made, the inspection of parts on CMMs and CNC machines still represents islands of automation within the overall manufacturing process. Another important aspect regarding inspection of discrete components is standardization. STEP, AP219, and STEP-NC standards [3–5] are now being extensively developed to provide the basis for standardization and integration of part inspection [6].

It is well recognized that further research is required regarding inspection planning, accuracy of
part inspection at a CNC machine tool, and the role of DMIS in the future. With the aim of enabling quality control across the whole product life cycle, this paper outlines an inspection framework based on STEP STEP-NC, and DMIS combined with additional information requirements.

2 REVIEW OF INSPECTION PROCESS

Inspection planning and programming are necessary to reduce the time and effort involved in component inspection. This is evident from a large number of planning systems developed in research over the last 15 years. Hopp [7] presented a research framework that outlines path planning for components, and an expert system for inspection planning (implemented in PROLOG) was developed by El-Maraghy and Gu [8]. Other systems include the rule-based inspection planning system (IPPEX) of Brown and Gyorog [9] and the inspection planning system for sculptured surfaces of Menq et al. [10].

In his research, Corrigall [11] focused on the automation of inspection planning and programming. He proposed an inspection plan and code generation (IPCG) system within a design to manufacture environment. Based on feature-based design, Merat and Radack [12] defined an automatic inspection planning system. Yau and Menq presented a dimensional inspection path planning system for inspection of dies and moulds on CMMs [13]. A system of flexible vision inspection was presented by Lee and Chan [14], providing information about the dimensions and location of the part to be inspected. Kim and Chang [15] proposed an offline inspection planning system for CMMs.

The object-oriented inspection planner presented by Gu and Chan [16] consists of two knowledge-based planning systems, i.e. an inspection process planner and an inspection path planner. Fan and Leu [17] presented a probing path planning method, while Lin and Murugappan [18] presented an algorithm focusing on collision-free probing paths.

A great deal of research work has been done in the area of feature-based inspection. Such work recently reported by Bagshaw [19] defined an integrated inspection system outlined in a production data analysis framework. Zhang et al. [20] presented the idea of an inspection prototype that included five integrated functional modules, i.e. tolerance feature analysis, accessibility analysis, a clustering algorithm, path generation, and inspection process simulation.

Kramer et al. [21] presented an architecture for a feature-based inspection and control system (FIBICS) based on STEP features for machining and inspection. Recently, Hwang et al. [22] have proposed an efficient set-up and probe path planning specifically for the inspection of prismatic parts on CMMs to reduce inspection times.

The research outlined above has mostly focused on probe path planning for inspection up to the early 1990s. This resulted in different types of native programming system for CMMs. Although several knowledge-based inspection planning systems have been developed, these are subject to different specifications and standards. An effort is therefore required to standardize the whole inspection process to a single or number of ISO standards.

In spite of all the reported research into inspection processes for discrete components, there are still some key issues that need to be explored and properly addressed. These issues are as follows.

1. Automation of inspection processes still largely remains vendor specific.
2. Online probing of parts during machining is advantageous in the context of process control but is based on non-standard bespoke G/M canned cycles with very limited mechanisms for feedback of inspection results.
3. The process planning and feature-based machining of parts are quickly moving towards integration and standardization with the evolution of new standards such as STEP and STEP-NC, although for process control there is a lack of integration of standards for inspection.

The future research needs identified by the authors are:

(a) to define a STEP-compliant inspection framework for parts on the basis of product and resource information models that extracts an output data file for inspection of a component for both CMMs and CNC machine tools;
(b) to specify and implement product information models and inspection information models that integrate the inspection CAx process chain on the basis of standards such as STEP-NC and DMIS and add other non-standard information required;
(c) to identify a relationship between a CMM and CNC machine tool for component inspection, and also compare the current inspection standard DMIS with the new STEP and STEP-NC standards for inspection.

Based on these needs, as stated in the introduction, this paper investigates the area of discrete component inspection and develops an IT framework that supports standards such as STEP (ISO10303 AP224 [23] and AP219), ISO14649 (parts 1, 10, and 16), and DMIS with additional non-standard inspection information. The framework encompasses product information, inspection procedure information, and resources used.
3 STEP-COMPLIANT COMPONENT INSPECTION

The STEP-NC standard presents the opportunity to develop a new structure for feature-based process planning for manufacturing through the direct use of CAD data which form the direct input format into the NC. This departure from the traditional process chain is shown in Fig. 1. The novel ability of the STEP-NC standard as the basis for programming both CNC machines and CMMs facilitates closure of the manufacturing inspection loop.

Based on this STEP-NC standard, a framework has been developed for the STEP-compliant inspection process. A major feature of this STEP-compliant framework for inspection planning of components is the inclusion of high-level and detailed information in terms of an inspection workplan, working steps, and a mechanism to feedback inspection results across the total CAx process chain. This has been achieved through the use of STEP-NC (ISO14649-16) [25] and AP219 as the basis for representation of product and manufacturing models.

Inspection planning and programming can be considered at different levels, firstly with the strategic inspection planning at a company level, planning for a batch of components, and inspection planning for individual parts. It should be recognized that the focus in the STEP-compliant framework is upon inspection of individual prismatic components and its features.

The process of component inspection can be presented in several steps:

(a) identification of the geometric shape of the part, the individual features present, and the association of tolerances with these features;
(b) identification of the inspection resource such as a CNC machining centre with probe measuring capability or a CMM;
(c) inspection planning and inspection programming of the component on the basis of product information and available resources;
(d) the execution of an inspection program;
(e) the analysis of inspection results and feedback.

The STEP-compliant framework has been developed basically to cover three main aspects of component inspection:

(a) standardized product information which includes the geometric dimensions and shape of

![Fig. 1](Comparison of process chains based on the G/M code (ISO6983) and STEP-NC adapted from reference [24])
the component, feature identification, and information about geometric tolerances attached to the part dimensions and individual features;

(b) standardized inspection planning information which includes strategy, inspection procedures, execution of an inspection program, and resources, i.e., a CNC machining centre or a CMM and the probe used;

(c) standardized analysis of the inspection data obtained to give meaningful results and feedback to facilitate integrated process control across the CAx process chain.

The STEP-compliant framework consists of generalized inspection planning which is based on a manufacturing data model and an analysis model. An extract of the authors' component information and its inspection planning is depicted in Fig. 2 for a STEP-compliant data structure.

The STEP-compliant inspection planning framework provides a set of inspection procedures based on the available resources and product model information and then generates an output inspection program to be executed that is either in a DMIS or a STEP-NC output format. It uses product information from the product model to create part geometry, identify features, add tolerances, and define a work plan and working steps for inspection. In addition to the product information, resources information is provided by a manufacturing model in order to generate specific probe paths for inspecting major part dimensions and features. The analysis of inspection results uses AP219, and feedback is sent to the design phase or the planning and programming phase.

3.1 Product information models for component inspection

The product model provides information about the shape, form, and features of the part to be manufactured and inspected and the knowledge of the tolerances defined for the part dimensions and individual features. This product model is considered to be a part of both the design and manufacturing phase, i.e., an overlap of the manufacturing and design cycle. Knowledge of shape, geometry, features, and tolerances in the product model is provided by STEP standards and various application protocols, e.g., information about features in the product model is provided by AP224 [23].

The product information model, as illustrated in Fig. 3, is a necessary element of the proposed inspection framework and contains information relating to:

(a) the overall geometric information of the component as defined in STEP (ISO10303) and

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**Fig. 2** UML representation of an extract of the STEP-compliant component inspection data
DMIS, which includes the shape of the part and its main dimensions, e.g. width, length, depth, etc.;

(b) individual features present in the part, e.g. holes, pockets, etc., and the dimensions of features as defined in AP224 and AP219;

(c) interaction of features or compound features;

(d) geometric and dimensional tolerances involved with the part as defined in ISO14649-16 and DMIS;

(e) geometric and dimensional tolerances involved with features of the part as defined in ISO14649-16 and DMIS.

3.2 Manufacturing/inspection information models

The manufacturing/inspection process model encompasses data relating to inspection process planning, resources, the execution of inspection programming, analysis, and feedback of inspection results. The inspection planning and programming of the part to be inspected depend upon the resources used, i.e. a CNC machine tool or a CMM.

The manufacturing/inspection model interacts with the product model as shown in Fig. 4 and includes:

(a) component information from the product model;
(b) the datum reference for inspection of the part;
(c) the location of manufacturing features with respect to the datum reference;
(d) identification of inspection items (e.g. the length of the part or the diameter of the hole feature);

(e) identification of inspection activities and tasks;
(f) resource information.

4 IMPLEMENTATION OF THE STEP-COMPLIANT FRAMEWORK FOR GENERATION OF INSPECTION FILES FOR PARTS WITH SIMPLE FEATURES

The STEP-compliant inspection framework, illustrated in Fig. 5, is currently being implemented for prismatic parts with regular features such as holes, pockets, steps, slots, etc. For a part to be inspected, its geometrical shape, main dimensions, and features (as defined in AP224) are identified. Both geometric and dimensional tolerances (as defined in ISO14649 part 16 and DMIS) are added to the part and its features. The inspection specifications for the part and its features are provided, i.e. defining entities to be measured (e.g. the length of the part, the diameter and circularity of the hole, etc.) and the reference datum for inspection on the part. These tasks are defined using the STEP-compliant product model.

The information about resource and inspection activities (e.g. measuring the diameter), such as using the touch trigger probe for inspection, the work plan and probing working step, and probing strategies, is provided by the STEP-compliant manufacturing model (based on ISO14649 part 16 and DMIS).

The output from these two models is a generalized inspection plan that generates an interoperable STEP-compliant inspection file containing the inspection work plan, the entities to be measured, strategies, the working steps, etc. This file is interpreted to a specific inspection program for a CNC...
machine tool (e.g., Siemens’ CNC controller with SHOPMILL) or converted into a native inspection routine for a CMM.

The actual inspection of the component on the machine (CMM or CNC machine tool) yields inspection data which are interpreted into an updated STEP-compliant inspection file. The updated file feeds back results to the STEP-compliant product and manufacturing models where comparative tolerance analysis (e.g., checking deviations from the nominal) is undertaken by an inspection results analysis module. The results analysis module is based on AP219 which provides information about managing dimensional inspection of solid parts or assemblies, including analysing and archiving the inspection results.

5 CONCLUSIONS

The automation of inspection planning and the inspection process in the 1990s was primarily vendor specific. Although the primary aim was to reduce the time of inspection, the reported research has resulted in different types of native programming system for coordinate measuring machines. A need for an integrated approach towards the inspection of discrete components, including both CNC machine tools and CMMs, is required in order to close the loop between manufacture and quality control.

This novel inspection framework provides significant potential to close this inspection loop through integration of information across the CAx process chain. The information input from STEP-NC and DMIS standards and the related application protocols (AP219, AP224) to the inspection framework are in the final stages of development and will be fully reported in the near future.

REFERENCES


