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Towards an intelligent approach for CMM inspection planning of prismatic parts

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ABSTRACT

This paper presents a model of prismatic parts (PPs) inspection planning on CMMs, in terms of an intelligent concept of inspection planning. The developed model is composed of Inspection Feature Construction, Sampling Strategy, Probe Accessibility Analysis, Automated Collision-Free Generation, and Probe Path Planning. In this model, the simulation of a measuring probe path is based on three algorithms: Algorithm for Measurement Points Distribution, Algorithm for Collision Avoidance, and Algorithm for Probe Path Planning. The simulation output is a measuring protocol for CMM UMM500. An experiment was performed on two PPs that have been produced for the purpose of this research. The inspection results show that all tolerances for both PPs are within the specified limits. The proposed model presents a novel approach for the automatic inspection and a basis for the development of an integrated, intelligent concept of inspection planning. The advantages of this approach imply the reduction of preparation time due to an automatic generation of a measuring protocol, a possibility for the optimisation of measuring probe path, i.e. the reduction of a time needed for the actual measurement and analysis of a workpiece, and an automatic configuration of measuring probes.

1. Introduction

Research and development of intelligent systems for inspection planning on coordinate measuring machines (CMMs) present a precondition for the development of a new generation of metrological systems and their application in a digital quality concept, which is based on a global product interoperability model [1–5] where CAD-CAM-CAI information are integrated within a digital platform [6,7]. This approach presents a basis for virtualization, simulation and planning of inspection based on knowledge, particularly for the inspection of prismatic parts (PPs) on CMM. From the other side, digital manufacturing presents a framework for the development of a new generation of technological systems based on virtualization, digital model of a product and application of cloud computing concept [3,5].

Prismatic parts (PPs) are an important group of mechanical parts frequently used in industry. PPs are consisted from the basic geometric features such as plane, cylinder and cone. From the metrological aspect, this group also implies free from surfaces whose inspection is not strictly required, and they are present mainly due to esthetical or some related reasons. PPs are present in almost all types of manufacturing. In this paper, our focus is on parts with medium and high quality of tolerances precision used to build machine tools.

Literature review shows that the development of inspection planning on CMMs in the last three decades has passed through the following phases: manual planning, planning generated by CAI software (which is still the most commonly used approach), planning obtained by an expert system [8], and an intelligent concept of inspection planning [9–14]. The common element of all these approaches is a workpiece, i.e. the touching object used for measurements. According to the manner of an analysis and

Abbreviations: PP(s), prismatic part(s); SAT, standard ACIS text; MIP, Model for off-line Inspection Planning; PAA, Probe Accessibility Analysis; IGES, initial graphics exchange specification; SS, Sampling Strategy; PPP, Probe Path Planning; CS(s), coordinate system(s); STL, stereo lithography; IFC, Inspection Feature Construction; ACFG, Automated Collision-Free Generation; AMPD, Algorithm for Measurement Points Distribution; ACA, Algorithm for Collision Avoidance; APPP, Algorithm for Probe Path Planning.

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synthesis of workpiece geometric information (tolerances), three approaches could be distinguished: (i) analysis of geometry [15–17], (ii) analysis of tolerances [18–23], and (iii) combined approach [24–26].

It is well known that the inspection process is composed of few key elements such as path planning, collision avoidance, accessibility analysis and a workpiece setup, as well as configuration of measuring probes. A complete system for inspection planning contains all mentioned key elements. Hwang's approach for the inspection planning [27] involves some of these elements, such as a workpiece setup and configuration of measuring probes. A purpose of Weckenmann's analyses the practicability of extensive analytical comparison tests of different 1D, 2D and 3D artefacts [28] is the determination of meaningful positioning of the artefact in the measuring volume of the machine. Several related researches show the approaches for path planning [29–33], collision avoidance [34,35], accessibility analysis [36–43], and configuration of measuring probes [44–49]. The inspection planning could be also analysed through the local and global inspection planning [50]. Systems for inspection planning could be feature-based [51–56] and knowledge based [57]. Wong's approach [58] presents the off-line measurement planning system composed of three modules: module for input data, module for measurement planning, and module for statistical analysis. An example of the extraction of geometric information from CAD model and formation of input data is presented in [59]. An automatic inspection planning on CMMs based on B-representation of solid model in SAT format is given in [60], and at the end CMM program is generated in DMIS format.

One of the first steps in the development of an intelligent inspection concept is the integration of geometry and tolerances of prismatic parts (PPs) that participate in planning of PPs inspection. In order to accomplish this, the knowledge base was developed [69] to shows geometric feature that participates in the tolerance creation. Novelty in this paper refers to the development of collision-free measuring path based on the geometry and tolerances defined in knowledge base. The geometry of a part is presented by a set of points or point-to-point measuring path, where the path corresponds to inspection of the given PP tolerances.

The main difference between the model proposed in this paper and the approaches from the literature is in the definition of the workpiece, i.e. an object of a measurement. In coordinate metrology, the definition of the workpiece from the geometric aspect and the aspect of tolerances should be considered together. In the analysis of PPs, from the geometrical aspect the workpiece is characterised by geometric features (e.g. plane, cylinder), but from the aspect of tolerances the workpiece is characterised by metrological features (e.g. distance between two planes or two cylinders). The link between these two types of features (geometric and metrological) implies the type of tolerance. Based on this, the measuring probe path could be considered as a set of points composed of three sub-sets: (i) the first sub-set contains measuring points that can be obtained based on geometric information; (ii) the second sub-set contains the remaining points that measuring probe uses for the inspection of one geometric feature, that could be also obtained from geometric information; (iii) the third sub-set enables to avoid a collision, and this set must be defined based on tolerance information (i.e. link between two geometric features).

The proposed research is consisted of a Model for off-line Inspection Planning (MIP) of PPs on CMM and simulation of measuring probe paths based on this model. The main idea is to generate the measuring probe path based on CAD model of PP and its tolerances.

2. The proposed model for inspection planning of PPs on CMM

The elements of an off-line inspection planning of PPs are coordinate measuring systems (of measuring machine, measuring probe and workpiece), configuration of measuring probes, principle of collision avoidance, module for metrological recognition of PPs, local inspection plan and global inspection plan. The configuration of measuring probes is a result of Probe Accessibility Analysis (PAA). The module for metrological recognition is based on CAD model of PPs in an external record (IGES file) and on Inspection Feature Construction. The local inspection plan is a consequence of a Sampling Strategy (SS), and the global inspection plan is represented by the Probe Path Planning (PPP).

The inspection process of PPs based on an intelligent, integrated model for inspection planning of PPs on CMM is presented in Fig. 1. The main difference in comparison to the existing models is in the achieved level of automation of inspection planning process. The human involvement in majority of decision-making operations reduces the automation level. The limitation for application is also one of the criteria for the distinction of models; there are models designed exclusively for rotational parts, models for prismatic parts, and models for free form surfaces.

The vast majority of software developed for inspection planning is not open for modifications and upgrades made by user. This in particular refers to impossibility of the measuring path optimisation using some of the artificial intelligence (AI) techniques (e.g. fuzzy logic, Hopfield networks, swarm intelligence, etc.), directly related to the reduction of the inspection time. The path generated by software is fixed for the selected measuring strategy and tolerances are manually imputed. In the inspection planning process, the relationship between geometry (feature) and PP tolerances does not exist in a form of record.

Our approach implies the system open for modifications/upgrades, which integrates all elements of measuring process (sampling strategy, configuration of measuring probes, collision avoidance, etc.) with minimal human intervention, aiming to reduce the time needed for PPs measurement on CMM.

Fig. 2 shows a Model for off-line Inspection Planning (MIP) for PPs on CMM.

Relaying on the existing software for inspection on CMMs based on CAD representation of PPs, the inspection principle is carried out based on the following formula:

$$ {}^{M}\mathbf{r}_{P_i} = {}^{M}\mathbf{r}_{W} + {}^{W}\mathbf{r}_{P_i} \quad (1) $$

where

${}^{M}\mathbf{r}_{P_i}$ - probed point's position vector in machine coordinate system,
${}^{M}\mathbf{r}_{W}$ - workpiece system's position vector in machine coordinate system,
${}^{W}\mathbf{r}_{P_i}$ - probed point's position vector in workpiece coordinate system.

In the proposed model, the inspection principle for PPs in MIP is based on the following equitation:

$$ {}^{M}\mathbf{r}_{P_i} = {}^{M}\mathbf{r}_{W} + {}^{W}\mathbf{r}_{F} + {}^{F}\mathbf{r}_{P_i} = {}^{M}\mathbf{r}_{F} + {}^{F}\mathbf{r}_{P_i} \quad (2) $$

where

${}^{W}\mathbf{r}_{F}$ - feature system's position vector in workpiece coordinate system,
${}^{F}\mathbf{r}_{P_i}$ - probed point's position vector in feature coordinate system,
${}^{M}\mathbf{r}_{F}$ - feature (plane) system's position vector in machine coordinate system.