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Towards a more comprehensive understanding of Tolerance Engineering research importance

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Abstract

This paper discusses the Research Question (RQ) "Can the tolerance engineering community benefit from an extended research focus?" We look at current research trends within the product development domain and also compare the current research front of the CIRP-CAT community with current industrial practice. We additionally draw on knowledge from two separate surveys in Germany and Norway among industry professionals. Empirical data from these sources show similar indications that the important activities of tolerance engineering remain a difficult subject within industrial practice. In addition there seems to be a relatively low degree of academic attention to tolerances within other PD-research communities; in contrast to its high practical industrial importance. Our contribution to theory is seen in the proposals as to how to raise the awareness of the importance of tolerance engineering. A list of potential research areas are proposed for the community.

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1. Introduction

Tolerance Engineering (TE) represents an important activity within industrial product development practice [1]. Tolerances are typically defined at an early stage of product development (PD) and so they become a main part of the "developers dilemma" where decisions are made without insight into all limiting conditions [2]. Re-applying existing tolerance limits on similar designed parts can result in legacy-based substandard TE [3]. Such practice is undesirable but obviously still occurs as Zhang states "many parts and products are certainly over-toleranced or haphazardly toleranced, with predictable consequences" [4]. The resulting negative effects of inappropriate tolerances with increased costs and the loss of product quality will emerge at a late stage of the product-development [5]. At this stage tolerance definitions can be changed into appropriate ones only with a very large effort [6] and many man-hours spent [7]. Substandard TE practice can be hidden outside of the field of attention of the organization. Loss of quality and increased costs becomes visible long after tolerance definitions are made; or as [8] states; "all industry is suffering, often unknowingly, of the lack of adequate academic attention on tolerances". Yet the research community on Computer Aided Tolerances (CAT) has produced a large set of contributions over the years [9], [10]. A major makeover of several existing norms and standards has been introduced in later years [11], [12]. Recent reflections [13] on the mathematical and algorithmic advances within the CAT community conclude that "Industry will struggle with the magnitude of such changes". Considering the current low academic attention to tolerancing courses that have; "gradually been removed from the curriculum at universities and have been replaced by other product development courses" [8] a deficiency is seen in curriculum focus. Only a few universities offer dedicated courses and seminars on this topic [14].

In between the three domains of (i) Forefront CAT-research, (ii) PD-research, and (iii) Current industrial challenges, areas of challenge and subsequent potential research activities arise (Tab.1).

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Table 1. Outline of perceived tolerance engineering challenges

Domain	Challenges
CAT-research (section 3.1)	Making advances accessible and desirable to apply in industry and to teach at universities.
PD-research (section 3.2)	Increased focus on human aspects, teams etc. Low specific focus on tolerancing topics.
Industry (section 3.3)	Suffering unknowingly due to substandard CAT-practice. Lacking resources to adapt practice.

To deal with these challenges we search for strategies to approach them and to make tolerancing research more accessible and desirable to teach (universities) and apply (industry). Tolerances would normally have a natural place in PD-courses, and PD literature has a copious set of engineering models [15], strategies [16] and approaches [17] with different foci. Yet, a comprehensive listing of selected models [2] does show a low specific focus on tolerances. This is reflected in current PD research where respectively only 5 out of 450+ contributions [18] and 5 out of 98 [19] on two PD flagship conferences covered tolerances in one way or another. Not only have tolerances low specific attention within academia and current PD-research; but industry managers are also lacking tools to address tolerancing activities. Recent management initiatives focus on variation (TQM and Six Sigma) [20]. On the contrary few management toolboxes focus specifically on tolerances. This is a paradox as appropriately determined tolerances can reduce the subsequent need for variation management. Tolerances lack a similar "toolbox" for management attention and organizational change. They have in later decades typically been handled with (i) a high degree of technical focus [21], [22], (ii) kept its focus on tolerancing norms or standards [23], [24] or (iii) communicated the content of the established [25], [26] and coming [27], [28], tolerancing language within the domain of geometrical limits.

Quality initiatives, such as Six Sigma-inspired approaches [29] originate from manufacturing [30], but have in recent years been moved "upstream" and adapted to fit the activities within PD [31]. There exists a plentiful set of suggestions on how to implement the principles within an organization [32]. Several lessons have been learnt as to how they can be adopted within an organization, [33] and the potential resistance it might face [31], [34]. Several of these lessons learnt address the importance of management commitment, visualization and frequent communication in order to gain broad acceptance for the improvement activities. We therefore look at other activities in parallel research communities to explore additional approaches to further raise attention to the important tolerancing topics with a broader audience.

2. Methodology

The aim of this paper is to discuss the RQ *"Can the tolerance engineering research community benefit from an extended research focus?"*. We therefore look beyond the tolerancing tools and methods and aim to understand some factors that influence industrial adoption of new tolerancing practice. An additional aim is to explore how universities can make fully trained graduates available and applicable tolerance research accessible to the industry.

We draw on knowledge from a literature review and two separate surveys on tolerance engineering practice conducted in Germany and Norway respectively. Further we draw on insight from industry professionals, as well as impressions from industry and academia. A discussion based on this information is presented.

3. Background

We compare technical achievements within the CAT- (3.1) and other PD-research communities (3.2) with current industry tolerancing practice (3.3).

3.1. Recent CAT-research achievements

TE emerged early in the last century as statistical insights and methods found their way into several research areas [35]. Pre-computer tolerancing research (before 1960) focused mainly on the use of statistics and applications in industrial engineering problems [35], [36]. However, due to the rise of computers in the late 1950s the tolerance research focus shifted towards the "nearly unlimited" possibilities of numerical methods and computational tools [37], [38]. This trend continued during the last century and is still clearly visible in today's tolerancing community [39]. We have reviewed and categorized the CIRP-CAT conference proceedings of 2005 and 2012 based on their content, scientific contribution and research approach (Table 2). We observe that in 2012 about ~48 % of the contributions were associated with the category "methods and tools". Only ~16 % deal with industrial applications and challenges, less than those handling metrology (~27 %). The number of contributors with industrial background/application at the CIRP-CAT conference seems to be relatively constant. The ~6 % in 2005, slightly increased to more than 10 % in 2012 (2007: ~9 %; 2009: ~11 %). By studying the author affiliations of CAT-papers we notice an industrial (i) vs. academic (a) author ratio with a strong bias towards academia: 8 (i)/120 (a) (2005), 11/105 (2007), 15/124 (2009), 15/137 (2012). Similarly low industry attendance is seen at other conferences [40] yet, CIRP-CAT topics ought to be particularly interesting for industry striving for quality excellence and reduced costs.

Table 2. CAT-conference papers categorized according to content

CAT-paper Category	2012 (#)	2005 (#)
Methods and tools	48.4 % (31)	63.7 % (28)
Standardization and norms	4.7 % (3)	4.5 % (2)
Industrial applications and challenges	15.6 % (10)	15.9 % (7)
Others (Teaching etc.)	4.7 % (3)	6.8 % (3)
Metrology	26.6 % (17)	9.1 % (4)

3.2. Current movements within PD-research

As tolerancing is a very central activity within PD we look at research trends within parallel PD research communities. Within the plentiful number of PD-models and approaches [2] (p.20-24) few focus specifically on tolerances and tolerancing. Such activities are often indirectly addressed within activities