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Beyond Lean and Six Sigma; Cross-Collaborative Improvement of Tolerances and Process Variations - A Case Study

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Abstract

Good tolerance- and variation management is essential to achieve high value adding products with cost-effective processes. The link between Tolerance Engineering and popular manufacturing improvement philosophies such as Lean and Six Sigma is, however, not always that clear. The possibilities and limitations of these two approaches on Tolerance Engineering are discussed in this paper. The case describes cross-collaborative improvement work within industry on tolerance and variation management which is similar to a work model called "Closed Loop Tolerance Engineering" (CLTE). The case is focused on the process of revising existing drawings and tolerance specifications for the manufacturing of products with a long lifetime. Although both Lean and Six-Sigma have been important for the improvement work in the case company for several years, there is still a gap to be filled on tolerance and variation management. The novelty of this paper is found in the link between an industrial case on improvements and an academic model (CLTE) for cross-collaborative engineering on variation and tolerances.

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1. Introduction

The management of product specifications, process variations and quality inspections is central to any manufacturing company, and tolerances represent the main way to specify limits to geometry and other parameters. Optimal tolerances are important for product function, correct fit in assembly processes, selection of process steps, inspection strategy and manufacturing methods, and thus bridge several steps in the product lifecycle. Lack of coherence between the product design, manufacturing and the inspection can lead to quality problems. The tolerance standards such as Geometrical Dimensioning and Tolerancing (GD&T) [1] can be seen as a general "language" to communicate the limits of specifications related to geometrical parameters. Zhang [2] states: *"A bridge between design and manufacturing, functional tolerances are absolutely necessary…..".* Creveling [3] states "*tolerances are critical to the successful manufacture and performance of the product over its intended life cycle"*. Optimisation software has given the designer new tools for optimising tolerances. The link to manufacturing and inspection is, however still crucial to achieve cost-efficient manufacturing with good quality. Current quality and efficiency paradigms such as TQM, Lean and Six Sigma [4] do to some extent address variations management in manufacturing and quality inspection. There is, however, still a lack of a good connection between tolerance synthesis in the design phase, manufacturing process capabilities and variations as well as quality inspection. The case in this paper shows how collaboration focused on tolerance- and variation-topics enabled to bridge the gap between product development, manufacturing & inspection; an approach similar to Closed Loop Tolerance Engineering [5].

2. Theoretical Background

In spite of the central role tolerances play in manufacturing, they seem not to have a prominent place

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in engineering and academic literature. Literature such as Day [6] and the standards such as ASME Y14.5M [7] covers the essentials of GD&T but focusing on their purpose as tolerancing norms mainly in the product design phase. The ISO/TC213 committee [8], [9] works on joint GD&T principles for design, manufacturing and metrological principles. The human aspect in the tolerance management process is, however, not addressed.

A lack of awareness of tolerancing in engineering education is addressed by authors such as Watts [10] *"GD&T has gradually been removed from the curriculum at universities and has been replaced by other product development courses*. Zhang et al. [11] address this to some extent, describing GD&T to be *"trainable but not teachable"*. Watts addresses what he calls the *"GD&T knowledge gap in industry"* as he claims to see that *"all industry is suffering often unknowingly"* of the lack of *"adequate academic attention"* in mechanical engineering design courses. Parameter Design activities after the 1950, such as the Taguchi Method [12], take a Design of Experiments (DoE) approach to product and process design, and Nair [13] organizes the discussion between engineering and statistical-based approaches at an early stage.

An accessible entry point to tolerance engineering can be found in a literature review such as that by Hong [14]. Horvàth [15] justifies the latest trend towards human aspects in engineering design as seen in books by Lindemann [16], Badke-Schaub [17] or Frankenberger [18]. Product design literature such as Cross [19], Ulrich & Eppinger [20], Ehrlenspiel [21] and Pahl & Beitz [22] are all examples where GD&T unfortunately is given little focus. Creveling addresses collaboration on tolerances directly in his book on Tolerance Design [3].

3. Tolerancing in Lean and Six Sigma

Lean is a philosophy that promotes continuous improvements with its roots in the Japanese automotive industry [23]. Six-Sigma is another strategy for problem solving and engineering improvements with its roots in the American electronics industry. Both initiatives have been powerful movements for improved product quality, optimised material flow, reduced waste and numbers of defects within manufacturing and service worldwide. The zero defects philosophy in these approaches implies a need for understanding and reduction of variation in manufacturing. Tolerance management is, however, only indirectly addressed. Deming [24] focuses directly on "variation" in several of his managements principles but does not address tolerances as such. Even though Lean and Six Sigma initiatives have further been moved towards product development through initiatives such as Lean Product Development (LPD) and the loosely defined Design for Six Sigma (DfSS) [25], the focus on Tolerancing is still lacking. An illustrative comparison between the principles, practices and tools of LPD and DFSS is provided by Fouquet et. al. [26]. Hasenkamp [27] argues that the important driver for implementing a robust design is the awareness of variation. We will argue that awareness of tolerances and their link to manufacturing variation holds similar importance.

4. Closed Loop Tolerance Engineering.

The model of Closed Loop Tolerance Engineering (CLTE) is presented [5] as a contribution to closing the gap between product design, manufacturing, inspection and product performance. The CLTE model (see Fig 1) contains four *activities;* (i) defining functional requirements, (ii) defining tolerances, (iii) considering production capabilities and, (iv) confirming functional performance. CLTE activities are organised into two dimensions; (a) The normative dimension which includes the activities (i) & (ii), and (b) the empirical dimension, which includes the activities (iii) & (iv). A bridge is needed to connect the product development participants (how things should be) and the manufacturing participants (how things really are) with regard to their work on tolerances. Each activity stands in a relation to a following or preceding activity. CLTE contains altogether 6 pairs closed loops of relations. Each *relation* has some key elements which represent typical examples of the context-dependent content in each relation. An explanation of the participants, practices, information, knowledge and tools for this context is listed in [5].

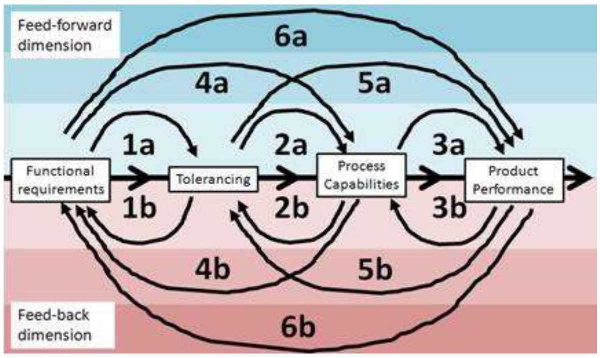

Fig. 1: Four activities and the 6 pairs of closed loop relations in CLTE

CLTE includes several *participants* as it can be considered as an integrated engineering workmode. The need for cooperation across functional borders within product development is described among others by [28] and [21]. In a typical CLTE context, participants will be; designers, project leaders, quality assurance (QA) engineers (incl. meteorology), manufacturing operators, test engineers, process engineers, foremen etc. The CLTE *tools and practices* support the participants in