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The online quality control method for reassembly based on state space model

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ABSTRACT

The online quality control for reassembly (remanufacturing assembly) process is one of the key technologies to ensure the quality of reassembly influenced by uncertain, nonlinear and dynamic environment. According to the characteristics of reassembly process, this paper constructs the state space model which takes assembly operation and part attributes as the input vector, work-in-process as the state vector, and assembly quality as the output vector. Then, a transfer function for assembly quality is established, which is used to characterize the coupling mechanism of assembly error. Furthermore, considering the uncertainty of remanufactured parts, the modified operation index for reassembly workstation is calculated. On the basis of the studies above, the online quality control method of reassembly is put forward by the grading method. Finally, the online quality control method for the axial clearance and gyroscopic moment of remanufactured crankshaft is studied. The results of the case study indicate that the methods can improve the reassembly precision.

1. Introduction

In the present world, the resource depletion and environmental disruption have seriously influenced the rapid development of manufacturing industry. Application and promotion of remanufacturing is one of the most optimal approaches to solve these problems, which have become an important technology for the realization of sustainable development and ecological civilization (Xu, 2007). According to statistics, the global remanufacturing industry output is already more than $100 billion in 2005. In recent years, the global remanufacturing industry average annual growth rate reached 10%, and it is expected to reach $250 billion in 2015. However, there are two contradictions existing in remanufacturing engineering. For one thing, the abundant resource for remanufacturing is available, while the scale of remanufacturing industry is small. For another, the remanufactured product is low-carbon and environmentally friendly, but the quality could not meet customer requirement and market demand (Gönsch, 2015; Mitra, 2016). Therefore, it is crucial for the scale development of remanufacturing industry to guarantee the quality of remanufactured product not lower than that of the original.

Evidence from eBay shown that they are positively correlated the quality and the market prices of remanufactured, used and new items (Neto et al., 2016). The consumers value remanufactured products less than new products (Debo et al., 2005). The quality of remanufactured products can't meet consumers' expectation is the bottle-neck for the scale development of remanufacturing industry. Reassembly process quality control is one of the key links to guarantee the quality of remanufactured product (Liu et al., 2015). It decides the ultimate quality and performance of remanufactured product. Therefore, the online quality dynamical control has become a problem to be solved in reassembly quality control theory and method which is influenced by uncertain, nonlinear and dynamic environment.

To ensure the quality of remanufactured product not lower than the original one, scholars at home and abroad have carried on deep exploration in remanufacturing. Such as nondestructively disassembling, remanufacturing mobile additive and its verification (Xu et al., 2013; Binshi et al., 2012), life prediction of remanufactured parts (Du et al., 2012), active remanufacturing (Liu et al., 2013), development obstacles for remanufactured enterprises (Dou et al., 2014; Tian et al., 2014), and remanufacturing technology assessment (Li et al., 2014; Jiang et al., 2014). The study in reassembly quality is as follows:

In remanufacturing quality management: Mark Ferguson et al. from Georgia Institute of Technology research the value of quality

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classification in reassembly process, and present a greedy heuristic algorithm to compute the optimal solution (Ferguson et al., 2009). Based on fuzzy analytic hierarchy process, a quality evaluation model is raised to quantify the reusability of recycle wheel loader parts by Jun Zhou (Zhou et al., 2012). And they develop a recycling process management system to strengthen the system administration. From the perspective of quality improvement, product lifecycle and quality loop, Chen put forward remanufactured product quality continuous improvement method based on generalized Product Multi-Life Cycle (Chen et al., 2007). Aiming at uncertain problems of parts reprocessing route and reprocessing time, an open-loop queuing network model for parts reprocessing system is established, and parts quality calibration method is proposed by Tang X. from Southeast University (Tang et al., 2011). They also explore the influence of parts quality uncertainty to its reprocessing time. Shen W talked the air tightness of remanufactured engines' cylinder block and head as the research target and proposes a quality control method based on the Jacobian-torsor model for reassembly (Shen et al., 2015). Through analyzing product key factor on air tightness of remanufactured engine cylinder head, an uncertainty measurement model is constructed. (Ge et al., 2014).

In reassembly strategy: Jin X et al. from University of Michigan explore the modular recombination optimizing strategy when the quality of recycle product is uncertainty, and the requirement of customers for recombination product is diversity. They also build the product recombination optimum control strategy with variable quality (Jin et al., 2013). An optimal recycling and remanufacturing production strategy for hybrid manufacturing/remanufacturing system with different quality level parts is researched by Cai X and Lai M from The Chinese University of Hong Kong (Cai et al., 2014). Considering the uncertainty of recycled product's quality, Su Chun from Southeast University studies the buffer allocation problem of hybrid manufacturing/remanufacturing (Su and Xu, 2014). On the basis of classification matching and entropy model, Liu M put forward the reassembly control strategy on analyzing the uncertainty factors of reassembly (Liu et al., 2014a,b).

On analyzing the research achievement above, research status and its limitation at home and abroad are displayed in the following aspects:

① In remanufacturing quality management, existing studies are more likely to conduct exploration on quality grading, product multi-Life cycle and quality house. Researches that aim at reassembly process quality control are relative poor.
② In the aspect of reassembly strategy, the current literature are mainly focus on matching method of remanufactured parts with different quality grade. And through recognize, dispose and optimize the uncertain factors during reassembly process to promote the quality of reassembly. However, fewer studies has been carried on reassembly process parameter optimization.

Aiming at the research situation, this paper put forward the reassembly online quality control method based on state space model. Its goal is to ensure the quality of reassembly influenced by uncertain, nonlinear and dynamic environment, and improve the efficiency of resource utilization of remanufacturing assembly. Meanwhile, the effectiveness and feasibility is proofed by the case study to provide theory support in guaranteeing the quality of remanufactured product. The method is to enhance the core competitiveness of remanufacturing business.

The structure of the paper is organized as follows. The status of remanufacturing assembly quality is introduced in Section 1. The characteristic of reassembly is analyzed in Section 2. Section 3 studies state space model for reassembly error transmission. Section 4 presents this method in the reassembly process control of remanufactured crankshaft to verify the feasibility and validity. The summarization and outlooks of paper are illustrated in Section 5.

2. Characteristic analysis of reassembly

Remanufactured product is a hybrid structure assembly which consists of reused parts, remanufactured parts and new parts. According to certain assemble sequence to reach several technical requirements. The characteristics of reassembly are as follows:

(1) Quality attributes uncertainty of remanufactured parts

There are two kind of remanufactured parts. One is the part that through mechanical processing technology such as grinding, polishing, burnishing and revising. The quality attributes (including measurement, fatigue, longevity and strength) of this part are worse than that of the original one. Another is the part that via remanufacturing remediation technology (like brush plating, resistance fusion welding, plasma spray and laser cladding) and mechanical processing remediation. The quality attributes (including measurement, fatigue, longevity and strength) of this part are better than that of new parts. Shape change and performance change of this remanufactured parts with multiple heterogeneous materials-coating layer has become the key point that affect the reliability of remanufactured product.

(2) Uncertainty of reassembly process

Because of the randomness in remanufactured parts' assembly-line reaching time, quantity and quality, the dispersion degree of assembly shop logistics time-varying interval is bigger, the punctuality control ability is lower, and the range of assembly workstation production rate is enlarged than that of the traditional manufacturing. The problems above have contributed to the increase of reassembly plan and scheduling, thus accelerating the difficulty in the validity of reassembly information.

(3) Uncertainty of reassembly control

Compare with traditional assembly process, there are differences in reassembly quality attribute and quality control point because of the differences in remanufactured parts' type, quantity and quality. And there are more changes during formulation, transmission, fusion and coupling of reassembly error. Therefore, it is difficult to unify the reassembly control and the original assembly control. To guarantee the reliability of remanufactured product quality, we should take corresponding quality control method according to the characteristics of remanufactured product.

(4) Drastic change of reassembly error

Because of the interaction of multi-field intensity like temperature, pressure and corrosion during reassembly process and work condition, remanufactured parts and reused parts will appear deviation more or less. This deviation is showed as assembly error in specific circumstances, which will reduce the reliability of remanufactured product, and affect the service security of remanufactured product.

(5) Diversity of reassembly scheme

Remanufactured product is consists of remanufactured parts, reused parts and new parts. The quantity and type of