A Unified Methodology for Variation Management and Reduction in Multistage Manufacturing Processes

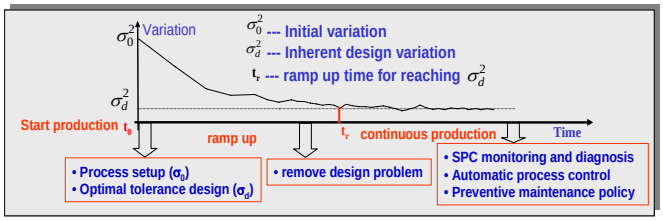
Michigan Engineering
Industrial and Operations Engineering

Data Fusion Lab

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Motivation

- Variation reduction is critical for improving product quality, increasing process productivity, and reducing manufacturing cost.
- Variation reduction efforts aim to reduce initial process variation, process ramp up time, and maintain the mass product at a minimal inherent variation level.
- In multistage Manufacturing Processes (MMPs), variation reduction is a challenging research due to the complexity of variation propagation among stations and the interactions between workpiece quality and tool reliability.



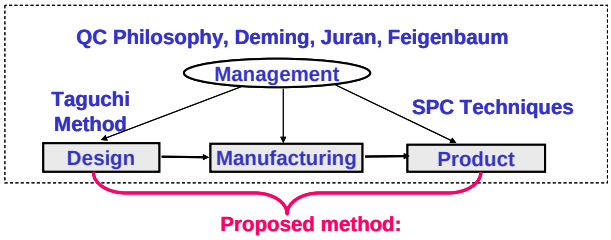
State-of-the-Art

(1) In the design phase, robust design based on response surface modeling is usually not effective in a MMP due to the complexity of DOE design with many interaction factors among stations.

(2) variation simulation analysis (VSA), based on product-oriented tolerance stack-up models and Monte Carol simulation, is only suitable for design evaluation, but cannot lead to an optimal design and tolerance synthesis (or allocation).

(3) In the manufacturing phase, the conventional Statistical Process Control (SPC) oriented techniques are mainly reactive, rather than proactive, to process changes, thus requiring time-consuming efforts in root cause identification.

(4) The existing tool reliability analysis and preventive maintenance decision do not consider the interactions between the propagated workpiece quality variation and tool reliability due to the lack of a model to understand the variation propagation in a MMP.

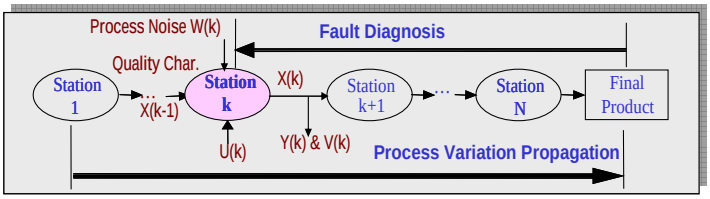


Objectives and new features

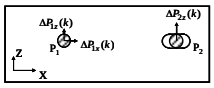
This CAREER plan is to develop, implement, and teach a unified, systematic, and generic methodology for variation management and reduction of multistage manufacturing processes (MMPs), which can accommodate:

- **analytical** (rather than empirical) modeling of MMP variation and its propagation;
- **synthesis** and optimization (rather than analysis and evaluation) of product/process tolerance in design;
- **root cause identification** (rather than change detection) of process variation in manufacturing;
- **prognostics** (rather than defect inspection) for defect prevention throughout the manufacturing lifetime.

Proposed approaches



$$X(k)=A(k)\,X(k-1)+B(k)\,U(k)+W(k)$$
$$Y(k)=C(k)\,X(k)+V(k)$$

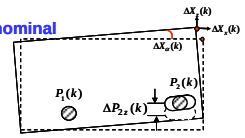


1. **Input Vector U(k): tooling tolerance and fault error**

$$U(k)=[\Delta P_{1x}(k),\ \Delta P_{1z}(k),\ \Delta P_{2x}(k)]^T$$

2. **State vector X(k): part dimensional deviation from nominal**

$$X(k)=[\Delta X_x(k),\ \Delta X_z(k),\ \Delta X_\alpha(k)]^T$$

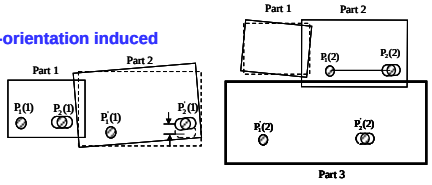


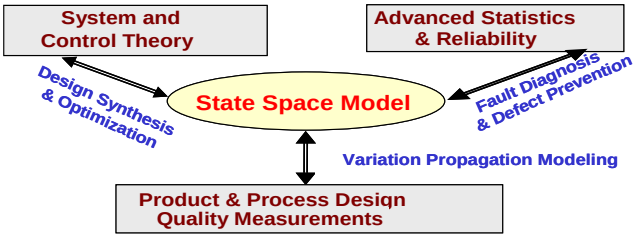
3. **Input matrix: tooling error induced part error**

$$U(k)\xrightarrow{B(k)}X(k)$$

4. **Dynamic Matrix: locator re-orientation induced propagation error**

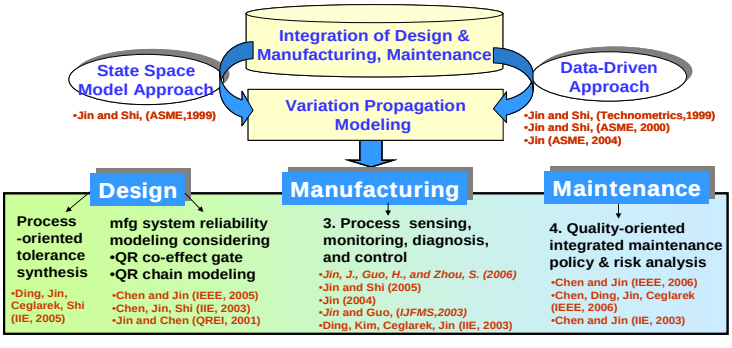
$$X(k-1)\xrightarrow{A(k-1)}X(k)$$





Accomplishments

Related Research Topics and Achievements for Unified Methodology Development



Impact of Work

- Develop a science base to systematically model and analyze variation propagation for variation reduction and management in MMPs.
- Have broad potential applications in multistage assembly, transfer/progressive die stamping, and semiconductor manufacturing.

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