Simulation-Based Development of Industrial Robots

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Outline

- ABB
- Why Simulation-Based Development?
- Structure Optimization
  - Two examples of topology optimization
  - Sensitivity w.r.t. loads
  - Dynamic behavior
- Concluding Remarks
ABB Ltd: Divisional Structure and Portfolio

- **Power Products**
  - Sales: $8.7 billion
  - Transformers, high- and medium-voltage switchgear, breakers, automation relays

- **Power Systems**
  - Sales: $5.2 billion
  - Substations, FACTS, HVDC, HVDC Light, power plant & network automation

- **Automation Products**
  - Sales: $7.8 billion
  - Low-voltage products, drives, motors, power electronics, and instrumentation

- **Process Automation**
  - Sales: $5.8 billion
  - Control systems and application-specific automation solutions for process industries

- **Robotics**
  - Sales: $1.3 billion
  - Robots, peripheral devices and modular manufacturing solutions for industry

- **ABB: A $29 billion company with 112000 employees**

- **Integrated solutions for power distribution, productivity and energy efficiency**

* 2007 revenues
Why Simulation Based Development?

Major motivations:

- Shorten time-to-market
- Increase reliability
- Evaluate robot kinematics/dynamics
- To utilize components and material more effectively

Structural optimization
Why Simulation Based Development?

Example of development of ABB Robots

ABB Robot (2001)
- Payload 225kg
- Reach 2.55m
- Weight 1700kg

ABB Robot (2007)
- Payload 235kg
- Reach 2.55m
- Weight 1300kg
- More accurate (sophisticated control)
Structural Optimization

Important aspects on structural parts of a robot

- **Cost**
  - Direct cost of manufacturing (amount of material, complexity to manufacture, geometry tolerances, …)

- **Weight**
  - High weight increases requirement on drive train (higher mass/inertia of robot itself gives less performance per cost)

- **Stiffness**
  - Stiffness affects robot dynamic performance (vibrations, damping time, absolute accuracy, …)
Some design criteria

- Cables running through hole in the center to lower arm via electronics box
- Separate part to hold balancing cylinder to limit size of component
- Bending/rotation of balancing cylinder limited to ensure functionality
- …and more
Structural Optimization Examples – Topology Optimization Setup of Stand

- Design volume gradually refined to find e.g. optimal placement of motor
- Consider multiple load cases simultaneously to yield robust design
- Optimization constraints: draw, min/maxdim, stress
- Back-side supported balancing cylinder (back arm in separate model)
Structural Optimization Examples – Optimization Result and Realization of Stand

- About 20% saved material
- Compliance about 80% of original for design load cases
- Feasible design due to optimization constraints
Structural Optimization Examples –
Topology Optimization Results for Lower Arm

- Original design
- Use topology optimization to determine optimal coreless design

Final Result:
Lower Arm
Structural Optimization Examples – Realization and Properties of Lower Arm

- About 20% saved material
- Obvious cost reduction due to core-less design
- Compliance almost twice of original for design load cases!
Optimized shape is specialized on design load cases. Study design w.r.t. probability for “over-loading”:

- Stress histograms computed in chosen regions for large number of cycles
- Found slightly increased probability for “over-loading” of the optimized part as compared to the traditionally designed part
Structural Optimization Examples – Dynamic Behavior of Robot with Open Casting

- The dynamic behavior of the robot is important in many robot applications and must be considered in the design process.

The structural components are part of a system.

Example:
- Flexible multi-body model with topology optimized lower arm.
- The lowest eigenfrequency in point A is decreasing with 10%.
- Also mode shape affected.
Summary and Concluding Remarks

- The requirements on the structural parts of a robot (cost, weight, and stiffness) makes topology optimization suitable.

- Potential weight reduction found using topology optimization, not always accompanied with reduction in stiffness.

- Commercial software (HyperWorks®) for structural optimization may be used in industrial environment with good result and efficiency.
Power and productivity for a better world™
"Product specification” optimization

- Product specification optimization – to make optimal selection of drive train components and balance performance requirements with cost

Identify cost drivers

Select optimal components for given specification

Find optimal cost performance ratio
Why Simulation Based Development?

- Shorten time to market
- Increase reliability
- Evaluate robot kinematics/dynamics
- Increase cost effectiveness

Cost effective – To maximize utilization of components and material
  - Major part of cost determined by drive train – “Product Specification” Optimization
  - Structural parts need to meet cost, stiffness and weight requirements – Structural Optimization
Structural Optimization

- Input to structural optimization is the loads acting on the structure.
- For this study a probabilistic approach is used to calculate the loads.
- Large number of random paths are simulated.
- Acceptable risk level gives load case.