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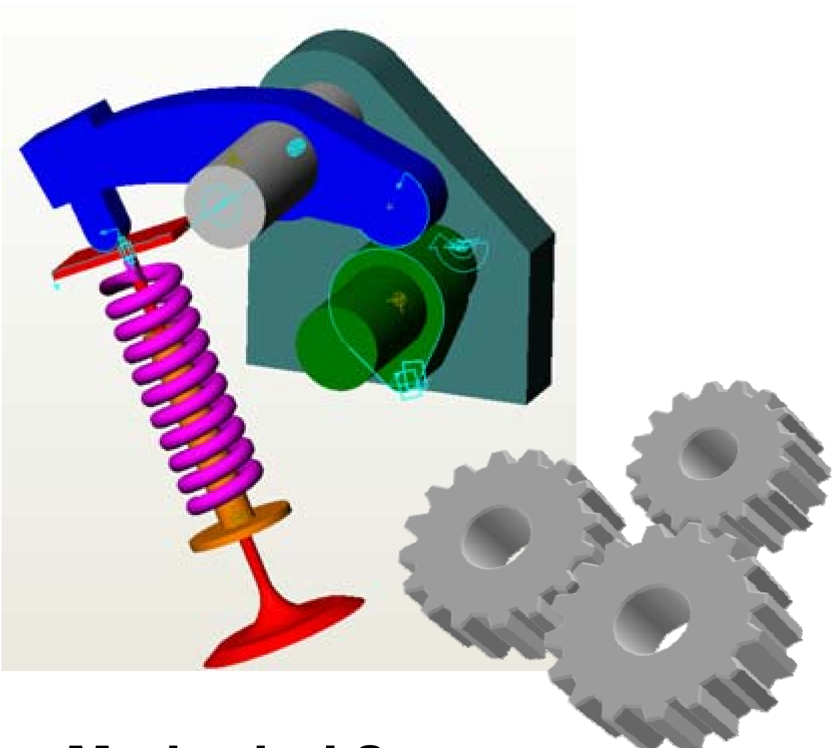
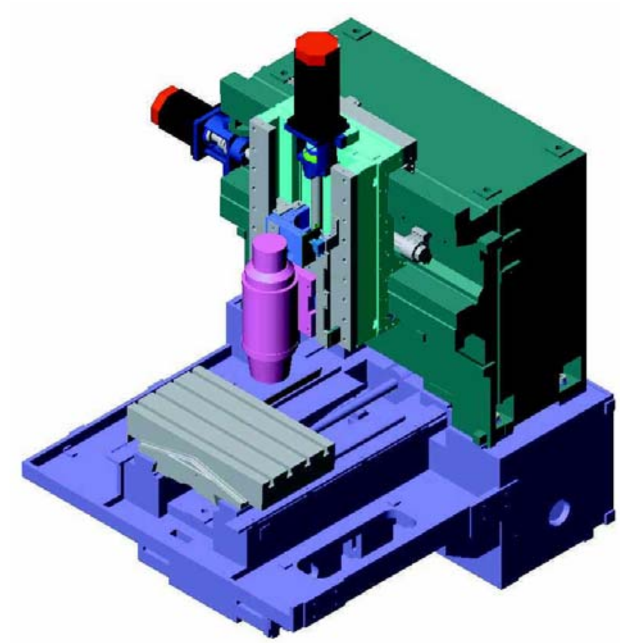
NATIONAL INSTRUMENTS

# Mechatronics Approach and tools for more efficient machine designs

# The Evolution of Machines





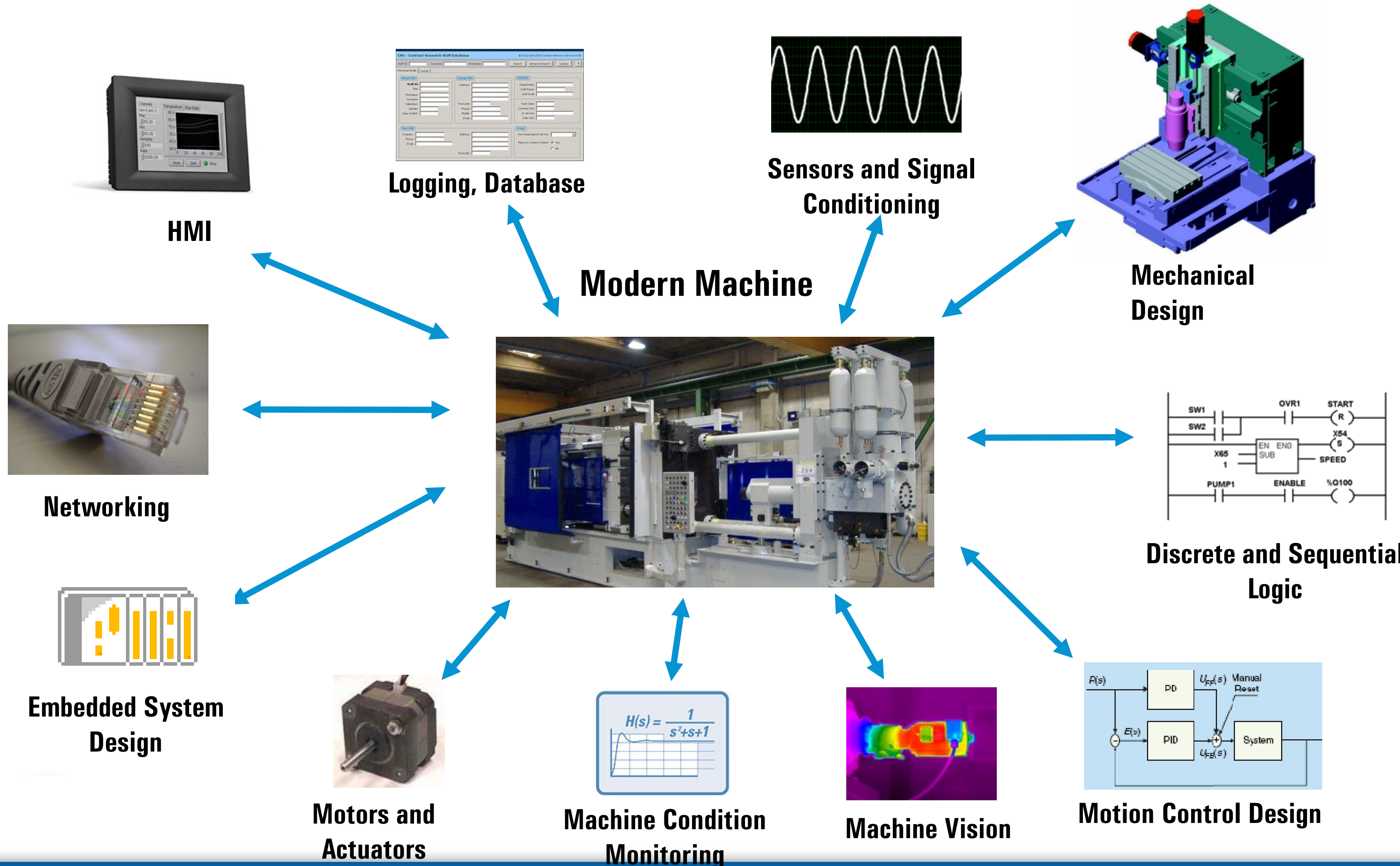
**Mechanical System**

Gears, cams, and limit switches

**Electromechanical System**

Electronic controls,
motor drives

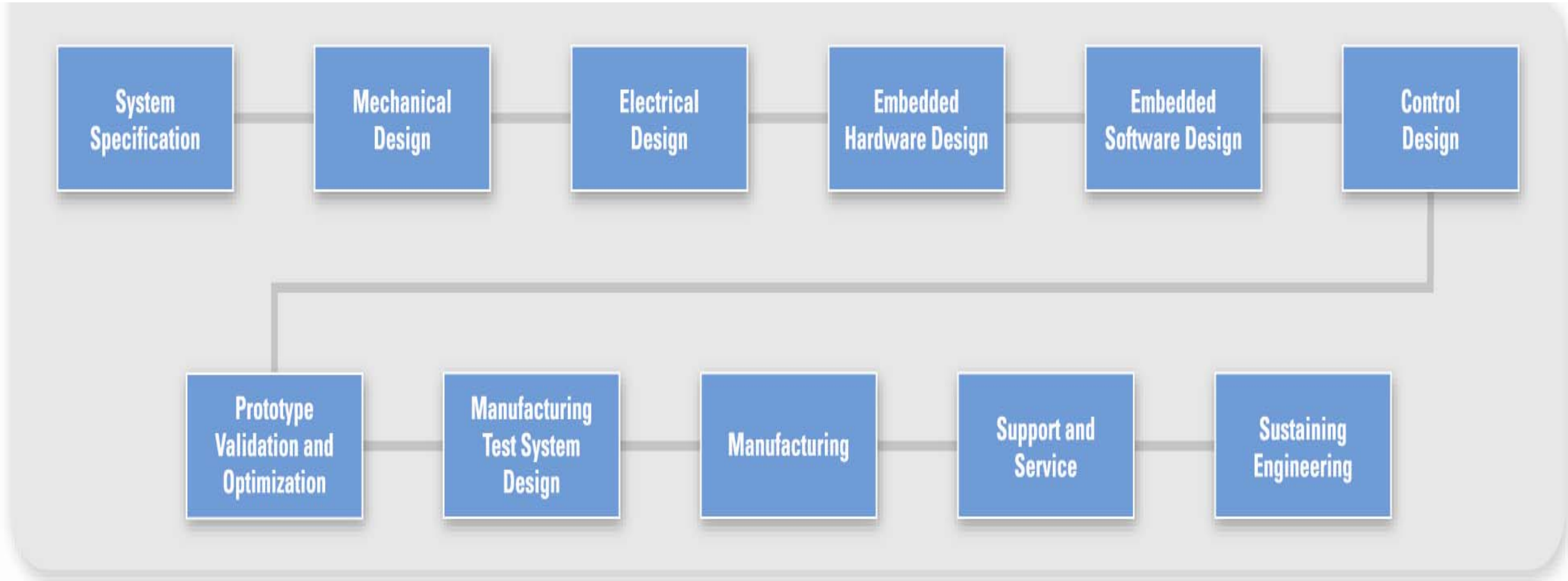
# Modern Machine Builder's Diverse Requirements



# Trends to Reduce Development Time

| | | |
|---|---|---|
| Sequential Design | → | Concurrent Design |
| Physical First Prototype | → | Virtual First Prototype |
| Separate Design Tools | → | Integrated Design Tools |

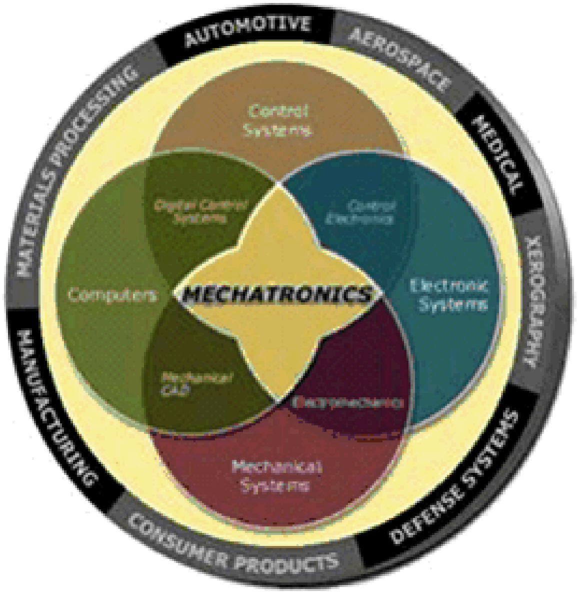
# Traditional Approach to Electromechanical Machine Design




- Poor communication between design groups
- Long development time with high risk
- Poorly optimized design

# Mechatronics

- Mechatronics is a holistic approach to designing machines that combines mechanical, electrical, control and embedded software



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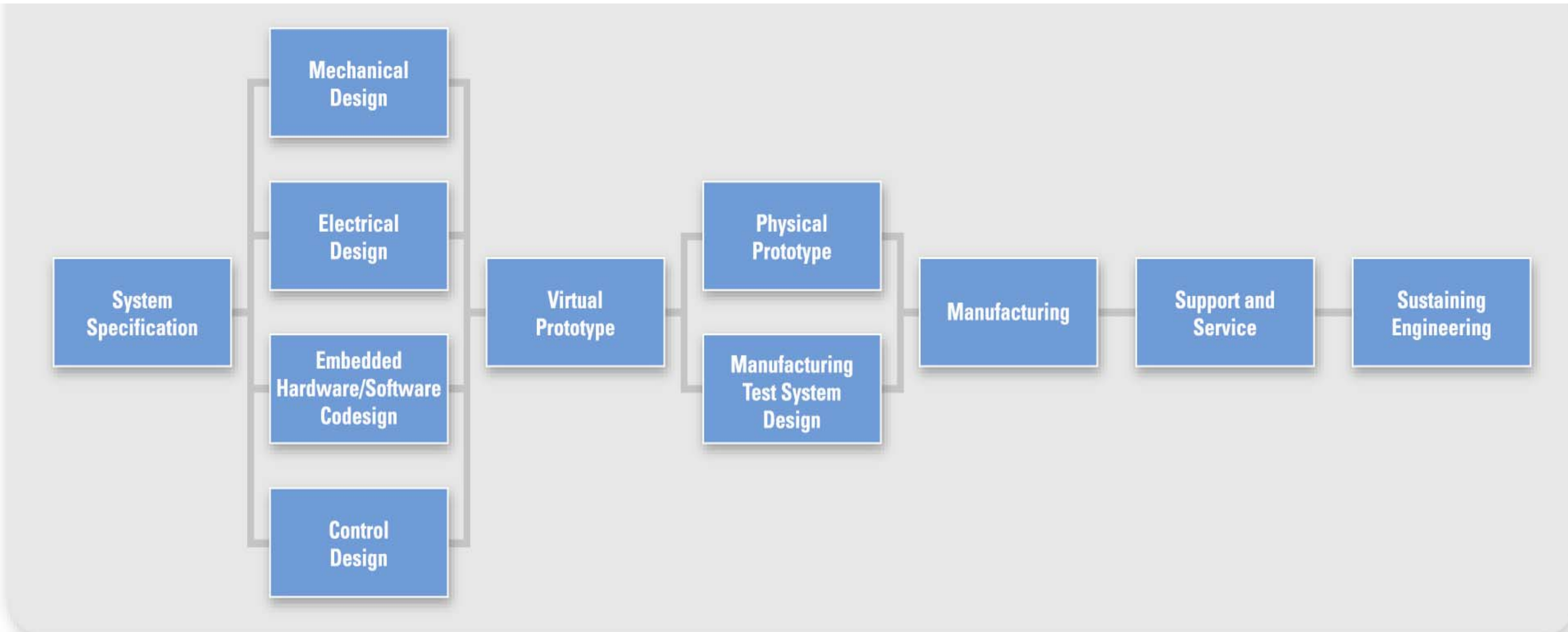
# Mechatronics Approach to Electromechanical Machine Design




- Shorter, lower cost development cycles
- Improved quality, reliability, and performance

# 1. Design Tool Integration

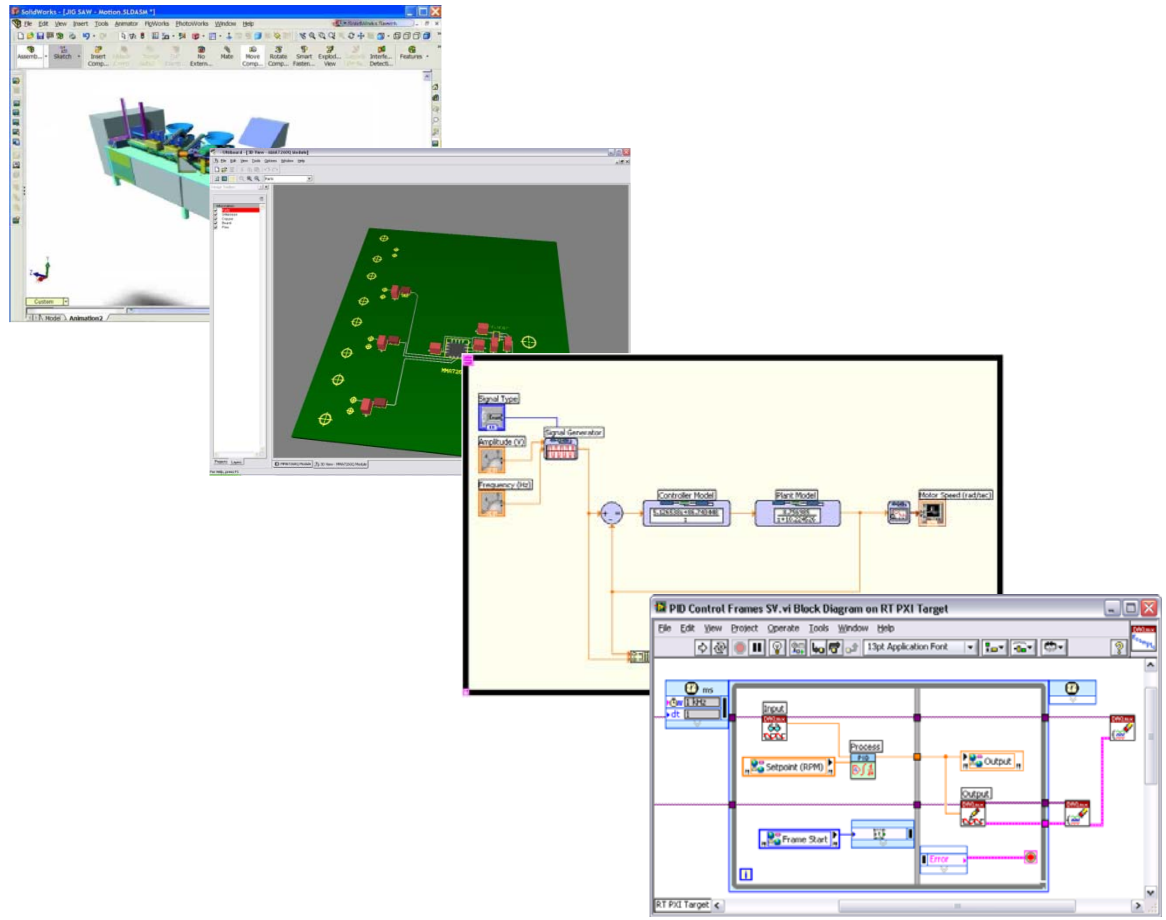
**Mechanical Design**

**Electrical Design**

**Control Design**

**Embedded Design**

**Virtual Prototype (Simulation)**



# Level of Design Tool Integration

- *Ultimate – One design tool for all disciplines*
- Manual – Manually pass data between tools
- Basic – Data transferred via standard file formats
  - Motion profile data as CSV file to CAD
- Advanced – Complete tool automation
  - NI LabVIEW automating SolidWorks through ActiveX

# Open Connectivity to Design Tools

## Mathematics
NI **LabVIEW** Math
The MathWorks, Inc. **MATLAB**®
Maplesoft **Maple**
MathSoft **Mathcad**

## Electrical Design
NI LabVIEW (Motor Sizing)
NI **Multisim**
ORCAD **PSpice**
Ansoft **Designer**

## Control Design
NI **LabVIEW Control Design**
The MathWorks, Inc. **Simulink**®
Dynasim **Dymola**
Plexim **PLECS**

## Embedded Software
NI **LabVIEW** Real-Time/Embedded
Wind River **Workbench**
Analog Devices **VisualDSP++**
Freescale **Code Warrior**
Xilinx **System Generator**

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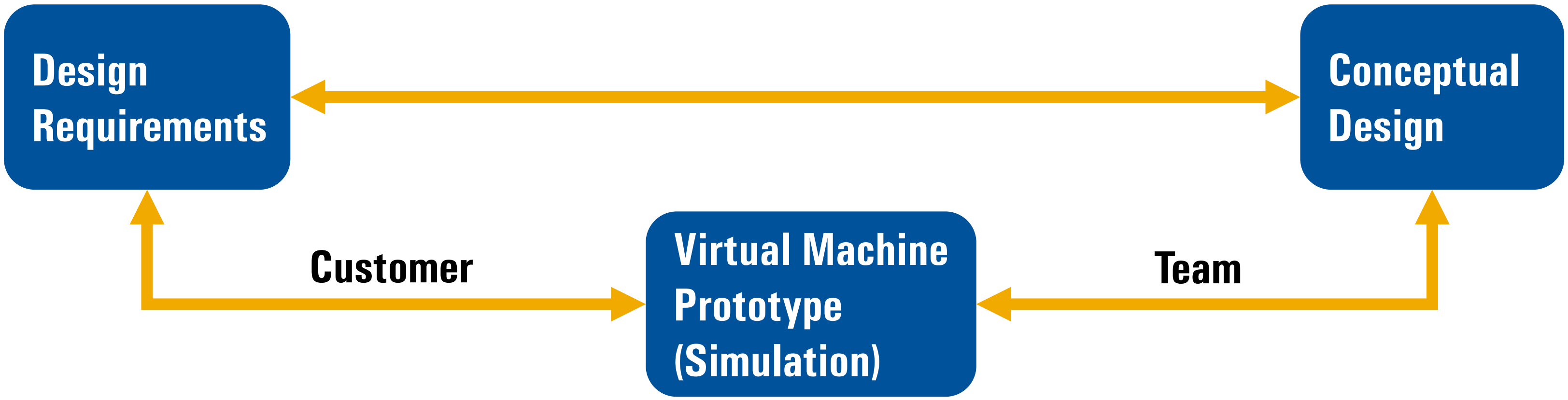
LabVIEW

## Mechanical Design
SolidWorks **SolidWorks**
PTC **Pro/Engineer**
MSC **Nastran** and **Adams**
Autodesk **AutoCAD**

# Virtual Machine Prototyping




Mechanical: *Design visualization*

Electrical: *Motor sizing*

Control: *Verify control logic*

Embedded Software: *Easy implementation*

# Mechanical Design Challenges

## Challenge: Understanding the requirements

## *Solution: Electromechanical simulation*

- *Use control logic to visualize the working machine.*

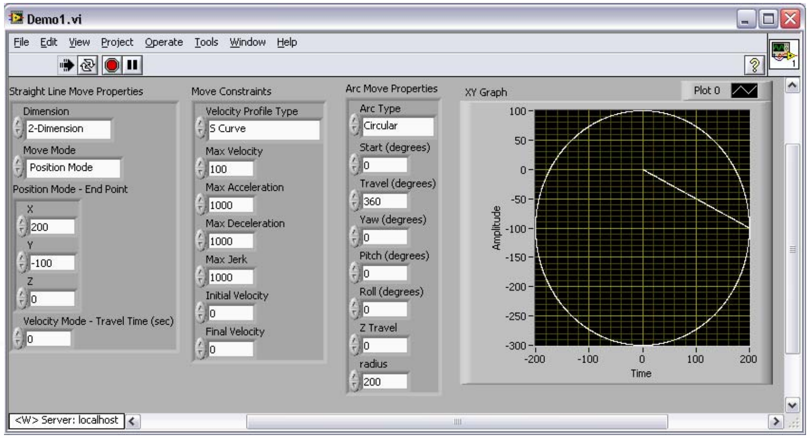
## *Benefits:*

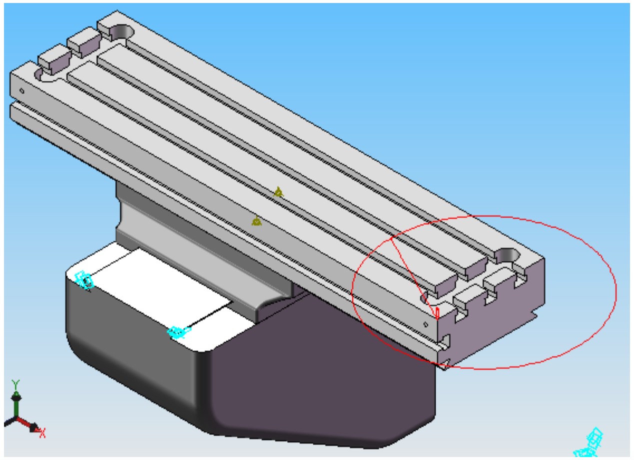
✓ Improved customer communication
  - Confidence builder: showing proof of concept
  - Competitive advantage in the bidding process

✓ Improved design team communication
  - Refining design specifications
  - Evaluating high-level architectural design

# Electromechanical Simulation Steps

1. Determine machine logic
2. Generate profile data with virtual prototyping software
3. Send to 3D design tool
4. Use CAD tool to animate machine functionality

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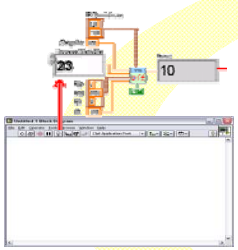
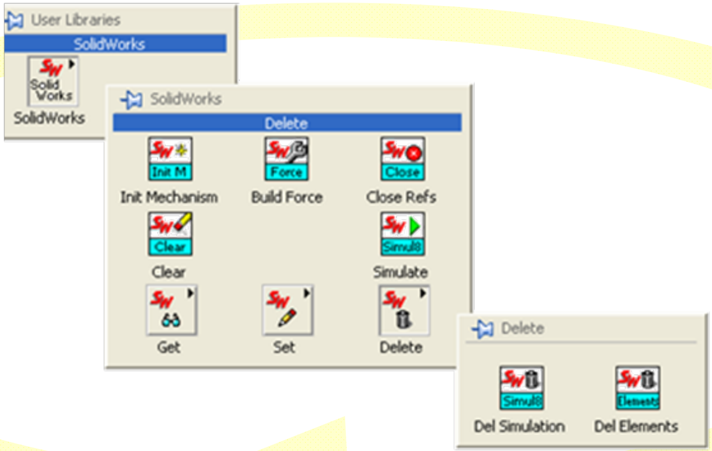
# Software Tools

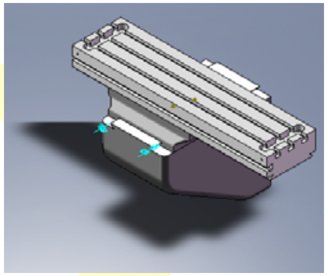
- SolidWorks Professional
  - COSMOSMotion
- LabVIEW Professional
  - Free SolidWorks/LabVIEW ActiveX Interface VIs
  - NI Motion Assistant




LabVIEW




SolidWorks – LabVIEW
Interface Functions



SolidWorks



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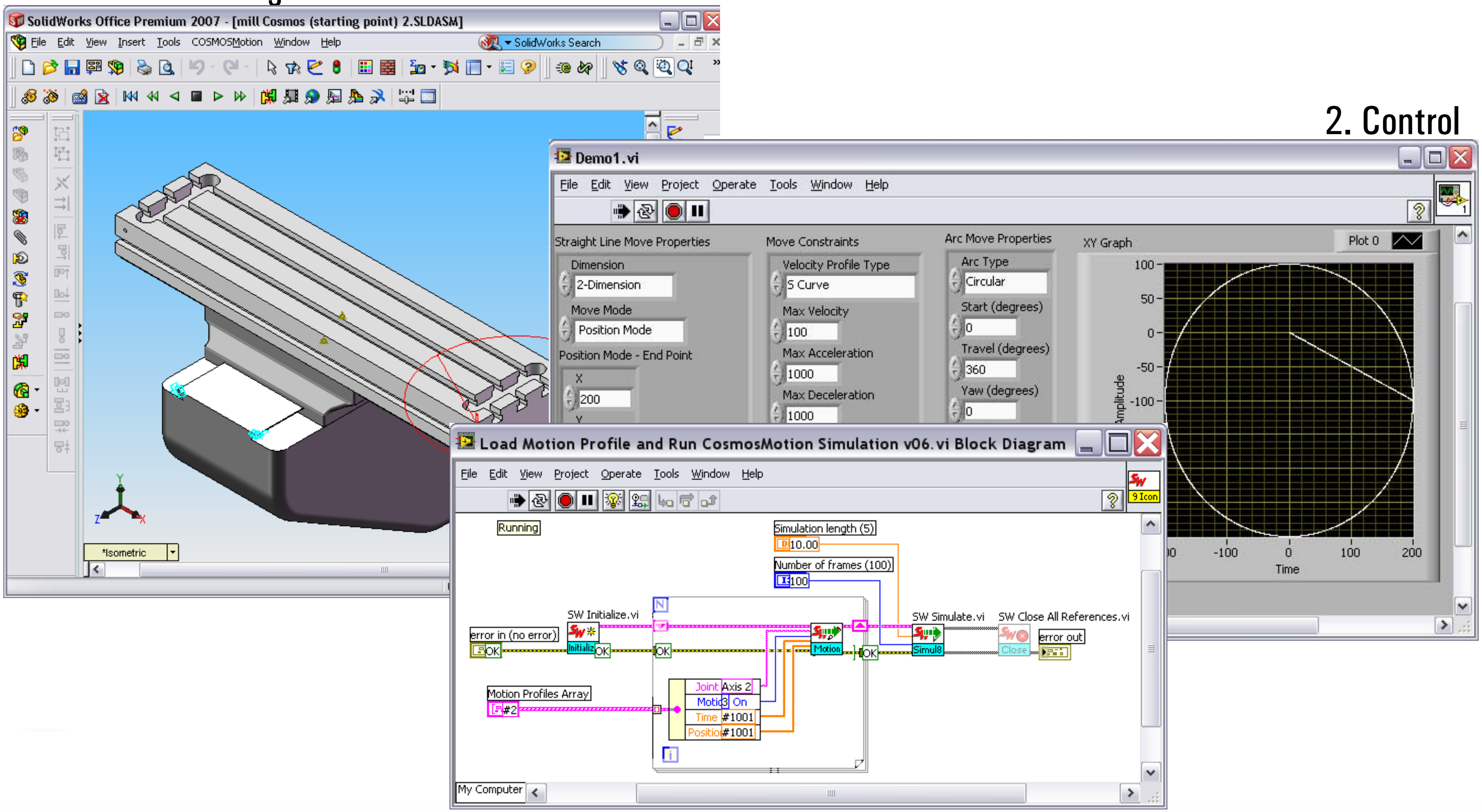
# Demo: LabVIEW Automates Design Visualization

1. Mechanical Design

2. Control



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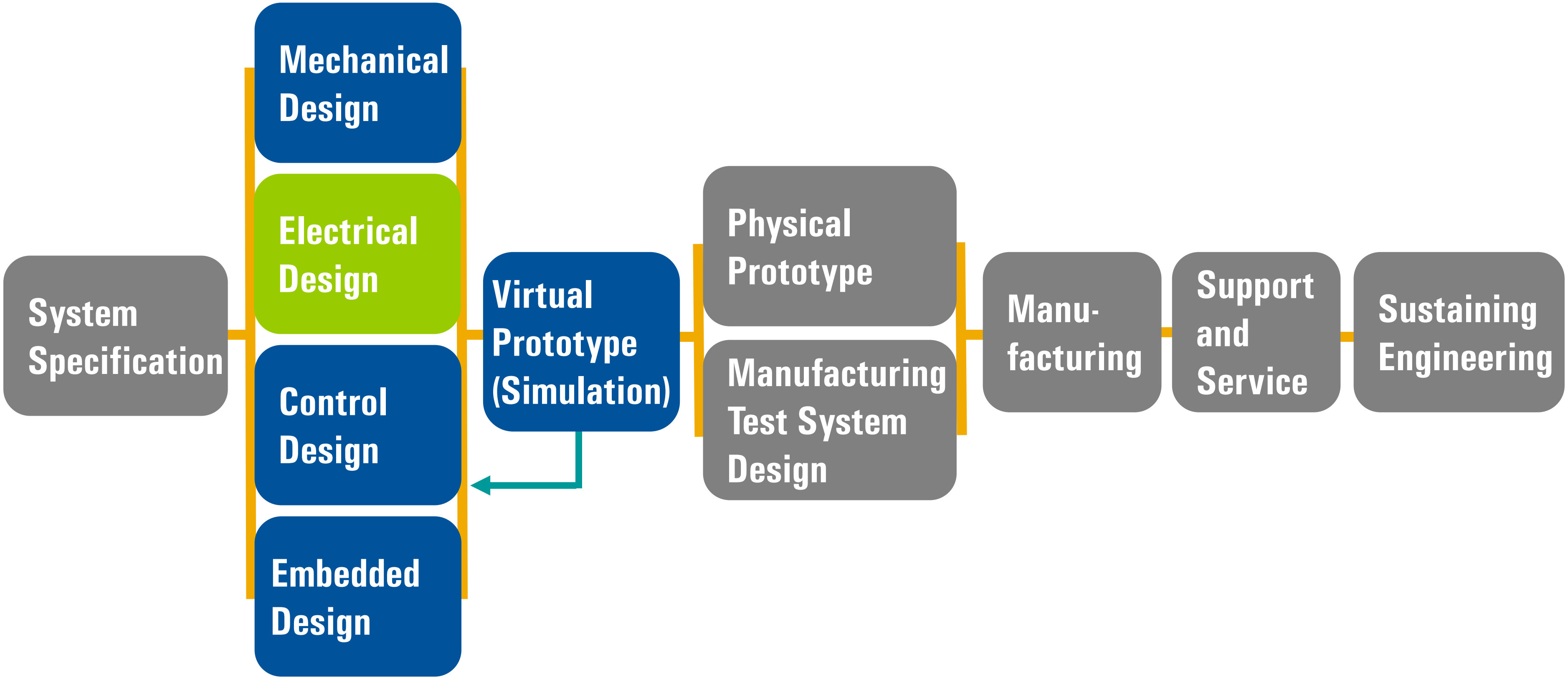
# Electrical Design



# Electrical Design Challenges

**Challenge:** Specifying correct motor size

- Type (AC/DC, brushed, and so on)
- Torque versus speed requirements
- Heat dissipation

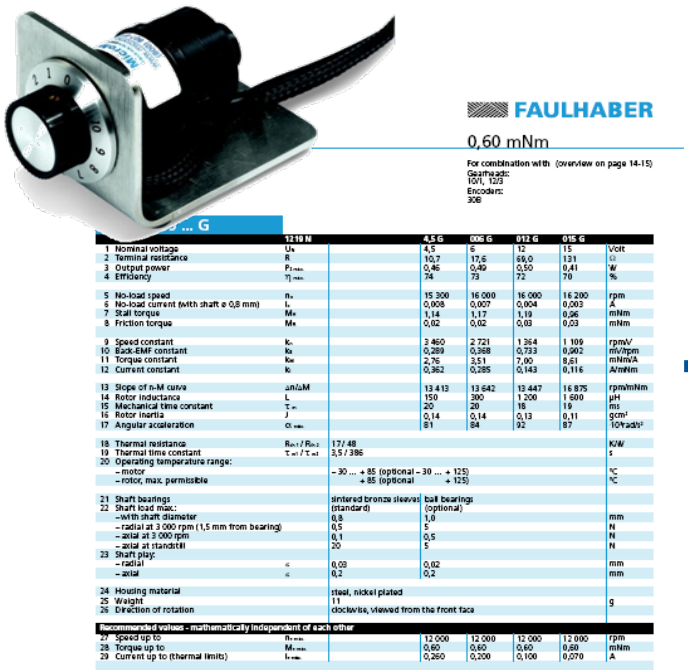
***Solution: Virtual motor sizing***

***Benefits:***

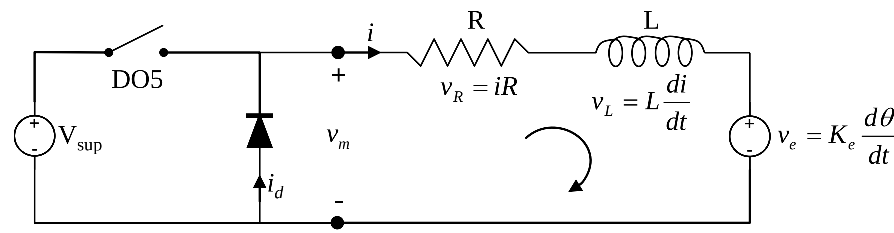
✓ Apply motor sizing principles interactively
✓ Virtually test various motors

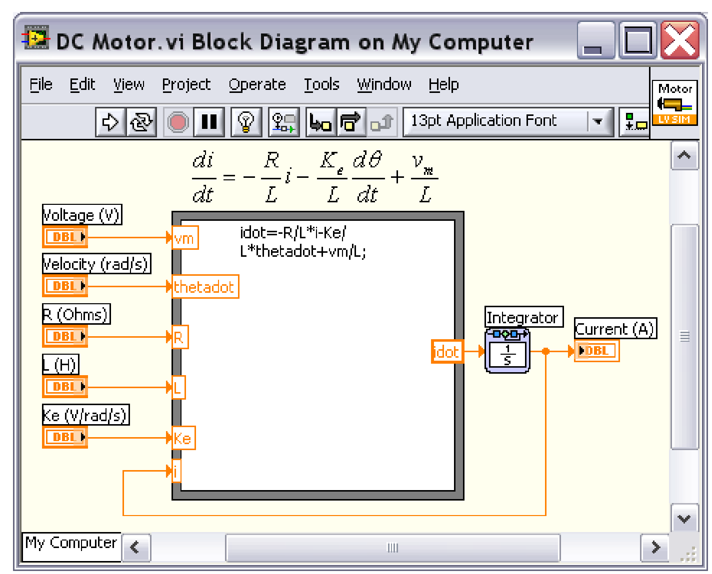
# Virtual DC Motor Sizing

1. Acquire motor specifications from data sheet
2. Simulate motor response to velocity and torque profile from CAD

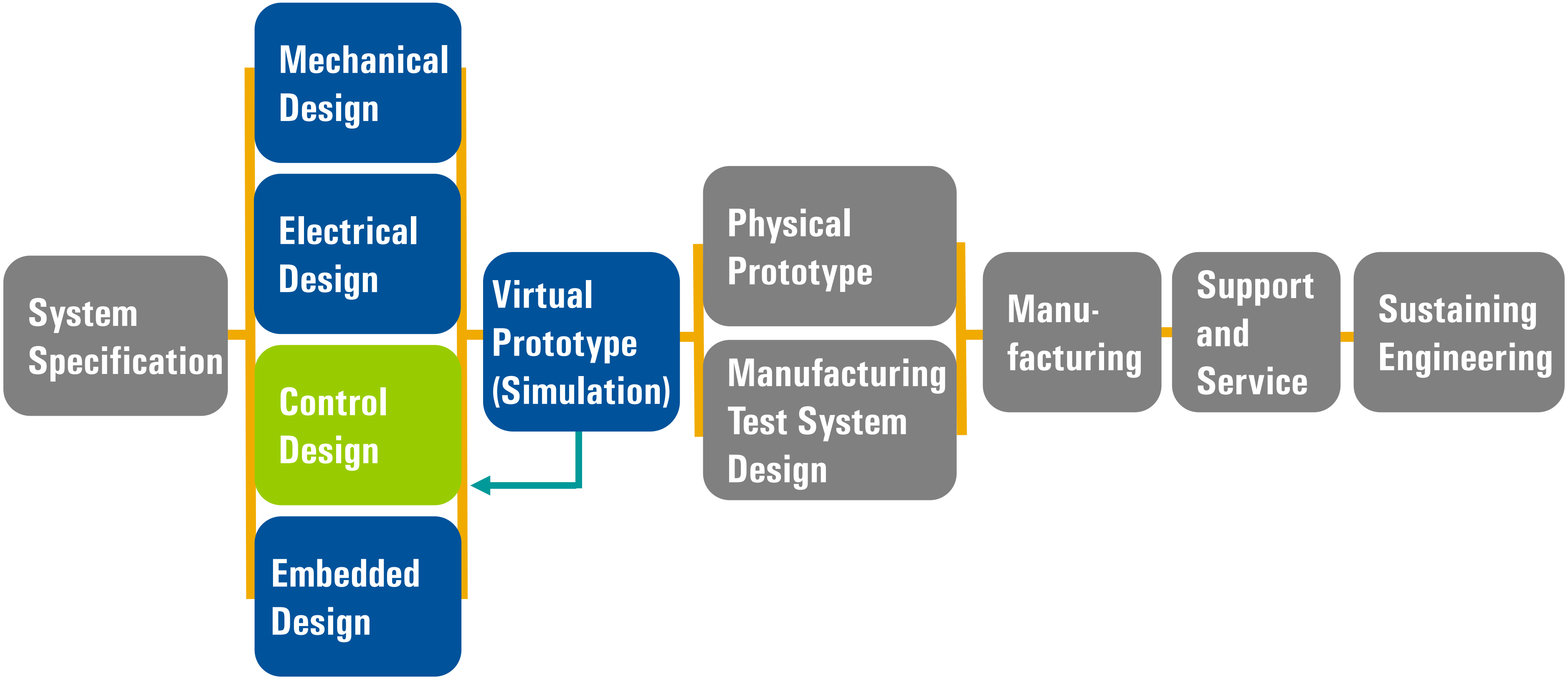



| | | 1219 N | | 4,5 G | 006 G | 012 G | 015 G | |
|---|---|---|---|---|---|---|---|---|
| 1 | Nominal voltage | $U_N$ | | 4,5 | 6 | 12 | 15 | Volt |
| 2 | Terminal resistance | R | | 10,7 | 17,6 | 69,0 | 131 | Ω |
| 3 | Output power | $P_{2\,max.}$ | | 0,46 | 0,49 | 0,50 | 0,41 | W |
| 4 | Efficiency | $\eta_{max.}$ | | 74 | 73 | 72 | 70 | % |
| 5 | No-load speed | $n_0$ | | 15 300 | 16 000 | 16 000 | 16 200 | rpm |
| 6 | No-load current (with shaft ø 0,8 mm) | $I_0$ | | 0,008 | 0,007 | 0,004 | 0,003 | A |
| 7 | Stall torque | $M_H$ | | 1,14 | 1,17 | 1,19 | 0,96 | mNm |
| 8 | Friction torque | $M_R$ | | 0,02 | 0,02 | 0,03 | 0,03 | mNm |
| 9 | Speed constant | $k_n$ | | 3 460 | 2 721 | 1 364 | 1 109 | rpm/V |
| 10 | Back-EMF constant | $k_E$ | | 0,289 | 0,368 | 0,733 | 0,902 | mV/rpm |
| 11 | Torque constant | $k_M$ | | 2,76 | 3,51 | 7,00 | 8,61 | mNm/A |
| 12 | Current constant | $k_I$ | | 0,362 | 0,285 | 0,143 | 0,116 | A/mNm |
| 13 | Slope of n-M curve | $\Delta n/\Delta M$ | | 13 413 | 13 642 | 13 447 | 16 875 | rpm/mNm |
| 14 | Rotor inductance | L | | 150 | 300 | 1 200 | 1 600 | µH |
| 15 | Mechanical time constant | $\tau_m$ | | 20 | 20 | 18 | 19 | ms |
| 16 | Rotor inertia | J | | 0,14 | 0,14 | 0,13 | 0,11 | $gcm^2$ |
| 17 | Angular acceleration | $\alpha_{max.}$ | | 81 | 84 | 92 | 87 | $\cdot 10^3 rad/s^2$ |
| 18 | Thermal resistance | $R_{th1} / R_{th2}$ | 17 / 48 | | | | | K/W |
| 19 | Thermal time constant | $\tau_{w1} / \tau_{w2}$ | 3,5 / 386 | | | | | s |
| 20 | Operating temperature range: | | | | | | | |
| | – motor | | – 30 ... + 85 (optional – 30 ... + 125) | | | | | °C |
| | – rotor, max. permissible | | + 85 (optional + 125) | | | | | °C |
| 21 | Shaft bearings | | sintered bronze sleeves (standard) | | ball bearings (optional) | | | |
| 22 | Shaft load max.: | | | | | | | |
| | – with shaft diameter | | 0,8 | | 1,0 | | | mm |
| | – radial at 3 000 rpm (1,5 mm from bearing) | | 0,5 | | 5 | | | N |
| | – axial at 3 000 rpm | | 0,1 | | 0,5 | | | N |
| | – axial at standstill | | 20 | | 5 | | | N |
| 23 | Shaft play: | | | | | | | |
| | – radial | ≤ | 0,03 | | 0,02 | | | mm |
| | – axial | ≤ | 0,2 | | 0,2 | | | mm |
| 24 | Housing material | | steel, nickel plated | | | | | |
| 25 | Weight | | 11 | | | | | g |
| 26 | Direction of rotation | | clockwise, viewed from the front face | | | | | |
| | **Recommended values - mathematically independent of each other** | | | | | | | |
| 27 | Speed up to | $n_{e\,max.}$ | | 12 000 | 12 000 | 12 000 | 12 000 | rpm |
| 28 | Torque up to | $M_{e\,max.}$ | | 0,60 | 0,60 | 0,60 | 0,60 | mNm |
| 29 | Current up to (thermal limits) | $I_{e\,max.}$ | | 0,260 | 0,200 | 0,100 | 0,070 | A |



# Control Design



# Control Design Challenges

**Challenges:**

- Software development in critical path
- Physical prototype needed to test control algorithm

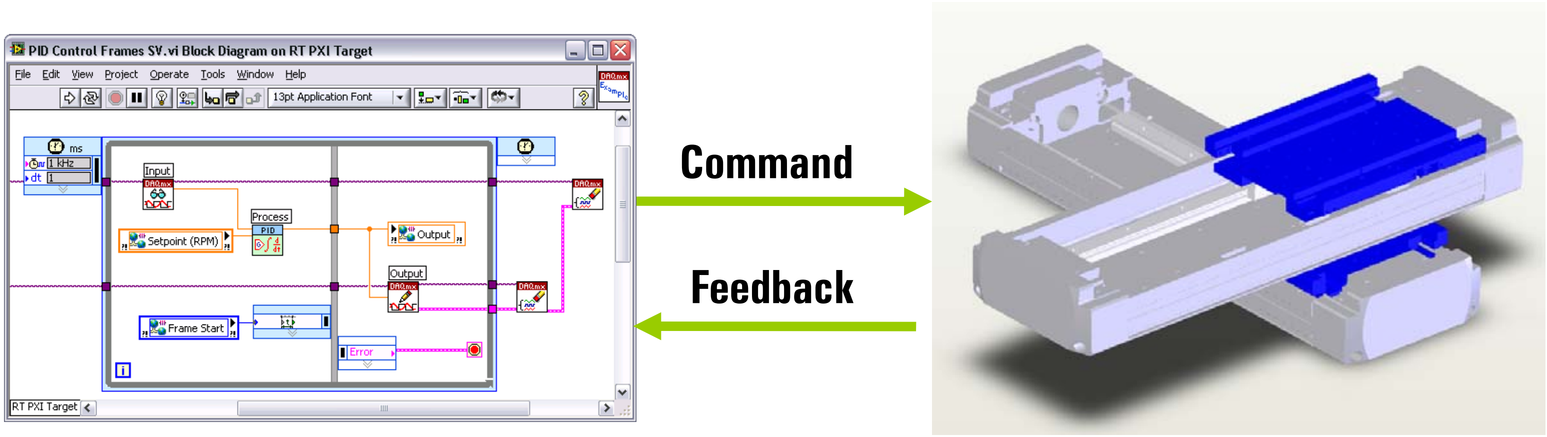
**Solution:** Develop and test control algorithm on virtual model

**Benefits:**

- ✓ Get head start on control development
- ✓ Refine control strategy before physical prototyping
- ✓ Detect interferences and resonance

# Integrating Control and Mechanical Design

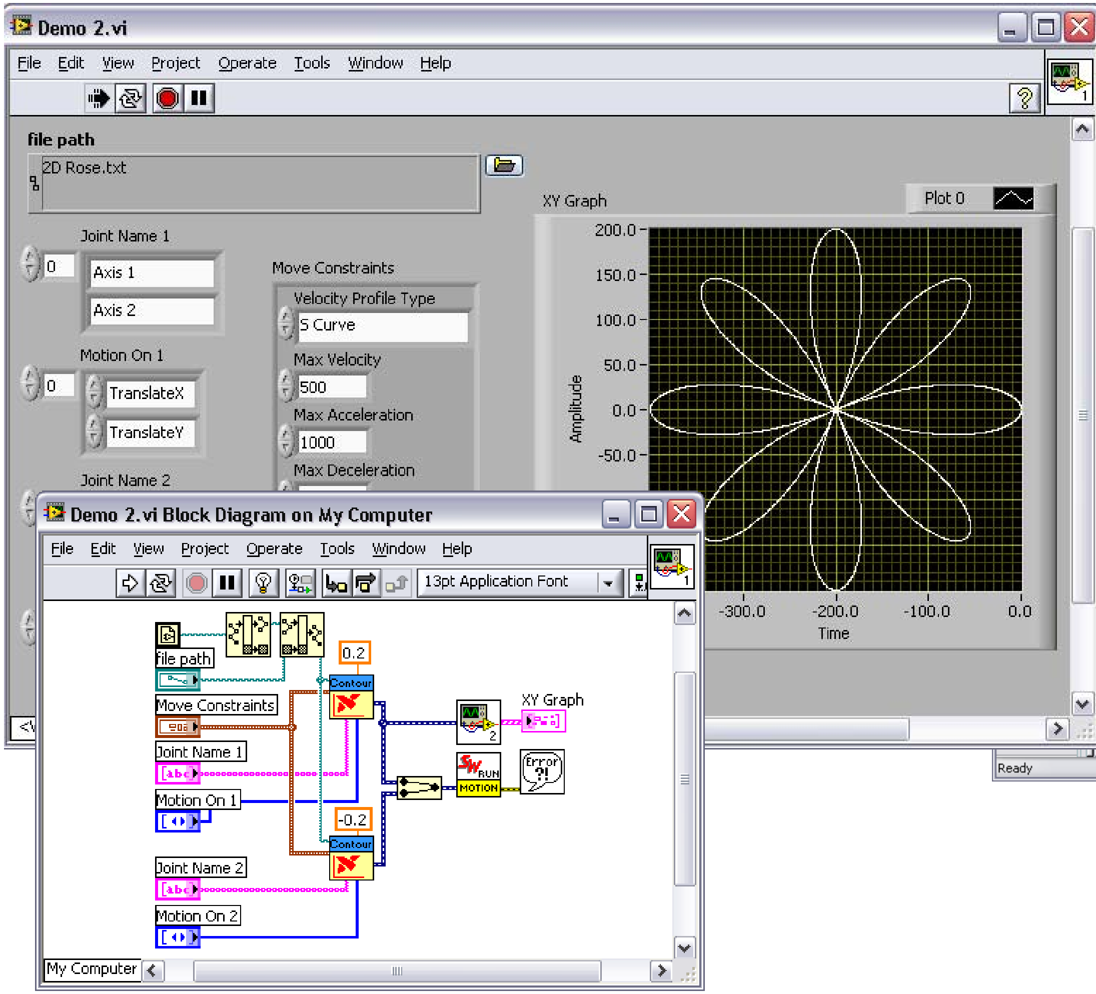
## Control Software        Simulation



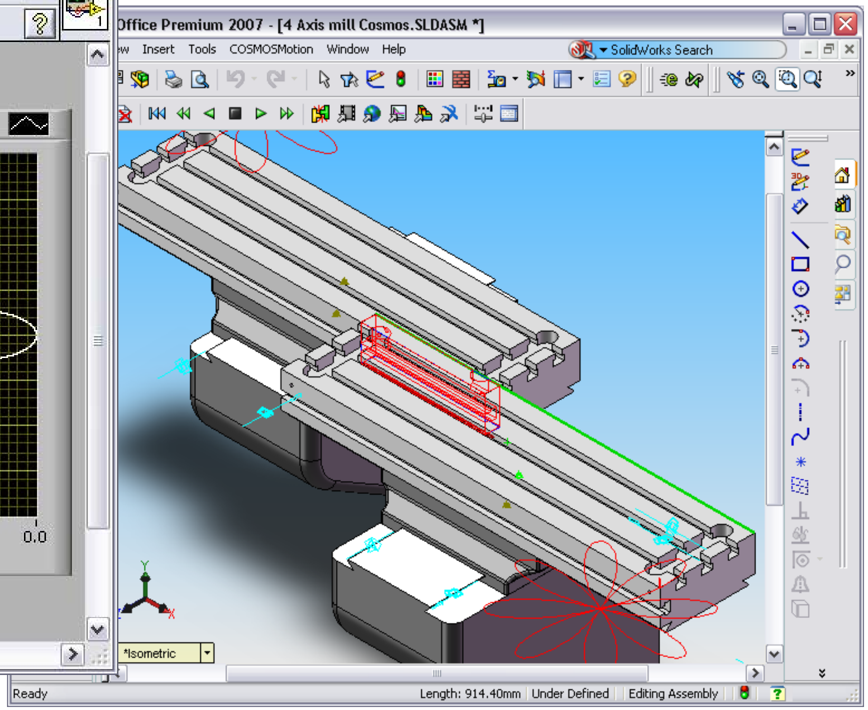

1. Develop machine control logic
2. Animate model and identify potential issues

# Demo: Interference Detection

1. Motion Profile




2. Interference Detection



# Control Design Challenges

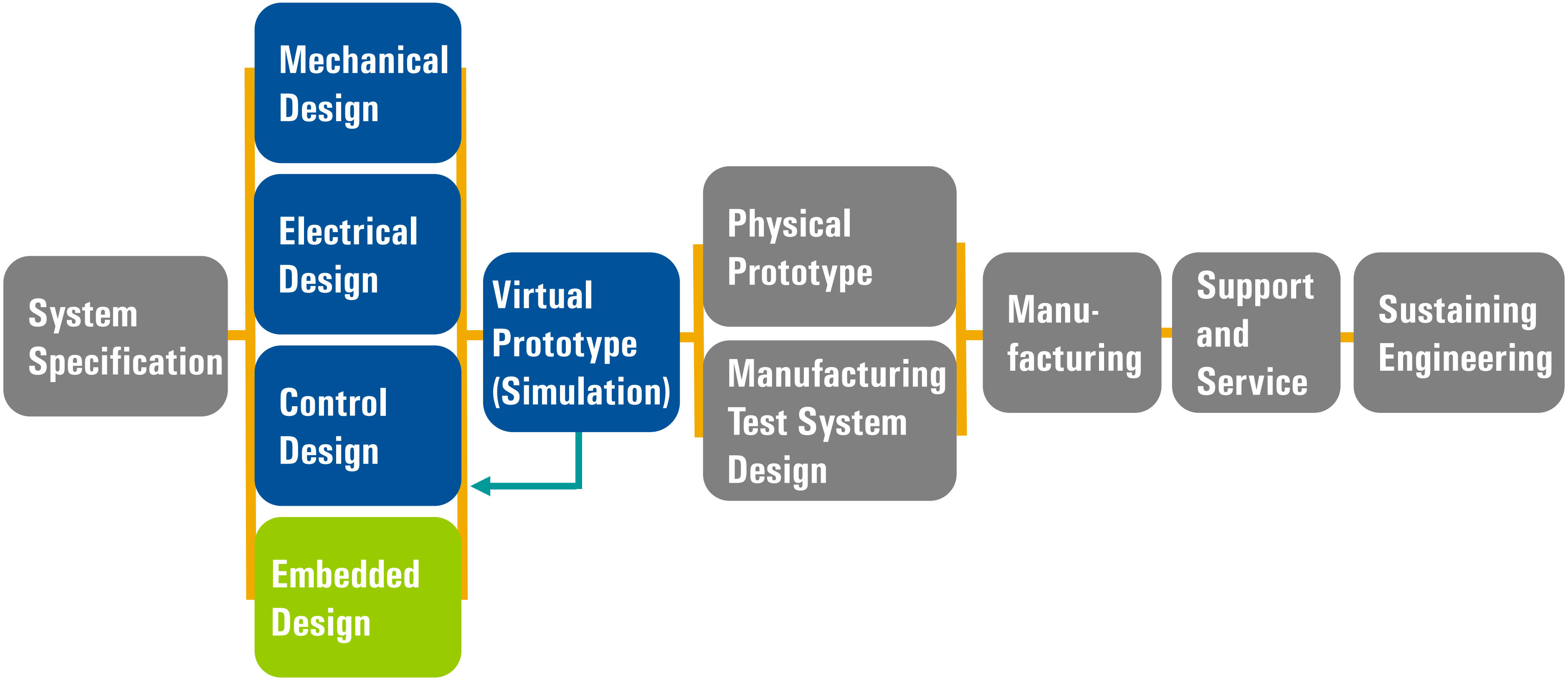
**Challenge:** Finding an alternative for conventional PID, which is not tuned for all machine states

**Solution:** Using advanced PID or other control algorithms

**Benefits:**

- ✓ Achieve more precise control
- ✓ Choose from PID, advanced PID, and model-based and model-predictive control
- ✓ Reduce wear and tear on machine parts

# Embedded Software Design



# Embedded Software Design Challenges

**Challenge:** Implementing embedded algorithms

- Rewriting code for hardware platform
- Flexibility to implement advanced algorithms

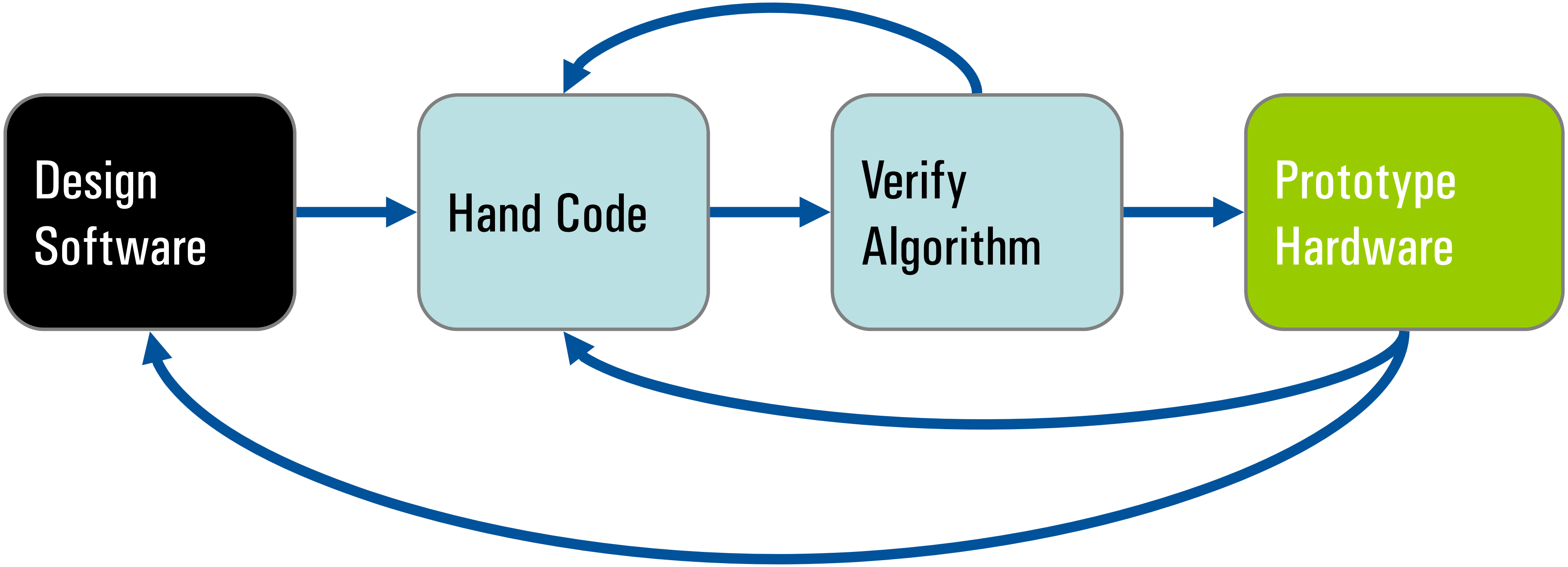
**Solution:** Using control design software that runs natively on embedded hardware

**Benefits:**

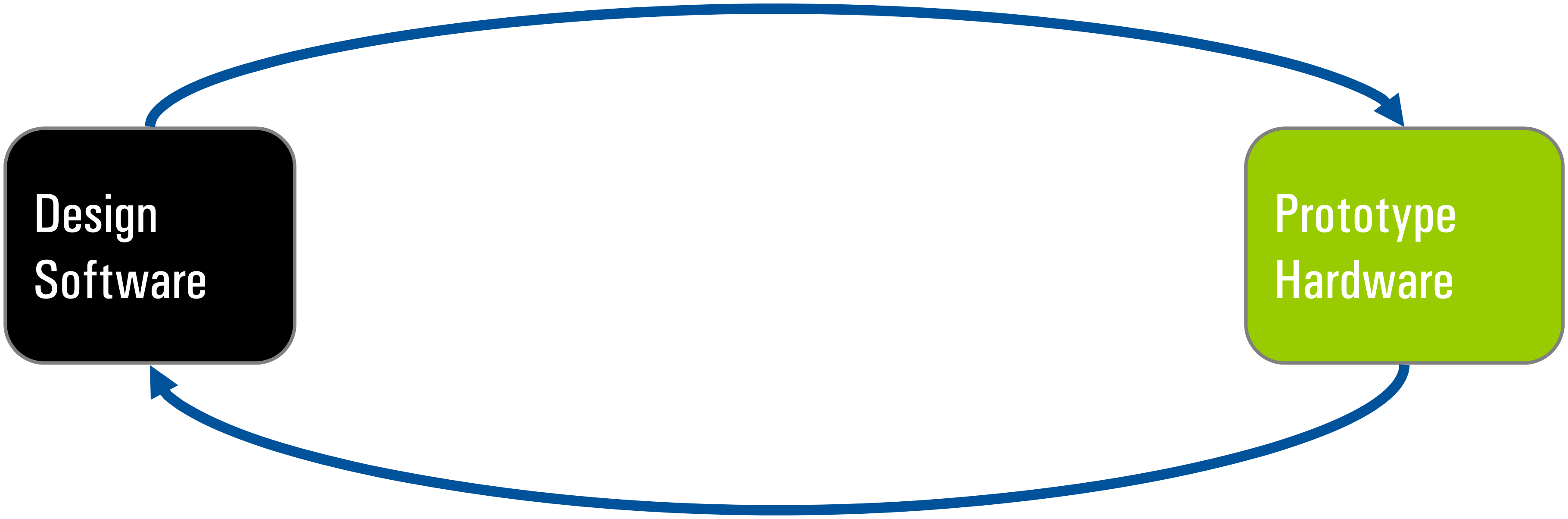
✓ Reduced development time and cost

✓ Less chance for translation errors

# Algorithm Engineering



# Algorithm Engineering



# Prototyping and Deployment Challenges

**Challenge:** Choosing the right prototyping platform

- Controller speed and memory
- I/O from specialty signals
- Ability to implement advanced control algorithms

**Solution:** Using packaged FPGA-based PAC hardware platform

**Benefits:**

✓ Reliably run custom control algorithms

✓ Integrate any I/O including machine condition monitoring and vision

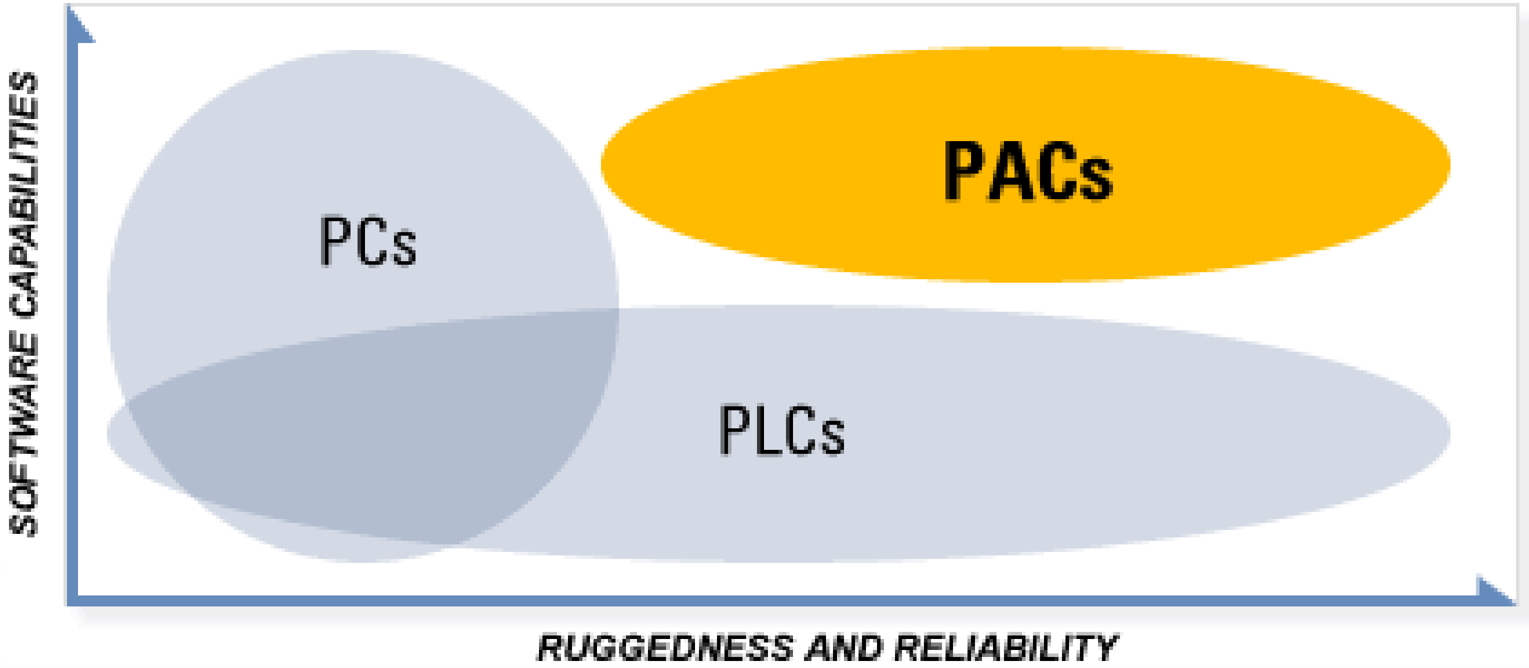
✓ Protect IP (Intellectual Property)

# Deployment Hardware

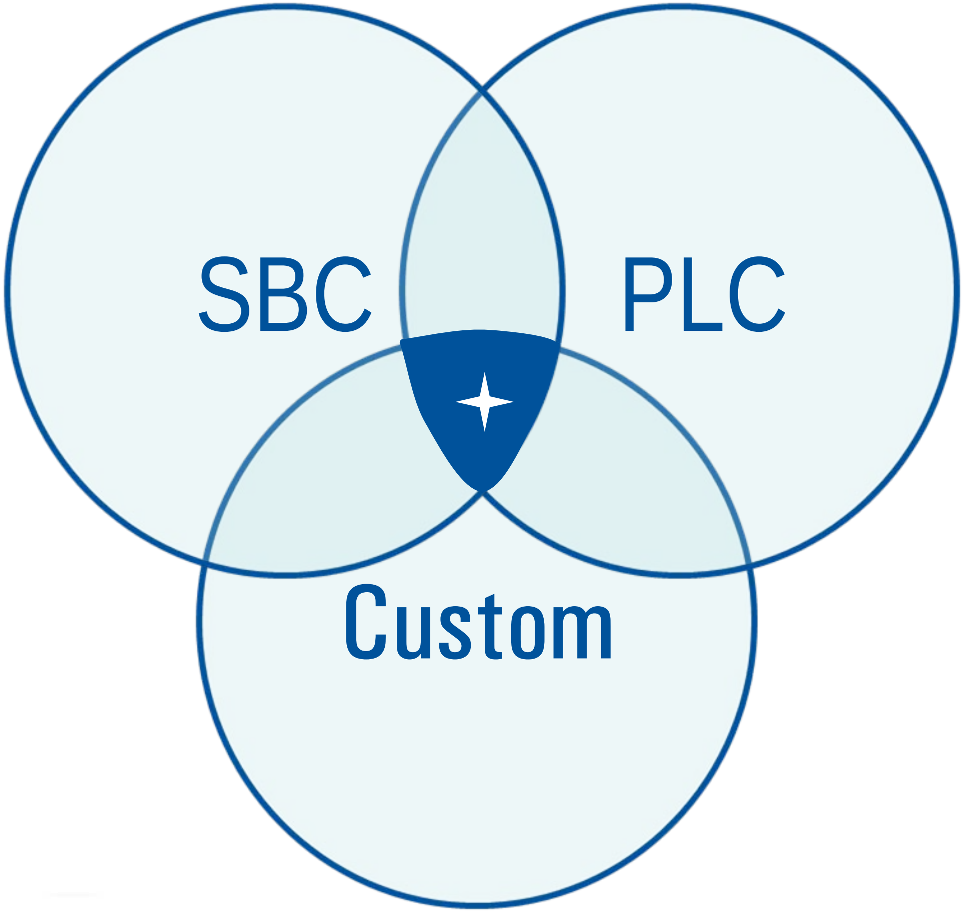
- Desktop PCs
- Industrial PCs
- Programmable automation controllers (PACs)
- Programmable logic controllers (PLCs)
- Custom boards

# Programmable Automation Controller (PAC)

- Ruggedness and reliability of PLC
- Software capabilities of PC
- Modular and diverse I/O



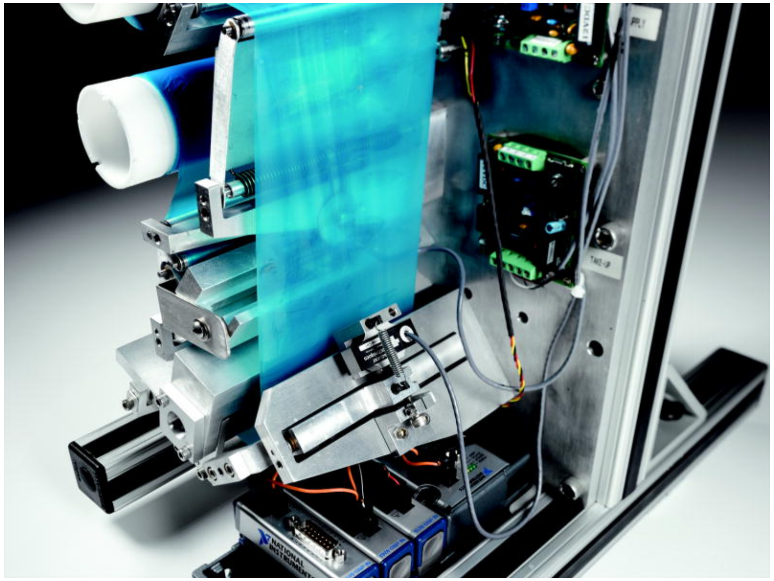
# FPGA-Based Programmable Automation Controller




*NI CompactRIO*

# Case Study: Digital Photo Kiosk Design

- **Application**
  - Precise web tensioning
- **Challenge**
  - Vibrations from cutter head
  - Varying motor speed
  - **PID will not work**
- **Solution**
  - **Simulation**
  - **Sixth-order control algorithm**
- **Result**
  - ***10X faster photo printing than competition***



BOSTON ENGINEERING

# Additional Design Considerations: High-Performance Motion Control

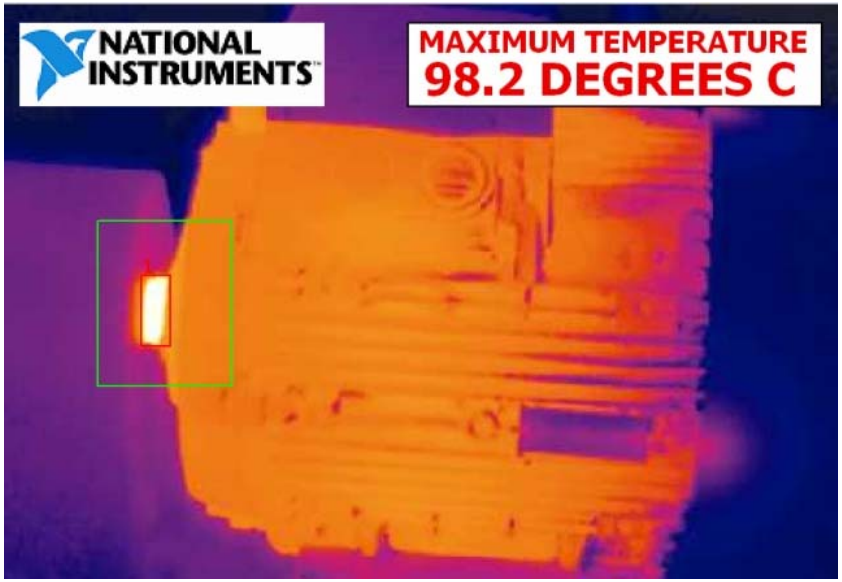
- Integral part of all mechatronics systems
- Improves machine productivity
- NI PACs for motion control:
  - PCI and CompactPCI/PXI
  - Custom motion control with FPGA
  - Distributed motion over CANopen

# New for NI Motion

- Two new stepper drives
  - 1-axis, DC-powered: 300 W
  - 1-axis, AC-powered: 525 W
- Range of 30 new stepper mo
  - NEMA 17, 23 and 34 sizes
  - Torque up to 1710 oz-in
- Motor sizing software
- ni.com/motion/stepper

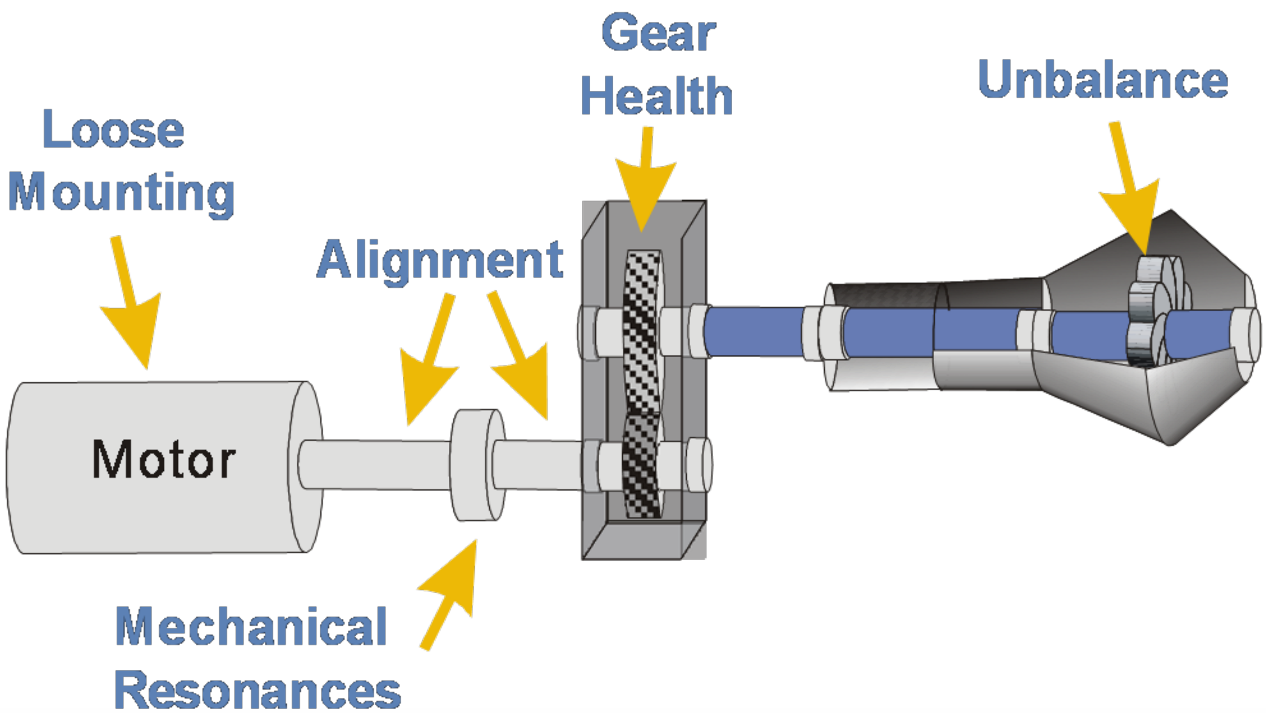
# Additional Design Considerations: Machine Vision

- Why use machine vision?
  - Increase product throughput
  - Reduce product inspection cost
  - Use infrared, X-ray
- Applications
  - Manufacturing
  - Product testing
  - Product packaging
  - Robot guidance



# Additional Design Considerations: Machine Condition Monitoring

Data Acquisition → Data Analysis → Diagnosis and Control



# Conclusion

- Mechatronics concurrent development:
  - Reduces development time and risk
  - Requires design tool integration
- NI offers an easy path to deploy mechatronics systems

NATIONAL INSTRUMENTS LabVIEW