User Experience with Collaborative Robots – Ford Motor Company

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Technical Expert – Robotics and Automation
Ford Motor Company
Agenda

1. 1. What are collaborative robots?

2. What internal and external specifications apply to this new technology?

3. What kinds of collaborative robots have been planned for use at Ford?

4. New Safety Paradigms

5. Benchmarking findings

6. Summary
Collaborative Robots

- New form of **force and power limited** robots that are designed to be able to collaborate with humans directly. This robotic technology has the potential for Ford to place robots on the line right next to people without perimeter guarding.

- Even though these robots are force and power limited they can still represent a hazard to workers and may require risk mitigation methods to be applied.
Collaborative Robot Market Snapshot

We evaluated a large number of collaborative robot suppliers before settling on two mgfrs.

1) Universal Robotic for pick and place applications

2) KUKA LBR for force controlled assembly tasks

A large number of robot manufacturers were evaluated for payloads, reach, controls interfaces...etc.

Note: There are new collaborative manufactures coming out with new products frequently
Universal UR10 vs. KUKA LBR

**Universal UR10 Robot**
- 10kg payload, 1.2m reach
- 6 axis robot
- Easy programming interface with Polyscope scripting hidden underneath the main script language

**KUKA LBR**
- 14kg payload, 1.2m reach
- 7 axis robot
- Force control applications
- Java programming interface
Collaborative Robots vs. Humans

<table>
<thead>
<tr>
<th>Collaborative Robot</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can use sensors to “see” certain trained things (camera,</td>
<td>Vision – can see and understand what they are seeing</td>
</tr>
<tr>
<td>laser scanner, light curtain, pressure mat)</td>
<td></td>
</tr>
<tr>
<td>Can limit forces imparted to the environment by programmed</td>
<td>Can have a gentle touch, and understand how to use contact forces</td>
</tr>
<tr>
<td>means</td>
<td>to acquire or position parts</td>
</tr>
<tr>
<td>Specific process switches and other inputs can be used to</td>
<td>Other senses available – hearing, taste, smell</td>
</tr>
<tr>
<td>make decisions</td>
<td></td>
</tr>
<tr>
<td>Strong and never tire</td>
<td>Relatively weak and prone to repetitive stress injury</td>
</tr>
<tr>
<td>Can be moved and explicitly re-programmed</td>
<td>Easy to redeploy, very flexible, with minimal instruction</td>
</tr>
<tr>
<td>Can be pre-programmed to handle process variation</td>
<td>Handles process variation well</td>
</tr>
<tr>
<td>Highly precise positioning</td>
<td>Imprecise</td>
</tr>
<tr>
<td>Can be explicitly programmed for assembly</td>
<td>People are naturally good at assembly</td>
</tr>
</tbody>
</table>
Collaborative robots expand the range of robotic applications.
Collaborative Robot Standards

External

• **ISO 10218 Parts 1&2**, Robots for industrial environments
  – Main ISO document that applies worldwide to our Ford robot cells, including collaborative robot cell requirements. Harmonized with American National Standard for Industrial Robots and Robot Systems- Safety Requirements (revision of ANSI/RIA R15.06-1999)

• **ISO TS/15066**, Robots and robotic devices – Collaborative Robots (Feb 2016)
  – Biomechanical force and pressure limits for various body parts for onset of pain

Internal

• **FAS08-131** is the top robot document
• **Core Controls Attachment 14** – Robot Programming Specification
Use of the ISO TS/15066 Biomechanical Limit Tables are the generally accepted method for evaluating collaborative robot safety.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Specific body area</th>
<th>Quasi-static contact</th>
<th>Transient contact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$P_s$ N/cm$^2$</td>
<td>$P_t$ N</td>
</tr>
<tr>
<td>Skull and forehead</td>
<td>Middle of forehead</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Temple</td>
<td>110</td>
<td>not applicable</td>
</tr>
<tr>
<td>Face</td>
<td>Masticatory muscle</td>
<td>110</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>Neck muscle</td>
<td>140</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Seventh neck muscle</td>
<td>210</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back and shoulders</td>
<td>Shoulder joint</td>
<td>160</td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>Fifth lumbar vertebra</td>
<td>210</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>Sternum</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Pectoral muscle</td>
<td>170</td>
<td>2</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Abdominal muscle</td>
<td>140</td>
<td>110</td>
</tr>
<tr>
<td>Pelvis</td>
<td>Pelvic bone</td>
<td>210</td>
<td>180</td>
</tr>
<tr>
<td>Upper arms and</td>
<td>Deltoid muscle</td>
<td>190</td>
<td>150</td>
</tr>
<tr>
<td>elbow joints</td>
<td>Humerus</td>
<td>220</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower arms and</td>
<td>Radial bone</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>wrist joints</td>
<td>Forearm muscle</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arm nerve</td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>
New Safety Paradigm

Robot presence sensing may not be required for collaborative power and force limited robots if the forces / pressures are under the ISO TS/15066 Biomechanical Limits for the onset of pain.

1. Verify forces and pressures are under the ISO TS/15066 limits, eliminating the need for slowing or stopping the robot if a person is in the work envelope of the robot

-OR-

2. If the forces or pressure are too high, the use other forms of control such as administrative controls, or controls such as laser scanners, pressure mats, light curtains...etc. to detect personnel intrusions to slow or stop the robot if people are near
Risk Mitigation Methods and Impact on the Risk Assessment

1. Elimination - Design out high forces and pressures
2. If forces/pressure cannot be designed out and exceed the TS/15066 limits then an action like the ones below should be done:
   a. Block access to hazard with peripheral equipment eliminating access to hazardous area
   b. Add a presence sensing device to slow/stop robot
   c. Provide administrative keep out areas using floor markings and simple barriers
Benchmarking Showing We Are On Track
Summary

1. There are new kinds of force and power limited robots, often referred to as “collaborative robots”, can be engineered to be safe working along side of people with no hard perimeter guarding to prevent access to the robot.

2. The ISO standard 10218 Parts 1&2, and the ISO specification TS/15066 are the guiding documents to determine if the collaborative robot is Safe to operate.

3. Risk Assessments matter – A broadly cross functional risk assessment Team is the right kind of team to do a Risk Assessment with to avoid subjectivity and to properly identify all the real risks

4. The End Effector design matters - In terms of pressure, so if it has sharp edges that cannot be shielded from the operator, it will be extremely hard to have forces and pressure less than the ISO TS/15066 limits.

5. Operator position matters – In terms of potential pinch points with the robot during it’s motion. Care must be taken to not produce a potential entrapment point of a body part between the robot and other objects as a basic design criteria when using collaborative robots
Contact Information

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Supply Chain...Global Scale, Local Presence

- 70 factories in 22 countries
- 40% in emerging markets... 60% by 2018
- “Vital organs” in 5 key hubs/local assembly distributed
- 500 equipment deliveries/day ... 250,000 devices/day
- 600 products ... 100,000 skus
- 6,000 suppliers across the globe

- US, UK, Netherlands
  Nuclear imaging media production...
  24 hours from cyclotron to patient

- US, Europe, China, Korea, India
  35,000 Ultrasound machines/year
  2 week lead time

- Ireland, China, Norway
  60 million units of contrast media...
  one dose every 2 seconds

- US and China
  36,000 miles of superconducting wire goes in 1000 MR machines each year
World-Class Imaging

Matching product development with market needs

Avg Selling Price

**Women’s Health**
- Seno
  - ~$100k-500k
- Lunar
  - ~$20k-200k

**Interventional Cardiology & Radiology**
- Image Guided Systems
  - ~$0.5-2MM

**General Imaging**
- Revolution CT
  - ~$0.2-3MM
- SIGMA MR
  - ~$0.5-10MM

**Molecular Imaging**
- Discovery
  - ~$0.2-3MM

**Surgery**
- Surgical C-Arms
  - ~$20-200K

**ULTRASOUND**

**Women’s health – Voluson**
- $25-150k

**Cardiac**
- Vivid $25-200k

**General imaging**
- LOGIQ $25-200k

**Primary care**
- Vscan
  - $7-25k

- Market-backed new product introduction
- Care area and value-based segmentation is key
- Accretive margins across the value chain
A Broad Life Sciences Portfolio

Research
- Research and Applied Markets
  - Research instruments
  - Consumables
  - Cell therapy tools

Bioprocessing
- Biopharmaceutical manufacturing
  - Cell culture media
  - Filtration systems
  - Chromatography

Diagnostics
- Contrast media, SPECT & PET imaging
  - Contrast Media
  - SPECT imaging
  - PET imaging

Leveraging best of GE Store: GRC + GGO footprint + Predix™
AME Technology Center...
Driving Technology to Sites

- Launching pad for new technologies
  - Cobots, Inspection, Additive, Augmented Reality...

- Driving productivity, quality, capacity through Technology

- Rapid proto-typing, Training, Development, Design
AME Technology Center...
Touching Multiple Products & Sites

Disruptive Product/Productivity Enabler

**ABB YuMi**
- 5OK - Dual Arm (7-axis)
- + 0.02 mm repeatability
- Cognex Camera's included
- 500g/Arm max load

**Rethink Sawyer**
- 30K - Single Arm (7-axis)
- + 0.1 mm repeatability
- Cognex camera included
- 8.8 lb max load

**Universal UR3,5,10**
- 18K-36K Single Arm (6-axis)
- 6.6/1/2.2 lb max load
- + 0.1 mm repeatability

**Fanuc CR-35iA**
- 15 Arm - Waist, Arms, Neck
- 3-6 lb max load
- + 30 μm repeatability
- 3D stereo vision, hand cameras

**Tecnalia - Hero**
- Dual Arm (7-axis)
- Force sensor grippers
- Two Inspection Cameras
- 3D forehead camera
- Impedance Control

**Pi4 Robotics workerbot**

**Collaborative Tech. Drivers**
- Human-robot interaction
- Mobile perception
- Mapping & localization
- 3D obstacle detection & avoidance
- Dynamic environments
- Proxemics & Space

Now

3-5 Yrs

5-10 Yrs

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Robotic Industries Association
National Robot Safety Conference
AME Technology Center...
Touching Multiple Products & Sites

Active & Potential Cobot Project Sites:
- Cardiff, Uppsala, Mexico, China, Electric Avenue, Madison, Umea, Uppsala, Oslo, Rehovot, Cork...

Products, Applications, Business units
- Pressure Cuffs, Ultrasound probes, Anesthesia valves, filter plates, Mercury packs, Contrast media, etc.
- Loading, unloading, packaging, palletizing, testing, machine tending, etc.
- ISS, Ultrasound, LCS, Life Sciences...

Cardiff – Life Sciences
DNA Kit

BOP - Pressure Cuffs
Oslo - Contrast Media
EA - ISS Mercury Packs
Uppsala - Chromatography Media
Wuxi - Ultrasound
GEHC Cardiff Site...

Easicollect Assembly Process

Three pieces of CE marked Equipment to be incorporated into one manufacturing cell

- Assembly Machine (Master)
- Speed-pack bagging machine
- UR 5 arm

Universal Robot (UR5)

Easicollect Assembly Machine
GEHC Cardiff Site...

Easicollect Assembly Components

- Mitsubishi PLC Control System
- Pilz Estop relay
- Dedicated Compressed air supply, isolation and dump valve
- ioLogik E1212
  - Moxa Remote Ethernet I/O 8DI/8DIO 2-port Switch

Easicollect Assembly Machine

- Collaborative Robot arm, no robot guarding will be used
- OS32C Safety Laser Scanner Safety Range 3M
- ioLogik E1212
  - Moxa Remote Ethernet I/O 8DI/8DIO 2-port Switch
  - Compressed air feed from assembly process

Universal Robot (UR5)

- ioLogik E1212
  - Moxa Remote Ethernet I/O 8DI/8DIO 2-port Switch
  - Dedicated Compressed air supply, isolation and dump valve

Audion Speedpack
GEHC Cardiff Site...
Perform a Risk Assessment

Task Identification
• Frequency and duration of human presence
• Frequency and duration of operator/robot interaction.
• Transition between non-collaborative and collaborative operation modes.

Design Considerations
• Limited forces and speed on robot
• Eliminate pinch points, sharp edges
• Understand restricted space boundaries
Task Identification
- Identify the risks
- Identify the risk level
- Mitigate risk
- Re-identify risk level
- Is it low enough?
- If not – re-evaluate

### Risk Priority Listing

<table>
<thead>
<tr>
<th>Priority</th>
<th>Hazard No</th>
<th>Name</th>
<th>PHR</th>
<th>Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>Robot impact</td>
<td>75</td>
<td>Significant Risk</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>Robot impact to head during reject bin emptying</td>
<td>75</td>
<td>Significant Risk</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>Robot contact betweenassy mach and robot motor</td>
<td>75</td>
<td>Significant Risk</td>
</tr>
<tr>
<td>4</td>
<td>1.6</td>
<td>Robot trap point in wrist</td>
<td>75</td>
<td>Significant Risk</td>
</tr>
<tr>
<td>5</td>
<td>4.1</td>
<td>Missing awareness means</td>
<td>N/A</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>6</td>
<td>1.7</td>
<td>Robot movement beyond restricted space</td>
<td>37</td>
<td>Low Risk</td>
</tr>
<tr>
<td>7</td>
<td>1.2</td>
<td>Robot contact at assay machine unload dial</td>
<td>12</td>
<td>Very Low Risk</td>
</tr>
<tr>
<td>8</td>
<td>1.3</td>
<td>Robot contact at bagger</td>
<td>12</td>
<td>Very Low Risk</td>
</tr>
<tr>
<td>9</td>
<td>2.2</td>
<td>Adequate minor servicing protective measures</td>
<td>1</td>
<td>Negligible Risk</td>
</tr>
<tr>
<td>10</td>
<td>3.2</td>
<td>Adequate safety control system</td>
<td>1</td>
<td>Negligible Risk</td>
</tr>
<tr>
<td>11</td>
<td>2.1</td>
<td>Adequate hazardous energy control</td>
<td>N/A</td>
<td>Acceptable</td>
</tr>
<tr>
<td>12</td>
<td>3.1</td>
<td>Adequate emergency stop function</td>
<td>N/A</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>

### Risk Estimation and Evaluation

<table>
<thead>
<tr>
<th>Degree of Possible Harm</th>
<th>Possibility of Avoidance</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2.5</td>
<td>EN ISO 13855 ISO TS 15066</td>
</tr>
<tr>
<td>Probability of Occurrence of a Hazardous Event</td>
<td>Frequency And / Or Duration of Exposure:</td>
<td>4</td>
</tr>
<tr>
<td>2.5</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pilz Hazard Rating (PHR)</th>
<th>Summary Level:</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>Significant Risk</td>
</tr>
</tbody>
</table>

### Risk Reduction

With an effective mass of 7.5 Kg, the robot must be limited to 705 mm/s to stay below the minor injury threshold for a chest impact. Implement a laser scanner to limit the robot to below 705 mm/s when an operator approaches the robot. Set the boundary at the safe distance to ensure the robot has dropped to below the limit before the robot is reached. The safety function PLe.<
GEHC Cardiff Site...

Easicollect Risk Reduction

• Risk reduction measures
  • Covers over valve and fittings with rounded edges
  • Force and speed limits
  • Use of laser scanner to reduce speed on approach
  • Moving the reject bin outside robot zone
  • Use of clear floor markers

• Use of 3rd party to risk assessment the design and validate the forces and speed
Easicollect... Final Thoughts

- Drives productivity
- Eliminates EHS risks
- Increases quality
- Lowers cost to produce
- 3<sup>RD</sup> Risk Assessment of new application by Pilz safety expert “Elena Dominguez”

Happier customers
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User Experiences with Collaborative Robots Panel

Chris Ihrke
Staff Engineer
General Motors
Collaborative Robots in GM

- Currently have Fanuc CR-35iA collaborative robots in 5 plants doing 6 unique applications
  - Target positioning
  - Headlight aiming
  - Dispensing
  - Fastening
  - Vision inspection
  - Pick and place MH

- Working on more
  - Adhesive wet-out on a moving line
  - Vision error proofing of stampings and assembly
  - Material Handling of engine head assemblies, PCB’s

- We expect our use of collaborative robots to grow exponentially in the coming years
Collaborative Applications

• Target Positioning
  – Active Safety Calibration

• Headlight Aiming
  – Tool Changing with Active Safety Target
Collaborative Applications

- Hot Glue Dispensing
  - Headliner Assembly
- Fastening
  - Turbocharger Assembly to Engine
Collaborative Applications

- Vision Inspection
  - Sheet metal quality
- Pick and Place MH
  - Spare tire handling
## Risk Assessment

- **GM Standard Risk Assessment Process (G-Risk)**
- **Observations (partial list)**
  - Possibility of an observer coming in contact with moving robot (or tool, or carried tire).
  - Possibility of placing fingers between gripper and tire while gripper is engaging tire.
  - Possibility of placing hand between tires at drop location.
  - Possibility of robot dropping tire from too high over stack.
  - Possibility of loss of air or power while robot is holding a tire.
  - Possibility that another person enters robot envelope while someone is Teaching robot.
  - Manual backup operation.

<table>
<thead>
<tr>
<th>Mitigation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A B C D E L</td>
</tr>
<tr>
<td>A C F</td>
</tr>
<tr>
<td>A C H I</td>
</tr>
<tr>
<td>H I J</td>
</tr>
<tr>
<td>F G</td>
</tr>
<tr>
<td>A E</td>
</tr>
<tr>
<td>M N O Q</td>
</tr>
</tbody>
</table>
Mitigation Strategies

A. Collaborative active safety features
B. Collaborative passive safety features
C. Sensitivity selection
D. Envelope restriction by DCS
E. Awareness measures
F. EOAT mechanical design
G. EOAT pneumatic design
H. Path programming
I. Program logic
J. Fault recovery position
K. Sensor positioning
L. High visibility paint
M. Overhead cable routing
N. Dolly stop design
O. Safe Operating Procedures
P. MPS placard
Q. Awareness training
Risk Mitigation Examples

• Gripper
  – Soft covering
  – Extended diameter
  – Finger details retract into cast rubber “bumper”

• Gravity
  – Monitoring of cart in position
  – Monitoring of stack height
  – Cross-checking of stack counts with sensor measurements
  – Air Circuit

• Trip Hazards
Third Party Validation

• Required Fanuc achieve TÜV certification of their collaborative robot product safety function.

• For the configurable elements of the safety system
  – A checklist and procedure was created to verify all of the mitigations from the Risk Assessment that were implemented in safe software (DCS).
  – SICK, Inc. was contracted as a third party to perform the validation.

<table>
<thead>
<tr>
<th>DCS Configuration Requirement from Risk Assessment</th>
<th>Verification Procedure</th>
<th>Validator Notes</th>
<th>Verified</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Forces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1 Force sensitivity is configured such that the threshold force is 105N everywhere in the robot envelope except as verified in the following</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspect the configuration of Collaborative Robot Force Limit #1 in DCS. Verify the force setting is 105N. Inspect the logic associated with disabling input SIR[1], which allows this limit to be disabled only when the</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Words of Wisdom

For First Time Implementation

• Choose the right application
  – Limit risk and complexity
  – Initial success is important

• Engage the right people as early as possible
  – Safety Community, Union, Maintenance, Production, Validator

• Pay attention to the details
  – Risk Assessment, Validation, Training

• Follow your safety process
  – Adapt it where necessary
Contact Information

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User Experience with Collaborative Robots – Procter & Gamble

Mark Lewandowski
Global Engineering Robotics Innovation Leader
Procter & Gamble
Agenda

• P&G At a Glance
• Why Use Collaborative Robots?
• Selecting Applications for Cobots
• Ensuring Safe Applications
P&G At A Glance

• $65B in sales
• 21 brands with annual sales > $1B
• 11 brands with annual sales $500M - $1B
• Consumers in more than 180 countries
Innovation – The Lifeblood of P&G

Products

Process
Why Use Collaborative Robots?

- Robots are cool!
- Collaborative robots are even cooler!
Selecting Applications - General

• Simple to implement and use

• Advantages in:
  – Cost of implementing
    • “Cage-Free” Robotics
      – Eliminates guarding
      – Reduces Floor Space
    • Reduced Engineering Costs
  – Flexibility
    • Adaptive and reconfigurable
      – Easy and intuitive programming
    • Portable
      – Move robot to the applications as needed
Selecting Applications - General

For Robotics in General

• Look for processes and tasks that are:
  – Dull
  – Dirty
  – Dangerous/Ergonomic Issues
Selecting Applications - Cobots
Key Collaborative Advantage

Enables partial automation opportunities where it was “All or Nothing”
Successful Application Features

Cobots provide value and succeed when:

• Low speed - 6-8 cycles per min
• Low payload - less than 10kg typically
• Little or no robotics expertise available
• Processes/Machinery with Low Utilization
• Processes previously seen as uneconomical or too complex where partial automation may be feasible or desirable
Ensuring Safe Applications

• Follow the standards
  – U.S. – RIA 15.06
  – International – ISO 10218
  – ISO TS 15066

• Key Requirement in Each:
  
  **RISK ASSESSMENT!!!!!!**
Collaborative Risk Assessment

Not just for the robot

–A comprehensive risk assessment is required to assess not only the robot system itself but also the environment in which it is placed, i.e. the workplace. “ (TS 15066)

4.3 Hazard identification and risk assessment

Shall consider:

• Robot related hazards
• Hazards related to the robot system
• Application related hazards
Risk Assessment Process

Reference RIA TR R15.306-2014 as guide to Risk Assessment Process
Hazard Mitigations Methods

- Design out by geometry and limits
- Padding
- Collision detection
- Envelope or reach limiting
- **Force or speed limiting**
- Selective use of scanners or traditional guarding in critical areas

Reference RIA TR R15.306-2014 as guide to Risk Assessment Process
Force Limiting

- Defined in TS15066
- Based on affected body area
Measuring Forces

Measurement device/technique not specified by standards

Potential Options

– Fraunhofer IFF Test Lab
– Spring Gauge
– Digital Gauge (high sampling frequency required to capture impact)
– High Speed Video
Contact Information

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