Zero Backlash, Low Inertia, Completely Disengaging
**Torque Limiter**

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Sponsored by:

**nexen**

ENGR 480/481 Senior Design Clinic
Spring 2003

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**Team Member Assignments**

- **Jim Roche:**
  - Project Leader
  - Researching diaphragm springs, developing math model, contacting spring supplier and detail drawings of shaft.

- **Raia Ottman-Rak:**
  - Project Engineer
  - Developed math model, report writing and detail drawings of the hub.

- **Craig Prothero:**
  - Project Engineer
  - Working on the modeling of final design in SolidWorks and detail drawings of the spring retaining ring.

- **Luis Zamorano:**
  - Project Engineer
  - Researching diaphragm springs, developing math model, report writing and detail drawings of the ball retaining ring.

- **Nexen Contacts:**
  - Dave Hein: Project team leader and Nexen Group company representative
  - Kevin Weiss and Jeff Maher: Nexen Group engineers and project advisors.
About Nexen Group

- Manufacturer
  - Brakes, clutches, torque limiters, overload protection devices, and control systems
  - Web control systems
- Headquartered in Vadnais Heights, MN
- Manufacturing facility in Webster, WI
- 40 worldwide sales offices and 1,500 worldwide distributor sales outlets
- 120 U.S. and international patents

What is a Torque Limiter?

- Overload protection device
- Disengages at a predetermined torque level
- Three typical engagement methods
  - Mechanical
  - Pneumatic
  - Electric
- Used for:
  - Positioning
  - Overload protection
  - Disconnecting a machine
  - Positive drive
  - Machine timing
- Current Nexen model is pneumatically engaged
Project Requirements

- Design and Submit Manufacturing Quality Drawings for Prototype Torque Limiter
  - Mechanically engaged
  - Zero-backlash
  - Completely disengaging
  - Adjustable torque range of 50 - 90 ft-lbs
  - L10 bearing life greater than 5000 hours
  - 5/8” diameter shaft
  - Maximum rotational speed of 7,000 RPM
  - 2000-5000 units in five different sizes sold yearly
- Detailed assembly and design drawings of final product
- Math model of the final product performance
- Cost effective
- Fit well with existing Nexen manufacturing processes

Concept Generation: Alternative Designs
Concept Generation: Trade-off Chart

<table>
<thead>
<tr>
<th>Design Concept</th>
<th>Zero-backlash</th>
<th>Completely disengaging</th>
<th>Easy to reengage</th>
<th>Adjustable Torque</th>
<th>Patentable</th>
<th>Low Inertia</th>
<th>Low Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>??</td>
<td>yes</td>
<td>??</td>
<td>yes</td>
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<tr>
<td>#2</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>??</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>#3</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>??</td>
<td>no</td>
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<tr>
<td>#4</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>??</td>
<td>yes</td>
</tr>
<tr>
<td>#5</td>
<td>yes</td>
<td>??</td>
<td>??</td>
<td>yes</td>
<td>??</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>#6</td>
<td>yes</td>
<td>yes</td>
<td>??</td>
<td>??</td>
<td>yes</td>
<td>??</td>
<td>yes</td>
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<tr>
<td>Mayr</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
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</table>
Prototype Design

- Cost advantage over competitive designs
- Utilizes an “over-center” diaphragm spring to trigger complete disengagement
- Torque transfer balls around circumference of mechanism interface with hub and shaft
  - Diaphragm spring forces them into position
- At overload spring flips over center
  - Balls completely disengage from hub to achieve complete disengagement
- Risks
  - Unanticipated spring behavior
  - Not enough time for sufficient testing

Assembly
Spring Characteristics

- Material Specification: 51CrV4
- Outer Diameter: 120.00 mm
- Inner Diameter: 60.00 mm
- Thickness: 1.25 mm
- Unloaded height: 5.50 mm
- Life: 23,000 cycles
- Configuration: Two springs in parallel

Disengagement operation
Bill of Materials

<table>
<thead>
<tr>
<th>Part #</th>
<th>Part Name</th>
<th>Qty</th>
<th>Mfg</th>
<th>Description</th>
<th>Material</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Shaft</td>
<td>1</td>
<td>N/a</td>
<td>See DWG</td>
<td>700XX10, STEEL, HR, 4140</td>
<td>$0.00</td>
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<tr>
<td>2</td>
<td>Ball Retaining Ring</td>
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<td>N/a</td>
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<td>700XX10, STEEL, HR, 4140</td>
<td>$0.00</td>
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<tr>
<td>3</td>
<td>Hub</td>
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<td>N/a</td>
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<td>700694, STEEL, HR, 4140</td>
<td>$0.00</td>
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<td>4</td>
<td>Spring Retaining Ring</td>
<td>1</td>
<td>N/a</td>
<td>See DWG</td>
<td>700694, STEEL, HR, 4140</td>
<td>$0.00</td>
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<tr>
<td>5</td>
<td>Diaphragm Spring</td>
<td>2</td>
<td>N/a</td>
<td>Special Order</td>
<td>510124 Spring Steel</td>
<td>$1.29</td>
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<td>6</td>
<td>External Snap Ring</td>
<td>1</td>
<td>N/a</td>
<td>External Springs</td>
<td>100, 114</td>
<td>$7.25</td>
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<td>7</td>
<td>Internal Snap Ring</td>
<td>1</td>
<td>N/a</td>
<td>Internal Springs</td>
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<td>8</td>
<td>Bearing</td>
<td>1</td>
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<td>9002 BE</td>
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<tr>
<td>9</td>
<td>Locking Collar</td>
<td>1</td>
<td>N/a</td>
<td>TUL-14-14-F (175-14 Base) (or Trip Lever 643 REL 75)</td>
<td>Steel</td>
<td>$2.25</td>
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<td>10</td>
<td>Ball Bearings</td>
<td>24</td>
<td>N/a</td>
<td>McMaster Carr</td>
<td>902K3128 (0.22&quot; dia, qty 10000g, $1.59/ea)</td>
<td>Chromium Steel</td>
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<tr>
<td>11</td>
<td>14-20 Bolts</td>
<td>4</td>
<td>N/a</td>
<td>McMaster Carr</td>
<td>901-244-A07 (8.5&quot; Total Length, 90.52 ea)</td>
<td>Zinc Plated Steel</td>
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</tbody>
</table>

Analysis of Design: Math Model

### Input Values

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>English</th>
<th>Metric</th>
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<tbody>
<tr>
<td>Rb</td>
<td>Radius of Ball</td>
<td>0.125 in</td>
<td>3.175 mm</td>
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<tr>
<td>Rs</td>
<td>Radius of Shaft</td>
<td>0.3125 in</td>
<td>7.9375 mm</td>
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<tr>
<td>Th</td>
<td>Thickness of Shaft to base of ball</td>
<td>0.8686 in</td>
<td>22.0624 mm</td>
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<tr>
<td>qa</td>
<td>Detent Angle at Point A (Input)</td>
<td>90 deg</td>
<td>90 deg</td>
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<tr>
<td>qb</td>
<td>Detent Angle at Point B (Output)</td>
<td>60 deg</td>
<td>60 deg</td>
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<tr>
<td>Tinput</td>
<td>Input Torque acting at point A</td>
<td>800 in-lbs</td>
<td>90.38786 N*m</td>
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<tr>
<td>Coef Friction</td>
<td>Coefficient of Friction</td>
<td>0.2 ()</td>
<td>0.2 ()</td>
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</table>

### Output Values

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>English</th>
<th>Metric</th>
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<tbody>
<tr>
<td>Fx</td>
<td>X component of Force from Torque at Input</td>
<td>-606.951 lbs</td>
<td>-2689.85 N</td>
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<tr>
<td>Fz</td>
<td>Z component of Force from Torque at Input</td>
<td>58.08813 lbs</td>
<td>258.3899 N</td>
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<tr>
<td>Ff</td>
<td>Friction Total Spring Force Required</td>
<td>545.0028 lbs</td>
<td>2424.293 N</td>
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<tr>
<td>110% of Total Spring Force</td>
<td>599.5031 lbs</td>
<td>2666.723 N</td>
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</table>

(takes into account spring's force tolerance) 10% more 10% more
Project Management: Gantt Chart

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
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<td>Tongue farther education</td>
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<td>Market research of competitor products</td>
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<td>Deepshape spring education</td>
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<td>Develop path model</td>
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<td>Package deepshape spring</td>
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<td>Product design</td>
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<td>Detail prototype drawings</td>
<td>40 days</td>
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<td>Design Analysis</td>
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<td>Bill of materials</td>
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</table>

Project Management: Budget

- Estimated prototype cost of $8,000
- Estimated tooling of $15 – 20,000 per spring size
- Estimated per unit cost of $100
  - Competitive product list price of $600
- Estimated 656 work-hours accrued by team and Nexen engineers
Summary of work completed

- Torque limiter market research
- Evaluated alternative designs
- Design concept chosen
- Development of math model completed and spring selected
- Springs ordered for further research and development
- Bill of materials completed
- Print package completed to Nexen manufacturing standards
**Design Conclusions**

- **Strengths:**
  - Cost reduction over competitor product
  - Innovative design
  - Prototype ready for manufacture

- **Weaknesses:**
  - Inelegant re-engagement mechanism
  - Possible high inertia
Process Conclusions

- Reflections on process:
  - Excellent introduction to manufacturing standards
  - Developed sound design concept skills
  - Completed complex force analysis on design
  - Communicated effectively with industry suppliers
  - Learned importance of quality teamwork
  - Increased understanding of time constraints and project planning

Conclusions: What went wrong

- Underestimated time required to move through design process
- Inadequate communication of desired outcomes between Nexen and team
- Underdeveloped alternative designs
- Difficulty in understanding key parameters
Conclusions: What went right

- Project provided excellent introduction to industry
- Provided Nexen with foundation for further development of design
- Nexen’s original design concept was developed and proven to be viable
- Valuable experience in bringing design concept through to manufacturing stage