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

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Sponsored by:

nexen

ENGR 480/481 Senior Design Clinic

Spring 2003

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 Zamarano:
  - 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

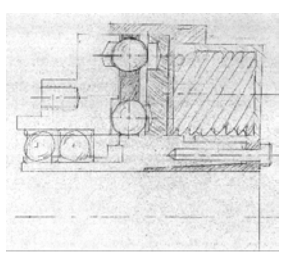
What is a Torque Limiter?

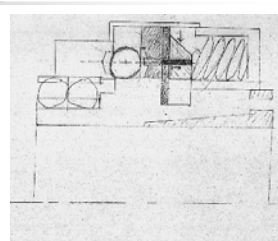
- Overload protection device
- Disengages at a predetermined torque level
- Three typical engagement methods
  - Mechanical
  - Pneumatic
  - Electric
- Used for:
  - Positioning
  - Overload protection
  - Disconnecting a machine
  - Positive drive
  - Machine timing
- Current Nexen model is pneumatically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

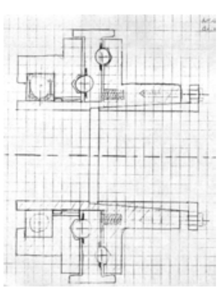
Project Requirements

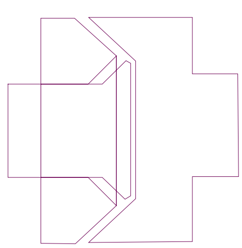
- Design and Submit Manufacturing Quality Drawings for Prototype Torque Limiter
  - Mechanically engaged
  - Zero-backlash
  - Completely disengaging
  - Adjustable torque range of 50 - 90 ft-lbs
  - L10 bearing life greater than 5000 hours
  - 5/8” diameter shaft
  - Maximum rotational speed of 7,000 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

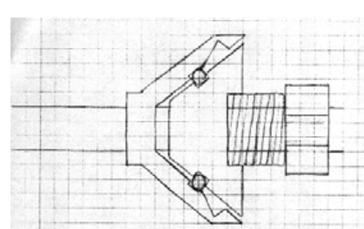
Concept Generation: Alternative Designs

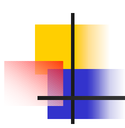








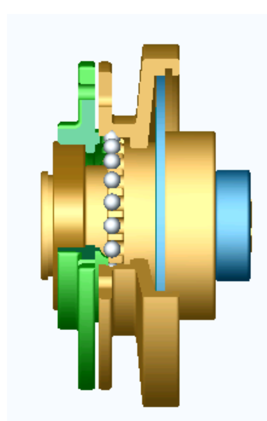


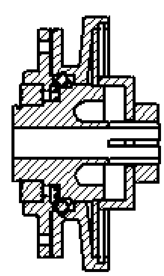


Concept Generation: Trade-off Chart

Design Concept	Zero-backlash	Completely disengaging	Easy to reengage	Adjustable Torque	Patentable	Low Inertia	Low Cost
#1	yes	yes	no	??	yes	??	yes
#2	yes	yes	no	yes	yes	??	no
#3	yes	yes	yes	no	yes	??	no
#4	yes	no	no	yes	yes	??	yes
#5	yes	yes	??	??	yes	??	no
#6	yes	yes	??	??	yes	??	yes
Mayr	yes	yes	yes	yes	yes	yes	yes

Concept Selection: Prototype Design

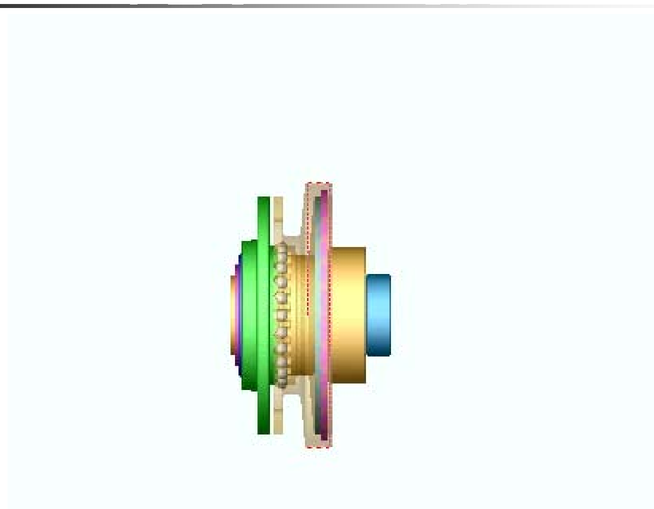




Prototype Design

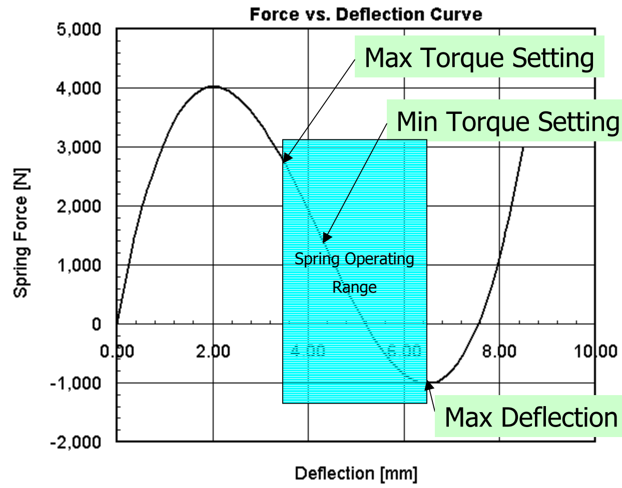
- Cost advantage over competitive designs
- Utilizes an “over-center” diaphragm spring to trigger complete disengagement
- Torque transfer balls around circumference of mechanism interface with hub and shaft
  - Diaphragm spring forces them into position
- At overload spring flips over center
  - Balls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

Assembly

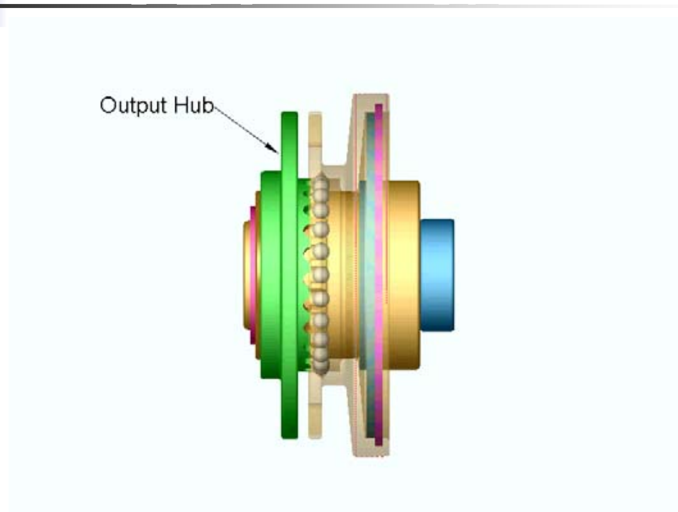


Spring Characteristics

- 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



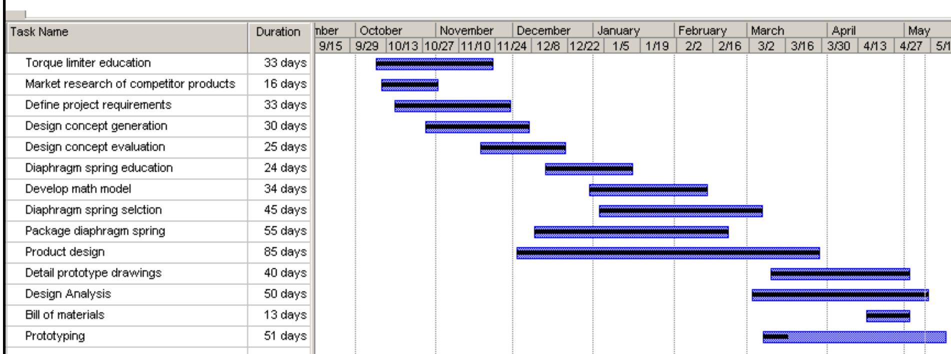
Bill of Materials

Part #	Part Name	Qty	Mfg	Description	Material	Cost
1	Shaft	1	Nexen	See DWG	700XXX, STEEL,HR,4140 ANLD,03.000 OD	$20.00
2	Ball Retaining Ring	1	Nexen	See DWG	700XXX, STEEL,HR,4140 ANLD,03.000 OD	$20.00
3	Hub	1	Nexen	See DWG	700656, STEEL,HR,4140 ANLD,05.500 OD	$20.00
4	Spring Retaining Ring	1	Nexen	See DWG	700656, STEEL,HR,4140 ANLD,05.500 OD	$20.00
5	Diaphragm Spring	2	Christian Bauer	Special Order	51CrV4 Spring Steel	$1.50
6	External Snap Ring	1	Truarc	External Series 5100-156		$1.25
7	Internal Snap Ring	1	Truarc	Internal Series N5000-475		$1.25
8	Bearing	1	Nachi	6908ZE		$10.00
9	Locking Collar	1	Ruland (or McMaster Carr)	TCL-14-14-F (7/8-14 Bore) (or McMaster: 6438K28)	Steel	$2.25
10	Ball Bearings	24	McMaster Carr	9528K15 (0.25" dia, qty 100/pkg, $3.55/pkg)	Chrome Steel	$3.55/pkg $0.89 for 24
11	1/4-20 Bolt	4	McMaster Carr	90124A537 (0.5" Total Length, $0.59 ea)	Zinc Plated Steel	$0.59 ea. $2.36 total

Analysis of Design: Math Model

Input Values					
Symbol	Description	English		Metric	
R_b	Radius of Ball	0.125	in	3.175	mm
R_s	Radius of Shaft	0.3125	in	7.9375	mm
T_h	Thickness of Shaft to base of ball	0.8686	in	22.06244	mm
θ_a	Detent Angle at Point A (Input)	90	deg	90	deg
θ_b	Detent Angle at Point B (Output)	60	deg	60	deg
T_{input}	Input Torque acting at point A	800	in-lbs	90.38786	N*m
Coef Friction	Coefficient of Friction	0.2	()	0.2	()
Output Values					
Symbol	Description	English		Metric	
$F_{\tau ax}$	X component of Force from Torque at Input	-606.951	lbs	-2699.85	N
$F_{\tau az}$	Z component of Force from Torque at Input	58.08813	lbs	258.3889	N
F_c w/ Friction	Total Spring Force Required	545.0028	lbs	2424.293	N
	110% of Total Spring Force	**599.5031**	lbs	**2666.723**	N
	(takes into account spring's force tolerance)	10% more		10% more	

Project Management: Gantt Chart

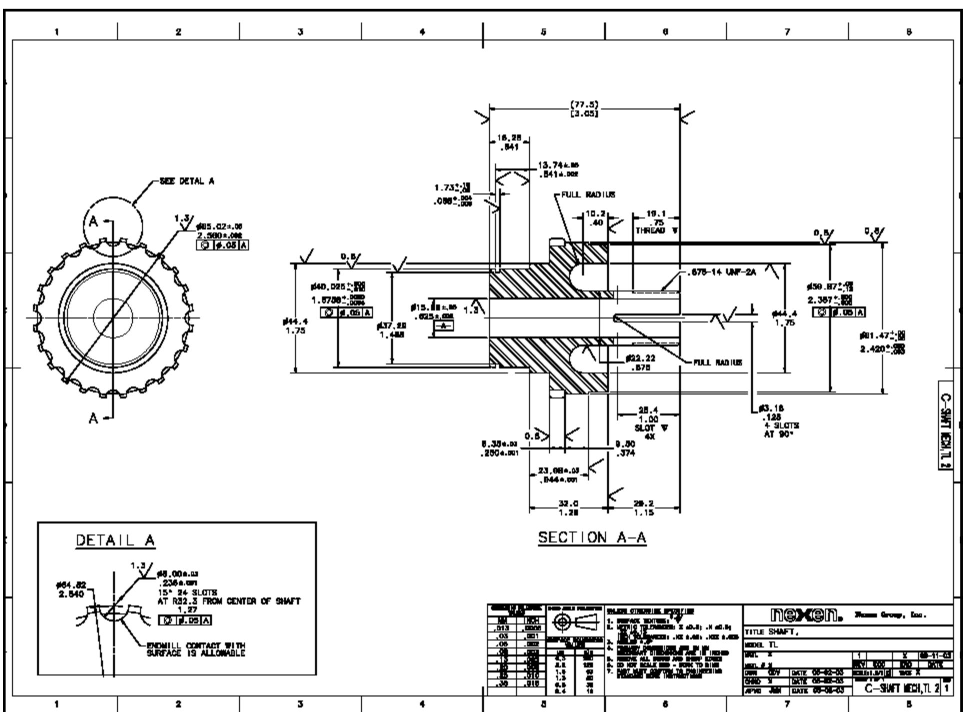


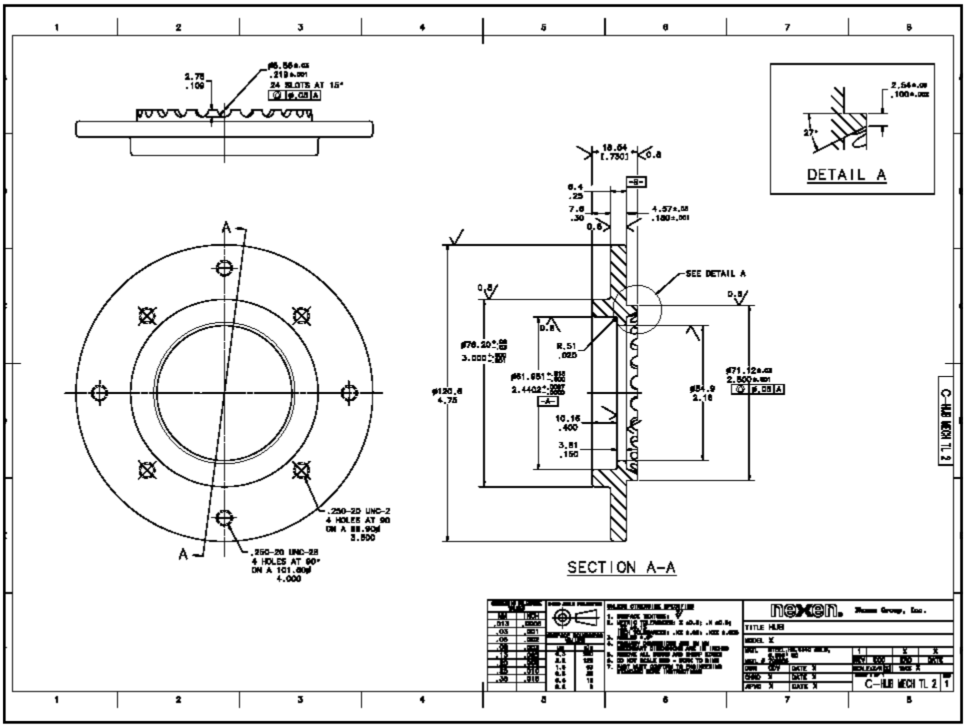
Project Management: Budget

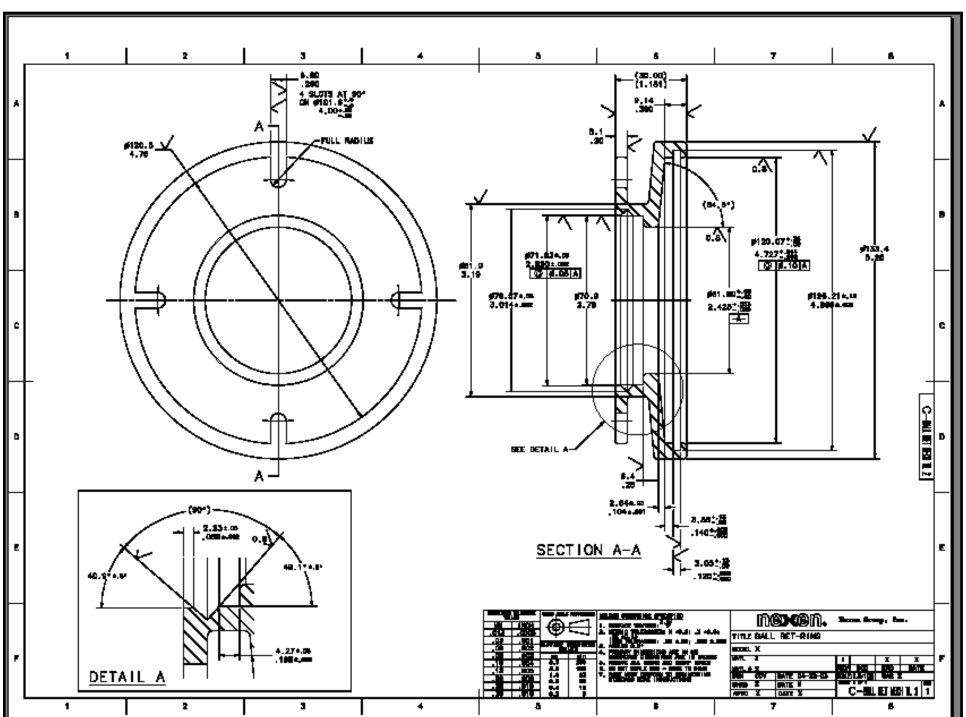
- Estimated prototype cost of $8,000
- Estimated tooling of $15 – 20,000 per spring size
- Estimated per unit cost of $100
  - Competitive product list price of $600
- Estimated 656 work-hours accrued by team and Nexen engineers

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




24 SLOTS AT 15°
SEE DETAIL A
DETAIL A
SECTION A-A
.250-20 UNC-2
4 HOLES AT 90
.250-20 UNC-2B
4 HOLES AT 90°
nexen
TITLE HUB
C-HUB MECH TL 2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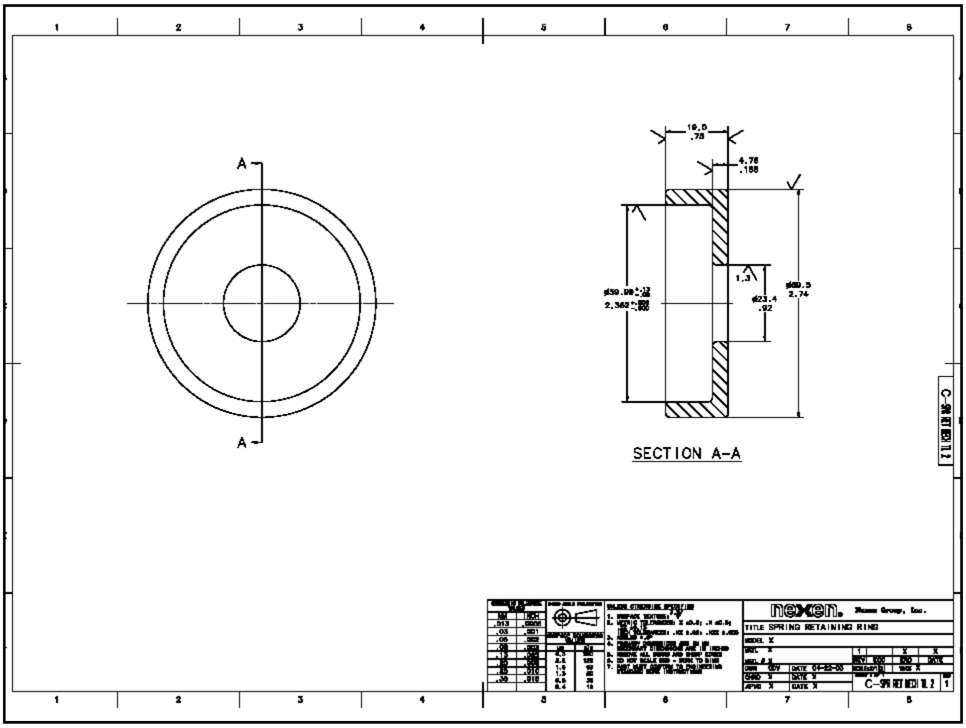
FULL RADIUS
SEE DETAIL A
SECTION A-A
DETAIL A
nexen
TITLE BALL RET-RING



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