



Electric Park Brake Actuator (EPBA)

**Technical Presentation
Livonia, February 21, 2003**

Pollak



A Stoneridge Company

Actuator Products Division



Agenda

- **Introduction**
- **Review of Proof of Concept test Data**
 - Design Validation
 - Actuator Noise Analysis
- **Production Intent Design Review**
 - Design Concept
 - Engineering Analysis and Calculations
- **Manufacturing Process**
 - Description
 - Proposed line layout
- **Program Timing**
 - Timing
- **Open Issues**



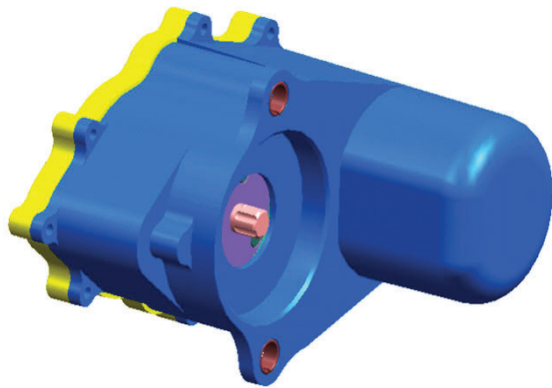
EPBA Team Roster

Project Manager
Program Manager
Project Engineer
Design Engineer
Gear Engineer
Manufacturing Engineer
Advanced Quality Engineer
Sales Account Manager
Purchasing
Account Manager (D)
Account Manager (MI)

Tom Schregardus
Curt Albee
Gary Kinnear
Bill Farmer
Henry Minasian
Yuly Yanishevsky
Peter Sulfaro
Rolf Patrick
John Sullivan
Greg Weber
Mark Schulte



Pollak POC Design Concept

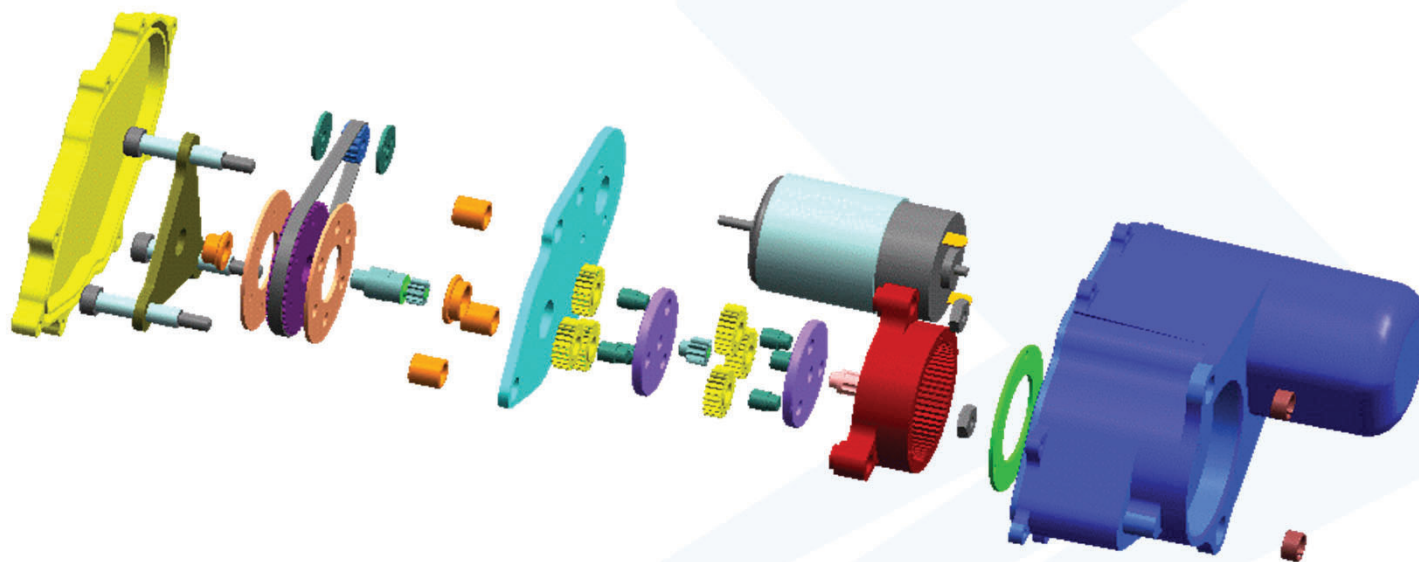


- 600 series motor
- 141:1 power train ratio
- First stage timing belt drive
- 2 stage planetary gear reduction set
- Provision for added sound/vibration isolation.



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Pollak POC Design Concept



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Gear Train Ratio

	Type	Drive	Driven	Ratio
1 st Stage	Timing belt	14	46	3.286
2 nd Stage	Planetary	11	61	6.545
3 rd Stage	Planetary	11	61	6.545

Overall gear ratio 140.8



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Design Verification

Specification Parameter	Value	Pollak Test Results
Output RPM TS 6-10-102, Section 6.1.1	65 RPM @20C & 12vdc	68 to 73 RPM measured over 200,000 cycle durability testing
	53 RPM @ -40C & 9vdc	55 to 57 RPM measured @ -40C & 9vdc
	80 RPM @ +120C & 12vdc	73 to 77 RPM measured @ +120C & 12vdc
Operating Voltage TS 6-10-105, Section 2.1.1 TS 6-10-110, Section 2.1.1	7 to 16 vdc	Motor calculations indicate minimum stall torque of 16.6 Nm @ 7 vdc



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Design Verification

Specification Parameter	Value	Pollak Test Results
No Load Current TS 6-10-102 Section 2.0	Less than 2 A @ +20C & 12 vdc	Measured no load current of 2 to 4 A over 200,000 durability cycles @ +20C & 12vdc
TS 6-10-102 Section 6.1	Less than 9 A @ -40C & 12vdc	Measured no load current of 4.3 to 6 A
	Less than 2.5 A @ +120C & 12vdc	Measured no load current of 1.7 to 2.0 A
15 Nm load Current TS 6-10-102 Section 2.0	Less than 17 A @ +20C & 12 vdc	Measured load current of 14 to 17 A over 200,000 durability cycles @ +20C & 12vdc
TS 6-10-102 Section 6.1	Less than 25 A @ -40C & 12 vdc	13 to 19 A measured @ -40C & 12 vdc
	Less than 19 A @ +120C & 12 vdc	17 to 19 A measured @ +120C & 12vdc
Inrush current TS 6-10-102 Section 2.0	Less than 37 A @ +20C & 12 vdc	Measured inrush current of 34 to 37 A

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Design Verification

Specification Parameter	Value	Pollak Test Results
Output torque, normal operating, TS 6-10-102, Section 2.0	15 Nm	16.6 Nm calculated stall torque at minimum conditions
Maximum output torque resistance, X TS 6-10-102, Sections 2.0 & 6.3.2	25 Nm	25.7 calculated maximum stall torque @ 12 vdc & +20C, 24 to 27 Nm measured stall torque from dynamometer tests performed every 10,000 cycles



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Design Verification

Specification Parameter	Value	Pollak Test Results
Overall gear train efficiency TS 6-10-102, Section 2.0	60% minimum after 1X life'	69% to 78% efficiency range observed over 200,000 durability cycles
Actuator Life TS 6-10-102, Section 6.3.1	100,00 cycles, 0-15 Nm apply, 15-0 Nm release	3 actuators have successfully completed 200,000 cycles durability. Extended durability testing to 400,000 cycles has been completed on the gear train and drive belt
Temperature Range TS 6-10-102, Section 4.0	-40C to +120C, Housing withstands +180C for 30 minutes	Meet requirements



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Durability Testing Results

- 200,000 cycle durability life successfully completed
- Post test conditions
 - Sun gear wear at first stage
 - Motor winding failures
- Motor issue due to failure to rebuild calipers at recommended intervals
- Rebuilt actuators have attained 400,000 durability life cycles



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Actuator Sound Level Testing

- Test equipment configuration
 - Mounted on caliper and placed on suspended platform
 - Microphone 150 mm from and at right angle to motor housing
 - 12 VDC and 20 C
- Test Data
 - Operated unloaded, 6 sec apply, 6 sec release
 - Operated loaded, extend and retract sampled together, 2.5 sec extend, 3 sec rest, 1.75 sec release



Dominant Frequencies

■ No Load

- 2485 Hz Belt/Pulley mesh
- 1770 Hz Motor commutator
- 885 Hz Armature poles
- 595 Hz 1st sun gear mesh
- 270 Hz 1st planet/ring mesh
- 196 Hz Belt span
- 175 Hz Motor shaft
- 90 Hz 2nd sun gear mesh
- 70 Hz Belt flex
- 55 Hz Driven pulley shaft
- 40 Hz 2nd planet/ring mesh
- 25 Hz 1st planet gear shaft

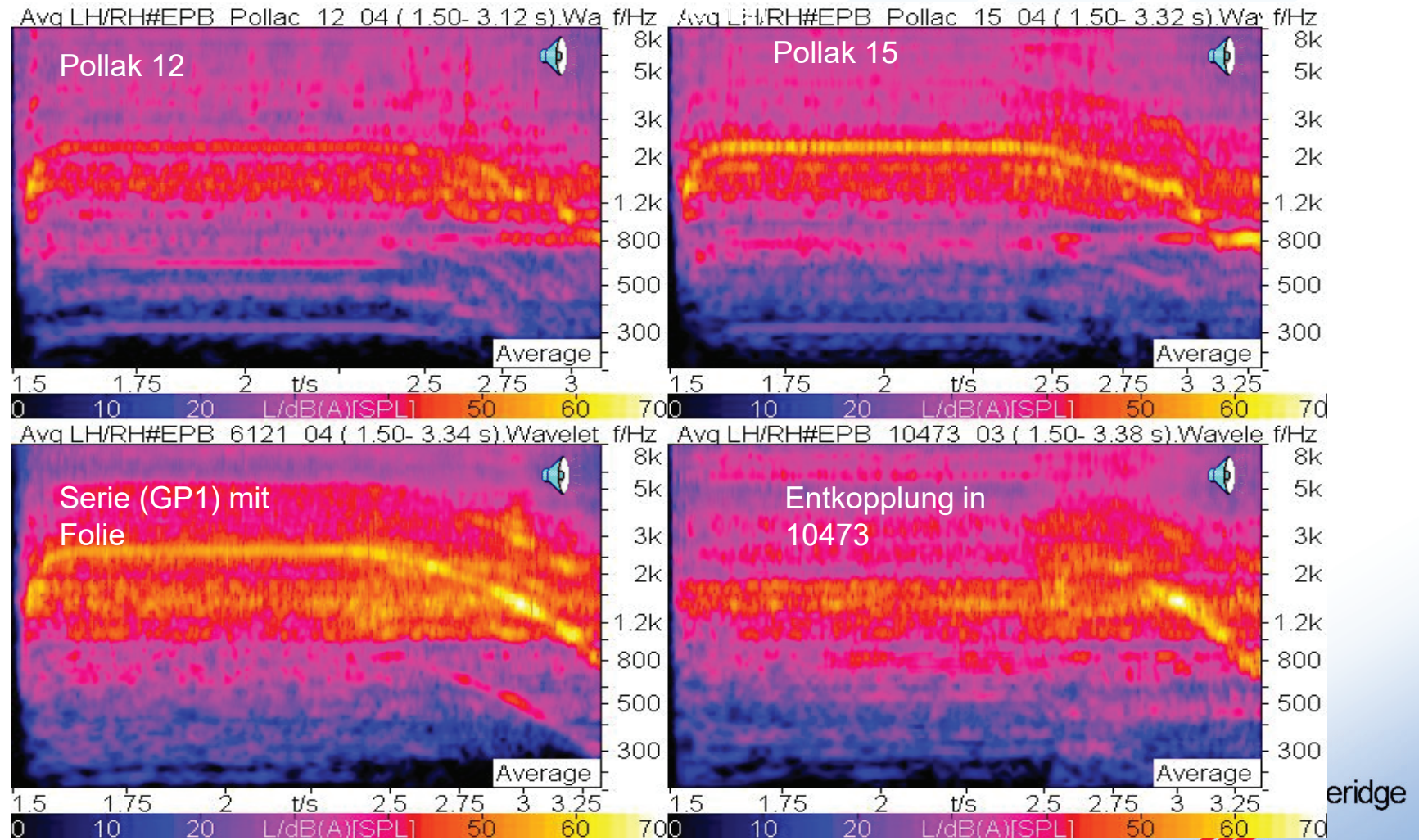
■ @ 15 Nm Load

- 1520 Hz Belt/Pulley mesh
- 1085 Hz Motor commutator
- 540 Hz Armature poles
- 365 Hz 1st sun gear mesh
- 196 Hz Belt span
- 165 Hz 1st planet/ring mesh
- 110 Hz Motor shaft
- 70 Hz Belt flex
- 55 Hz 2nd sun gear mesh
- 35 Hz Driven pulley shaft
- 25 Hz 2nd planet/ring mesh
- 15 Hz 1st planet gear shaft



TRW Sound Test Results

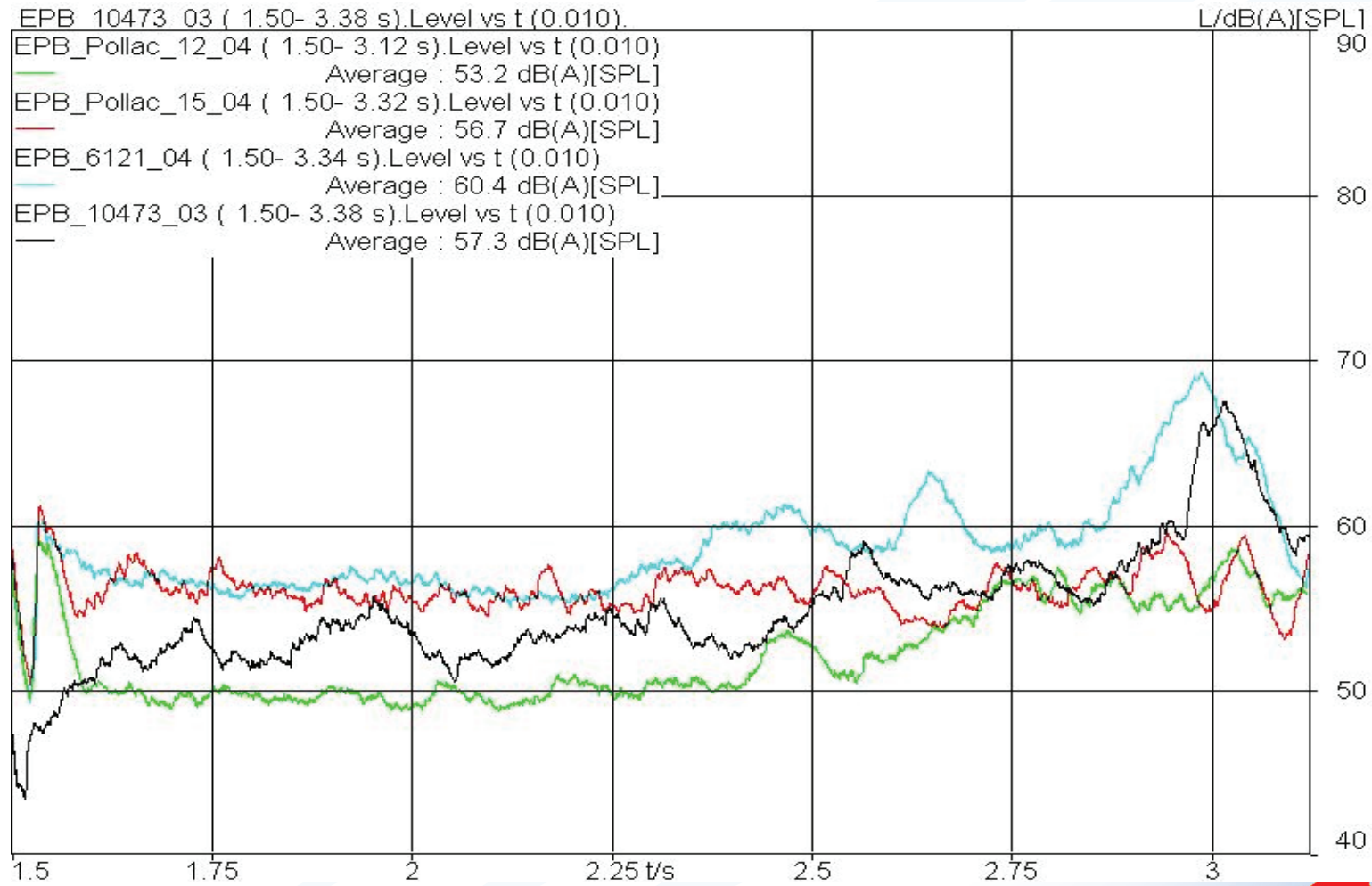
Wafelet HMS Average LH/RH



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TRW Sound Test Results

Level vs. Time HMS Average LH/RH



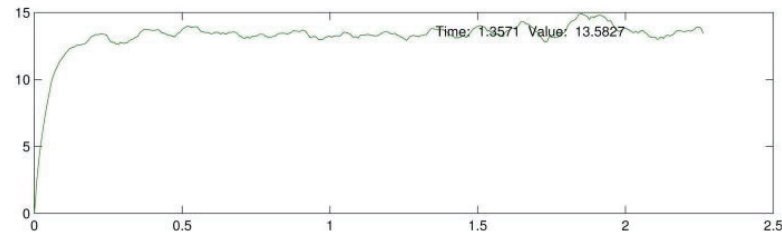
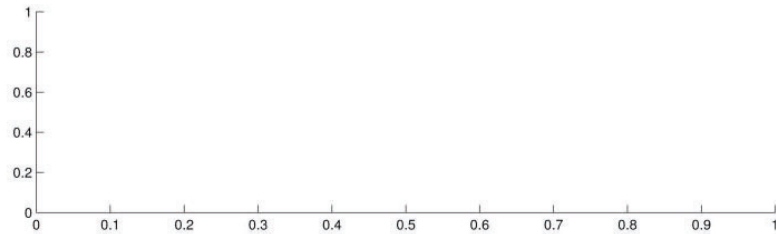
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Stoneridge

Pollak Sound Test Results

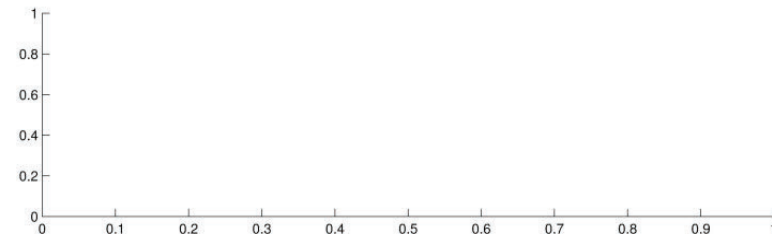
Pollak POC12 - Apply No Load

File Name: apply2.wav	Calibration File: cal test 01 11-11-02.wav
File Path:	Component Type: Power Adjustable Pedals
Description: TRW EPB POC12 @ 12vdc min 150mm away applied run2	
Average Loudness (L/R): 13.4679 13.467	Metric 2 (L/R):
Metric 3 (L/R):	Metric 4 (L/R):



Current Design - Apply No Load

File Name: current_caliper unloaded_extend.wav	Calibration File: cal test 01 11-18-02.wav
File Path: S:\X7104 TRW Park Brake	Component Type: Locks
Description: Deschler Unloaded condition extend direction @ 12vdc	
Metric 1 (L/R):	Metric 2 (L/R):
Metric 3 (L/R):	Metric 4 (L/R):

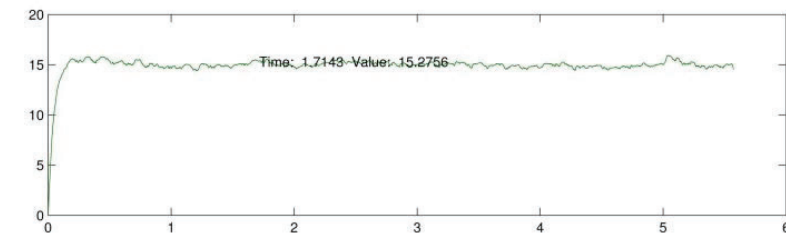
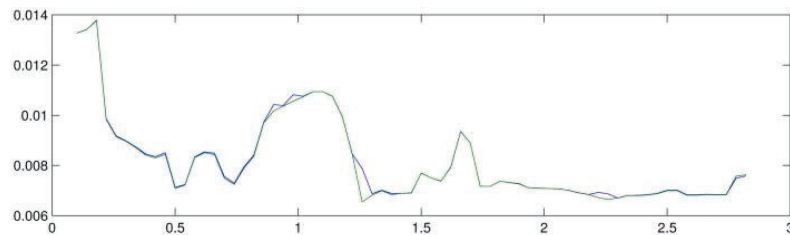


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Pollak Sound Test Results

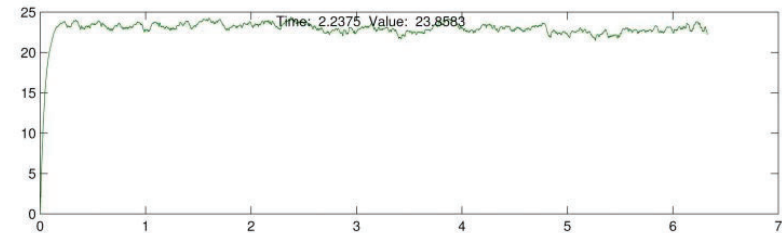
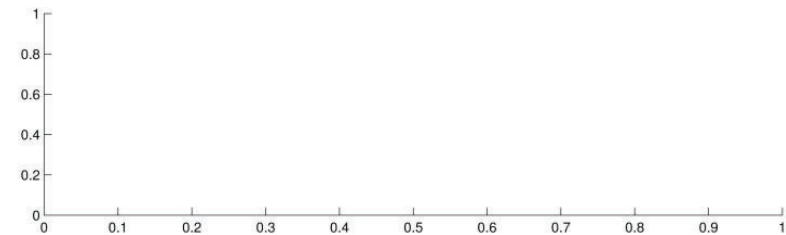
Pollak POC12 - Release No Load

File Name: release1.wav	Calibration File: cal test 01 11-11-02.wav
File Path:	Component Type: Power Adjustable Pedals
Description: TRW EPB POC12 @ 12vdc mic 150mm away release run1 unloaded	
Average Loudness (L/R): 15.0279 15.0266	Average Fluctuation (L/R): 0.0081773 0.0081362
Metric 3 (L/R):	Metric 4 (L/R):



Current Design - Release No Load

File Name: current_caliper_unloaded_retract.wav	Calibration File: cal test 01 11-18-02.wav
File Path: S:\X7104 TRW Park Brake	Component Type: Locks
Description: Deschler Unloaded condition retract direction @ 12vdc	
Metric 1 (L/R):	Metric 2 (L/R):
Metric 3 (L/R):	Metric 4 (L/R):



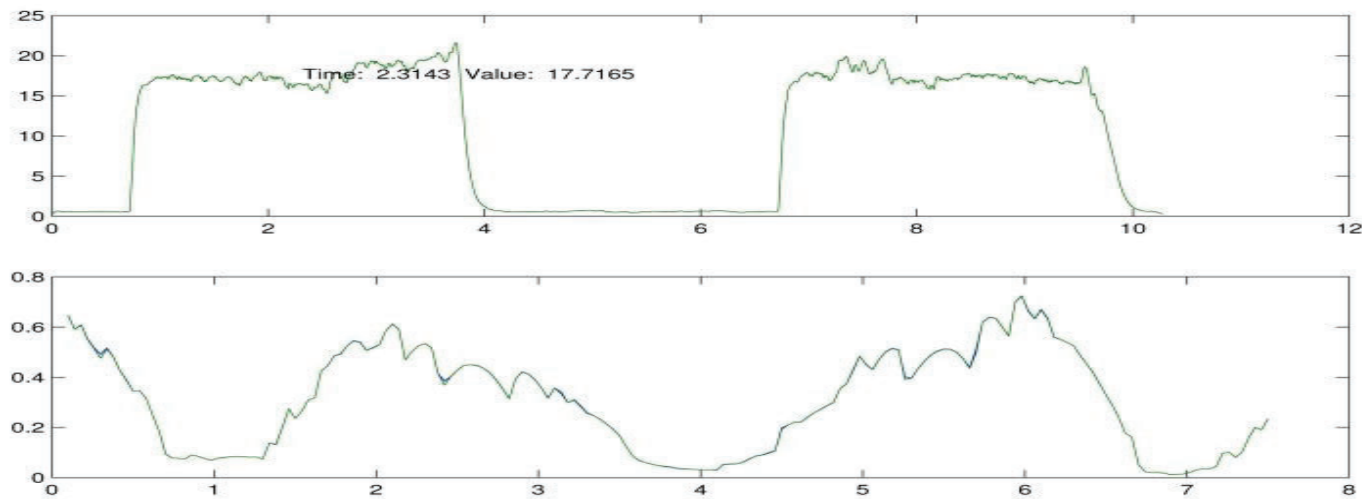
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Pollak Sound Test Results

Pollak POC12 - Apply & Release with Load

File Name: apply1.wav	Calibration File: cal test 01 11-11-02.wav
File Path:	Component Type: Power Adjustable Pedals
Description: TRW EPB POC12 @ 12vdc min 150mm away applied run1	
Average Loudness (L/R): 10.7914 10.7896	Average Fluctuation (L/R): 0.30512 0.30478
Metric 3 (L/R):	Metric 4 (L/R):

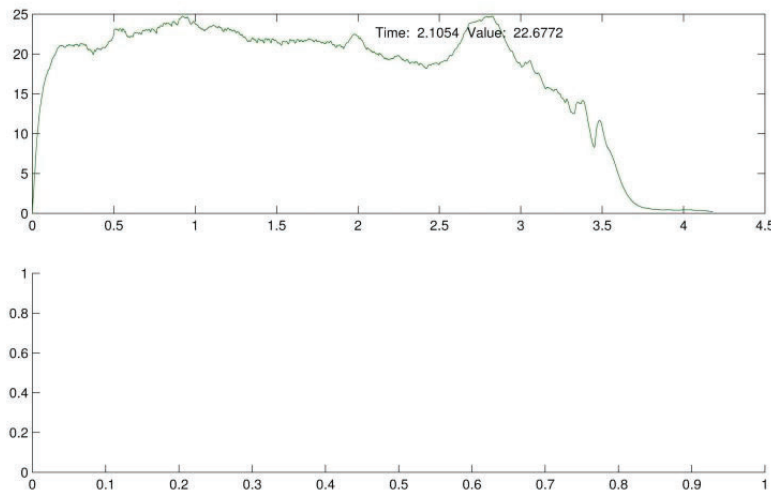


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Pollak Sound Test Results

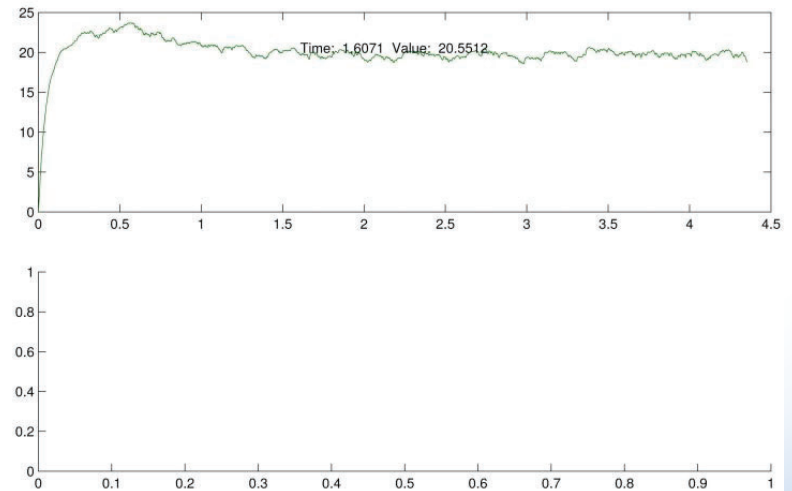
Current Design - Apply w/Load

File Name: current_caliper loaded_extend.wav	Calibration File: cal test 01 11-18-02.wav
File Path: S:\X7104 TRW Park Brake	Component Type: Locks
Description: Deschler Loaded condition extend direction @ 12vdc	
Metric 1 (L/R):	Metric 2 (L/R):
Metric 3 (L/R):	Metric 4 (L/R):



Current Design - Release w/Load

File Name: current_caliper loaded_retract.wav	Calibration File: cal test 01 11-18-02.wav
File Path: S:\X7104 TRW Park Brake	Component Type: Locks
Description: Deschler Loaded condition retract direction @ 12vdc	
Metric 1 (L/R):	Metric 2 (L/R):
Metric 3 (L/R):	Metric 4 (L/R):



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Pollak Sound Test Summary

Unit	Apply No Load	Apply With Load	Release No Load	Release With Load
POC #12	13.5 sones	18 sones	15 sones	18 sones
Current Design	22 sones	22.7 sones	23.9 sones	20.6 sones



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Pollak Production Intent Design

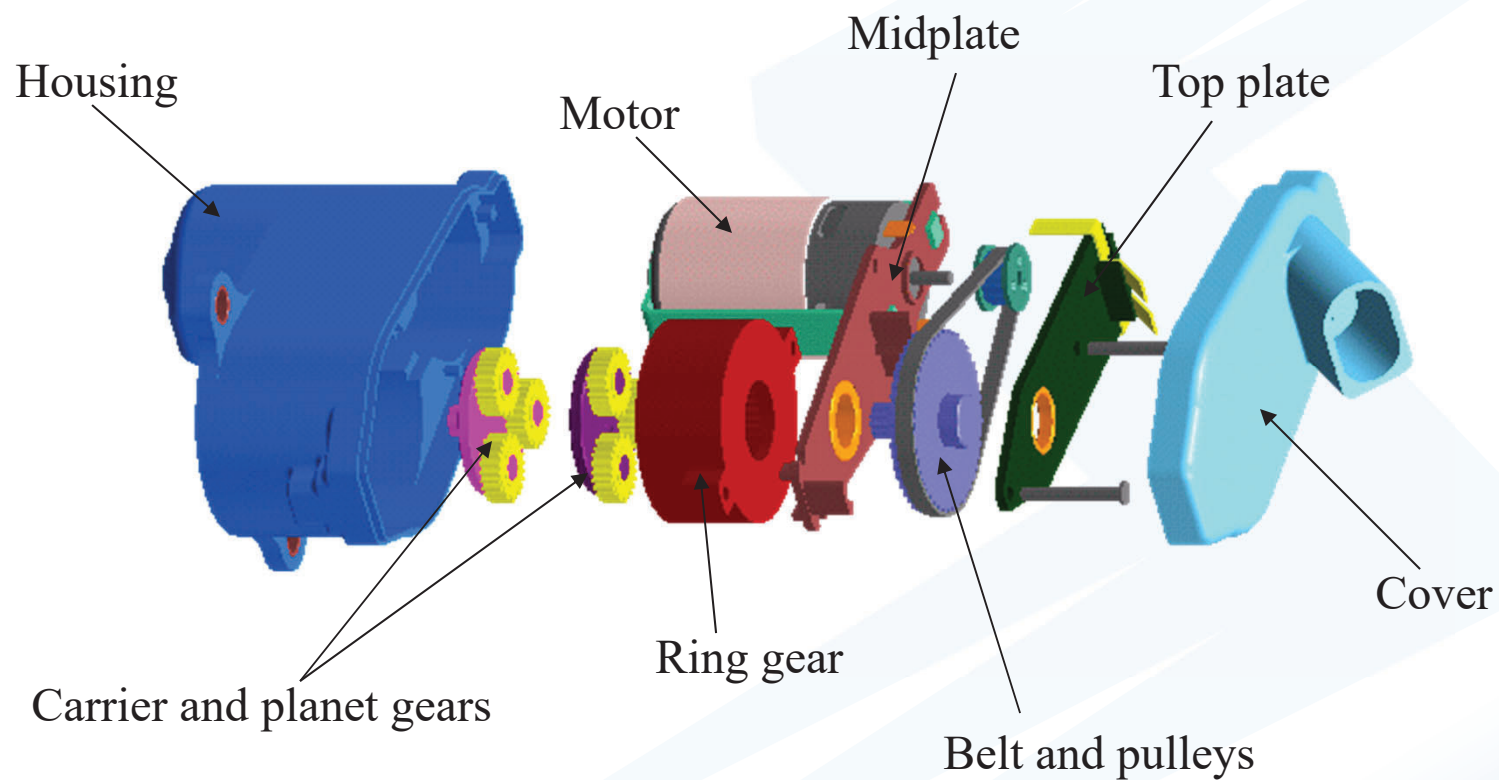


- 600 series motor
- 141:1 power train ratio
- First stage timing belt drive
- 2 stage planetary gear reduction set
- Provision for added sound/vibration isolation.



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Pollak Production Intent Design



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Pollak Production Intent Design

Bill of Material

Component	Material
Housing, Drive & Driven pulley	Nylon 46, 40% glass filled
Cover & Top plate	Nylon 46, 15% glass filled
Midplate	Aluminum A380
Ring gear, Carriers, Planet gears, Driven pulley	Powder metal, FL 8528, 6.9 g/cc density, post heat treated
Belt	EPDM with fiberglass cords
Bearings	SAE 841 sintered bronze
Lubricant	Gear quality synthetic hydrocarbon PAO or POE based
Terminals	Brass, C26000, tin pre-plated
Motor mount	Cold rolled steel, zinc pre-plated



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Belt Tension Analysis

- Timing belt with HTD tooth profile
- 4.3 mm width
- EPDM rubber with fiberglass cords
- 0 N minimum & 10 N maximum belt tension pre-load
- 32 N load contribution at 25 Nm output torque
- Maximum belt tension load of 42 N at 25 Nm output torque
- Belt power rating 0.12 kw
 - Actual power transmitted 0.10 kw
 - Calculated service factor 1.2



PV Calculations

Driven pulley shaft

	No Load	15 Nm Load
Top bearing velocity	2.16 m/s (426 Fpm)	1.32 m/s(260 Fpm)
Bottom bearing velocity	2.16 m/s (426 Fpm)	1.32 m/s(260 Fpm)
Top bearing pressure	.34 N/mm ² (15 psi)	.51 N/mm ² (50 psi)
Bottom bearing pressure	.51 N/mm ² (50 psi)	.77 N/mm ² (75 psi)
Top bearing PV	.734 (6,400)	.673 (13,000)
Bottom bearing PV	1.10 (21,300)	1.02 (19,500)

- Performance calculated for sintered bronze bearings.
- Maximum bearing pressure 13.79 N/mm² (2000 psi).
- Maximum surface speed of 6.10 m/s (1200 fpm)
- Maximum PV 1.75 (50,000)



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PV Calculations

1st & 2nd Planetary stages

	No Load	15 Nm Load
1 st Stage axle velocity	.493 m/s (97 Fpm)	.300 m/s (59 Fpm)
1 st Stage axle pressure	N/A	2.34 N/mm ² (339 psi)
1 st Stage PV	N/A	.702 (20,000)
2 nd Stage axle velocity	.103 m/s (20.3 Fpm)	.062 m/s (12.2 Fpm)
2 nd Stage axle pressure	N/A	14.00 N/mm ² (2,050 psi)
2 nd Stage PV	N/A	.868 (25,000)



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Gear Tooth Bending Stress

1st Planetary Stage

	15 Nm Load	Safety Factor	Metric 25 Nm	Safety Factor
Sun gear tooth load	42.4 N (9.53 lb)		70.7 N (15.89 lb)	
Sun gear stress	44.6 Mpa (6,500 psi)	14.6	74.4 Mpa (10,800 psi)	8.7
Planet gear tooth load	42.4 N (9.53 lb)		70.7 N (15.89 lb)	
Planet gear stress	34 Mpa (4,950 psi)	19	56.7 Mpa (8,250 psi)	11.5
Ring gear tooth load	42.4 N (9.53 lb)		70.7 N (15.89 lb)	
Ring gear stress	25.2 Mpa (3,700 psi)	26	41.9 Mpa (6,100 psi)	15

- Gear material FL 8528, 6.9 g/cc density
- Minimum yield strength 650 Mpa (94,000 psi)
- Loads are based on output torque divided by 2.85
Safety factor based on minimum yield stress



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Gear Tooth Bending Stress

2nd Planetary Stage

	Metric 15 Nm	Safety Factor	Metric 25 Nm	Safety Factor
Sun gear tooth load	253 N (56.9 lb)		421 N (94.6 lb)	
Sun gear stress	266.1 Mpa (38,600 psi)	2.44	443.5 Mpa (64,300 psi)	1.47
Planet gear tooth load	253 N (56.9 lb)		421 N (94.6 lb)	
Planet gear stress	202.8 Mpa (29,300 psi)	3.2	338 Mpa (47,900 psi)	1.92
Ring gear tooth load	253 N (56.9 lb)		421 N (94.6 lb)	
Ring gear stress	149.9 Mpa (21,800 psi)	4.3	249.9 Mpa (36,300 psi)	2.6

- Gear material FL 8528, 6.9 g/cc density
 - Minimum yield strength 650 Mpa (94,000 psi)
 - Loads are based on output torque divided by 2.85
- Safety factor based on minimum yield stress

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Carrier Axle Stress 1st Stage

	15 Nm Load	Safety Factor	25 Nm Load	Safety Factor
Axle Load	72.1 N (16.2 lb)		120.2 N (27 lb)	
Shear Stress	2.3 Mpa (350 psi)		3.8 Mpa (550 psi)	
Bending Stress	7.3 Mpa (1,100 psi)		12.2 Mpa (1,800 psi)	
Combined Stress	7.6 Mpa (1,100 psi)	85	12.7 Mpa (1,850 psi)	51

- Gear material FL 8528, 6.9 g/cc density
- Minimum yield strength 650 Mpa (94,000 psi)
- Loads are based on output torque divided by 2.85
Safety factor based on minimum yield stress



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Carrier Axle Stress 2nd Stage

Component	15 Nm Load	Safety Factor	25 Nm Load	Safety Factor
Axle Load	430 N (101 lb)		717 N (161 lb)	
Shear Stress	13.6 Mpa (1,980 psi)		22.7 Mpa (3,300 psi)	
Bending Stress	43.5 Mpa (6,300 psi)		72.4 Mpa (10,500 psi)	
Combined Stress	45.5 Mpa (6,600 psi)	14.3	75.9 Mpa (11,000 psi)	8.6

- Gear material FL 8528, 6.9 g/cc density
- Minimum yield strength 650 Mpa (94,000 psi)
- Loads are based on output torque divided by 2.85
Safety factor based on minimum yield stress



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Manufacturing Strategy

Low Volume Production

High Volume Production



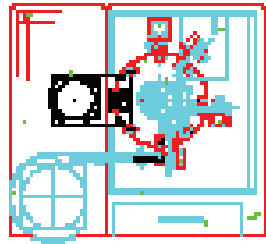
Low Volume Production

- Assembly Line Description
 - Progressive Assembly Line
 - Eight Operators
 - Material Flow Left to Right
 - Bench Top Assembly Fixtures
 - Flexibility to Balance the Line
 - Stand Alone Automated Carrier Assembly Machine

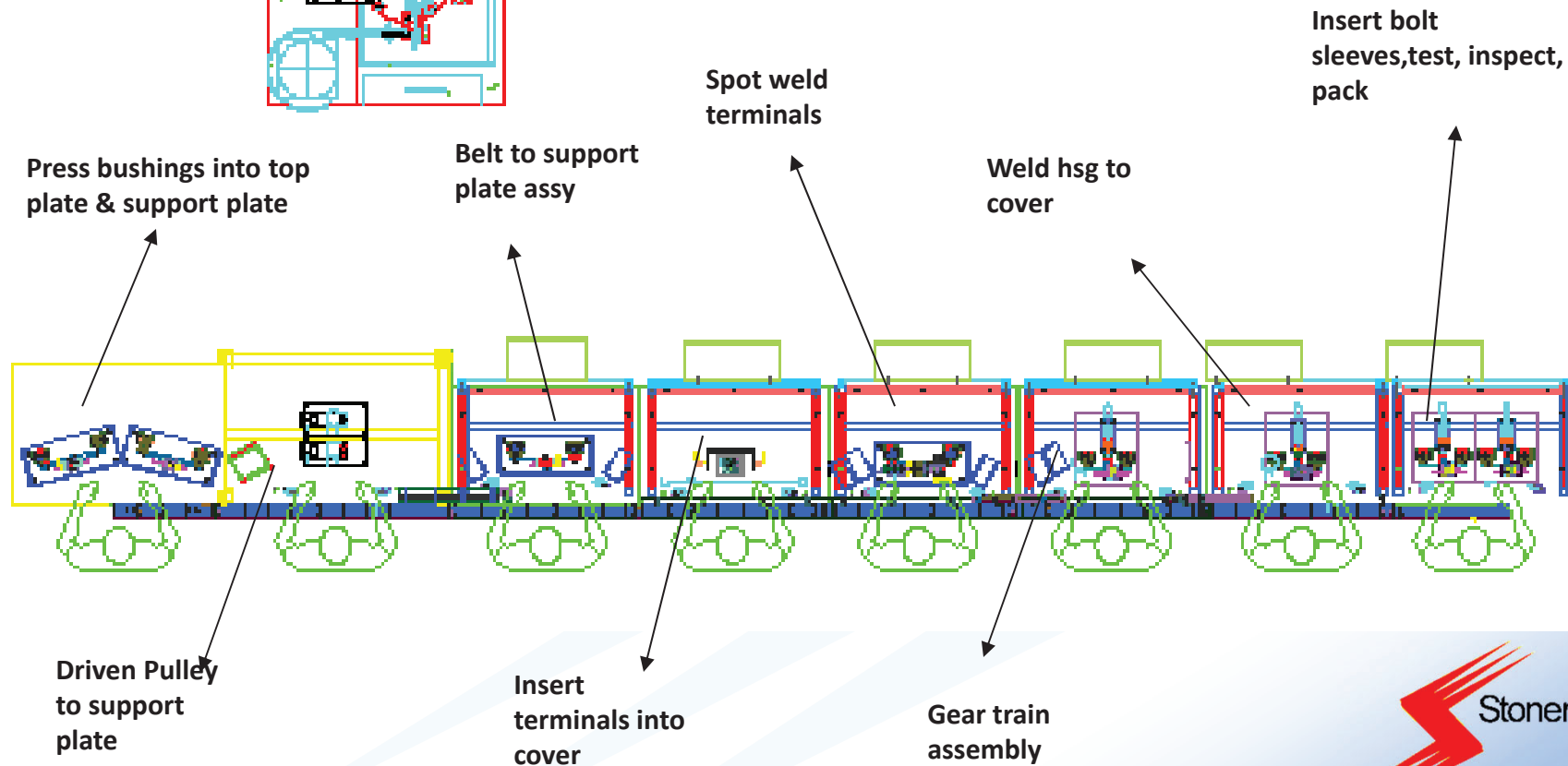


Equipment Layout

Carrier Assembly machine



Production Rate 240Pcs/hr



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Manufacturing Strategy

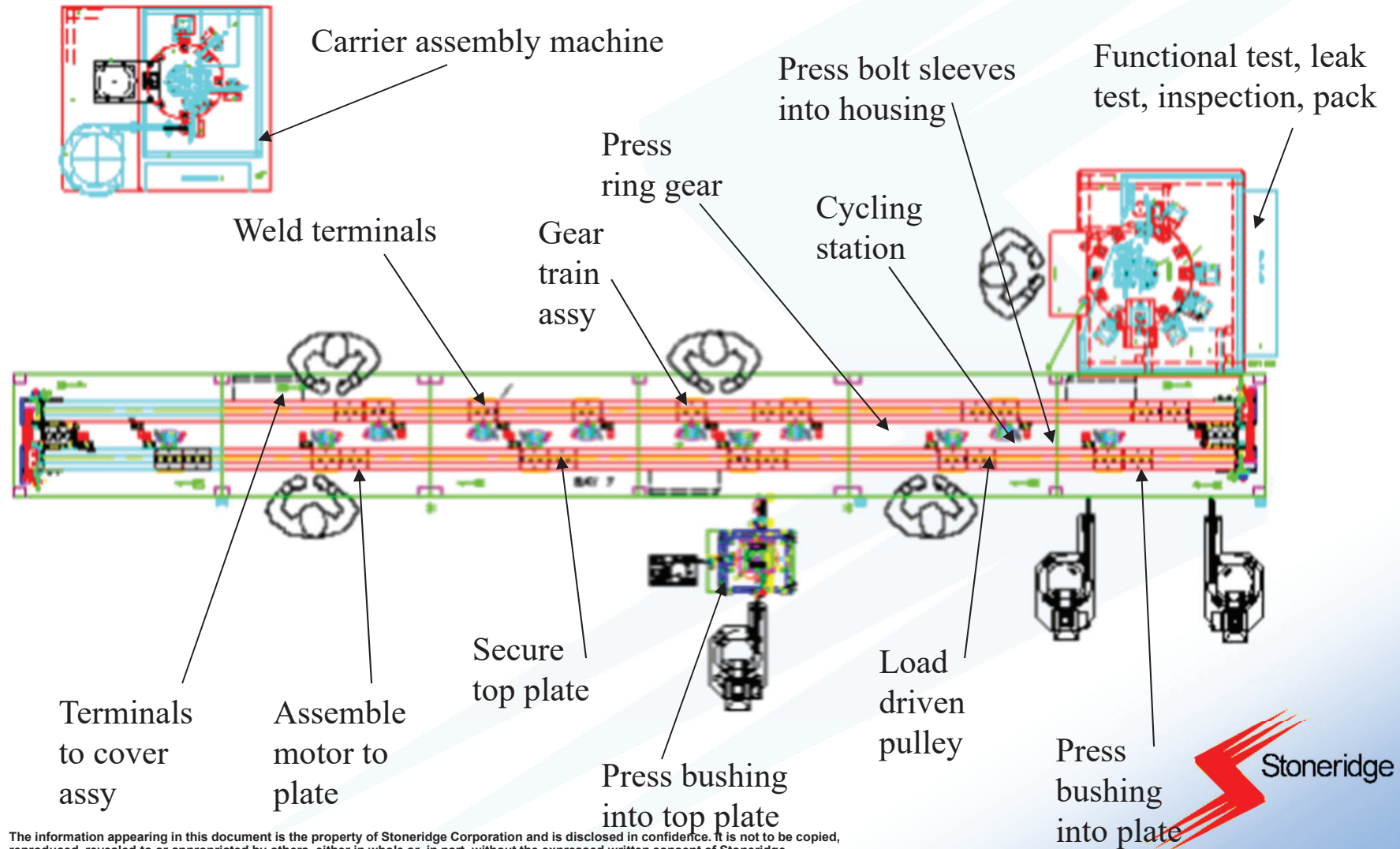
High Volume Production

- Line Description
- Asynchronous, semi-automated assembly line
- Five operators
- Flexibility to add automation cells to reflect production ramp up plan
- 9 sec cycle time



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Manufacturing Layout



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Program Timing

TRW Electric Park Brake (EPB) Actuator Pollak X7104																																								
ID	Task Name	Dur	Start	Finish	2002												2003												2004											
					A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1																																								
2	✓ Concept Development	6 wks	4/30/02	6/10/02																																				
3	✓ POC	26 wks	6/10/02	12/9/02																																				
4	✓ Design Review & PO	0 wks	6/10/02	6/10/02																																				
5	✓ Design	6 wks	6/11/02	7/22/02																																				
6	✓ Part Fabrication	8 wks	7/23/02	9/16/02																																				
7	✓ Assembly	1 wk	9/17/02	9/23/02																																				
8	✓ Debug	1 wk	9/24/02	9/30/02																																				
9	✓ Burn-In	1 wk	10/1/02	10/7/02																																				
10	✓ Evaluation Testing	2 wks	10/1/02	10/14/02																																				
11	✓ 2 Units Available for Customer	0 wks	11/11/02	11/11/02																																				
12	✓ Continued Evaluation Testing	8 wks	10/15/02	12/9/02																																				
13	✓ 3 units Available to Customer	0 wks	11/27/02	11/27/02																																				
14																																								
15	✓ Customer visit to Boston	0 wks	12/5/02	12/5/02																																				
16																																								
17	Customer Evaluation / Testing	8 wks	12/18/02	2/11/03																																				
18																																								
19	Tooled Prototypes	31.8 wks	12/5/02	7/15/03																																				
20	Design Updates	10 wks	12/5/02	2/12/03																																				
21	Receive Customer Commitment	0 wks	2/11/03	2/11/03																																				
22	Component Tooling	16 wks	2/12/03	6/3/03																																				
23	Assembly Equipment	8 wks	2/12/03	4/8/03																																				
24	Test Fixtures	8 wks	2/12/03	4/8/03																																				
25	Build	1 wk	6/4/03	6/10/03																																				
26	First Parts Available	0 wks	6/10/03	6/10/03																																				
27	DV Testing	5 wks	6/11/03	7/15/03																																				
28	DV Parts Available	0 wks	7/15/03	7/15/03																																				
29																																								
30	Customer Evaluation & Test	34 wks	7/16/03	3/9/04																																				
31																																								

Open Issues

- What is the targeted North American platform?
- What other efforts to attract other OEM platforms?



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