GEARS 2019

Technical Awareness Seminar

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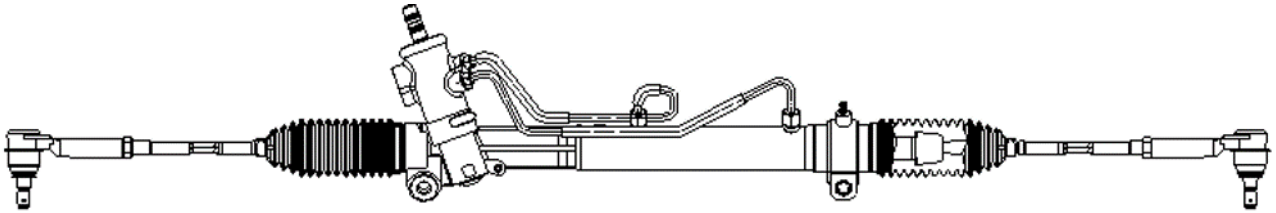
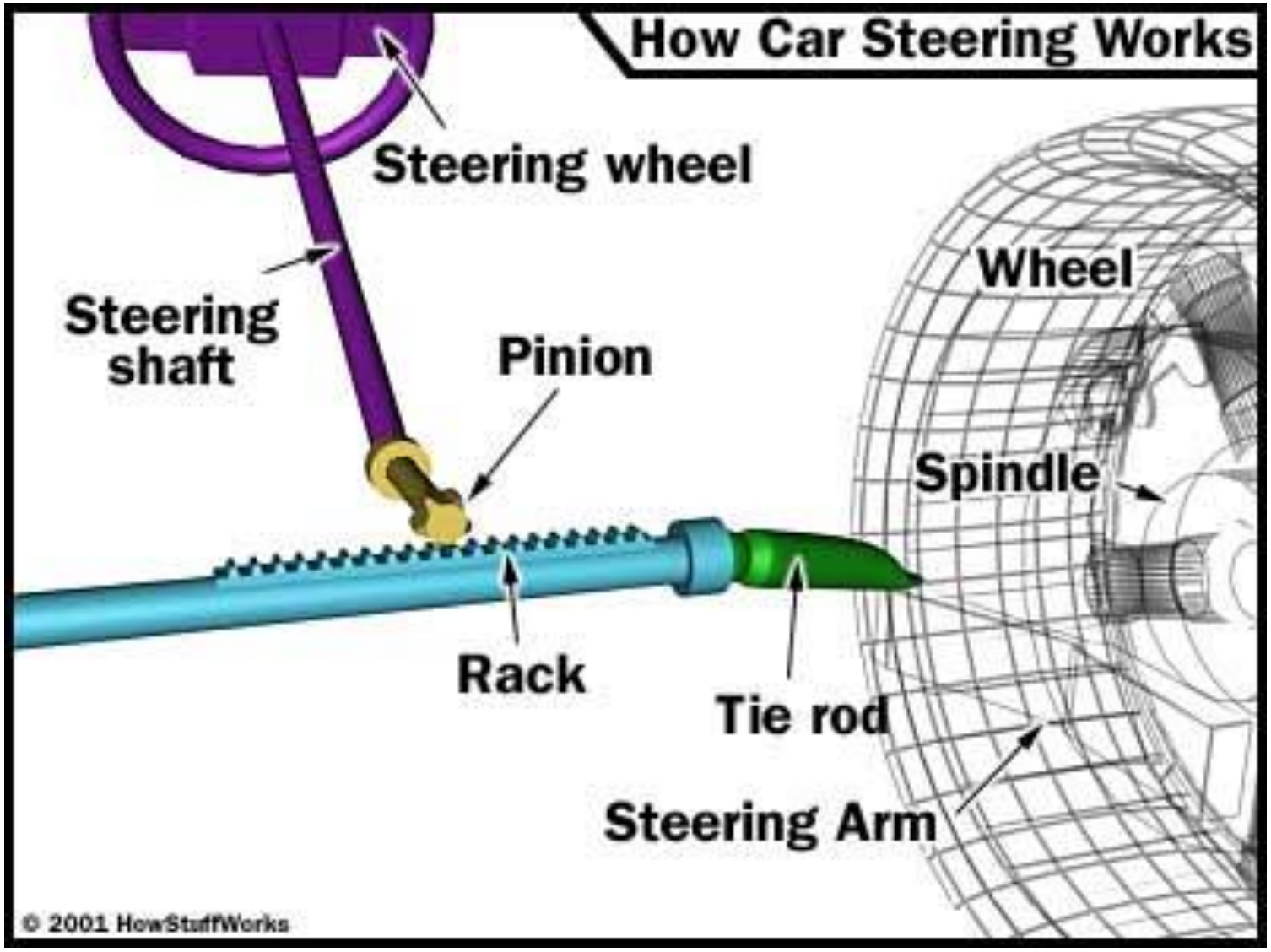
Meeting Functional Requirements for a Hydraulic Rack & Pinion Steering Gear



Denis G Sexton CEng MIMechE

BGA
British Gear Association

Steering Gear Mechanical System

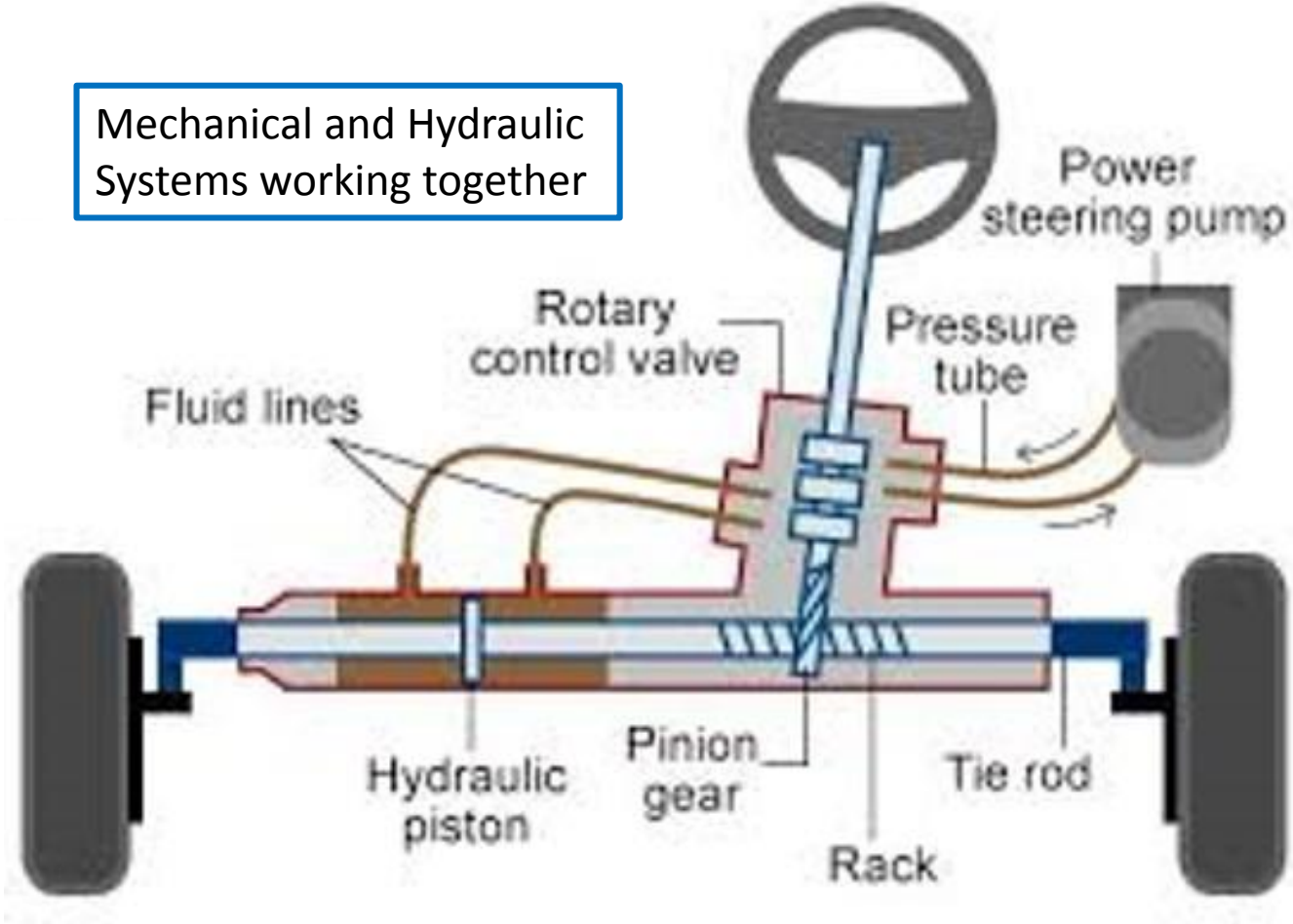


Rack & Pinion Tooth Dimensional Data (partial)

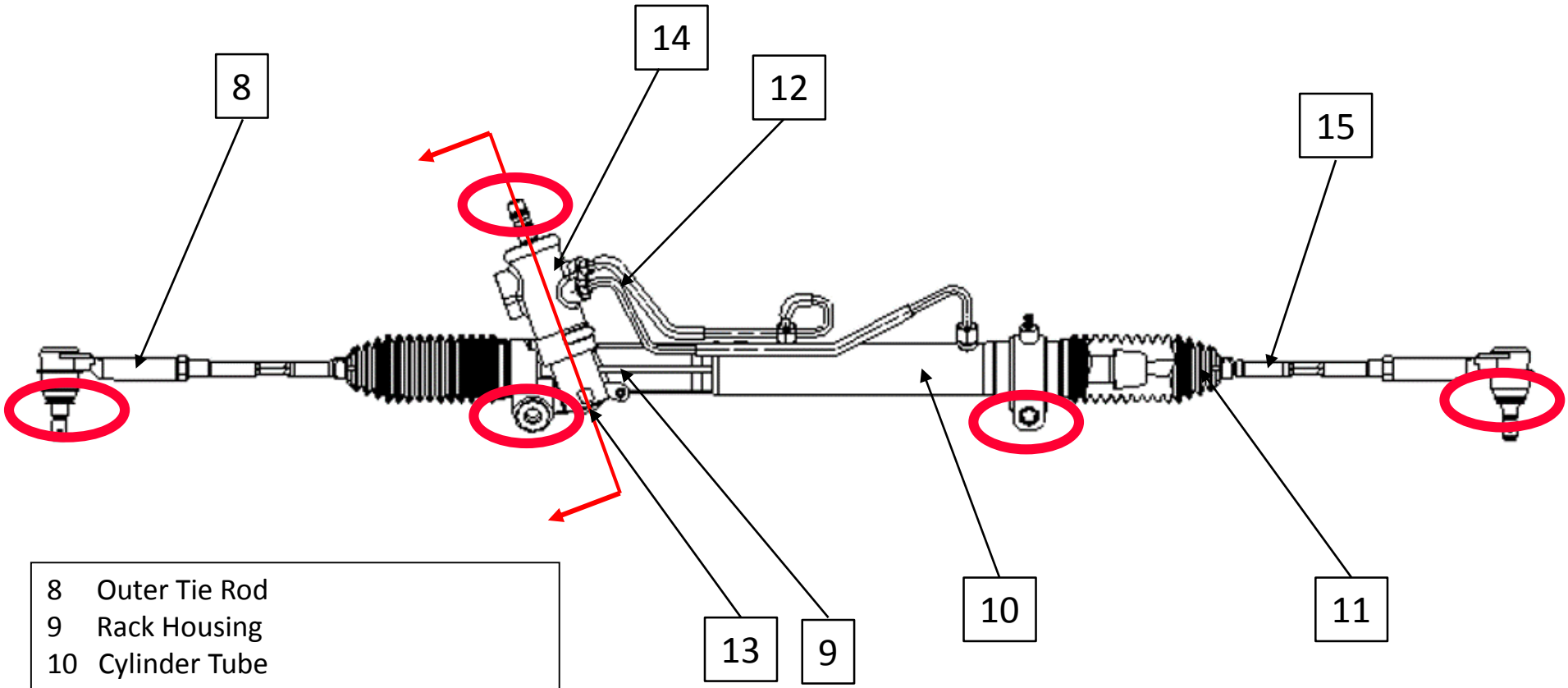
Feature or Characteristic	Rack	Pinion
Number of Teeth	30	9
Whole Tooth Depth	3.441 mm	2.967 mm
Normal Circular Pitch	5.36 mm	5.36mm
Normal Pressure Angle	20	20
Normal / Circular Tooth Thickness	1.798 mm	3.562 mm
Normal Diametral Pitch (American Standard)	14.89 mm	N/A
Normal Module	N/A	1.706 mm
Pitch Diameter	N/A	17.083 mm
Lead (Left Hand)	N/A	110.035 mm
Rack Diameter O/D over 3.0mm Gauge Pin	26.372 - 26.500 mm	N/A
Pinion tooth distance over 2.769 mm balls	N/A	21.968-21.872 mm
Addendum	N/A	2.031 mm
Dedendum	N/A	0.936 mm
Total Lead Tolerance	N/A	0.035 mm max
Average Lead Tolerance (4 teeth)	N/A	0.025 mm max
Total Surface Roughness	1.6 Ra	1.6 Ra
Pitch Varation	N/A	0.023 mm
Total Index Variation	N/A	0.055 mm max
Profile Tolerance	N/A	Ref detail
Toth to Tooth Composite Tolerance	N/A	0.02 mm max
Total Composite Tolerance	N/A	0.025 mm max
Major Diameter	N/A	21.206 - 21.081 mm
Minor Diameter	N/A	15.360 - 15.060 mm

Overview of an Automotive Hydraulic Steering System

Mechanical and Hydraulic Systems working together

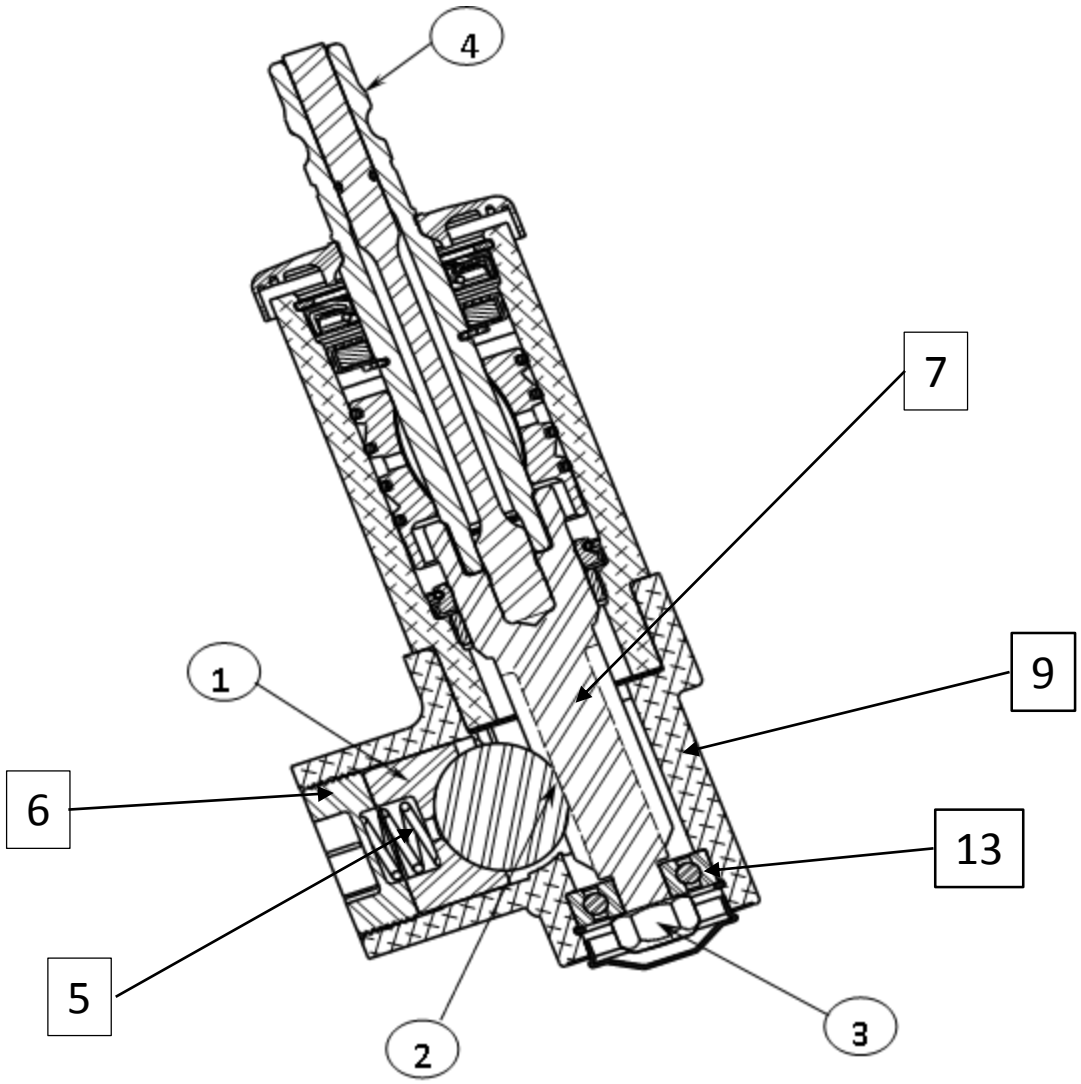


Principal Components (BOM) External View



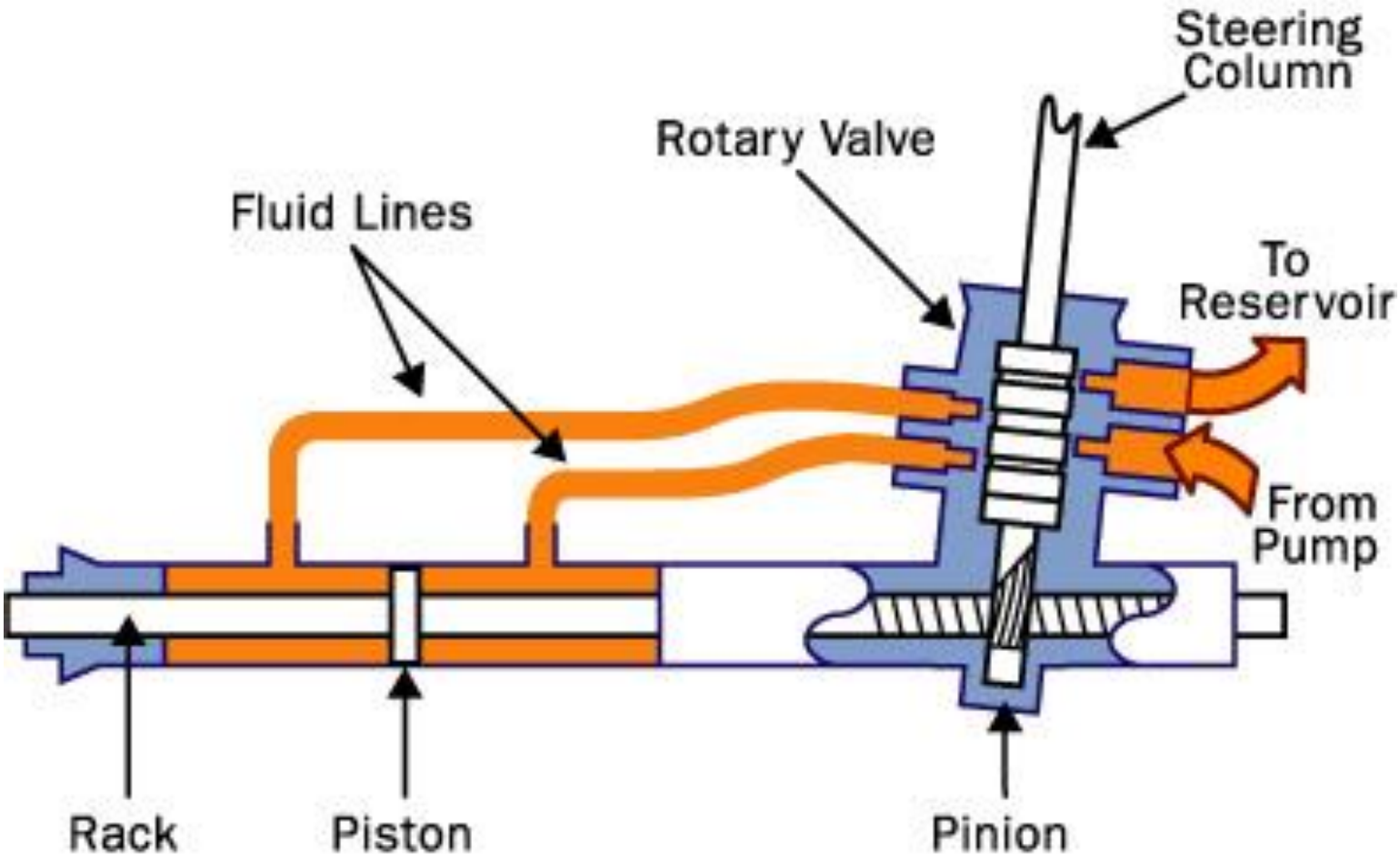
8	Outer Tie Rod
9	Rack Housing
10	Cylinder Tube
11	Boot
12	Cylinder Lines
13	Pinion Bearing (see next view)
14	Valve Housing
15	Inner Tie Rod

Principal Components (BOM) Section View



1	Rack Guide Bearing
2	Rack (at pinion contact).
3	Pinion locknut
4	Valve Assembly
5	Adjuster spring
6	Adjuster plug
7	Pinion
13	Pinion Bearing

Gear Hydraulic System



Hydraulic Rotary Valve Functional Specifications

Function Test Rig Parameters

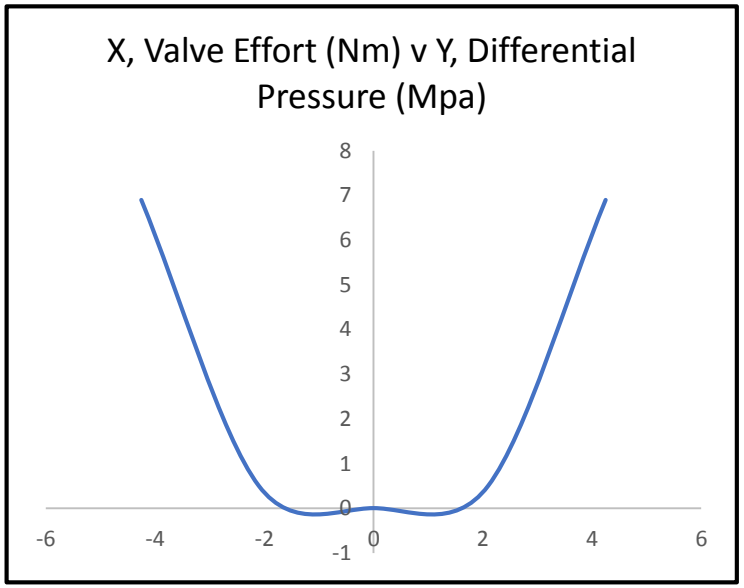
Fluid Type Caltex 27168 DX II

Fluid Temperature 60°C ± 3C

Fluid Flow 7.1 ± 0.1 L/min

Rotational Speed 0.01 ± 0.0035 Rad/sec

Rotary Pressure Effort Diagram



Valve Characteristics Required

Noise (Hiss) Spec exists, but not defined here

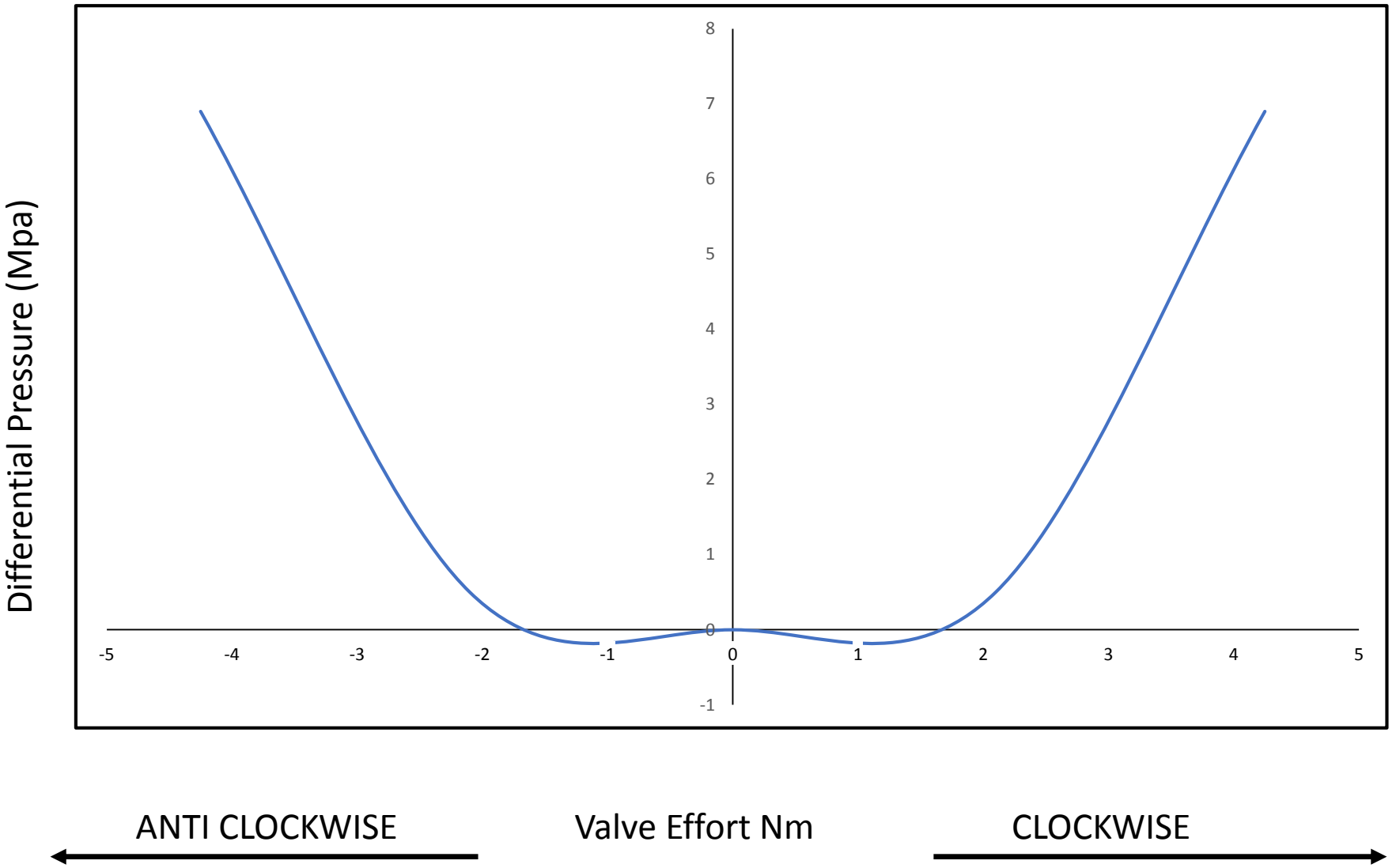
Back Pressure The difference between input and return not to exceed 0.3 Mpa

Valve Balance 0.25Nm max of being equal at 0.5 Mpa in addition to back pressure

Leakage Must not exceed 900 cm^3/ min, at 8.05 ± 0.25Mpa with valve spool in full Offset under above defined function test parameters. Leakage spec is for internal.

Hysteresis Must be less than 1Nm (from 0-8Mpa) @ 2.0 Mpa

Rotary Valve Pressure Effort Diagram



Full Gear Hydraulic and Functional Testing

The following functional specifications were developed by the Engineering design team. Every gear rack was tested to ensure these specifications were met at final Assembly on the gear function machine. . Test conditions for all functions were at rack speed of 15.87 mm/sec, pinion speed of 28 RPM and hydraulic oil temperature of 60C ± 3C, and flowrate @ 7.1 ± 0.1 L/min

Regular Static Friction (Dry) 0.7 – 1.47 Nm Max

Peak to Peak 0.39 Nm (Max difference across full travel of Rack)

Forward Efficiency 4.95 ± 0.55 Nm against a resisting force of 2000 N

Peak to Peak 0.25 Nm (Max difference across full travel of Rack)

Returnability (Reverse Friction) 190 N +/- 80 N (presentation follows)

Peak to Peak 60 N (Max difference across full travel of Rack)

Internal Leakage Max leak no more than 900 CC /min @ 10.3Mpa

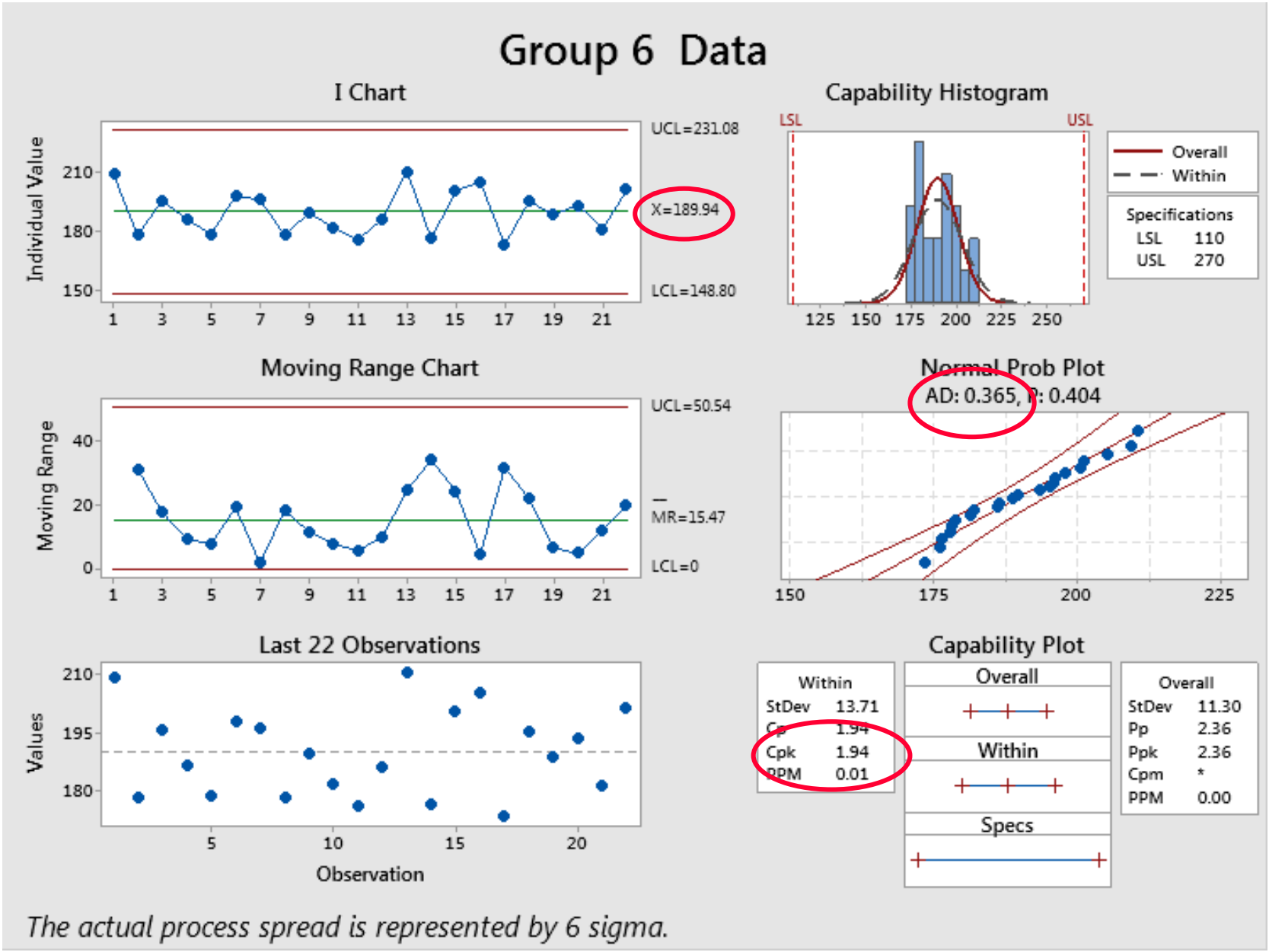
External Leakage Max leak no more than 3.5 CC /min @ 0.28Mpa

Gear Returnability Original Factor Parameters (N)

Factor	Level +	Level -
A, Rack Speed	25.4 mm/sec	15.87 mm/sec
B, Pinion Speed	40 RPM	28 RPM
C, Oil Temp & Flow	60°C & 7.1 L/min	38°C & 6.0 L/min

	Factor A Rack Speed	Factor B Pinion Speed	Factor C Temp C	AB	AC	BC	ABC	Results	Grand Mean-Diff	Squared
Group 3	-	-	-	+	+	+	-	223.75	5.18	26.81
6	-	-	+	+	-	-	+	189.94	-28.63	819.73
7	-	+	-	-	+	-	+	224.95	6.38	40.65
5	-	+	+	-	-	+	-	205.07	-13.50	182.30
2	+	-	-	-	-	+	+	235.47	16.89	285.34
8	+	-	+	-	+	-	-	212.76	-5.81	33.78
1	+	+	-	+	-	-	-	241.83	23.26	541.07
4	+	+	+	+	+	+	+	214.81	-3.76	14.15
SUM								1,749.0		
Mean								218.60		
SST										1943.8

Group 6, Returnability Analysis in Time Series (units N)



The actual process spread is represented by 6 sigma.

Observations

The design team initially used Caltex 27168 DX II hydraulic test oil which was designed to be used at a temperature of 60°C, and a flow rate of 7.1 L/min

The statistical stability and capability was impressive, but maintaining the hydraulic oil temperature at 60°C ± 3C on the functional test rig proved a problem under production conditions, (as well as a possible safety issue).

The initial cycle time for the gear assembly was 92 seconds which was felt to be too long to maintain both 100% test requirements in the required cycle time.

An alternate hydraulic fluid was sourced (Caltex ATF DXII) for testing the gear Assembly. This had a lower optimal operating temperature of 38°C, and a reduced flow rate of 6 L/min. Changing to this Lower temperature oil, it was possible to maintain stable control over temperature and to replicate the tests for ALL of the specific characteristics under test, under new test parameters.
We only report on returnability here, but the results of the dry testing, as well as all The other parameters including leak (if any) were recorded.

Gear Returnability, Alternate Factor Parameters (N)

Factor	Level +	Level -
A, Rack Speed	25.4 mm/sec	15.87 mm/sec
B, Pinion Speed	40 RPM	28 RPM
C, Oil Temp & Flow	60°C & 7.1 L/min	38°C & 6.0 L/min

	Factor A Rack Speed	Factor B Pinion Speed	Factor C Temp C	AB	AC	BC	ABC	Results	Grand Mean-Diff	Squared
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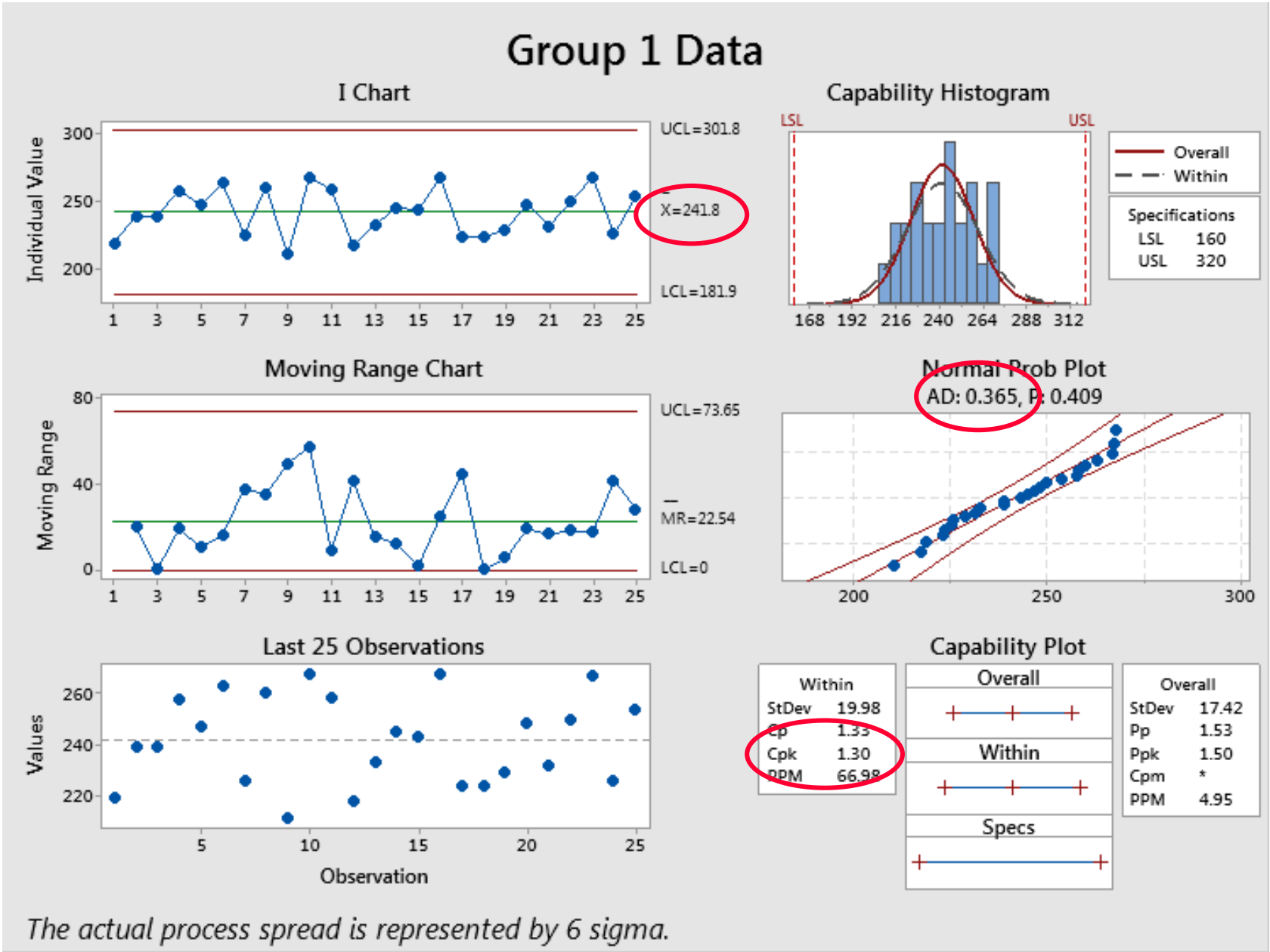
6	-	-	+	+	-	-	+	189.94	-28.63	819.73
7	-	+	-	-	+	-	+	224.95	6.38	40.65
5	-	+	+	-	-	+	-	205.07	-13.50	182.30
2	+	-	-	-	-	+	+	235.47	16.89	285.34
8	+	-	+	-	+	-	-	212.76	-5.81	33.78
1	+	+	-	+	-	-	-	241.83	23.26	541.07
4	+	+	+	+	+	+	+	214.81	-3.76	14.15
SUM								1,749.0		
Mean								218.60		
SST										1943.8

Group 1, Returnability Analysis in Time Series (units N)



The actual process spread is represented by 6 sigma.

Next Steps

- Test the gears under the new test conditions resulted in Cycle time being reduced from 92 seconds to 65 seconds

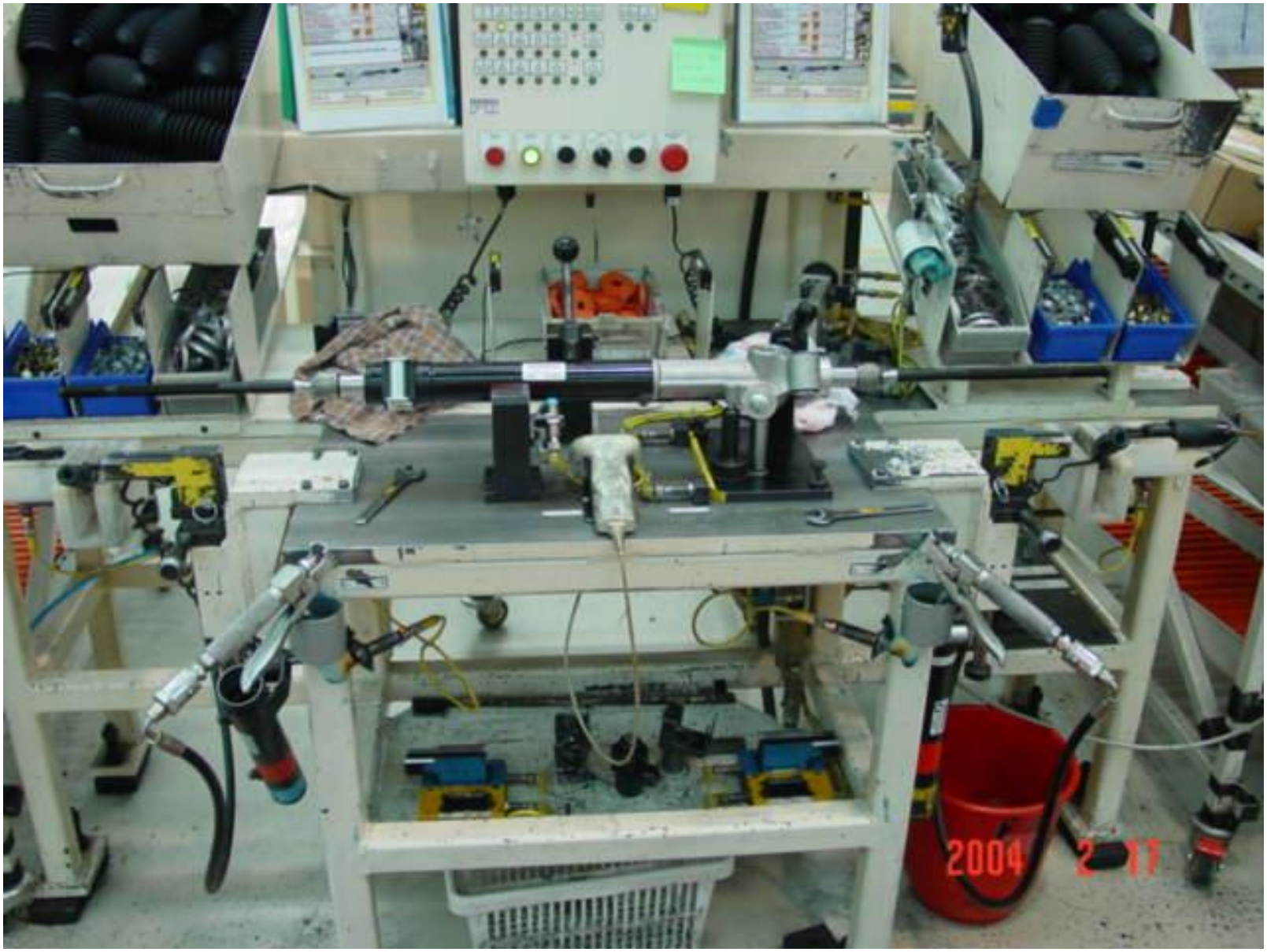
- Process Capability was reduced from 1.94 Cpk to 1.30 Cpk. This resulted in a Potential increase in DPMO from 9 to 8198 PPM. This sounds a lot, but in practice it resulted in only one or two extra re-tests a day, so was considered a small price to pay for the much improved throughput.

- New mean value for returnability at 241.8 N was within the original design spec of 190 N ± 80N, and the original design spec was developed under a different test medium.

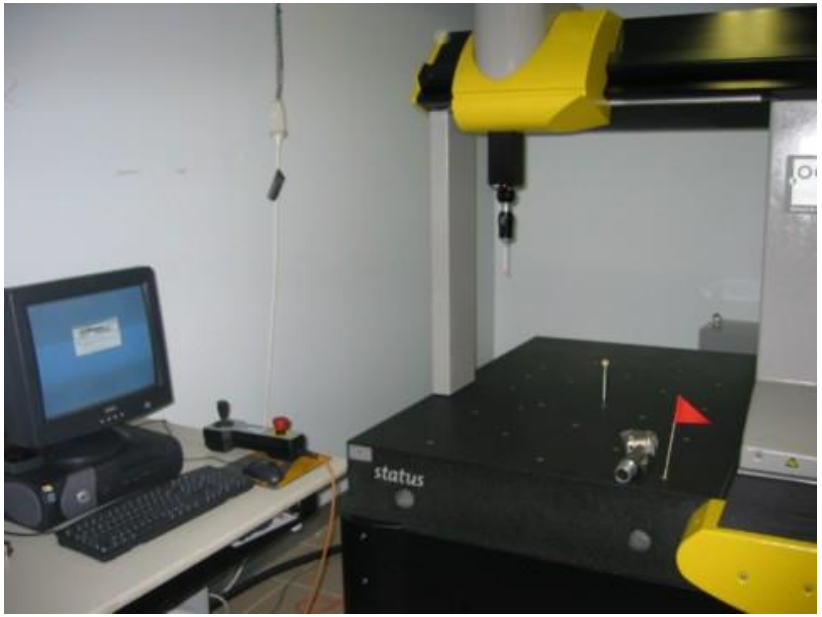
- The results for forward efficiency and leakage were also revised in line with the new test parameters, and the customer engineering function was fully informed of final trial results.

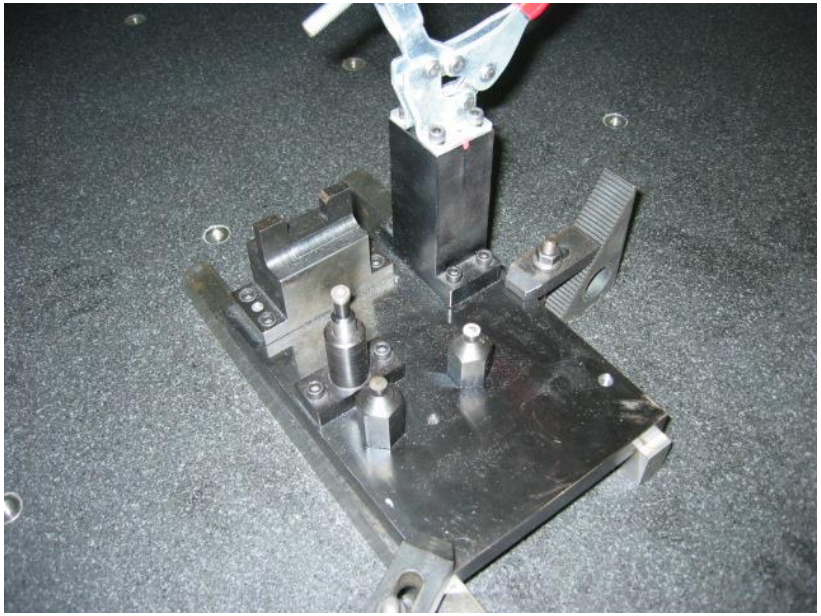
- The new specification of 240 ± 80N for returnability was accepted under the revised input parameter conditions as were revised specifications for forward efficiency and leak rate. Manufacturing capability proved very capable, the next model business was also won.

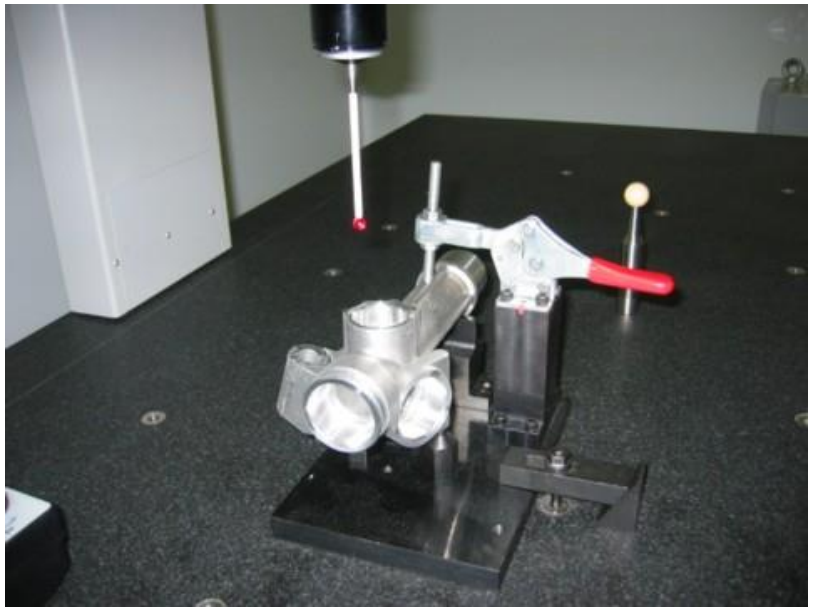
Production Assembly

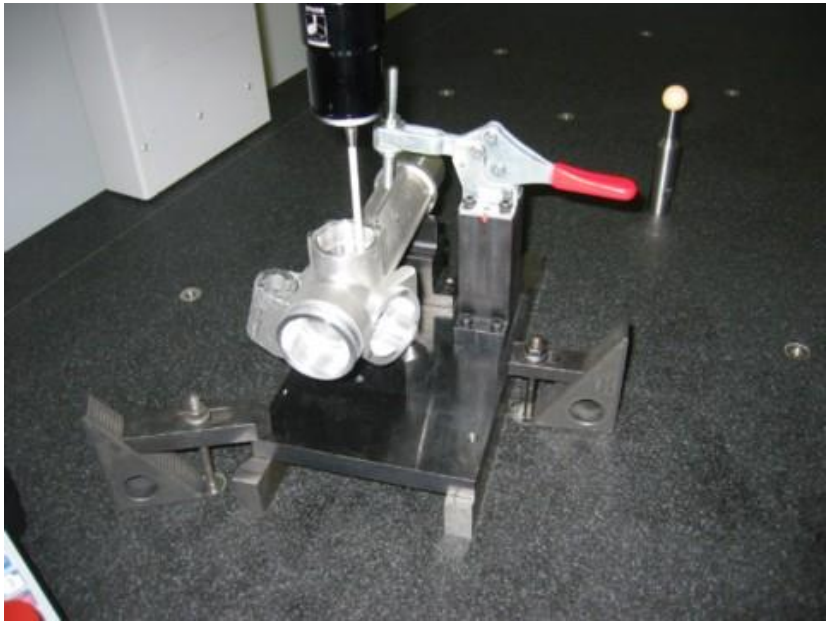


Rack Housing Inspection









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Thank you for your attention, Questions?

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