Summary of the Liner Measurement Workshop
Southwest Research Institute – December 18, 2001
PerkinElmer – December 19, 2001

Introduction

The attendance list is attached. The 2001 liner measurement round robin data and the liner measurement procedures were reviewed and discussed. The data and the procedures are attached. The discussion centered on the leveling differences between the PDI and Talysurf instruments. The T-10 wear steps show elevated wear levels as well as some wear at the second ring turnaround. The two instruments do not level these types of traces in the same manner, thus causing significant differences in the measured wear result. Additional concern was expressed over the age of the Talysurf software/algorithm. The labs also agreed that a 500 micro-inch step should be used for the instrument calibration check before each set of measurements.

Measurement Trial # 1

- Round Robin Liner #6, 11:00 position
- Both PDI and Talysurf
- Results:

	Talysurf		PDI	
Lab	1	2	1	2
EG	50.37	50.70	55.51	55.13
EV			53.97	53.80
LZ			55.40	57.10
MB	47.82	41.92	56.33	55.78
SR	39.50	49.76	62.40	63.00
SR			63.50	63.40

- Discussion:
  - Talysurf and PDI significantly and unacceptably different
  - PDI variability larger than expected
  - Leveling techniques felt to be root cause
    - Talysurf leveling is fully automated, misses some wear. Believed to be incapable of capturing true wear picture for all traces. Refer to Figure 1.
    - Operator leveling techniques varied on PDI. Felt to be cause of PDI variability. Refer to Figures 2 and 3.

- Recommendations:
  - Discontinue the use of the Talysurf
  - Make the following refinements to the PDI procedure:
    1. Leveling Lines: set left line at 20 mm from right end of trace (right level line), unless anomalies in the trace are noted.
    2. Wt Bracket Lines: left bracket line placed to the left of maximum depth; the intersection with the trace must be below the leveling line.
    3. Anomalies: right side anomalies (trace tails either up or down) to be excluded from both the Wt and the leveling brackets (i.e. move lines to the left of anomalies).
    4. Anomalies: left side anomalies (humps or dents in the trace) require operator judgment to capture best leveling line. The trace should not be skewed up or down, but should be horizontal.

5. Anomalies: scratches below maximum wear depth require that the Δz measurement must be used. Operator judgment must be used to determine the best level.
6. Output: Both the Wt and the leveling brackets must be shown. The trace must show both waviness and texture (to help judge true wear area).

- These changes were used for measurement trials 2 and 3.

Measurement Trials 2 and 3

- Trial 2 at SR, Trial 3 at EG
- Results:

Liner 1 3:00	Trial 2	Trial 3
SR	53.23	47.81
EG	52.70	49.16
MB	52.56	49.28
LZ	52.16	49.32
EV	52.64	48.84
Liner 1 8:00	Trial 2	Trial 3
SR	32.17	29.63
EG	32.01	29.16
MB	32.27	30.02
LZ	31.99	29.64
EV	32.31	29.17
Liner 2 9:00	Trial 2	Trial 3
SR	10.85	8.77
EG	10.25	9.02
MB	10.87	8.80
LZ	10.54	8.42
EV	10.83	8.49

- Discussion of Trials 2 and 3
  - Trial 2 data looks good
  - Trial 3
    - Severity shift from SR to EG
    - Some additional variability between operators. Focus on positioning of liner on V-block.

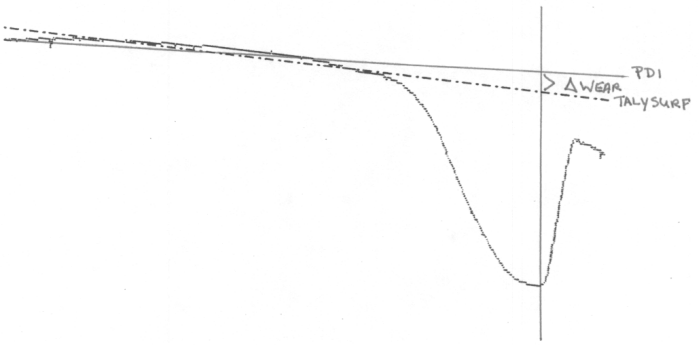
Summary Discussion

- Once leveling technique was standardized, positioning may be the large contributor of variability. The liner must be snug to the v-block and the trace must cover the true center line of the wear step.
- Stylus Concerns: 0.0001 in. radius tip is desired, labs to confirm.

Post Workshop Developments

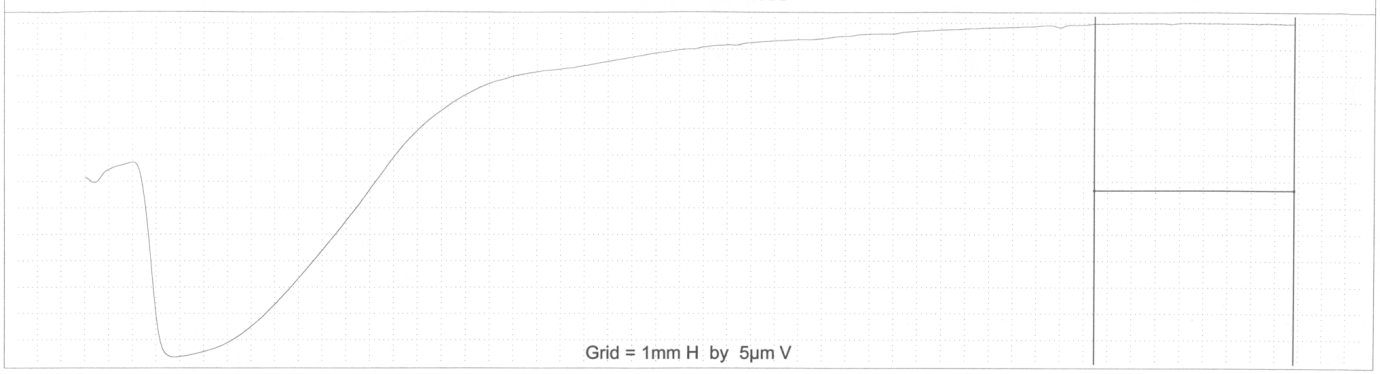
- SR and EG to investigate severity shift between trials 2 and 3
  - exchange tracer heads and re-run trials
  - examine difference in liner mounting blocks
- SR and EG to contribute set of liner to start round robin.

FIGURE 1



SOUTHWEST RESEARCH INST.

Profiles: Waviness



Settings

```
Software: 2.42; Advanced; 3.95
Data
  Collected: Thu Aug 30 10:51 2001
  By: Larry Garcia
  At: SOUTHWEST RESEARCH INST.
  Tracer Used: PDT-6-1520
  Sampled Length: 50.80 mm
  Sample Spacing: 0.48 µm
Description
  T-10 Liner Roundrobin # 6, Round #2
  PDI # 02, Trace # 611
  Ch. No. 08-01912-105
  File: C:\S-2000-2\DATA\T9LINE~1\RR6-2-2.611
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000 3051
  Current Tracer:PDT-6-1520
  Travel Distance: 50.80
  Trace Velocity: 0.76 mm/s
Form
  Form Type: Least-Squares Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.80 mm
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 0.50 µm
  High Spot Count Threshold: 0.50 µm
  tp Reference Percent: 5 %
```

Parameters

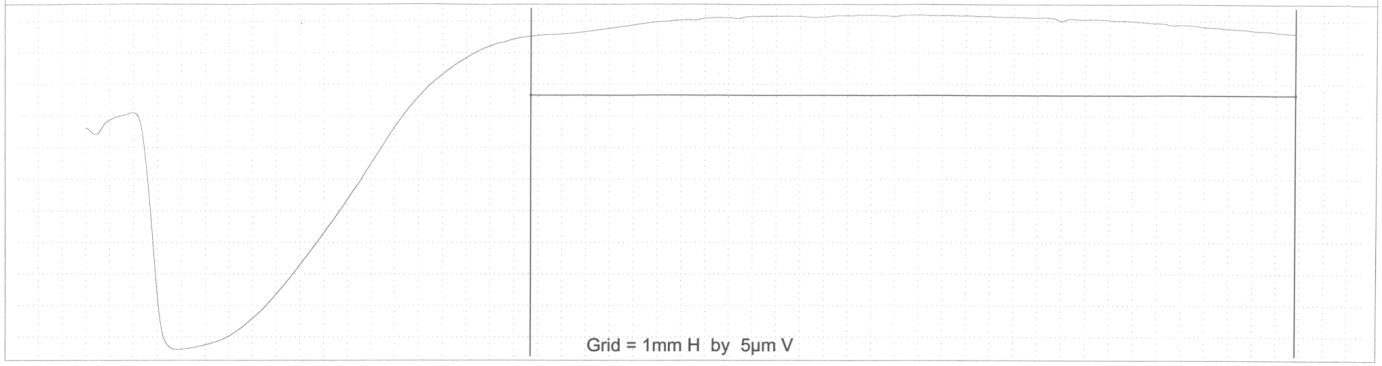
PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Roughness Height Parameters:		
Ra	0.16	µm
Rsk	-5.47	
Waviness Parameters:		
Wt	63.36	µm

FIGURE 2

Precision Devices, Inc. MicroAnalyzer 2000

SOUTHWEST RESEARCH INST.

Profiles: Waviness



Settings

```
Software: 2.42; Advanced; 3.95
Data
  Collected: Thu Aug 30 10:51 2001
  By: Larry Garcia
  At: SOUTHWEST RESEARCH INST.
  Tracer Used: PDT-6-1520
  Sampled Length: 50.80 mm
  Sample Spacing: 0.48 µm
Description
  T-10 Liner Roundrobin # 6, Round #2
  PDI # 02, Trace # 611
  Ch. No. 08-01912-105
  File: C:\S-2000-2\DATA\T9LINE-1\RR6-2-2.611
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000 3051
  Current Tracer:PDT-6-1520
  Travel Distance: 50.80
  Trace Velocity: 0.76 mm/s
Form
  Form Type: Least-Squares Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.80 mm
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 0.50 µm
  High Spot Count Threshold: 0.50 µm
  tp Reference Percent: 5 %
```

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Roughness Height Parameters:		
Ra	0.16	µm
Rsk	-5.46	
Waviness Parameters:		
Wt	53.02	µm

FIGURE 3

Precision Devices, Inc. MicroAnalyzer 2000

T-10 Liner Workshop 12/18-19/01

NAME	Company	Phone	Title
Jeff Clark	ASTM TMC	412 365 1032	
John Haeseli	P.E.	210 523 4483	
Randy Mallen	SwRI	522-3341	
Oscar T. Peterman	SwRI	(210)522-2867	
Charles McMillan	PE	210 647-9438	
JOHN DINGLER	PE	210-647-9438	
Mark Daniels	Lubr. zol	440-347-2442	
DON BRYANT	LUBRIZOL	440-347-2159	
PERRY GROSCH	SwRI	210-522-2815	
Scott A. Richards	SwRI	210-522-3567	Engineer
Kevin R. Hurst	ExxonMobil	832-224-2222	
CARL BLANK	ExxonMobil	865-224-2947	
JACK KOBRINETZ	ETHYL	804-788-5251	
JIM MORITZ	PERKIN ELMER	210 523-4601	ENGINEER

2001 Liner Measurement Round Robin

Lab	Instrument	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6	Average
A	PDI #2	61.88	48.48	42.19	20.31	31.42	52.45	42.8
A	PDI #2	61.38	47.88	41.53	20.11	31.49	52.58	42.5
A	PDI #1	61.48	48.99	41.50	19.93	30.64	51.94	42.4
A	PDI #1	61.29	48.33	41.33	19.78	30.48	51.80	42.2
B	PDI	60.34	47.22	40.59	18.75	29.37	49.30	40.9
G	PDI	60.11	45.71	40.55	19.09	29.72	49.60	40.8
G	PDI	59.97	45.83	40.49	18.88	29.92	49.64	40.8
F	PDI	59.04	46.46	40.59	18.90	29.40	49.42	40.6
F	PDI	59.20	46.06	40.38	18.87	29.16	49.24	40.5
D	PDI	58.74	46.06	40.29	19.01	29.13	48.90	40.4
D	PDI	58.80	46.03	40.08	18.72	29.44	49.03	40.4
B	PDI	59.08	46.98	40.08	17.81	28.91	49.21	40.3
G	Talysurf	57.14	43.35	40.25	17.22	28.32	47.38	38.9
G	Talysurf	57.74	43.71	39.39	16.87	28.38	47.45	38.9
A	Talysurf	57.98	44.84	41.01	16.35	25.90	43.02	38.2
A	Talysurf	57.91	41.83	38.29	14.25	27.19	47.59	37.8
F	Talysurf	55.13	40.28	37.89	14.39	27.19	42.63	36.3
F	Talysurf	55.33	38.19	36.78	13.71	29.21	42.00	35.9
PDI	**Mean**	60.1	47.0	40.8	19.2	29.9	50.3	41.2
	Std. Dev.	1.2	1.2	0.7	0.7	0.9	1.5	1.0
	Min.	58.7	45.7	40.1	17.8	28.9	48.9	40.3
	Max.	61.9	49.0	42.2	20.3	31.5	52.6	42.8
Talysurf	**Mean**	56.9	42.0	38.9	15.5	27.7	45.0	37.7
	Std. Dev.	1.3	2.5	1.6	1.5	1.2	2.7	1.3
	Min.	55.1	38.2	36.8	13.7	25.9	42.0	35.9
	Max.	58.0	44.8	41.0	17.2	29.2	47.6	38.9
Overall	**Mean**	59.0	45.3	40.2	17.9	29.2	48.5	40.0
	Std. Dev.	2.0	2.9	1.4	2.1	1.4	3.2	2.0
	Min.	55.1	38.2	36.8	13.7	25.9	42.0	35.9
	Max.	61.9	49.0	42.2	20.3	31.5	52.6	42.8
Matrix Test Results		55.9	42.2	39.1	16.5	27.7	46.5	38.0

A10. INSTRUCTIONS FOR MEASURING T-9 CYLINDER SLEEVES USING THE PRECISION DEVICES, INC. MICROANALYZER 2000

A10.1 Use a *green* Scotchbrite fiber pad and WD40 to clean the sleeve inside diameter above ring travel. Be sure to remove any traces of carbon. Clean away any remaining oil or dirt residue by wiping with a lens cleaning tissue dipped in alcohol.

A10.2 The sleeve shall be marked every 30° (use the clock face positions numbered in a clockwise direction). Looking at the top of the sleeve, *front* shall be the 12 o'clock position.

A10.3 It is recommended that the sleeve be fixed in V-blocks for tracing of the Wt data. This allows a full 360 degrees rotation of the sleeve on a common centerline. In order to obtain the ± 0.1degree slope tolerance, the V-block should also be adjustable to facilitate rough leveling. Finer leveling can be accomplished by tilting the motor drive to align profile slope.

A10.4 The stylus and trace area dimensions are shown in Fig. A4.1. The overall length of the trace shall be 50.8 mm (2 in). Note that 2.54 mm (0.1 in) of the trace shall be above top ring turnaround.

A10.5 Set the Trace Velocity to 0.63 mm/s. Set the Form Type to Least-Squares Line. Set the Roughness Filter Type to Gaussian and the Cutoff to 0.80 mm. Refer to Fig. A10.1.

A10.6 After taking the wear step trace, bracket the level lines below the wear step to include as much of the unworn surface as possible. Position the left parameter line at a point in the trace just above the wear step. Position the right parameter line at the far end of the trace, below the wear step. Waviness Parameter Wt represents the measured wear step value. Click on "Measure" from the top pull down menus. Select "Waviness Evaluation Length" brackets to generate a proper wear step value. Placements of lines are shown in Fiq. A10.1

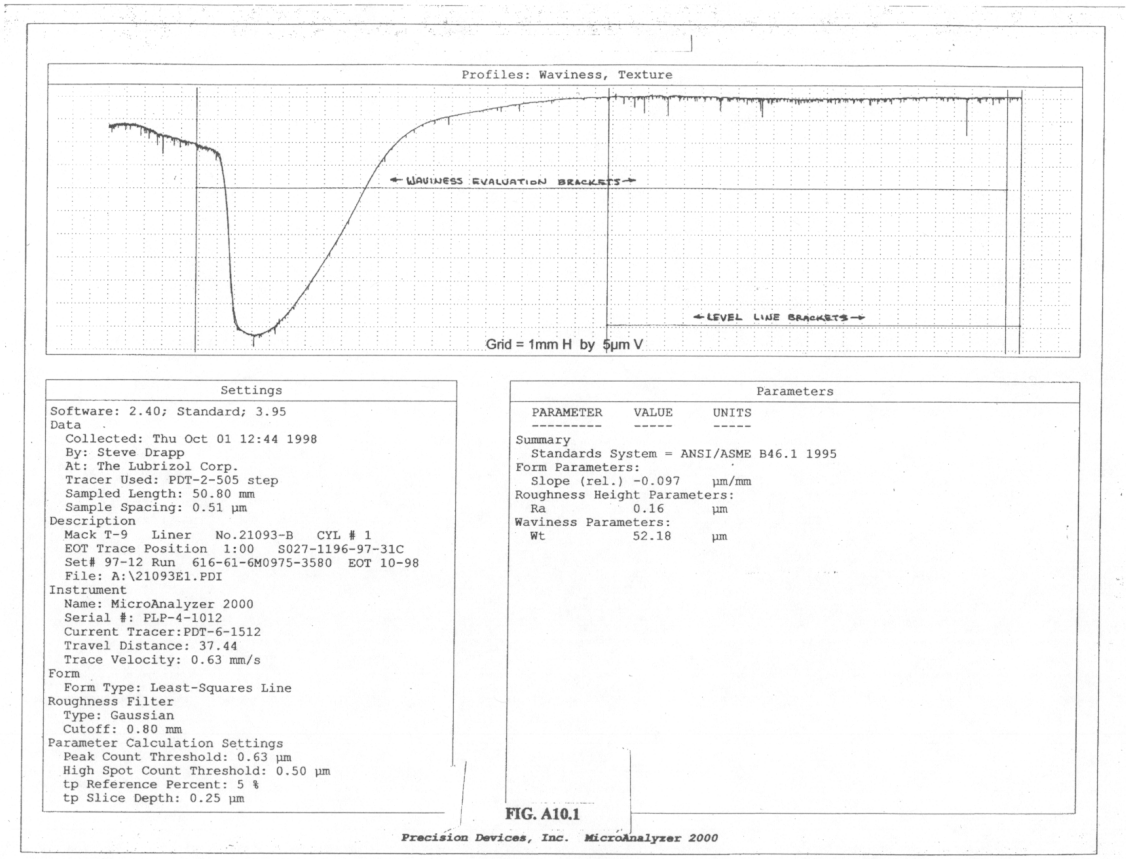

Profiles: Waviness, Texture
WAVINESS EVALUATION BRACKETS
LEVEL LINE BRACKETS
Grid = 1mm H by 5µm V
Settings
Software: 2.40; Standard; 3.95
Data
Collected: Thu Oct 01 12:44 1998
By: Steve Drapp
At: The Lubrizol Corp.
Tracer Used: PDT-2-505 step
Sampled Length: 50.80 mm
Sample Spacing: 0.51 µm
Description
Mack T-9 Liner No.21093-B CYL # 1
EOT Trace Position 1:00 S027-1196-97-31C
Set# 97-12 Run 616-61-6M0975-3580 EOT 10-98
File: A:\21093E1.PDI
Instrument
Name: MicroAnalyzer 2000
Serial #: PLP-4-1012
Current Tracer:PDT-6-1512
Travel Distance: 37.44
Trace Velocity: 0.63 mm/s
Form
Form Type: Least-Squares Line
Roughness Filter
Type: Gaussian
Cutoff: 0.80 mm
Parameter Calculation Settings
Peak Count Threshold: 0.63 µm
High Spot Count Threshold: 0.50 µm
tp Reference Percent: 5 %
tp Slice Depth: 0.25 µm
Parameters
PARAMETER VALUE UNITS
Summary
Standards System = ANSI/ASME B46.1 1995
Form Parameters:
Slope (rel.) -0.097 µm/mm
Roughness Height Parameters:
Ra 0.16 µm
Waviness Parameters:
Wt 52.18 µm
Precision Devices, Inc. MicroAnalyzer 2000

FIG. A10.1

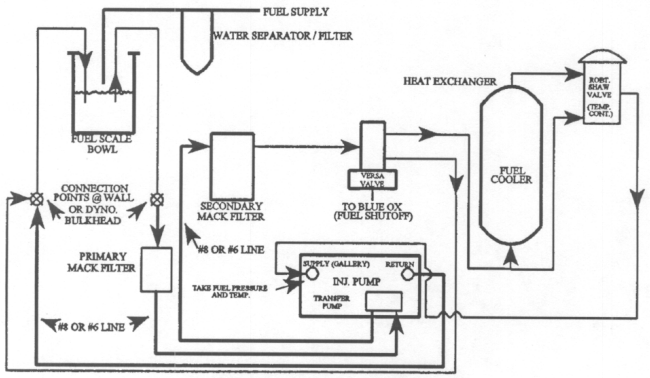


FIG. A2.9 Test Cell Fuel System Schematic

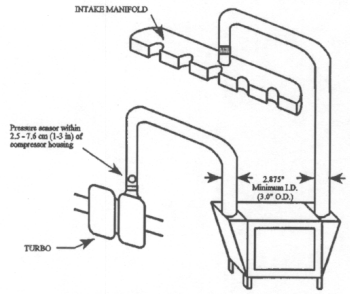


FIG. A2.10 Test Cell Intercooler Arrangement

A4. INSTRUCTIONS FOR MEASURING T-9 CYLINDER SLEEVES USING TAYLOR HOBSON FORM TALYSURF

A4.1 Use a *green* Scotchbrite fiber pad[20] and WD40 to clean the sleeve inside diameter above ring travel. Be sure to remove any traces of carbon. Clean away any remaining oil or dirt residue by wiping with a lens cleaning tissue dipped in alcohol.

A4.2 Mark the sleeve every 30° (use the clock face positions numbered in a clockwise direction). Looking at the top of the sleeve, *front* shall be the 12:00 position.

A4.3 It is recommended that the sleeve be fixed in a V-block for tracing of the PRt data. This allows a full 360° rotation of the sleeve on a common centerline. To obtain the ± 0.1° slope tolerance, the V-block should also be adjustable to facilitate leveling. It is recommended that the V-block be located on the thin wall section of the sleeve, just below the sleeve seat, and that a weight, such as a piston pin, be placed inside the sleeve so that it will maintain good contact with the V-block.

A4.4 The stylus and trace area dimensions are shown in Fig. A4.1. The overall length of the trace shall be 50.8 mm (2 in). Note that 2.54 mm (0.1 in) of the trace shall be above top ring turnaround.

A4.5 The required settings for trace length, multiple reference, and unfiltered mode are shown in the Screen View No. 1 portion of Fig. A4.2.

A4.6 A representation of a completed trace is shown in the Screen View No. 2 portion of Fig. A4.2. Note that F2 reference is set for straight. Before computing, the operator shall set cursor lines to bracket the wear area. Do not expand this area. Compute on the area below top ring travel, outside the cursor lines.

A4.7 The result of the computation is shown in the Screen

[20] Available from local hardware retailers.

TABLE A3.1 New Parts for Each Rebuild

NOTE 1—A P/N 57GC3116 Cylinder Rebuild Kit contains items 1, 2, and 3. Six kits are required per engine rebuild. A P/N 57GC2120B Filter Kit contains items 5, 6, 7, and 8. A P/N 62GB2401 Service Bearing Pair contains one each of P/N 62GB328 and P/N 62GB327 (Item 11).

Part Name	Mack Part Number	Quantity
1. Cylinder liners	509GC471	6
2. Piston assembly	240GC2256M	
Piston crown	240GC5114M	6
Piston skirt	240GC5119M	6
3. Piston ring set	353GC2141	
#1 Compression ring	349GC3107	6
#2 Compression ring	349GC3108	6
Oil ring	350GC343	6
4. Overhaul gasket sets	57GC2115A	2
	57GC2118A	1
	57GC2119	1
5. Spin-on filters	485GB3191B	2
Centrifugal filter cartridge	239GB244A	1
6. Engine coolant conditioner	25MF435B	1
7. Primary fuel filter	483GB444	1
8. Secondary fuel filter	483GB440	1
9. Valve guides	714GB222	1
10. Valve stem seals	446GC296	24
11 Connecting rod bearings		
Upper	62GB327	6
Lower	62GB328	6

View No. 3 portion of Fig. A4.3. The data is shown in the Screen View No. 4 portion of Fig. A4.3. Exclude any scratch that goes below the valley of wear from the trace by using the cursor lines to bracket the scratch using the F5 key.

A4.8 When excluding any part of the profile, obtain the PRt value from the graph in Screen View No. 3 (see Fig. A4.3). The Taylor Hobson instrument will not change the PRt value on the data screen when excluding any portion of the profile.

A4.9 The parameters shown in Screen View No. 4 (see Fig. A4.3) are defined in Table A4.1.

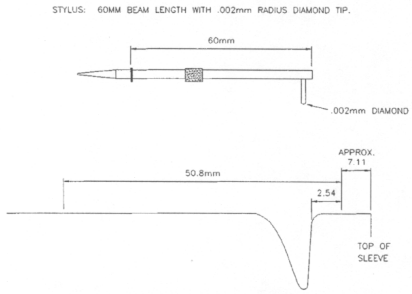


FIG. A4.1 Stylus and Trace Area Dimensions

SCREEN VIEW NO.1

CLASSIFICATION

F1 – Analysis
F2 – Units . . . . . IMPERIAL
F3 – Mode . . . . . UNFILTERED
F4 – Traverse
Length . . . . . 2.08 in

F6 – Reference . . . . . MULTIPLE
F7 – Ignore Length . . . 8%
F8 – Reverse . . . . . AUTO CLEAR
F9 – Bump Increment . . 1
F10 – Host Filename . . . ***RTH***

F11 – Language . . . . . .ENGLISH
F12 – Absolute Radius . . .008822E 98 in.
F13 – Traverse Speed . . 0.5 MM/SEC

SCREEN VIEW NO.2

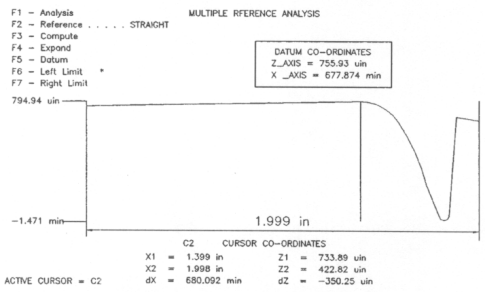


FIG. A4.2 Screen Views No. 1 and No. 2

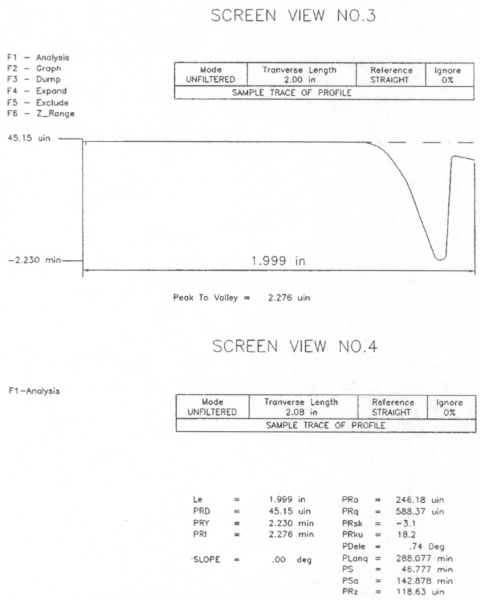


FIG. A4.3 Screen Views No. 3 and No. 4

TABLE A4.1 Trace Length Parameter Definitions

Parameter	Definition
PRp	Highest part of profile in trace length
PRv	Lowest part of profile in trace length
PRt	Distance from highest point to lowest point

A5. SAFETY PRECAUTIONS

A5.1 *General*:

A5.1.1 The operating of engine tests can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation, and operation of engine test stands.

A5.1.2 Each laboratory conducting engine tests should have their test installation inspected and approved by their safety department. Personnel working on the engines should be provided with proper tools, be alert to common sense safety practices, and avoid contact with moving or hot engine parts, or both. Guards should be installed around all external moving or hot parts. When engines are operating at high speeds, heavy duty guards are required and personnel should be cautioned against working alongside the engine and coupling shaft. Barrier protection should be provided for personnel. All fuel lines, oil lines, and electrical wiring should be properly routed, guarded, and kept in good order. Scraped knuckles, minor burns, and cuts are common if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines, and no loose or flowing clothing, including long hair or other accessory to dress that could become entangled, should be worn near running engines.

A5.1.3 The external parts of the engines and the floor area around the engines should be kept clean and free of oil and fuel spills. In addition, all working areas should be free of tripping hazards. In case of injury, no matter how slight, first aid attention should be applied at once and the incident reported. Personnel should be alert for leaking fuel or exhaust gas. Leaking fuel represents a fire hazard, and exhaust gas fumes are noxious. Containers of oil or fuel cannot be permitted to accumulate in the testing area.

A5.1.4 The test installation should be equipped with a fuel shut-off valve, that is designed to automatically cutoff the fuel