1998 BMW R1100RT
LCD Temperature Gauge Scale Calibration
LCD Fuel Gauge Calibration
Fuel Sender Testing and Cleaning

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1. ABSTRACT

The following text is a compilation of various testing and calibration I have performed for my 1998 R11RT. Changes are noted with the date of change.

2. Oil Temperature and Gauge

2.1. Introduction

My 1998 BMW R1100RT came with an LCD temperature gauge that shows horizontal black bars in a vertical motif, to indicate temperature. This is difficult to interpret at speed (how many bars are exposed?) and does not actually tell me what the oil temperature is.

2.2. Normal Operation

The bike seems to run at 5 or six bars under normal conditions. It appears that the oil thermostat for the cooler is set to '5 bars'.

2.3. Over Heating

The LCD panel indicates that 8 bars is the maximum normal operating temperature. It would be useful to know what the actual temperature is. Modern oils have a normal operating temperature of approximately 110 degrees Celsius and will not show any serious degradation[ii] at this temperature.

The maximum sustained operating temperature (at the bearing surface) is approximately 130 degrees Celsius for any oil formulated in the past 5 years and some high performance synthetics will not appreciably degrade even at this temperature.

However, the degradation curve is a polynomial and degradation will increase rapidly with increasing temperature. According to the oil's formulation (pure synthetics will show the least increase with temperature), by approximately 160 degrees Celsius (or about 300 degrees Fahrenheit), oil degradation can be up to 10 times faster then at 110 Deg. C.

2.4. Scale

To fix the 'number of bars' problem, I determined that an overlay with numbers would be the best idea.

2.4.1. Addendum

The number scale became too much to maintain. Rather than this, I cut a mm or so wide stripe out of the self sticking stripping meant for the side of a car. Using a red material, I put it through the middle of the fifth bar of both the temperature and fuel display. The stripe is slightly smaller than the thickness of the bar. This allows me to tell when I am at normal operating temperature and when approximately half a tank is used.

2.5. Temperature Calibration

When the bike was apart for its winter service, I decided that I would calibrate the temperature transducer and the LCD gauge.

2.6. Results

The summary of the results and some charts and tables are contained in the remainder of this document. The graphs were generated with 'cvrPLOT', a shareware program and the PERL calculations were done on a Sun SPARC running RedHat Linux V.5.1 .

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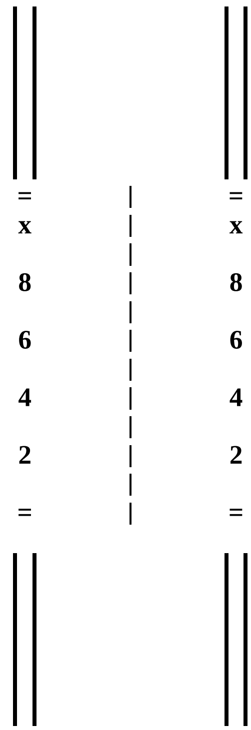
2.7. LCD Bar Mask for the Temperature Gauge



See End of Document for a Master Chart.

2.8. Create The Scale Mask

1. Print to a clear plastic sheet; the plastic used for overhead projectors is ideal. A laser printer is better then an ink jet since the ink for most popular *ink jet printers* is water soluble.
2. The spacing of the above mask will cover the complete gauge and place each of the numbered columns at the outer edge of the clear section of the LCD. The left will be the temperature gauge and the right the fuel gauge. I only use the one vertical strip for the temperature gauge, and the instructions that follow are for that installation. If you choose to use both sections, then simply cut the middle out rather then completing the vertical cuts.
3. Place double stick tape (transfer tape) on the non-printed side of the plastic, under the printed portion.
4. The bottom of the strip will be the lower edge of the bottom equal sign (=). This is the position where a zero would be if the numbering were complete. Make a horizontal cut using a good straight edge and an X-acto knife (or single edge razor blade) through the lower line of the bottom equal sign.
5. The top of the strip is the bottom line of the top equal sign (actually, anything above the ‘x’). Again, make a horizontal cut across this line.
6. Now, make two vertical cuts using the witness lines above and below the used portions of the strip.
7. Remove the used portion of the strip.
8. Remove the paper from the double stick tape.
9. Place the numbered strip such that the top line of the lower equal sign is even with the top of the black mask that surrounds the clock and the number are over the clear portion of the LCD display. Place the strip as far to the left as possible.
10. The bars will go directly through the numbers and counting is no longer necessary.

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2.9. Experimental Data

2.9.1. Resistance in Ohms Vs Number of Bars Exposed

1. Remove the fuel tank.
2. Disconnect the wire from the temperature transducer (in front of the computer).
3. Connect a precision potentiometer to the connector where the temperature transducer was[iii].
4. Re-connect the fuel tank[iv]; positioning it above the bike and out of the way.

Bar	Resistance in Ohms		
	Low	High	Avg.
0	1500	1500	1,500.0
1	1000	1490	1,245.0
2	475	791	633.0
3	390	470	430.0
4	280	380	330.0
5	130	270	200.0
6	73	120	96.5
7	55	68	61.5
8	38	54	46.0
9	32	37	34.5
10	31	31	31.0

2.10. Temperature Vs Transducer Resistance

The following is the method and results of gradually heating the temperature transducer and measuring its resistance. A laboratory hot plate was used to heat the oil, a calibrated digital thermocouple (4 significant figures) was used to measure the temperature of the oil bath and the resistance was measured with a 5 1/2 significant figure digital volt meter. The oil was heated until the temperature was stable for at least 5 minutes, before recording the experimental data. In addition, the thermocouple was checked with a laboratory thermometer (mercury) at 25, 50, 75 and 100 degrees Celsius.

1. Remove the temperature transducer.
2. Place a can of high temperature oil (ATF was used) on an electric hot plate.

1 Place the tip (up to the bottom of the threads) into the can of oil.
2 Place a precision thermometer into the oil and gradually heat it.
3 Connect a precision ohm-meter (a 5 significant figure electronic DVM was used).

Transducer OHMS	Temperature Degrees C	Temperature Degrees F
44100	3	37.4
2100	25.0	77.0
1595	34.0	93.2
1090	45.2	113.4
604.0	64.5	148.1
475.0	73.0	163.4
435.0	75.5	167.9
293.0	90.0	194.0
282.0	91.5	196.7
265.0	94.5	202.1
244.0	97.5	207.5

Transducer OHMS	**Temperature Degrees C**	**Temperature Degrees F**
219.0	102.0	215.6
172.1	110.5	230.9
130.8	120.0	248.0
92.0	135.0	275.0
74.7	144.0	291.2
70.7	147.0	296.6

2.11. Fit Constants, Power Polynomial

The program that was used to plot the information also performs curve fits using a power polynomial. The raw mathematical information and data generated using it, is in the following sections.

2.11.1. Degrees Celsius

Curve fit information

- A1 = 2.960211360439462E+02
- A2 = -8.266256888857990E+01
- X TBL/COL: 1 1 Y TBL/COL: 1 2 Fit type 0 Degree 1 Xaxis=LOG Yaxis=LIN
- Deg_C = A1 + A2 * log10(resistance)

2.11.2. Temp. for Bars Using The Curve Fit Equation

2.11.2.1. PERL Script

The following PERL program was written to calculate the temperature indicated by the average resistance for each bar. The program was run under PERL Version 5.x on a Sun SPARC Station running RedHat Linux Version 5.1. It should run on any machine/Operating System that supports PERL Version 5.x.

```
#!/usr/bin/perl
use lib “/usr/local/lib/perl” ;
use strict;

my($A,$B,$C,$Q,$R,$S,$I,$J,$K,$K,$M,$N);

my @DATA = ( 1500, 1245, 633, 430, 330, 200, 96.5, 61.5, 46, 34.5, 31 ) ;

my $Ln210 = log( 10 ) ;
my $SPACE = "   " ;
my $hold  = 0 ;
my $line  = 0 ;
my $A1 = 2.960211360439462E+02 ;
my $A2 = -8.266256888857990E+01 ;

printf("%3s%s%4s%s%6s%s%6s%s%6s\n",
                    "BAR",$SPACE,"Ohms",$SPACE,"Temp",$SPACE,"Diff",$SPACE,"Temp");
printf("%3s%s%4s%s%6s%s%6s%s%6s\n",
                               "",$SPACE,"",$SPACE,"C  ",$SPACE,"C  ",$SPACE,"F  ");
print "=" x 37 . "\n" ;

foreach $A ( @DATA )
{
   $B = $A1 + ( (log($A)/$Ln210) *  $A2 ) ;
   $C = ($B * 9 )/5 + 32 ;
   if ( $hold != 0 ) {
         $hold = $B - $hold ;
```

```
        }
        printf("%-3d%s%4d%s%6.2f%s%6.2f%s%6.2f\n",
                        $line,$SPACE,$A,$SPACE,$B,$SPACE,$hold,$SPACE,$C );
        $hold = $B ;
        ++$line ;
    }
```

2.11.2.2. Data Chart From PERL

This is the data output from the PERL program.

BAR	Temp Degrees C	Temp Degrees F	Difference From Previous Deg. C	Average Resistance Ohms
0.	33.48	92.26	0.00	1500
1.	40.17	104.30	6.69	1245
2.	64.45	148.01	24.28	633
3.	78.33	173.00	13.88	430
4.	87.83	190.10	9.50	330
5.	105.81	222.46	17.98	200
6.	131.98	269.56	26.16	96
7.	148.15	298.67	16.17	61
8.	158.57	317.43	10.43	46
9.	168.90	336.02	10.33	34
10.	172.74	342.93	3.84	31

2.12. Summary Information

From all of the above information, the approximate temperature for each bar is ...

1. **040 °C ~= 105°F**
2. **065 °C ~= 150 °F**
3. **080 °C ~= 175 °F**
4. **090 °C ~= 190 °F**
5. **105 °C ~= 225 °F**
6. **130 °C ~= 270 °F**
7. **150 °C ~= 300 °F**
8. **160 °C ~= 320 °F**
9. **170 °C ~= 340 °F**
10. **175 °C ~= 350 °F**

2.12.1. Temperature Values

Modern oils are designed to work best in the range of 110 °C .. 130 °C. This would be 5 or 6 bars. Above 150 °C, oil breakdown increases exponentially and by about 160 °C, degradation is quite rapid. Petroleum based oils will cease to lubricate with any effect, at about 170 °C and synthetics at about 190 °C.

It is worth noting that in an Automatic Transmission, the peak oil temperature at the gears can easily reach 200 °C. Since Automatic Transmissions seem to last a long time, it is evident that oils can be formulated to work well at sustained high temperatures. In addition, the lubrication of gears is difficult. Gears try to push the oil out of the way (which is why gear type oil pumps are used). This is less severe then the impact of the connecting rod in the reciprocating parts but is far more severe then simple rotating lubrication.

The problem with a reciprocating engine is that the forces on the rod and main bearings are not pure rotary. When the piston move up and down, there is a substantial transient impact load on the bearing. This impact will try to squeeze the oil film out of the way. If this happens and the journal and bearings touch, the engine is trash. For this reason, engine oil has different properties then most other common lubricants. Its also a good reason to keep the engine and transmission oils separate.

2.13. Recommendations

2.13.1. Oil Changes

Considering that the bike mostly runs with 5 or six bars exposed, a 6,000 mile oil change is reasonable (5,000 miles would be better). However, in traffic or at high speed with two up, 7 bars is not that rare. I would suggest 4,000 mile oil changes with a good synthetic under these circumstances. Since part of the oil degradation is loss of detergent ability, the filter is critical and MUST be changed with every oil change.[v]

2.13.2. Traffic and High Temperature

When in traffic, especially if going uphill and/or the day is very hot, the oil can easily hit eight bars exposed. As soon as you get moving at a steady pace, the temperature quickly drops.

This is not good situation. I've owned air cooled machines before that I installed temperature gauges and oil coolers to, and have not seen this sudden rise in temperature. Therefore, I examined the bike looking for an answer.

It is possible that not enough of the engine is exposed to allow convection cooling (the body work covers a considerable portion of the engine). Also, the oil cooler is boxed to allow the air going through it to be directed to the vents on the side of the fairing. This would preclude any convection cooling, the plastic box would trap the hot air.

The only cure I see for either of these situations would be to mount an electric fan in the back of the air box to 'pull' the hot air out of the box. Perhaps eliminating the box would be a good idea.

2.13.3. Addendum -- Wednesday, 19 July, 2006

This is a summary of things done since the original text.

2.13.3.1. Sudden Temperature Rise and Traffic

This seems to have mostly gone away. Some of this may be age, the engine is looser. Also, the oils have improved. The current synthetics are better than ever at conducting heat and forming thin films.

2.13.3.2. FAN

I mounted a 50mm computer fan to the back of the box. I put the fan on a switch and use it when the RID goes to 7 bars. It seems to make a small difference in traffic.

2.13.3.3. Change Interval

I would estimate that a normal oil change of 5,000 miles would be fine for all but the most sever duty. This assumes a state of the art synthetic and a new filter.

3. Fuel Gauge Calibration and Tank Capacity

3.1. Calibration Using The RID and Adding Fuel

The owner's manual gives two different capacities for the tank, and some reviews give additional different numbers. Therefore, during a service session that required the removal of the tank, I did the following :

- With the tank removed, all the fuel in it was removed. There was none left, the removal procedure was not a simple drain, but included blowing out the tank and wiping out any residue.
- When the tank was re-installed, a measured quantity of fuel was added to the tank. For each addition, a few minutes was allowed for the gauge and warning light to come to equilibrium.

3.1.1. Summary of Results

Gauge / Lamp Status	Fuel Remaining (Fuel Added to the Tank)
1 bar	greater then 1 gal. and less then 1.5 gal.
light is on	slightly less then 2 gallons
2 bars	almost exactly 2 gallons

3.1.2. Conclusions

3.1.2.1. 1 bar

Assuming that the last 1/2 gallon should never be used, one bar (when it first becomes the only indication) represents approx. 1 gallon of fuel remaining.

3.1.2.2. Warning Light

When the lamp comes on, using the same 1/2 gallon never to be used criteria, there would be approx. 1.5 gallons of fuel remaining.

3.1.2.3. 2 bars

With the same assumptions as above, there would be approx. 1.5 gallons of fuel remaining.

3.1.3. Summary

Based on a safe margin of fuel and worst case fuel economy, this is how to figure the gauge and/or odometer. BMW seems to want approx. 2 to 3 liters of fuel remaining in the tank under all circumstance. In addition, they calculate capacities based on a normal fill, and not to the overflow plate.

3.1.3.1. Normal Fill and Three Liters Remaining

- 1 BAR 0.5 gal 20 miles
- Warning Light 1.0 gal 45 miles
- Tank Capacity 7.3 gal 328 miles

3.1.3.2. Overfill

Fill to the Overflow Plate and Only Two Liters Remaining

- 1 BAR 1.0 gal 40 miles
- Warning Light 1.5 gal 65 miles
- Tank Capacity 7.5 gal 338 miles

3.2. Tank Capacity

From experience, I know that the bike will take almost exactly 6 gallons of fuel when the warning light comes on. This is a bit of an overfill but the figure is consistent with BMW's claim of 7.26 gallons, since BMW allows for some fuel remaining in the tank that will NOT be consistently fed by the pump. They also warn against running the tank dry and knowing BMW, they make sure it cannot happen.

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3.3. Calibration of the RID w/ A Decade Resistor Box <<Wednesday, 19 July, 2006>>

The various manuals and the Internet groups all give conflickting information on how the fuel gauge works. When the tank was apart for a major service (filter, clean the fuel pump sock, clean out the tank), the long cylinder that is also in the tank was removed; this is the one labeled '*sender*' on some of the diagrams.

Checking of the factory schematic and the observed wiring lead me to conclude that the gauge in the Rider Information Display (RID) operates from the long cylinder and the low fuel lamp from the swinging arm with the float that is part of the fuel pump/filter flange.

While the cylinder was out, I measured its resitance when the take would be full and when empty.

3.3.1. Fuel Sender Minimum (full tank)

approx. 3 ohms

3.3.2. Fuel Sender Maximum (tank empty)

approx. 73 ohms

3.3.3. Experimental Setup

To confirm the operation, the flange was connected to the bike's wiring without connecting the battery voltage for the fule pump. This would allow for normal operation of the gauge and lamp without running the pump while dry. With the three wires connected, a decade resistor substitution box was connected across the leads that would normally go to the fuel level sender (the long cylinder). The following chart is the results of a rough plot of resistance Vs. bars exposed.

NOTE:

1. There is a 20..25 second delay between changing the resistance and the bars changing. The circuit diagram shows a delay timer in the gauge and lamp circuit so I would assume this is the cause.
2. At all levels, the lamp arm was put in each of its extreme position; this had no effect on the gauge.
3. The lamp seems to have an approx. 30 second delay for changes.
4. The switch goes from a few ohms at its lamp on position, increases to a kilohm or more about 1/3 of the way to its 'full' position and than goes 'open circuit' from ther to the end of its travel. Not sure why its not just a simple switch, unless its used for something else on a different bike.
5. The measurements were taken starting from low resistance to high. To actually plot the gauge response Via a curve fit, would require going in the other direction to compensent for the discrete nature of the readout. Since the gauge is not linear in my experience, I did not bother.

3.3.3.1. Measurement Matrix

Resistance from Low to High At Which The Bars First Change	Bars Exposed
2	10
3	10
4	9
9	8
17	7
23	6
28	5
37	4
43	3
49	2
58	1
65	0

3.4. Cleaning the Sender

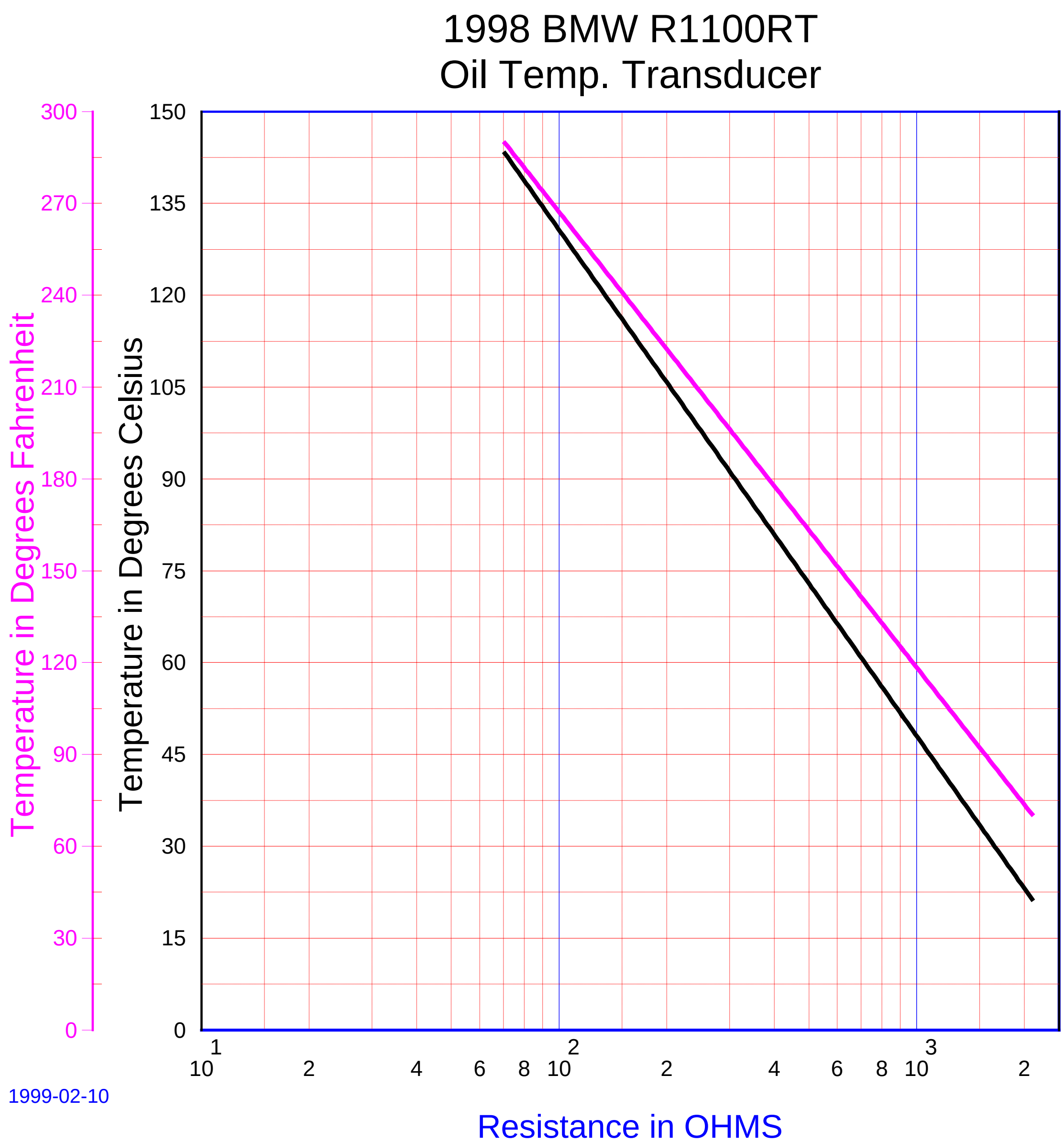
Remove the sender column. This is fastened to the top of the tank with a bulkhead flange and is also connected to the fuel pump/filter assembly Via a wire and the two vent hoses that go to the filler cap.

1. Remove the fuel pump/filter plate.
2. Make sure to mark the position of the flange (plate) on the tank (use tape) and the steel plate (use a marker).
3. When the unit is partially out, remove the wire connector that goes to the sending unit.
4. Remove both vent hoses. WARNING: If you still have the cannister, the hoses are different and their position must be marked prior to removal; they must go back on to the same fitting from which they came.
5. One the plate is out, you can see the long sending unit. It will have ‘O’ rings used as rubber bands to hold the two vent hoses and the wire.
6. Mark the top flange’s postion in relation to the tank.
7. Remove the top flange, slowly working the hoses off the tube from the hole left by the fuel pump flange.
8. There is no obvious way to disassemble the unit. The single small nut is bound into the fitting with bent taps.
9. Run denatured ethanol through the tube and rotate the tube a few times to make sure the float is free.
10. Put it all back together. Note that the rubber vent hoses will have to be threded back on to the tube along with the ‘O’ rings that keep them there.
11. Make sure that the spring on the botton of the tube bottoms squarly in the tank. If you work the flange down slowly and carefully, it will find the correct place automatically.

4. Tables and Charts

4.1. Temperature Vs Transducer Resistance

Curve was obtained by placing transducer in a hot bath of oil. The oil was heated using a controlled temperature hot plate. Temperature measurements were with a precision dial thermometer, resistance measurements with a precision DVM.



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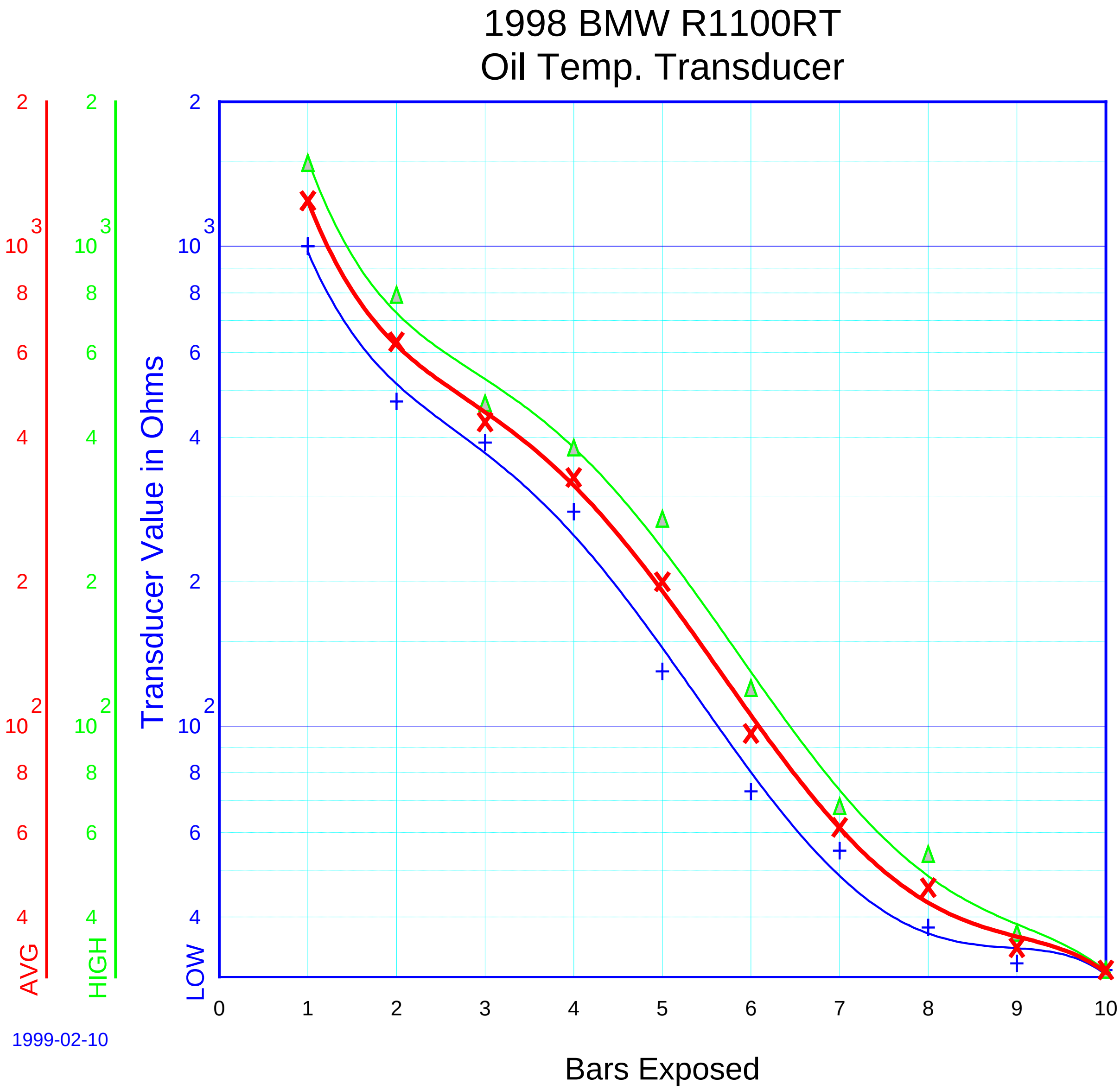
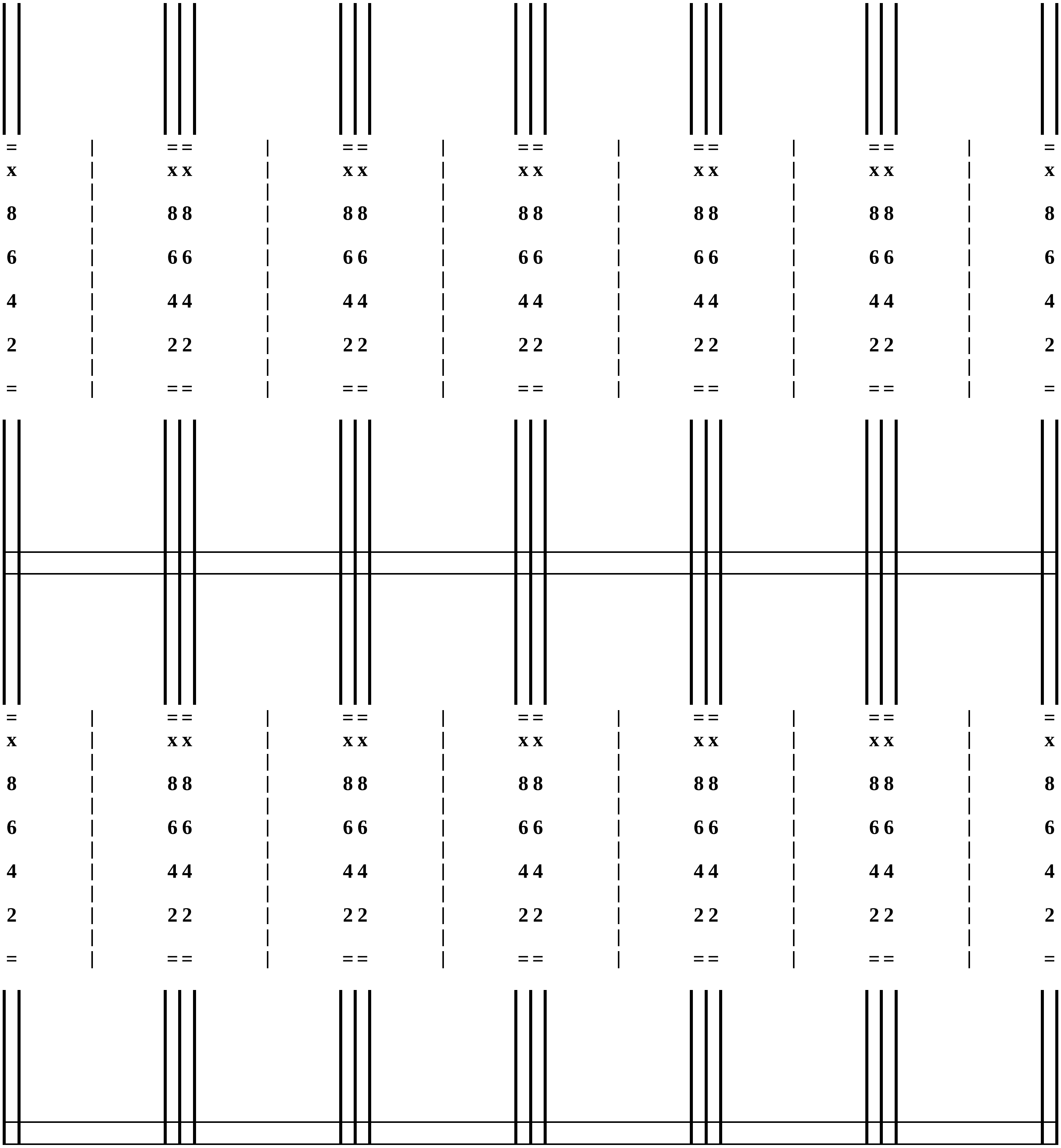
4.2. Bars Exposed Vs Transducer Equivalent Resistance



4.3. LCD Multiple Mask for Printing



5. Index

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[i] **ORIGINAL TEXT**

The original text was started on 31 July 1998, about three weeks after I took possesion of the bike. The calibrations and calculations were performed during November and December of 1998.

[ii] Oil Degradation

Oil (lubricants) degrade in a number of fashions. Most important in the short term, is their ability to lubricate. In a internal combustion engine, this constitutes a number of competing services. There is the simple rotary lubrication of shafts and sleeve bearings, the compression lubrication of gears and the ability to persist (maintain a lubricating film) under the impact of the reciprocating parts (e.g., the big end rod bearings). As temperature increases, the normal viscosity of the oil will decrease. Special chemicals are added that have a negative temperature index and their viscosity will increase with temperature (over a short range). The difficulty is that these chemical will crack under extreme temperature and in the presence of oxygen. Once their long changes break, they no longer perform the magic trick of inverse viscosity coefficient and the oil will not be able to cope with increased temperature. Pure synthetic oil suffer less from this in that their formulation can include a mix of custom designed molecules that perform all of these tricks and also will lubricate with thinner films. Also, the synthetic molecule can be made chemically active so that it will form a covalent bond to the bearing and journal surfaces.

[iii] Resister substitution box ...

A decade box with 10 steps per dial, 5 dials. The ranges are 0-1 by 0.1 , 0-10 by 1 , 0-100 by 10 , 100 to 1000 by 100 and 1000 to 10000 by 1000.

[iv] Re-connecting the fuel tank

Examination of the circuit diagram shows the temperature transducer going to the computer, and in parallel with at least one other transducer. Since there is a possibility of this being an active circuit, the tank was plugged back in to make sure that all circuit elements were present.

[v] Oil Filter

Many years ago, when I was working as a Chemical Engineer for Exxon, we performed an interesting oil test on various engines. To make the test interesting, we used an OHC 4 from a Ford, a Chrysler 225 Slant Six and Chevrolet 350 CID V8. Two of each engine was connected to a dynamometer and run against a programmed load that represented mixed driving. One engine of each pair had only its oil changed every 2,000 mile equivalent and the other only its filter with the oil topped up. The filter changed engines showed less wear after 30,000 miles of this.