TIRE PRESSURE AS A MEANS OF CONTINOUSLY MONITORING WHEEL CALIBRATION FACTOR IN THE RRTC BICYCLE METHOD FOR COURSE MEASUREMENT

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Introduction

The wheel calibration factor (e.g. rev/km) in the RRTC Bicycle Method for course measurement can be derived as an average of pre-calibration and post-calibration rides over a calibration course. Since the factor obviously decreases with temperature, for this to work well the temperature during course measurement should be the average of the temperature for the calibration measurements, but unfortunately this is rarely the case. The situation is particularly bad when the calibration course is distant from the race course, and often where adjustment of the course is mandated after a post-calibration, a measurer has to try to arrange for this over the telephone. A measurer can ameliorate matters by finding a suitable location and setting up a temporary calibration course near the race course, but even if he operates in Ohio where such sites are presumably plentiful, this involves a lot of extra work and the finding of an assistant. The main value of a post-calibration measurement would seem to be not for the calibration factor, but for its ability to detect a major leak in the tire. It does so though too late to salvage a day's work.

Mike Sanford in the UK has attempted to determine the calibration factor during measurement on the race course by taking the temperature at frequent intervals. The factor is derived from the previously determined relationship with temperature for the tire after correction for deflation. The relationship is derived by determining calibration factors on a calibration course at different temperatures over a period of five days. Tire pressure is not adjusted during the five days so a correction must be applied for deflation. The deflation itself is measured through the calibration factor over a period of several days by correcting results to a standard temperature and is expressed as the change in the factor per day. All this of course is too complicated for most measurers, and is particularly impractical in the US where unlike in the UK the mandate is for at least two determinations of the course.

I intuitively felt that the only significant effect of temperature on the calibration factor might be through its effect on the tire pressure and use of pressure might yield a more practical method of monitoring factor changes. Research in this direction has been discouraged in the past by the lack of accurate pressure gauges for the bicycle tire. Peter Riegel tried to use a commercial gauge to get data on the tire pressures of measurers at an Olympic trial course, but gave up the attempt as hopeless because the gauge spilled so much air as to render measurements meaningless. Therefore a first task in my investigation was the devising of suitable gauges.

Materials

Gauges were ordered from the Gauge Distributing Co (getagauge.com) with the following description:

K160X Accu-gage 1-1/2" 160 psi gauge with straight chuck and without epoxy glue on threads

A photograph is shown later in this report. These we made to my own specification, but as the company generously does not charge for customization, the cost was only $8 each.

I purchased metal tire valve caps of a suitable dimension from Pep Boys.

I had on hand Presta valve stem nuts and neoprene tubing (9.5 mm od x 5.0 mm id).

Tools shown below were made from an old Presta valve and an old automobile Schrader valve.

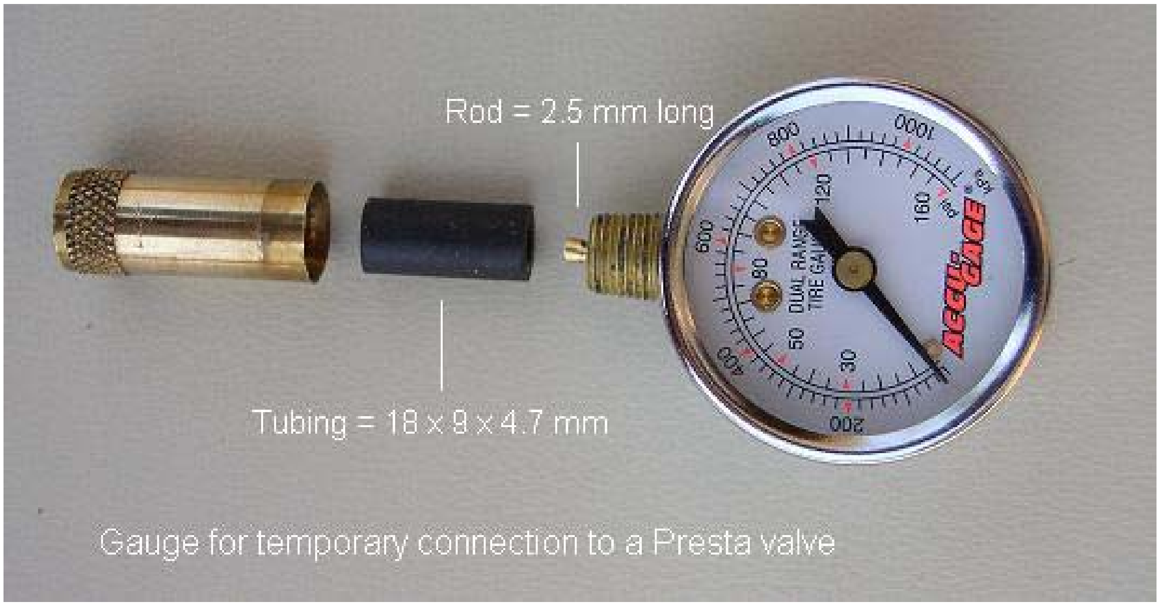
Gauges

1. Push-on Schrader Gauge

Gauge for temporary connection to a Scharader valve

As described under “Materials” this gauge (K160X) can be purchased directly from the Gauge Distributing Co using my specifications. As the gauge is pushed onto the valve the internal rubber tube makes an excellent seal with the top of the valve tube before the brass rod opens the valve. After the reading is taken, the reverse takes place as the gauge is removed. If the operator is reasonably adept he will find that the only air lost is the insignificant amount under pressure in the gauge and so consecutive readings are identical.

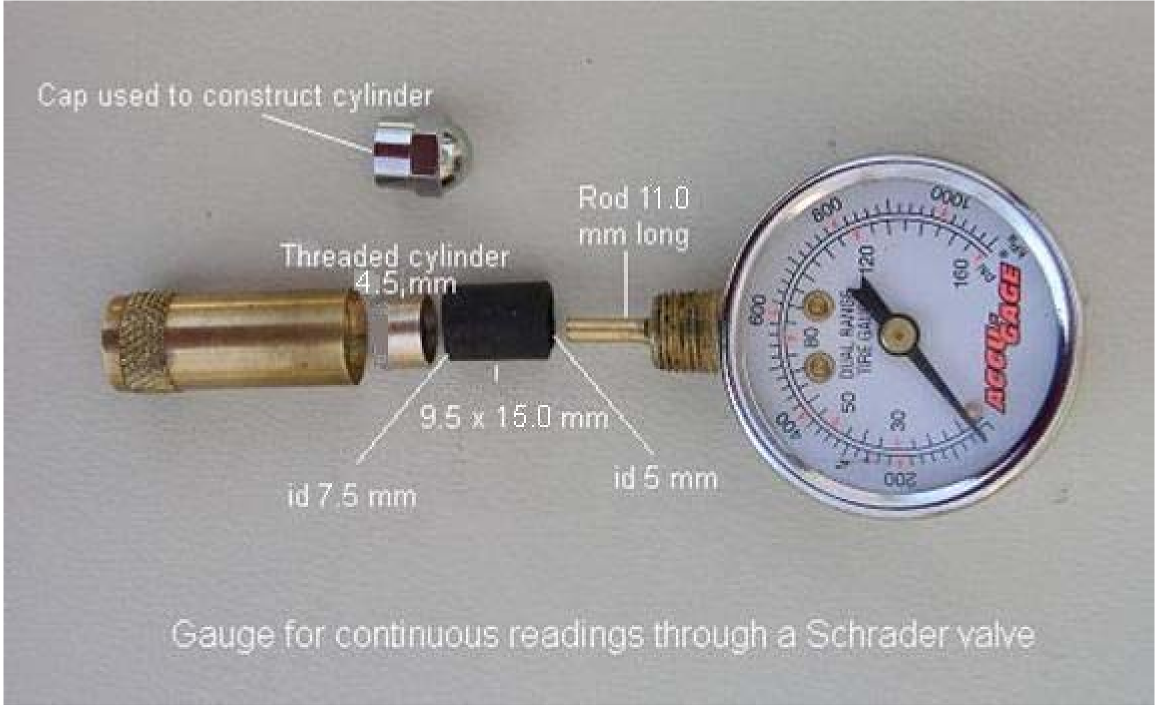
2. Push-on Presta Gauge



Gauge for temporary connection to a Presta valve

This gauge is easily constructed from the K160X by cutting down the neoprene tubing down from a length of 19.0 mm to 18.0 mm and the brass rod to 2.5 mm. To take a reading, the tiny nut on the Presta valve is screwed back as far as possible, and the gauge pushed onto the valve stem. Again the tubing fully seals the gauge onto the side of the valve stem before opening the valve and it is not difficult to get identical consecutive readings. It helps to put a little grease on the stem and if the stem is a threadless one.

3. Screw-on Schrader Gauge



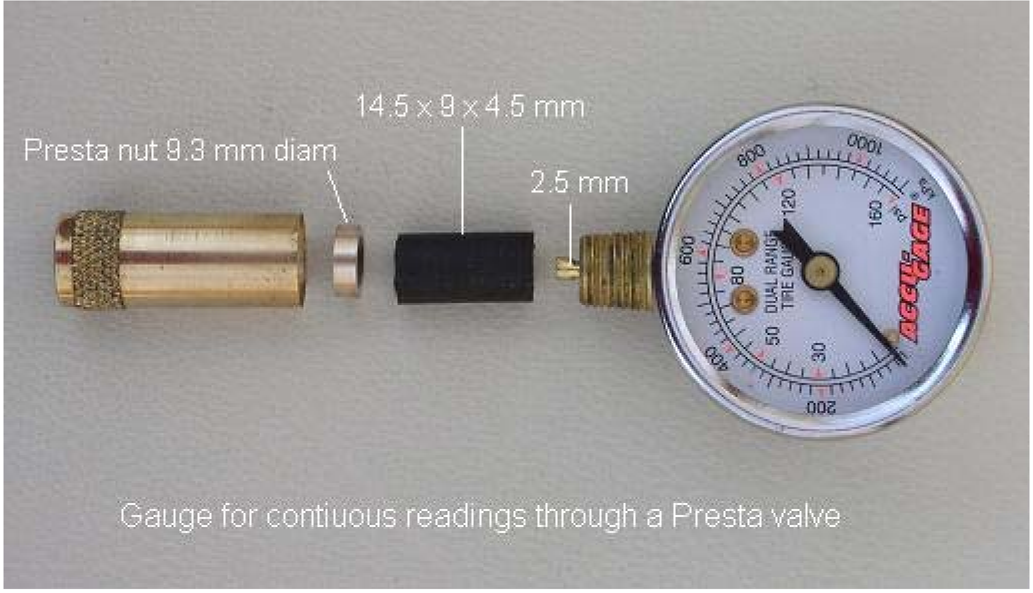
Gauge for continuous readings through a Schrader valve

To make the threaded sleeve for this gauge, the valve cap was screwed onto the end of the Schrader tool and the other end of the tool fixed into the chuck of a drill. The cap was then ground down by rotating it at high speed over first a coarse file and then a fine one until when inserted into the large brass cylinder of the gauge it was a very tight fit. The ends of the cap were then filed down to give a sleeve 4.5 mm long. Finally the sleeve was screwed onto the tool again and driven to the bottom of the large brass cylinder.

The neoprene rubber tube was constructed from the tubing I had on hand rather than from that supplied with the gauges and was a little harder. One end was honed out with a cone-shaped grinding tool used in a high-speed Dremel tool until the id at that end was 7.5 mm. A little grease was applied to the tube and it was pushed into the brass cylinder with the 7.5 mm id end going into the tube first.

A little grease is applied to the Schrader valve and the gauge is screwed on for eight turns. The gauge spins easily onto the valve for six turns and then turning becomes a little stiff. Pressure is registered after seven turns and a final turn given. During these last stages of mounting, the valve stem will have to be held with a pair of grips. During removal a second pair of grips on the brass cylinder will have to be used. (The second pair of grips can be avoided if the pressure head is screwed into the cylinder with epoxy glue on the threads, but this makes taking the gauge apart difficult.)

4. Screw-on Presta Gauge



Gauge for contiuous readings through a Presta valve

To adjust the diameter of the Presta nut to fit the brass cylinder it was screwed onto the end of the Presta tool to a point at which a burr prevented further rotation. The other end of the tool was fixed into the chuck of a drill which was rotated at high speed over first a coarse file and then a fine one until when the nut was inserted into the large brass cylinder of the gauge, it was a very tight fit. Finally the nut was driven to the bottom of the cylinder.

To mount the gauge first coat the threaded valve stem with a little grease. Screw on the gauge until pressure registers and then for about one more turn. This requires only a very light touch and anything heavier means something is wrong. If the valve is a bent, a little air will be lost in taking the gauge on and off but this normally is of no importance. The gauge may be taped to the spokes to prevent vibration and rotation.

Results

1. New Gauges

Previously (http://home.earthlink.net/~caverhall/pressandcalib.htm) I described a push-on Presta and a screw-on Schrader gauge for accurately determining tire pressure, and the present report describes new Presta and Schrader gauges with both types of connection.

I have ridden over 200 miles with the screw-on Presta attached to the wheel with no problems and no noticeable effect on bicycle handling. As the gauge is attached, it forms a very effective seal around the Presta valve tube long before the valve is opened, so no special attention is needed to avoid loss of air. The gauge can be attached for weeks with no detectable loss of air other than that by diffusion through the wall of the inner tube.

Although I have not had as much experience with the screw-on Schrader, it should be even more rugged. It suffers from the disadvantage though that a pair of grips are needed to hold the valve during the last turn of installation and two pairs for its removal. Also, it is much more difficult to construct than the Presta version. I therefore recommend that measurers with Schrader tubes switch to Presta tubes and use the Presta gauge.

An adapter to convert Schrader rims to accept Presta tubes costs only about $0.50 and if tire pressure is kept fairly high it may be possible to dispense with an adapter. A major advantage of the Presta valve is its ease of connection to a pump. I have found that the simplest and most reliable way to connect a floor pump to a Presta valve is to use a hose that forms a snug fit over the valve and hold it in place by squeezing on a wire hose clamp. The hose is reliably leak-free during inflation and so readings of the pump gauge are reliable.

The screw-ons can be conveniently read by holding the back wheel with your foot and swinging the front wheel to eye level.

Gauges should be tapped lightly with the finger before taking a reading and care taken to avoid parallax.

2. Pressure Coefficient

In an April-05 report (http://home.earthlink.net/~caverhall/pressandcalib.htm) I established that there is a linear relationship between tire pressure and circumference that is not significantly affected by temperature. One tire, (Hutchinson Carbon Comp 700 x 23), mostly over a pressure range of 80-115 psi or 5.52-7.93 bar (after allowing for a gauge zero error of 10psi) showed a pressure coefficient of 0.211 mm of circum /psi (-0.0070 rev/km/kPa).

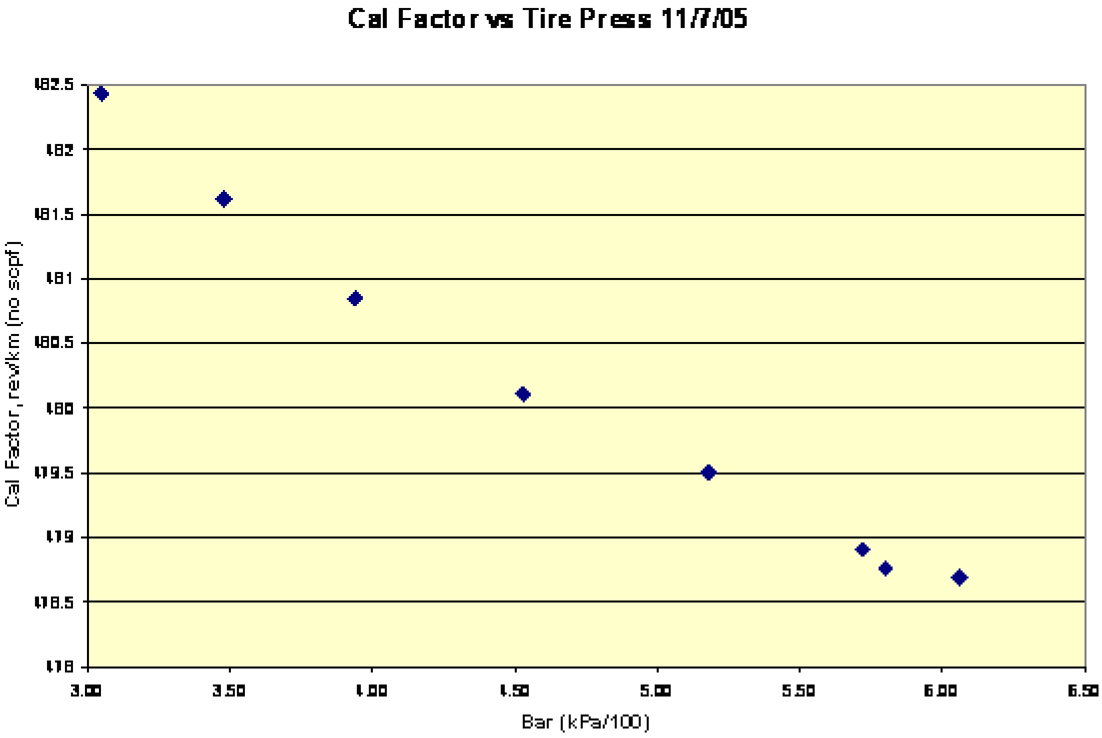
The present work gives further results from the Hutchinson tire using the screw-on Presta gauge as shown in the table below:

Date	**Press, bar**	**Cal fac, rev/km**

	kPa/100	**(no scpf)**
11/5/2005	7.40	477.509
	6.01	478.469
	4.95	479.662
	3.90	480.862
11/7/2005	6.06	478.688
	5.80	478.762
	5.72	478.910
	5.18	479.508
	4.53	480.109
	3.94	480.848
	3.48	481.621
	3.05	482.434

1 bar = 100 kPa = 14.504 psi
1 psi =6.8948 kPa

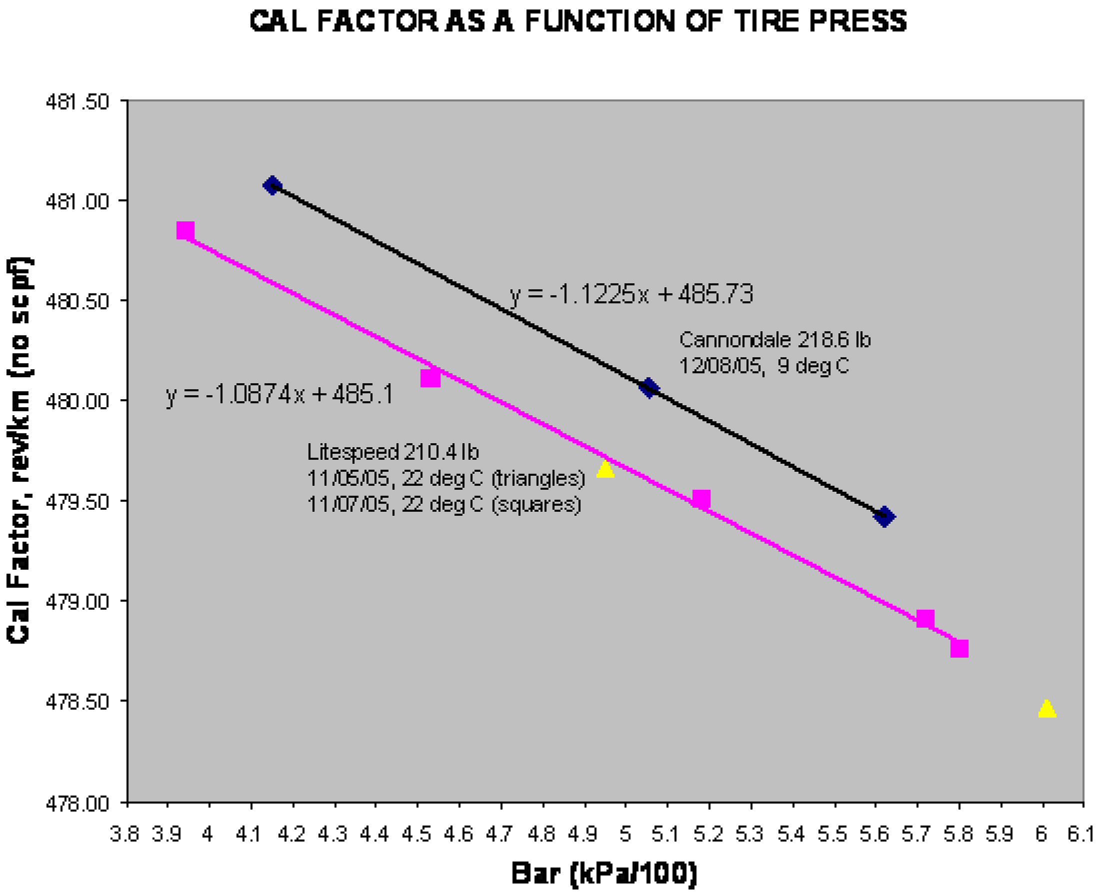
A plot of the data from 11/7/05 is shown below:



Although a decent straight line may be drawn through all the plotted points, better lines can be drawn through the points below 4 bar, those in the range of 4-5.72 bar, and those at and above 5.72 bar. Moreover the slopes of the lines decrease going to higher pressure. Clearly in going to higher pressures, the pressure coefficient becomes slightly less negative.

When data from the above table in range of 3.94-6.01 bar is plotted as shown below (red squares and yellow triangles) a very nice straight line is obtained with a slope or pressure coefficient of -1.087 rev/km/bar (-0.01087 rev/km/kPa). This is higher than the value obtained in April (0.0070 rev/km/kPa), but that was obtained at higher pressures. If one calculates the coefficient from data obtained at the two highest pressures in the above table, agreement is excellent:

(477.509-4778.469)/(7.40-6.01) = -0.0069



While obtaining the above data using my Litespeed bicycle, I became aware that the handlebars had started to become spongy and tightening the bolts on the stem had no effect. I at first thought of postponing disassembly to locate the problem until after an upcoming long validation trip to the NE, but luckily I changed my mind. To my horror I found that the steering tube on my $350 carbon fiber forks had cracked halfway through. Although I negotiated with the manufacturer to get a $130-replacement, I had to turn to my Cannondale in the meantime. The first calibration with the Cannondale using the same front wheel that I had used with the Litespeed is shown below and the data are plotted above as blue stars. Note the shift in the plot from that of the Litespeed, which I attribute mainly to the fact that the loaded Cannondale was 8.2 lb heavier than the Litespeed. More importantly though the slope of the plot or the pressure coefficient was almost exactly the same. Weight evidently does not affect the coefficient.

Cannondale 12/8/05

Bar	**Calib fac, rev/km**
5.620	479.42
5.055	480.06
4.150	481.07

The pressure coefficient would seem to be highly suited to course measurement, because in the same pressure range it probably does not change significantly for the life of the tire, with temperature, or with bicycle total weight.

Application of Tire-Pressure Monitoring to Course Measurement

There are obviously many ways to apply the concept of pressure monitoring to race course measurement (Of course it goes without saying that for best results total weight of bicycle with rider should be kept as constant as possible throughout measurements.)

The simplest is to adjust pressure at the start of course measuring to that used in the calibration. This is probably more appropriate with the push-on gauges than with the screw-ons. An average pressure during measurement differing by less than 10 kPa from that of the calibration can probably be ignored. For instance a coefficient of –0.011rev/km/kPa and a calibration factor of about 479.75 rev/km are equivalent to -0.011 x 100/ 479.75 = -0.00229 %/kPa. Thus an average difference of 10 kPa on a 5 km course would be equivalent to only 0.00229 x 10 x 5000/100 = 1.145 m.

The most accurate method involves use of the pressure coefficient, which can be determined quite simply and is probably good for years. It can then be applied with very simple calculations. For instance, pressure can be read at the start and end of a 5-km measurement. These readings are averaged, the calibration pressure subtracted, and the result multiplied by the coefficient and 5 km to give the course correction in rev. Similarly, for a 25-km measurement pressure can be read at intervals of 5 km. At the end, the amounts that the average pressure differs from the calibration pressure for each 5 km are added with regard to sign, and the result multiplied by the coefficient and 5 km to give the overall correction in rev. If temperature conditions are fairly stable, it may be sufficient to record pressure only at the beginning (b), the midpoint (m), and the end (e) of the course. The weighted average pressure is then (b+2m+e)/4.

Of course, whatever method is chosen, the post-calibration is redundant.

An example of a 5-km measurement is as follows. A measurer has a new tire and wishes to certify a 5-km course. At an average pressure of 471 kPa he determines the calibration factor is 481.01 rev/km (with scpf). He adjusts pressure and finds that at an average of 560 kPa the factor is 480.03 rev/km. Therefore the pressure coefficient is (480.03 – 481.01) / (560 – 471) = -0.0110 rev/km/kPa. He makes no further pressure adjustments but finds that at the first measurement of the course, pressure has risen to 580 kPa at the start and 590 kPa at the finish. The average pressure of 585 kPa differs from that of the last calibration by 25 kPa. He makes a correction of 25 x -0.0110 x 5 = -1.37 rev to his finish point. At 590 kPa the calibration factor is 479.70 (480.03 – 30 x 0.011). In his second measurement he marks the splits, and because pressure is 590 kPa at the start, he uses 479.70 rev/km to calculate their position. At the finish, pressure is still at 590 kPa and the finish point is 0.30 rev short of that in his first measurement. He therefore uses the finish point from his first measurement as the certified finish.

An example of a marathon measurement is as follows. A measurer performs a calibration at a pressure of 550 kPa using a tire with known pressure coefficient of -0.011 rev/km/kPa. He measures a marathon course using the calibration factor derived from the 550 kPa calibration and records a tire pressure of 560 kPa at the beginning, 580 at the midpoint, and 570 kPa at the end.

Ave weighted pressure = (560 + 2x580 + 570)/4 = 572.5
Correction = (572.5 - 550) x (-0.011) x 42.195 = -10.44 rev

Advantages of Tire Pressure Monitoring

1. Improved accuracy.

2. Post-calibration not needed.

3. A temporary calibration course does not have to be set up.

4. Frequent recalibration rides during course measurement not needed.

5. Return to the race site to make adjustments in the measurements not needed.

6. Early alert of a slow leak in the tire so no wasted efforts.

7. Temperature measurements not needed.

8. Easier scheduling of measurements (e.g. do not have to get back for post-calibration before dark and rapid drop in temperature).

9. Calculations usually simplified.

10.Tire puncture during measurement just a minor problem.