The weight indicator U2375 from Unisystem has a separate two axis tilt transducer, U9027, with which tilt up to ±16% may be compensated. There is a general EU type approval, FI98.1.02 Revision 1, according to the directive 90/384/EEC, for use up to 16% tilt in two axis and 4000 verification intervals. Unfortunately, according to WELMEC 2.4, until further experience has been gained, it may not be applied to weighing instruments built in trucks. However many tests may be omitted for a new TAC (Type Approval Certificate).

A certain trigonometric knowledge is necessary for the following discussion. The following formulas have connection with the problem.

$\cos x = 1 - x^2/2! + x^4/4! - .....$ (1)

$\sin x = x - x^3/3! + x^5/5! - .....$ where $n! = n(n-1)(n-2)....\cdot 2\cdot 1$ (2)

$\cos a + \cos b = 2\cdot\cos(a + b)/2 \cdot \cos(a - b)/2.$ (3)

The load cell is the electromechanical component, which transforms force to electrical signal.

The signal from more parallel load cells is the sum of their output currents or output voltages divided by respective output resistance. In the following it is assumed, that the output signal is standardized to 1 and consequently all output currents are equal.

For an ideal load cell, the output signal varies with cosine for the tilt angle x between the load cell and the direction of gravity. When x is 90°, the signal is zero. However practically, also without load, there is a constant zero signal, which is red on the indicator. It must not be tilt compensated and is entered in calibration step (Cs) 30 at calibration. If the signal is too low, a high resistor must be added between + excitation and + signal.

The load cell may be mounted with a small angle deviation a, which also may depend on internal deviations. The signal then varies as cos(x+a). When the load cell is turned 90° (but not the force), the signal is cos(x+a-90°) = sin(x+a). This is the sensitivity for side forces. It changes sign at x=-a.

When 2 load cells are mounted with small angle deviations a_1 and a_2 , from (3) the signal is:

$2\cdot\cos(x + (a_1 + a_2)b/2) \cdot \cos(a_1 - a_2)/2$. The last factor is constant and compensated for at calibration. It thus may be set to 1.

When n load cells ar mounted with small angle deviations a_1, a_2,.... and a_n, the signal is:

$\cos(x+a_1) + \cos(x+a_2) + ... + \cos(x+a_n)$ or approximately: $n\cdot\cos(x + (a_1+a_2+....+a_n)/n)$ (4)

Thus the total angle error is the mean value.

A small angle b between load cell(s) and tilt transducer means a + b = c.

The indicator calculates Weight·cos(x+c), which must be as constant as possible for x. But:

$\cos(x+c) = \cos x \cdot \cos c - \sin x \cdot \sin c.$ (5)

Cos x is calculated by the tilt compensation software.

Cos c is a constant close to 1 and is included in the weight calibration Cs23 to 25.

Sin x is approximately x, which is used in the Cs30 and 31 compensation.

Sin c may be added in Cs30 and 31. It is calculated at 80 to 90% of max tilt from the AD-value and angle in Cs31 and 32 respectively.

In order to meet tilt compensation up to 16% at 4000 intervals, one have to be very careful, when aligning the components and calibrating. If possible suggest less tilt and/or multiple range e.g. 2000 intervals in two ranges instead of 4000. Below a table of corrections in intervals at 4000 intervals. The correction for cos x is made automatically. c = 1° has been used.

Tilt.	cos x	c=1°
15%	45.3	10.6
10%	20.1	7.0
5%	5.0	3.5

High c increases the correction considerably. Try to make mechanical corrections.

If c gives an unsymmetric error, e.g.-6 and +10 intervals, this means, that the cos x calculation is wrong by 2 intervals. Probably Cs 30 has wrong value. If not, the analog calibration in the tilt transducer may have changed. Do not change this signal if your are not quite sure of what you do. Consult Unisystem.

In the present European standard max tilt is 5%. The WELMEC group has recommended 10% in Welmec2, issue 3 point 3.1.13. 16% meets all practically used tilts, although one may find tilt more than 20%, one does not stop there. Practically the demand is higher along the vehicle (pitch) then abeam (roll). The indicator U2375 calculates up to 16% in both directions, but simultaneously about 11% tilt is acceptable in both direction for 16% total tilt.

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Calibration, when the zero value ADZ in Cs30 is not known.

Suppose:
The value in Cs30 is AD_{ZN}, (Default 29000).

In e.g. Cs 31 (Pitch) the following AD-values are measured: AD_-, AD_0 and AD_+ for the angles α_-, 0 and α_+ respectively. The angles must be at least 80% of max. In order to get a simple calculation according to the formula below, the absolute value of the angles must be as equal as possible.

$$ADZ = AD_{ZN} + 2((AD_- + AD_+)/2 - AD_0)/(\pi(\alpha_+ - \alpha_-)/360)^2 \quad (1)$$

$$Q_P = (AD_- - AD_+)10^6/((AD_0 - ADZ)(\alpha_+ - \alpha_-)) \quad (2)$$

Example:
$AD_{ZN} = 29000$
$AD_- = 649005$
$AD_0 = 650000$
$AD_+ = 651405$
$\alpha_- = -7.97$
$\alpha_+ = 8.05$

From (1)
$ADZ = 29000 + ((649005 + 651405)/2 - 650000)/(\pi(7.97 + 8.05)/360)^2 = 49978$

From (2)
$Q_P = (649005 - 651405)10^6/((650000 - 49978)(8.05 + 7.97)) = -250$