Ball Roll Behavior

The Functional Relationship of the Ball Roll Distance and the Timing Gate Method

How to Calculate the Ball Roll Distance from Timing Gate Measurements

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The Ball Roll Distance is an important property of synthetic turf surfaces for both Hockey and Soccer. The original determination method uses a ramp with a set slope from which a soccer (hockey) ball is allowed to freely roll down and then out onto the synthetic turf with the distance of the roll then being measured. This is a direct method of determination. The primary disadvantages of this method are mainly due to the length of the rolling distance. With results of up to 20 meters, lab testing becomes extremely difficult due to normal laboratory space limitations, required sample size and preparation time (turf + in-fill). In the field, the distance of the roll can be subject to the influence of wind or wind gusts that may exceed the acceptable maximum. Thus, a method using less space or size of the tested surface would be a major advantage in facilitating the performance of the test both in the lab and in the field. Such a test was developed in England and described in the British Standard BS7044 Part 2 Section 2.1. The criticism of this Timing Gate method is that it provides indirect information about the Ball Roll Distance with no conversion of the Timing Gate readings into Ball Roll Distance.

Although the two test methods are aimed at the same surface property, they express it in different terms, the relationship of which is assumed but not yet proven. At this point, the existence of this relationship has been shown through correlative measurements gathered by Alastair Cox for the English Football Association and Morten Gabrielsen of the Norwegian Building Research Institute (NBI). They carried out both test procedures on a large number of turf surfaces (natural and artificial) and plotted the results against each other. The correlations are rather tight, but still correlations and not a functional relationship. A second formula with a correlating character has also been included in the FIFA Football Turf Manual by Dr. Eric Harrison.

With the varied correlating procedures it becomes difficult to accept the Timing Gate method for verification of a system's compliance to the Ball Roll Distance requirement since there is still a statistical uncertainty. UEFA has accepted the Timing Gate method to assess compliance to Ball Roll Distance (≤ 8.0 m) but only with the requirement of $\Delta v \geq 0.7$m/s. However, this was then an acceptable compromise in order to keep the test method "onboard" the UEFA concept.

A rather simple technique may help to solve this issue.

According to the various specifications a normal soccer ball (see FIFA Rule Book) is released on a 45 to 60º ramp from a height of 1.00 m. Using physics we can determine that the ball has a potential energy of

$$Energy(initial) = m * g * h$$

where m = mass of the ball in [kg]
g = natural acceleration constant = 9.81m/s^2
h = height in [m]

If the ball were dropped instead of being released down the ramp the speed of the ball when striking the ground/surface would be

$$v = (2 * g * h)^{1/2}$$ which is 4.43 [m/s].

If the ball is released from a ramp the inert mass comes into play: Thus, the rolling speed v is calculated from the following relationships (potential energy at the beginning of the test and kinetic energy after reaching the surface must be equal):

$$m * g * h = 1/2 * v^2 + 1/2 * I * w^2$$

where

$v = 2 * r * \pi * w$ with w = rotational velocity in [rad/s] and r = radius of ball in [m]

$I = 2/3 * m * r^2$ moment of inertia assuming the ball to be a hollow sphere

This gives $v = 3.46$ m/s for a 1 m ramp drop. Friction (air and ramp) lowers this. Measurements with FIFA approved balls showed that the speed is actually 3.20m/s.

The relationship of rotational and translational energy depends on the design of the ball: how large the dynamic inert moment caused by the distance of the ball mass from the ball center is (assuming the mass and the diameter of the ball = constant). Simply stated, this means that the speed of the ball at the end of the ramp is dependent upon the properties of the ball. This provides an easy method to control the appropriate condition of the ball by measuring the speed of the ball with the timing gate device.

The timing gate method uses two timing gates each represented by two light barriers in a defined distance (10 or 20cm). The timing gates are set up in a distance *dist* of 1 or 2 m (BS and FIFA are using 1.000m: UEFA is using 2.000m). While the ball is running through the gates, its speed is calculated from the times needed to pass the light barriers (v_a for 1st gate, v_b for 2nd gate). The named standards use the speed difference $\Delta v = v_a - v_b$ as a parameter to describe the ball roll resistance (which is the reason for the specific ball roll length) of the surface tested. The disadvantage of this procedure is that the speed difference is bound to the distance of the timing gates so that the two results cannot be compared. A better approach is described in DIN 18035-7 where the average deceleration *dec* in [m/s^2] of the ball is determined:

$$dec = (v_a^2 - v_b^2) / (2 * dist) \quad [m/s^2]$$

This parameter is independent of the timing gate distance and the results from tests with different timing gate distances would be the same if the deceleration remained constant. Unfortunately, the deceleration depends on the speed and decreases the slower the ball rolls. This is the situation which has to be taken into account when developing the calculation of the Ball Roll Distance with timing gate measurements.

If the ball's influence on the deceleration of the rolling speed is known, the Ball Roll Distance for a certain initial ball roll speed can be calculated with an iterative method. The calculation is easy if the ball roll process is seen reversed as an accelerated process starting at the end of the ball travel where the speed is zero. The ball roll acceleration is integrated until the speed has become 3.20m/s.

For a given sports surface, the relationship between ball speed and deceleration is determined by running the ball down from various heights, preferably 1.00m, 0.75m, 0.50m and 0.25m (note: the exactness of the release heights is not important/critical). Plotting the *dec* values against the average speed between the timing gates results in a more or less straight line of the form

$$dec = a + b*v \quad \{1\}$$

where *a* and *b* are constants gained from the graph. For the determination of a and b the mathematical regression method is used. The parameters *a* and *b* must be determined for each surface product individually.

In a spreadsheet the rolling process can be mathematically controlled stepwise in time increments Δt of say 0.2 seconds. During the 1st time interval the speed increases from zero to

$$v_1 = -dec_0 * \Delta t$$

where Δt is the time interval in *[s]* and $dec_0 = a$.

The rolling distance during this interval is

$$s_1 = 0.5 * dec_0 * \Delta t^2 .$$

For the next interval the acceleration dec_1 is determined with the equation {1}. The speed and the rolling distance at the end of the next interval are consequently

$v_2 = v_1 + dec_1 * \Delta t$ and
$s_2 = s_1 + v_1 * \Delta t + 0.5 * dec_1 * \Delta t^2$

This procedure is continued with n = 3,4,5...until v_n = 3.20 m/s is reached. The value s_n represents the BallRollDistance.

Since

$dec = v * dv/ds$ $\qquad$ $dv/dt = a + b * ds/dt = ds/dt * dv/ds$

there is also a functional mathematical solution (which has still to be verified).

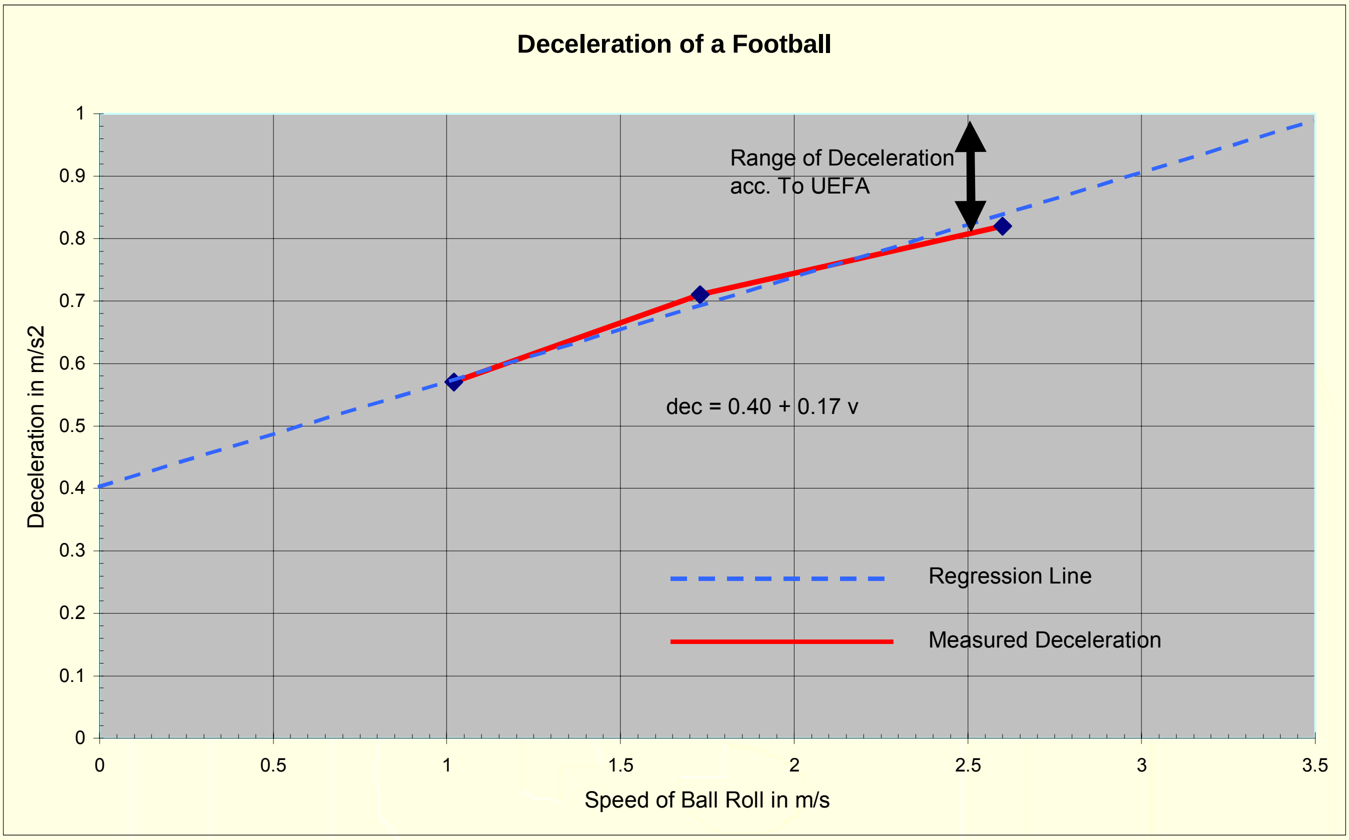
The method described above allows to determine the functional relationship between the results of the BallRollDistance and the TimingGate method. This is reasonably different from a correlation which describes a statistical relationship.

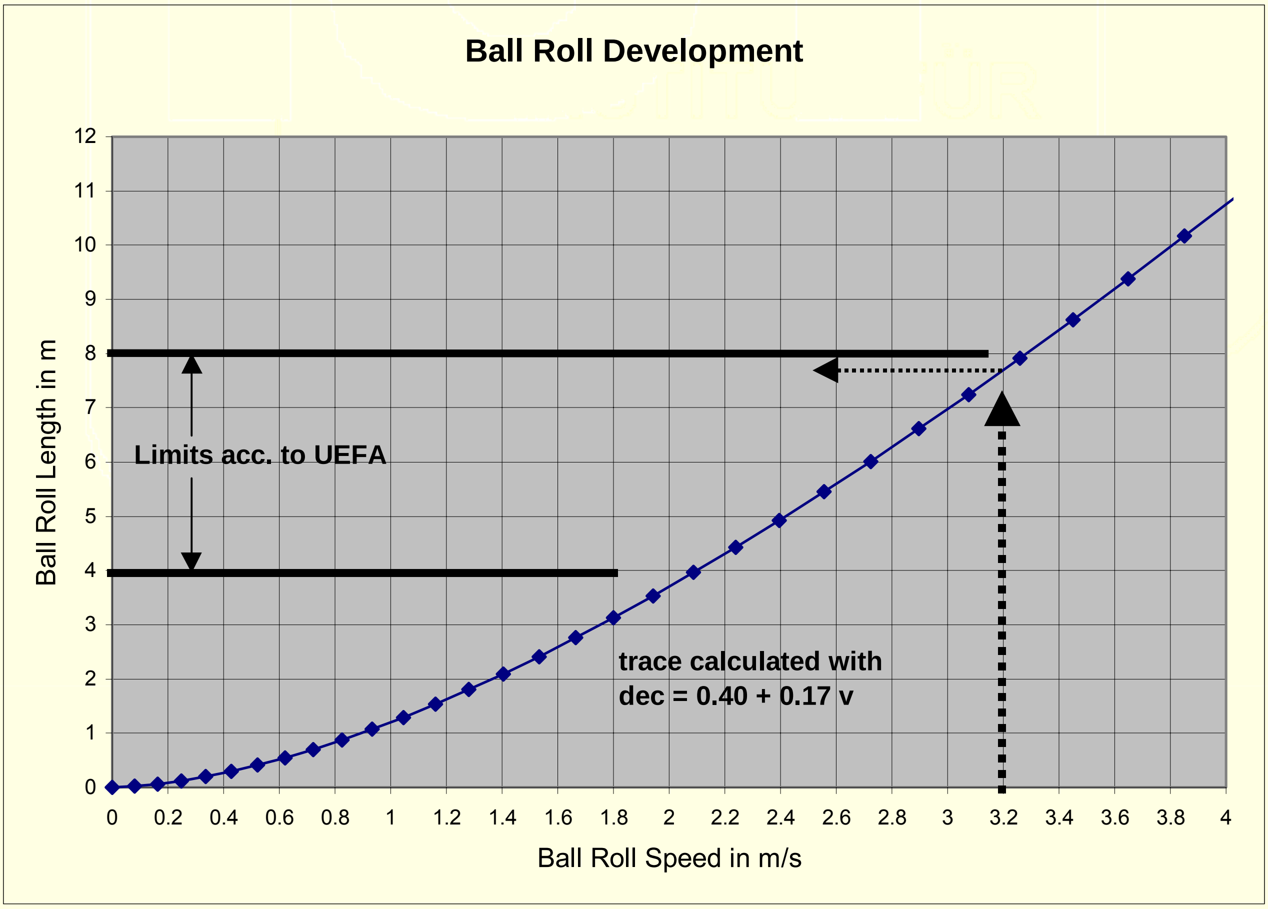
A typical graph of *dec* versus *v* is shown in figure 1. In figure 2 the development of ball roll speed and travel length is plottet. From the chart can be seen how the BallRollDistance is determined: the trace must cross the 3.2m ordinate below 8.0m and above 4.0m (UEFA system).

Now, considering the UEFA rule for the TimingGate method, a speed difference of 0.7m/s means a deceleration of about 0.8 to 1.0 m/s^2 at a speed of about 2.5m/s. The chart shows clearly that checking the BallRollDistance property with the TimingGate method puts a turf product at a disadvantage since the turf must exhibit a much higher deceleration than necessary to meet the UEFA BallRollDistance criterion. This was to make sure that a product tested positively with the TimingGate method certainly meets the BallRollDistance criterion.

With the method described above this handicap has been eliminated: the result is given as a calculated BallRollDistance without compromising assumptions. In addition, the accuracy of the test is improved since the release height of the ball is not crucial any more different from the BallRollDistance test. On rubber in-filled turf surfaces the exact determination of the release height is difficult.

Equivalent considerations may be performed with hockey balls.


Deceleration of a Football
Range of Deceleration acc. To UEFA
dec = 0.40 + 0.17 v
Regression Line
Measured Deceleration
Deceleration in m/s2
Speed of Ball Roll in m/s
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5


Ball Roll Development
Limits acc. to UEFA
trace calculated with
dec = 0.40 + 0.17 v
Ball Roll Length in m
Ball Roll Speed in m/s
0
1
2
3
4
5
6
7
8
9
10
11
12
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4