A Modified Stimpmeter for Small-plot Turfgrass Research

Roch Gaussoin¹

Department of Horticulture, University of Nebraska, Lincoln, NE 68583-0724

Jeff Nus²

Golf Course Management, Golf Course Superintendent Association of America, Lawrence, KS 66049-3859

Larry Leuthold

Department of Horticulture, Kansas State University, Manhattan, KS 68583-0724

Abstract. Golf ball roll is measured with a United States Golf Association (USGA) Stimpmeter. Three Stimpmeters were fabricated identically to the USGA Stimpmeter, except for the location of the ball release notch. The modified Stimpmeters had ball release notches located at 57, 38, and 19 cm, rather than at 76 cm from the beveled end. The modified Stimpmeters were tested on a creeping bentgrass green located at Mead, Neb., at three mowing heights (4.8, 4.0, and 3.2 mm). The Stimpmeters were effective in measuring golf ball roll distance and provided reasonable and consistent estimates of friction. Modified Stimpmeters are relatively inexpensive to construct and can be used on small turfgrass research plots.

The Stimpmeter was introduced in 1977 by the United States Golf Association (USGA) to measure golf ball roll as a means of estimating putting green speed (Beard, 1982; Oatis, 1990). The Stimpmeter is an extruded aluminum bar 0.9 m long with a V-shaped groove extending along its length and a ball-release notch located 76 cm from the tapered end. The notch is designed to release a golf ball when the Stimpmeter is raised to 20° from horizontal (Radko, 1980).

By classical mechanics, ball roll distance is related to its initial kinetic energy at the beginning of the roll across the turf and friction, the force of resistance between the ball and the turf, which is assumed to be constant. (Equation variables are defined in Table 1.)

$$KE = S \times F \quad [1]$$

Initial kinetic energy is the product of the weight of the ball and its altitude of gravitation acceleration adjusted for its angle of incidence with the turf surface. Adjustment is accomplished by $\cos(20^\circ)$, a measure of the horizon-

tal component of momentum retained at the beginning of the roll.

$$KE = M \times A \cos(20^\circ) \quad [2]$$

It is assumed that kinetic energy is all translational (linear) momentum, and none is angular (rotational). The consequence of violating this assumption will be discussed later in our paper. Surfaces have a characteristic coefficient of friction proportional to the load and the friction.

$$F: f = F/M \quad [3]$$

Therefore, from [Eqs. 1, 2, and 3], in the case of a golf ball rolling across turfgrass, the coefficient of friction is the adjusted altitude of the Stimpmeter divided by the ball roll distance.

$$f = A \cos(20^\circ)/S \quad [4]$$

If the model is complete, then ball roll distance is directly proportional to the altitude of the Stimpmeter. For Stimpmeters of varying lengths operated at the same angle, ball roll distance is directly proportional to Stimpmeter length.

Cultural practices, such as close mowing, excessive verticutting, frequent grooming, and low fertility can markedly increase putting speed but often are detrimental to turfgrass stress tolerance (Oatis, 1990; Rothenberg, 1987; Throssell, 1981). Golf putting green research dealing with these cultural practices seldom measures ball roll. This is an important omission because ball roll is an integral measure of putting green quality. Ball roll is often omitted because no Stimpmeter is available to measure ball roll on typically sized research plots (Lodge, 1992). Lodge (1992) described

an apparatus of relatively complex construction for measuring greens speed on small research plots, the resultant data were significantly correlated with USGA Stimp-meter ball roll measurements. Our research was conducted to evaluate a simple modification of the USGA Stimpmeter for use on small turfgrass research plots.

Materials and Methods

Modified Stimpmeters were fabricated from oak, following similar specifications outlined by Radko (1980), with the exception that ball release notches were located at 57, 38, and 19 cm, instead of the standard 76 cm. The modified Stimpmeters were tested on a creeping bentgrass (*Agrostis palustris* Huds. 'Penn-cross') green at the John Seaton Anderson Turfgrass Research Facility located near Mead, Neb.

The surface was essentially flat (slope $<0.5^\circ$). The diameter of the golf ball was 4.27 cm. Ball roll distance was averaged across the 50 releases as repeated measures, within combinations of mowing height and Stimpmeter length. Ball roll distance was corrected by 1) subtraction of $\tan(10^\circ)$ ball radius = 0.38 cm, because the ball hit the ground slightly after the vertical projection of its center passed the end of the Stimpmeter and 2) subtraction of the ball radius (2.13 cm) because measurements were taken at the distal edge of the ball, not the center. Stimpmeter effective length was corrected by subtraction of $\tan(10^\circ)$ ball radius = 0.38 cm, for the same reason as previously explained. Ball release altitude was calculated by multiplying effective Stimpmeter length by $\sin(20^\circ)$ and was adjusted by multiplying again by $\cos(20^\circ)$ to express the result based on horizontal momentum. The corrected distance of ball roll was plotted against adjusted ball release altitude.

Least-squares estimates were determined using nonlinear regression (SAS Institute, 1988) for coefficient of friction for each mowing height and a common correction factor, the x-intercept, which is subtracted from the adjusted ball-release altitude.

$$S = [A \cos(20^\circ) - A']/f \quad [5]$$

A USGA Stimpmeter was used to release a golf ball 50 times at mowing heights of 4.8, 4.0, and 3.2 mm, and the length of the subsequent ball-roll distance was measured and recorded. This procedure was repeated along the same line and direction of travel using the modified Stimpmeters. Solved regression equations are reported (Fig. 1). Within the ob-

Table 1. Variable descriptions.

Variable	Descriptions
A	Altitude of gravitation acceleration
A'	Common correction factor
F	Friction, the force of resistance between the ball and the turf
f	Coefficient of friction
KE	Kinetic energy
M	Weight of the ball
S	Ball roll distance

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¹To whom reprint requests should be addressed.

²Technical Editor.

served range of Stimpmeter lengths and mowing heights, distance of golf ball roll was highly predictable (coefficient of determination = 0.995). This result is consistent with the assumption that a particular turfgrass area mowed at a particular height has a characteristic coefficient of friction, which can be measured by Stimpmeters of varying lengths. Conversely, knowing the coefficient of friction from one Stimpmeter makes it possible to predict the distance of golf ball roll from another length Stimpmeter, such as the USGA standard.

The negative x-intercept (positive correction factor = 1.600) was surprising. A positive intercept (negative correction factor) might be expected because of static friction, the minimum force needed to move a ball. There are three possible explanations. 1) The negative x-intercept may represent bias in initial velocity, due to tipping the ball out of the notch. 2) If friction varies with velocity, the true response of ball roll may be curvilinear, and the correction factor is arbitrary. 3) The consequence of ignoring angular velocity is to overestimate the coefficient of friction to a degree that might vary among Stimpmeters of differing lengths. According to rigid body dynamics, a solid uniformly dense sphere that rolls without slipping has a translation momentum equal to 1/1.4 of total momentum; the proportion due to angular momentum is $1 - (1/1.4)$. Because only translational momentum is reduced by angle of incidence, initial velocity is greater—by 1.8%—in the case of rolling without slipping; this value would not be achieved in the case of rolling with slipping, as might occur with long Stimpmeters. Whatever the explanation for the unusual x-intercept, shortened Stimpmeters seem to be a simple tool for measuring a fundamental aspect of the turfgrass surface.

Modified Stimpmeters of various lengths were effective in measuring distance of golf ball roll and provided reasonable and consistent estimates of friction. The most closely mown turfgrass had the lowest estimate of friction (0.092), but the tallest mown turfgrass had the highest (0.121). These data are reasonable if resistance to golf ball roll is due to inelastic bending of turfgrass blades. The shortened Stimpmeters are relatively inexpensive to construct and can be used in small turfgrass research plots.

Fig. 1. Corrected distance of golf ball roll as a function of Stimpmeter length and adjusted ball-release altitude, for three mowing heights (3.2, 4.0, and 4.8 mm). Error bars represent sd for 50 observations per data point. Regression lines have been projected toward the origin for purposes of visualizing their common x-intercept.

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