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Frictional Forces Required for Unrestrained Locomotion in Dairy Cattle

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ABSTRACT

Most free-stall housing systems in the Netherlands are equipped with slatted or solid concrete floors with manure scrapers. A slipping incident occurs when the required coefficient of friction (RCOF) exceeds the coefficient of friction (COF) at the claw–floor interface. An experiment was conducted to measure ground reaction forces (GRF) of dairy cows (n = 9) performing various locomotory behaviors on a nonslippery rubber-covered concrete floor. The RCOF was determined as the ratio of the horizontal and vertical components of the GRF. It was shown that during straight walking and walking-a-curve, the RCOF reached values up to the COF, whereas for sudden stop-and-start responses, the RCOF reached values beyond the maximum COF that concrete floors can provide. Our results indicate that concrete floors do not provide enough friction to allow natural locomotory behavior and suggest that tractional properties of floors should be main design criteria in the development of better flooring surfaces for cattle.
(**Key words:** cattle lameness, claw disorder, animal welfare, biomechanics)

Abbreviation key: COF = coefficient of friction, **GRF** = ground reaction force, **RCOF** = required coefficient of friction.

INTRODUCTION

Most free-stall housing systems in the Dutch dairy industry are equipped with slatted or solid concrete floors with manure scrapers (Braam and Swierstra, 1997; Somers et al., 2003). Since the introduction of loose housing with these types of floors, the incidence of (sub)clinical claw disorders and lameness has increased drastically. There are also indications that the slipperiness of concrete floors forces cows to adapt and limit their natural locomotory behavior (Galindo and Broom, 2002; Metz and Bracke, 2003). Cows walk on slippery floors with a "stiff" gait. The range of motion of their proximal joints is small, and they must walk at a greater movement frequency to maintain speed (Phillips and Morris, 2000, 2001). Moreover, an increased risk of slipping is common, predisposing cattle to potential injury and potentially being a reason for culling (Whitaker et al., 2000).

Because insufficient friction leads to most slip incidents, several studies, mainly in humans, have determined the slip properties of floors. The main factor in relation to slipperiness is the coefficient of friction (**COF**). The COF determines the horizontal (frictional) force that can be generated between the contact surfaces of 2 objects per unit of vertical force between these objects (Hall, 1995; Chang et al., 2001). The amplitude of this force depends on the character of the mechanical and molecular interactions between the 2 surfaces in contact. The COF is obtained by measuring the dimensionless ratio of the horizontal and vertical force just before the objects start to slide relative to one another (static COF) or during sliding at a given speed (dynamic COF). When sliding (dynamic), the magnitude of the dynamic COF remains constant and theoretically below the value of the static COF (Hall, 1995).

In cattle locomotion, the COF depends on the properties of the claw horn, the concrete floor, and their contact interface. Intervening fluids (e.g., water, slurry, etc.) affect its value. The COF was found to range from 0.25 to 0.54 using different measuring methods; the

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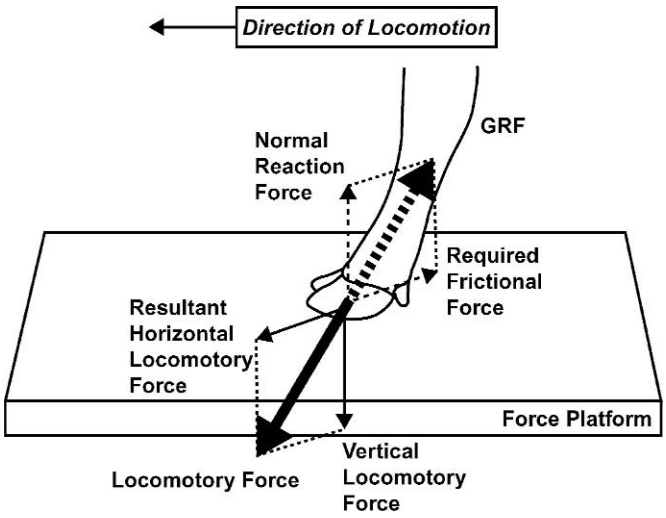

Figure 1. A snapshot of the locomotory (action) force exerted on the floor and an equal but opposite force in direction, corresponding to ground reaction force (GRF), in addition to the horizontal and vertical components of these forces (thin arrows), at a certain time during the initial part of the stance phase of a walking cow. The GRF is used to determine the minimum required coefficient of friction (RCOF) for unrestrained locomotion. The resultant horizontal locomotory force is equal to the frictional force generated at the claw-floor interface. Therefore, the RCOF can be determined according to the following deduction of Newton's third law of reaction: 1) action = –reaction; 2) resultant horizontal locomotory force = required frictional force; 3) resultant horizontal GRF = RCOF × vertical GRF; 4) RCOF = resultant horizontal GRF ÷ vertical GRF. The RCOF is equal to the ratio of the $GRF_{horizontal}$ and the normal reaction force ($=GRF_{vertical}$).

median value on concrete was about 0.3 (Webb and Nilsson, 1983; Phillips et al., 1998, 2000; Phillips and Morris, 2000, 2001). A COF to allow locomotory behavior was hypothesized to be at least 0.4 (Webb and Nilsson, 1983). Those researchers, however, did not provide experimental evidence for their postulate. To assess the risk of slipping in the cattle housing, one must know the minimum required coefficient of friction (**RCOF**) for the displayed locomotory behavior.

The cow exerts a force to the floor during foot contact that can be resolved in a vertical and horizontal component. In our study, the ground reaction force (**GRF**), a force equal but opposite in direction to the force the cow applies to the floor, was measured by means of a force platform. Whether the claw will slip is determined by the ratio of the horizontal and vertical force (Figure 1). On slippery floors, cows will try to adapt their gait to ensure that they do not slip, by keeping the RCOF for the intended behavior below COF values of the floor.

The aim of this study was to determine the amount of friction required for unrestrained locomotion. To allow unrestrained locomotion, the experiments were performed on a floor covered by rubber matting with a very high COF. In addition to normal walking, 3 behaviors that require high frictional forces were selected: walking through curves, suddenly stopping, and suddenly starting.

MATERIALS AND METHODS

Nine nonlame dairy cows (Holstein-Friesians, age = 3.4 ± 1.3 yr, BW = 631 ± 51 kg) were subjected to an experiment at the end of the grazing period. The cows originated from a herd with typical Dutch dairy production l (8000 kg per lactation) and were maintained at the experimental farm "De Tolakker" of the Faculty of Veterinary Medicine. The hind claws of the cows were trimmed routinely approximately every 5 mo. The last trimming was performed 1 mo before the experiment was initiated. The cows were on pasture during the day, and were maintained in a free-stall housing with slatted concrete floors at night. The walking areas were cleaned automatically every 20 min by means of a manure scraper.

The following behaviors, which tend to occur frequently and involve relatively high frictional forces, were selected to analyze the GRF: 1) walking a curve, 2) starting, 3) stopping, and 4) straight walking, which was used as a reference. In a pilot study, stepping into a free stall (height = 13 cm) was analyzed, but it was found that GRF values were in the order of the values obtained at straight walking. Therefore, this behavior was not investigated further.

A Kistler force plate (type Z4852, dimensions 600 × 900 mm; Kistler Instrumente AG, Winterthur, Switzerland) was embedded in a concrete pathway to measure the vertical and the 2 horizontal (longitudinal and transverse) components of the GRF with a sampling frequency of 2500 Hz. The pathway and force plate were covered with a 5- to 6-mm thick rubber mat to ensure enough traction to allow natural locomotion and to prevent slippage. Covering of the force plate also prevented potential awareness of the system. The data captured by the force plate was converted from analog to digital and stored in a computer for later analyses.

Experimental Procedures

Walking trials. The cows were repeatedly walked down the path, led by 2 experienced handlers, one in front of and the other behind the cow to control the direction of locomotion. The experimenter initiated the GRF acquisition by having the software start to sample for up to several minutes to measure a few trials in a row. The forelimb and hind limb on the same side of the cow were measured in a single trial. The trials