XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

AN INSTRUMENT FOR MEASURING THE SKID RESISTANCE OF FLOORS IN LIVESTOCK HOUSING

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CSBE100936 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment Conference

ABSTRACT The improvement of the flooring materials performance on animal health and welfare requires the support of reliable testing techniques. This is particularly relevant with the synthetic soft coverings used for walking areas since the friction coefficient is not only depending on the surface characteristics, but also on the penetration of the animal hoof into the material. The paper presents the functioning of a new instrument capable of reproducing more closely the real interaction between the floor surface and the animal foot. The instrument is simple and portable and is suitable both for laboratory measurement and real housing conditions. The measure is made in two steps: first a probe shaped as a cow hoof and contacting the testing floor surface is loaded with a vertical force to obtain a pressure similar to that exerted by the animal; then a pushing force parallel to the floor is applied, at a constant speed, producing a displacement along the surface. The values of the vertical and horizontal strengths required for skidding and the angle of the instrument are continuously measured and by them various parameters can be calculated. The results of the tests carried out in laboratory and in real dairy houses are shown and the main floor properties obtained from the new instrument discussed.

Keywords: Dairy cows, Floors, Test instrumentation.

INTRODUCTION The influence of the flooring materials on health, welfare, and social behaviour of cows is more and more relevant in dairy housing due to the increasing sensitivity of the high yielding animals to the environment and, in particular, to the walking surfaces. This fact is confirmed by the growing frequency of leg injuries and hoof pathologies occurring in dairy herds.

In recent years several investigations have been carried out on alternative materials and techniques to obtain less hard, slippery and abrasive floors than the common made of concrete. In particular the soft floorings, made of rubber mats, have revealed very interesting according to the results of various researches showing their beneficial effects on animal health and welfare (Jungbluth et al. 2003; Vokey et al. 2003; Telezhenko and Bergsten., 2005; Vanegas et al. 2006; Flower et al. 2007).

However the wide variety of products available on the market requires the support of reliable testing techniques to evaluate the effect of each proposed solution on the animal welfare with special reference to the skid resistance, being the slipperiness one of the main factors of hoof and leg injuries. To this purpose the friction coefficients, static and dynamic, are the parameters commonly used for a specific evaluation; but the measurement techniques generally adopted in the testing procedures appear not very suitable since not capable of reproducing the real interaction between the animal foot and the floor surface (Telezhenko and Bergsten, 2005; Van der Tol et al., 2005; Rushen and de Passillé, 2006).

In fact whereas with the hard floors the friction coefficient is only depending on the surface characteristics, so that the values are not depending on the contact pressure exerted by the instrument on the tested material, with resilient floors the penetration of the hoof, function of the vertical load, has a great influence since the skid resistance is also depending on the hoof imprint into the material. Nor a separate evaluation of the surface friction and the penetration depth can be sufficient to reproduce the complex interaction between animal hoof and floor occurring just before and during the sliding movement.

In addition there are no instruments yet available (as far as we know, see also Steiner and van Caenegem, 2003) capable of making this kind of testing in real housing conditions and with the real load entity. This is a drawback because if such instruments were available it would be possible to assess the variation of the flooring performance during the time and in different conditions of use.

For these reasons we decided to carry on a work aimed at realizing an instrument suitable for the measurement of the skid resistance of all kind of flooring materials since capable of evaluating the combined effect of the surface texture and the deformability of the materials, being also portable and suitable for specific tests in real housing conditions. The functioning of the instrument and the results of laboratory tests are presented in this paper. Also the first results of field tests will be shown.

MATERIALS AND METHODS The instrument, based on the drag method, consists of the following parts (fig. 1): a) a device (coil spring) capable of exerting a vertical force up to 250 daN; b) a test body in the shape of a claw (60 cm^2), made of polypropylene, set on a sled; c) a pushing device capable of exert a horizontal force and move the sled at a constant speed; d) a system of sensors and load cells measuring various parameters (vertical and horizontal force, tilting angle, penetration of the test body into the sample material).

The ratio of the horizontal limit force (immediately before the claw displacement) to the vertical force gives the static coefficient of friction (COF). The same ratio during the movement represents a sort of dynamic COF, variable with the decrease of the vertical force. This is not exactly what is commonly called dynamic COF, but it can well indicate the reaction of the floor to the hoof continuously slipping, while the load is progressively transferred to the other feet.

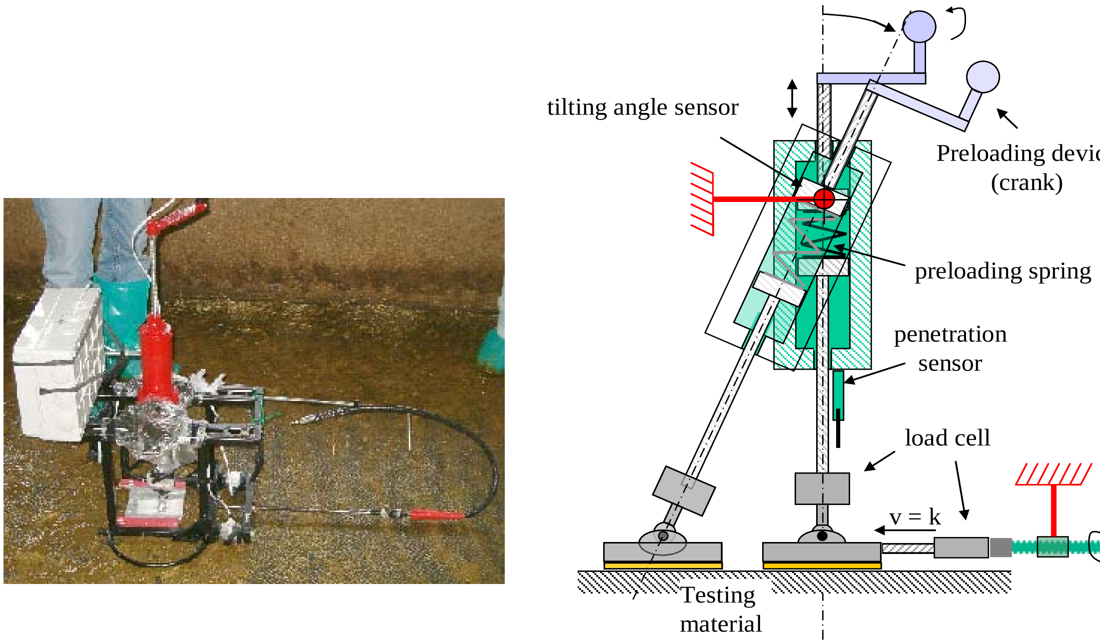

Figure 1. Instrument used to asses the flooring material properties (**FMPI**), picture and scheme.

In the first laboratory trials nine commercial flooring materials were tested, eight rubber mats, with or without burls on the bottom side, and one a highly abrasive hard floor made of an epoxy resin coat with coarse aggregates on a concrete base. When burls are not present in the bottom side, grooves are present (see fig. 2, middle column). Testing laboratory conditions were: 1) clean and dry floors; 2) floors covered with wetted clay (to simulate a real dirty floor).

In a second step, field tests were conducted in real condition on four different floor materials: three mats (B, C, F), and a Resin. Furthermore, the concrete floorings of the feeding alley in two barns were tested too.

Table 1. Main characteristics of the tested materials.

floor type	total thickness (mm)	rubber height (mm)	burl height or depth of the groove (mm)	burl/total height ratio	burls or grooves (B/G)
A	18.0	13.5	4.5	0.25	B
B	23.0	18.0	5.0	0.22	B
C	19.5	15.0	4.5	0.23	B
D	17.0	13.0	4.0	0.24	G
E	12.0	9.5	2.5	0.21	G
F	17.5	12.5	5.0	0.29	G
G	18.5	13.5	5.0	0.27	B
H	27.0	14.5	12.5	0.46	B
RESIN	5.0 [1)]	--	--	--	--

1) Indicative value

Conventional tests were carried out to calculate the dynamic COF (so called *cD_COF*) pulling the sled through the FMPI in a changed configuration (the pushing device is used in a reverse mode to pull the sled, loaded with a ballast of 60 N).

The main parameters obtained directly from the FMPI test are: Static COF (*S_COF*); sinking depth of the claw in the floor, after the loading procedure, and just before pushing. Other calculated parameters calculated are: *D_COF10*, the integral of the COF for the first 10 degrees of the loading jack rotation (the maximum rotation angle is 40 degrees). *D_COF10* represents a sort of dynamic COF measured during the sled movement with a varying load. The Integral of the pushing force (*IPF*) to the time divided by the total time, calculated as the integral of the horizontal force for the whole test (or until the probe escaping). The measuring unit of *IPF* is in N.

In tab.1 some characteristics of the examined flooring materials are reported, while in fig. 2 the pictures of three samples are presented.

Figure 2. Top and bottom view of three tested materials: on the left, rubber mat with burls; in the middle, mat with grooved bottom side; on the right the resin coat.

RESULTS In tab.2 the results of the laboratory and field tests (only for floors B, C, F, and RESIN). In field condition two concrete floors have been tested too.

Tab.2 Laboratory tests on nine commercial mats and field tests on two concrete floors.

Flooring mat	S_COF clean	cD_COF (clean)	S_COF dirty		D_COF10 dirty		IPF (N)		Sinking (mm)	Sinking[2] (%)	Foot escape
			lab.test (clay)	Field test[1] (manure)	lab.test (clay)	Field test (manure)	lab.test (clay)	Field test (manure)			
A	0.78	0.65	0.39	--	0.16	--	22.5	--	3.4	18.6	No
B	0.48	0.61	0.35	0.50	0.21	0.41	25.7	29.3	2.3	9.9	No
C	0.68	1.06	0.37	0.47	0.20	0.37	25.3	27.4	3.7	18.8	No
D	0.60	0.55	0.36	--	0.15	--	17.4	--	2.4	14.2	Yes
E	0.74	0.48	0.37	--	0.14	--	15.4	--	1.4	11.3	Yes
F	0.63	1.10	0.39	0.57	0.23	0.45	34.4	33.7	1.8	10.1	No
G	0.58	1.07	0.36	--	0.17	--	21.6	--	3.1	16.5	Yes
H	0.61	0.91	0.36	--	0.20	--	26.3	--	3.8	14.1	No
RESIN	0.51	0.48	0.44	0.42	0.25	0.25	22.3	21.6	0.6	--	Yes
Concrete_A	--	--	--	0.37	--	0.22	--	15.5	0.5	--	Yes
Concrete_B	--	--	--	0.44	--	0.28	--	21.3	0.6	--	Yes

1) Field tests are intended with manure in the feeding alley

2) Sinking, % on total thickness

Trends of vertical and horizontal forces are shown in fig. 3 as recorded during field tests, for concrete floor and rubber floor (F type) in feeding alleys. In fig. 4 COF values are presented as calculated from data of fig. 3. In field tests floor surface is covered with cow manure. In the case of concrete floor, the probe, after a displacement of about 9 cm, lost the contact with the soil surface resulting in a rapid slipping, here called *foot escape*.

In tab. 2, *S_COF clean* reveals to be not adequate to characterize the very slippery floors (those with foot escape D, E, G, and RESIN): in fact we would have expected always lower values for less slippery floors, but it is not true for floors D and RESIN. For example, floor E has *S_COFclean = 0.74*, much higher than floor B with *S_COFclean = 0.48*. When wetted clay was added *S_COF* became similar for all the floor mats,

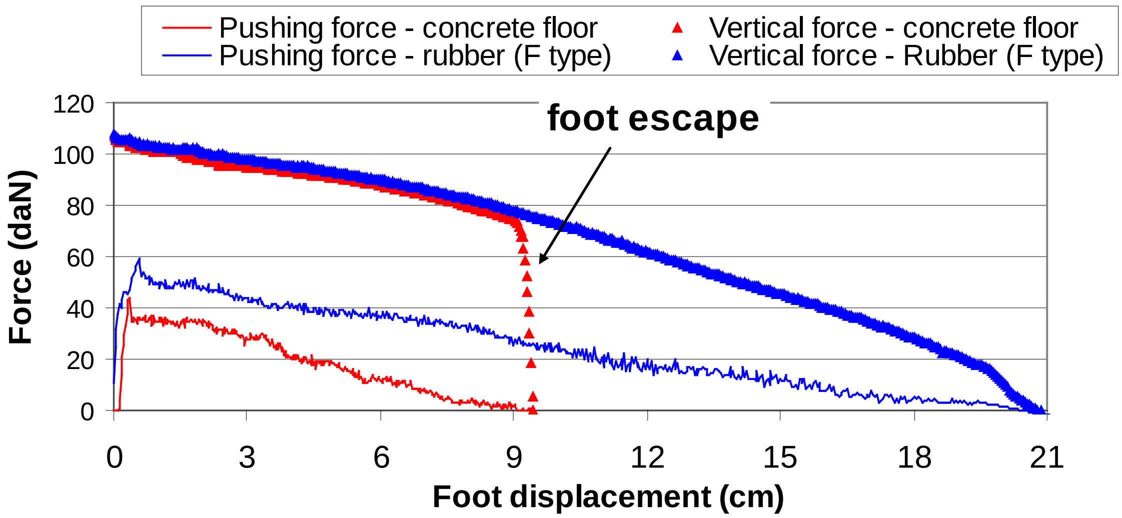

Figure 3. Vertical and pushing forces in field tests.

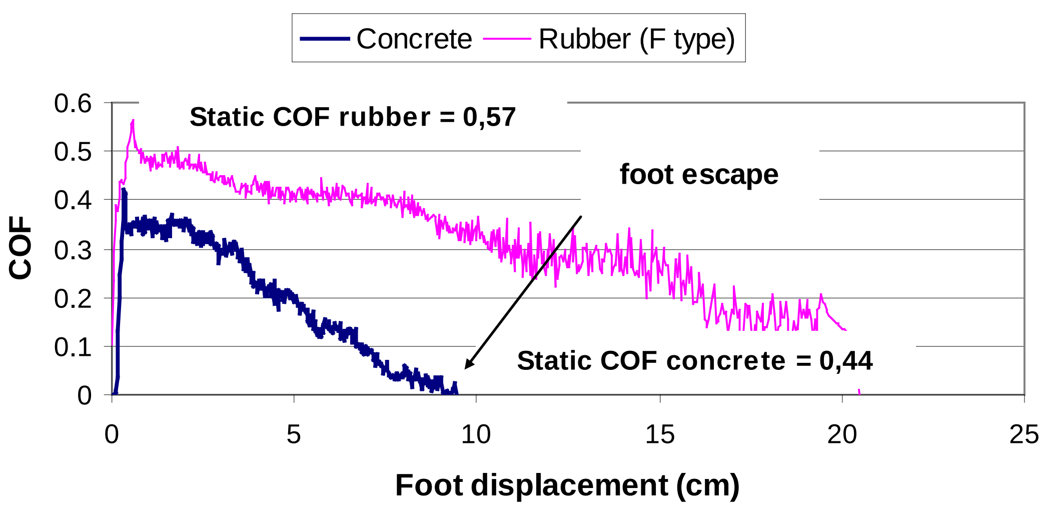

Figure 4. Calculated COF for the same tests in fig. 3.

except for RESIN. The parameter *cD_COF* could be better representative because more slippery floors have lower values, except for floor G with the second highest value. *D_COF10* is a good parameter to discriminate the slipperiness level of floors, but even better is the parameter *IPF*. This parameter discriminates correctly among the floors with foot escape and the other, included the RESIN. As first indication we can say that slipping can happen with *IPF* value lower than 22.3 N.

Again in tab. 2, we can see that concrete floors in the field tests present both a strong slipping behaviour, and *IPF* values are lower than the discriminating threshold of 22.3 N above proposed: 15.5 and 21.3 N respectively for A and B floors.

Foot escape depends not only by an insufficient *S_COF*, but also by the residual friction reaction of the floor after foot sliding is started. This aspect is well represented by *IPF* parameter.

Comparing the lab. test and the field test (possible only for B, C, F, and RESIN mats) we can see that *IPF* shows a good correspondence. Whilst if we compare *S_COF* (using clay in lab. test and manure in field test), we can see that clay acts more as lubricant than manure.

The parameter *IPF* does not seem to have a direct correlation with hoof sinking (r = 0.13). Better correspondence we have if considering the ratio burl height to total thickness (*BTR*, r = 0.38). Good correlations are presented by *TD_COF* (r = 0.68) and the presence of burls on the bottom side of the mats (r = 0.7). In the attempt of correctly evaluating the real contribution of each parameter to the independent variable *IPF*, we did a statistical multiple regression. In a first application, we tried to analyze the following model:

$$IPF = \alpha \times cD\_COF + \beta \times sinking + \chi \times sinking\% + \delta \times thickness + \varepsilon \times BTR + \phi \times BG + u \qquad (1)$$

Where:
IPF = integral of the horizontal force;
cD_COF = Coeff. of friction with fixed load (see Mat. & Meth.);
BTR = burl height by total thickness ratio;
BG = presence of burls or tracks in the bottom side;
Sinking, sinking depth in mm, *sinking%* = sinking in % of thickness;
a, b, c, d, e, f, and *u,* regression parameters.

In this model forme the model presented a R2 = 0.883, but due to a partial multicollinearity the number of independent variables was reduced in the following way:

$$IPF = \alpha \times cD\_COF + \delta \times thickness \qquad (2)$$

So, only two variables were used in the model with a contribution of 68% for *cD_COF* and 32% for *thickness* ($R^2 = 0.55$).

In fig. 5 the comparison of the regression model applied to laboratory and field test data is presented. Although R^2 is not so high, predicted values are in well agreement with measured values, except for F and G mats that present relevant deviations. This because these mats have similar characterizing parameters (see tab.1), but different FMPI response (with G mat presenting the foot escape event). So, in these two cases, the simplification brought by the regression model is inadequate to predict the real behaviour. However the high contribution in the model of *cD_COF* shows the relevance of the superficial texture of the floor. Instead, it appears quite strange the absence of the sinking parameters in the final model.

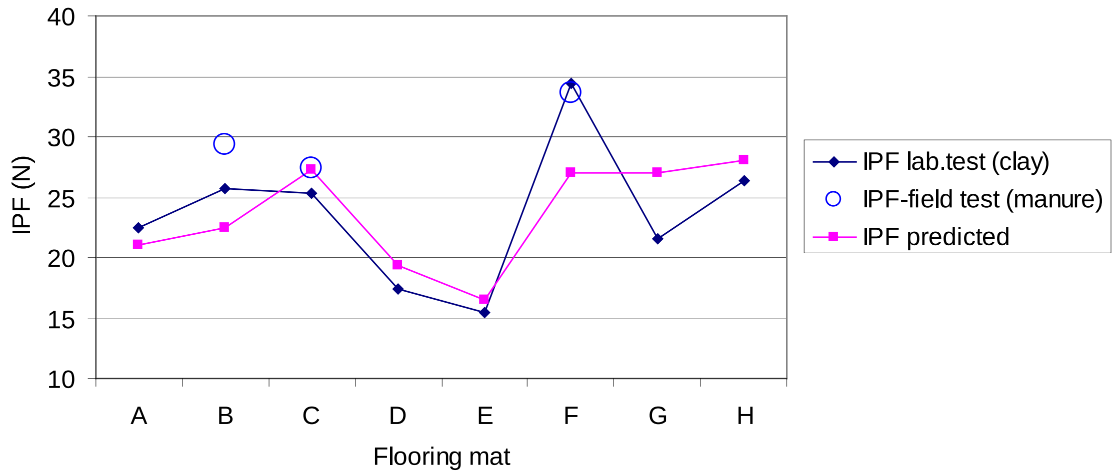

Figure 5. Comparison of the regression model with lab. and field test data.

CONCLUSION The first trials showed a good performance of the experimental instrument and, especially, a good capability of appreciating the performance of the softer materials in farming conditions thanks to a more similar behaviour to the real foot biomechanics than the common laboratory instruments. This fact due to the possibility of determining the static COF under vertical forces as greater as those exerted by the animal hoof on the floor, and also since highlighting the material performance during the foot sliding movement.

In addition the instrument is portable and designed to be suitable for tests in any use conditions. To this purpose a specific calibration is required to ascertain whether a reduction of the vertical load can be applied, to facilitate its practical use, following a reduction of the test body dimensions.

Further field trials will put into evidence the efficiency and reliability of the instrument in real housing conditions and permit to appreciate the effect of the indicated parameters on the animal welfare and health.

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