World Tribology Congress 2013
Torino, Italy, September 8 – 13, 2013

Experimental device to identify friction levels for airport applications

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Abstract

This paper presents an experimental device aimed at identifying different road friction levels; it has been designed at the Politecnico di Torino as part of the research program AWIS (Airport Weather Information System: study and realisation of a system for the prediction, monitoring and management of meteorological winter emergencies in airports) funded by Regione Piemonte.

Introduction

The research carried out at the Dipartimento di Ingegneria Meccanica e Aerospaziale concerns the identification of tire-road friction levels on airport runaways. This information, together with those obtainable from other sensors (e.g., temperature, humidity, etc.) will allow to determine the recommended amount of the of de-icing fluid to be spread, thus granting safety conditions while reducing expenses and unnecessary fluid waste.

Some researchers have face similar problems [1-3], aiming at determining the value of the potential or actual tire-road friction: different methods and instruments are described, each showing advantages and drawbacks. One of the most reliable methods is based on a dedicated redundant braked wheel (Norse meter), which allows estimating the value of the tire-road friction coefficient at high slip values. However, it has several disadvantages: it cannot provide a continuous measurement of friction coefficient since it works intermittently; furthermore, due to its complexity, it is very expensive and prone to frequent breakdown [3].

Since none of the solutions available on the market or proposed in literature met the required specifications (especially in terms of cost), the authors designed a simple device, based on a slipping pad, intended to be used only on flat surfaces and at low speed (as on airport tracks). The choice of the pad is based on the following considerations: low cost, simple construction, no need for additional control systems, ease of mounting on airport spreading vehicles. Obviously, the sliding block solution has its disadvantages: the measures are possible only when the vehicle is in motion, it can only give a mean dynamic friction force measure, it does not allow to obtain force versus slip characteristics and, above all, it does not measure the actual coefficient between tire and road. In fact, it only measures the sliding friction coefficient between the road and the pad coating. Hence, if the aim is to determine the tire slip or the available grip, this device is not suited for the task; on the contrary, it can be used to detect the presence of icy or slippery conditions on the airport runaways, thus allowing to classify the road conditions in different levels of friction, each requiring different safety procedures.

From this point of view, it meets the requirements of the research project AWIS, since it is designed to work in cooperation with other monitoring and measuring systems to be installed in airport facilities, e.g. meteorological radars, or directly on spreading vehicle, e.g. temperature and humidity sensors [4, 5].

Nomenclature

α	connecting rod angle
φ	friction angle
f	road/pad friction coefficient
F	force exchanged between pad and connecting rod
L	pad length
M	pad mass
N	vertical component of pad-road force
R	pad/road total force
T	horizontal component of pad-road force
V	vehicle speed
x	horizontal direction
y	vertical direction

Pad configuration analysis

The first part of the research has been devoted to the analysis of the best configuration and geometric parameters sensitivity (Fig.1) aiming at:

- obtaining a uniform pressure distribution and therefore a uniform wear of the sliding part of the block;
- minimising the sensibility of the measure respect to the inclination variations of the force transducer's axis due to the vehicle vertical motion;
- maximising the gain between the friction coefficient and the force sensed by the device.

After a first experimental phase devoted to study the influence of the pad coating material, it was decided to use a Nyoil superficial coating in order to exploit the best performance and endurance from the pad.

The proposed solution, shown in Fig. 1, consists of a block having mass M to be attached to the rear of the spreading vehicle through a connecting rod on which the force transducer is installed.

This simple solution allows expressing the measured force F exchanged by the pad and the link as

$$F = \frac{fMg}{\cos\alpha + f\sin\alpha}. \tag{1}$$

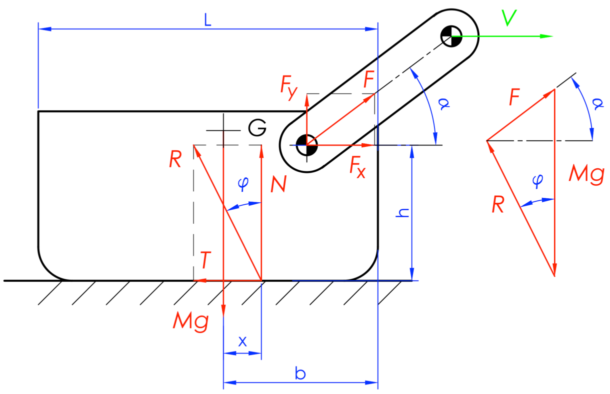

Figure 1 Simplified pad model: the load cell sensor measures force F along the connecting rod

Hence, it is quite straightforward to get the friction coefficient:

$$f = \frac{F\cos\alpha}{Mg - F\sin\alpha}. \quad (2)$$

Equation (2) allows estimating the friction coefficient by directly measuring the force F with a load cell; the other quantities, i.e., mass and rod angle are supposed known and constant. Last hypothesis is reasonable when the system is mounted on a vehicle travelling at constant low speed on a smooth surface, as in case of airport applications.

The real system, as visible in Fig. 2, consists of a pad on which additional masses can be accommodated in order to analyse the dependence on the vertical load. The connecting rod is in fact a cylinder in which the force sensor is inserted, with adequate protection against overloads.

The proposed system has been improved after the initial tests, passing from a load cell mounted on a rigid arm to a load cell in series to a spring, in order to avoid sensor damages. A further evolution is under design, based on a displacements sensor mounted in series to a spring, thus constituting a mechanical low pass filter.

Experimental tests

The experiments consist of tests on different surfaces with a dedicated trolley. In particular the pad has been tested on dry asphalt and tile pavement at the Politecnico di Torino (Fig. 3) and on dry/wet ice at the Turin Ice Stadium (Fig. 2-4).

The prototype mounted a load cell (range -1:+1 kN, accuracy 0.2% F.S.); measured inclination angle was $\alpha = 35.5°$; moreover the system was equipped with a low pass hardware filter (analog Butterworth filter, with cut-off frequency of 1 Hz).

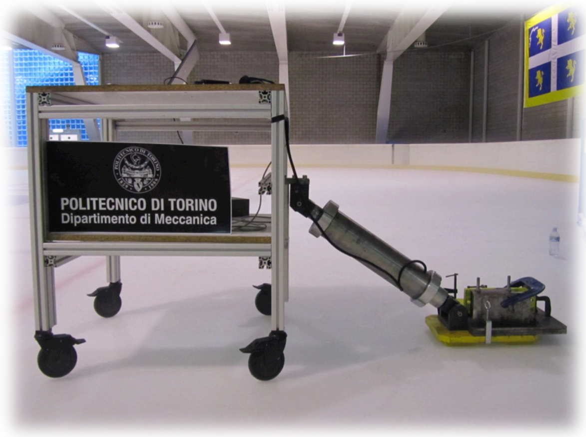

Figure 2 The prototype in action at Turin Ice Stadium

The pad was loaded with different masses, in order to investigate the dependence of the friction estimates on the vertical load acting on the system (from 400 to 1800 N, see also Fig. 5).

Results

Results from the experimental test have been analysed, using both raw values obtained from the load cell and hardware filtered data. Though the speed was limited by the manual activation of the device, on some surfaces the force signal shows high peaks (right part of Fig. 3), in correspondence of the passages from one tile to the next one.

Plots in Fig. 3 and 4 show the raw (black solid line) and filtered (red dashed line) data, plus the mean value of the friction estimated during the test on the different pavement surfaces.

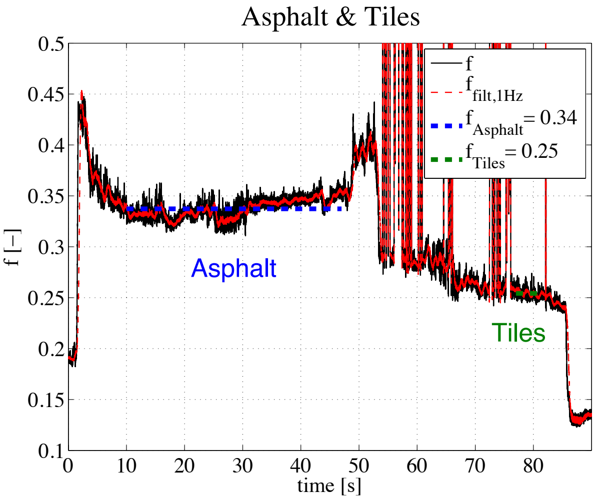

Figure 3 Experimental results: friction jump from asphalt to tiles

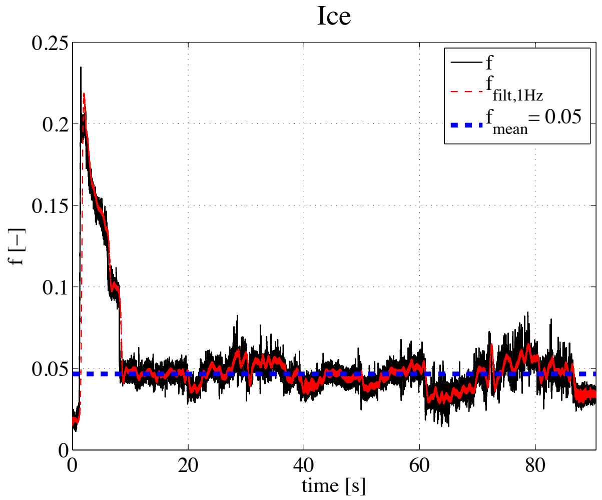

Figure 4 Experimental results on ice (Turin Ice stadium)

In both figures it is evident that, at the beginning of the tests, the sensor measures a static friction coefficient, higher than the dynamics value. The difference is particularly relevant in the case of icy surface: moreover the static value, in case of icy surfaces, shows a dependence on the rest time, i.e., on the duration of the pause from one test to the next, probably caused by the peculiar behaviour of ice.

Experimental results show that it is possible to classify surfaces with different friction. In particular, Fig. 5 shows that through the proposed sensor is possible to estimate clearly separate values of the friction coefficient for different surfaces. Moreover, it appears that the dependence on vertical load is small: only in the case of icy surface, the system sensed some differences with load, probably due to the very small value of the horizontal component of the friction force developed in the contact between Nyoil pad and ice.

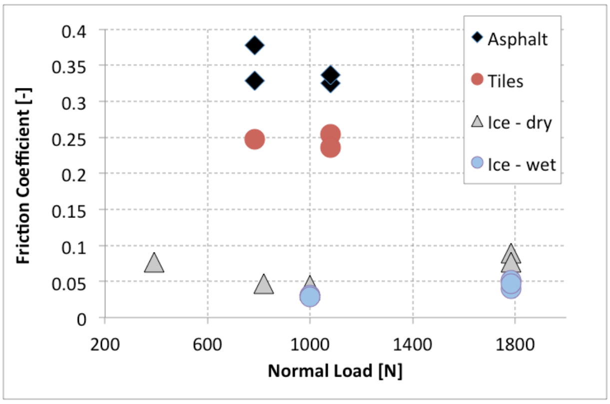

Figure 5 Experimental results

Multibody model

Aiming at improving the estimate of the friction level even in dynamic condition, e.g., when the vehicle accelerates or during cornering, a multibody model has been developed, as shown in Fig. 6.

The pad multibody model aims at evaluating the effect of removing the hypothesis of ideal system on friction coefficient estimation (e.g., friction in joints, as visible in Fig. 7); moreover it allows analysing the risk of detachment from the road due to vertical variations or motion in turn.

Furthermore, the multibody model allows considering the inertia of all the parts; consequently it is possible to analyse the behaviour of the sensed force also during transient motion (start, stop and cornering) on non-ideal surfaces.

Finally, a newer version of the sensor has been modelled, consisting in a displacements sensor mounted in series to a spring: this solution would act as a mechanical filter. Moreover, the sensor should be improved through the installation of an accelerometer, thus allowing to compensate the effects due to the vehicle accelerations and the road irregularities (Fig. 8).

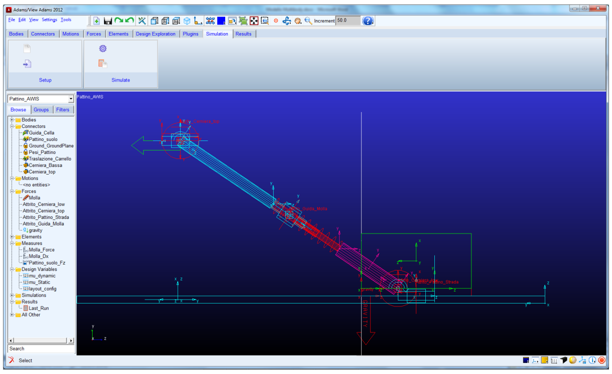

Figure 6 Multibody pad model

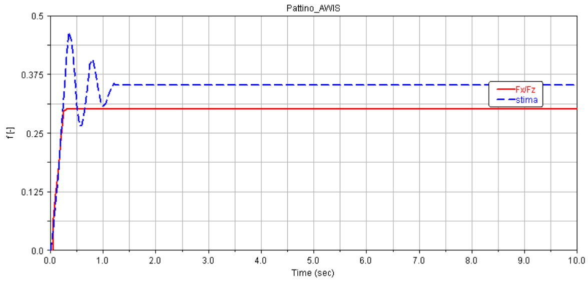

Figure 7 Comparison between friction coefficient: model (red) and estimate (blue)

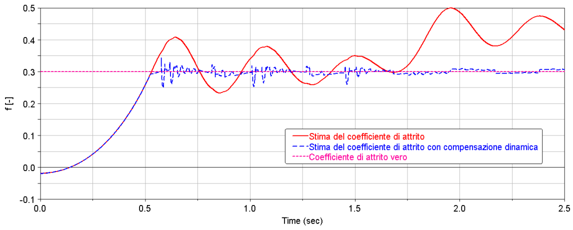

Figure 8 Comparison between friction coefficient estimates: model (magenta), estimate without (red) or with (blue) acceleration correction

Conclusions

A prototype of a device able to estimate friction levels has been developed and tested, for use in airports.

The experimental results appear promising, since also the first rough device was able to detect friction differences between surfaces and friction changes when facing mu-jump conditions.

Prototypes of the device, presenting some design improvements, are under study, in order to overcome some of the current limits, e.g., the use only on airport tracks: its use in real word driving scenario would require a tri-axial accelerometer to compensate of the dynamic effects.

References

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