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MEASURING SYSTEM FOR CHARACTERISATION OF THE INTERACTION BETWEEN CROSSWIND AND GONDOLA INCLINATION OF ROPEWAYS

Klaus Hoffmann, Robert Liehl

Institute for Design Engineering and for Transport- Handling- and Conveying Systems,
Vienna University of Technology, Getreidemarkt 9, A-1060 Vienna, Austria

Abstract − The crosswind stability of an operating ropeway is an essential factor for its system security in adverse weather conditions. This paper introduces a mobile measuring system for characterisation of the crosswind stability of ropeways, firstly describing the measuring concept and the measuring sensors, then presenting some data records of the cross inclination of the gondola and the corresponding wind speed.

Keywords: Ropeway security, Crosswind stability

1. INTRODUCTION

Safety engineering aspects of ropeways are always basic criteria which call for special attention during the planning phase, initial operation, at routine checks and also during periodic checks. Just recently major efforts have be made to achieve further improvements in system security.

In this context, the question of crosswind stability of ropeways is of particular importance for the ropeway manufacturers and the responsible authorities as well as the ropeway operators. Strong crosswinds result in unacceptable inclination of the gondola, particular while crossing the towers. With the gondola in this situation there could be considerable risk for the whole ropeway as well as for passengers. Especially with bicable ropeways, safety disposition of the hauling rope in the line rollers at the towers should be ensured during strong crosswinds. There is considerable interest on the part of ropeway manufacturers to be able to ensure operational reliability of their ropeways at higher wind speeds, but at present there is no reliable information about the real cross inclination of the gondola and its correlation to wind speed and direction on an operating ropeway. To date, only observations of operating staff have been recorded. The initial step in this project was to conduct a theoretical study [2]. Based on these theoretical results, it was then necessary to acquire concrete measuring data on an operating ropeway.

Provision is made for taking measurements during regular operation of the ropeway throughout the season. The following essential features are relevant for implementation of this mobile measuring system and the choice of this sensors:

- Simple handling of the measuring system for the operation staff of the ropeway;
- Low maintenance;
- Due to bad weather conditions in the mountains, a high degree of reliability is necessary for the sensors and data acquisition system;
- No danger to persons during ropeway operation with the measuring gondola;
- Battery installation and removal in the ropeway stations (for recharging) during the period of circulation;

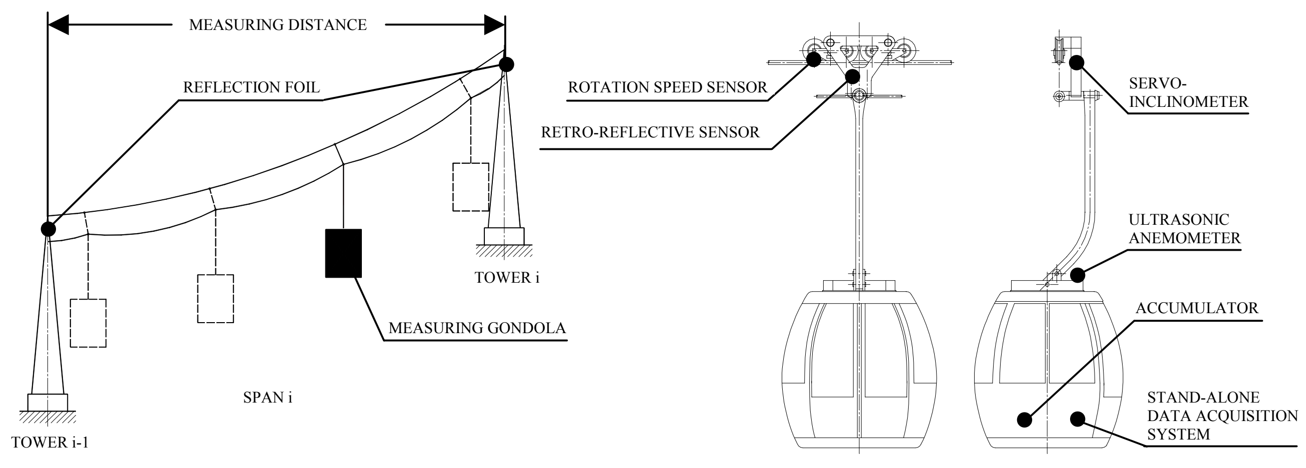

Fig. 1. Measuring distance and arrangement of the measuring sensors on the gondola of a bicable ropeway

- There must be no risk of collision between the mounted measuring sensors on the gondola and the tower or station parts during all operational modes. Therefore the measuring sensors can only be mounted on specific places on the gondola.
- Topographic conditions along the ropeway section create widely differing wind conditions, occasionally precluding the acquisition of measurements. Therefore measuring data are only acquired between a defined distance, particularly over the selected span where unfavourable wind conditions occur.

2. MEASURING METHOD

On the basic of the results from the theoretical study, the inclination depends on the position of the gondola in the span. Therefore it is important to ascertain the exact position of the gondola in the span. The rotation speed signal allows the correction of the airstream from the signal of the wind measuring sensor and also the positioning of the gondola in the span. Figure 1 shows the measuring distance between the two reflection foils which are attached on the lower and upper tower. In order to ascertain the exact position of the gondola in the span, the storage of the measuring data starts with a reflection light beam at the lower tower and stops at the upper tower.

The inclination sensor is mounted on the main girder of the carriage, as near as possible to the turning point of the gondola and measures the inclination of the gondola in relation to the ropeway axis. The wind-measuring sensor is connected to the roof adapter of the gondola with wind speed and direction as output signal. The stand-alone data acquisition system and the accumulators for the power supply of the measuring system are located in two aluminium boxes in the passenger area.

3. MEASURING SENSORS

An ultrasonic anemometer is used for measuring wind speed and direction (Fig. 4). This sensor consists of four ultrasonic converters which are fixed in pairs face to face, thus forming two rectangular measuring lines in plane. In these lines the two direction-components of wind speed are determined by measuring the spreading speed of sonic. A movement of air in the direction of sonic-spreading leads to a higher spreading speed than would exist in calm air and vice versa. As the speed of sound is very dependent on the air temperature, the propagation time for the sound is measured on both of the measurement paths in both directions. Thus the influence of the temperature-dependent speed of sound on the measurement result can be eliminated by subtracting the reciprocals of the measured propagation times. The measurement results of the sum and the angle of the wind speed vector in the form of rectangular components are obtained by combining the two measuring paths which are at right angles to each other. After the rectangular velocity components have been measured over the measurement path, they are then transformed by the μ-processor of the anemometer into polar coordinates and output as sum and angle of wind speed.

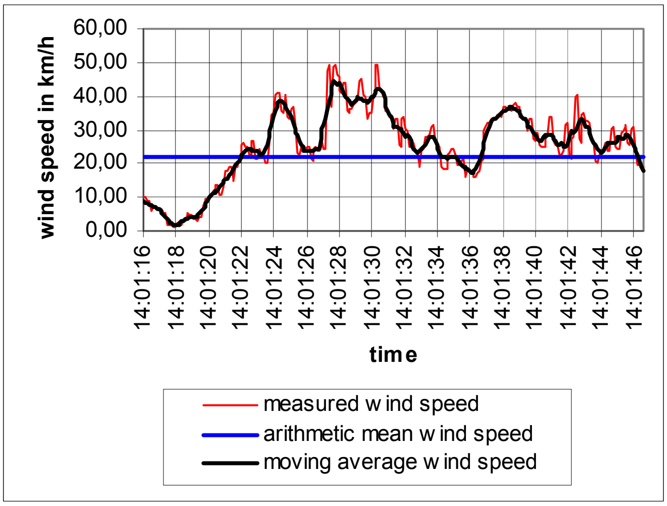

Fig. 2. Characteristic measuring curve of gusts measured with an ultrasonic anemometer

The anemometer has an internal rate of 100 measuring data per second and, unlike conventional paddle-anemometers, it is ideal for inertia free measuring. The maximum output rate of the ultrasonic anemometer is 10 Hz. Therefore it is well suited for recording gusts and peak values (Fig. 2). With conventional paddle-anemometers generally level off wind peaks due to the mass moment of inertia of the rotating parts. The anemometer is provided with an automatic heating device for the instrument body as well as for the sensors so that the measuring results, in case of critical ambient temperatures, are not affected by ice, snow or rainfall. The measured data are available as analogue signals or as a data telegram over a serial interface.

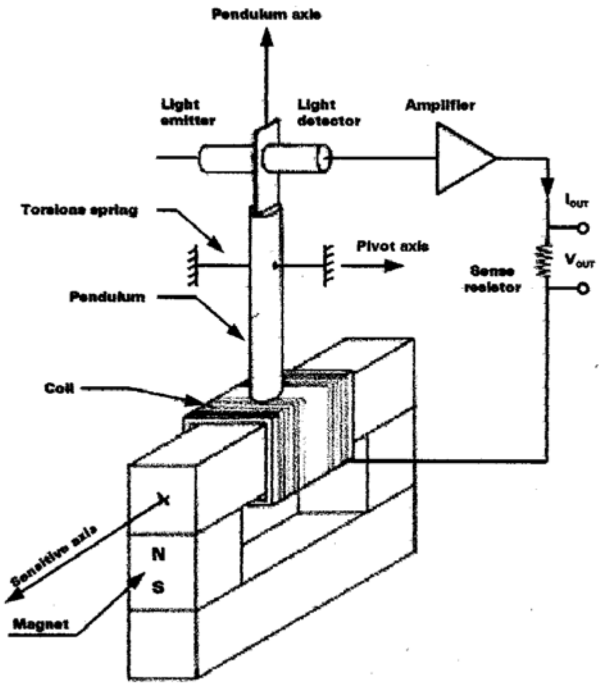

Fig. 3. Operation principle of a servo-inclinometer

The cross inclination of the gondola is measured by a servo-inclinometer (Fig. 5), which functions as follows: this device uses a torsion spring suspended pendulum, whose rotation can be induced by a linear acceleration along its sensitive axis (acceleration mode), or by a component of the gravity force along that axis caused by tilt (tilt mode). The pendulum displacement is detected by a photoelectric position sensor, the output of which is amplified and fed to a coil attached to the pendulum, generating an electromagnetic torque (Fig. 3). The polarity of the connection is chosen to produce a reaction torque which tends to return the pendulum to its zero position. Since the input and reaction torques exactly balance each other, the current producing the reaction torque is a very accurate and linear function of the acceleration and is used as output. In the tilt measuring mode, the output is proportional to the sine of the angle of tilt. This fact limits the effectiveness of the sensor for tilt angles approaching ± 90°.

The selected servo-inclinometer has a measuring range of ± 30° and is characterised by a very high resolution of less than one arc-second, short time of response and high precision.

The rotational speed of the carriage-sheave is measured with an inductive oscillatory sensor (Fig. 6). Oscillatory sensors comprise a high frequency oscillator which includes a coil L and a capacitor C. The coil L is wound around a core open to one side. This coil core may be compared to a pot which opens to one side. It is within this range that the alternating field generated by the coil can be influenced. If a metallic body is moved into this range, induction causes eddy currents or remagnetisation. This also causes energy to be drawn from the field and the resonant circuit to be attenuated. The oscillation amplitude in the oscillator circuit is thus diminished.

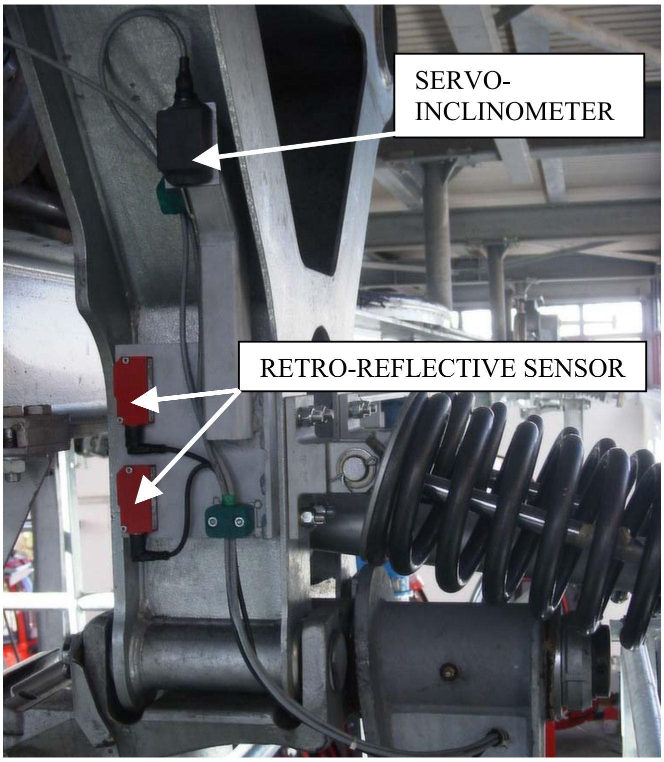

Fig. 5. Servo-inclinometer and two retro-reflective sensor mounted on the main girder of the carrier

Inductive oscillatory sensors allow the detection of keyways, bolts, screw heads and similar shaft-mounted objects. They are normally used where only one or a few pulses per revolution need to be detected. This sensor type also allows a large sensing distance between the sensor head and the detected part.

A retro-reflective photoelectric sensor with polarisation filter and visible red light is used for triggering data acquisition. When detecting high glass finished objects such as reflective metal parts, a polarising filter may be needed with a conventional retro- reflective sensor to prevent

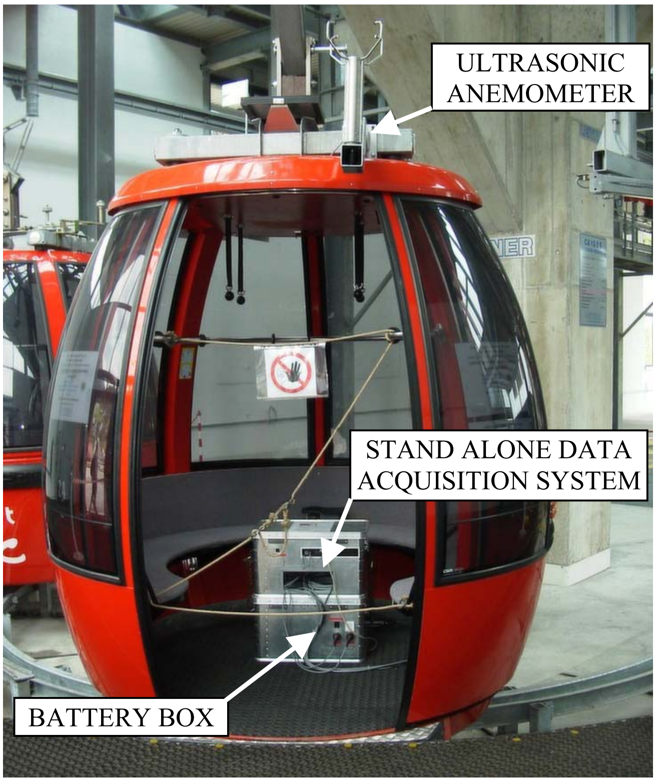

Fig. 4. Measuring carrier during operation

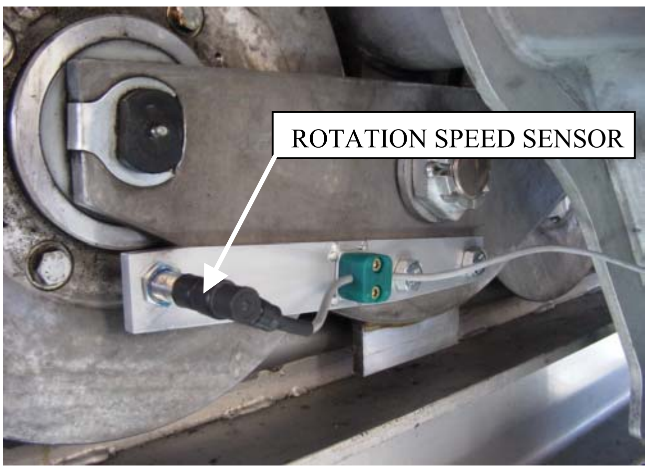

Fig. 6. Rotation speed sensor fixed on the carriage of the gondola

Fig. 7. Reflection foil mounted on the track rope saddle of the tower

skipping errors. The polarised light of the transmitter impinges on the reflector which turns the polarisation level around 90°. Only the light that is reflected by the reflector would be detected by the receiver (Fig. 7). A high switching frequency of 1000 Hz permits acquisition of high level signals. Furthermore the autocollimation principle applied ensures that the device functions reliably over the full operating range from 0 to 3 m.

4. MEASURING RESULTS

The mobile measuring system was first used on a detachable bicable ropeway in Italy during the summer season 2002.

Figure 8 shows the cross inclination of the gondola and the component of the wind speed across the driving direction depending on the horizontal position of the gondola in the span beginning at the lower tower 1. Data record 1 was acquired in almost calm conditions with a load of seven persons, data record 2 at a maximum wind speed of 5,7 m/s and with a load of one person.

To also obtain measuring data at higher wind speeds, the mobile measuring system will be used on the same ropeway during the summer season 2003.

5. CONCLUSIONS

Before being put into use on an operating ropeway, the mobile measuring system and its individual components were comprehensively tested for function in the laboratory [1]. An important part of this examination was to obtain information on the influence of cross-acceleration on the servo-inclinometer. In practice it is not possible to attach the inclinometer at the turning point of the cross-pendular movement. Results of various tests show that a short distance from the turning point horizontally in combination with an expected long oscillation time leads to only a small deviation of the measuring value.

The Institute of Design Engineering and for Transport, Handling and Conveying Systems will also be carrying out a simulation of the crosswind stability of ropeways employing a multibody dynamic analysis program. Conclusions derived from measurements on an operating ropeway will be required to verify these simulation results.

The measuring results are also important to obtain detailed information concerning the wind stability and system security of ropeways.

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Authors: Ao.Univ. Prof. Dr. Klaus Hoffmann, Institute for Design Engineering and for Transport, Handling and Conveying Systems, Vienna University of Technology, Getreidemarkt 9, A-1060 Vienna, Tel.: ++43-1-58801-30746, Fax: ++43-1-58801-30799, E-mail: hoffmann@ft.tuwien.ac.at

Dipl.-Ing. Robert Liehl, Leitner GmbH, Resselgasse 1, A-2201 Gerasdorf, Tel.: ++43-1-7342115-112, Fax: ++43-1-7342115-333, E-mail: Liehl.Robert@leitner-lifts.com

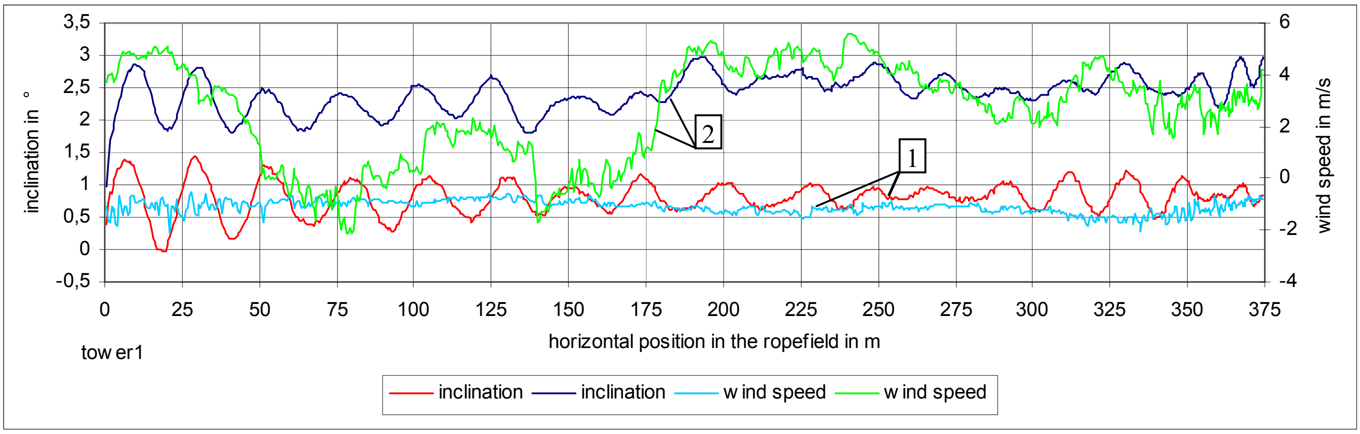

Fig. 8. Data records of cross inclination of the gondola and crosswind speed; 1 : load of seven persons and calm conditions; 2 : load of one person and at max. wind speed of 5,7 m/s