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Wireless Data Transfer System for Rotating Machinery - Very Robust Against Electromagnetic Interference

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Abstract

For measurements on rotating machinery, e.g. torque, it is necessary to transfer data from the rotating to the stationary system. Telemetry equipment is normally used for this task, transferring data electromagnetically by means of antennae to a telemetry receiver mounted on the stationary system. The telemetry principle works well for applications with weak electromagnetic interference (EMI). However it does not work with an acceptable degree of reliability in many industrial applications where EMI is very strong, especially for measurements on AC adjustable-speed drives. In some cases it does not work under any circumstances. Therefore a very cheap, robust frequency modulated infrared data transfer system was developed for such ambient conditions. This principle, combined with a suitable optical shielding against stray light and electromagnetic shielding of the electronic components leads to a highly reliable system. It was used and tested for measurements on a large ropeway with two speed-regulated asynchronous motors, 190 kW each, an ambience where a commercial telemetry system, based on a radio transmitter, did not work.

Keywords: wireless data transfer, infrared, rotating machinery, measurement, EMI

1 Introduction

Measurements on rotating machinery such as motors, generators or turbines, are very important for the analysis of errant behaviour, to improve their efficiency or for monitoring their status [1]. The determination can be done indirectly by measuring the stator voltages and stator currents combined with an electromagnetic model of the motor (e.g. [2]) or by using a platform to measure the stator-reaction forces [3]. In these cases measurements were accomplished stationary without the need of a data transfer system but with all the disadvantages of an indirect measurement, e.g. uncertainties of the model, inertia effects, etc.

For direct measurements on rotating machinery, data has to be transmitted to a stationary system. A radio frequency (RF) telemetry system is normally used for this task. The measurement is carried out with standard sensors such as strain gauges or piezo-electric sensors applied to or mounted on the rotor. The sensor signal is pre-amplified and prepared for transfer (pulse width modulated, frequency modulated, etc.). Finally, the signal is transferred wireless either by the aid of antennae [4] or due to capacity electrodes [5]. Both, antennae and capacity electrodes exhibit a significant influence on the reliability of the data transfer if a stronger electromagnetic interference (EMI) occurs due to the cable [6] or the motor itself [7], especially if the measurements have to be carried out on speed-controlled motors with high power. The EMI generated by power electronics and the stray magnetic field of an electric motor can also lead to serious disturbances or to a malfunction of such a wireless data transfer system.

Alternatively, optical systems were used for contact-free measurements on rotating shafts, such as torque [8], or to transfer data by means of optical transmitters and receivers [9]. The disadvantage of the method described in [8] is that it can be used only for torque measurements and it measures the torque only once on each rotation, whereas optical transmitter and receiver permit more measuring principles on the rotating shaft, such as torque, rotor vibration, temperature, etc.
All in all, optical principles provide for a very reliable data transfer or measuring system, if good shielding against stray light and EMI is prepared for the optical sensors and the electronic components.

In this paper a very cheap and robust optical data transfer system is introduced.

2 Data transfer system

2.1 Operating principle

Measuring on rotating machinery offers the advantage of well-defined and constant distance between two cylindrical parts mounted on the rotating and the stationary system. Depending on the shaft dimensions of the investigated drive, a cylindrical housing with a suitable outer and inner diameter is necessary. Both cylindrical parts are mounted in an axial distance of about 20 mm. Optical data transfer is carried out by the infrared (IR) transmitter and receiver array (figure 1). The minimum number of photo transistors needed ($n_{IRT,min}$), depends on the diameter of the investigated shaft (D_{shaft}), the offset in shaft diameter (D_{offset}, space for the IR photo transistor positioning and other electronic components), the distance between IR diodes and photo transistors (a), the radiation angle of the IR photo transistor (β, defined at 50 % intensity) and a safety factor (S).

$$n_{IRT,\min} \geq \frac{(D_{shaft} + D_{offset})\pi}{2a \tan\beta} S$$

For the realized prototype with a shaft diameter of 100 mm, D_{offset} = 20 mm, radiation angle β = 70 ° (IR photo transistor OP505), a distance a = 20 mm and a safety factor S = 3, at least eleven IR photo transistors are necessary in an equidistant position d_{IRT} around a circle.

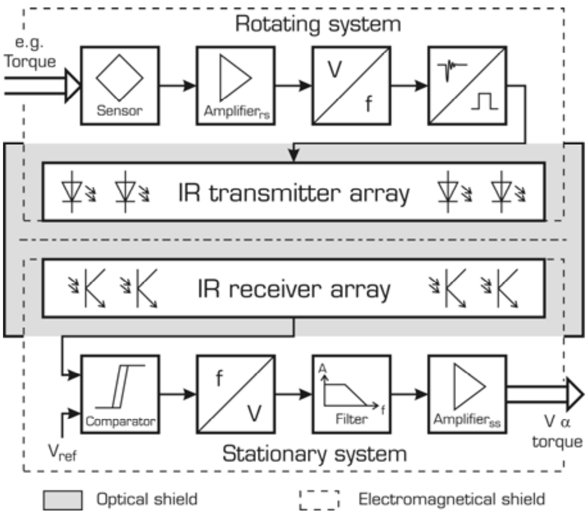

Figure 1: Block diagram of the measuring system.

The minimum number of IR emitting diodes ($n_{IRD,min}$) is one. More reliability is obtained if two IR diodes are arranged with half the distance d_{IRT}.

In the described application six IR emitting diodes (VX-301) in series are used to increase the power efficiency of the IR transmitter array and additionally to increase the resistance to stray light. For the IR receiver array twelve IR photo transistors are chosen (figure 2).

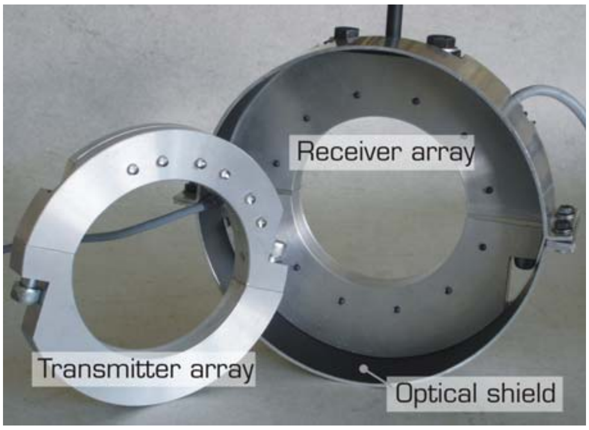

Figure 2: Housing of the IR array units.

The measuring signal, in this case the torque of the rotating shaft, is obtained by a strain gauge bridge. The signal is pre-amplified and converted into a proportional frequency signal (mid frequency 10 kHz, dynamic range ± 5 kHz). For the prototype, parts of a commercial RF telemetry system are used: a bridge amplifier, the voltage to frequency converter and a battery power supply. Only the output signal from the voltage to frequency unit was prepared for the new opto-electronic data transfer system. A pulse transformer is used to obtain the required current (13 mA_{rms}) and to form a sufficient pulse width ($t_{PW} = 25\ \mu s$) for the IR transmitter array.

The IR photo transistors of the receiver array are connected in parallel. Their output signal is compared with an adjustable reference level to obtain a jitter- and distortion-free input signal for the frequency to voltage converter. This frequency-modulated signal is converted into a torque proportional analogue signal by a frequency-to-voltage converter, a low pass filter (upper frequency limit f_u = 1.6 kHz) and a low impedance output amplifier.

The power for the prototype of the rotating system was supplied by a 9 V battery. The next version will be supplied either by a battery or by a wireless power supply, such as a transformer. The stationary system can be fed either by battery or a filtered highly stable line supply.

2.2 Industrial application

2.2.1 Investigated drive

Torque measurements have been carried out on the electric drive of a special ropeway system at Lünersee in the Austrian Alps (figure 3). The Lünersee system is a special reversible bicable ropeway with only one cabin running on one track.

Figure 3: View of the investigated ropeway.

The longitudinal section of the ground situation is shown in figure 4. It can be seen that two line support structures are situated close to the top station. This requires a reduction of operation speed to reduce the longitudinal oscillation of the cabin while the cabin crosses the support structure.

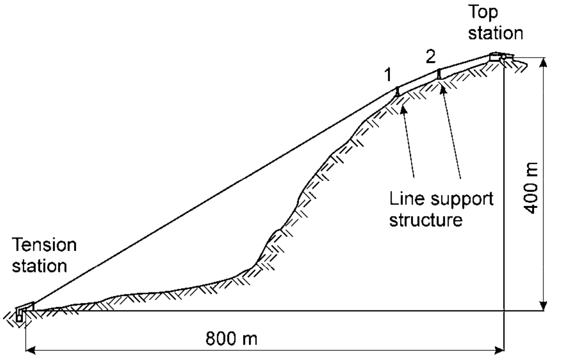

Figure 4: Longitudinal section of Lünersee ropeway.

The drive unit in the top station consists of two speed-controlled asynchronous motors which are connected with a planetary gear (motor speed range: 0 rpm to 1500 rpm). The third shaft of this differential gear powers the drive pulley and the haul rope (figure 5).

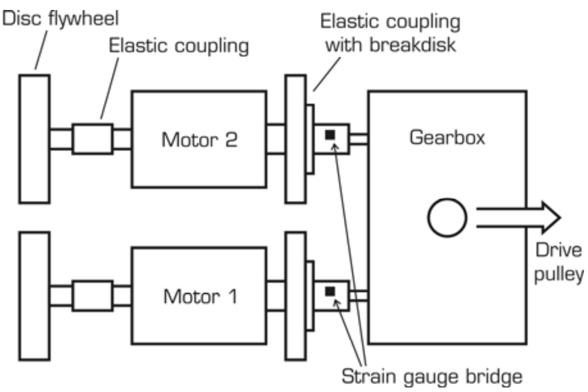

Figure 5: Block diagram of the drive system.

2.2.2 Application on the driving system

For this application two optical systems as described above were mounted on the drive system which can be seen in figures 6 and 7.

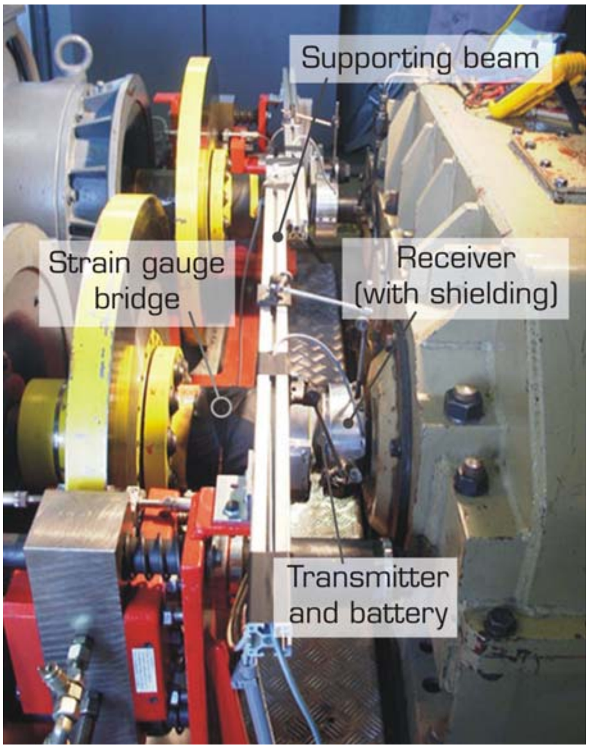

Figure 6: Measurement application on both shafts.

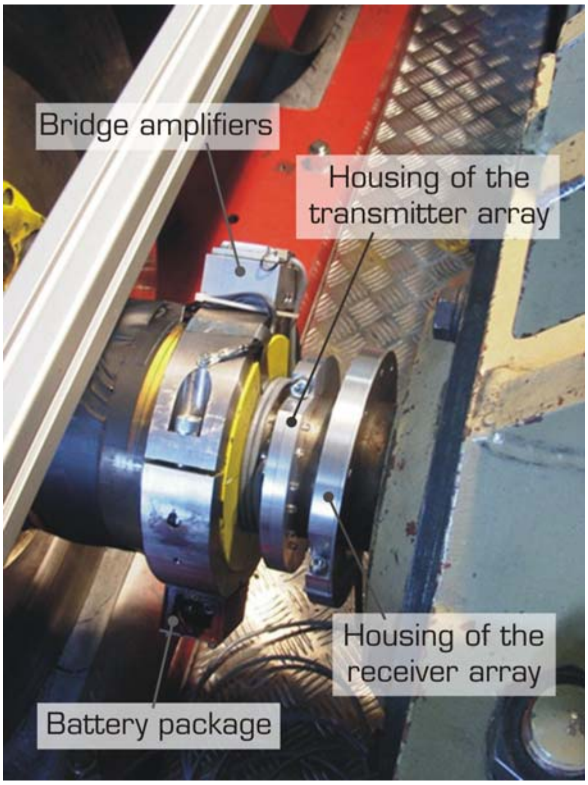

Figure 7: Details of the application on one driving shaft (without optical shield).

The measurement task was to record simultaneously the torque signal on both driving shafts during a complete round trip of the cabin. These measurements were necessary to check the partitioning of the driving power between both driving shafts. Strain gauge bridges were applied on both shafts between coupling and gearbox for torque sensing.

Finally, data acquisition was carried out by means of PC measuring techniques (data acquisition card 6062E and data acquisition program based on LabVIEW, National Instruments).

2.2.3 Calibration of the system

For the calibration of the measurement chain, a controlled force was applied by a chain hoist (figure 8). The calibration curves thus obtained show good linearity (figure 9).

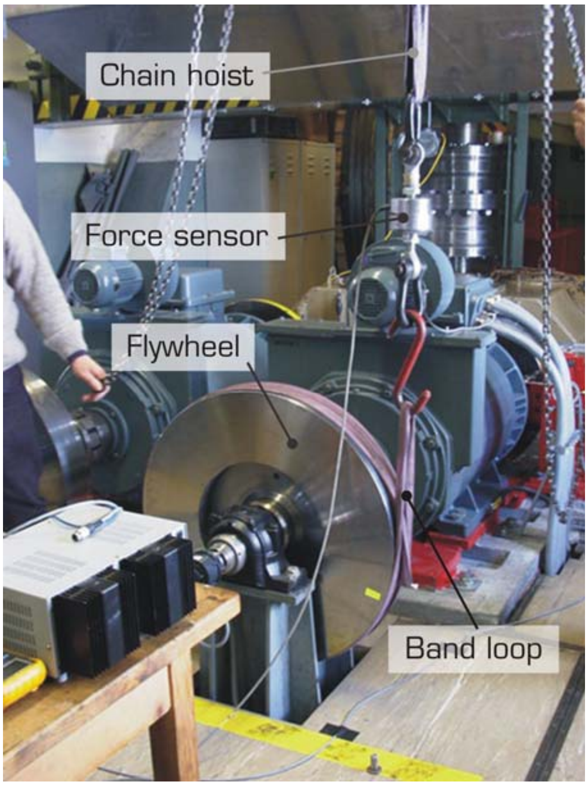

Figure 8: Arrangement for the calibration of the measurement chain.

2.2.4 Measuring results

Many measurement curves were recorded under differing operating conditions. One example of torque measurements from one turn-around cycle is shown in figure 10. This cycle consists of a drive down from the top station to the tension station, followed by a short stop for passenger embarkation and finally a drive up to the top station again. The corresponding time-dependent operation speed is depicted in figure 11. It should be pointed out that the speed is reduced from the normal speed of 10 m/s to 7 m/s while the cabin crosses the line support structures. In figure 10 it is clearly recognizable that both shafts are loaded with similar amounts of torque. The small differences are caused by different efficiencies and different numbers of gear pairs in both power trains. During the acceleration phase at the beginning of the drive down from the upper station the values of torque are very different. The reason is an unequal acceleration of both motors caused by the control system.

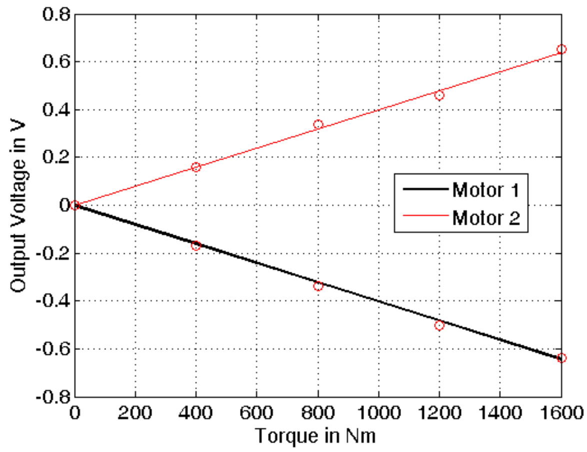

Figure 9: Calibration results of measurement chain.

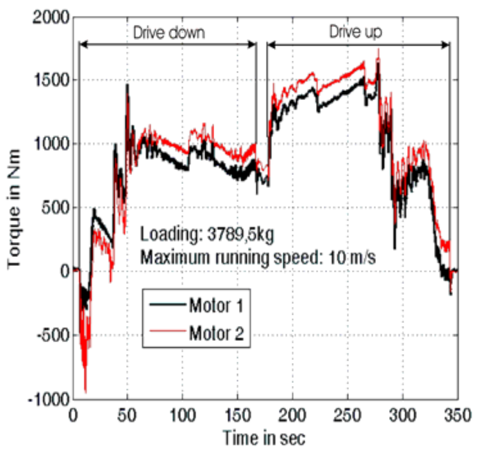

Figure 10: Example of the measuring results obtained with the described system.

Figure 11: Operation speed of the measurement cycle corresponding to figure 10.

3 Conclusion

Initiated by an unsuccessful torque measurement in a high power electric drive with a commercial RF based telemetry system, a cheap optical telemetry system has been developed. It is based on frequency-modulated optical data transfer using IR transmitter and receiver arrays. Because of the chosen IR data transmission method the reliability of this system is not affected by the speed of the rotor. It works from 0 rpm up to the limit of the additional mechanical components or the maximum speed of the drive unit (motor, generator or turbine). For the EMI shielding of all electrical devices only a simple aluminium housing is necessary mainly designed for the required mechanical strength. In addition, simple shielding against stray light should be provided for the two IR arrays.

This wireless data transfer system can be easily adapted to different shaft diameters. If the motor power changes, only the sensitivity of the probe arrangement and the preamplifier have to be adjusted in order to obtain the optimal dynamic range of the measurement chain.

The reliability and robustness of this system were successfully tested during torque measurements on a ropeway with two speed-controlled 190 kW asynchronous motors. It shows satisfactory linearity of the whole measurement chain.

As a measurement result it could be shown that the control system of the driving device gives proper partitioning of the driving power between both power trains.

4 References

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