The Induction Motor as a Mechanical Fault Sensor in Elevator Systems

A. Q. Flores[1], A. J. M. Cardoso [2], J. B. Carvalho [3]
[1, 3] Oporto Engineering School (I.S.E.P); Department of Electrical Engineering, Porto, Portugal
aqf@isep.ipp.pt[1], jbc@isep.ipp.pt[3],
[2] University of Coimbra, FCTUC/IT; Department of Electrical and Computer Engineering, Coimbra, Portugal
ajmcardoso@ieee.org[2]

***Abstract*- An efficient maintenance carried out on a building elevator system can contribute to guarantee a safer people transportation. An elevator failure must be avoided as much as possible, as it may have negative consequences on different levels, as fear, trust lack, people's elevator phobia or even people's life. This paper presents a method that uses the induction motor as a sensor, to diagnose mechanical faults in the worm gear reducer of an elevator system. This study complements another work already done, by the same authors, concerning elevator guides remote monitoring.**

I. INTRODUCTION

"Lifts provide an essential means of comfortable and safe access to modern buildings. (...) The safety of lifts installations may be considered practically absolute, so much so that it may be said, backed up by incontrovertible data, that today the lift is the safest means of transport that people can use" [1].

In order to achieve this goal, maintenance routines include cleaning, lubricating, bulb replacements, inspecting and adjusting of components to ensure the correct functioning and safety of the elevator installation. Besides, by law, lifts must have a valid Certificate of Lift Maintenance and Testing [2].

The European Parliament and Council Directive 95/16/EC of 29 June 1995 [1] on the approximation of the laws of the Member States relating to lifts establishes European legal requirements for the design, installation and placing on the market of new lifts. It also sets out the conformity assessment procedures to be followed by lift installers to ensure conformity with these requirements. The provisions of the Directive are implemented in the national law of each Member State of the European Union. The Directive covers new lifts permanently installed in buildings and constructions for carrying passengers or passengers and loads.

The Directive 2006/42/EC of the European Council of 17 May 2006, on machinery, amends Directive 95/16/EC (recast) and regulates the issues related to the conditions concerning the introduction of machinery and safety components on the market, establishing minimal safety and health conditions in relation to this category of machinery and components [3].

Maintenance companies have a large group of lift machines to look after and may not be able to follow precision maintenance practices as they should. To evaluate equipment condition, predictive maintenance can take advantage of non-intrusive testing method, such as the motor current signature analysis.

II. INDUCTION MOTOR CURRENT ANALYSIS

Motor Current Signature Analysis (MCSA) is a diagnosis methodology based on the recognition that an induction motor, driving a mechanical system, also acts as an efficient and permanently connected transducer, detecting short torque variations generated within the mechanical system. MCSA can also identify different mechanical degradation types prior to failure and assess their severity. Current signals can be analyzed in the time domain or frequency domain. The former is also capable of analyzing systems during transients, such as during the initial or final operation of the system [4]. MCSA has been used for condition monitoring of different mechanical components such as bearings [5-7], motor fan [8], rotor unbalance [7] [9] and gearboxes [4] [10] [11], giving information about the fault localization.

A mechanical load fault associated with the increase of the torque demand, caused by a mechanical failure in the worm gear reducer of an elevator, can be seen, by the induction motor, as a load torque variation. As an example, the worm wheel speed can achieve 1.8 to 7 seconds per turn. To detect faults in this slow process, a high resolution Root Mean Square, RMS, plot of the induction motor current was used (1kHz sampling rate; RMS calculated for each set of 20 samples). Knowing its normal behaviour, it is possible to identify unexpected patterns that happen along the running process that could help identifying any mechanical malfunction and its exact location and severity.

There is a cause-effect between a load torque fluctuation and a stator current signature. Using the elevator induction motor as a torque sensor of its own driven load can be a valuable method to quickly diagnose the entire mechanical system.

III. ANALYSIS OF THE WORM GEAR REDUCER FED BY THE INDUCTION MOTOR OF AN ELEVATOR

A classical elevator system is composed by a driving induction motor, a worm gear reducer, a grooved sheave, the cabin, the counterweight, the lifting wire ropes and the guide rails, as represented in Fig. 1.

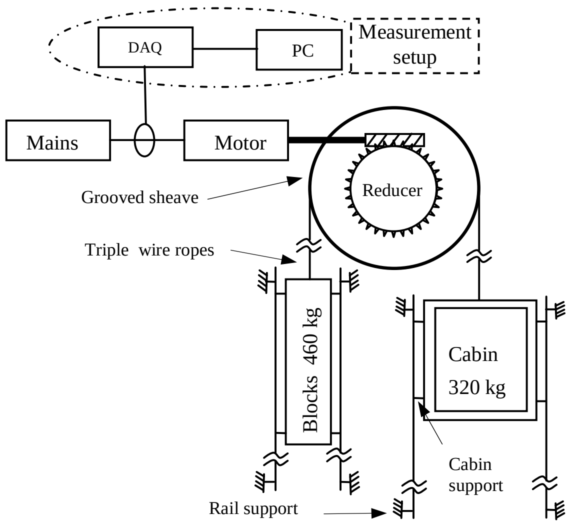

Fig. 1: Classical elevator system and measurement setup.

The worm gearing is used in elevator systems because a large torque is needed at the driven shaft at a greatly reduced speed.

Fig. 2: Worm gears.

The worm, with its continuous helix, forms one continuous tooth, engaging the worm wheel (Fig. 2). The shape of teeth of the worm wheel allows large forces to be transmitted from the worm to the worm wheel. Unlike other gearing systems, in which the output may drive the input, the worm (the input) always drives the worm wheel and they are self-locking [12].

Besides the high reduction ratio, other advantages of the worm gears are the fewer moving parts and fewer places to fail. The main problem with a worm gear is its power transfer, by sliding motion [13].

Worm gears are inefficient because gears experience sliding, rather than rolling contacts, presenting unique lubricating demands. Several different factors affect worm gear efficiency: lead angle of the worm, sliding speed, lubricant, surface quality and installation conditions [14].

Fig. 3: Detail of a worm showing surface wear.

With a worm gear, sliding motion is the only way power is transferred. As the worm slides across the teeth of the wheel, it slowly rubs off the lubricant film, until there is no lubricant film left, and as a result, the worm rubs at the metal of the wheel in a boundary lubrication regime. When the worm surface leaves the wheel surface, it picks up more lubricant, and starts the process over again on the next revolution [13]. The worm gear surface fatigue limiting load, also called the wear capacity, should be enough in order to guarantee a satisfactory performance. Fig. 3 shows clearly the wear of a worm gear caused by sliding friction.

The total gear tooth load is the result of nominal load and external factors as misalignment tooth inaccuracies and deflections, etc.

For satisfactory performance, the total gear tooth load, also called the dynamic load F_d, must be less than the strength of the bending fatigue, F_b, and surface fatigue F_s strengths

$$F_b \geq F_d \text{ and } F_s \geq F_d \qquad (1)$$

When the above condition is not fulfilled a machine breakdown may occur: the teeth may crack or even the worm may break as shown in the example of Fig. 4.

Fig. 4: Detail of a broken worm.

In order to study and prevent failures within the worm gear reducer, several tests and measurements were made using the Motor Current Signature Analysis (MCSA).

IV. EXPERIMENTAL SETUP

The tests were carried out using an EFACEC induction motor BF 4 132 M10 6/16FS, 50Hz, 4.4/1.1 kW, cos φ 0.75/0.5, 1400/310 RPM and a VALVATA reducer, speed ratio 1/45 type RM-140E, 300Kg load, 1 m/s speed, oil J680(Shell) (Fig. 5). The current was measured in one phase by a clip-on current transducer connected to an acquisition board (National Instruments DAQ 6800).

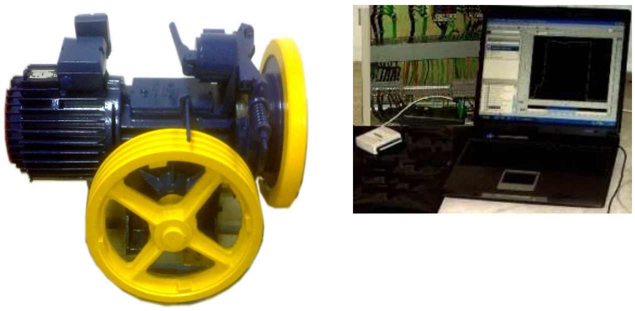

Fig. 5: Left: Induction motor, worm gearing reducer, friction wheel. Right: clip-on current transducer, acquisition board and computer.

The above referred driving elevator set, composed by an induction motor, worm gear reducer, clamping brake and grooved sheave was used in order to find how far the Motor Current Signature Analysis could be helpful in worm gear mechanical fault diagnosis. The induction motor current was measured and it was found that a repetitive signal appeared in the absorbed current both at low, (310 rpm), and at high, (1400 rpm), speeds. Two different current behaviours were obtained depending on the shaft speed:

- At high speed the motor current increased each 1.8 seconds (Fig. 6)
- At low speed the motor current decreased each 7.4 seconds Fig. 7).

As the time that the friction wheel takes for a full revolution is 1.8 seconds at high speed and 7.4 at low speed, it makes us believe that these current signatures could be related to some mechanical fault in the reducer.

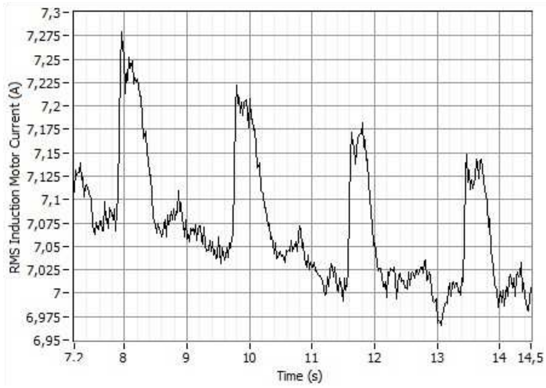

Fig.6: The induction motor current was measured at 1400 RPM.

When the induction motor runs at high speed the gears become well lubricated and the motor current increases just when the damaged wheel teeth area reaches the worm, corresponding to an extra mechanical torque demand. The general motor current decrease is due to a lubrication increase, diminishing friction between gears.

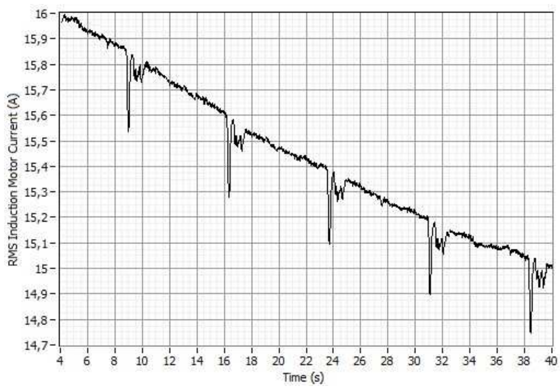

Fig. 7: The induction motor current was measured at 310 RPM.

At slow speeds the torque is affected by static friction and by the lack of lubricants that stay immobilized at the bottom of the worm wheel. In fact, when the worm wheel was turned slowly by hand, it can be noticed a hard friction during certain rotational angles, confirming the plot presented in Fig. 7.

The reducer was disassembled and some damaged teeth were found in the worm wheel (Fig. 8). This kind of damage could be caused by incorrect handling during assembly operations.

Fig. 8: Detail of a worm wheel showing tooth damage.

After fixing the above referred mechanical faults in the reducer worm wheel, the induction motor current plot was smoothed without the spikes as shown in the previous tests.

The periodic induction motor current signals, due to mechanical faults in the wheel worm reducer, can be easily distinguished from the ones due to the guides support misalignment, presented in a previous paper [15]: the time intervals are different and also the ones due to the guide problems have normally different amplitudes, as the support misadjustments are not closely related to each other.

V. Conclusion

This paper presents an experimental study in order to understand the current signature of an induction motor that drives a worm gear used in elevator systems. The results showed that this method may contribute to remote monitoring of this kind of faults. Besides, it is a non-invasive method that can be carried out during the normal operation. This technique is simple and can contribute to an efficient preventive maintenance by regularly monitoring the induction motor current. Thus, besides its main role of supplying mechanical energy to the load, the induction motor can play a second role as an efficient and permanently connected transducer, helping to detect faults within its mechanical load system.

VI. Acknowledgment

The authors gratefully acknowledge the financial support of Fundação para a Ciência e Tecnologia (FCT) under ref. SFRH / BD / 37208 / 2007 and would also like to thank Schmitt+Sohn Elevadores Lda. – Portugal, regarding the experimental setup.

References

[1] EU Directive 95/16/EC, The European Parliament and the Council of the European Union, 29 June 1995.

[2] Commission Recommendation 95/216/EC, The European Parliament and the Council of the European Union, 8 June 1995.

[3] EU Directive 2006/42/EC of the European Council, The European Parliament and the Council of the European Union, 17 May 2006,

[4] P. Pillay, Z. Xu, "Motor current signature analysis", in Conference Record of the *1996 Industry Applications Conference*, Volume 1, Oct. 1996, pp. 587-594.

[5] L. Ere, M. J. Devany, "Bearing damage detection via wavelet packet decomposition of the starting current", *IEEE Transactions on Instrumentation and Measurement*, vol. 53, no. 2, pp. 431-436, Apr. 2004.

[6] A. M. Knight, S. P. Bertani, "Mechanical fault detection in a mediumsized induction motor using stator current monitoring," *IEEE Trans Energy Convers*., vol. 20, no. 4, pp. 753-760, Dec. 2005.

[7] J. Jung, J. Lee, B. Kwon, "Online diagnosis of induction motors using MCSA," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 6, pp. 1842-1852, Dec. 2006.

[8] E. L. Bonaldi, L. E. Oliveira, L. E. Silva, "Proposing a Procedure for the Application of Motor Current Signature Analysis on Predictive Maintenance of Induction Motors", *Proceedings of the 20th International Congress & Exhibition on Condition Monitoring and Diagnostic Engineering Management, COMADEM'07, Portugal, 2007*, pp. 495-503.

[9] Blodt, M., Regnier, J., Faucher, J., "Distinguishing Load Torque Oscillations and Eccentricity Faults in Induction Motor Using Stator Current Wigner Distributions" in *Conf. Rec. Annual Meet. IEEE Ind*. Appl. Conf., Vol. 3, Oct 2006, pp. 1549-1556.

[10] A. R. Mohanty, C. Kar, "Fault Detection in a Multistage Gearbox by Demodulation of Motor Current Waveform," *IEEE Transactions* on *Industrial Electronics*, vol. 53, no. 4, pp. 1285-1297, June 2006.

[11] H. B. Attia, I. Belkhodja, J. Hapiot, B. Dagues, "Analysis of distortion of stator current in an induction machine caused by damages of the mechanical gear driven", *Proceedings of the International Conference on Electrical Machines* (2004).

[12] Harte, J., Electromechanics: Principles, Concepts and Devices, Prentice Hall, Inc, 1995.

[13] Black,A., "The Ins and Outs of Worm Gears", *Practicing Oil Analysis* Magazine. September 2007.

[14] Thibault, R., "Lubrication of Worm Gears". Machinery Lubrication Magazine. May 2001.

[15] Flores, A., Cardoso A., Carvalho, J., "Mechanical Fault Detection in an Elevator by Remote Monitoring", *Proceedings of the XVIII International Conference on Electrical Machines*, ICEM'08, Vila Moura, Portugal, 6 a 9 de Setembro de 2008.