Open access • Proceedings Article • DOI:10.1109/DEMPED.2015.7303699

Effects of transmission belt looseness on electrical and mechanical measurements of an induction motor — Source link

Etienne Fournier, Antoine Picot, Jeremi Regnier, Christian Andrieux ...+2 more authors

Institutions: University of Toulouse

Published on: 26 Oct 2015

Topics: Transient state, Transmission belt, Steady state (electronics) and Induction motor

Effects of Transmission Belt Looseness on Electrical and Mechanical Measurements of an Induction Motor

Etienne Fournier, Antoine Picot, Jérémi Regnier, Christian Andrieux, Jacques Saint-Michel, Pascal Maussion

To link to this article : DOI :10.1109/DEMPED.2015.7303699
URL : http://dx.doi.org/10.1109/DEMPED.2015.7303699

Effects of Transmission Belt Looseness on Electrical and Mechanical Measurements of an Induction Motor

Etienne Fournier, Antoine Picot, Jérémi Régnier, Christian Andrieux,
Jacques Saint-Michel and Pascal Maussion

***Abstract*—This article explores the impact of belt looseness on electrical and mechanical quantities of a system driven by an induction motor and a belt-pulley transmission. The effects of this defect, for example the belt slipping or the apparition of spectral signatures in some measurements, are first investigated under steady state operation. Transient state tests are then performed to analyse, in the time domain, the system response to a step of the speed reference. The behaviour of different variables (slip, speed, currents, etc.) is studied for different health conditions and the increase of the belt looseness clearly impact the electric and mechanical variables' waveforms. The experimental tests carried out in this study, under steady or transient state, show promising results for the diagnosis of belt degradations. Perspectives of this work are therefore detailed at the end of this paper.**

***Index Terms*—Fault diagnosis, Condition monitoring, Maintenance, Induction motors, Inverters, Variable speed drives, Belts, Spectral analysis, Current measurement, Mechanical variables measurement.**

NOMENCLATURE

d or d_i	Center distance between motor and load.
$\Delta\Omega$	Speed reference step level.
f_f	Supply frequency.
$f_{r,belts}$	Rotation frequency of the belts.
$f_{r,load}$	Rotation frequency of the load.
$f_{r,motor}$	Rotation frequency of the motor.
f_s	Sample frequency.
γ_a	Axial vibration signal.
γ_r	Radial vibration signal.
i_1, i_2, i_3	Motor phase currents.
IA	Currents instantaneous amplitude.
IM	Induction motor.
Ω_{belts}	Belts speed.
Ω_{load}	Load speed.
Ω_{motor}	Motor speed.
R_t	Transmission ratio.
S_Ω	Absolute belts slip.
s_Ω	Relative belts slip.
$X(f)$	Fourier transform of variable $x(t)$ at the frequency f

E. Fournier is with Leroy Somer, Angoulême, France and the Université de Toulouse, INPT, UPS, LAPLACE (Laboratoire Plasma et Conversion d'Énergie), ENSEEIHT, 2 rue Charles Camichel, BP 7122, F-31071 Toulouse cedex 7, France.

M. Picot, J. Régnier, and P. Maussion are with the Université de Toulouse, INPT, UPS, LAPLACE (Laboratoire Plasma et Conversion d'Énergie), ENSEEIHT, 2 rue Charles Camichel, BP 7122, F-31071 Toulouse cedex 7, France.

C. Andrieux and J. Saint-Michel are with Leroy Somer, Angoulême, France.

I. INTRODUCTION

Electromechanical systems are often critical elements in industrial plants. Their failure may provoke safety issues or unexpected production shutdowns. Developing efficient condition monitoring methods for electrical machines and transmission elements is therefore necessary to optimize their maintenance.

Recent studies [1] have mainly focused on the diagnosis of faults relative to electrical motors such as bearing faults [2]-[7], rotor faults [8]-[11] or winding faults [12]-[14]. Some research has also been done in the condition monitoring of coupling elements, such as gears [15]-[16], which are critical parts of the power transmission chain. However, few attention has been paid on the condition monitoring of belt-pulley drives [17].

Belts are widely employed in industrial applications such as fans, pumps, compressors, etc. and especially flat and trapezoidal belts (or V-belts). This extensive use is mainly due to their benefits such as their high efficiency, the non-necessity of aligned shafts, their tolerance for misalignment and their low cost [18]. However, belt-pulley systems are subject to wear and mechanical fatigue and can therefore lose their mechanical properties during their lifetime. Belt looseness is an important failure mode which increases the belt slip and thus accelerates the wear process of the transmission system. This is caused by a tension loss which may be caused by a variation of the center distance between motor and load or by wear belts or pulleys. In worst cases, belts deterioration may lead to pulleys' grooves damages, critical slip between the motor and his load and finally to the belts breakage [19]-[20].

In this context, the effects of belt looseness on a system driven by an induction motor (IM) are studied in this paper. First, the experimental system composed of an induction motor, a belt-pulley transmission system and a load is presented and the degradation protocol is explained. Secondly, the spectral content of several mechanical and electrical quantities measured on the system is analysed for the different health states of the belts in steady state operation. Then, the behaviour of the same variables is studied in transient state condition when a step of speed reference is applied to the motor.

Finally, a comparison of belt looseness effects under steady and transient state condition is done and perspectives of this work are detailed.

II. Material

A. Test bench

The test bench used in this study is composed of :

- a squirrel cage IM with one pair of poles, a rated power of 30 kW and a rated speed of 3000 RPM,
- a transmission system composed of two 160-mm diameter pulleys and two trapezoidal belts with a length of $L_{belts} = 1600mm$ (Texrope® VP2 1600 SPA),
- a direct-current machine used to vary the torque delivered by the IM.

and is illustrated in Fig. 1. The IM is fed by a PWM-inverter with a constant V/f open-loop control law. Moreover, the center distance d between the load machine and the induction motor is adjustable and can be changed to increase or decrease belts tension. In this way, tests can be carried out for healthy conditions, with a proper tension of the belts, and for faulty conditions by gradually decreasing the center distance d between the motor and its load. Finally, since diameters of the driven pulley D_{driven} and the driver pulley D_{driver} are equals, the transmission ratio $R_t = D_{driven}/D_{driver}$ is equal to 1. An overall representation of the experimental system is illustrated in Fig. 2.

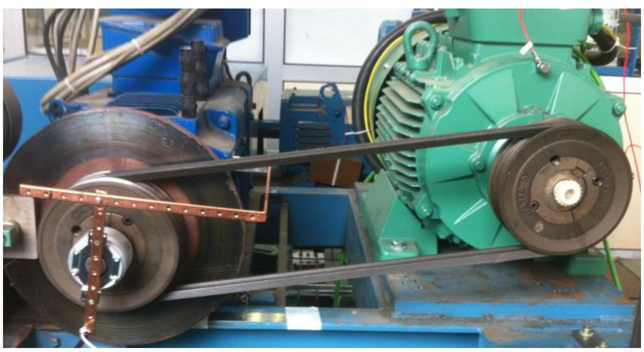

Fig. 1. Experimental test bench composed of an 30-kW IM (right), a belt-pulley transmission system (middle) and a direct-current machine (left).

B. Measurements

With a sample frequency $f_s = 100kHz$, a 8-synchronous channels data acquisition system has been used to measure mechanical and electrical quantities of the system such as:

- radial and axial vibration signals (respectively γ_r and γ_a) via two accelerometers (Dytran™ 3055A2) placed on the motor frame,
- motor and load mechanical speed signals (respectively Ω_{motor} and Ω_{load}) by using two encoders,
- motor phase currents i_1, i_2 and i_3.

All recordings have a constant length $T_{recording}$ equal to $5s$. Belts slip, noted S_Ω, is calculated from both speed measurements Ω_{motor} and Ω_{load} according to

$$S_\Omega = \Omega_{motor} - R_t.\Omega_{load} \quad (1)$$

or defined in relative terms by

$$s_\Omega = \frac{S_\Omega}{\Omega_{motor}} \cdot 100 \quad (2)$$

for all measurements.

Tests have been carried out for different center distances

$$d_1 > d_2 > d_3 > d_4 \quad (3)$$

which correspond to the different belts looseness conditions represented in Table I. The center distance d_1 corresponds to a correct belts tension which ensures an optimal functioning of the system. On the contrary, the center distance d_4 provokes a critical looseness of the belts which even prevents the system to work under the rated load and speed. Between these two extreme cases, tests have been carried out for two intermediate center distances d_2 and d_3 which produces respectively moderate and strong belts looseness.

TABLE I
Center distances and related belts condition used during the experimental tests.

Center distance	Belts condition
d_1	Healthy belts
d_2	Moderate belts looseness
d_3	Strong belts looseness
d_4	Critical belts looseness

Tests have been realized for different speed and load conditions of the IM. The operating conditions are however presented in section III and IV since functioning points are defined differently under steady and transient state tests.

III. Effect of belt looseness on mechanical and electrical quantities under steady state operation

A. Operating conditions

All results presented in this section have been obtained under steady state conditions of the motor speed and load. Tests have been realized for two motor speeds $\Omega_n/2 = 1500$RPM and $\Omega_n = 3000$RPM and under five load levels $I_0 \simeq 15A$, $I_n/2 \simeq 26A$, $3I_n/4 \simeq 38A$, $7I_n/8 \simeq 45A$ and $I_n \simeq 52A$. For clarity reasons, spectra are only presented in this section for $\Omega_{motor} = 1500$RPM and $I_{motor} = 52A$ but results are similar for the other speed and load levels.

B. Belts slip

A priori, looseness affects the slip of the belts in two ways :

- The average value of the belts slip is susceptible to increase with the decrease of the belt tension.

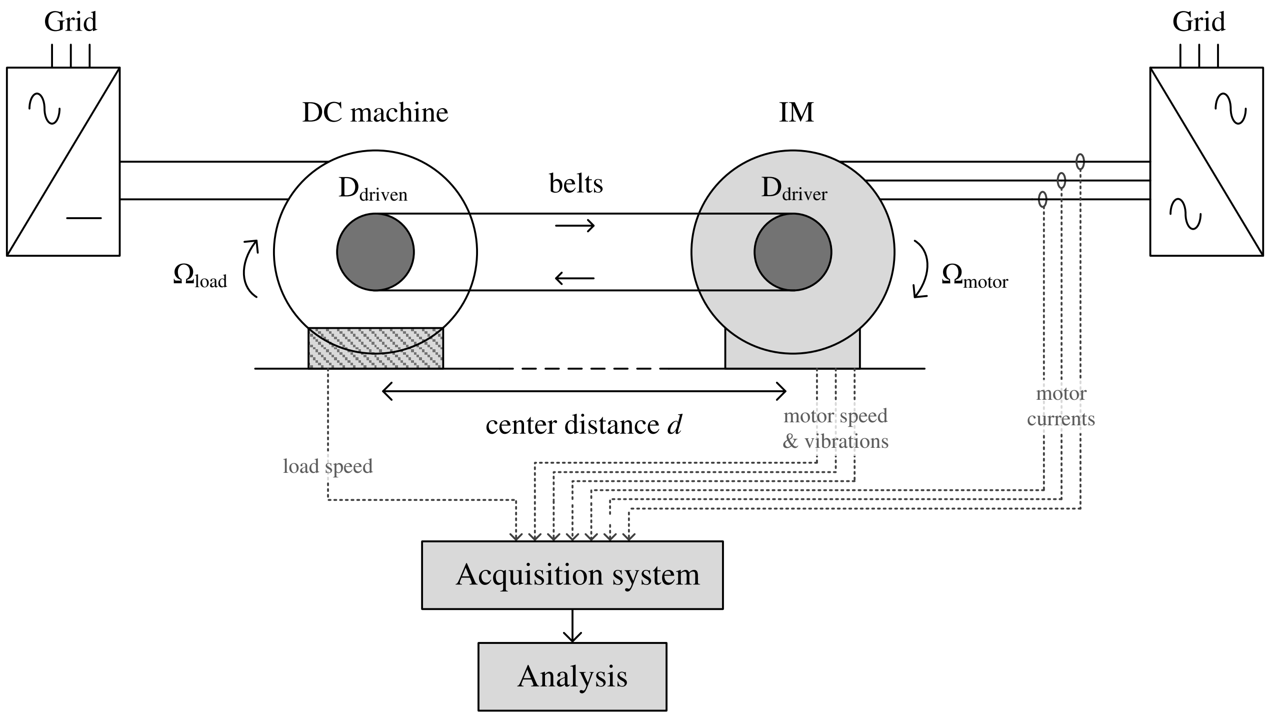

Fig. 2. Illustration of the experimental test bench used to carry out the different tests of the study. A inverter-fed induction motor (right) drives a DC machine (left) through a pulley-belt system (middle). The center distance d between the motor and its load is adjustable in order to change the belts looseness level.

- The spectral content of the belts slip may vary with the looseness condition because of an eventual change of belts grip behaviour or a possible belts flapping.

First, the evolution of the relative belts slip has been plotted in Fig. 3 for different load conditions and for $\Omega_{motor} = 1500$RPM. It is clearly visible in Fig. 3 that belts looseness tends to increase the average value of belts slip s_Ω, especially for high load levels. Indeed, s_Ω value is below 2% for all load levels in healthy conditions whereas it reaches up to 8% for critical belts looseness.

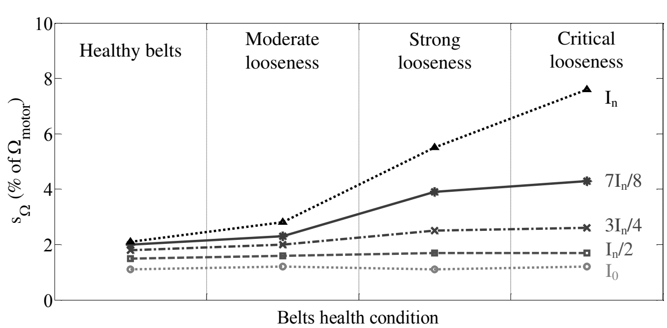

Fig. 3. Evolution of the average value of the relative belts slip s_Ω with the looseness severity for different load levels and $\Omega_{motor} = 1500$RPM.

Secondly, spectra of the belts slip S_Ω have been computed for the different health conditions of the belts and are plotted in Fig. 4. We can notice that the three harmonic families $S_\Omega(k.f_{r,belts})$, $S_\Omega(k.f_{r,load})$ and $S_\Omega(k.f_{r,motor})$ dominate the belts slip spectrum and are impacted by the looseness level of belts. The rotation frequency of the two belts is noted $f_{r,belts}$ and is defined according to

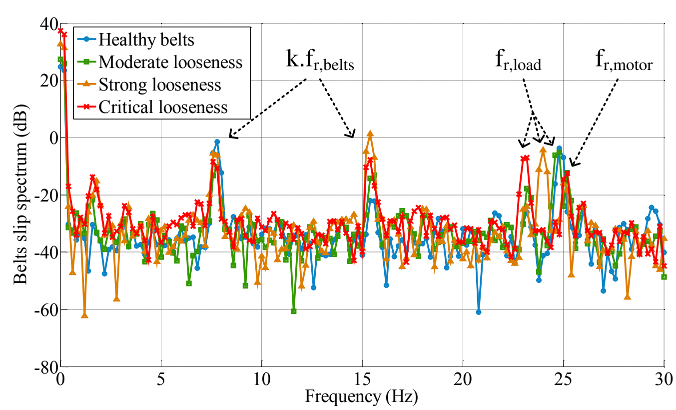

Fig. 4. Evolution of the belts slip spectrum $S_\Omega(f)$ with the looseness severity for $I_{motor} = 52A$ and $\Omega_{motor} = 1500$RPM.

$$f_{r,belts} = \frac{\pi D_{driver}}{L_{belts}} \cdot f_{r,motor} \quad (4)$$

It is visible that harmonics $S_\Omega(f_{r,belts})$ and $S_\Omega(2f_{r,belts})$ respectively decrease and increase with the severity of the fault. We also remark a shift of the harmonic $S_\Omega(f_{r,load})$ with the fault level since the rotation frequency of the load $f_{r,load}$ decreases with the belts looseness level. Its level remains stable for the four belts condition. Finally, it is difficult to state on the behaviour of harmonic $S_\Omega(f_{r,motor})$ since its frequency is close to the one of $S_\Omega(f_{r,load})$ for the two healthiest belts conditions. However, its level seems to increase with the looseness severity for the two poorest health conditions of the belts.

C. Motor vibrations

As illustrated in Fig. 2, two accelerometers have been placed in radial and axial position on the IM frame. The spectra of the vibration signals $\gamma_r(t)$ and $\gamma_a(t)$ thus obtained have been computed for the different health conditions of the belts. For clarity reasons and since the spectral content of both vibration signals is alike and evolves similarly with the considered fault, only axial vibrations spectra $\Gamma_a(f)$ are represented in Fig. 5. The three frequency families $k.f_{r,belts}$,

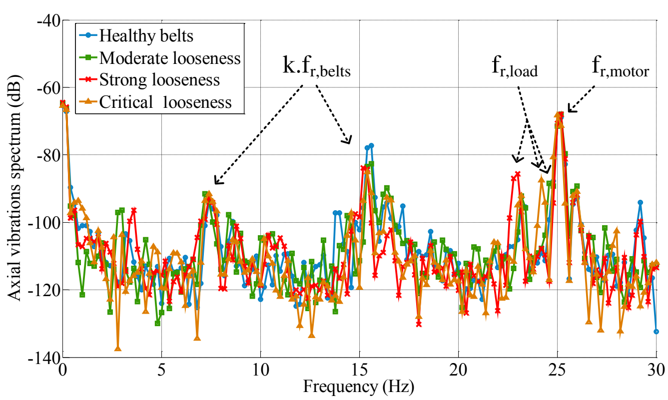

Fig. 5. Evolution of the axial vibrations spectrum $\Gamma_a(f)$ with the looseness severity for $I_{motor} = 52A$ and $\Omega_{motor} = 1500$RPM.

$k.f_{r,load}$ and $k.f_{r,motor}$ also dominate the low frequency part of the vibrations spectral content. However, the evolution of the looseness severity hardly affects their level. Only the shift of harmonic $\Gamma_a(f_{r,load})$ betrays the tension loss of the belts.

D. Motor speed

The motor speed, as well as the load speed, has been measured by an encoder and recorded for each health condition of the belts. Its spectral content may also be affected by a change of the transmission system properties. Therefore, the spectrum $\Omega_{motor}(f)$ of the motor speed has been plotted in Fig. 6 for the four looseness levels. Several observations can be made on the motor speed spectrum and on its evolution with the looseness level. First, the shift of the harmonic $\Omega_{motor}(f_{r,load})$ is also visible in the speed spectrum but it is accompanied here by a rise of its level with the fault severity. Secondly, harmonics $\Omega_{motor}(f_{r,belts})$ and $\Omega_{motor}(2f_{r,belts})$ are also impacted by the considered default and evolve in the same way that harmonics $S_\Omega(f_{r,belts})$ and $S_\Omega(2f_{r,belts})$ with its severity. Finally, it is visible that the harmonic $\Omega_{motor}(f_{r,motor})$ strongly increases with the belts looseness level.

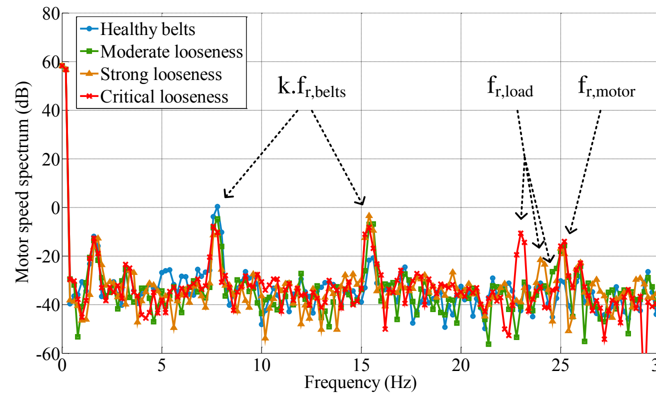

Fig. 6. Evolution of motor speed spectrum $\Omega_{motor}(f)$ with the looseness severity for $I_{motor} = 52A$ and $\Omega_{motor} = 1500$RPM.

E. Motor phase currents

The study of mechanical variables have shown that several frequency families , such as $k.f_{r,belts}$, $k.f_{r,load}$ and $k.f_{r,motor}$, are susceptible to react with the increase of the belts looseness. Vibration and motor speed signals are however not automatically measured by industrial variable speed drives, specially for low power systems. This remark is even more valid for the load speed signal. In view of industrial detection of belt looseness, it is therefore interesting to analyse the spectral content of the IM phase currents since they are often available for control purposes. The spectrum $I_1(f)$ of motor phase current i_1 is plotted in Fig. 7 for the different belts looseness conditions. The frequency families considered in the

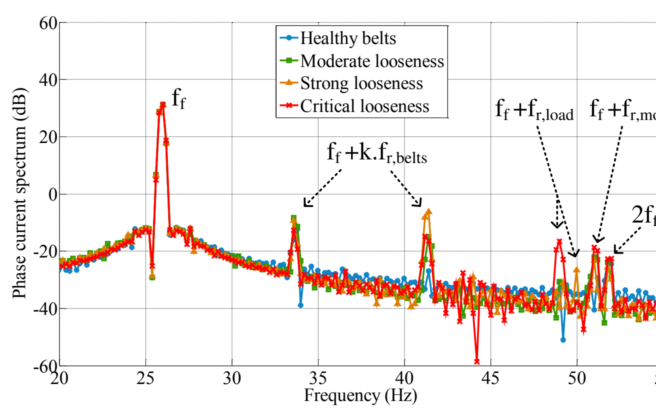

Fig. 7. Evolution of phase current spectrum $I(f)$ with the looseness severity for $I_{motor} = I_n$ and $\Omega_{motor} = 1500$RPM.

study of mechanical quantities are modulated by the supply frequency f_f in the case of phase currents. It is observed in Fig. 7 that the behaviour of harmonics $I(f_f + k.f_{r,belts})$, $I(f_f + k.f_{r,load})$ and $I(f_f + k.f_{r,motor})$ with the increase of belts looseness is strongly similar to the one of the motor speed harmonics $\Omega_{motor}(k.f_{r,belts})$, $\Omega_{motor}(k.f_{r,load})$ and $\Omega_{motor}(k.f_{r,motor})$. Mechanical effects of belts looseness are therefore well reflected in the spectral content of electrical quantities such as motor phase currents. Moreover, since load speed and belt slip are usually not measured on industrial drives, harmonics $I(f_f + k.f_{r,belts})$ and $I(f_f + k.f_{r,load})$ may be difficult to track if belts slip changes over time. Current harmonics $I(f_f + k.f_{r,motor})$ are however easy to calculate since the rotation frequency of the motor $f_{r,motor}$ is measured or estimated on most variable speed drives. A belt diagnosis strategy may therefore be defined for industrial systems by monitoring the current harmonic $I(f_f + f_{r,motor})$. The mean elevation of the harmonic $I(f_f + f_{r,motor})$ from its value with healthy belts has been calculated for each belts condition. These values have been computed with a number of recording $N_{rec} = 20$ for each operating point and results are presented in table II. It is clearly visible that the

TABLE II
EVOLUTION OF THE CURRENT HARMONIC $I(f_f + f_{r,motor})$ AVERAGE VALUE WITH THE BELTS LOOSENESS SEVERITY AND FOR DIFFERENT LOAD CONDITIONS AT $\Omega_{motor} = 1500$RPM.

Load level	Moderate looseness	Strong looseness	Critical looseness
$I_0 \simeq 15A$	+ 1dB	+ 0dB	+ 0dB
$I_n/2 \simeq 26A$	+ 16dB	+ 15dB	+ 18dB
$3I_n/4 \simeq 39A$	+ 10dB	+ 16dB	+ 18dB
$7I_n/8 \simeq 45A$	+ 14dB	+ 13dB	+ 19dB
$I_n \simeq 52A$	+ 12dB	+ 11dB	+ 14dB

increase of the belts looseness provokes an elevation of the considered harmonic. This rise tends to be greater with the fault severity but it is not always valid. Moreover, a minimal load torque seems necessary to observe this phenomenon. The level of $I(f_f + f_{r,motor})$ is indeed not affected by the tension loss of the belts for no load condition ($I_{motor} = I_0$). Results are however significant and show the possibility of monitoring belts looseness condition from the motor current measurements.

IV. Effect of Belt Looseness on Mechanical and Electrical Quantities under Transient State Operation

The belts looseness degradation has a clear influence on the spectral content of mechanical (speed, belts slip, vibrations) and electrical variables (phase currents) under steady state operation. However, the mean elevation of the belts slip illustrated in Fig. 3 is not efficiently used to diagnosis the belts condition. Therefore, the main idea of this section is to exacerbate the belts slip with sudden accelerations imposed to the system and to analyse the dynamic response of the different system's variables under different belts looseness conditions.

A. Operating conditions

In this section, a speed reference step $\Delta\Omega$ is applied to the system at a time $T_{step} = 1s$. The motor speed reference therefore rises from $\Omega_1 = 2000$RPM to $\Omega_2 = 2500$RPM under the load condition $I_{motor} = 38A$. All dynamic tests have been carried out for two conditions of the belts : healthy belts and moderate belts looseness.

B. Belts slip

The step response of the relative belts slip $s_\Omega(t)$ has been illustrated in Fig. 8 for the two belts looseness condition considered in this section. We first observe in Fig. 8 that belts

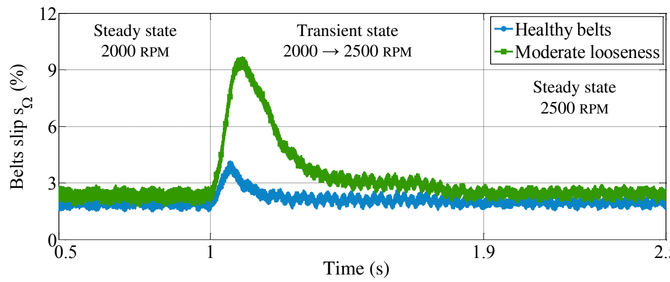

Fig. 8. Dynamic response of the relative belts slip $s_\Omega(t)$ to the speed reference step $\Delta\Omega$ for healthy and loosen belts under the load level $I_{motor} = 38A$.

slip, during steady state conditions (before $t = 1s$ and after $t = 1, 9s$), is slightly higher with moderate belts looseness than in healthy case, as it was illustrated in Fig. 3. However, the torque impact due to the sudden motor acceleration provokes an important rise of the belts slip which reaches up to 10% with loosen belts compared to only 4% when using healthy belts.

C. Motor speed

The drop-out of the belt-pulley adherence observed in Fig. 8 surely affects other physical variables of the system, starting with the motor speed. The step-response of $\Omega_{motor}(t)$ has therefore been illustrated in Fig. 9 for both looseness conditions considered in this section. We can observe that the

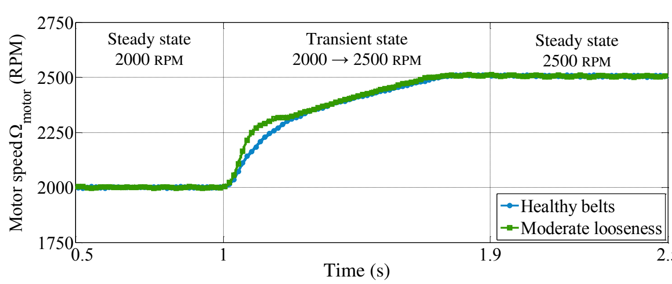

Fig. 9. Dynamic response of motor speed $\Omega_{motor}(t)$ to the speed reference step $\Delta\Omega$ for healthy and loosen belts under the load level $I_{motor} = 38A$.

speed rise is clearly affected by the tension loss of the belts during the acceleration phase. With loosen belts, the motor speed first increases faster since the load is not fully driven (high value of s_Ω). In the second part, the motor speed Ω_{motor} rises slower and merges with its dynamic response obtained in healthy condition since the belts slip falls and the load has to be fully accelerated too.

D. Motor phase currents

The change in the motor speed behaviour between healthy and loosen belts may change the dynamic response of electrical quantities. The response of phase current i_1 has been plotted in Fig. 10 in order to observe this phenomenon. The current

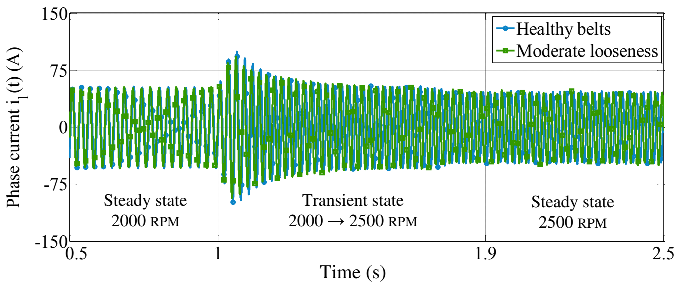

Fig. 10. Dynamic response of motor phase current $i_1(t)$ to the speed reference step $\Delta\Omega$ for healthy and loosen belts under the load level $I_{motor} = 38A$.

increase due to the system acceleration is clearly visible at $T_{step} = 1s$. However, the difference between healthy and loosen belts is difficult to observe because of the sinusoidal waveform of i_1 (t). In order to overcome this problem, the instantaneous amplitude $IA(t)$ of phase currents $i_1(t)$, $i_2(t)$ and $i_3(t)$ has been calculated by using the Concordia transform. Details about $IA(t)$ calculation are presented in [21]. The results obtained for both belts conditions are illustrated in Fig. 11 and the impact of the looseness level is better noticed from signal $IA(t)$ than from the current signal itself. Indeed,

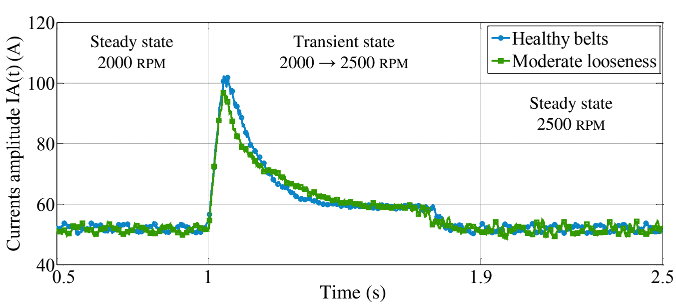

Fig. 11. Dynamic response of motor currents instantaneous amplitude $IA(t)$ to the speed reference step $\Delta\Omega$ for healthy and loosen belts under the load level $I_{motor} = 38A$.

the dynamic response of the currents instantaneous amplitude $IA(t)$ is distorted when the belts looseness level increase. The currents' amplitude peak is attenuated in the first part of the step-response when loosen belts are used instead of healthy belts. Moreover, the drop of $IA(t)$ is visibly slower in faulty condition.

Phenomena observed in this section, i.e. the distortion of the dynamic response of motor speed and currents, are also visible for different load conditions. The load level visibly enhances the changes between healthy and faulty belts condition as it was the case for steady state results. Moreover, higher ($\Delta\Omega_{high} = 1000$RPM) and lower ($\Delta\Omega_{low} = 100$RPM) speed reference step have been used and the same distortions in the variables' responses are observed, with an amplitude depending on the speed reference step applied to the system.

V. Discussion, conclusion and perspectives

Belts looseness effects on mechanical and electrical variables of a system driven by an inverter-fed IM and a belt-pulley coupling have been studied in this paper. The spectral analysis performed under steady state on the different measurements have shown that several frequency families are sensitive to the belts looseness condition. Spectral signatures are particularly visible on phase currents which are often available in industrial drives for control purposes. A belt diagnosis strategy can therefore be envisaged by monitoring the phase current harmonic $I(f_{r,motor})$.

Transient state tests have also been carried out by applying a speed reference step $\Delta\Omega$ to the motor. The belts slip is clearly exacerbated and the dynamic response of the motor speed Ω_{motor} and of the currents IA are consequently distorted. As it stands, it seems difficult to use these transient state phenomena to produce a fault signature related to the belts condition. Time domain quantities such as currents' overshoot or rise time indeed appears not to be optimal fault indicators because they do not reflect the entire distortion of the considered variable.

An interesting perspective however consists in applying a square-wave speed reference signal to the system and to study the variables' responses in the frequency domain. Indeed, a square-wave signal with a small amplitude $\Delta\Omega_{square}$ and a frequency f_{square} may be added to the steady state speed reference Ω_{ref} and will hardly affect the system performances during the recording time. Any distortion of their response due to belt looseness will produce a change in their spectral content at well known frequencies multiple of f_{square}. A few tests have been realized with square-wave speed reference signal in order to detect belts looseness and the study of harmonics $IA(k.f_{square})$ show promising results. A complete test campaign of this pseudo-steady state method will be achieved for different speed and load conditions and results will be presented in a future paper. Moreover a comparison between the steady state results presented in section III and those obtained with the pseudo-steady state tests will be provided too.

Acknowledgment

The authors would like to thank Hervé Egreteau from Leroy Somer for his precious help and advices during the experimental tests carried out in this study as well as for the time he dedicated to perform them.

References

[1] M. Riera-Guasp, J.A. Antonino-Daviu and G-A. Capolino, "Advances in Electrical Machine, Power Electronic and Drive Condition Monitoring and Fault Detection: State of the Art," *Transactions on Industrial Electronics*, DOI 10.1109/TIE.2014.2375853.

[2] A. Picot, Z. Obeid, J. Regnier, S. Poignant, O. Darnis, P. Maussion, "Statistic-based spectral indicator for bearing fault detection in permanent-magnet synchronous machines using the stator current," *Mechanical Systems and Signal Processing*, vol. 46, no. 2, pp. 424-441, June 2014.

[3] T.W. Rauber, F.A. Boldt and F.M. Varejao, "Heterogeneous Feature Models and Feature Selection Applied to Bearing Fault Diagnosis," *Transactions on Industrial Electronics*, vol. 62, no. 1, pp. 637-646, January 2015.

[4] V.C.M.N. Leite, J.G.B. da Silva, G.F.C. Veloso, L.E.B. da Silva, G. Lambert-Torres, E.L. Bonaldi, L.E. de Lacerda de Oliveira, "Detection of Localized Bearing Faults in Induction Machines by Spectral Kurtosis and Envelope Analysis of Stator Current," *Transactions on Industrial Electronics*, DOI 10.1109/TIE.2014.2345330.

[5] A. Soualhi, G. Clerc, H. Razik, and F. Rivas, "Long-Term Prediction of Bearing Condition by the Neo-Fuzzy Neuron," *Proc. of SDEMPED*, August 2013, pp. 586-591.

[6] W.S. Gongora, H.V.D. Silva, A. Goedtel, W.F. Godoy and S.A.O. da Silva, "Neural Approach for Bearing Fault Detection in Three Phase Induction Motors," *Proc. of SDEMPED*, August 2013, pp. 566-572.

[7] M. Delgado, G. Cirrincione, A.G. Espinosa, J.A. Ortega and H. Henao, "Dedicated Hierarchy of Neural Networks applied to Bearings Degradation Assessment ," *Proc. of SDEMPED*, August 2013, pp. 544-551.

[8] H. Razik, M.E.K. Oumaamar and G. Clerc, "A Hybrid Kangaroo Algorithm to Assess the State Of Health of Electric Motors," *Proc. of SDEMPED*, August 2013, pp. 43-48.

[9] A. Soualhi, G. Clerc and H. Razik, "Detection and Diagnosis of Faults in Induction Motor Using an Improved Articial Ant Clustering Technique," *Transactions on Industrial Electronics*, vol. 60, no. 9, pp. 4053-4062, September 2013.

[10] M.Y. Kaikaa and M. Hadjami, "Effects of the Simultaneous Presence of Static Eccentricity and Broken Rotor Bars on the Stator Current of Induction Machine," *Transactions on Industrial Electronics*, vol. 61, no. 5, pp. 2452-2463, May 2014.

[11] K.N. Gyftakis, D.K. Athanasopoulos and J. Kappatou, "Evaluation of Different Broken Bar Fault Diagnostic Means in Double-Cage Induction Motors with FEM," *Proc. of SDEMPED*, August 2013, pp. 36-42.

[12] F.R. Blnquez, C.A. Platero, E. Rebollo and F. Blzquez, "Evaluation of the Applicability of FRA for Inter-Turn Fault Detection in Stator Windings," *Proc. of SDEMPED*, August 2013, pp. 177-182.

[13] B. Aubert, J. Regnier, S. Caux and D. Alejo , "Kalman Filter Based Indicator for On-line Inter-Turn Short-Circuits Detection in Permanent Magnet Synchronous Generators," *Transactions on Industrial Electronics*, DOI 10.1109/TIE.2014.2348934.

[14] K-H. Kim, "Simple Online Fault Detecting Scheme for Short-Circuited Turn in a PMSM Through Current Harmonic Monitoring," *Transactions on Industrial Electronics*, vol. 58, no. 6, pp. 2565-2568, June 2011.

[15] S. H. Kia, H. Henao, G. A. Capolino, "Gear Tooth Surface Damage Fault Detection Using Induction Machine Electrical Signature Analysis," *Proc. of SDEMPED*, August 2013, pp. 358-364.

[16] D. Zurita, M. Delgado, J.A. Ortega Redondo, L. Romeral, "Intelligent Sensor based on Acoustic Emission Analysis applied to Gear Fault Diagnosis," *Proc. of SDEMPED*, August 2013, pp. 169-173.

[17] F. Gu, Y. Shao, N. Hu, B. Fazenda and A. Ball, "Motor Current Signal Analysis using a Modified Bispectrum for Machine Fault Diagnosis," *Proc. of ICROS-SICE International Joint Conference*, August 2009, pp. 4890-4895.

[18] H. Yamashina, S. Okumura and I. Kawai, "Development of a diagnosis technique for failures of V-belts by a cross-spectrum method and a discriminant function approach," *Journal of Intelligent Manufacturing*, vol. 7, pp. 85-93, July 1995.

[19] H.P. Bloch and F.K. Geitner, Installation and Maintenance of V-belt Drives in Practical Machinery Management for Process Plants : volume 4, 1997, ch. 7, pp. 310-328.

[20] Belt and chain drives in Handbook of Reliability Prediction Procedures for Mechanical Equipment, Technical report, Naval Surface Warfare Center, 1998, ch. 21.

[21] E. Fournier, A. Picot, J. Regnier, M. TientcheuYamdeu, J-M. Andrejak and P. Maussion , "Current-based Detection of Mechanical Unbalance in an Induction Machine Using Spectral Kurtosis with Reference," *Transactions on Industrial Electronics*, DOI 10.1109/TIE.2014.2341561.

Etienne Fournier got his MSc in electrical engineering from Supélec Gif-sur-Yvette, France in 2012. He is now a PhD Student at the Laboratory of Plasma and Energy Conversion (LAPLACE) in Toulouse, France. His Scholarship is funded under an industrial agreement with Leroy Somer Motor, Angoulême, France. His work focuses on preventive diagnostic of electrical machines under variable-speed control.

Antoine Picot graduated from the Telecom Department of the Institut National Polytechnique (INP) Grenoble, France in 2006. He received the MSc degree in signal, image, speech processing and telecommunications in 2006 and his PhD in automatic control and signal processing in 2009 from the INP Grenoble. He is actually an associate professor at the INP Toulouse. He is also a Researcher with the Laboratory of Plasma and Energy Conversion (LAPLACE), Toulouse. His research interests are in monitoring and diagnosis of complex systems with signal processing and artificial intelligence techniques.

Jérémi Régnier was born in 1975. He received the PhD degree in electrical engineering from the Institut National Polytechnique (INP) Toulouse, France in 2003. Since 2004, he has been an Assistant Professor with the Electrical Engineering and Control Systems Department, INP Toulouse. He is also a Researcher with the Laboratory of Plasma and Energy Conversion (LAPLACE), Toulouse. His research interests include modelling and simulation of faulty electrical systems as well as the development of monitoring techniques using signal-based and model-based methods.

Pascal Maussion got his MSc and PhD in Electrical Engineering in 1985 and 1990 from Institut National Polytechnique (INP) Toulouse, France. He is currently full Professor with the University of Toulouse and with the Laboratory of Plasma and Energy Conversion (LAPLACE), Toulouse. His research activities deal with control and diagnosis of electrical systems (power converters, drives, lighting) and with the design of experiments for optimisation in control and diagnosis. He is currently Head of Control and Diagnosis group in LAPLACE. He teaches control and diagnosis in a school of engineers.

Christian Andrieux was born in 1957. He received the degree in engineering from ENSEEIHT, Toulouse, France, and the Ph.D. degree from the University of Toulouse in 1983 and 1986 respectively. In 1986, he joined the electronic E&D division of Leroy-Somer Motor, Angoulême, France. He is currently the Product Manager for large electronic drives in the Leroy Somer M&D division of Emerson Industrial Automation.

Jacques Saint-Michel was born in 1949. He received the degree in engineering from Ecole Centrale de Paris, Paris, France, in 1972, and the Ph.D. degree from the University of Paris VI, Paris. From 1972 to 1982, he was with the French National Scientific Research Center (CNRS). In 1982, he joined Jeumont Schneider as the Head of the Design and Planning Department and remained with them until 1990. In 1990, he joined Leroy Somer Motor, Angoulême, France, as a Technical Manager, becoming Scientific Director in 1998.