Investigative techniques for detecting torsional stresses of shaft lines of a ball mill

Mounir LAHLIMI[1] Xavier THOMAS[2]

[1]Dynae
7 Rue Capitaine Vuillanier - 20250 Casablanca
mlahlimi@dynae.fr

[2]Dynae
29 rue Condorcet - 38090 Villefontaine, France
xthomas@dynae.fr

Abstract

Torsional loads of shaft lines are difficult to measure with conventional methods of vibration or acoustic analysis. However, they generate significant stresses which may lead to failure of couplings or worse, shafts themselves. It is therefore necessary to implement other measurement techniques.

For the vibratory expertise of a ball mill which presents, once a year, a breakdown of the intermediate shaft of the main gearbox, Dynae used different analysis techniques, each with its own advantages and disadvantages. We will see in this case study that the most relevant remains torque measurement.

The use of strain gauges on the spacer allows to record directly via a telemetry system, the dynamic torque fluctuations with a very good sensitivity. However, this technique requires a significant instrumentation time, related to the careful implementation of the system in an industrial environment. The analysis of the stator current and the measurement of the instantaneous speed are two other techniques that can easily complete instrumentation and correlate the results.

The measurements were performed for several transient phases of start-up and shut down of the ball mill. A torsional resonance phenomenon has been clearly identified by torque measurements on these transient phases. Current measurements and instantaneous speed were used to validate the results and refine the diagnosis.

Based on these findings, several recommendations were made to the operator to reduce the effect of this phenomenon and improve the life of the gearbox.

1 Introduction

In this paper we propose the case study of torsional vibration of a ball mill used for cement manufacturing process. A picture of the mill is shown in Figure 1. The main mechanical elements consisted of an asynchronous motor with electrolytic resistance starter, a two-stage reducer gearbox, and a pinion / girth gear for the drive of the mill.

Motor rated power [P] = 1000 kW
Motor speed [N] = 995 rpm
Reducer gearbox ratio = 6.56
Pinion shaft speed = 152 rpm
Teeth pinion/girth = 25/218

Figure 1: the picture of the Mill

In recent years, this mill has suffered recurring damage from the intermediate shaft of the gear unit (4 breaks since 2010) which come from the keyway of the pinion. For this purpose, dynae recommended an experimental torsional analysis in order to characterize the dynamic behavior of drive lines, identify the cause of these damages and to finally propose corrective actions

2 Field instrumentation

The details of the instrumentation used for the measurements are listed in this section.

2.1 Torque measurement

The torsional vibration investigation involved measuring torque on the shaft in order to assess torsional resonance that may have caused the damages. For this purpose, strain gauges were mounted 180° apart on the spacer; Also, a telemetry system was used to transfer the measured signals from the rotating shaft to the an FM receiver. The system consists of a wheaston bridge and a transmitter that are fixed to the rotating shaft and transmits the signals directly to the stationary receiver unit. The receiver unit is connected to multichannel acquisition system. The transmitter and receiver units are illustrated in Figure 2.

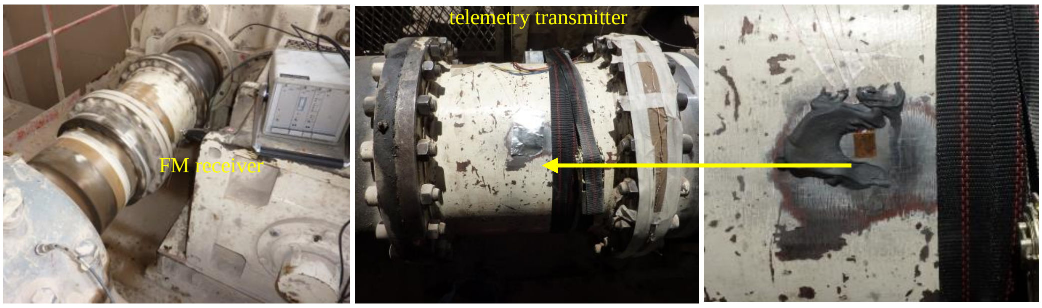

Figure 2: Instrumentation on the output shaft of the gearbox

In order to ensure the accuracy of the torque measurement by telemetry, some precautions have been required; the placement of the strain gauges requires a special preparation of the surface of the rotating shaft which must be well polished and shiny (mirror-polished surface) The gauge bridges electrical connections must be welded cleanly and the bridges circuit must be calibrated.

2.2 Fluctuation speed measurement

The shaft angular velocity was measured by fixing an adhesive tape with alternate black and white strips. This zebra strip and the reflective light intensity optic sensor are shown in Figure 4. This system was placed on the high speed shaft between the motor and the gear unit. The resolution of 54 segments is sufficient for evaluate correctly the instantaneous speed of the low speed shaft

Figure 3 Zebra tape encoder and the optical transducer

2.3 Electrical current measurement

The stator current measurement was carried out from the CT (1: 200 ratio) see figure 5 right picture and the rotor current measurement from the rotor terminal box see figure 5 left picture.

Figure 5 : measurement of Stator current and Rotor current

3 Experimental results

3.1 Torque signature analysis

The records were analyzed and several distinct characteristics were identified. As illustred in figure 6 :

Phase 1 : Maximum switch-on torque . Transient torque peak at the motor start up
Phase 2 : Torque fluctuations as the mill accelerates . Torsional resonance of the lines shaft close to the speed of 172 rpm of high speed shaft excited by the pinion/ girth gear mesh frequency,
Phase 3 : Torque peak at short-circuit step – the transient torque peak when the motor slip rings are short circuited by the contactor of the LRS starter once the mill has reached full speed

Kinematic analysis reveal that the frequency of the fluctuations is corresponding to the pinion / girth gear mesh frequency. These are amplified by a torsional natural frequency located around 10.8 Hz during the run up phase.

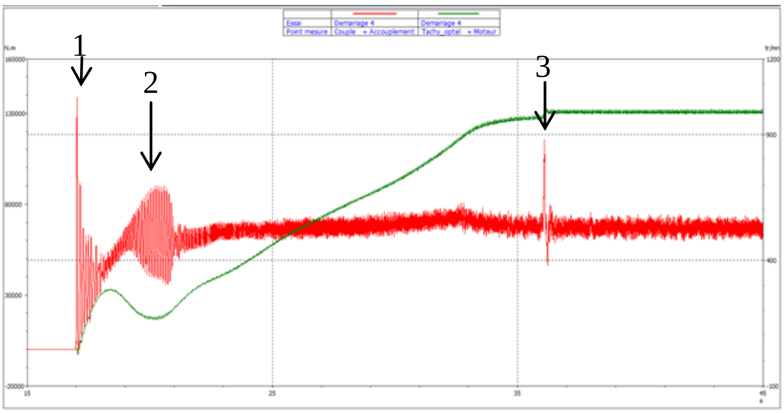

Figure 6 – torque measurement (red) and instantaneous velocity (green)

The graph below shows the comparison of the torque measurements for three different start-up:

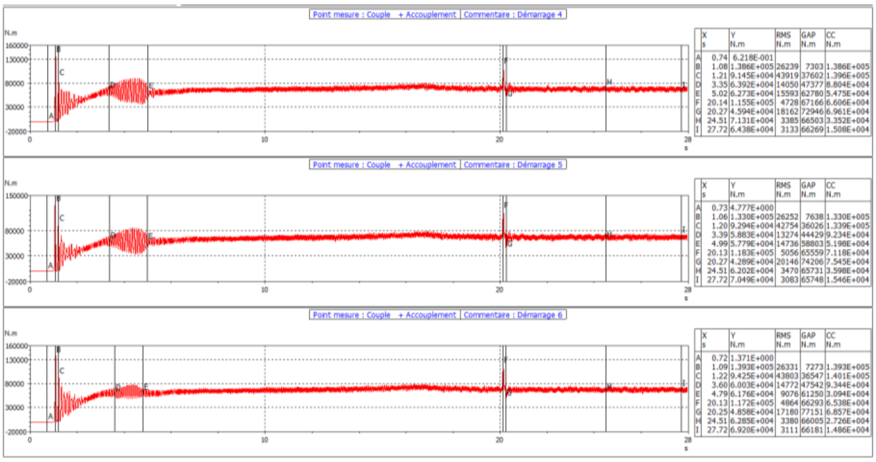

Figure 7 - Comparison three repeated start – Torque measurment

The comparison of the three repeated startup shows that the first peaks recorded at the run-up are of the same order of magnitude . The duration of the torsional resonance is also equal on the three records (about 2 seconds).

The raw measurements in the stabilized phase of torque clearly show a normal fluctuation due to the pinion / girth gear mesh frequency at 62.6 Hz. The torque spectrum shows dome at 12.4 Hz (see figure 9). Under load, there is no kinematic frequency in coincidence with the torsion mode.

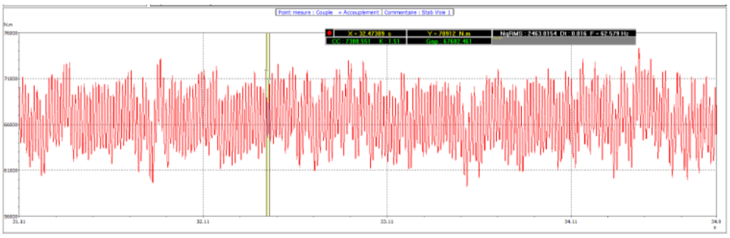

Figure 8 – torque measurement in the stabilized phase

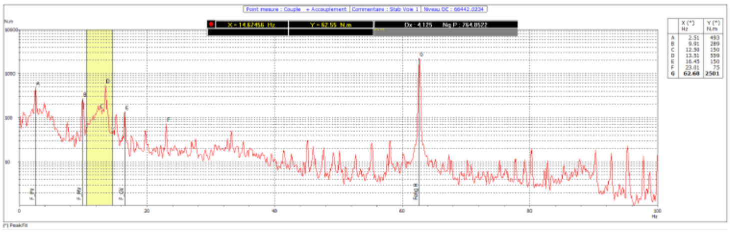

Figure 9 – Spectrum of the torque measurement in the stabilized phase

3.2 Instantaneous speed analysis

The measurements of the instantaneous speed of the input shaft of the gearbox reveal several phases (the figure 10):

A first phase of acceleration about 1.3 seconds,

A deceleration phase of about 2 seconds between marks B and C of the curve below, This is due to a high load phase before material begin to move in the mill shell.

A second phase of acceleration between the marks C and D,

Phase of rotor short-circuit which reach its nominal speed (between the marks D and E).

The zoom around the mark C in figure 10, shows the speed fluctuations on the first startup seconds. The zone identified as having strong torque fluctuations clearly show fluctuations in the instantaneous velocity due to the torsionnal resonance. These fluctuations are 14 rpm for a shaft input speed of 172 rpm (8%).

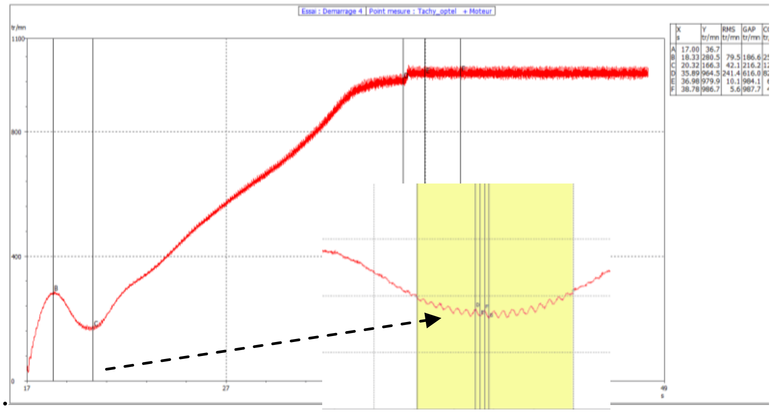

Figure 10 - Instantaneous speed

The spectrum of the instantaneous velocity measurement at stabilized load gives information similar to the torque measurements by identification of the torsion mode around 12.4 Hz with the presence of a dome noted in yellow band see figure 11.

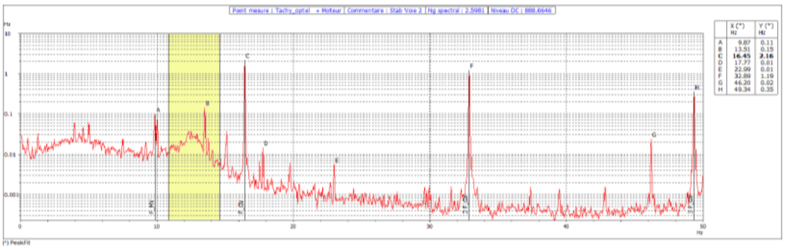

Figure 11- Spectrum FMF of the instantaneous speed in stabilized phase

3.3 Electrical current analysis

The raw signal of a stator current is shown in figure 12. In this illustration, only two maximum peaks are identified. The first peak correspond to the start (mark B) when the motor is energized and second peak is corresponding to the rotor rings short circuited (mark C). During the run-up, no natural frequency is observed in the stator current signal. However, at stabilized speed, the amplitude demodulation spectra around the grid frequency at 50 Hz clearly show a dome of energy at 12.4 Hz corresponding to the torsional mode which is not excited by any kinematic frequency. This spectrum is illustred in figure 13.
Torque fluctuation can induce amplitude modulation of stator current absorbed, as shown in Figure 14, in the case of another mill cement which illustrates at the end of the start-up a good coherence between torque and current fluctuations when the torsional resonance is reached just before the nominal speed.

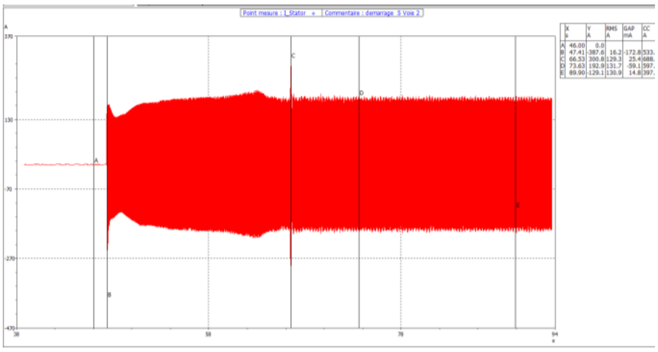

Figure 12 – raw signal of a stator current

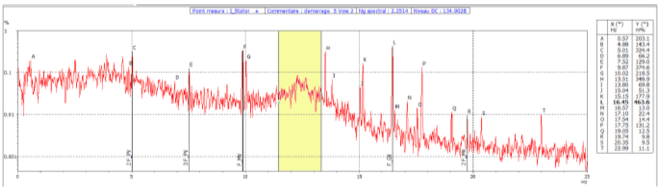

Figure 13 - spectrum FMA of a stator current

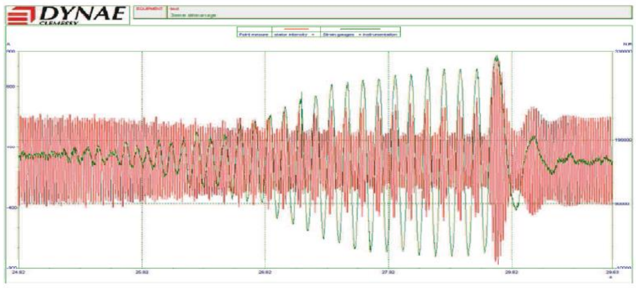

Figure 14 – Example on an other mill : stator current (red) and dynamic torque (green)

4 Conclusion

The measurements and analysis of the transient phases highlighted the presence of a torsional resonance of the shaft lines of the ball mill at 10.8 Hz. This phenomen correspond o the excitation of a torsional natural frequency by the pinion / girth gear mesh frequency. This phenomenon is clearly identifiable on the torque and the instantaneous speed measurements when the gear mesh frequency is close to 10.8 Hz.
The repeated excitation of this torsional natural frequency at each start up and run out is the main root of the Intermediate shaft breakage. Indeed, the first mode of torsion corresponds to a movement inopposite phases between the motor side inertias and the mill side inertias, which implies a vibration node in the middle of the shaft lines. This node can therefore be located at the level of the intermediate shaft of the gearbox, generating a very high concentrated stress.

References

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