White Paper

Detection of Coupling Slippage in Encoder Systems

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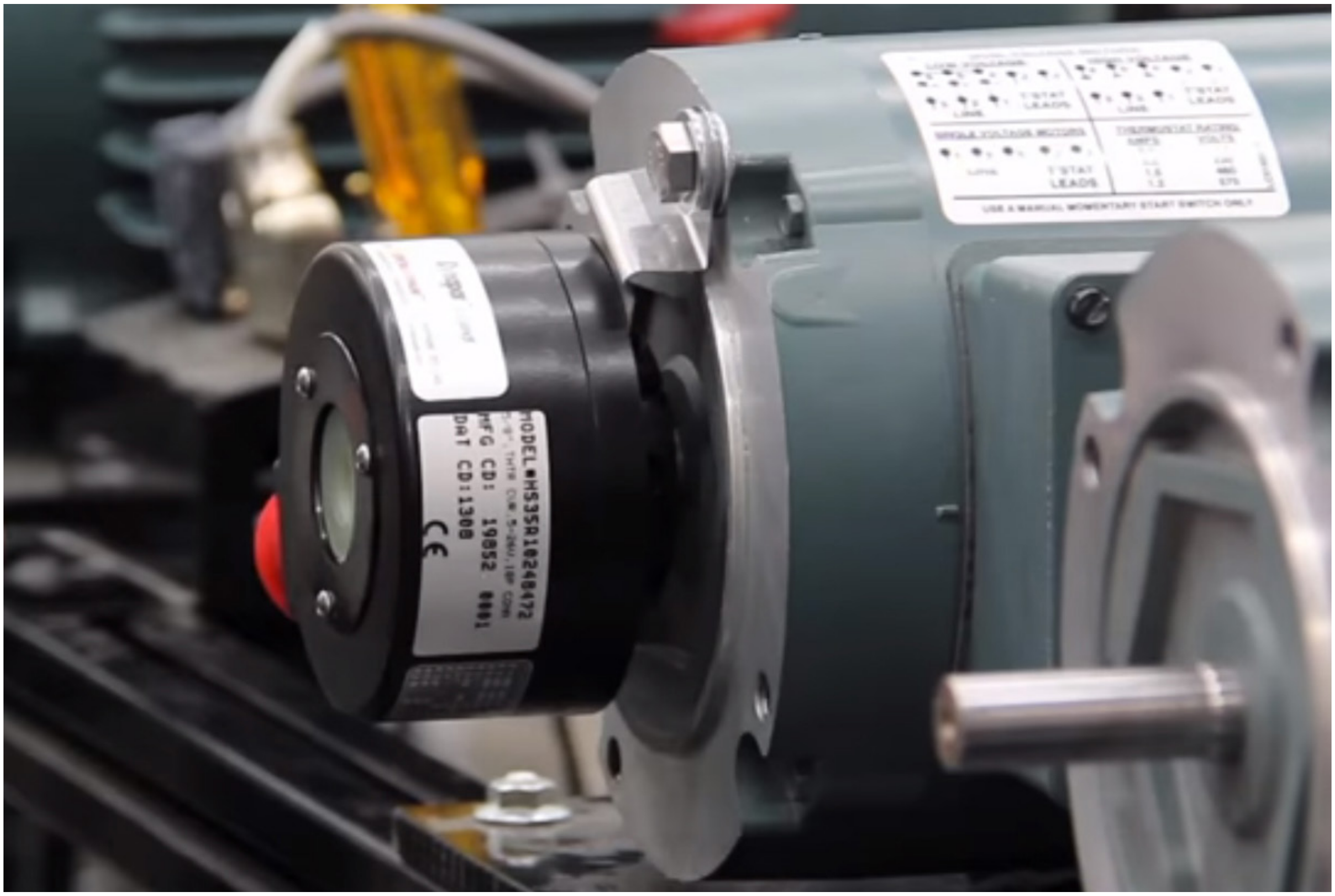

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Detection of Coupling Slippage in Encoder Systems

By Robert Cachro, Sr. R&D Engineer

Abstract: Detection of mechanical coupling slippage in rotary encoder systems is derived from an analysis of rapid changes in an encoder shaft's angular position. Slippage occurrence of the mechanical coupling is detected when an interval between a negative peak acceleration and a positive peak acceleration is less than what would generally be seen in standard control applications.

Introduction

The present disclosure provides an overview of the detection of mechanical coupling slippage in rotary encoder systems. Rotation detection sensors, or rotary encoders, are standard sensor devices used to measure the rotation of a rotating member, e.g., an axle, shaft, wheel, etc. Problems with installing encoders in encoder systems often arise from improper mechanical coupling of the encoder to the system being monitored. A mechanical coupling is often used to attach the rotating member of the equipment being monitored (the driving shaft) to an input shaft, or similar mechanism, of the rotary encoder (the driven shaft). Such couplings are mechanical elements used to connect two shafts to transfer power or motion from one shaft to another and can deteriorate over time, sometimes resulting in slippage of either the driving or driven shaft within the coupling. If not detected promptly, such slippage can result in control system failure and possible equipment damage.

Coupling Slip Theory

At least in the earliest stages of such occurrences, a coupling slip event is manifested by a substantial magnitude decrease in angular velocity, when the coupling first slips, quickly followed by a correspondingly significant magnitude increase in angular velocity, when the coupling once again "catches up."

Coupling Slip Algorithm

With an understanding of the underlying physics, we can now go ahead and examine the techniques used to identify coupling slippage events in encoder systems as demonstrated by the flow chart in Figure 1.

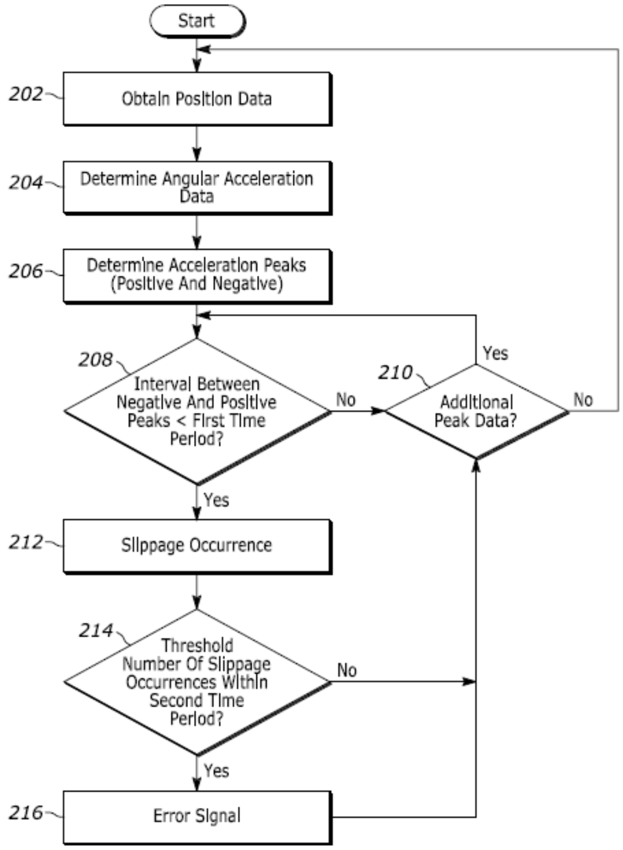

Fig 1. Flow chart illustrating processing of coupling slip phenomenon.

Processing begins at block [202], wherein encoder position data samples are obtained and processed in a batch or “windowed” manner and are continuously buffered until enough position data samples are obtained. In each buffer or window, the number of samples to be processed will depend on the sampling rate and precision (pulses per revolution) provided by the encoder. However, it will typically comprise several hundred to a few thousand samples. Overlap between successive windows can be employed to ensure correct identification of slippage occurrences that may otherwise span successive, non-overlapping windows. Having obtained enough position data samples, processing continues at block [204], where angular acceleration data is determined based on the position data samples. Using known derivative techniques, this is accomplished by first calculating angular velocity data based on the position data samples. An example of this is illustrated in the top graph of Figure 2, in which angular velocity data (expressed in rotations per minute (RPM)) is plotted vs time. The angular velocity data shown here is centered around about 1800 RPM and is inherently noisy as a result of the derivative calculation. As further shown in this example, there are multiple instances of significant velocity deviations [302-308] consistent with slippage occurrences.

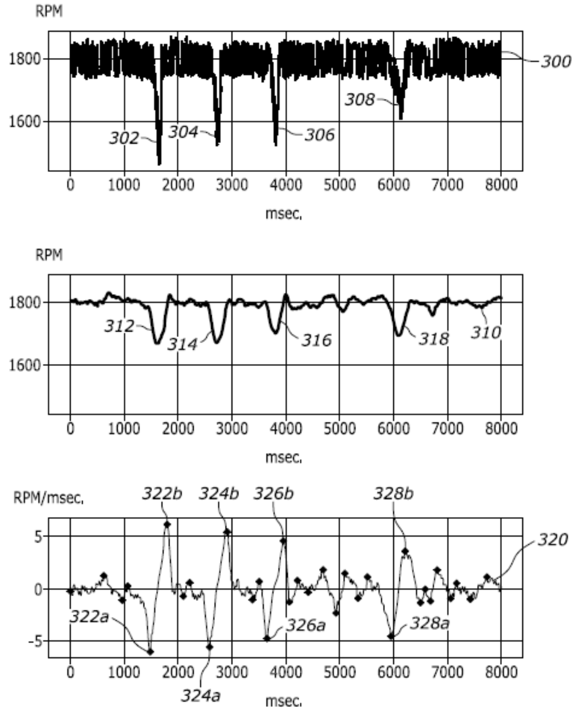

Fig 2. Graphs illustrating the detection of acceleration peaks based on position data samples.

To clean up the data, the angular velocity data is filtered, and the middle graph of Figure 2 illustrates an example of the resulting filtered angular velocity data (again shown in terms of RPM). Such filtering will minimize potential false-positive detections of slippage occurrences to the extent that such events are characterized by rapid changes in velocity, much like the low-level noise otherwise present in the unfiltered angular velocity data. Despite this filtering, it is noted that the filtered angular velocity data [310] still includes significant velocity deviations [312-318] indicative of slippage occurrences. Finally, in keeping with the well-known relationship that the derivative of a time-varying velocity signal is a time-varying acceleration signal, a derivative operation is performed on the filtered angular velocity data to determine angular acceleration data, an example of which is shown in the bottom graph of Figure 2 (expressed as RPM/msec.). As expected, given that the filtered angular velocity data is mainly constant in this example, the angular acceleration data likewise largely varies around the zero value with significant deviations time-aligned with the corresponding deviations in the filtered velocity data.

Now that we have determined angular acceleration data, processing continues at block [206], where at least two acceleration peaks, including a negative and positive acceleration peak, are detected in the angular acceleration data. This is achieved by inspecting successive, in time, data points of the angular acceleration data and identifying a local most negative angular acceleration data point followed by a local most positive angular acceleration data point, i.e., pairs of locally most negative and most positive angular acceleration data points. Examples of this are illustrated in the bottom graph of Figure 2, in which pairs of such angular acceleration data points are highlighted with dark diamond symbols, e.g., a first pair is identified between about 0 and 750 msec., a second pair is identified centered on 1000 msec., a third pair is identified between about 1500 and 2000 msec., etc. As shown in the bottom graph of Figure 2, the various peak pairings [322-328] corresponding to slippage occurrences may be differentiated from other peak pairings (resulting from remaining noise in the angular acceleration data [320]) in terms of their respective magnitudes. Thus, the determination of peak pairings [322-328] potentially corresponding to a slippage occurrence is refined by identifying such pairings only when a difference between the locally negative peak [322a-328a] and its corresponding locally positive peak [322b-328b] is greater than a difference threshold. An example of this is illustrated in Figure 3, where a local most negative acceleration data point [402] and a corresponding local most positive acceleration data point [404] have a difference, Δ, greater than a pre-defined difference threshold, Δth. By making this difference threshold sufficiently large, the lower-level peak pairings shown in the lower graph of Figure 2 may be effectively filtered out, thereby better minimizing the chances of false-positive detections.

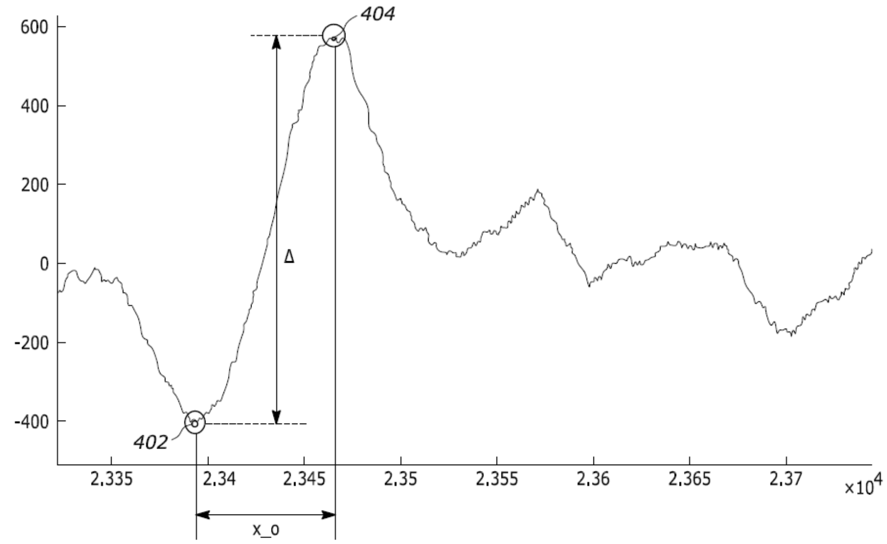

Fig 3. Graph illustrating detection of a slippage occurrence based on acceleration peaks.

Returning once again to Figure 1, having determined at least two acceleration peaks (one negative and one positive) in the available angular acceleration data window, processing continues at block [208], where, for any given negative/positive acceleration peak pair, a determination is made if an interval between the negative acceleration peak and the corresponding positive acceleration peak is less than a set period. Thus, in effect, paired negative and positive acceleration peaks are deemed to indicate a slippage occurrence if they are of sufficient magnitude and within a relatively short period, i.e., if anomalously large and successive negative and positive accelerations are identified within a relatively short period. An example of this is illustrated in Figure 3, where an interval, x_0, is shown between the illustrated negative and positive acceleration peak. If x_0 is less than the pre-defined period threshold, a slippage occurrence is indicated, as shown at block [212] in Figure 1. On the other hand, if a given negative/positive acceleration peaks pair is separated by an interval greater than the pre-defined period threshold, then no slippage occurrence is indicated. Processing continues at block [210] of Figure 1, where it is determined if additional acceleration peak data samples remain to be processed, in which case such additional acceleration peaks are once again processed at block [208]. If no additional acceleration peak data remains in this iteration, processing continues at block [202], where steps [202-208] are repeated based on newly obtained position data samples.

Coupling Slip Fault Notification

Although detection of any given slippage occurrence may indicate a malfunctioning coupling, providing an alert or error signal each time may result in an excessive number of false positives. To counter this possibility, each time a slippage occurrence is detected at block [212] in Figure 1, processing continues at block [214], where a determination is made whether a threshold number of slippage occurrences have been detected within an extended period of time. For example, if three or more slippage occurrences were found to have occurred within a 10-second window, processing continues at block [216], where a coupling error signal is generated. Of course, the specific threshold number and second period may be selected as a matter of design choice. It will often depend on the configuration and expected performance of the given encoder system. As further shown in Figure 1, if a given instance of a slippage occurrence does not give rise to an error signal at block [216], processing will instead continue at block [210] as described above.

Example Encoder with Coupling Slip Detection

The HS35iQ encoder with PulseIQ™ Technology utilizes the principles above to detect coupling slip and other common encoder fault conditions. [Learn more about the HS35iQ encoder here]

Image 1. HS35iQ hollowshaft encoder with PulseIQ™ Technology

Conclusion

Based on the techniques described here, the ability of encoder systems to identify instances of mechanical coupling slippage is facilitated based on the analysis of position data obtained by rotary encoders. By detecting instances of sufficiently anomalous accelerations in such data, reliable error signals may be provided, thus further facilitating systems diagnostic or maintenance work that prevents system damage or downtime.

About Dynapar

Dynapar is an industry leading supplier of encoders, and resolvers. From small kit encoders to large mill-duty tachometers, Dynapar has a strong market presence in a wide range of industries including steel, paper, elevator, oil and gas, aerospace & defense, medical, material handling and industrial servo manufacturing. Dynapar offers a broad array of encoders and resolvers through our well established Dynapar™, Hengstler™, NorthStar™ and Harowe™ brands. Dynapar supports global customers with local sales and production locations in USA, Germany, Slovakia, China, and Brazil.