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Impact of the non-uniform angular sampling on mechanical signals

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ABSTRACT

Angular sampling is a useful tool to study cyclic rotating machine vibrations. It can be implemented by using computer order tracking, directly, or by extracting position information from an acceleration signal. Instantaneous speed can also be angularly sampled using a counter technique. Angular sampling is sensitive to hardware imperfections (optical encoder precision, electrical perturbation, etc.). Angular sampled signal quantification step or sampling frequency determination is not identical to time domain. Angular sampling is also not adapted to study time domain signals like impulse response. Some of these imperfections can be viewed as non-uniform sampling.

Non-uniform sampling consists in introducing a jitter in an angular sampling position. This jitter is random and different for every position. This jitter can be caused physically by some inaccuracies in position sensor measurements. Sampling a time domain relative signal against the angle can also be viewed as a non-uniform sampling. In this case the jitter is caused by speed fluctuation (constant speed case). Non-uniform sampling introduces an additional noise (that can be cyclostationary at order 2 if the original signal is cyclostationary at order 1). Non-uniform sampling also acts as a low pass filter. Its cut-off frequency depends on jitter standard deviation.

An experimental bench was built. This bench uses a synchronous data acquisition board, an arbitrary generator, and a non-uniform clock generator. Experimentations are performed using various jitter values (from 0.1% to 20%) and are corroborated by previous theoretical studies.

1. Introduction

Rotating machines produce cyclic signals. When the machine parameters (load, speed, etc.) are almost constant or slowly vary, the cycle will introduce periodicity into the acceleration (i.e. the acceleration signal shows cyclostationarity). Since the cycle is linked to the angular part, it seems natural to use the angle as a sampling variable instead of time. Therefore, the signal becomes synchronized to the machine cycle. The use of angular (or synchronous) sampling has shown very interesting results [1–5].

Unfortunately, the synchronization with mechanical events obtained by angular sampling cannot be used to study the impulse response associated with these events (or some structural damage). Impulse response sampling in angular domain

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can be viewed as a non-uniform sampling of a time domain signal. Therefore, the choice between angular sampling and classical temporal sampling can be a dilemma. Moreover, a sharp position information is required to sample signals according to the angle. Position sensor imperfection can cause a jitter in sampling angle and introduces a non-uniform sampling.

In the past, the degradation of cyclostationarity properties introduced by the influence of temporal sampling has been studied [6]. The purpose of this paper is to study the influence of angular sampling on mechanical signals.

In a first part, angular sampling and its imperfections are introduced. Next, non-uniform sampling tools are used to take into account some of these imperfections and show the impact on the sampled signal. Finally, some of these imperfection effects are illustrated by experimentation.

2. Angular sampling

Accelerometric signals generated by rotating machinery are often recorded using time based sampling. This kind of sampling is suitable for modal analysis in order to study impulse response that depends on time.

When rotating elements are studied, it is useful to use angular sampling as the number of samples per revolution becomes constant and independent from the speed fluctuation. Angular frequencies (i.e. order) associated with synchronous mechanical events also become constant. This synchronization makes the signal statistics periodic (cyclostationarity) and enables us to take advantage of kinematics and cyclostationary tools for diagnosis [1].

Mechanical structures act as a filter (with an impulse response). This impulse response can be studied to detect structural defects or resonance. It introduces time domain linked expression in equations. Unfortunately, angular sampled signals are no longer synchronous with the time. It means that the sampling frequency varies against the time. Therefore, it could be difficult to study the filtering effect when speed fluctuation is high (variation of the sampling frequencies).

2.1. Principle and examples

According to the hardware, angular sampling can be taken directly or after acquisition by software.

2.1.1. Computer order tracking

Computer order tracking can be used with a classical time domain data acquisition board. The signal(s) of interest (acceleration, etc.) and a position signal are time based sampled.

The next steps (estimation of position from the position signal and interpolation to reconstruct angular domain signal) are generated by a software.

Angular position estimation can be done in different ways.

An optical encoder (Fig. 1) can be used to give indication of angular position. It contains a disk with holes (or lines) 360/*res* degrees apart (where *res* is the resolution in dots). The hole is detected by an optical system (LED and light sensor). This device produces a square shaped signal which corresponds to the passage or the masking of the light. Each rising edge of the square signal corresponds to a displacement of 360/*res* degrees, where *res* is the encoder resolution. The instantaneous period δ_{Ti} between each rising edge is measured.

If the position signal comes from an optical encoder:

- Estimation of the encoder signal pulse time of arrival can be done using a software trigger and an edge detector as shown in Fig. 2. Since the angle between two pulses is known, the angular position against the pulse time can be computed. Missing positions between pulses can be estimated by fitting a second order polynomial (i.e. assuming that there is a constant acceleration) [7].
- An alternative to the previous method is to transform the square wave into a sine wave by filtering around the fundamental frequency. Thanks to the analytic signal it is possible to estimate the sine wave phase that corresponds to the angular position multiplied by the encoder resolution [8].

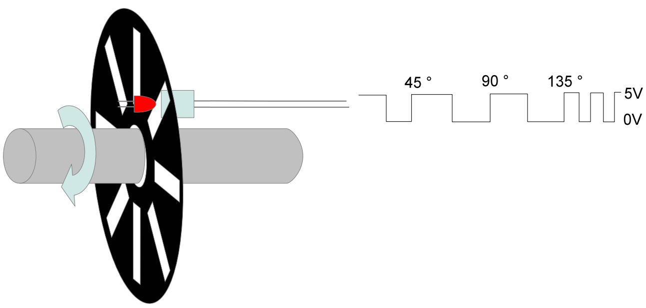

Fig. 1. Optical encoder.