PREDICTION OF SMALL DIAMETER DRILL BIT BREAKAGE USING METRIC ENTROPY

H.E.Sevil, S.Ozdemir
Artificial *İyte*lligence & Design Lab
Mechanical Engineering Department,
İzmir Institute of Technology, 35430 İzmir, Turkey

Tel: +90 (232) 750 6603
Fax: +90 (232) 750 7890

erhansevil@iyte.edu.tr
serhanozdemir@iyte.edu.tr

Abstract

In this study, a series of condition monitoring experiments on drill bits were carried out. Small diameter drill bit run-to-failure test rig was constructed and the prediction tests were performed. In the experiments, 10 small drill bits (1 mm ϕ) were tested until they broke down, while vibration data were consecutively taken in equal time intervals. A consistent decrement in variation of metric entropy just before the breakage was observed. As a result of the experiment results, metric entropy variation could be implemented as an early warning system.

Keywords : Fault prognosis, nonlinear time series analysis, condition monitoring

Introduction

The predictability of time series can be indicated by metric entropy which is a measure of the rate of loss of predictability. Metric entropy (also known as Kolmogorov – Sinai Entropy) obtains that how far the future can be predicted with a given initial information. In [1], Drongelen et al. demonstrated the feasibility of using analysis of the Metric Entropy of the time series to anticipate seizures in pediatric patients with intractable epilepsy. Anticipation times varied between 2 and 40 minutes.

In the condition monitoring field, tool condition monitoring has a great significance in modern manufacturing processes. Also, several techniques on the detection of tool breakage for monitoring the drilling processes have been developed over the past years [2, 3].

This study attempts to correlate the chaos invariants with the changing conditions of a drilling process. Also, prediction of small drill bit breakage was examined by using metric entropy. Briefly, the aim of this study is to introduce a possible early damage detection method for mechanical systems. The computation of the invariants was carried out by various MatLAB codes and *Culpertus*[*], which is a time series analysing program created by the authors.

[*] For further information please visit ***http://www.iyte.edu.tr/~erhansevil/culpertus.htm***

Correlation Dimension

Correlation dimension is a measure of the fractal dimension of the time series, which measures the complexity that quantifies the geometry and shape of strange attractor. The correlation sum is used to estimate the correlation dimension. The correlation sum for a collection of points $\mathbf{s}_n$ in some vector space is the fraction of all possible pairs of points which are closer than a given distance "epsilon" (ε) in a particular norm.

The correlation sum of a time series is computed by;

$$C(\varepsilon) = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} H(\varepsilon - \|\mathbf{s}_i - \mathbf{s}_j\|)$$

The correlation sum just counts the pairs ($\mathbf{s}_i$ $\mathbf{s}_j$) whose distance is smaller than ε. In the limit of an infinite amount of data ($N \rightarrow \infty$) and for small ε, it is expected that C to scale like a power law;

$$C(\varepsilon) \; \alpha \; \varepsilon^D$$

According to this power law property a dimension value D, where based on the behavior of a correlation sum, can be defined. This dimension is called *correlation dimension* and it's a characteristic quantity for time series.

$$D(\varepsilon) = \lim_{\varepsilon \to 0} \lim_{N \to \infty} \frac{\log C(N, \varepsilon)}{\log \varepsilon}$$

Metric Entropy (Kolmogorov – Sinai Entropy)

The metric (Kolmogorov – Sinai) entropy is a kind of measure to characterize chaotic motion of a system in an arbitrary-dimensional phase space. The metric entropy is proportional with the rate of loss of information at the current state of a dynamical system in the course of time. Meanwhile, metric entropy is a measure of the rate of the loss of predictability. Metric entropy originate from information theory. If the observation of a system is considered as a source of information with a stream of numbers, then the information theory can supply quantitive answer to how much info can be possessed about the future when entire past have been observed. Metric entropy has units of inverse time (for continuous systems) or inverse iteration (for discerete systems). The metric entropy of a time series is;

$$K = \lim_{m \to \infty} \lim_{\varepsilon \to 0} \log \frac{C(m, \varepsilon)}{C(m+1, \varepsilon)}$$

Drill Bit Breakage Test Rig & Data Analysis

The experimental setup for prediction of small drill bit (1mm ø) breakage is shown in Figure 1. The test rig comprises PCB (printed circuit board) drill, drill stand, drill bit, scale weight, accelerometer, power supply/coupler and a personal computer.

The 4 Channel Piezoelectric Sensor Power Supply/Coupler (Kistler 5134A1E) provides constant current excitation required by accelerometers and decouples the DC bias voltage from the output signal. Ceramic Shear triaxial accelerometer (Kistler 8762A50) measures vibration simultaneously in three axis with high sensitivity.

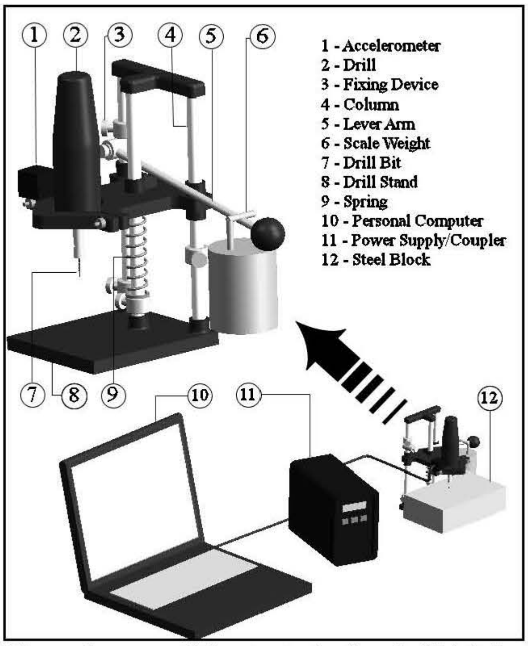

Fig.1. The schema of the test rig for drill bit breakage

Drill bit breakage tests were performed by drilling the steel block with 1mm ø drill bits. Drill bits were mounted to the drill, while the drill was fixed to the drill stand with same height and plunge depth arrangement repetitively. The signals were firstly passed though coupler which was set with low-pass filter (cut-off frequency: 30 kHz), and the signals were sent to a computer. Analog signals were converted to digital data by sound card of the computer, and the vibration data was stored using Virtins software with 192 KHz sampling rate.

With 500 grams scale weight, it is calculated that approximately 20N force is applied to the drill downwards as feeding. So that, with this experiment adjustment, 1 mm drill bits can have a life which vary between 5 and 10 minutes.

The vibration data of the setup was taken in every minute until the bit was broken down. All the measurements were 0.1 seconds long which equals to 19200 samples in each measurement. This sample number allows correctly representing the systems which have attractor dimension equals to 6, according to Nyquist Sampling Rate Theorem.

Results & Conclusions

The time series of the drill bit breakage prediction experiment were firstly tested for nonlinearity with surrogate data method. After the computation period, the variations of metric entropy were computed. In 7 of 10 drill bits' variation of metric entropy, just one time step before the bit breakage, there is an obvious decrement, while in other situations metric entropy nearly remains constant (Figure 2). Owing to metric entropy extraction which is equal to the average value of the plateau where the all dimensions converge in metric entropy graph, a 5% error margin is indicated in variation of metric entropy.

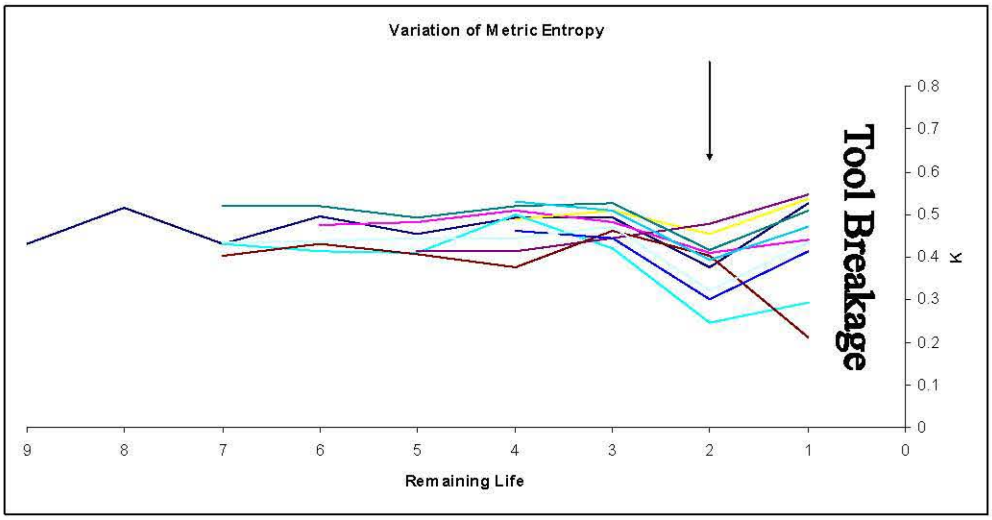

Fig.2. The metric entropy variations of all 10 drill bits.

In this study, the prediction of small drill bit breakage by metric entropy was attempted. The experimental results showed that there is a consistent decrement in metric entropy just before the tool breakage. Although the lifetime of the drill bits varies, which is thought to be caused by material characteristics and process uncertainties, the results are consistent for a new prognosis technique for mechanical systems.

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