Spur Gear Failure Detection using Support Vector Machine

Richard Siregar¹, Ikhwansyah Isranuri¹, Suherman¹

¹Faculty of Engineering, Universitas Sumatera Utara, Medan, Indonesia

E-mail: suherman@usu.ac.id

Abstract. Torsional vibration generated by the spur gear as result the imperfection may generate geometrical error that can lead to spur failure. In order to prevent error propagation, preventive maintenance by detecting and analyzing vibration should be performed. Existing work has been dealt with torsional vibration detection either using tools and/or employing intelligent system. This paper proposed evaluation prototype with support vector machine to differentiate normal and broken spur gears. The assessment results show that gear states were easily determined by using some features. The accuracy achieves 100% in several trials with average accuracy 99.35%.

1. Introduction

Mechanical energy is converted into work and avoided to generate vibration as vibration is wasted energy and an imperfection sign [1]. Vibration indicates element mismatch that may cause deforming mechanical properties.

Gear is used to transmit power and torque in compact and simple design but is able to receive high capacity load with small slip factor. Gear is made of solid material that has unchangeable shape. Spur gear is the easiest machining gear used for parallel transmission. This gear is suitable for high torsional force as it does not exert axial force [2]. Figure 1 shows Spur gear design with some specifications such as pitch circle, pinion, pitch circle diameter, pitch diametral, circular pitch, module, addendum, dedendum, working depth, clearance circle, pitch point, operating pitch circle, addendum circled, dedendum circle, width of space, pressure angle, total depth, face width, tooth space, backlash, face of tooth, flank of tooth, and top land.

Figure 1. Spur gear specifications
Torsional vibration is wasted energy in angular direction that is typically a shaft along of rotation axis. Torsional vibration is measured as the variation of rotational speed such as revolutions-per-minute (RPM). Its vibration level is affected by some parameters, such as material properties, temperature, load, and others [3]. Torsional vibration may induce high cycle vibration fatigue that generally occurred sporadically or a transient phenomenon that is caused by for instance, sudden load changes. The resonances may result high stress of the surrounding object [4]. Torsional vibration can be used for locating failure as part of predictive maintenance [5].

Spur gear torsion vibrations may result spacing and pitch error as part of geometrical failure. These errors can be detected as an emerged of additional frequency in vibration spectrum [6]. The appearance of this frequency can be analyzed by using sideband frequency analysis [7], by diagnostic tools [8], signal analysis such as Fourier transform [9, 10], statistical analysis [11] and by employing intelligent system [12, 13].

This paper analyses spur gear failure by using support vector machine. One of the order strategies that gets a ton of consideration as cutting edge in design characterization is the Support Vector Machine (SVM) [16]. Support vector machine (SVM) is able to classify states based on features extracted from prerecorded/supervised events. SVM is a cutting edge characterization technique for a parallel order [17]. SVM classifier has been used by many researchers to diagnose spur gear, such as [14] that combined SVM and neural network, and [15] used histogram features. This paper proposed spur gear failure detection by combining laser vibration detection and support vector machine.

2. Experiment design

The bearing evaluated in this paper is NTN UCP 204 D1, with specifications plotted in Table 1. Bearings were tested under conditions of new and damage. The bearings were examined for rotation speed of 400 to 1200 rpm, outer race damage, inner race damage, rolling element damage, and cage damage. This paper examines spur gear failure by analyzing torsional vibration, varying speed and adjusting axial deviation. A prototype is built as the experimental tool as show in Figure 2.

Table is 500x500x500 mm, with two 20 mm diameter and length of 300 mm and 500 mm poles placed on top. Four pillow blocks NTN UCP 204 is fitted with mild steel holders; two spur gears of 33 and 2.5 is attached and varied at the poles. A 60 mm type-A V-pulleys and a V-belt A39 coupled a 3-phase, 1380 rpm, 0.75 kW LM-Motor to the evaluated mechanic. One HP 3 phase inverter acted as power source. Four condition spur gears were assessed (Figure 3).
Spur gear vibrations were assessed by using a laser sensor connected to a computer by labjack interface to convert analog data into digital readable form. Experiment set up is shown in Figure 4.

3. Evaluation results

Figure 5 shows the samples of time domain vibrations for both normal and broken gear. Signal is distinguishable, where broken part causes signal amplification in some parts. In order to analysis the states of the gear using SVM, features are extracted from data by using mean (µ), root mean square (RMS), skewness (γ), kurtosis (K), beta kurtosis (BK), velocity (v), angle speed (ω), and rpm (n).
Figure 5. Normal and broken gear vibrations

\[ \mu_j = \frac{1}{n} \sum_{i=1}^{n} x_{ij} \]  (1)

\[ \text{RMS} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x^2(t)} \]  (2)

\[ y = \frac{E(x - \mu)^3}{\sigma^3} \]  (3)

\[ K = \frac{M_{ij}}{\sigma^4} \]  (4)

\[ BK = \frac{m_x}{(\sigma^2)^2} \]  (5)

\[ X = \int \dot{X}(t) = A \sin \omega t \]  (6)

\[ \ddot{X} = \frac{d\dot{X}}{dt} \]  (7)

\[ \omega = 2\pi n/60 \]  (8)

The SVM easily predicts the states of gears with accuracy 100% dominate the trials (Figure 6). The first 6 trials convincingly decide that the gear is broken. The selected features are not sufficient to differentiate the types of failure which requires multiclass SVM. The average accuracy is about 99.35%.

Figure 6. Broken gear prediction
4. Conclusions
This paper has discussed the use of laser sensor and SVM to determine the states of the gear within the evaluated mechanic. Vibrometer along with labjack is successfully recording the torsional vibrations. The SVM is able to determine gear failure with 99.35% accuracy. The highest accuracy is 100% for the first six trials and the lowest accuracy is 99.30%. The lower accuracy occurred at the last trials as it may be affected by the precision decrement of the employed sensor due to minor replacement.

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