V-belt Tension Reduction Diagnostic Method By Using Multi-Frequency Current Power Spectrum Density

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Abstract

Motors are used in many factories and need stable operation. A V-belt is a device that transmits motor power to a load, and its tension decreases with prolonged use, which degrades the motor efficiency and causes such abnormalities as wear and cracks. The timing of belt replacement when the belt tension decreases is presently determined by regular inspections. An automatic diagnosis of belt-tension decrease is required to lower labor costs. One automatic diagnosis method applies FFT analysis to the phase current that is applied to the motor and focuses on the signal intensity at a specific frequency. Since this method can only detect belt tension after it has progressed, early detection is necessary. Our new method using motor phase current enabled early detection of belt-tension decrease.

Definitions of characters

f: frequency of side-band peaks caused by belt anomalies

f_b: belt rotation frequency

r_m: pulley diameter on motor side

l_b: belt length

f_s: current source frequency

s: slip

p: number of poles

n: harmonic order (natural number)

m: harmonic order (an integer containing negative numbers)

I_{m_normal}: signal intensity at $f_s + mf_b$ of current power spectrum density under normal tension

$I_{m\_abnormal}$: signal intensity at $f_s + mf_b$ of current power spectrum density under abnormal tension

$I_{\_abs\_diff\_sum}$: total difference absolute value in signal intensity of current power spectrum density between normal and abnormal tension

$I_{m\_abs\_diff}$: differential absolute value in signal intensity of current power spectrum density between normal and abnormal tension on $f_s + mf_b$

1. Abstract

As a power source for mechanical equipment in factories and water and sewage plants, motors drive various load equipment (Kanemaru, Tsuki, Miyauchi, & Hayashi, 2017). In some cases, motors and loads are connected by belts.

When V-belts are used for some months, the tension decreases due to fatigue, causing such abnormalities as wear and crack of the belt (Ueda, Kagotani, Koyama, & Nishioka, 1995). Belt tension is regularly checked by visual inspection and automatic diagnosis is required to reduce inspection resources (Toyoda, 1991).

One automatic motor diagnostic method uses a motor phase current (Schoen, Habetler, Kamran, , & Bartfield, 1995). This diagnostic technique can be applied simply by connecting the current sensor to a power cable in the distribution board, an approach that is both feasible and inexpensive. However, diagnostic method for V-belt tension by using motor phase current has not been established.

In this study, we proposed a method that automatically determines V-belt tension.

2. Testing Equipment

2.1. Test equipment details

We made test equipment to obtain the motor phase current when the load torque and belt tension were arbitrarily changed. A scheme of the test equipment is shown in Fig. 1. The test motor is a standard three-phase induction motor with

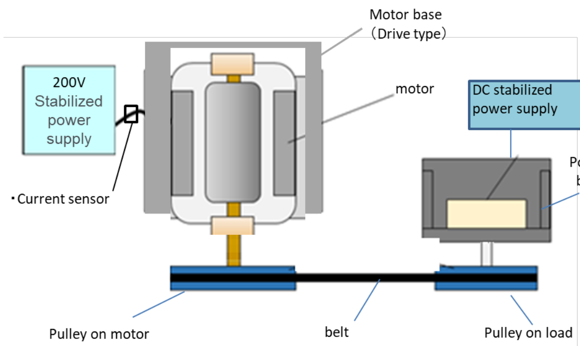

Fig. 1 Scheme of the test equipment

Table. 1 Five load tension patterns measured

9 %	31 %	49 %	79 %	100 % (proper tension)

Table. 2 Six load torque patterns measured

0.0 Nm	1.0 Nm	1.3 Nm	2.0 Nm	2.8 Nm	3.8 Nm (0.9 times the rated load)

a rated output of 0.75 kW and a 4-pole model. The motor was lined up in parallel with the powder brake and connected by a V-belt. V-belt length is 1219.2 mm. Motor slip is 0 ~ 0.03 and motor slip increases with load torque increase.

The motor was placed on a motor base that can be driven horizontally, and the V-belt tension can be adjusted by changing the motor position; the load torque can be adjusted by a powder brake.

The motor side pulley is 88.9 mm in radius, and the powder brake side pulley is 76.2 mm in radius. The motor is driven by a stabilized power supply of 200 V and 60 Hz. A current sensor is connected to a three-phase power line (u-, v-, and w-phases) that is connected to the motor to acquire the phase current.

The tension was varied from 7 to 100% (proper tension) in five patterns. For each tension, the load torque was varied from no load to 90% of the rated load (nearly rated load): 3.8 Nm in six patterns. The measured load is listed in Table. 1.

The sampling frequency of the current measurement was 10 kHz, and the measurement time was 60 s.

3. Current Power Spectrum Analysis

3.1. Current power spectrum analysis results

One method, which detects abnormal belt tension with a motor phase current, uses current power spectrum analysis (Kang, Yang, Park, Hyun, Lee, and Teska 2018; Fournier, Picot, Régnier, Andrieux, Saint-Michel, and Maussion, 2015; Picot, Fournier, Régnier, Yamdeu, Andréjak, and Maussion, 2017; Sumoto, Liu, Matsumoto, Fang, and Shinohara, 2022).

When a belt tension abnormality occurs, the sideband peak on the current source frequency increases:

$$f = f_s \pm n f_b \tag{1}$$

$$f_b = \frac{2\pi r_m f_m}{l_b} \tag{2}$$

$$f_m = \frac{2(1-s)f_s}{p}. \tag{3}$$

The frequency of side-band peaks(f_b) caused by the belt abnormality is calculated in Eqs. (1) ~ (3) (Kang, Yang, Park, Hyun, Lee, and Teska 2018; Fournier, Picot, Régnier, Andrieux, Saint-Michel, and Maussion, 2015; Picot, Fournier, Régnier, Yamdeu, Andréjak, and Maussion, 2017; Sumoto, Liu, Matsumoto, Fang, and Shinohara, 2022). The value of f_b is 13.3 ~13.7 Hz calculated by inputting the value of the test equipment.

Fig. 2 shows the current power spectrum analysis results of the motor phase current at no load, and Fig. 3 shows the results at 90% of the rated load.

Fig. 2 shows that the signal intensity on $f_s \pm 2f_b$ decreases when the tension changes from 100% to 79%, and the signal intensity on $f_s \pm 3f_b$ increases when the tension changes from 100% to 49%. Fig. 3 shows that on the nearly rated load, the signal intensity on $f_s \pm 2f_b$ is barely changed by the tension, and the signal intensity on $f_s \pm 3f_b$ increases when the tension changes from 100% to 79%.

These results indicate that a harmonic order with high influence differs depending on the applied load torque when the belt tension is decreased.

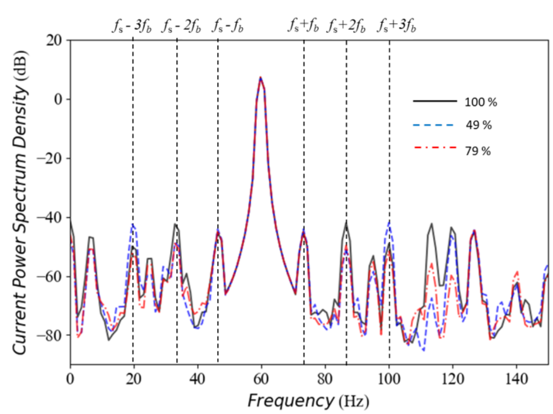

Fig. 2 Current power spectrum analysis results

at no load

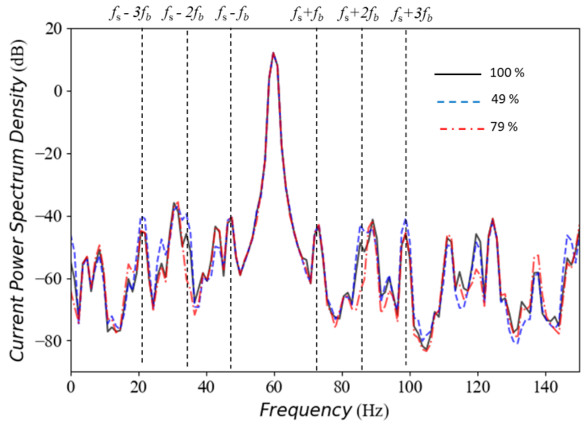

Fig. 3 Current power spectrum analysis results at nearly rated load

3.2. Tension dependence in the signal intensity of current power spectrum density at frequencies caused by belt abnormalities

Next we confirmed the tension dependence in the signal intensity at the frequency caused by the belt abnormal.

Among the side-band peak caused by the belt abnormal, Fig. 4 shows the signal intensity on the $f_s - f_b$ component: I_{-1} and the proper tension ratio dependence in each load torque. Fig. 5 shows the signal intensity on the $f_s - 2f_b$ component: I_{-2} and the proper tension ratio dependence in each load torque.

As shown in Fig. 4, the signal intensity of I_{-1} increases at 7 % of proper tension ratio or less, except for *Torque* = 1.3 Nm. From these results, when diagnosing abnormalities by using I_{-1} as an index, it is detectable in fewer than 10% of cases. However, 7 % of proper tension ratio is a condition where almost no tension is transmitted, which is insufficient for detection accuracy.

Also shown in Fig. 5 , I_{-2} exhibits an increasing signal intensity trend from 31 % of proper tension ratio tension at *Torque* = 1.0 Nm and 49% tension at 2.8 Nm, which is more accurate than I_{-1}, although no change was observed from normal at the other load torques. Therefore, the diagnosis using I_{-2} is only useful in some load conditions.

The accuracy varies with the load torque shown in Fig. 2 and Fig. 3, because the harmonic order of influence when the belt tension is lowered depends on the load torque.

Therefore, when making a diagnosis that focuses on a specific frequency, we must select a frequency of the proper order of each load torque.

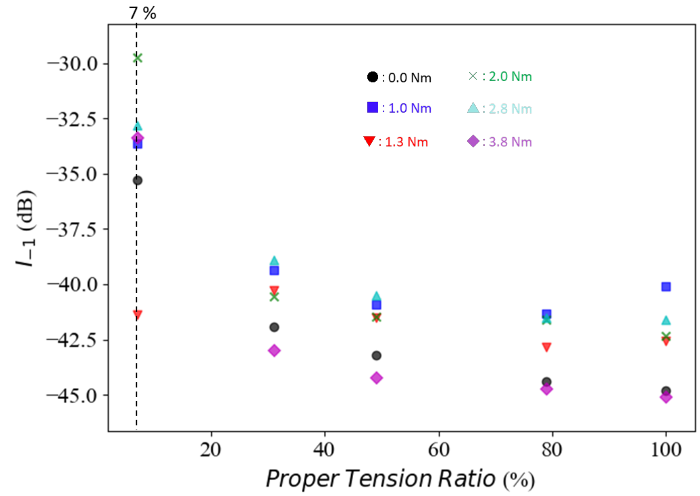

Fig. 4 I_{-1} and proper tension ratio dependence

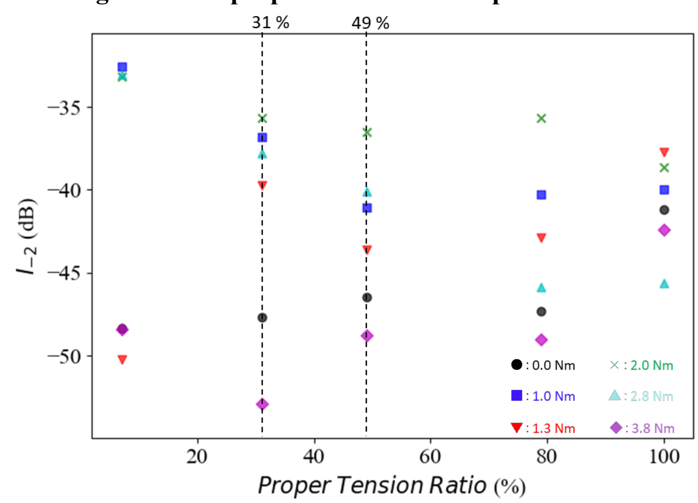

Fig. 5 I_{-2} and proper tension ratio dependence

4. V-Belt Tension Reduction Diagnostic Method

4.1. Proposed method

We proposed a diagnosis method based on feature parameters calculated using signal intensity at multiple belt rotation frequencies.

We calculated feature parameters $I_{m\_abs\_diff}$ by using the absolute value of the difference between the normal and abnormal signal intensities, as in Eq. (4):

$$I_{m\_abs\_diff} = \left| I_{m\_normal} - I_{m\_abnormal} \right| \tag{4}$$

The feature parameters are calculated by summing the first to third order components for both the upper and lower sides, as in Eq. (5):

$$I_{abs\_diff\_sum} = \sum_{m=-3}^{-1} I_{m\_abs\_diff} + \sum_{m=1}^{3} I_{m\_abs\_diff} \quad (5)$$

The belt tension decrease is diagnosed by using $I_{diff\_abs\_sum}$. As shown in Fig. 2 and Fig. 3 , the frequency order with the greatest influence differs for each load torque. In proposed method, the frequency with the greatest influence can be selected without omission under any load condition by summing all the frequency orders.

The method was applied to the acquired data to verify its accuracy.

4.2. Results with proposed method

$I_{\mathrm{diff\_abs\_sum}}$ and the proper tension ratio dependence in each load torque is shown in Fig. 6 . When feature parameters are used, they tend to increase as the proper tension ratio decreases in either load, and there is a positive correlation between the increase in the feature parameters and the proper tension ratio except 31 % of proper tension ratio at *Torque* = 1.3 Nm. And, under each loading conditions, at 79% of proper tension ratio, the feature value shows at least 6 dB and tension anomalies can be detected. This tension ratio value is higher than that of the method using single frequency I_{-1} and I_{-2}, which enables early detection.

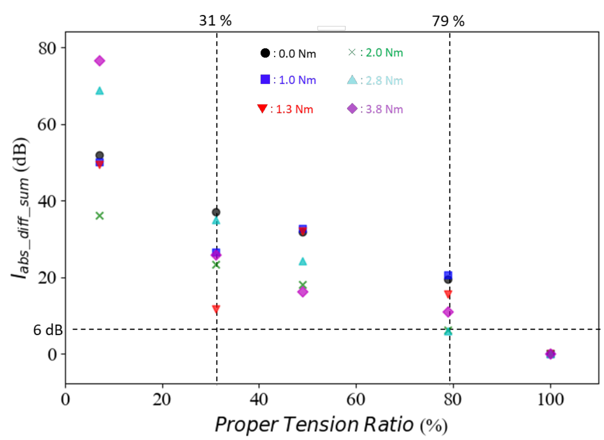

Fig. 6 $I_{\mathrm{abs\_diff\_sum}}$ and proper tension ratio dependence

5. Conclusion

We proposed a method that uses the sum of absolute difference values from normal as a feature parameter for anomaly diagnosis with respect to the signal intensity of multiple feature frequencies.

We applied this method to five tension patterns and six load torque conditions, belt tension patterns can be detected from 79% of proper tension ratio tension at any load conditions. This detectable proper tension ratio is higher than the value using single frequency value. Early detection is possible by using this method.

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