Observed Case / Control	Lateral Vibration Control in Belt Drive System	Transportation machinery

Object Machine

Test apparatus on crawler undercarriage (Fig.1)

Observed Phenomena

During high speed operation of a test apparatus placed on the crawler undercarriage, vibration occurred on the crawler (belt), thus making high speed operation unavailable. In some cases, the vibration amplitude grew up to a size equal to the pulley radius due to resonance of the 1st mode string vibration (Fig.2). Fig.3 illustrates a Campbell diagram representing the relationship between the resulting vibration frequency and the magnitude of amplitude (diameter of circles) versus crawler traveling speed. The vibration components of the belt pass frequency (the rotational frequency of belt joint) and the multiples were problematic.

Cause Presumed

In order to gain a basic understanding of how to ensure vibration control of this kind of belt vibration, a simplified belt drive unit (Fig.4) was fabricated to examine the control method in a basic experiment. The right hand side of this belt drive unit was the motor drive side and the left hand side the driven pulley side. Belt tension was to be adjusted by pressing the left side pulley, while belt vibration was measured using a laser displacement sensor.
Fig.5 is a Campbell diagram under non-control. It can be observed that the 1st order of the pulley rotational speed and the excitation force of belt pass frequency and the belt 1st order natural frequency resonated. Since the pulley rotor had a large eccentricity, the problem was in the resonance (the biggest circle) of 1st order of the pulley rotation speed (1X), so that vibration control was applied to this vibration.

Analysis and Data Processing

As the pulley rotor had a large eccentricity ε, it was assumed that the string was vibrating. Then, a vibration control system was considered where an excitation input was applied so as to adjust the tension by changing the motor driving force. The corresponding equation of motion is given by the Mathieu equation:

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2\,[1 + h\cos(\nu t + \alpha)]\,x = \varepsilon\omega^2\cos\,\omega t \qquad \text{………………(1)}$$

where:
ζ = damping ratio, ω_n = natural frequency, h = tension variation, ν = excitation frequency due to tension control, α = excitation phase due to tension controln, ε = pulley rotor eccentricity, ω = rotational speed of pulley, and g = gravity

Assuming that control would be applied when in resonance, and by setting the control excitation input under the following conditions

$$\omega_n = \omega = \nu,\ h = \varepsilon\omega^2/g,\ \alpha = 0 \qquad \text{………………(2)}$$

It is possible to cancel the pulley rotor eccentricity excitation. As the total compelling force (the sum of rotor eccentricity excitation and the tension control force) will be zero, vibrations will be reduced, which is of the same principle as the cancellation of balance for reduction of vibration due to rotor unbalance.

In order to implement such a control, a circuit illustrated in Fig.6 was introduced, where COS signal in synchronization with the pulley rotation was generated in response to a rotating pulse signal from the pulley. Then, the sum of this control signal and a motor speed command voltage was used as a command voltage for the DC servomotor. In this way, speed variations of the drive pulley were introduced to the driving motor, resulting in tension control.

Countermeasures and Results

In fact, the magnitude of tension control "h" and the phase angle "α" were manually operated to attain optimal values, as shown in Fig.7. Vibrations before applying a control input were drawn in a polar diagram, and then manual operation was made so as to allow the effect vector to move toward the origin by a control input. We see the optimal phase of -20° in the figure. Fig.8 indicates the vibration waveforms with control and without control, which shows that resonance vibrations are attenuated.

Fig.9 is a Campbell diagram under the tension control. The 1st order resonance vibration of the belt that was large before control (Fig.5) has undoubtedly been decreased under control (Fig.9). Still, however, the resonance vibration of a belt pass frequency still remains.

The vibration control system, wherein the rotational pulse of a resonance frequency were generated to form COS waves in synchronization with the rotation, which were added and input into the DC servomotor so as to vary tension. It has been found effective by basic experiment of this belt drive unit of Fig.4. Thus, it is planned to take a permanent countermeasure by generating pulses of the pulley rotation speed and also pulses with a frequency of the belt pass frequency for the test apparatus placed on the undercarriage.

Lesson Learned

The "v-BASE data No.94-1-16" on the procedure to cancel the compelling force of torsional control was instrumental, wherein torque variations were input from an auxiliary motor in accordance with engine torque variations so as to reduce idling vibrations of an automobile. Depending on your perspective, all the vibration controls should follow the principle "vibrations shall be controlled by vibration inputs", the effectiveness of which has been recognized. The control system utilizing gravity is ineffective for a belt running in the vertical direction is useless, thus requiring an alternative.

References

The v-BASE data No.94-1-16 "Reduction of Automobile Idling Vibrations by Torque Control of Electric Auxiliary", D&D '94 (No.940-26), Akita-City (July 12, 1994)

Keyword

Belt, crawler, string, lateral vibration, motor torque control, Mathieu equation, gravity

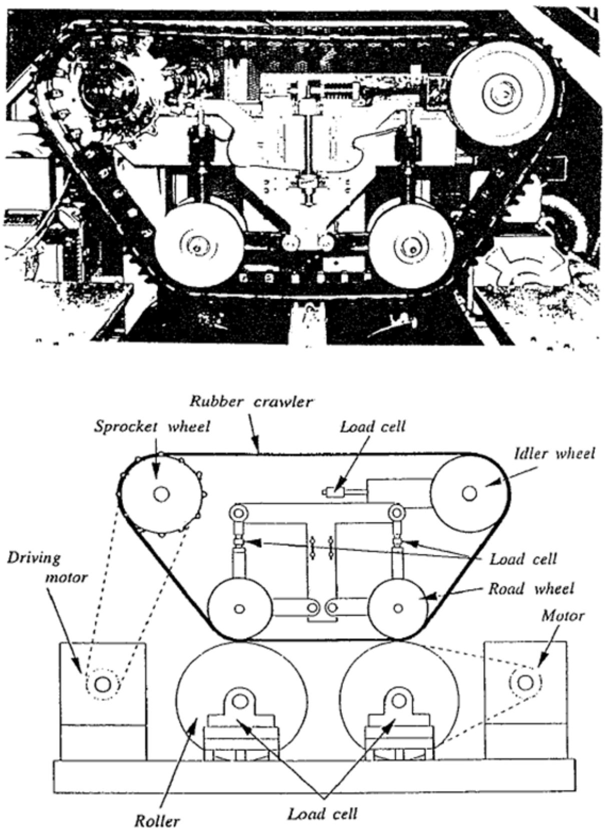
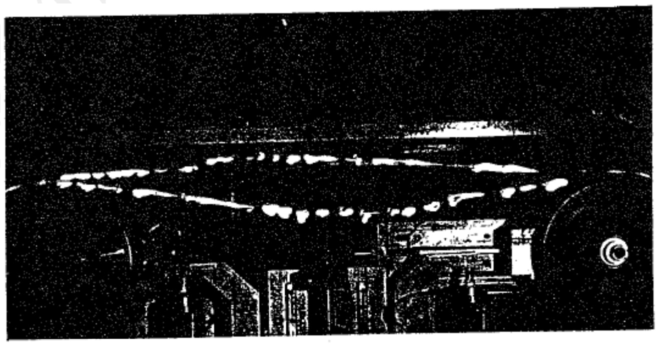
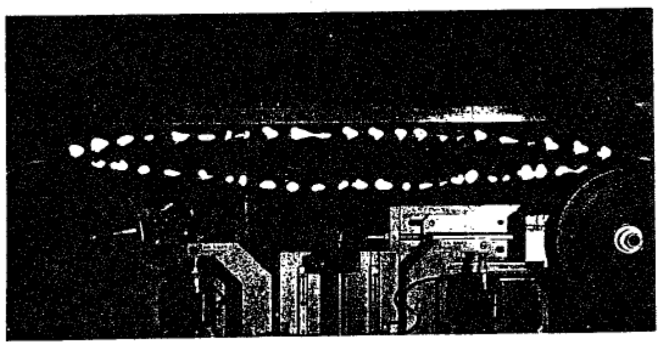


Fig.1: Test apparatus on crawler undercarriage



(a) For crawler track velocity $V_t = 6.0$ m/s



(b) For crawler track velocity $V_t = 8.0$ m/s

Fig.2: Resonance vibration mode of crawler

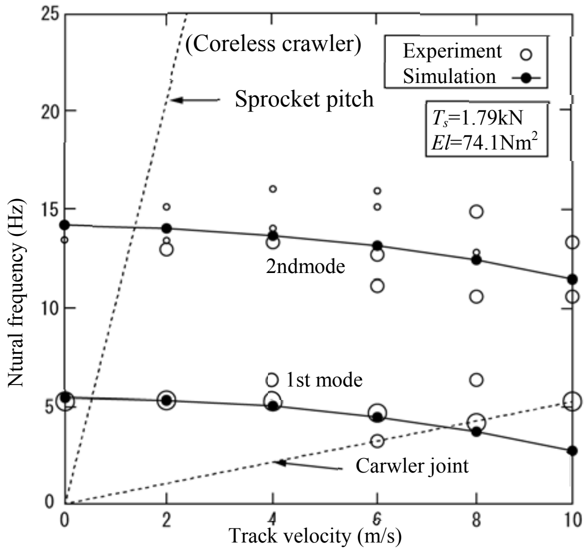


Fig.3: Campbell diagram of crawler vibration

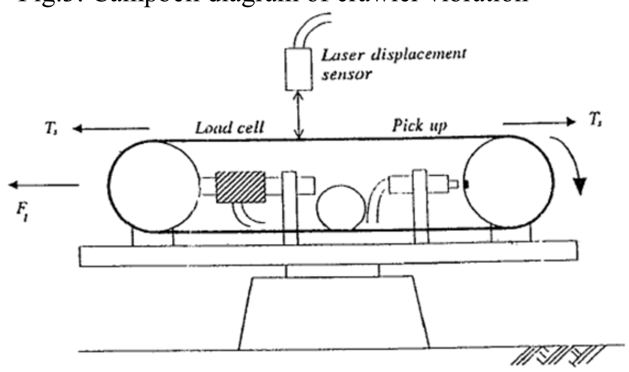


Fig.4: Belt drive unit

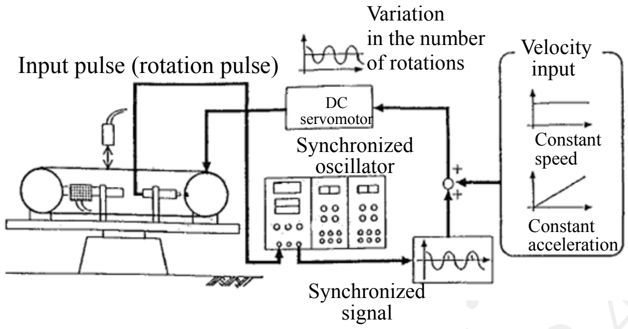


Fig.6: Control system

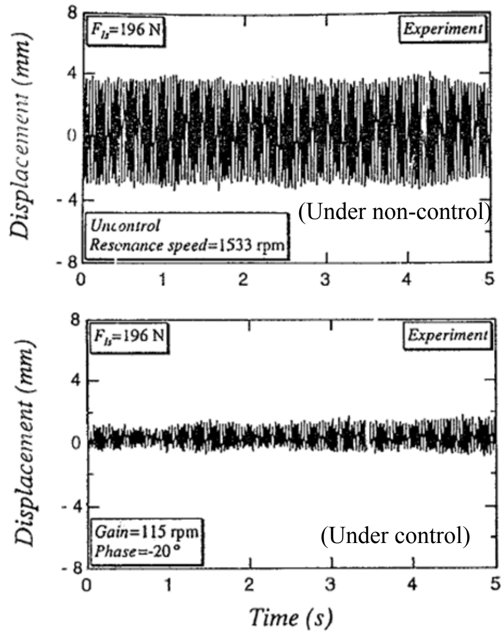


Fig.8: Waveforms of belt resonance vibration

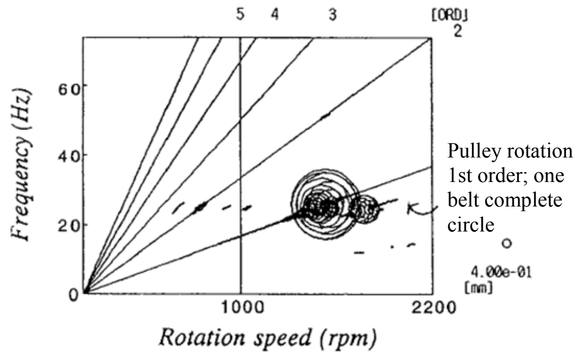


Fig.5: Campbell diagram of belt (under non-control)

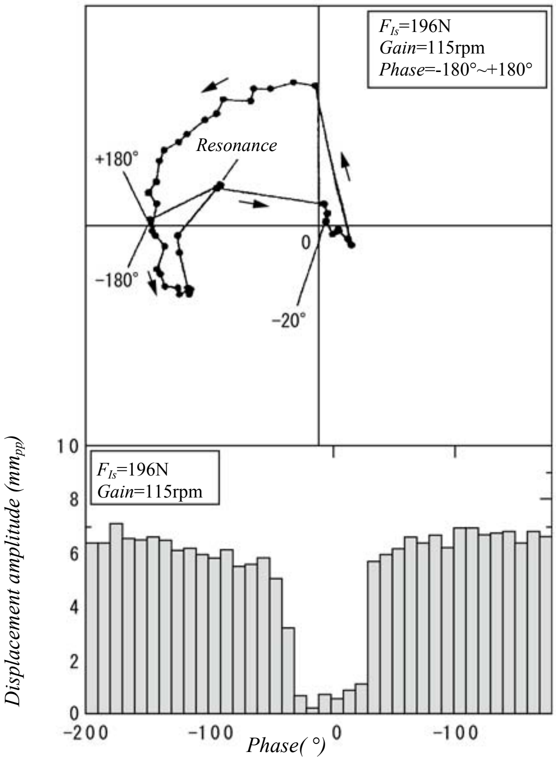


Fig.7: Manual operation of excitation input

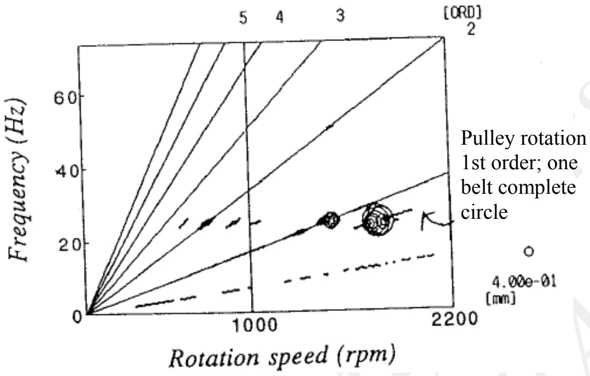


Fig.9: Campbell diagram of belt (under control)