Vibration	Countermeasures against Resonance of Torsional Vibration System of CVT Belt Testing Equipment	Rotating Machinery
Resonance		

Object Machine

Continuously variable transmission (CVT) belt testing equipment (outline: Fig.1 (a), photograph: Fig.1 (b)): testing equipment to evaluate the durability performance by rotating a CVT belt under a test condition of a constant speed (Ω_1) and constant load torque (TM1) (target: Ω_1 = max 58.3rps, TM1 = max 180Nm). By measuring Ω_1, ASR (automatic speed regulation) is performed through INV1/M1 (inverter 1/motor 1). And also by measuring TM1, ATR (automatic torque regulation) is performed through INV2/M2. In this experiment, ASR was performed with a feedback control (r1), while ATR was performed according to a torque command (r2) without a feedback control.

Observed Phenomena

In this test conditions, the rotational speed Ω_1 was kept ~~set~~ at a constant speed 58.3rps, while the maximum load condition was targeted by 200Nm, and the load was gradually increased up to this targeted value. This equipment had experienced excessive vibrations at TM1 = 145Nm of Fig.2, as already indicated in D&D 2017 ***v_BASE*** ,No.14. As the countermeasure, a dynamic damper (DM1) was attached to the input shaft as shown with the result given in Fig.3. This solution allowed that the operation was possible up to TM1 = 180Nm. On the other hand, however, it caused the similar excessive vibration problem on the output shaft (TM2). The same solution was attempted for the output shaft.

Cause Estimation

As indicated in Fig.4, a frequency analysis revealed that the problem occurred at 177Hz, and it was also clarified that this frequency slightly decreased with an increasing load, as shown in Fig.5. Thus, it has been identified that the frequency of power spectrum during test decreased, and as shown with doted lines in the above figure, when the natural frequency of the output shaft became three times the input shaft number of revolutions, that is, under a condition $\omega_2 = 3\Omega_1$ (= 3 × 58.3rps = 174.9Hz), oscillations hardly occurred.

Countermeasures and Results

In order to avoid the frequency condition ω_2 =175Hz =$3\Omega_1$, a dynamic damper 2 (DM2, Fig.6) that was tuned to a frequency equal to the major component ω_2 = 175Hz was fabricated and assembled into a position near the output shaft CVT belt (bottom of Fig.7). The shaft natural frequency after assembly was dispersed into {145～225} as successfully shown in Fig.8 ~~shows~~ the operation result. As a component ω_1 = 175Hz disappeared, operation was made possible up to the targeted torque of TM1 = 210Nm.

Lesson

Regarding this equipment, the following two feedbacks ~~reflections~~ can be pointed out:

(1) Initially, we thought that excessive vibrations occur when the difference between the single shaft system natural frequency of the input shaft and the output shaft (ω_1 - ω_2 = 198 - 175Hz) matches the number of revolutions of the output shaft Ω_2. Thus, it was intended to break up this relationship by modifying ω_1 - ω_2 of both shafts, but because of the equipment restrictions, ω_1 and ω_2 could not be changed adequately. As a result, this condition was avoided by the addition of DM1. The shaft system was originally designed to allow the easy occurrence of this condition, "ω_1 - ω_2", which should have been reflected.

(2) As mentioned in this Report, the problem this time was that resonance was liable to occur when the natural frequency of the output shaft ω_2 became nearly three times the input shaft number of revolutions Ω_1 ($\omega_2 = 3 \times \Omega_1$), thus DM2 was added. At the initial stage of addition of DM1, the necessity of DM2 should also have been considered automatically to fix it on the output shaft.

References

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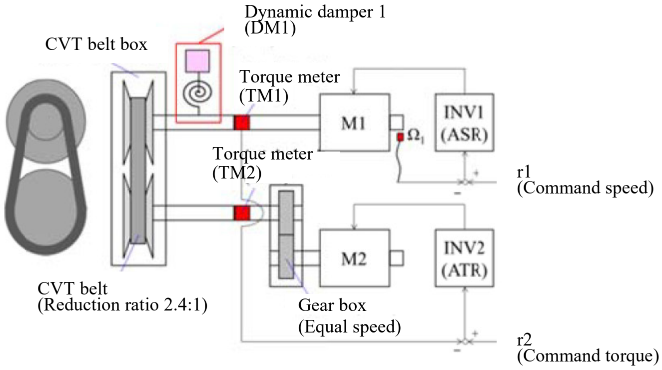
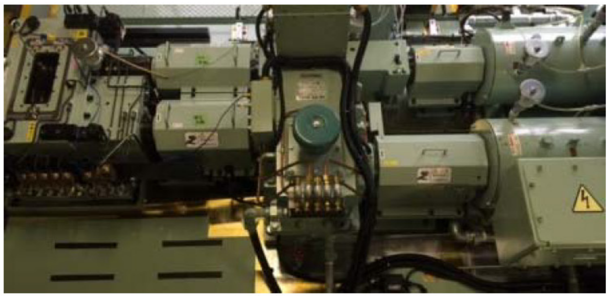
(2) MATSUSHITA Osami et al., "Vibration of rotating machinery (Basis of practical vibration analysis), Corona Publishing (2009.10)
(3) MIYAKAWA Keisuke, KAMIYA Hideaki, MATSUSHITA Osami, "Torsional vibration measures of CVT belt testing equipment using a dynamic vibration absorber", Transaction of the Japan Society of Mechanical Engineers, Dynamic & Design Conference 2017 (2017) No.109

Keywords

Torsional inherent vibration, self-excited vibration, dynamic vibration absorber, parametric excitation, CVT belt testing equipment



(a) System configuration



(b) Photograph

Fig.1 CVT belt testing equipment

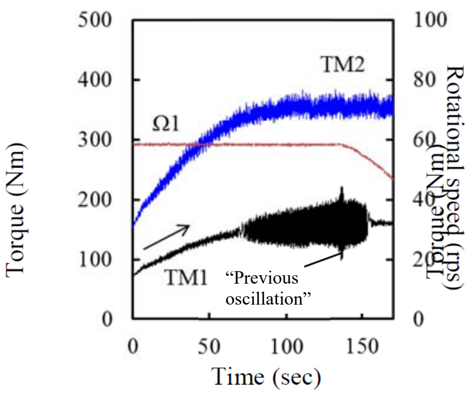


Fig.2 Temporal shaft vibration (without DM)

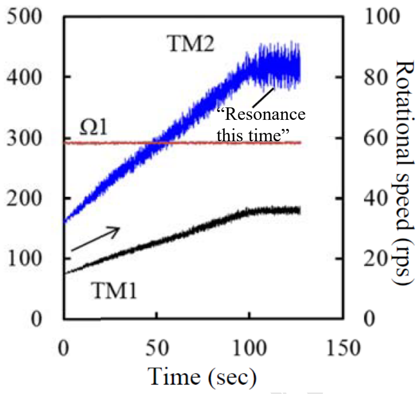


Fig.3 Temporal shaft vibration (DM1 installed)

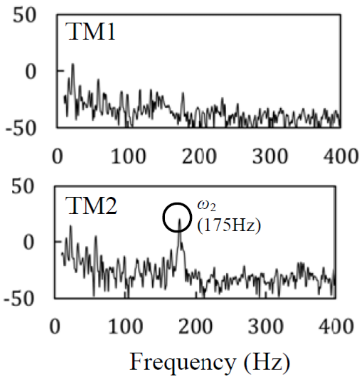


Fig.4 TM1/TM2 FFT

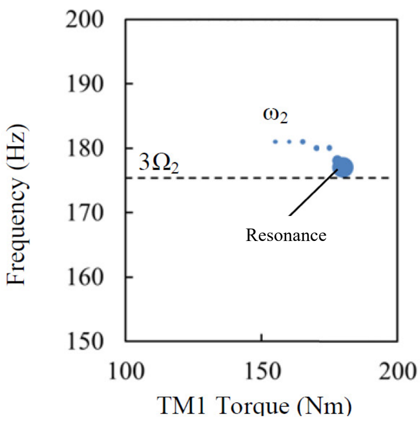


Fig.5 Load condition-frequency

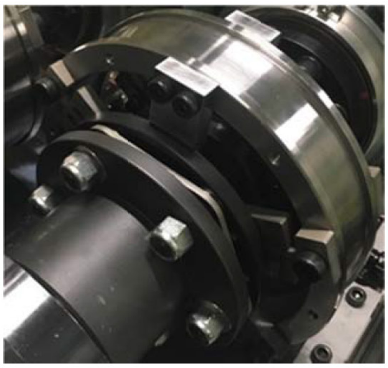


Fig.6 DM on output shaft

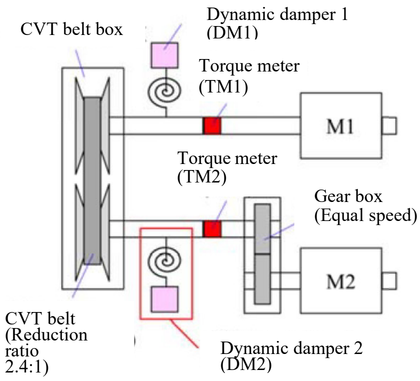


Fig.7 Installation position of DM2

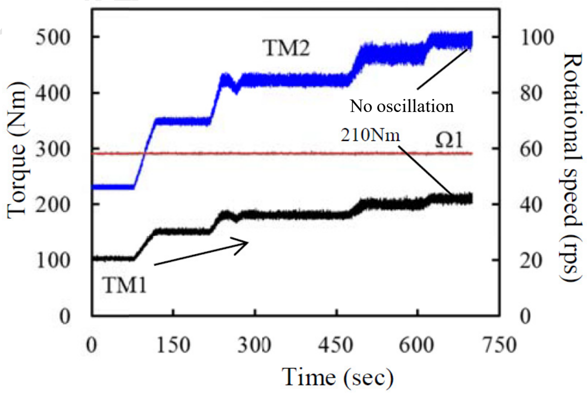


Fig.8 Temporal shaft vibration (DM1 , DM2 installed)