Vibration Monitoring and Analysis of Conveyor Driving Unit of a Coal Transporter

Harus Laksana Guntur[1] and Yanuar Krisnahadi[1]

Abstract—**This paper presents the result of vibration monitoring, simulation and the analysis of conveyor driving unit of a coal transporter. In steam power plant, coal transporter is on of the fundamental equiptment for coal handling and energy supply. Conveyor driving unit (CDU) is the unit in a coal tranporter which drive the conveyor and transport coal from the stockpile/coal yard to the burner. CDU failure cause instability in coal handling process and influence the production capacity of the power plant. To maintain the reliability of the coal transporter, vibration based condition monitoring is conducted. The vibration of CDU is affected by the tranported load, luffing angle and conveying rate. In this paper, the report is focused on the vibration monitoring result and analysis of the influence of the luffing angle and conveying rate (transported load) to the vibration.The CDU is mathematically modeled and its vibration is simulated. Here, conveyor belt tension at driver pulley is assumed to be the main source of vibration,which has frequency of 1.237Hz. Measurement results show that maximum amplitude occurs at frequency of 24.5 Hz, which is closed to the driving motor of the conveyor. The simulation results show that bigger luffing angle and conveying rate increase the vibration amplitude, specifically at horizontal (x) direction.**

Keywords—**vibration monitoring, conveyor dring unit, coal handling, coal transporter.**

Abstrak*— *Makalah ini menyajikan hasil pemantauan getaran, simulasi dan analisis unit penggerak konveyor pengangkut batubara. Di pembangkit listrik tenaga uap, pengangkut batubara merupakan peralatan fundamental untuk penanganan batu bara dan pasokan energi. Unit penggerak konveyor (CDU) adalah unit pengangkut batubara yang menggerakkan konveyor dan mengangkut batubara dari stockpile / coal yard ke burner. Kegagalan CDU menyebabkan ketidakstabilan proses penanganan batubara dan mempengaruhi kapasitas produksi pembangkit listrik. Untuk menjaga keandalan transporter batubara, pemantauan kondisi berbasis getaran dilakukan. Getaran CDU dipengaruhi oleh beban tranported, sudut luffing dan tingkat pengantaran. Dalam tulisan ini, laporan difokuskan pada hasil pemantauan getaran dan analisis pengaruh sudut luffing dan tingkat pengantaran (muatan yang diangkut) terhadap getaran. CDU dimodelkan secara matematis dan getarannya disimulasikan. Di sini, konveyor belt tension pada pulley pengemudi diasumsikan menjadi sumber utama getaran, yang memiliki frekuensi 1.237Hz. Hasil pengukuran menunjukkan bahwa amplitudo maksimum terjadi pada frekuensi 24,5 Hz, yang tertutup terhadap motor penggerak konveyor. Hasil simulasi menunjukkan bahwa sudut luffing dan laju pengangkatan yang lebih besar meningkatkan amplitudo getaran, khususnya pada arah horisontal (x).

Kata Kunci— ***pemantauan getaran, unit conveyer, penanganan batubara, pengangkut batubara.***

I. INTRODUCTION

Coal handling system is needed to guarantee the production process of electricity in a Steam-Electric Power Generating Plant. Coal handling system has two main processes, i.e.: loading process and unloading process. Loading process is the process of coal loading from stockpile into coal bunker. Unloading process is the process of coal transfer from ship into stockpile.

Coal Transporter or Stacker Reclaimer is the main unit in coal handling which transport coal from the stockpile/coalyard into the coal bunker and coal burner. During its operation, coal transporter can adjust the transported coal rate/capacity and the luffng angle at the stockpile. Failure in coal transporter can produce instability in coal handling process, which will affect to the decrease of coal handling capacity form 1100 t/h to 500 t/h and increase the production cost. To guarantee the reliability of the coal transporter, a steam-electric power plant implement a preventive maintenance (PM) and predictive maintenance (PdM). One of the PM is vibration monitoring and comparison with the baseline or trend. Vibration measurement and recording is carried out routinely during its operating time.

Yanuar Krisnahadi and Harus Laksana Guntur [1], reported a preliminary study on the influence of luffing angle and coal handling capacity on the vibration responses of a stacker reclaimer. Simulation and measurement was conducted to analyze the vibration trend and validate the model. The results show an initial information on how the vibration trend changes when the luffing angle and handling capacity change. Walter Bertelmus [2] carried out a dynamic modelling of gear box of a belt conveyor driving unit by varying non stationary load to detect the distributed fault. Two gear boxes are modelled, i.e. fixed-axis two-stage gearbox and planetary gearbox of belt conveyor and bucket wheel excavator. The results show that original transmission error is influenced by the technical condition and load values which is important in implementing condition monitoring.

In dynamic modelling and simulation, defining the excitation force of the system is important. Belt conveyor is one of the main vibration exciter in CDU, in addition to the motor. M. Musselman [3] conducted a research to study the dynamic movement of a belt conveyor. The research was carried out by implementing an excitation force to produce belt vibration in a material handling system. The results show that the belt transversal vibration is sensitive to the change of belt length, belt tension, belt misalignment, and excitation location. Selezneva [9] conducted a modeling and synthesis of tracking control for the belt drive system in a coal handling system and

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Ghalamchi [10] studied simple and versatile dynamic model of spherical roller bearing. They reported partial study and investigation of the coal handling system component.

In this paper, the research is focused on the vibration monitoring result and analysis of the CDU of a coal handling system. The CDU is mathematically modeled and its vibration is simulated. The conveyor belt tension at driver pulley is assumed to be the main source of vibration. The simulation results and vibration measurement are compared and studied.

II. METHOD

The research is started by literature study and technical data collecting. Parameters and dimension of the CDU are measured and collected. The CDU and coal transporter parameters and dimension are used to develop the mathematical model and simulation. From the collected parameters and dimension, the mathematical model is governed and simulation block diagram is developed. Figure 1 and 2 show the detail drawing of the Conveyor driving unit (CDU) and coal transporter, which mainly consists of motor, gear box, conveyor, belt pulley, swing base, torque arm and counterweight.

A. *Vibration measurement*

CDU's vibration measurement is carried out at various luffing angle 3^0 and 4^0, and at various conveying rate 300 t/h and 500 t/h. Measurements are conducted at several point, i.e. drive pulley inboard bearing (DPIB) vertical, DPIB horizontal, drive pulley outboard (DPOB) vertital and DPOB horizontal.The real image of the CDU and coal tranporter, and can be seen in Figure 3(b). To analyze the trend of vibration response of the CDU, vibration monitoring/recording was also conducted daily based, in addition to the actual coal tranporting rate in ton per hour [t/h].

B. *Mathematical modelling and simulation*

Figure 4 shows the dynamical/mathematical model of the CDU, the damper and stiffness of the system, and the direction of the conveyor belt tension at driver pulley which is assumed to be the main source of vibration [4][5].

From the dynamical model of the CDU and free body force diagram [6-8], the dynamic equation are governed and the state variable form are shown in equation (1) to (7).

$$\dot{v}_a = \frac{1}{m_a}[F(t) - k_1(x_a + x_aL_1) - C_1(\dot{x}_a + \dot{x}_aL_1) - k_2(x_a - (x_a + x_aL_1) - C_2(\dot{x}_a + \dot{x}_aL_2) - k_3((\dot{x}_a + \dot{x}_aL_3) - x_5) - C_3((\dot{x}_a + \dot{x}_aL_3) - \dot{x}_5) - k_4((\dot{x}_a + \dot{x}_aL_4) - x_5) - C_4((\dot{x}_a + \dot{x}_aL_4) - \dot{x}_5)] \tag{1}$$

$$\dot{\omega}_a = \frac{1}{J_a}[F(t)L_0 - k_1(x_a + x_aL_1)L_1 - C_1(\dot{x}_a + \dot{x}_aL_1)L_1 - k_2(x_a - (x_a + x_aL_1)L_2 - C_2(\dot{x}_a + \dot{x}_aL_2)L_2 - k_3((\dot{x}_a + \dot{x}_aL_3) - x_5)L_3 - C_3((\dot{x}_a + \dot{x}_aL_3) - \dot{x}_5)L_3 - k_4((\dot{x}_a + \dot{x}_aL_4) - x_5)L_4 - C_4((\dot{x}_a + \dot{x}_aL_4) - \dot{x}_5)L_4] \tag{2}$$

$$\dot{v}_b = \frac{1}{m_b}[k_3((\dot{x}_a + \dot{x}_aL_3) - x_5) + C_3((\dot{x}_a + \dot{x}_aL_3) - \dot{x}_5) + k_4((\dot{x}_a + \dot{x}_aL_4) - x_5) + C_4((\dot{x}_a + \dot{x}_aL_4) - \dot{x}_5) - k_5x_b - C_5\dot{x}_b] \tag{3}$$

$$\dot{v}_a = \frac{1}{m_a}[F(t) - k_1(y_a - \beta L_1) - C_1(\dot{y}_a - \beta L_1) - k_2(y_a - \beta L_2) - C_2(\dot{y}_a - \beta L_2) - k_3((y_a - \beta L_3) - (x_5 + \gamma L_5)) - C_3((\dot{y}_a - \beta L_1) - (\dot{x}_5 + \gamma L_5)) - k_4((y_a - \beta L_4) - (x_5 + \gamma L_5)) - C_4((\dot{y}_a - \beta L_4) - (\dot{x}_5 + \gamma L_5))] \tag{4}$$

$$\dot{\omega}_a = \frac{1}{J_b}[F(t)L_0 - k_1(y_a - \beta L_1)L_1 - C_1(\dot{y}_a - \beta L_1)L_1 - k_2(y_a - \beta L_2)L_2 - C_2(\dot{y}_a - \beta L_2)L_2 - k_3((y_a - \beta L_3) - (x_5 + \gamma L_5))L_3 - C_3((\dot{y}_a - \beta L_1) - (\dot{x}_5 + \gamma L_5))L_3 - k_4((y_a - \beta L_4) - (x_5 + \gamma L_5))L_4 - C_4((\dot{y}_a - \beta L_4) - (\dot{x}_5 + \gamma L_5))L_4] \tag{5}$$

$$\dot{v}_b = \frac{1}{m_b}[k_3((y_a - \beta L_3) - (x_5 + \gamma L_5)) + C_3((\dot{y}_a - \beta L_1) - (\dot{x}_5 + \gamma L_5)) + k_4((y_a - \beta L_4) - (x_5 + \gamma L_5)) + C_4((\dot{y}_a - \beta L_4) - (\dot{x}_5 + \gamma L_5)) - k_5(y_b + \gamma L_5) - C_5(\dot{y}_b + \gamma L_5) \tag{6}$$

$$\dot{\omega}_b = \frac{1}{J_b}[[k_3((y_a - \beta L_3) - (x_5 + \gamma L_5)) + C_3((\dot{y}_a - \beta L_1) - (\dot{x}_5 + \gamma L_5)) + k_4((y_a - \beta L_4) - (x_5 + \gamma L_5)) + C_4((\dot{y}_a - \beta L_4) - (\dot{x}_5 + \gamma L_5))]L_6 - [k_5(y_b + \gamma L_5) - C_5(\dot{y}_b + \gamma L_5)]L_5] \tag{7}$$

The simulation block diagram was governed based on equation (1) to (7). Table 1 to 3 are the parameters of the CDU used for the simulation .

Nomenclature:

F:Excitation force [N], *J*:moment of inertia [kg.m^2], *m*:mass [kg], *k*:stiffness[N/m], *c*:damping coefficient [Ns/m], θ-β-γ:angular displacement [rad], *L*:length [m], *x*-*y*:translational displacement [m], $\dot{x} - \dot{y}$:translational velocity [m/s], ω:angular velocity [rad/s], $\dot{v}$:translational acceleration[m/s^2], $\dot{\omega}$:angular acceleration [rad/s^2].

III. RESULTS AND DISCUSSION

A. *Vibration and conveying rate measurement results*

Figure 5 shows the outborad vibration measurement report of the bearing pulley conveyor of coal transporter, from Dec 2012 - Jan 2014. The RMS velocity of the vibration increases from 2.4 mm/s to 2.8 mm/s and decrease to 2.2 mm/s within february-april-july 2013.The RMS velocity reach its peak at 4 mm/s in November 2013. Figure 6 shows the actual coal conveying rate transported by CDU measured at luffing angle 3^0 and conveying rate 300 t/h. It is fluctuated from 200 to 700 t/h, and has its RMS value of 300 t/h. Table 4 shows the data of the vibration measurement results of CDU at frequency of 1.237Hz for various luffing angle and conveying rate. Maximum vibration of 1.22 [mm/s] is found at luffing angle 3^0 and conveying rate 300 t/h, at DPIB horizontal.Where 1.23 Hz is the operating frequency of the motor of the coal tranporter.

Figure 7 shows the CDU's vibration responses at luffing angle 3^0 conveying rate 300 t/h : a) DPIB horizontal, b) DPIB vertical. The frequency domain shows that peak velocity occurs at frequency of 25Hz, both for DPIB vertical and horizontal. The amplitude of vibration shown by its RMS velocity indicates that vibration at vertical direction is higher than at horizontal direction.Whereas the vibration responses of the CDU at luffing angle 3^0 conveying rate 300 t/h : a) DPOB horizontal, b) DPOB vertical shows similar phenomena, as seen in Figure 8.

B. Comparison of vibration measurement and simulation results

Figure 9 to 12 show the comparison between vibration measurement and simulation results of the CDU at luffing angle 3^0 and conveying rate 300 t/h, DPIB horizontal-vertical, and DPOB horizontal-vertical. In general, the simulation results show a single frequency response, whereas the measurement results show a multi frequency response. As vibration of a body is mainly influenced by the characteristic or frequency of the exciter (operating frequency) and its component's natural frequency, it is difficult for modelling and simulation to show similar phenomena with the measurement results for complex system.

The summary of RMS velocity responses and the comparison between measurement and simulation results are seen in Figure 13 for DPIB horizontal-vertical and Figure 14 for DPOB horizontal-vertical. The vertical (Y) axis is for vibration RMS velocity[mm/s] and effective tension[N], while the horizontal (X) axis is for luffing angle and conveying rate [t/h], as detailed in Table 5 to 8. Table 5 and 6 for DPIB horizontal-vertical, and Table 7 and 8 for DPOB horizontal-vertical.From the figure and table, the effective tension of the conveyor increase 0.1 mm/s from 1(luffing angle 3^0 and conveying rate 300 t/h) to 3(luffing angle 4^0 and conveying rate 300 t/h), for all measuring position, DPIB horizontal-vertical and DPOB vertical-horizontal.Meanwhile, the vibration tends to be constant. The table show the difference between RMS velocity obtained from measurement and simulation ranging from minimum value of 1.9% to maximum value of 64.5%. Maximum 64.5% difference occurs due to inaccuracy in determining the parameter, several assumption and simplification for CDU, which is a complex system for modelling.

IV. CONCLUSION

The outborad vibration of the bearing pulley conveyor of coal transporter, from Dec 2012 - Jan 2014 show the RMS velocity of the vibration increases from 2.4 mm/s to 2.8 mm/s and decrease to 2.2 mm/s within february-april-july 2013.The RMS velocity reach its peak at 4 mm/s in November 2013. The actual coal conveying rate is fluctuated from 200 to 700 t/h, and has its RMS value of 300 t/h. Maximum vibration of 1.22 [mm/s] is found at luffing angle 3^0 and conveying rate 300 t/h, at DPIB horizontal. The frequency domain shows that peak velocity occurs at frequency of 25Hz, both for DPIB vertical and horizontal. The amplitude of vibration shown by its RMS velocity indicates that vibration at vertical direction is higher than at horizontal direction.

The RMS velocity responses and the comparison between measurement and simulation results show that the effective tension of the conveyor increase 0.1 mm/s, from point 1(luffing angle 3^0 and conveying rate 300 t/h) to 3(luffing angle 4^0 and conveying rate 300 t/h), for all measuring position,whereas the vibration tends to be constant. The table show the difference between RMS velocity obtained from measurement and simulation ranging from minimum value of 1.9% to maximum value of 64.5%. Maximum 64.5% difference occurs due to inaccuracy in determining the parameter, several assumption and simplification for CDU, which is a complex system for modelling.

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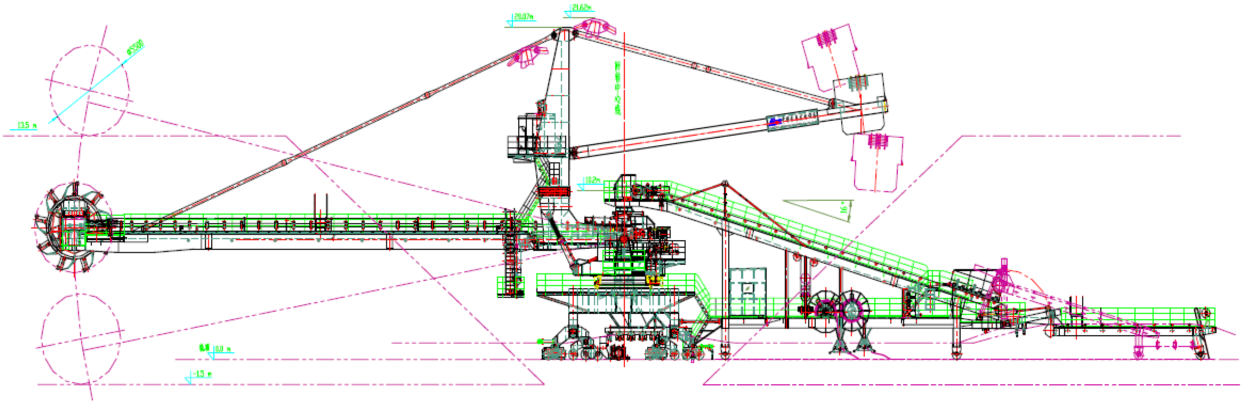


Figure. 1. Detail drawing of the coal transporter

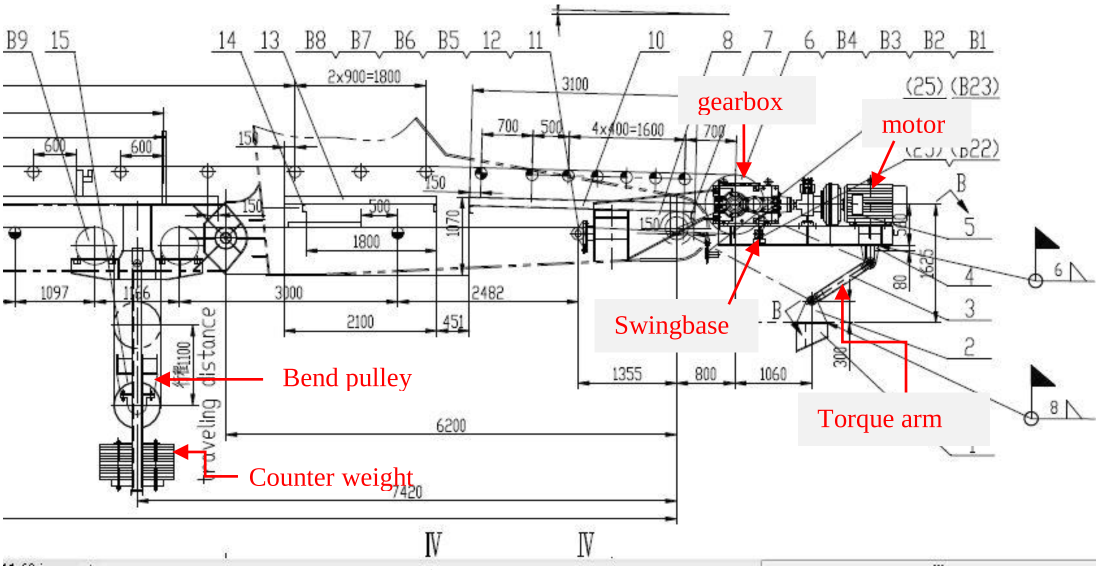


Figure 2. Detail drawing of the Conveyor driving unit (CDU) and coal transporter

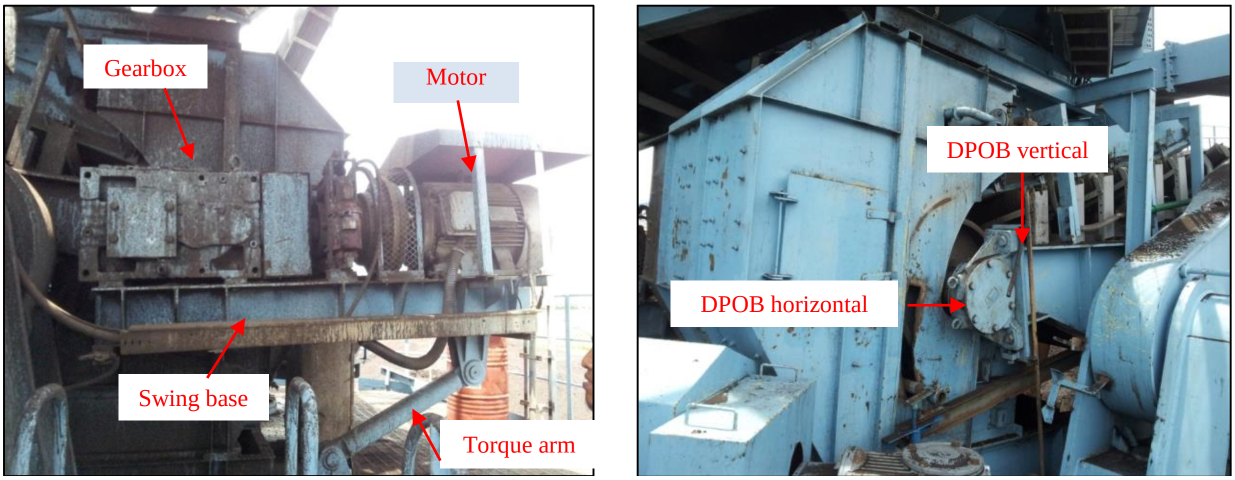


Figure 3. The real image of Conveyor driving unit (CDU) and coal transporter

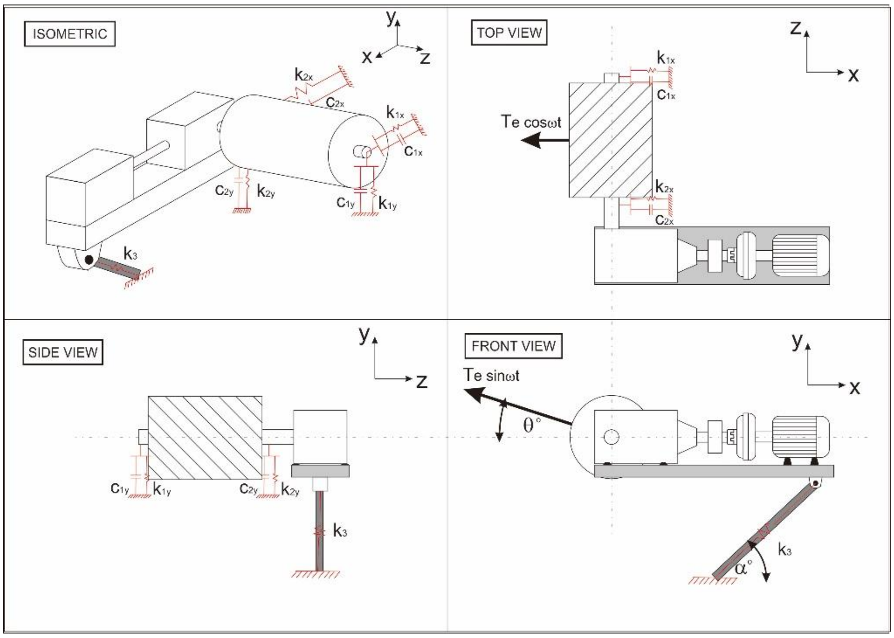


Figure 4. Schematic image of the Conveyor driving unit (CDU)

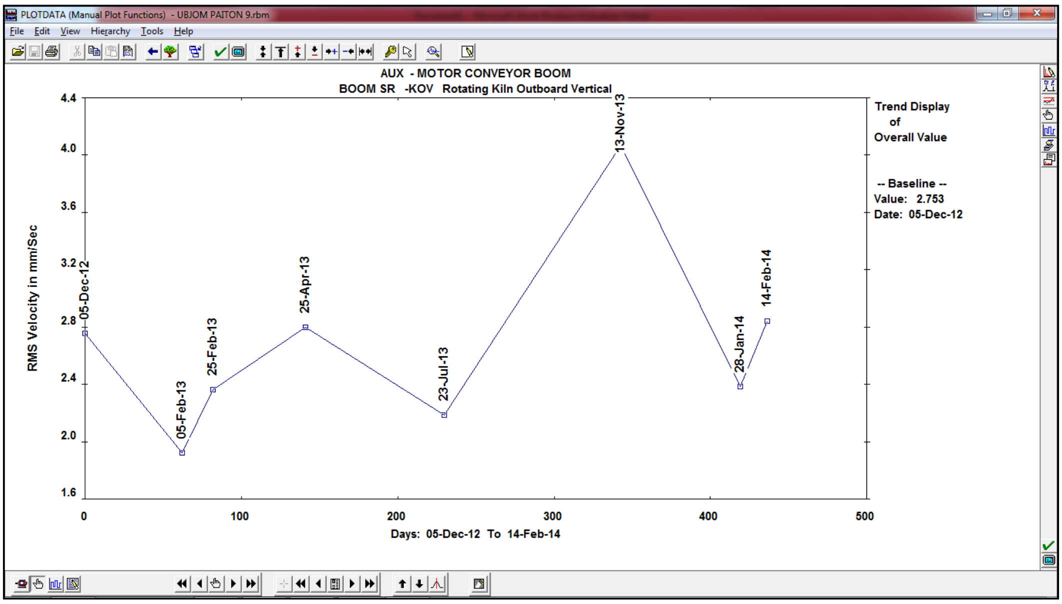


Figure 5. Outborad vibration measurement report of the bearing pulley conveyor of coal transporter

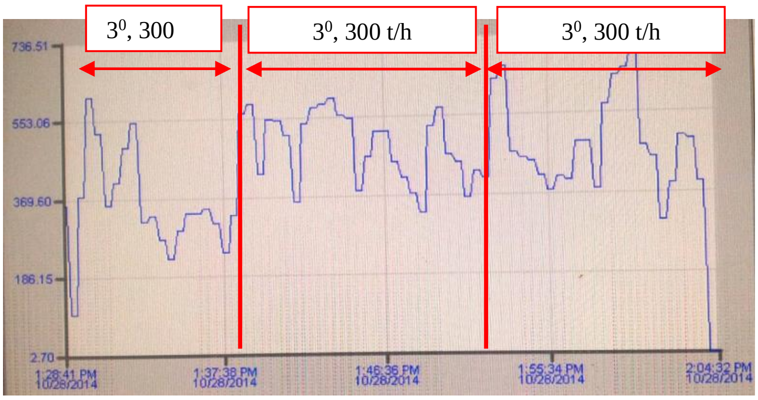


Figure 6. Actual coal conveying rate transported by CDU

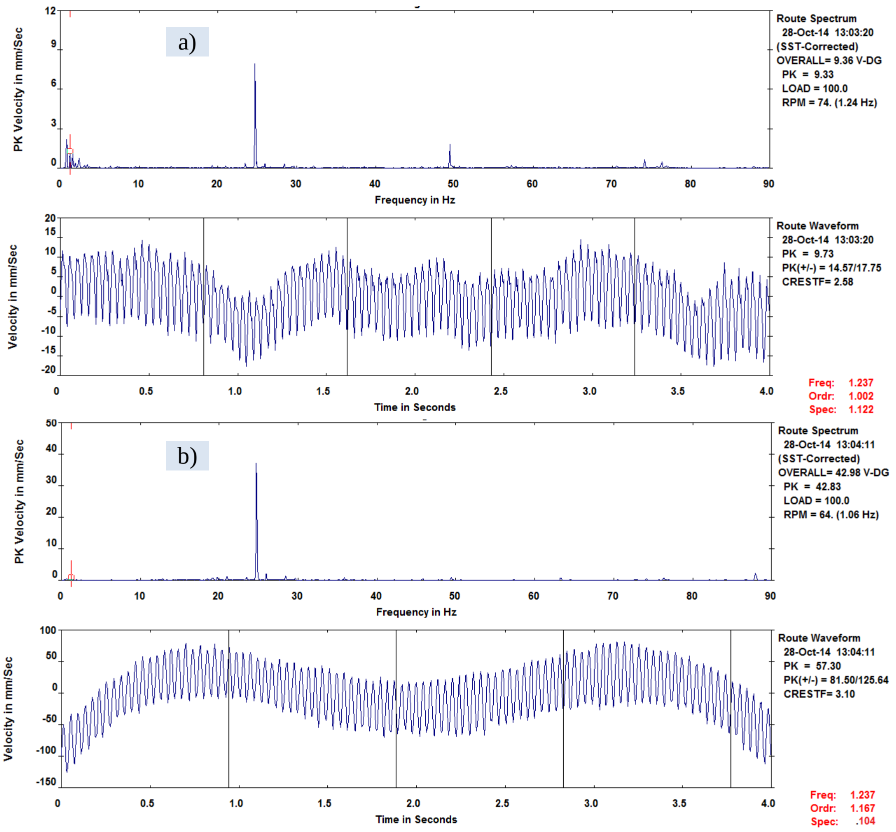


Figure 7. CDU's vibration responses at luffing angle 3^0conveying rate 300 t/h : a) DPIB horizontal, b) DPIB vertical

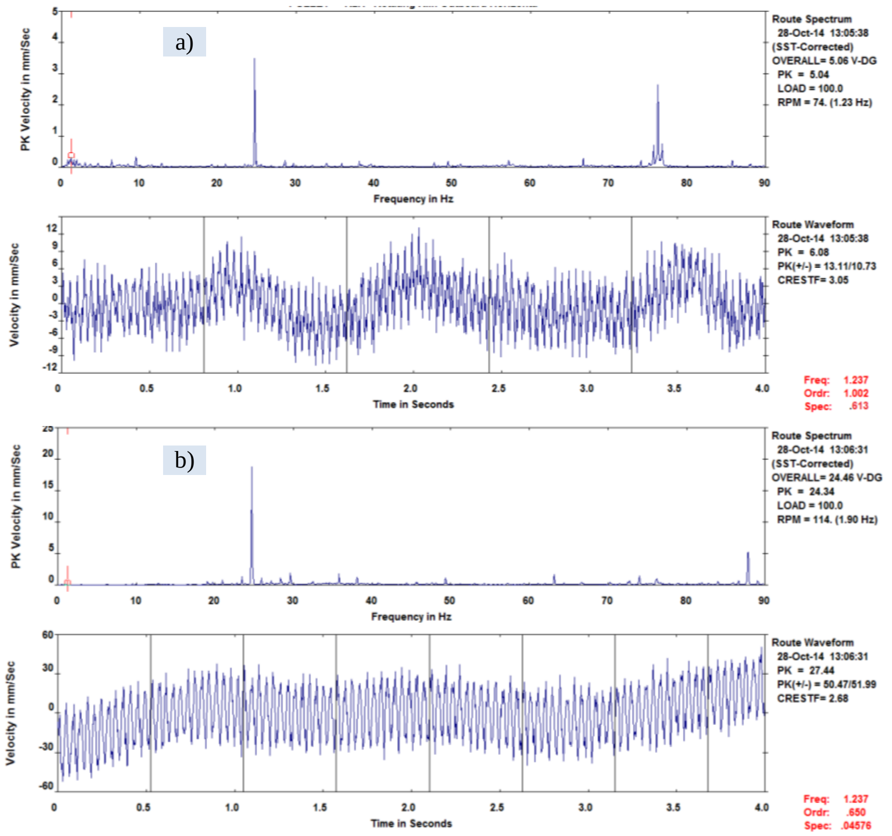
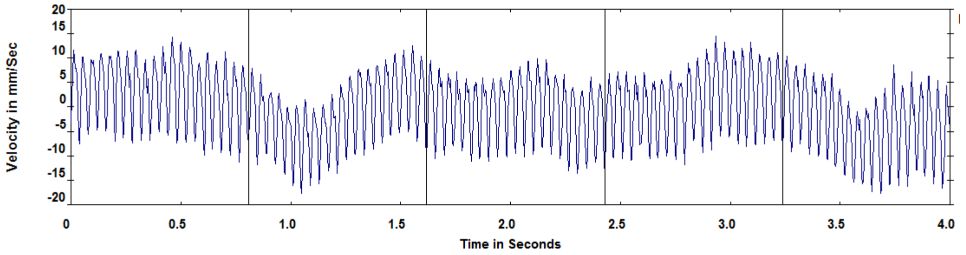
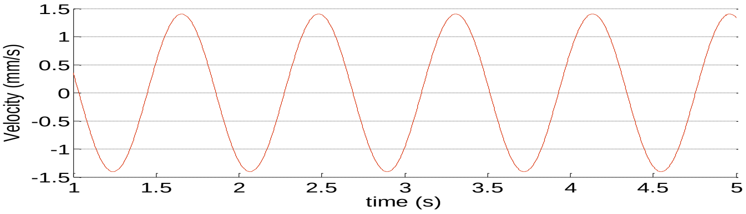


Figure 8. CDU's vibration responses at luffing angle 3^0conveying rate 300 t/h : a) DPOB horizontal, b) DPOB vertical

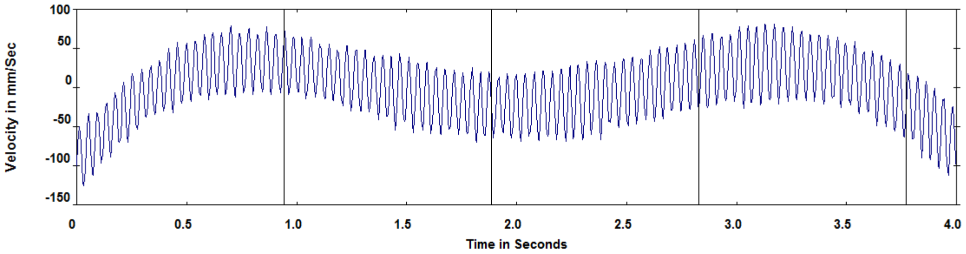


a) Measurement

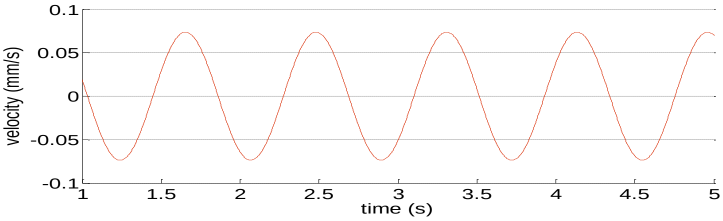


b) Simulation

Figure 9. CDU's vibration responses at luffing angle 3^0conveying rate 300 t/h DPIB horizontal : a) Measurement, b) Simulation

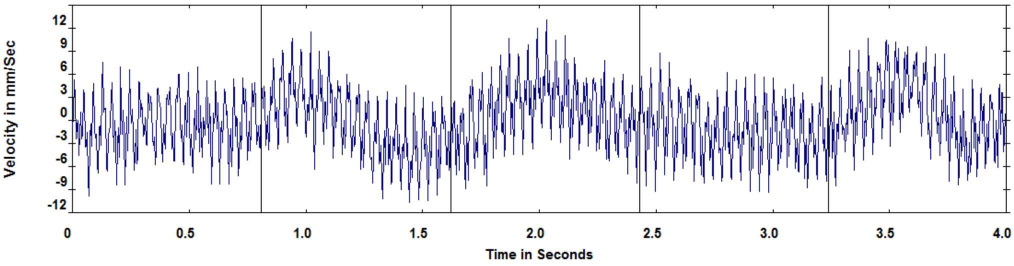


a) Measurement

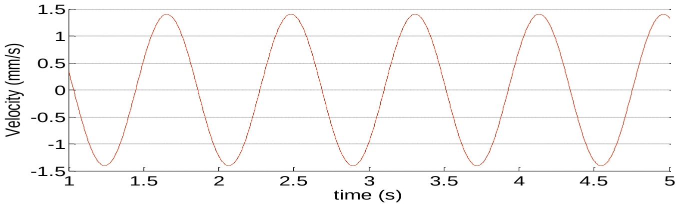


b) Simulation

Figure 10. CDU's vibration responses at luffing angle 3^0conveying rate 300 t/h DPIB vertical : a) Measurement, b) Simulation

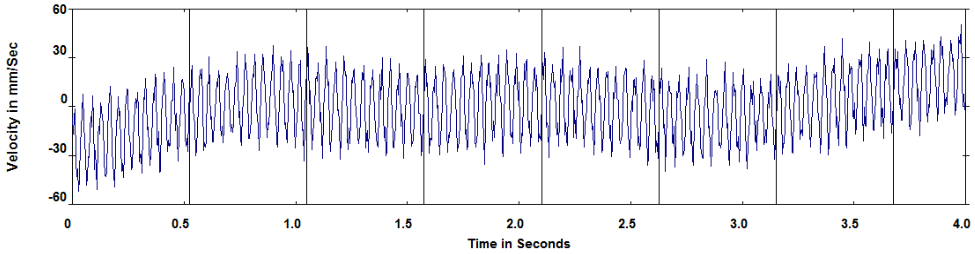


a) Measurement

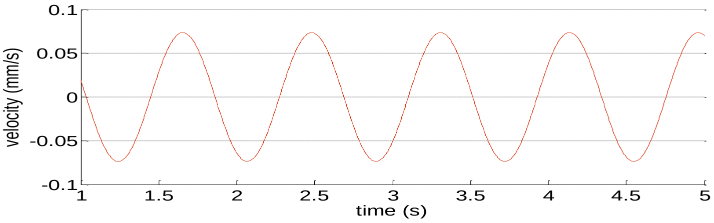


b) Simulation

Figure 11. CDU's vibration responses at luffing angle 3^0conveying rate 300 t/h DPOB horizontal : a) Measurement, b) Simulation



a) Measurement



b) Simulation

Figure 12. CDU's vibration responses at luffing angle 3^0conveying rate 300 t/h DPOB vertical : a) Measurement, b) Simulation

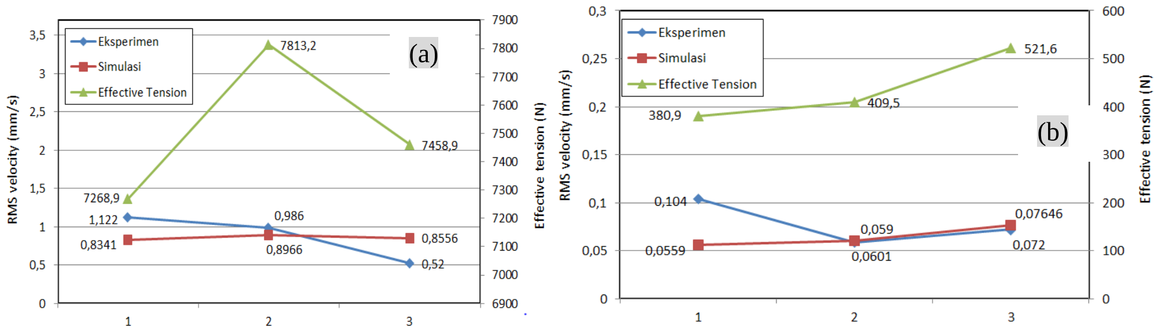


Figure 13. The comparison of RMS velocity obtained from measurement & simulation, and the effective tension at (a) DPIB horizontal, (b) DPIB vertical

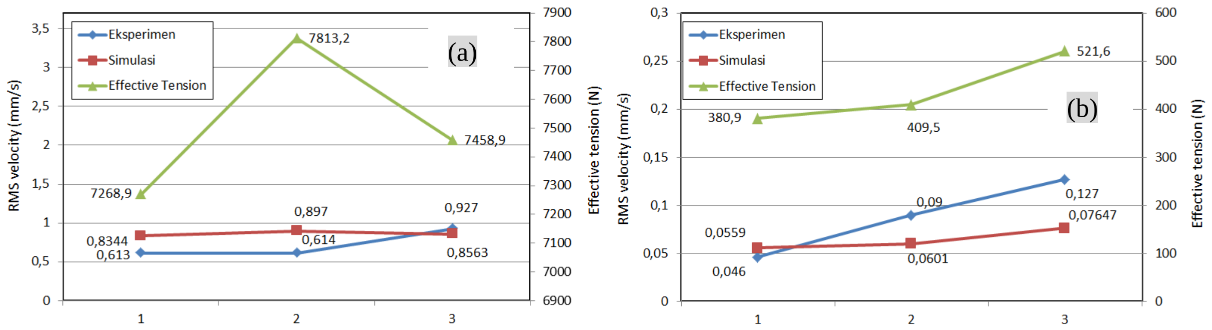


Figure 14. The comparison of RMS velocity obtained from measurement & simulation, and the effective tension at (a) DPOB horizontal, (b) DPOB vertical

TABLE 1.
CONVEYOR PARAMETERS

Boom Conveyor	
Grade	JIS-FR
Width	1400 mm
Caracass/ply	EP1000/5P
Cover top	6 mm
Cover bottom	3 mm
Totak thickness	17 mm
Lenght	39,9 m
Capacity	1500 t/h
Belt speed	3,15 m/s
Ambient temperature	30 C
Luffing angle	(+)12,6 - (-)11,18
idler diameter	159 mm
trough angle of idler	35

TABLE 2.
GEAR BOX PARAMETERS

Gearbox	
Manufacture	SEW-EURODRIVE
Type	MC3RLHF07
input/output speed	1480/23,9 rpm
Weight	780 kg
Transmision ratio	20 : 1
Absorbed power on input shaft	55 kW
Rated torque of the gear unit	35,6 kNm

TABLE 3.
MOTOR SPECIFICATION

Motor	
Type	Y280M-4
Power	90kW
Speed	1480 rpm
Current	164 A
Efficiency	93,50%
Fq	6475 N
x	433 mm

Table 4.
Vibration Responses Of Cdu At Frequency Of 1,237HZ

No	Luffing amgle	Conveying rate (t/h)	DPIB (mm/s)		DPOB (mm/s)	
			Horizontal	Vertical	Horizontal	Vertical
1	3^0	300	1,122	0,104	0,613	0,046
2	3^0	500	0,986	0,059	0,614	0,09
3	4^0	300	0,52	0,072	0,927	0,127

Table 5.
The Comparison Of Rms Velocity Obtained From Measurement & Simulation, And The Effective Tension At Dpib Horizontal

No	Luffing angle	Conveying rate (t/h)	Effective tension (N)	Measurement (mm/s)	Simulation (mm/s)	Error (%)
1	-3	300	7268,9	1,122	0,8341	25,7
2	-3	500	7813,2	0,986	0,8966	9,1
3	-4	300	7458,9	0,52	0,8556	64,5

Table 6.
The Comparison Of Rms Velocity Obtained From Measurement & Simulation, And The Effective Tension At Dpib Vertical

No	Luffing angle	Conveying rate (t/h)	Effective tension (N)	Measurement (mm/s)	Simulation (mm/s)	Error (%)
1	-3	300	380,9	0,104	0,0559	46,3
2	-3	500	409,5	0,059	0,0601	1,9
3	-4	300	521,6	0,072	0,07646	6,2

Table 7.
The Comparison Of Rms Velocity Obtained From Measurement & Simulation, And The Effective Tension At Dpob Horizontal

No	Luffing angle	Conveying rate (t/h)	Effective tension (N)	Measurement (mm/s)	Simulation (mm/s)	Error (%)
1	-3	300	7268,9	0,613	0,8344	36,1
2	-3	500	7813,2	0,614	0,897	46,1
3	-4	300	7458,9	0,927	0,8563	7,6

Table 8.
The Comparison Of Rms Velocity Obtained From Measurement & Simulation, And The Effective Tension At Dpob Vertical

No	Luffing angle	Conveying rate (t/h)	Effective tension (N)	Measurement (mm/s)	Simulation (mm/s)	Error (%)
1	-3	300	380,9	0,046	0,0559	21,5
2	-3	500	409,5	0,09	0,0601	33,2
3	-4	300	521,6	0,127	0,07647	39,9