Article

Vibration Diagnosis of Sand Units in Stone Crusher Plant: On-site Field Test

Seong-Hwan Kim[1], Bo-Kyu Kim[1], Dong-Soo Jung[1*], Seung-Bok Choi[1*], Jong-Mu Lee[2], and Kyu-Bong Lee[2]

[1] Smart Structure Systems Laboratory, Dept. of Mechanical Engineering, Inha University, Incheon 22212 Korea; neumann9177@naver.com (S.H. K); kims21006@nater.com (B.K. K); dsjung@inha.ac.kr (D.S. J);

[2] Maleun Environment Industrial Co. Ltd., Incheon, 21687, Korea; ljmsim@naver.com (J.M. L); sa@maleun.co.kr (K.B. L)

* Correspondence: seungbok@inha.ac.kr, dsjung@inha.ac.kr

Abstract: Due to limitation of natural sand from rivers and seas, artificial sand production from large stones or rocks is being increased. However, this sand manufacturing process is dangerous and causes several social problems such as high level of unwanted vibrations or noises. This study investigates vibration characteristics of sand and screen units in artificial sand production plant whose actuating operation is multiple with several different exciting frequencies. As a first step, vibration levels are measured at the sand and screen unit positions using accelerometers in time and frequency domains. The measurement is carried out at two different conditions: activating sand unit only and operating entire facilities such as stone crusher. Vibration signals acquired from several locations of the sand and screen units of the plant are collected and analyzed from waveforms and spectrums of the signals. It is identified that the vibration acceleration level of the screen unit is higher than that of the sand unit. In addition, it is found from the acceleration signals measured at plant office and shipping control center those places are far away from the plant location that the beating phenomenon is occurred by close driving frequencies for several sand units. In this work, the vibration caused from the beating is significantly reduced by adjusting the driving frequencies for the sand units so that they are sufficiently scattered to avoid the beating.

Keywords: artificial sand plant, stone crusher, screen unit and sand unit, beating phenomenon, vibration measurement and reduction

---

1. Introduction

Natural sand can be easily found in our surrounding natural environment, such as rivers and seas. Over the past many decades, humans have been required large amounts of sand for social overhead capital (SOC) facilities and infrastructure, including large scale construction of buildings, roads, bridges, airports, and harbor. However, as most of the natural sand is obtained from rivers and seas, its availability in the natural environment is limited. Moreover, indiscriminate collection of sand from rivers causes flooding and destruction of the natural environment such as river ecosystems, leading to various social issues. In case of the sand collected from the sea, it must proceed with removing the salt and drying process. Therefore, a method for manufacturing artificial sand using a stone or rock grinding mechanism is used as a solution to protect environmental destruction and sand depletion problems caused by massive natural sand production. The stone (or rock) breaking and crushing process plays an important role in minimizing the particle size of stone or rock for various construction activities such as building bridges or infrastructure. They can be obtained in large quantities from artificial sand production plant facilities such as jaw crusher, vibration screen units and sand units. In the artificial sand manufacturing process, which relatively large stones or rocks are first crushed, followed by screened, washed, and then fine-sized [1-6].

Artificial sand production system consists of large motors with high power output and jaw crusher or impact crusher to break rocks or large stones. In addition, hopper and cone crusher are

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

required to break large stones into small-sized stones or gravels. Then, the gravels and sands which are respectively transferred to the vibrating screen unit and sand unit are sorted by particle size through washing and screening process. Subsequently, the fine sand is moved to a designated storage place. Thus, the artificial sand production from crushed stones or rocks requires various types of equipment related to the full manufacturing processes. These facilities are large-sized and hence inevitably have a significant impact generating high level of vibration and noise. Therefore, artificial sand manufacturing plant should be built on large plains or mountain entrances where are far from densely populated residential areas and industrial complexes. However, if artificial sand manufacturing site is located close to a densely population area or a residential complex as well as an industrial complex, then there exist significant noise and vibration issues when the artificial sand manufacturing facilities are operating in such sites. Many complaints are also raised from the transmission of such vibrations, shock, and noise by the residents in the adjacent areas [4-6]. Most of the artificial sand production facilities include vibration-isolating devices that are operated by simply installing several coil springs parallelly around the device, and most structures comprise simple steel structures connected by welding H-beams. Therefore, the vibration generated in the facility is transmitted to the ground as it is. The noise generated during the operation of the production facility is more than 90 dB, and it is impossible to communicate in a moving path when the operator is moving among the manufacturing facility. It is difficult to quantify it as a speech interference level (SIL). The vibration level of an artificial sand facility plant is so high, and this vibration is propagated to the surrounding through floors and structures. This vibration can be also detected in nearby offices and residential areas located several hundreds of meters away. In addition, many social issues of environments are caused by complaining of discomfort caused by the propagation of the vibration-induced high noise levels to the surroundings. Despite the discomfort to the residents, the research report to reduce the unwanted vibration from the artificial sand plant is considerably rare.

Consequently, the main technical contribution of this work is to experimentally investigate vibration characteristics of the artificial sand production plant through the on-site measurement. More specifically, from the analysis of the measured signals in time and frequency domains, vibration isolations of the sand and screen units are evaluated as well as vibration sources are identified. To achieve this contribution, accelerometers are located on the sand and screen units by operating the sand unit actuators only as well as entire facilities of the plant. Subsequently, collected acceleration signals from various locations are analyzed in time and frequency domains. Especially, vibration acceleration level (VAL), isolation level rate (ΔVAL), percent isolation rate, and vibration transmissibility of the sand and screen units are calculated to evaluate the vibration isolation system. In addition, to find out the vibration source at the shipping control center and plant office located far away from the plant site, acceleration signals are measured and analyzed. From the analysis, it is identified that the main vibration source is the beating phenomenon occurred in multiple operations of the motors to activate sand units which have close driving frequencies. In other words, close driving frequencies for the simultaneous operation of three motors for the sand units cause the beating and hence the large vibration is occurred. In this work, the driving frequencies are adjusted to be sufficiently separated so that the beating is avoid in multiple operating of several actuating motors. Then, it is shown that unwanted vibrations are significantly reduced by adjustment of driving frequencies of the sand units.

2. Artificial Sand Production Plant

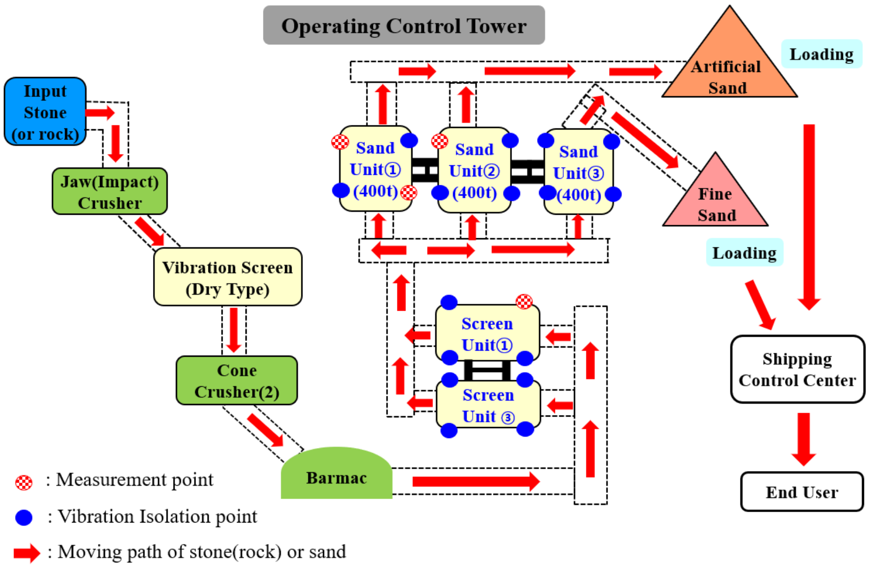
2.1. Overall Structure

To understand the artificial sand manufacturing production facilities, we overview the stone crusher plant shown in Figure 1 which includes various experimental equipment. Stone crushing plays a key role in the reduction of particle size of rocks or stones [1-3]. The jaw crusher is defined as a device for crushing large-sized rocks or stones. The crushed rocks and stones from the jaw crusher are screened on a dry type vibration screen and transported through a conveyor belt to a cone crusher.

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

The barmac is defined as a device for crushing stones conveyed from a cone crusher into smaller pieces. The operation of the artificial sand manufacturing production process using these facilities generates significant level of impulse or shock and vibration. The wet type vibration screen unit and sand unit are defined as a device for screening (or sorting) and washing the stones using the water, and it transported from the barmac into fine sized sand. In case of vibration screen unit, two wet type vibration screen units are operated by connecting to H-beam welded in parallel and three wet type vibration sand units are also operated by connecting to H-beam welded in parallel, respectively. The moving paths of raw materials (i.e., rocks, stones, or sands) are denoted by red arrow color in Figure 1(b). In the figure, the blue points denote vibration isolation representing the coil spring for screen units and sand units.

(a)



(b)

Figure 1 Artificial sand manufacturing plant and process: (a) Photograph of the artificial sand manufacturing production plant; (b) Overall process of artificial sand production

2.2. Vibration Isolation

Vibration isolation is a procedure by which the undesirable vibrations are eliminated or reduced. Basically, it involves the insertion of a resilient member (or isolator) between the vibrating mass (or equipment or payload) and the source of vibration so that the reduction in the dynamic response of the system can be achieved under specified vibration excitation condition. Therefore, this can be

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

achieved using not only passive but also controllable vibration isolators. It is well known that the isolation system can be classified into passive, active and semi-active. The passive isolator consists of a resilient material (stiffness), an energy dissipator (damper) and mass as a single degree of freedom of the mechanical system. The example of passive isolators in mechanical system includes metal coil spring, cork, felt, pneumatic springs and viscoelastic material such as elastomer or rubber springs. Among the passive isolators, the rubber springs have been popularly used in terms of the shear mode, or combinations of the shear and compression modes along with sophisticated viscoelastic elements. The active vibration isolator features actuators with a closed-loop feedback control system. Thus, the isolation performance of the active isolation is high, but it requires high cost and sophisticated sensors and control algorithms. The semi-active vibration isolation is featured by addition of damping property in real time manner. This method is known to be simple, but very effective. Among three vibration isolation approaches, the passive method is mostly used in the production of the artificial sand or in the building of the civil engineering structures. The vibration isolation for the artificial sand production plant is mainly achieved by utilizing rubber mounts or/and coil springs. More specifically, many rubber mounts and coil springs are installed under the structures of screen and sand units to reduce the vibration caused from driving (or exciting) actuators such as large-sized motors. Therefore, this isolation system is weak to external disturbances and time-varying uncertainty of the driving frequencies. This isolation system is normally designed to protect against the lowest frequency of the system since it causes the highest vibration amplitude. To achieve the vibration transmissibility of the artificial sand production plant, a single degree of freedom (DOF) model shown in Figure 2 can be considered.

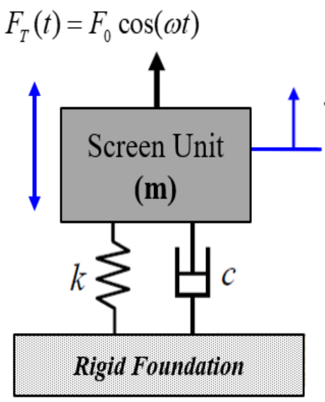


Figure 2 Single DOF vibration isolation model on rigid foundation

The resilient material is assumed to have both elasticity and damping and modeled as a spring k and a dashpot c, respectively. It is assumed that the operation of the sand manufacturing plant is undertaken by applying a harmonically varying force $F(t) = F_0 \cos \omega t$. Then, the governing equation of the machine sand unit (or screen unit) body is given by

$$m\ddot{x} + c\dot{x} + kx = F_0 \cos \omega t \tag{1}$$

Using the steady state solution of the above equation, the magnitude of the total transmitted force is determined by

$$F_T = \frac{F_0 \sqrt{k^2 + \omega^2 c^2}}{\sqrt{(k - m\omega^2)^2 + \omega^2 c^2}} \tag{2}$$

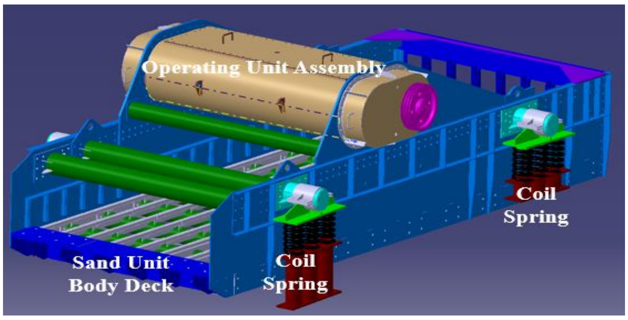
Thus, the transmissibility of the vibration isolation model is defined as the ratio of the magnitude of the force transmitted to the exciting force:

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

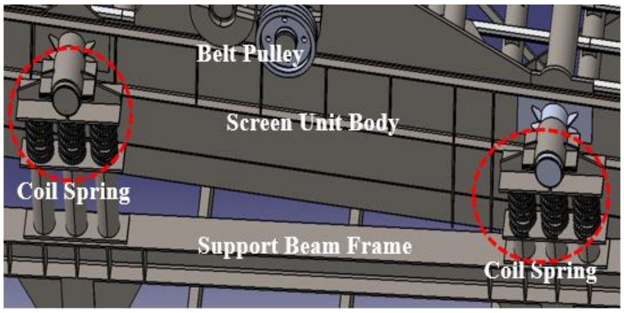
Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

$$T = \left|\frac{F_T}{F_0}\right| = \frac{\sqrt{k+\omega^2 c^2}}{\sqrt{(k-m\omega^2)^2+\omega^2 c^2}} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}} \tag{3}$$

In the above, F_T is the amplitude of the force transmitted to the sand unit, F_0 is amplitude of the excitation force from the sand unit body and r is the frequency ratio. It is defined by f / f_n, Here f is the exciting (or driving) frequency of the vibration source and f_n is the natural frequency of the sand unit which is mainly influenced by the stiffness of the sand unit structure. In Eq. (3), ζ is the damping ratio, which depends on the damping property of the system structures of the sand unit [7-12]. The vibration isolation design has three criteria or requirements as follows: i) the frequency ratio should be more than three ($f / f_n = r \geq 3$), ii) the vibration transmissibility (or percentage isolation) should be below 0.1(% I ≥ 90(%), iii) the minimum value should be under 12.5 % [7-12]. To meet the above requirements, most of artificial sand production devices including screen and sand units are built by coil springs to achieve vibration isolation as well as avoid the resonance phenomenon. In this plant, the coil springs are installed on each sand unit and screen unit as shown in Figure 3. The detained specifications of the coil springs used in this plant are given as follows. The outer diameter is 212 mm, diameter of the coil spring itself is 32 mm, number of coil turn is 7.5, static deflection is 25.3 mm, the maximum load is 2,950 kgs and the materials is stainless steel.



(a)



(b)

Figure 3 Sand unit assembly and coils spring installed in vibration isolation system: (a) Sand unit body and operating part assembly; (b) Side view of coil spring installed for screen and sand units

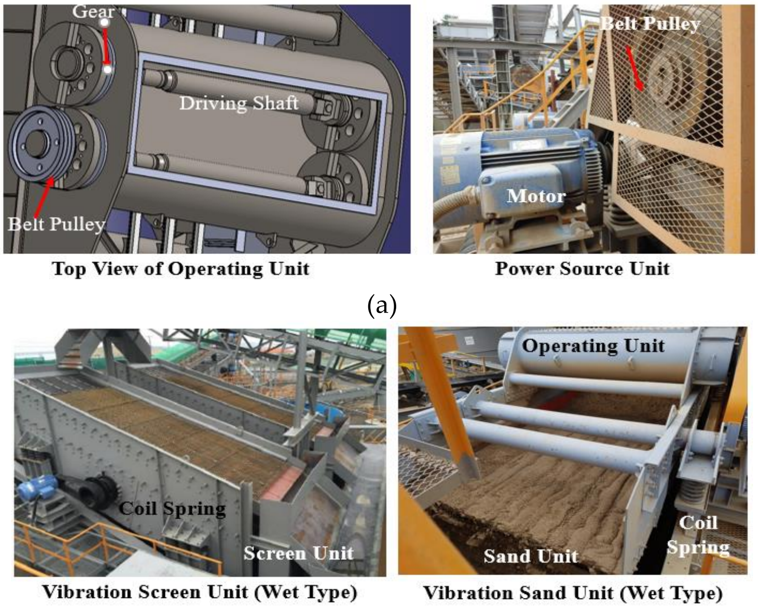
2.3. Vibration Sources

Vibration sources of the artificial sand production plant are very difficult to find out. Thus, the operating principles of the plant needs to be figured out as a first step. As a power source, large-capacity four-phase induction motor with from 60 to 200 horsepower is used and its operating speed ranges from 800 to 1,800 rpm. The power is transmitted to the drive shaft via a belt pulley. The drive

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at *Appl. Sci.* **2020**, *10*, 4327; doi:10.3390/app10124327

shaft and gear driving system are shown in Figure 4. The vibration occurred during the operation of the screen unit and sand units is transmitted the power to the shaft through the belt pulley directly related to the excitation force generated by actuating motors. At this time, the transmitted power is converted into rotational motion by the gear driving system. This rotational motion drives the screen and sand units to vibrate as well as screening the crushed particle size associated with the sorting and washing jobs. The construction and installation of the vibration isolation system in the screen and sand units is described in the next section. To find out the vibration problem occurred in the artificial sand manufacturing plant, we visited the field site several times to feel the vibration levels. In addition, many interviews with related peoples who reside at near place of the plant are undertaken discussing on the vibration characteristics felt by the residents. Then, the information got from the visiting and interviews, and measured vibration signals to be presented in a subsequent section are used to find out a main vibration source.



(b)

Figure 4 Vibration source of screen and sand unit and total assembly system: (a) Power source and power transmitted to the screen unit and sand unit: (b) Photograph of the screen unit and sand unit.

3. On-Site Vibration Measurement

3.1. Vibration level

To investigate the vibration level of the screen unit (600 ton) and sand unit (600 ton) during normal operation, two measurement positions of screen unit and sand unit are fixed as shown in Figure 5. Two uniaxial accelerometers (PCB, model 352CC/NC) are attached on both top point and bottom point (red color dots). In this work, the vibration level is measured by adopting difference of the vibration acceleration level (*VAL*) between the top and bottom of the coil springs. The *VAL* is numerically represented as the magnitude of vibration in decibel(dB) unit [7-11]. Thus, it is defined as the value obtained after dividing the vibration acceleration root mean square (RMS) value measured at the measurement point by the reference value of the acceleration which takes a logarithmic value expressed by

$$VAL = 20\log\left(\frac{a_{rms}}{a_0}\right) \quad [dB] \tag{4}$$

In the above, a_{rms} represents the vibration acceleration RMS value at the measurement point and

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

a_0 ($a_0 = 10^{-6}\ m/s^2$) and $a_{rms} = a_{peak}/\sqrt{2}$. The reference value of the vibration acceleration is based on the international standard ISO R1683 [7-11]. If the vibration isolation performance of system is good, the following formula is also used.

$$\Delta VAL = VAL_1 - VAL_2 = 20\log\left(\frac{1}{T}\right) \quad [dB] \tag{5}$$

$$\%I = (1-T)\times 100 \tag{6}$$

In the above, T represents the vibration transmissibility, VAL_1 represents the vibration acceleration level of the coil spring at the top point and VAL_2 represents vibration acceleration level of the coil spring at the bottom point, respectively. It is noted here that in this work, the four channels of data acquisition system and data processing are carried out utilizing NI 9234 hardware and Matlab software, respectively. In addition, it should be remarked here that the measurement of the vibration level is conducted at the shipment control center located 50 meters away from the manufacturing plant, and the company office located 250 meters away from the plant site. These vibration signals are to be used as comparative value after resolving the vibration source problem of the screen and sand units during the normal operation of the plant.

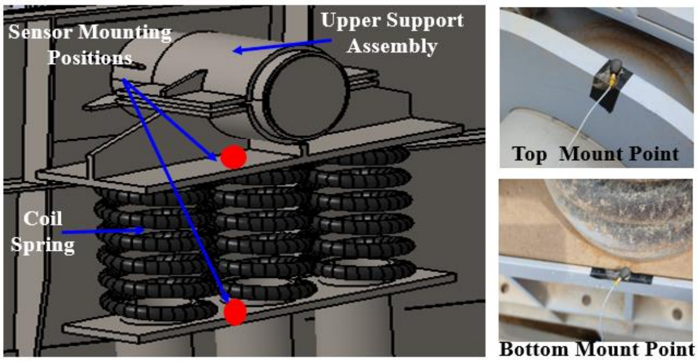


Figure 5 Vibration measurement points of the screen and sand units

3.2. Vibration analysis

Figure 6 presents measured vibration signals of the sand unit. More specifically, Figures 6 (a) and (b) shows the vibration responses in time and frequency domains measured at the top and bottom point of the coil spring, respectively, by operating the sand unit only (The other facilities are rest), while Figures 6 (c) and (d) presents vibration responses measured at the top and bottom point of the coil spring, respectively, by operating entire artificial sand manufacturing facilities including jaw crushers, cone crushers, barmacs, screen and sand units. It is clearly observed from the frequency spectrums of Figures 6 (a) and (b) that the operating speed of sand unit motor is about 1,080 rpm, and its harmonic excitation system has 18x(times) the fundamental frequency. Thus, the artificial sand manufacturing plant can be defined as an excited rotationally imbalanced system due to large amount of the water and sand entering the sand unit (unbalanced mass) [11-15]. Based on Eq. (4), the calculated VAL at the top point of the coil spring is 147 dB, and the calculated VAL at the bottom point of the coil spring is 116 dB, respectively. In addition, using Eq. (5), the ΔVAL (or isolation level) is determined by 31 dB. Thus, the transmissibility value is evaluated by 0.028, and the percent isolation rate is calculated as 97.2% using Eq. (6). This value indicates that the vibration isolation of the sand unit is good. When the entire artificial sand manufacturing facilities are operated, these values can be evaluated form the frequency spectrums shown in Figures 6 (c) and (d). The calculated VAL is 146 dB at the top point of the coil spring, and the calculated vibration level is 116 dB at the bottom point of the coil spring. The ΔVAL is 30 dB, and the transmissibility is calculated by 0.0316. Thus, the percent isolation rate is calculated as 96.4% which indicates high performance of the vibration

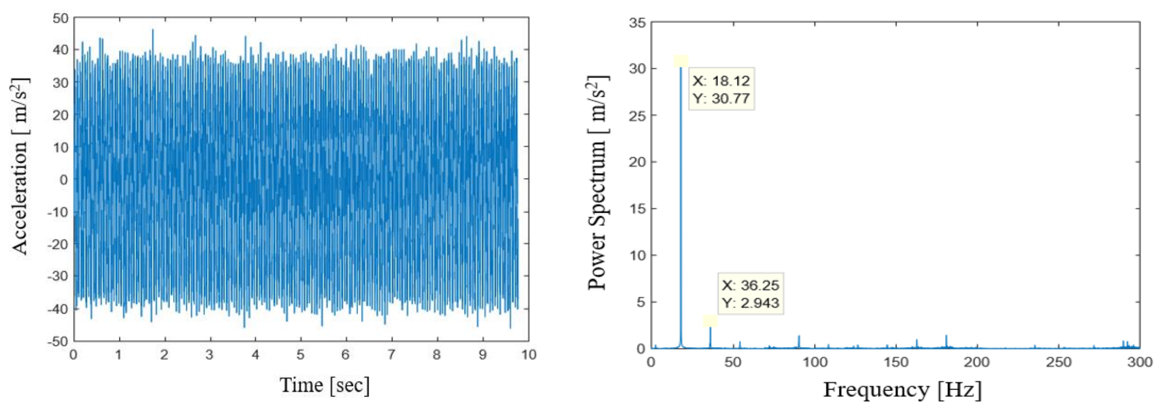
Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

isolation even entire facilities of artificial sand production plant are activated with multiple operating modes. From these results, it can be asserted that the sand unit has good vibration isolation performance itself and it is a valid design of vibration isolation. It is noted here that the waveforms shown in time domains of Figure 6 are the result of defects because of mass imbalance motion and misalignment in the rotating machinery systems [12-15].

Figure 7 presents vibration results of the coil spring installed at the upper and bottom positions of the screen unit when entire manufacturing components such as jaw crushers, cone crushers, barmacs, and sand units are operated. It is identified from the results that the operating speed of the sand unit motor is about 960 rpm, and it has also a harmonic excitation system having 16x(times) as fundamental frequency. It is observed form time domain signal shown in Figure 7 (b) that the signal waveform is much different from the sand unit signal data. This is caused from complex motion associated with rotor dynamics and bearing properties of the screen unit. The vibration acceleration level (*VAL*) at the upper point of the coil spring is calculated by 150dB, and the *VAL* at the bottom point of the coil spring is by 140dB, respectively. The Δ *VAL* (isolation level rate) is 10dB and the vibration transmissibility is evaluated as 0.316. Hence, the percent isolation rate is determined by 68.4%. Therefore, the vibration isolation of the coil spring for the screen unit is worse than that of the coil spring for the sand unit. This reason is identified from the time wave form of the acceleration signal which exhibits outer bearing defect in the screen unit. The result of defects is occurred from mass imbalance motion and misalignment in the rotating machinery systems. Thus, it needs to be investigated more precise analysis using more accurate diagnosis of rotary machine. It is concluded from the results shown in Figures 6 and 7 that the screen unit isolation system needs to be improved as much to that of the sand unit.

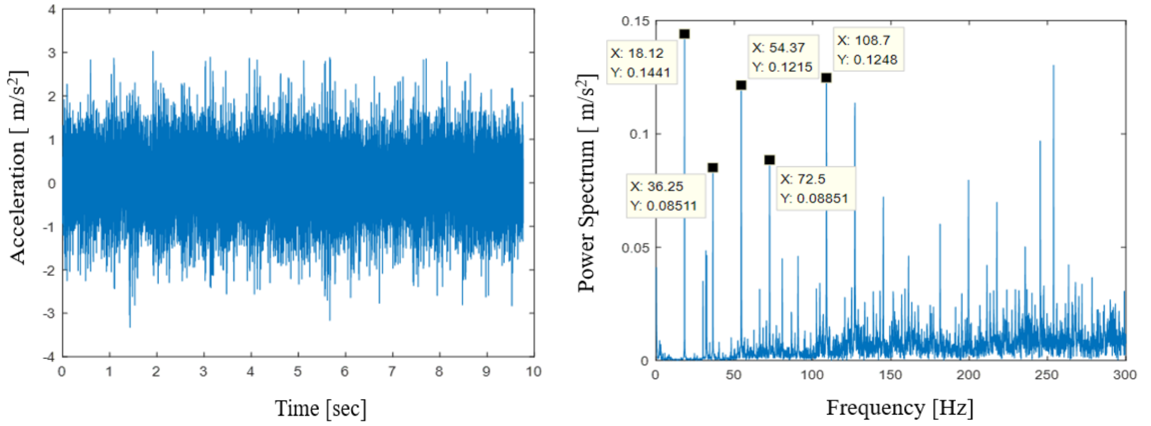
As for the next measurement, two most serious places are chosen to resolve many complaints raised from the transmission of such vibrations, shock, and noise by the residents in the adjacent areas. It is remarked that the shipping control center is located 50 meter and the plant office is located 250 meters from the main production facilities. Figures 8 (a) and (b) show vibration responses measured at the shipping control center and plant office by operating entire production facilities. It is clearly observed from this figure that the fundamental frequencies are 18Hz, 20Hz and 22Hz. These fundamental frequencies correspond to the driving (or exciting) frequencies of the large-power motors for the sand and screen units. The *VAL* at the shipping control center and plant office are calculated by 104dB and 97dB, respectively. These results confirm that the attenuation effect of vibration amplitude level is acquired with the increase of the distance from the plant location. Unlike the vibration signals at the screen and sand units, it is very interesting to observe the beating phenomenon from the signals at the shipping center and office floor. The beating is observed with short period from the time domain waveform. The beating phenomenon can be occurred by resonance when the fundamental frequencies corresponding to the driving frequencies of sand and screen unit actuators are close. The screen and sand units are independently connected by spot welding paralleled with H-beam. Therefore, the occurrence of the beating behavior is seriously considered as one of main reasons which can cause high vibration levels. This issue is to be discussed more details in the section for vibration reduction.



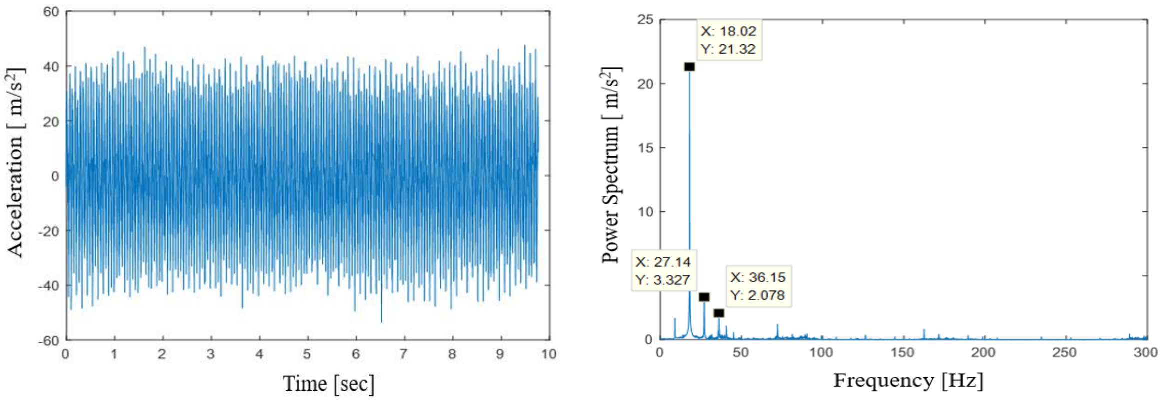
Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

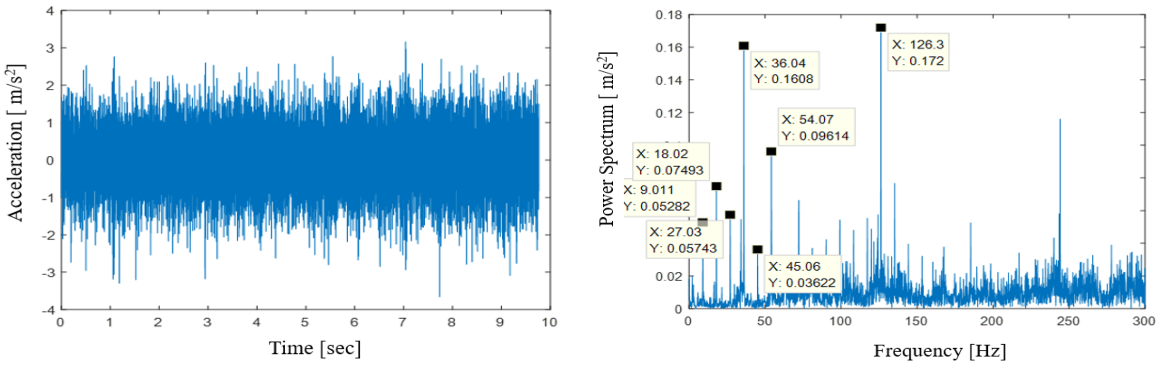
(a)



(b)

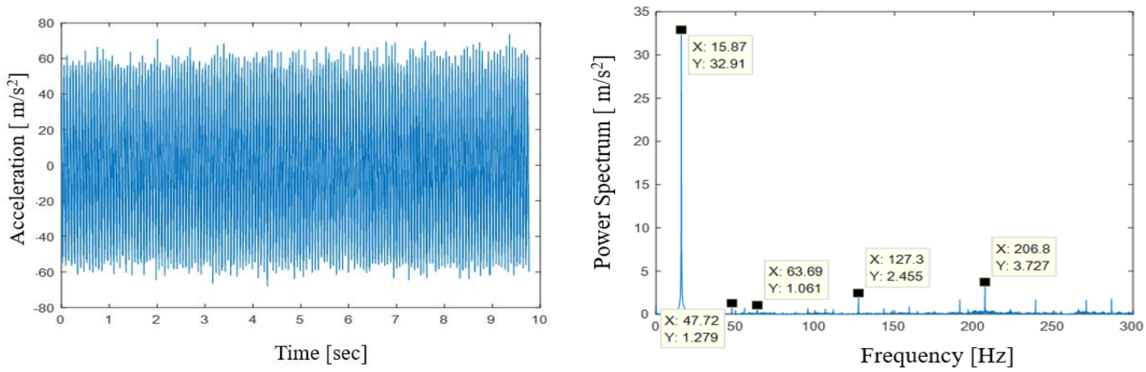


(c)

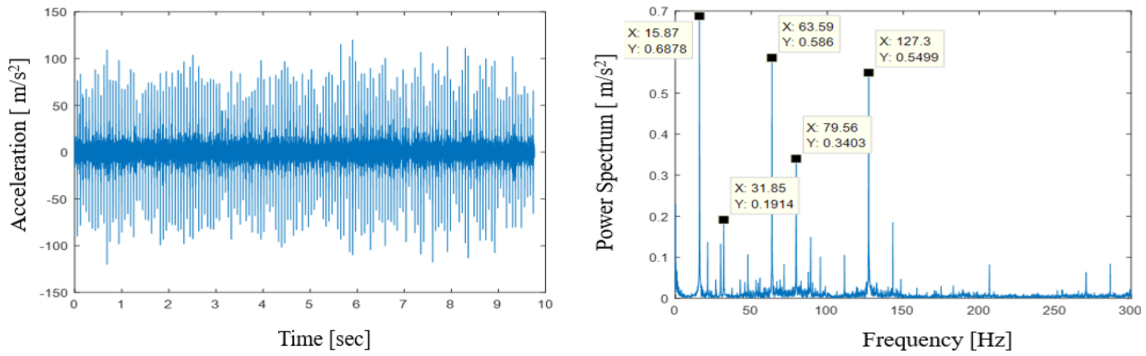


(d)

Figure 6 Vibration responses of the sand unit in time and frequency domains; (a) Vibration response at the top point of the coil spring: sand unit operating only; (b) Vibration response at the bottom point of the coil spring: sand unit operating only; (c) Vibration response at the top point of the coil spring: entire facilities operating condition; (d) Vibration response at the bottom point of the coil spring: entire facilities operating condition

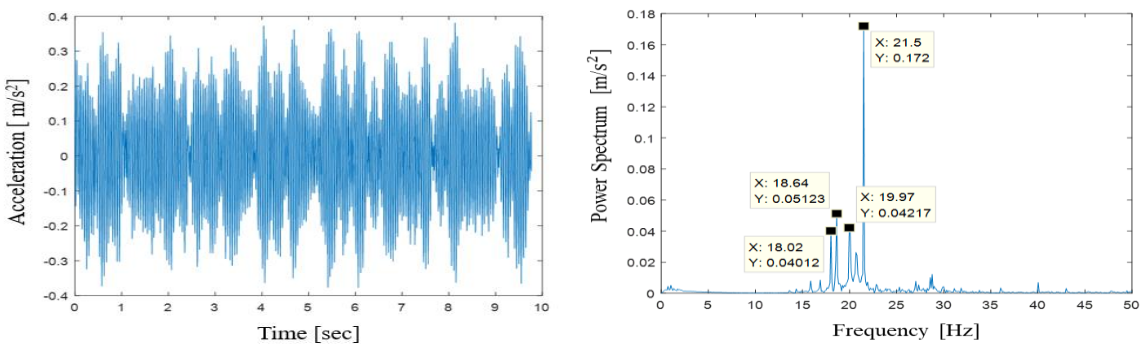


(a)

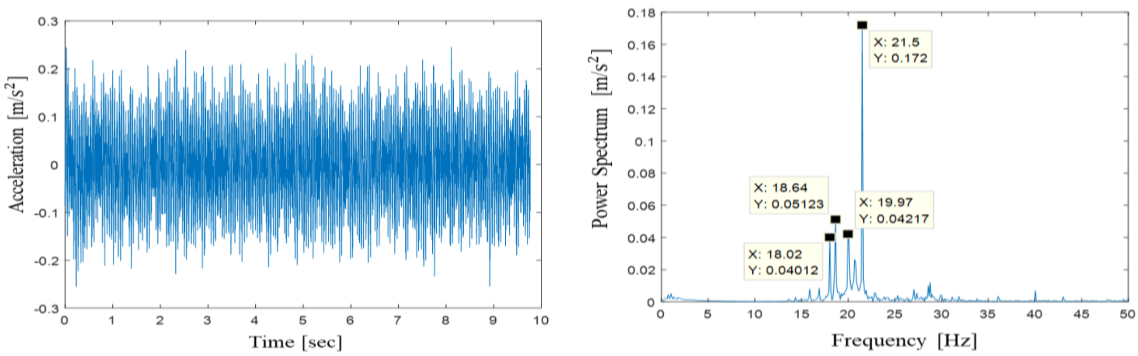


(b)

Figure 7: Vibration responses during multiple operations of entire facilities; (a) Vibration response at the top point of the coil spring in the screen unit; (b) Vibration response at the bottom point of the coil spring in the screen unit



(a)



(b)

Figure 8: Vibration responses under multiple operations of entire facilities; (a) Vibration response at the shipping control center; (b) Vibration response at the plant office floor

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at Appl. Sci. 2020, 10, 4327; doi:10.3390/app10124327

4. Vibration Reduction

As observed from the measured vibration signals shown in Figure 8 (a), the beating has been occurred due to close driving (or exciting) frequencies of actuating motors during multiple operation of the artificial sand manufacturing plant. The beating phenomenon at this plant was occurred within a short period of time with the pattern of the periodic propagation. It is well known that the beating phenomenon is frequently observed when two harmonic motions with frequencies close to each other are combined. To briefly review the beating, consider a displacement $x(t)$ that is produced by two harmonic forces f_1 and f_2 [11-15]:

$$f_1(t) = F_1 \cos \omega_1 t \quad \text{and} \quad f_2(t) = F_2 \cos \omega_2 t \tag{7}$$

Assume that the steady state responses to f_1 and f_2 are given by

$$x_1(t) = X_1 \cos(\omega_1 t + \phi_1) \quad \text{and} \quad x_2(t) = X_2 \cos(\omega_2 t + \phi_2) \tag{8}$$

Then, because of the linear properties of the system, the following equation is obtained:

$$\begin{aligned} x(t) &= (X_1 + X_2)\cos(\Omega_1 t - \Phi_1)\cos(\Omega_2 t - \Phi_2) \\ &\quad - (X_1 - X_2)\sin(\Omega_1 t - \Phi_1)\sin(\Omega_2 t - \Phi_2) \end{aligned} \tag{9}$$

where,

$$\begin{aligned} \Omega_1 &= \frac{\omega_1 + \omega_2}{2}, \qquad \Omega_2 = \frac{\omega_1 - \omega_2}{2} \\ \Phi_1 &= \frac{\phi_1 + \phi_2}{2}, \qquad \Phi_2 = \frac{\phi_1 - \phi_2}{2} \end{aligned} \tag{10}$$

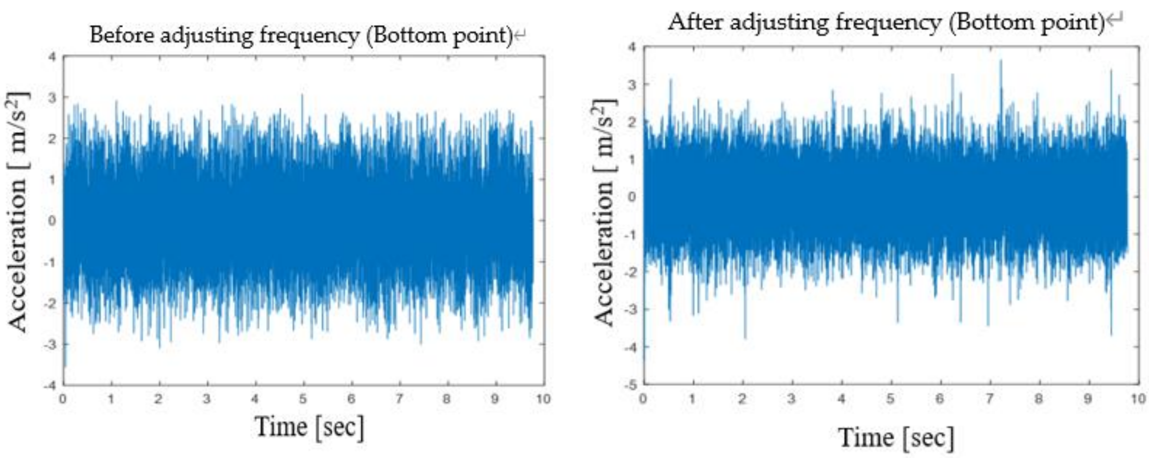
Therefore, the beating magnitude and cycle can be determined by the difference of two frequencies and phase angles. On the other hand, the vibration level due to the beating can be effectively reduced by adjusting the two frequencies. In this work, to avoid the beating behavior, the operating speed (or driving frequency) of the sand unit is adjusted. The original operating speeds of three motors for three sand units are fixed by 1320 rpm, but it is changed a little as time goes on. Therefore, three operating speeds for three sand units become close resulting in the beating behavior. In this work, after measuring the operating speed of each sand unit, it is adjusted by 1,050 rpm, 1320 rpm and 1,180 rpm for the sand unit #1, sand unit #2 and sand unit #3, respectively. Figure 9 presents vibration signals measured at the bottom point of the sand unit during full operation of entire experimental facilities for artificial sand production. It is clearly observed that the vibration level is significantly reduced after adjusting the operating speed (or driving frequency for motors to activate the sand units). More specifically, the power spectrum is remarkably reduced; ΔVAL is 28dB, and the transmissibility is 0.04. Thus, the percent isolation is calculated by 96% which is very high.

However, the vibration signals measured at the sand unit do not clearly show the beating phenomenon. Therefore, vibration signals are measured at the shipping control center and plant office under same operating conditions of three sand units. Figures 10 and 11 presents vibration signals measured at the shipping control center and plant office, respectively. It is noted that the shipping control center is located at 50 meter and the plant office at 250 meters from the main manufacturing facilities of artificial sand. It is clearly seen from the vibration signals in time domain

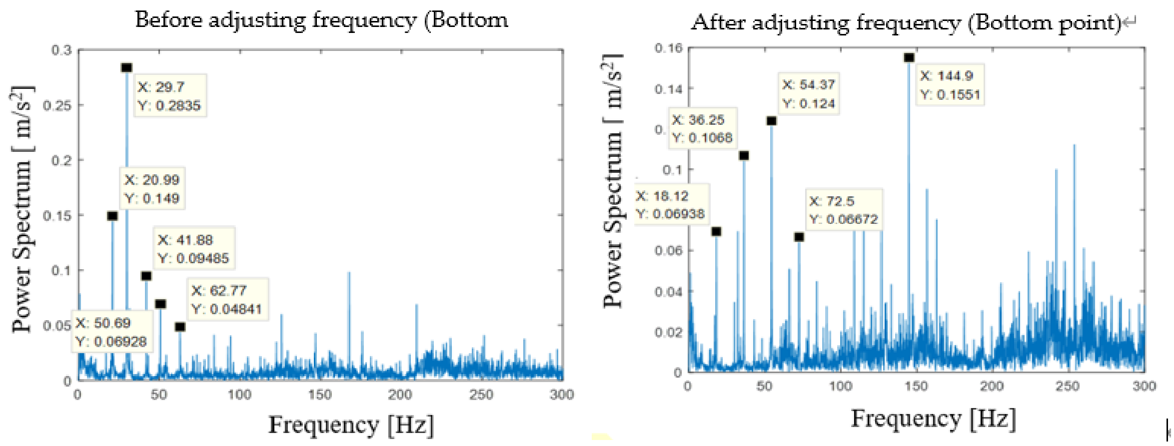
Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at *Appl. Sci.* **2020**, *10*, 4327; doi:10.3390/app10124327

that the beating is occurred at two locations due to the close driving frequencies of three sand units as mentioned in Figure 9. The beating at the shipping control center is more rigorous than that occurred at the plant office. However, the beating is remarkably reduced by adjusting the operating speeds of three sand unit actuators with sufficiently different speeds. The close frequencies of the original operation are seen in the spectrum plot before adjustment and the scattered frequencies are also seen in the spectrum plot after adjusting the operating speeds of the sand units. The vibration measurement and analysis presented in this work are quite self-explanatory verifying that high level of unwanted vibrations can be occurred from the beating phenomenon caused form the close driving frequencies of several actuators in multiple operation of entire facilities of the artificial sand manufacturing plant or any other civil engineering plant. Therefore, both construction of vibration isolation system having high performance and appropriate choice of the driving (or exciting) frequencies of actuators are required simultaneously in the case of multiple operation of several actuators.



(a)

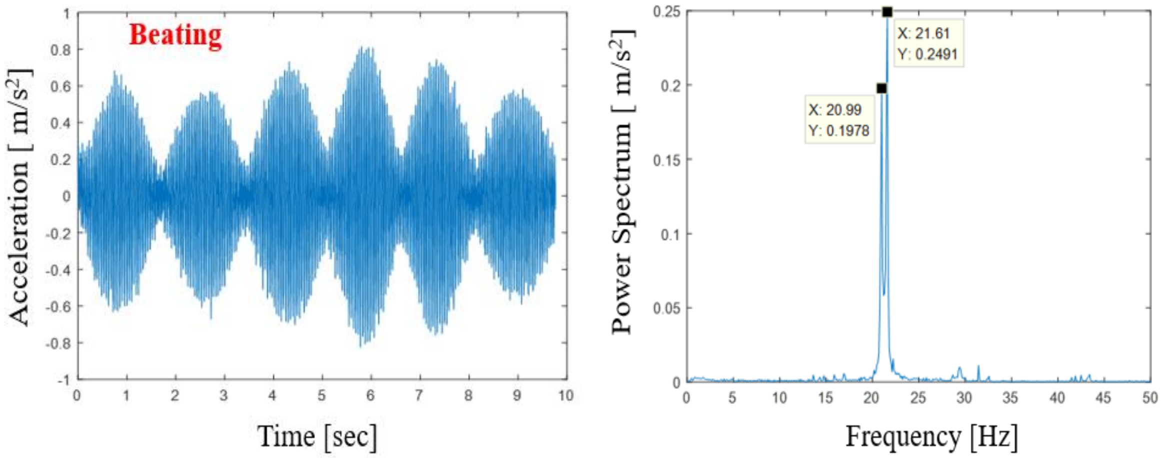


(b)

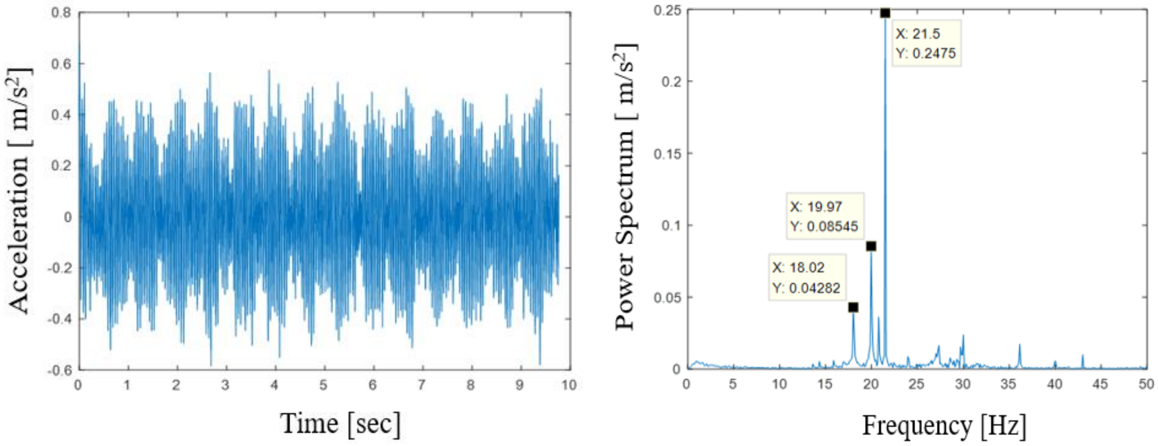
Figure 9 Vibration responses before and after adjusting driving frequency of the sand units: (a)Vibration response of the time domain at the bottom point of sand unit; (b)Vibration response of the frequency domain at the bottom point of the sand unit

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 June 2020 doi:10.20944/preprints202006.0004.v1

Peer-reviewed version available at *Appl. Sci.* **2020**, *10*, 4327; doi:10.3390/app10124327

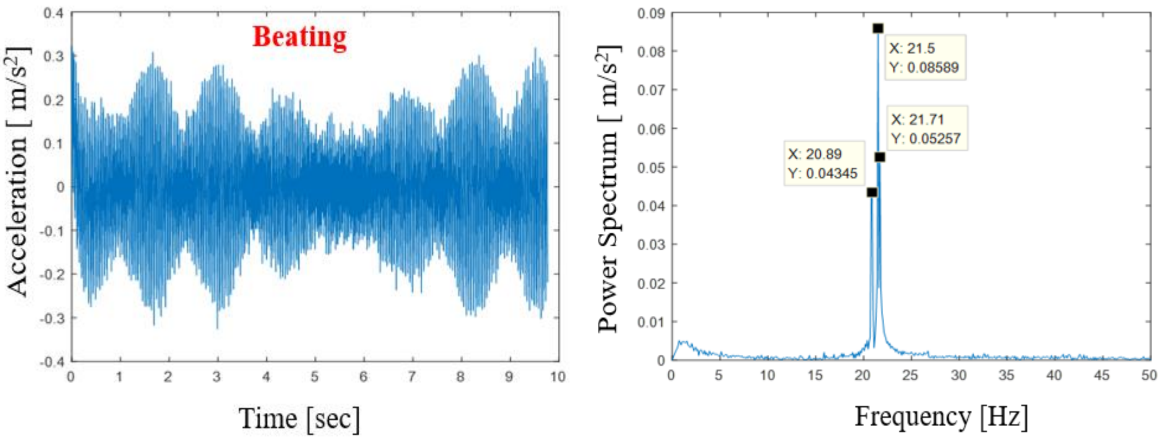


(a)

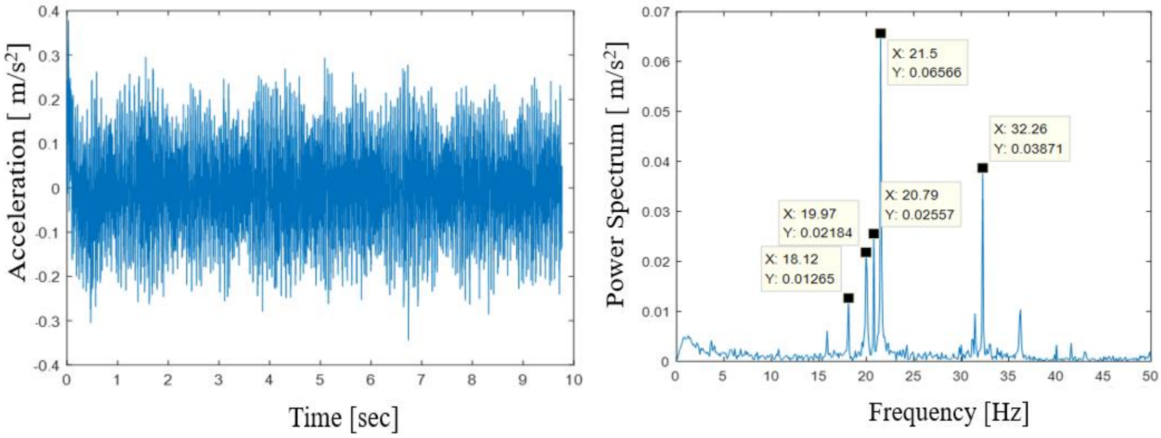


(b)

Figure 10 Vibration characteristics before and after adjusting driving frequencies of the sand units under full facilities operating condition: (a) Vibration responses at the shipping control center before adjusting driving frequency; (b) Vibration responses at the shipping control center after adjusting driving frequency



(a)



(b)

Figure 11: Vibration characteristics at the plant office before and after adjusting driving frequencies under full facilities operating condition: (a) Vibration responses at the plant office before adjusting driving frequency; (b)Vibration responses at the plant office after adjusting driving frequency

5. Conclusion

In this work, vibration levels of an artificial sand manufacturing plant are measured and evaluated in time and frequency domains. After briefly explaining the overall structure of the plant, vibration signals are acquired at the sand and screen units using several accelerometers. Then, using the measured data, vibration acceleration level (*VAL*), isolation level rate (ΔVAL), percent isolation rate, and vibration transmissibility are calculated. It is identified from the vibration analysis that the isolation system of the sand unit is much better than that of the screen unit. More specifically, for the sand unit, *VAL*, ΔVAL, transmissibility and percent isolation are calculated by 116 dB, 31 dB, 0.028, and 97.2%, respectively. However, for the screen unit, those are calculated by 140 dB, 10 dB, 0.316 and 68.4%, respectively. In addition, it is shown that the beating phenomenon is occurred at the shipping control center and plant office located away from the plant site by 50m and 250m, respectively. The beating is caused from the close driving frequencies of several sand units during simultaneous multiple operation of several motors. Thus, in this work unwanted vibrations caused from the beating are significantly reduced by adjusting the driving frequencies of the motors to activate the sand units so that these are sufficiently scattered to avoid the beating. The results and analysis presented in this work have done on the real site of the plant and hence can be effectively used for several plants where multiple operations of several actuators such as motors are to be simultaneously carried out. It is finally remarked that the existing vibration isolation needs to be improved to acquire high reliability and automatic adjustment system of the driving or exciting frequencies needs to be explored in a feedback control manner.

Acknowledgments: This research was supported by Maleun Environment Industrial Company, the authors gratefully appreciate this

Conflicts of Interest: The authors declare that they have no conflict of interest regarding the publication of this article.

References

1. Y. M. Zhao, C.S Liu, X. M. He, et.al., "Dynamic design theory and application of large vibrating screen," *The 6th Intl. Conference on Mining Science& Technology*, 2009, pp. 776–784.

Peer-reviewed version available at *Appl. Sci.* **2020**, *10*, 4327; doi:10.3390/app10124327

2. A.V. Mali, N.N Morey, and Atul. P. Khtri, "Improvement in the efficiency of the Stone crusher, Generic vibration criteria for vibration-sensitive equipment", *Intl. J. of Science, Engineering and Technology Research (IJSETR), Vol. 5, Issue 6, 2,* 2016, pp. 2265-2271.
3. Leonid I. Slepyan and Victor I. Slepyan, "Coupled mode parametric resonance in a vibration screen model", *J. of Mechanical System and Signal Processing*, 2014, pp. 295-304.
4. F. Wu, Y. J. Huang, and S. Xu, "Trispectrum and correlation dimention analysis of magnetorheological damper in vibration screen", *J. of Cent. South Univ.* 19, 2012, pp.1832-1838, https://doi:10.1007/ s117771-012-1216-x.
5. W. Raczka, M. Sibielak, J. Kowal, and J. Konieczny, "Application and SMA Spring for Vibration Screen Control" *J. of Mechanical Low Frequency Noise, Vibration and Active Control.* Vol.32, No.1, 2013, pp.117-132.
6. B. Bessason, C. Madshus, H. A. Frøysteinand, and H. Kolbjørnsen, "Vibration criteria for metrology laboratories", *Measurement Science and Technology*, **10**(11), 1999, pp. 1009-1014.
7. Asia Noise and Vibration Institute, "Noise and Vibration Control for Workplace", *Ybook, ISBN 978-89-967735-7-3*, 2013
8. Korean Society for Noise and Vibration Engineering, "A Handbook of Noise and Vibration", The Committee of the KSNVE, 1995
9. J. D. Irwin, and E. R. Graf, "Industrial Noise and Vibration Control" 2008, pp. 154–196.
10. I. R. Jung, J. Y. Kim, et. al., "Theory and Practice of Noise and Vibration", *Shinkwang Munhwa Sa*, ISBN 978-89-7432-131-4, 2006, pp.137-187.
11. Singiresu. S. Rao, "Mechanical Vibrations 4th International Editions", *Pearson Prentice Hall*, 2004
12. Thomson W, "Theory of Vibration with Applications", *CRC Press*, 1996
13. Andrew. D. Dimarogonas, "Vibration for Engineers 2nd Editions", Prentice Hall, ISBN 0-13-456229-1, 2001.
14. K. H., Shin, J. Hammond, "Fundamental of Signal Processing for Sound and Vibration Engineers", John Wiely & Sons. Ltd, ISBN 978-0-47051188-6, 2008.
15. B. S., Yang, Condition Monitoring and Diagnostics of Rotational Machinery, Inter Vison ISBN 89-5667-320-9, 2006