DOI: 10.21440/0536-1028-2022-3-16-23

Comparative analysis of experimental research into the effect of lasting self-synchronization on a laboratory shaker with three and two vibration exciters

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Abstract

Introduction. *Vibratory transport machines are widely used in the mining industry and other sectors of production. A more detailed analysis of working body oscillation parameters and vibration exciters self-synchronization is required to design vibratory transport machines with new properties. Vibratory machine dynamics was studied with a mathematical model, which made it possible to discover some interesting phenomena, for example, the effect that the authors called the effect of lasting self-synchronization.*

Research objective *is to experimentally confirm the discovered phenomena using a laboratory shaker and assess the degree of these phenomena resistance.*

Methods of research. *In order to confirm and carry out the follow-up study of the discovered phenomena, DVM-014 laboratory training facility was designed and manufactured. A set of experiments with two and three vibration exciters were carried out with the help of this facility.*

Results. *The article presents the results of experiments on detecting the effect of lasting self-synchronization under configurations with two and three vibration exciters and this phenomenon resistance to the changing position of the machine's center of mass. Changes in the machine parameters are also given when either one of the two or two of the three vibration exciters are switched off.*

Summary. *Several conclusions have been made based on the experimental results. The most important of them in terms of technology is the following. The phenomenon of lasting self-synchronization, if any, can be useful when there are pauses in the machine loading. It will significantly reduce energy consumption by switching off one or two motors.*

Keywords: *vibratory transport machines; vibrating screen; self-synchronization; vibration exciter; dynamics; mathematical model.*

Introduction. Vibratory transport machines (VTM) are widely used in the mining industry and other sectors of production [1–4]. A special place is occupied by the VTMs with independently rotating vibration exciters (VE) based on the employment of the VE self-synchronization phenomenon [5–9].

Articles [10–13] developed a mathematical model of VTM dynamics that considers the interaction between drive electric motors, vibration exciters and the working body of the machine. The dynamics of VTM with two, three, and four VE was studied with the mathematical model. A number of interesting features of such machines dynamics were discovered, in particular, the effect that the authors called the effect of lasting self-synchronization.

The effect is as follows. When the machine reaches the stationary synchronous oscillation mode, one of the two or even two of the three drive motors can be switched off, but the machine (under certain conditions) continues to work, the two or three VE still rotate synchronously. This synchronous movement lasts for an infinite span of time, supported by only one motor running. It should be noted that mathematical modeling considered the dynamics of VTM ignoring the influence of the transported material.

The research objective is to experimentally confirm the effect of lasting self-synchronization and assess its resistance.

Methods of research. DVM-014 laboratory training facility was designed and manufactured to confirm and carry out the follow-up study of the discovered phenomena. The exterior and scheme of the facility with the arrangement and numeration of VE are shown in Figure 1.

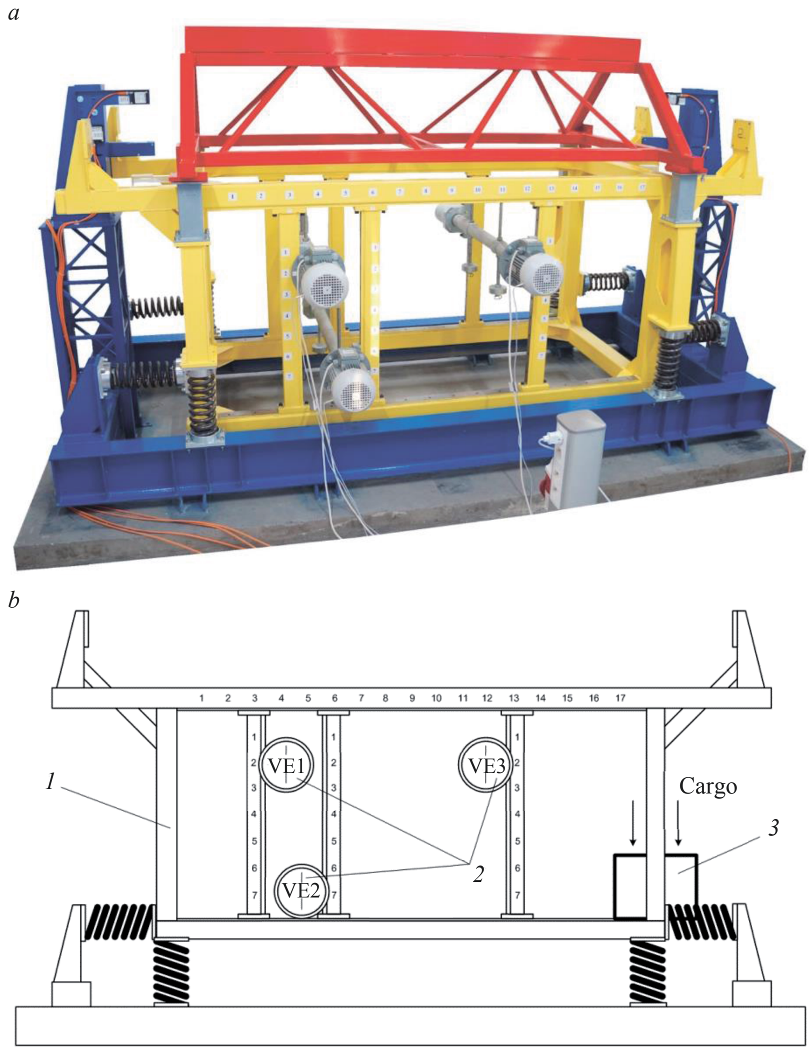

Figure 1. DVM-014 laboratory training facility:
a – exterior; *b* – scheme with the arrangement and numeration of VE; *1* – shaker's working body; *2* – vibration exciters with drive motors; *3* – bulk bin
Рисунок 1. Учебно-лабораторный комплекс ДВМ-014:
а – внешний вид комплекса; *b* – схема комплекса с расположением и нумерацией ВВ (VE1–VE3); *1* – рабочий орган вибростенда; *2* – вибровозбудители с приводными двигателями; *3* – бункер для груза

The facility is aimed at practical research and laboratory practicals on the study and optimization of the dynamics of single-mass and two-mass oscillatory systems under various arrangements of VE. A detailed description of the facility is presented in paper [14].

Results. Some sets of experiments with two and three VE were carried out on the facility. The experimental results showed that for a configuration with three VE, the continuation of the effect of self-synchronization after switching off two out of three VE motors, described in works [13, 15], proved resistant, including when the position of the center of mass changed and the total vibrating mass increased by 20%. Such result was obtained for all instances of VE rotation in one direction, as well as for two instances of rotation in opposite directions.

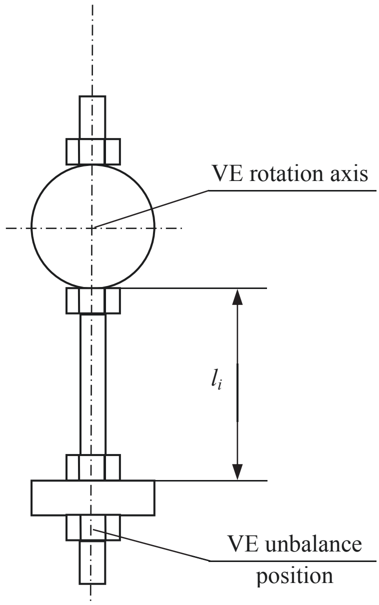

Figure 2. Scheme of unbalance VE: l_i – distance between the rotation axis and the i-th unbalance
Рисунок 2. Схема дебалансного ВВ: l_i – расстояние от оси вращения до i-го дебаланса

Since the placement of the added mass at the extreme point of the working body results in the most significant change in the position of the center of mass, it is arguable that the continuation of VE self-synchronization after switching off two of the three VE motors is resistant to the technological load within the specified limits.

Let us consider a set of experiments where DVM-014 facility simulated the operation of VTM with two VE. The effect of lasting self-synchronization in VTM with two VE rotating in one direction always manifests itself. For that reason, we were interested in the instance with VE rotating in opposite directions, as well as in the dependence between the effect manifestation and the first moment of the vibration exciters.

It the course of the experiments, the first moment changed as VE mass or distance from the rotation axis changed (Figure 2) and was determined by the formula:

$$S_i = m_i l_i,$$

where m_i is the mass of the i-th unbalance, kg; l_i is the distance from VE rotation axis to the i-th unbalance, mm.

The study was carried out under the single-mass mode of the facility. In each experiment, only two motors were initially operating, while the third one was switched off.

After the facility reached a steady state of oscillations, one of the two operating motors was switched off and it was observed whether the VE self-synchronization lasted. The experimental results have been summarized in Table 1.

It can be seen from Table 1 that when one of the two operating motors is switched off, the effect of lasting self-synchronization isn't present in all instances, and under $S_i = 0.116$ kg · m does not occur at all. Under $S_i = 0.158$ kg · m, lasting self-synchronization is stable and is confirmed for all experiments.

Based on the analysis of the data available from experiments, the power factor was calculated for each operating motor using the well-known formula [16]:

$$P = UI \cos \varphi,$$

where P is the active power of the phase, W; U is the effective value of the phase voltage, V; I is the effective value of the phase current, A; cos φ is the power factor of the electrical installation (the ratio of active power to apparent power).

The values of VTM parameters for the experiments with manifested lasting self-synchronization are given in Table 2 (in other experiments, the phenomenon was not observed).

Summary. Analysis of Tables 1 and 2 allows drawing the following conclusions.

Table 1. Experimental results
Таблица 1. Результаты экспериментов

Experiment number	First moment, kg · m	Initial configuration			Action (switching off)			Result		
		VE1	VE 2	VE 3	VE 1	VE 2	VE 3	VE 1	VE 2	VE 3
1	0.116			↻			↻			↻
			↺			⟲			×	
2	0.116			↻			⟳			×
			↺			↺			↺	
3	0.158			↻			↻			↻
			↺			⟲			⟲	
4	0.135			↻			⟳			⟳
			↺			↺			↺	
5	0.126			↺			↺			↺
			↻			⟳			×	
6	0.126			↺			⟲			⟲
			↻			↻			↻	
7	0.135	↻			↻			↻		
			↺			⟲			⟲	
8	0.135	↻			⟳			×		
			↺			↺			↺	

↻ – rotation under the action of the drive motor; ⟳ – rotation with the drive motor switched off; × – stopping down under the switched off motor.

When one of the two VTM drive motors is switched off (the third drive motor is not actuated) and VE rotate in one and in opposite directions, the power factor of the machine increases by an average of 24% in the experiments with the observed lasting self-synchronization. These data are given for various VE masses and various distances between the masses and the rotation axes. The corresponding experiments also show the decreased active power in the steady-state mode by at least 39%.

Let us compare the results presented above with the results obtained in [13, 15] for a machine with three VE. The phenomenon of lasting self-synchronization in the instance with two vibration exciters does not always occur and is not as resistant to the changing position of the center of mass, as was observed in the instance with three VE.

Table 2. The values of VTM parameters
Таблица 2. Значения параметров ВТМ

Experiment number (Table 1)	First moment, kg · m	VE rotation direction	Параметры					
			Rotation frequency, rpm	cos φ	Mean cos φ of the facility	Cos φ variation	Total active power of the facility, W	Change of the total active power of the facility
3	0.158	EM1 switched off	0	–	0.223	+25%	549	–40%
		EM2 L	994	0.224				
		EM3 R	994	0.221				
4	0.135	EM1 switched off	0	–	0.22	+24%	547	–39%
		EM2 L	994	0.220				
		EM3 R	994	0.219				
6	0.126	EM1 switched off	0	–	0.223	+23%	549	–39%
		EM2 R	996	0.225				
		EM3 L	995	0.220				
7	0.135	EM1 R	995	0.217	0.223	+23%	551	–39%
		EM2 L	995	0.228				
		EM3 switched off	0	–				

EM – electric motor; L – leftwards; R – rightwards.

In addition, when one of the two motors is switched off, the vibration direction changes significantly, much more significantly than the vibration ellipse orientation in the instance of three VE (even with two of them switched off). In view of the above, the possibility of using lasting self-synchronization in the VTM working cycle is called into question. However, this phenomenon, if any, can be useful when there are pauses in the machine loading. It will significantly reduce energy consumption by switching off one motor.

This is much better than keeping both motors running or switching both motors off, causing the machine to go through high amplitude resonant oscillations twice when running-out and restarting. Moreover, under the previously switched off motor, the machine enters the normal operating mode several times faster than when it was started, and this is not accompanied by any noticeable transient. This is due to the fact that, while operating in the lasting self-synchronization mode, the machine continued non-stop superresonance oscillations.

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Received 3 March 2022

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УДК 622.231 DOI: 10.21440/0536-1028-2022-3-16-23

Сравнительный анализ экспериментальных исследований эффекта сохраненной самосинхронизации на лабораторном вибростенде с тремя и двумя вибровозбудителями

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Реферат
Введение. *Вибротранспортные машины широко применяются как в горной промышленности, так и в других производственных сферах. Проектирование вибротранспортных машин с новыми качествами требует более подробного анализа параметров колебаний рабочего органа машины и самосинхронизации вибровозбудителей. Исследование динамики вибромашины с помощью математической модели позволило обнаружить ряд интересных новых явлений, например эффект, названный авторами эффектом сохраненной самосинхронизации.*
Цель работы. *Экспериментально подтвердить обнаруженные явления, используя лабораторный стенд, а также оценить степень их устойчивости.*
Методика. *С целью подтверждения и дальнейшего исследования обнаруженных явлений спроектирован и изготовлен учебно-лабораторный комплекс ДВМ-014. На этом комплексе проведены серии экспериментов с двумя и тремя вибровозбудителями.*
Результаты. *В статье приводятся результаты экспериментов по обнаружению эффекта сохраненной самосинхронизации в конфигурациях стенда с двумя и тремя вибровозбудителями и устойчивости этого явления к изменению положения центра масс машины. Приводятся также изменения параметров машины при отключении одного из двух или двух из трех вибровозбудителей.*
Выводы. *По результатам проведенных экспериментов в работе сделано несколько выводов. Наиболее важный из них в технологическом отношении следующий. Явление сохраненной самосинхронизации, в случаях, когда оно имеет место, может оказаться полезным при возникновении пауз в загрузке машины. Оно позволит значительно уменьшить потребление энергии за счет отключения одного или двух двигателей.*

Ключевые слова: *вибротранспортные машины; вибрационный грохот; самосинхронизация; вибровозбудитель; динамика; математическая модель.*

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Поступила в редакцию 3 марта 2022 года

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Для цитирования: Азаров Е. Б. Сравнительный анализ экспериментальных исследований эффекта сохраненной самосинхронизации на лабораторном вибростенде с тремя и двумя вибровозбудителями // Известия вузов. Горный журнал. 2022. № 3. С. 16–23 (In Eng.). DOI: 10.21440/0536-1028-2022-3-16-23
For citation: Azarov E. B. Comparative analysis of experimental research into the effect of lasting self-synchronization on a laboratory shaker with three and two vibration exciters. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering*. 2022; 3: 16–23. DOI: 10.21440/0536-1028-2022-3-16-23