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The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.

The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

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Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық рефеpативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық рефеpативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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ANALYSIS OF THE APPLICATION OF NON-DESTRUCTIVE TESTING METHODS FOR ASSESSING THE TECHNICAL CONDITION OF MINING EQUIPMENT MOTORS BASED ON VIBRATION PARAMETERS

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Abstract. *Relevance.* The reliability and failure-free operation of mining equipment engines largely depend on their vibration condition, which reflects dynamic loads, installation quality, and the technical state of components. The use of non-destructive vibration diagnostics enables early fault detection without shutting down equipment, which is critically important for diesel generator sets providing uninterrupted power supply at mining enterprises. *Objective.* To analyze the effectiveness of non-destructive vibration testing methods for assessing the technical condition of mining equipment engines using a Mitsubishi S12R diesel generator rated at 880 kW before and after alignment. *Methods.* Experimental studies of vibration parameters were carried out at the supports, engine crankshaft level, and generator shaft under various load modes. Measurements were performed using a noise and vibration analyzer with registration of harmonic components of vibration velocity $v_0(0.5)$, $v_0(1)$, $v_0(2)$, and total values $v\Sigma pik$ in vertical, transverse, and axial directions. The assessment was conducted according to manufacturer recommendations and standard vibration diagnostic methodologies. *Results and Conclusions.* The study revealed that vibration levels at the supports, as well as on the engine and generator before and after alignment, remain high in all operating modes, indicating resonance effects and reduced structural rigidity of mountings. The highest values were recorded in the transverse direction, particularly near generator bearings. The obtained results expand diagnostic indicators for identifying the causes of increased vibration and can be applied in developing monitoring and maintenance procedures for power units used in mining operations.

Keywords: vibration diagnostics, non-destructive testing, diesel generator, mining equipment, vibration velocity, alignment, technical condition, monitoring

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ДІРІЛ ПАРАМЕТРЛЕРІ БОЙЫНША ТАУ-КЕН ЖАБДЫҒЫ ҚОЗҒАЛТҚЫШТАРЫНЫҢ ТЕХНИКАЛЫҚ ЖАЙ-КҮЙІН БАҒАЛАУ ҮШІН БҰЗБАЙТЫН БАҚЫЛАУ ӘДІСТЕРІН ҚОЛДАНУДЫ ТАЛДАУ

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Аннотация. *Өзектілігі.* Тау-кен жабдықтары қозғалтқыштарының сенімділігі мен сенімділігі көбінесе олардың діріл күйімен анықталады, бұл динамикалық жүктемелердің деңгейін, монтаждау сапасын және тораптардың техникалық күйін көрсетеді. Діріл диагностикасының бұзбайтын әдістерін қолдану жабдықты пайдаланудан шығармай ақауларды уақтылы анықтауға мүмкіндік береді, бұл әсіресе тау-кен кәсіпорындарын үздіксіз энергиямен қамтамасыз ететін дизель-генератор қондырғылары үшін өте маңызды. *Мақсаты.* 880 кВт Mitsubishi s12r дизельді генераторының мысалында тау-кен жабдықтары қозғалтқыштарының техникалық жағдайын бағалау үшін бұзбайтын дірілді бақылау әдістерін қолдану тиімділігін талдау. *Әдістері.* Тіректердегі діріл параметрлеріне, қозғалтқыштың иінді білігінің деңгейіне және әртүрлі жүктеме режимдеріндегі генератор білігіне эксперименттік зерттеулер жүргізілді. Өлшеуді Шу мен діріл анализаторы V Гарм(0,5), v_0(1), vσ(2) діріл жылдамдығының гармоникалық компоненттерін және vσpik жиынтық мәндерін тік, көлденең және осьтік бағытта тіркей отырып жүргізді. Бағалау жоғары айналымды қозғалтқыштар өндірушілерінің нормативтік ұсыныстары және діріл диагностикасы әдістері бойынша жүргізілді. *Нәтижелер мен қорытындылар.* Тіректердегі, сондай-ақ қозғалтқыштағы және генератордағы туралауға дейінгі және кейінгі діріл деңгейлері барлық жұмыс режимдерінде жоғары болып қалады, бұл резонанстық құбылыстардың болуын және бекітпелердің құрылымдық қаттылығының әлсіреуін көрсетеді. Ең Үлкен мәндер көлденең бағытта, әсіресе генератордың мойынтіректер аймағында бекітілген. Алынған нәтижелер дірілдің жоғарылау себептерін бағалаудың диагностикалық белгілерін кеңейтеді және тау-кен өнеркәсібінің энергетикалық қондырғыларына мониторинг және техникалық қызмет көрсету регламенттерін әзірлеу кезінде пайдаланылуы мүмкін.

Түйін сөздер: діріл диагностикасы, бұзбайтын бақылау, дизель генераторы, тау-кен жабдықтары, діріл жылдамдығы, орталықтандыру, техникалық жағдайы, мониторинг

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АНАЛИЗ ПРИМЕНЕНИЯ МЕТОДОВ НЕРАЗРУШАЮЩЕГО КОНТРОЛЯ ДЛЯ ОЦЕНКИ ТЕХНИЧЕСКОГО СОСТОЯНИЯ ДВИГАТЕЛЕЙ ГОРНОДОБЫВАЮЩЕГО ОБОРУДОВАНИЯ ПО ВИБРАЦИОННЫМ ПАРАМЕТРАМ

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Аннотация. *Актуальность.* Надёжность и безотказность работы двигателей горнодобывающего оборудования во многом определяется их вибрационным состоянием, которое отражает уровень динамических нагрузок, качество монтажа и техническое состояние узлов. Применение неразрушающих методов вибрационной диагностики позволяет своевременно выявлять дефекты без вывода оборудования из эксплуатации, что особенно важно для дизель-генераторных установок, обеспечивающих бесперебойное энергоснабжение горных предприятий. *Цель.* Анализ эффективности применения методов неразрушающего вибрационного контроля для оценки технического состояния двигателей горнодобывающего оборудования на примере дизель-генератора Mitsubishi S12R мощностью 880 кВт до и после центровки. *Методы.* Проведены экспериментальные исследования вибрационных параметров на опорах, уровне коленчатого вала двигателя и валу генератора в различных режимах нагрузки. Измерения выполнялись анализатором шума и вибрации с регистрацией гармонических составляющих виброскорости $v_0(0{,}5)$, $v_0(1)$, $v_0(2)$ и суммарных значений $v\Sigma pik$ в вертикальном, поперечном и осевом направлениях. Оценка производилась по нормативным рекомендациям производителей высокооборотных двигателей и методикам вибродиагностики. *Результаты и выводы.* Установлено, что уровни вибрации на опорах, а также на двигателе и генераторе до и после центровки остаются высокими во всех режимах эксплуатации, что указывает на наличие резонансных явлений и ослабление конструкционной жёсткости креплений. Наибольшие значения зафиксированы в поперечном направлении, особенно в зоне подшипников генератора. Полученные результаты расширяют диагностические признаки оценки причин повышенной вибрации и могут использоваться при разработке регламентов мониторинга и технического обслуживания энергетических установок горнодобывающей отрасли.

Ключевые слова: вибрационная диагностика, неразрушающий контроль, дизель-генератор, горнодобывающее оборудование, виброскорость, центровка, техническое состояние, мониторинг

Introduction. The development of priority areas will increase the adoption of advanced digital technologies at all stages of the mining equipment lifecycle, which, in turn, will improve the safety and efficiency of mining operations. This safety depends largely on the reliability and trouble-free operation of power units and key machine components. Over the past period, the global and domestic mining industries have seen significant changes in the use and development of equipment condition monitoring systems, particularly for engines and drive systems. The results of continuous monitoring and assessment of the actual technical condition have become widely used both in daily operation and during scheduled preventive maintenance and certification checks of equipment. This approach is reflected in the requirements of modern international standards, industry regulations, and operating procedures (Varenik et al., 2023; Zaalishvili et al., 2024).

Diesel generator sets (DGS) for the mining industry are reliable and powerful solutions that provide a stable power supply where high performance and uninterrupted operation are essential. They are ideal for large industrial facilities, commercial buildings, infrastructure projects, and other applications where power outages are unacceptable. The generators operate in automatic mode, which minimizes the risk of failures and ensures voltage and frequency stability (Bosikov et al., 2023).

The Mitsubishi S12R industrial diesel generator with a capacity of 880 kW is used in mining applications for primary or backup power supply (Isametova et al., 2025).

The use of a large-displacement, multi-cylinder, radiator-cooled diesel engine with a constant speed of 1800 rpm ensures high reliability and maintainability. This model is an industrial diesel generator designed for continuous operation (Gendler et al., 2025).

This unit is designed for permanent installation and can be installed either outdoors (in a container or enclosure) or indoors (in an open configuration or enclosure). This model can be used for grid backup, and in continuous operation, the diesel generator can supply power to consumers (Khekert et al., 2025; Kondratev et al., 2023; Kondratev et al., 2020).

It is also used in power plants or similar industrial equipment to provide backup or primary power supply. The relevance of studying vibration parameters in industrial internal combustion engines (ICEs) is determined by several factors:

– the possibility of non-destructive testing of the technical condition, which allows determining the actual condition of a dynamically operating unit without lengthy equipment downtime (Kozhukhova et al., 2018; Malozyomov et al., 2025);

– fault detection.

Vibration parameter analysis helps identify defects such as system rigidity loss, wear of piston components, faults in the fuel supply and distribution system, crankshaft bearing damage, and more (Malozyomov et al., 2024; Shabanov et al., 2023).

Predicting vibration conditions during the design and development stages of engines using digital technologies (digital twins, CAE modeling) helps reduce structural vibration during process upgrades. This reduces the cost and time required to create prototypes and conduct full-scale experiments to refine vibroacoustic characteristics (Tananykhin et al., 2026; Tynchenko et al., 2024).

Therefore, studying the vibration parameters of mining diesel generator sets is important for equipment owners and service departments, as it helps reduce downtime, lower repair costs, and improve service quality (Filina et al., 2024).

Test object and conditions.

1. Engine at crankshaft level before and after alignment.
2. Generator at shaft level before and after alignment.
3. Supports before and after alignment.

− Test conditions:

− Mode I, idle speed (i/s), n = 1800 min^{-1} before and after generator alignment.

− Mode II, 25% of the rated load Ne_{nom}, n = 1800 min^{-1} before generator alignment.

− Mode III, 30% of the rated load Ne_{nom}, n = 1800 min^{-1} after generator alignment.

− Mode IV, 50% of the rated load Ne_{nom}, n = 1800 min^{-1} after generator alignment.

− Mode IV, 70% of the rated load Ne_{nom}, n = 1800 min^{-1} after generator alignment.

The inspection diagram in Fig. 1 shows the inspection procedure before and after the diesel generator set alignment.

The inspection was performed using the following measuring instruments:

SVAN 958 noise and vibration analyzer from Svantek Ltd (Poland), serial number 35031, with an SV85 vibration sensor, serial number D1198.

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Inspection results.

The results of the measurements, in accordance with the measurement point arrangement diagram, are presented in Tables 1 and 2, and Figs. 2–4.

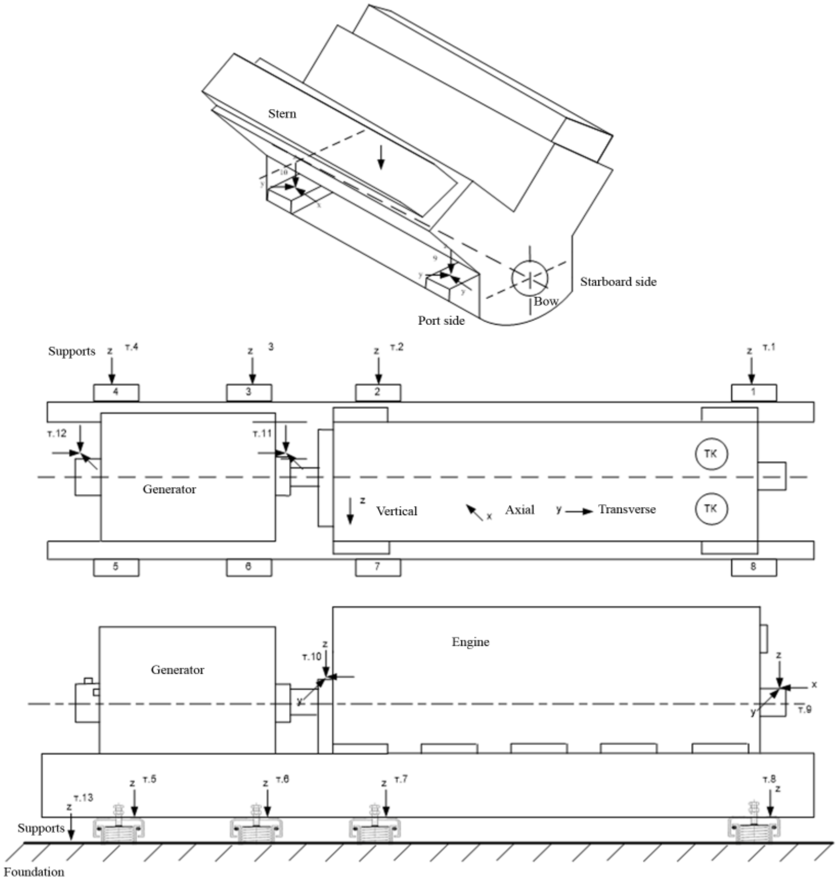

Figure 1. Schematic diagram of an industrial diesel generator set with a Mitsubishi S12R engine. Measurement points along the length of the machine: 1–8 (Z) supports; 9, 10 engine crankshaft level; 11, 12 generator shaft level, 13Z casing (foundation).

Methodological aspects. To diagnose the causes of increased generator vibration, a methodology developed by Caterpillar, a manufacturer of high-speed gas and diesel engines, was used.

To analyze generator vibration, the following vibration signal processing was performed in the vertical (Z), axial (X), and transverse (Y) directions of the vibration velocity value:

1) v_0 Peak at the frequency of the corresponding half-turn $v_{0(1/2)}$ and turn $v_{0(1)}$ and its harmonic $v_{0(2)}$ in the 1/8 octave frequency band of the engine 30 Hz (1800 min-

1) vibration values in accordance with the recommendations of the manufacturer "Caterpillar" are:

– for the internal combustion engine at the crankshaft level, and the generator at the shaft level ≤ 9.97 mm/s ("severe vibration operating conditions");

– for the diesel generator mounts, there are no recommendations from the manufacturer Caterpillar; according to operating experience, the vibration levels of the diesel generator mounts are half that at the engine crankshaft level.

2) $v_{\Sigma pik}$ is the sum of the values of v_0. The peak of all harmonics $v_{0(0,5)}$, $v_{0(1)}$, $v_{0(1,5)}$, $v_{0(2)}$, $v_{0(2,5)}$, $v_{0(3)}$, $v_{0(3,5)}$, $v_{0(4)}$, $v_{0(4,5)}$, $v_{0(5)}$, $v_{0(5,5)}$, $v_{0(6)}$, $v_{0(6,5)}$, $v_{0(7)}$, $v_{0(7,5)}$, $v_{0(8)}$ vibration values in accordance with the recommendations of the manufacturer Caterpillar are:

– for internal combustion engines at the crankshaft level, and generator at the shaft level ≤ 35 mm/s ("severe vibration operating conditions");

The results of the conducted control. From Table 1 it is evident that

– all diesel generator supports are heavily loaded in the transverse direction (y) and exhibit high maximum vibration levels in all operating modes of diesel generator #1 at points 1Y, 8Y;

– at point 7Y, the highest vibration level in idle mode after diesel generator alignment at double engine speed v0(2) is 8.89 mm/s, creating a resonance condition.

Figure 2 shows that vibration levels are virtually identical before and after diesel generator alignment, and sometimes even exceed the values slightly, for example, at support #8 at point 8Y. The effects of vibration forces on the supports before and after diesel generator #1 alignment are virtually identical.

From Table 2 shows that

– the vibration values on the engine and generator are maximum in the transverse direction (Y) and slightly exceed the maximum permissible values of the manufacturer of high-speed engines, Caterpillar, especially at point 12Y on the generator aft bearing in all operating modes before and after alignment of the diesel generator set.

– the vibration values $\boldsymbol{v}_{\boldsymbol{0(\Sigma)}}$ on the engines in the vertical direction at point 9(Z) reach their maximum values of 51.91 mm/s, which indicates a weakening of the engine structure fastening to the foundation (structural rigidity).

– the difference between the vibration parameter values $v_{0(0,5),}$ $v_{0(1),}$ $v_{0(2)}$ at all control points and operating modes of the engine and generator before and after the diesel generator alignment is more than two times higher, indicating a resonance condition (Figs. 2–4). For example, in mode V, 70% of Ne_{nom} after alignment, the difference in the vibration parameter values $v_{0(0,5),}$ $v_{0(1),}$ $v_{0(2)}$ is at points: 9Y – 1 mm/s; 10Y – 5 mm/s; 11Y – 7 mm/s; 12Y – 11 mm/s.

The following conclusions can be drawn from the study:

1. Vibration parameter values at the diesel generator supports before and after alignment are high in all operating modes, resulting in a resonance effect.

2. The values of the vibration parameters in the transverse direction (Y) at the level of the ICE crankshaft and the generator at the shaft level before and after alignment in all operating modes are high, however, with an increase in the load of the diesel generator, an increase in vibration is not observed, the effect of misalignment of the engine and the axle wiring equipment (displacement force) is not observed, however, the difference between the values of the vibration parameters $v_{0(0,5),}$ $v_{0(1),}$ $v_{0(2)}$ at all control points and operating modes of the engine and generator before and after alignment of the diesel generator is more than two times or higher, a condition for resonance to occur appears.

3. The vibration values $\boldsymbol{v}_{0(\sum pik)}$ at the level of the engine crankshaft and the generator at the shaft level before and after centering at some points and directions reach maximum values, a condition appears for weakening the fastening of the engine structure to the foundation (structural rigidity).

4. Check and adjust the supports. If the manufacturer's recommendations indicate the support replacement period has passed and the diesel generator set has reached the specified operating time, replace them.

5. Perform vibration monitoring every 720 hours, as the vibration levels of individual components of diesel generator No. 1 are close to "severe operating conditions," according to (the specifications).

6. To diagnose and analyze elevated vibration levels of the diesel generator, compare the parameters with those of a similar type of diesel generator.

Table 1. Vibration parameters on diesel generator supports before and after alignment, rotation frequency 30 Hz 1800 min^{-1}).

	Vibration velocity, mm/s															
	***I mode**, idle speed (i/s),* **before centering**															
	1Z	*1Y*	*2Z*	*3Y*	*3Z*	*3Y*	*4Z*	*4Y*	*5Z*	*5Y*	*6Z*	*6Y*	*7Z*	*7Y*	*8Z*	*8Y*
$v_{0(0,5)}$	1,31	-	0,43	-	0,57	-	1,22	-	1,1	-	0,63	-	0,81	-	1,05	-
$v_{0(1)}$	6,44	-	3,04	-	2,2	-	1,65	-	2,42	-	1,2	-	2,71	-	3,02	-
$v_{0(2)}$	2,46	-	0,67	-	1,25	-	4	-	6,84	-	0,95	-	1,75	-	3,99	-
	***I mode**, idle speed (i/s),* **after centering**															
$v_{0(0,5)}$	0,93	0,88	0,12	0,79	0,72	0,57	1,38	0,41	1,05	0,40	0,52	0,57	0,70	0,65	1,10	1,08
$v_{0(1)}$	5,15	12,58	3,74	6,23	1,98	7,67	2,19	4,89	2,76	5,24	1,62	7,82	3,32	5,91	3,92	11,04
$v_{0(2)}$	2,86	6,73	0,16	9,59	0,60	2,19	4,58	3,70	5,87	4,70	0,19	2,68	1,02	8,89	3,64	6,35
	***II mode**, 45 % of Ne_{nom},* **before centering**															
$v_{0(0,5)}$	1,92	-	0,35	-	1,13	-	2,39	-	2,5/	-	0,99	-	0,64	-	1,91	-
$v_{0(1)}$	6,71	-	3,9	-	2,37	-	1,66	-	1,97	-	1,01	-	2,39	-	2,54	-
$v_{0(2)}$	2,14	-	0,68	-	1,05	-	2,89	-	6,1	-	0,24	-	0,98	-	3,06	-
	***II mode**, 30 % of Ne_{nom},* **after centering**															
$v_{0(0,5)}$	0,75	1,42	0,55	0,63	0,89	0,55	1,76	0,28	1,47	0,46	0,60	0,66	0,68	0,73	1,52	1,15
$v_{0(1)}$	5,60	11,96	3,34	5,85	1,95	7,07	1,36	5,30	2,51	5,25	1,67	7,80	2,50	6,14	3,05	10,58
$v_{0(2)}$	2,39	6,94	0,64	7,62	1,13	3,26	5,75	3,11	5,95	4,22	0,45	4,78	1,21	8,52	2,73	6,13

	III mode, *50 % of* Ne_{nom}, **after centering**															
$v_{0(0,5)}$	1,75	1,43	0,36	0,79	1,07	0,66	2,85	0,40	2,03	0,63	0,75	0,71	1,12	1,31	2,87	3,19
$v_{0(1)}$	6,21	12,19	3,49	6,36	2,11	8,27	1,92	3,98	2,14	4,87	1,93	8,23	3,10	6,66	3,44	10,45
$v_{0(2)}$	2,04	5,72	0,29	8,47	1,22	4,23	5,43	2,41	5,80	2,96	0,40	5,05	1,39	7,61	2,99	5,08
	IV mode, *70 % of* Ne_{nom}, **before centering**															
$v_{0(0,5)}$	1,22		1,35		1,73		2,67		2,49		0,88		0,53		2,56	
$v_{0(1)}$	5,75		2,48		2,44		1,83		2,68		1,16		2,24		2,64	
$v_{0(2)}$	1,9		0,51		0,34		2,69		5,55		0,35		1,13		2,52	
	IV mode, *70 % of* Ne_{nom}, **after centering**															
$v_{0(0,5)}$	1,60	1,30	0,32	1,08	1,52	0,67	2,78	0,41	2,07	0,66	0,34	0,97	1,09	1,27	1,67	3,68
$v_{0(1)}$	5,29	11,22	2,55	6,32	1,95	7,60	1,21	5,42	2,52	4,64	1,79	8,89	2,88	6,32	2,78	9,72
$v_{0(2)}$	2,56	4,67	0,84	7,92	0,94	3,54	5,73	1,06	5,31	1,55	1,05	4,71	1,54	7,81	3,73	4,00

Table 2. Vibration parameters of the internal combustion engine and generator DG No. 1 before and after alignment, rotation frequency 30 Hz (1800 min^{-1}).

	Vibration velocity, mm/s												
	I mode, *idle speed (i/s)*, **before centering**												
	9Z	*9Y*	*9X*	*10Z*	*10Y*	*10X*	*11Z*	*11Y*	*11X*	*12Z*	*12Y*	*12X*	Note / Maximum permissible values
$v_{0(0,5)}$	0,84	1,55	2,44	0,46	0,29	0,94	0,50	0,20	0,36	1,30	0,32	0,25	≤9,97 [2,3]
$v_{0(1)}$	6,10	3,59	3,64	2,00	8,09	0,92	3,54	7,64	2,59	2,64	13,58	2,57	≤9,97 [2,3]
$v_{0(2)}$	1,85	0,83	2,73	2,23	0,58	1,39	2,08	1,02	1,43	6,60	1,62	1,23	≤9,97 [2,3]
$v_{0(\sum pik)}$	31,19	16,77	24,44	21,15	23,59	9,55	17,25	24,87	11,92	23,07	29,12	20,85	≤35 [2,3]
	I mode, *idle speed (i/s)*, **after centering**												
$v_{0(0,5)}$	4,13	1,18	4,67	0,65	1,06	0,35	0,44	0,15	0,30	1,34	0,14	0,26	≤9,97 [2,3]
$v_{0(1)}$	3,44	3,78	5,21	2,97	7,71	1,01	3,34	8,20	1,66	2,67	12,88	3,06	≤9,97 [2,3]
$v_{0(2)}$	2,23	1,82	1,34	1,06	1,27	0,51	1,72	1,21	0,99	6,31	0,88	1,24	≤9,97 [2,3]
$v_{0(\sum pik)}$	30,37	24,58	25,94	20,92	25,21	9,64	14,77	25,25	9,38	24,47	26,41	22,70	≤35 [2,3]
		II mode, *30 % of* Ne_{nom}, **before centering**											
$v_{0(0,5)}$	2,34	1,77	1,14	4,65	5,16	0,42	0,69	0,52	1,27	1,79	0,11	0,43	≤9,97 [2,3]
$v_{0(1)}$	5,53	2,41	3,17	2,71	8,70	1,48	3,48	8,89	1,56	2,19	12,84	3,49	≤9,97 [2,3]
$v_{0(2)}$	2,76	1,71	1,00	1,19	0,70	0,62	2,04	1,09	1,44	7,13	0,74	0,92	≤9,97 [2,3]
$v_{0(\sum)}$	36,94	29,54	18,49	29,65	35,89	15,14	19,79	34	12,14	25,83	34	30,38	≤35 [2,3]
	III mode, *45 % of* Ne_{nom}, **after centering**												
$v_{0(0,5)}$	1,83	0,73	0,37	2,00	4,00	2,13	0,97	0,82	0,34	2,50	0,18	0,58	≤9,97 [2,3]
$v_{0(1)}$	6,84	3,26	2,21	1,05	7,51	1,09	3,60	7,87	2,60	2,49	11,56	3,04	≤9,97 [2,3]
$v_{0(2)}$	1,83	2,53	0,55	1,38	1,72	0,78	1,43	1,18	0,95	4,92	1,73	0,81	≤9,97 [2,3]
$v_{0(\sum pik)}$	39,17	30,56	16,67	25,75	30,07	15,25	21,44	34,04	14,49	27,32	34,28	27,96	≤35 [2,3]
	IV mode, *50 % of* Ne_{nom}, **after centering**												
$v_{0(0,5)}$	3,24	2,52	1,65	3,38	2,19	1,32	1,15	0,26	1,04	3,67	0,10	0,57	≤9,97 [2,3]
$v_{0(1)}$	5,80	2,57	2,06	3,75	8,92	1,28	3,54	8,83	2,34	1,86	13,46	3,92	≤9,97 [2,3]
$v_{0(2)}$	3,04	2,12	0,97	0,84	1,16	0,65	1,92	1,50	1,12	6,66	1,22	1,04	≤9,97 [2,3]
$v_{0(\sum)}$	39,73	31,40	18,36	32,73	33,90	16,51	22,73	38,46	12,74	30,75	39,03	32,22	≤35 [2,3]

	***V mode**, 70 % of Ne_{nom}*, **after centering**												
$v_{0(0,5)}$	10,33	1,40	0,95	2,44	4,82	1,00	1,02	1,53	1,89	1,11	0,14	0,72	≤9,97 [2,3]
$v_{0(1)}$	5,96	2,89	4,10	4,49	10,64	1,36	3,49	9,11	2,32	1,74	12,56	3,73	≤9,97 [2,3]
$v_{0(2)}$	2,27	1,75	0,69	0,62	0,99	0,70	2,10	1,45	0,89	6,46	0,95	0,73	≤9,97 [2,3]
$v_{0(\sum pik)}$	51,91	30,70	21,79	34,76	39,15	18,03	25,89	41,31	12,47	30,18	36,16	32,54	≤35 [2,3]

The values at point 13Z in all operating modes before and after centering of DG No. 1 did not exceed 1.5 mm/s.

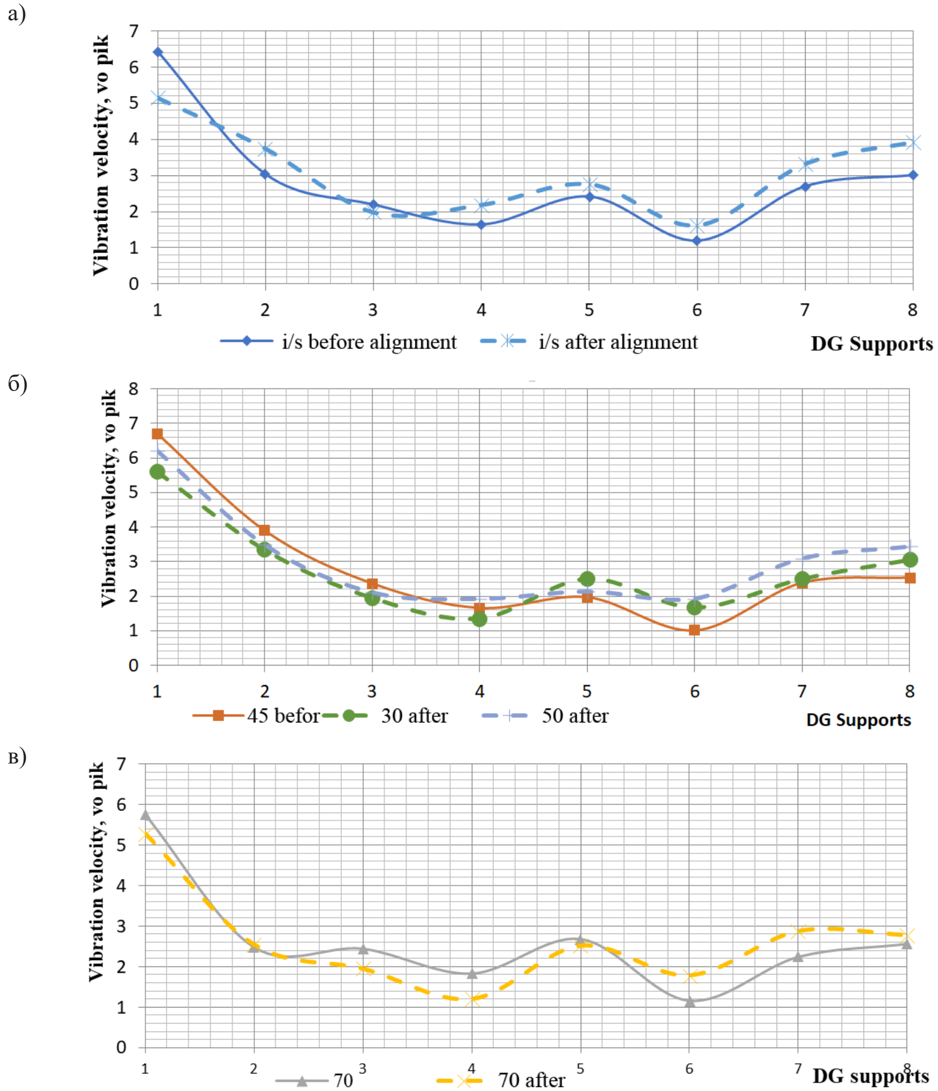

Figure 2. Dependence of vibration velocity levels at the rotational frequency $v_{0(1)}$ on the supports in the vertical direction (z) before and after alignment of the diesel generator set.
a) idle mode; b) 30%, 45%, 50% of Ne_{nom}; c) 70% of $Ne_{nom.}$

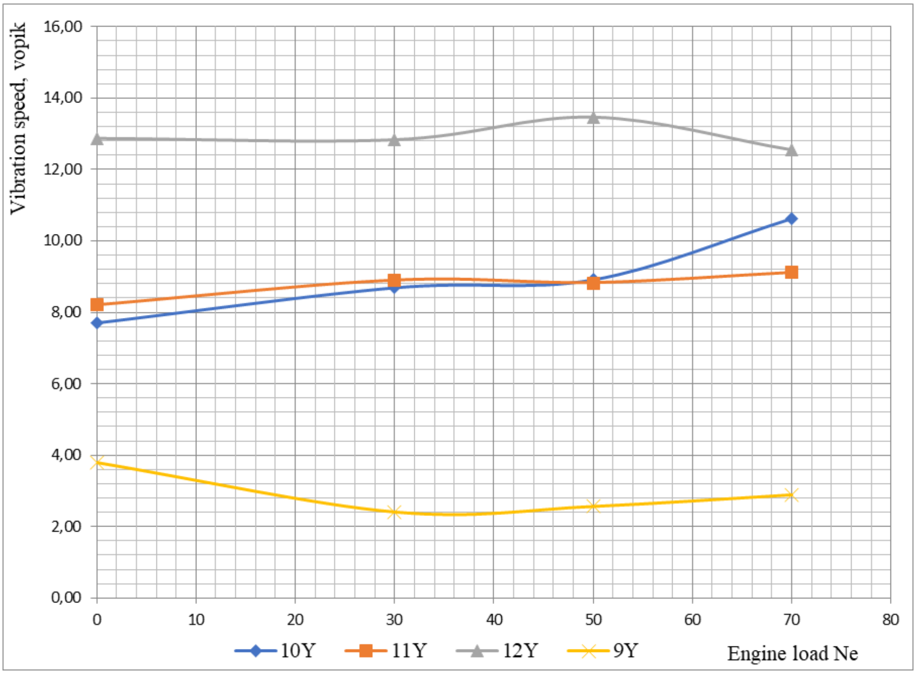

Figure 3. Dependence of vibration velocity $v_{0(1)}$ on engine load in the transverse direction of the engine and generator at different loads.

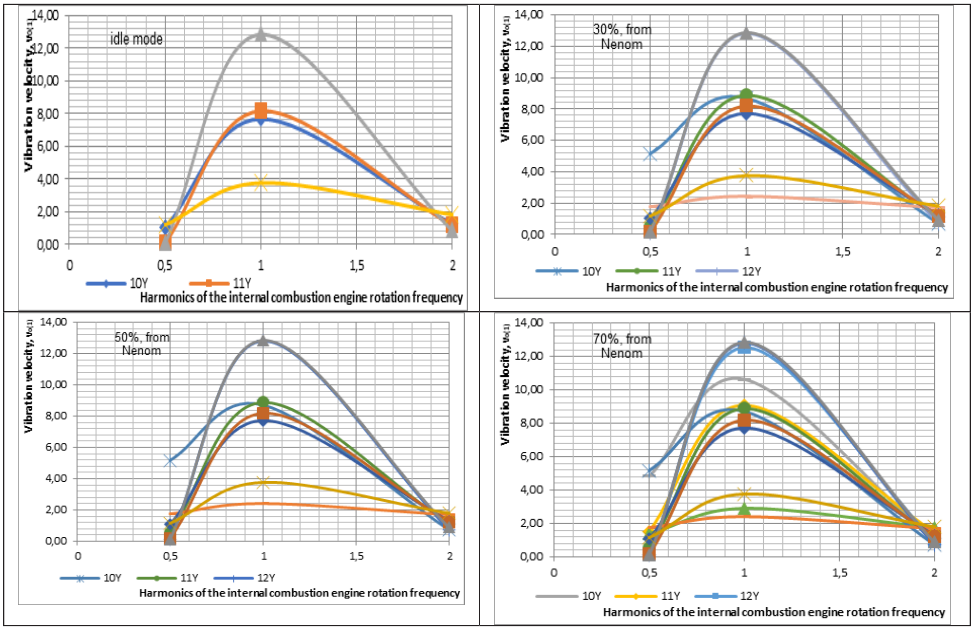

Figure 4. Dependence of vibration velocity v0(1) on engine load in the transverse direction of the engine and generator at different loads before and after alignment of the diesel generator set.

Conclusion. Vibration diagnostics is a standard and mandatory method for monitoring the technical condition of engines and components of mining equipment during operation.

The vibration characteristics criteria examined allow us to identify the impact of process disturbances, such as imbalance of rotating parts (imbalance) and displacement forces (misalignment); unbalanced torsional and forced vibration forces (torque and resonance); fuel combustion processes (detonation in internal combustion engines); and loose structural fasteners, on the technical condition and operating mode of diesel generator sets.

These studies expand the range of diagnostic indicators (rules) for assessing the causes of vibration at various stages of defect development in units and components of diesel generator sets used in mining equipment under operating conditions.

These vibration characteristics analysis results can serve as the basis for developing recommendations for determining the technical condition of diesel generator sets during scheduled inspections and maintenance.

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