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APPLICATION FEATURES OF THE SURFACE LASER SCANNING TECHNOLOGY WHEN SOLVING THE MAIN TASKS OF SURVEYING SUPPORT FOR RECLAMATION

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ABSTRACT

Purpose. Study of the effectiveness of topographical survey methods when solving the main tasks of surveying support for the disturbed lands reclamation.

Methods. Comparative analysis of the topographical survey results, which was conducted with the use of electronic total station and a surface laser scanner during reclamation. The heap leaching dump at the Belaya Gorka Site of the Rodnikovoye Field has been chosen as an object for topographical survey. To compare adequately, the electronic total station and the laser scanner were chosen of the same accuracy class. The determination of the values accuracy of the area and volume of an object during a tacheometric survey depends on the discreteness of surveying pickets. In practice, the density of the pickets' arrangement is limited by the working capacity of the surveying crew, which, as a rule, is several hundred pickets per day, and the density is two or three survey points per 100 m^2 of the object. To determine the dependence of measurement accuracy on the pickets' density during the tacheometric survey, it was carried out at four different scales, with the distance between the pickets from 5 to 25 meters. The density of points (pickets) of a surface laser scanner, which was used in the studies, is 500 points per 100 m^2 of survey area.

Findings. Based on the results of the tacheometric survey and surface laser scanning of the heap leaching dump, two variants of the topographic maps of the surface and its smoothed digital model have been obtained. Detailed surface laser scanning at an increased level in comparison with a tacheometric survey improves the topographic map accuracy. Improved accuracy when determining the volume on a survey scale of 1:500 – 1:2000 is 12%.

Originality. A new concept for topographical surveying is proposed when solving the surveying problems of reclaiming the disturbed lands, based on the methods of surface laser scanning.

Practical implications. Use of the surface laser scanning technology makes possible to obtain the prompt three-dimensional visualization of the surveyed area, to ensure high accuracy and degree of detailed survey, to increase the working capacity and field surveying conditions, to solve the main tasks of surveying support of the disturbed lands reclamation in the shortest possible time and with the required surveying quality.

Keywords: *reclamation, relief, dump, laser scanner, surveying, electronic total station*

1. INTRODUCTION

The rapid development of the surface mining technology leads to a significant expansion of disturbed land areas as a result of the construction and operation of quarries, thus creating environmental stress with unpredictable consequences (Cherniaiev, 2017; Dryzhenko, Moldabayev, Shustov, Adamchuk, & Sarybayev, 2017). To solve the environmental problems, it is necessary an effective organization of the disturbed lands reclamation (Pivniak, Pilov, Pashkevych, & Shashenko, 2012; Malanchuk, Moshynskyi, Korniienko, & Malanchuk, 2018).

Successful drawing up and implementation of projects for reclamation directly depends on the quality of topographic maps of the disturbed land area at all stages of work to recover its productivity (Sarycheva, 2003; Vagonova & Volosheniuk, 2012; Malanchuk, Moshynskyi, Malanchuk, & Korniienko, 2018). The surveying service of the mining enterprise is required to find a systematic approach to solving these problems using modern methods and techniques for geodesic-surveying measurements (Popov, Vorkovastov, & Stolchnev, 1989; Popov & Kalybekov, 2000; Popov, Bukrinskiy, Bruevich, & Borovskiy, 2010).

The objects for surveying at opencast mining are natural and technogenic relief, the contours of the flanks and bottom of the quarry, the slopes and the surface of waste dumps, ground-mounted engineering utilities, drainage ditches and other objects, the state of which should be considered when organizing the reclamation works (Anisimov, Symonenko, Cherniaiev, & Shustov, 2018; Chui, Moshynskyi, Martyniuk, & Stepanchenko, 2018; Kuzlo, Moshynskyi, & Martyniuk, 2018).

Based on surveying, the surveying plans and geodesic sections are drawn up, which are related to the design and implementation of individual stages of reclamation, and this requires a systematic monitoring of the disturbed land recovery in time and space both conventional (Gorova, Pavlychenko, Borysovs'ka, & Krups'ka, 2013) and unconventional method (Bondarenko, Lozynskyi, Sai, & Anikushyna, 2015). Therewith, the control of the vertical levelling is of significant importance, which can be performed with the use of both the conventional vanes and laser systems. When performing the backfilling works of the previously mined-out quarry spaces, the surveying control should be directed to ensure that the areas to be reclaimed fit well into the hydrographic network of the field development area (Popov, Bukrinskiy, Bruevich, & Borovskiy, 2010; Kalybekov, Rysbekov, & Sandibekov, 2018; Kalybekov, Sandibekov, & Rysbekov, 2018).

Therefore, a periodic surveying is carried out, the plans and sections are drawn up, based on which the current monitoring of the reclamation process is conducted, and if necessary, some amendments can be made while the recovery work performance.

2. ANALYSIS OF METHODS FOR SURVEYING THE MINING FACILITIES

It is often the case that the waste dumps, warehouses and storage facilities are difficult to access or have a complex shape, which can lead to errors when determining the volumes (Kovrov, 2007; Nesterenko, Volokhov, & Gusev, 2009; Kalybekov, Rysbekov, & Zhakypbek, 2015).

Traditionally, when drawing up the topographic maps, the tacheometric method of surveying is widely used. The distinctive feature of such a surveying is the discreteness, as it is conducted over rods or beacons. The rods or beacons are set in the survey points belonging to the characteristic contour bends or shapes of the objects to be surveyed. The density of the pickets' arrangement is determined by the scale of the topographical surveying and the nature of the object (Chrzanowski, 1993; Sapina, 2016).

Using these methods, surveyors are faced with a problem that is not always solvable. On the one hand, to improve the accuracy of calculating the rock volume, it is necessary to have a large number of survey points. However, on the other hand, the rapidly changing situation in quarries and dumps requires a high operativity when performing the surveying work. A discrepancy in elevations in the tacheometric survey is not permissible more than 4 cm per each 100 meters of distance (Bagratuni, Ganypin, & Danilevich, 1984).

As it is evident from the experience, the traditional surveying methods are not always effective, but time-consuming and not enough prompt. Moreover, the error in calculating the mine rock volumes when using them is 3% or more, therefore, to increase the accuracy of calculating the volume of the fertile soil layer, the surveyor needs to conduct a detailed surveying, increasing the number of survey points for quarries and dumps with complex configuration (Kovrov, 2007).

At the same time, based on the tacheometric survey results, other parameters should be determined, which are necessary for the qualitative drawing up of a topographic map: the coordinates of the points and the contour area, the dimensions of the object for reclamation may have significant errors as a result of approximation of the perimeter elements according to the measured points. Moreover, the accuracy of the surveying results is greatly influenced by the human factor, which is manifested in the subjective choice of measurement points (Mikhlin & Zhupiev, 1997).

Thus, the abundance of contours and a large number of separately located objects lead to inevitable errors when surveying, and a detailed survey of technogenic reliefs with considerable dimensions takes several weeks, taking into account the subsequent processing of surveying data.

To improve the efficiency of the tacheometric survey, modern electronic total stations are used, which allow to provide a high degree of accuracy. By now, a large number of electronic total station types have been developed and produced, differing in constructional features, accuracy and purpose. The measurement accuracy depends on the technical capabilities of the total station model, as well as on many external parameters: temperature, pressure, air humidity, etc. In modern total station models, the accuracy of angular measurements reaches 0°00'0.5'', the distance of 0.5 mm +1 mm/km (1 mm + 1 mm/km in reflectorless total station mode), which fits the requirements for high-quality surveying during the disturbed lands reclamation (Zheltko, Gura, Shevchenko, & Berdzenishvili, 2014; Zheltko, Gura, Pastukhov, & Shevchenko, 2015; Yinli, Haiyang, & Zhakypbek, 2016).

The use of modern electronic total stations in surveying focused on the information support of the disturbed lands reclamation process, significantly simplifies the solution of such tasks, but does not solve the problems associated with the surveying discreteness.

Solving these problems is a crucial task, which requires a new approach to surveying based on the use of methods that ensure the surveying continuity.

3. CHARACTERIZING THE SURFACE LASER SCANNING AS A NEW APPROACH TO SURVEYING

As it is evident from the experience, the traditional surveying methods are not always effective, but time-consuming and not enough prompt. It should be noted that any tacheometric survey is performed by a discrete set of survey points belonging to characteristic contour bends or shapes of the objects to be surveyed. By interpolating between these points, the contours of the objects to be surveyed and the shapes of the topographic surfaces are reproduced, which leads to a loss of objectivity in outlining these contours. The density of the pickets' arrangement is determined by the scale of the topographical survey and the nature of the object. In practice, the surveying density is limited by the working capacity of the surveying crew, which, as a rule, is several hundred pickets per day, that is, just two or three points per 100 m^2 of surveying (Fig. 1).

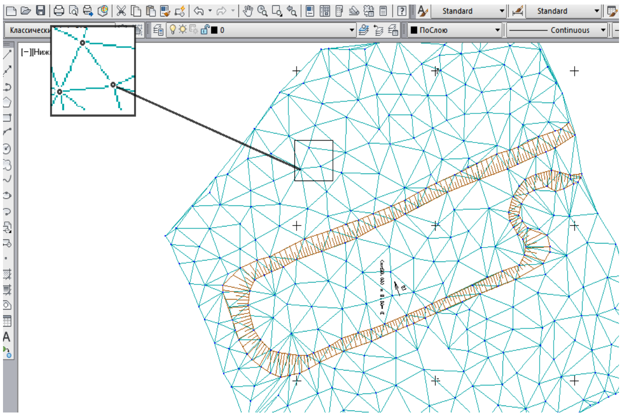

Figure 1. The number of survey points on an area of 100 m^2 (3 – 4 pickets)

At the same time, the actual density when surveying with the use of the surface laser scanning methods can reach 50 – 100 thousand of measurements per second (3 – 5 points per 1 m^2 of the earth's surface) (Fig. 2) (Triger, 2009).

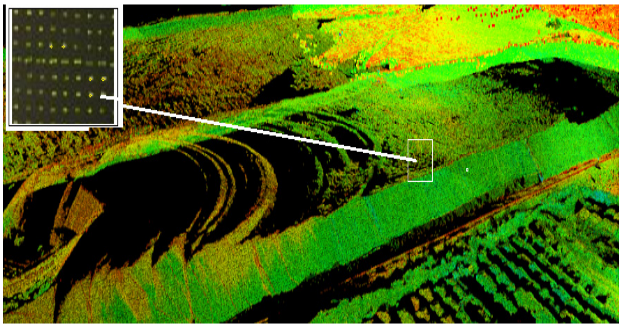

Figure 2. The number of survey points on an area of 100 m^2 (100 – 500 pickets)

As it was noted by the authors in the works (Mel'nikov, 2001; Gusev, Naumenko, Volokhov, & Golovanov, 2008; Gusev, 2009; Seredovich, Komissarov, & Shirokova, 2009), the laser scanning technology solves the problem of surveying discreteness due to the extremely high density of the points to be surveyed, the number of which can amount to tens of millions. Such a density makes it possible to obtain a natural 3D model of an object at the stage of surveying performance. Another conceptual difference is that the choice of the place for the picket setting in traditional methods is determined by the operator in each specific case based on the topological features of the surveyed object, while in surface laser scanning, the distribution of points is of random character. Another disadvantage of the traditional tacheometric survey is the omissions connected with the ocular estimation of the stations location on the ground, such as: insufficient completeness of surveying from the fixed benchmarks, which is manifested in the direct surveying from the attached stations of the surveying justification in the form of their unsuccessful location or insufficient number. In such cases, transient stations are set from the nearest reference geodetic station or the station of surveying justification, which significantly increases the scope of surveying work.

The use of surface laser surveying technology eliminates the drawbacks of the tacheometric survey and its processing, as well as eliminates the influence of the human factor when drawing up a plan for the dump contours, upper and lower edges of the ledges, etc.

The main advantages of surface laser scanning when solving the problems related to the collection of geospatial information about the objects to be surveyed in opencast mining are considered to be:

– prompt obtaining the three-dimensional model of an object;

– data collecting, a significant saving of time;

– safe surveying of dangerous and hardly accessible objects;

– obtaining the topographic map with the use of the virtual surveying;

– calculating the volumes value by means of comparison with previously obtained surveying results;

– completeness and detail of the results obtained;

– minimal "human factor" influence;

– the possibility to use the total station function on the direct referencing of benchmarks to a single coordinate system.

The development of surface laser scanning technology has been advanced due to the works of many scientists, such as E.A. Medvedev, S.R. Melnikov, V.A. Seredovich, A.V. Komissarov and others.

The implementation of surface laser scanning into the surveying practice of opencast mining can be called the most significant technological innovation in mining operations.

Recently, a surface laser scanning method has been used to provide for an accurate and complete data of monitoring in processes of the surface mining the mineral deposits. In the works (Vasil'yev, Zarovnyaev, & Shubin, 2013; Vasil'yev, Zarovnyaev, & Shubin, 2015; Zarovnyaev, Shubin, Vasiliev, & Varlamova, 2016), the authors distinguished the advantages of surface laser technology: prompt obtaining the necessary data, the system usability, multi-functionality, high accuracy and an essential reduction in labour costs when performing the tasks set.

Currently, the surface laser scanners are represented by a wide assortment of models with different technical parameters, the principle action, dimensions and methods of application (Aitkazinova, Soltabaeva, Kyrgizbaeva, Rysbekov, & Nurpeisova, 2016). Therewith, the main features, determining the device capabilities, are high action range and accuracy (Medvedev & Mel'nikov, 2002; Rysbekov & Amirov, 2011; Kuttykadamov, Rysbekov, Milev, Ystykul, & Bektur, 2016), which allow to solve problems of a wide spectrum from exploring to executive surveying, including monitoring of the disturbed lands. The scanners can provide obtaining the data with performance of up to 1 million points per second with an accuracy of 1 mm, while the action range reaches about 300 m (Mel'nikov, 2001; Gusev, 2009; Nesterenko, Volokhov, & Gusev, 2009).

4. METHODOLOGY OF CONDUCTING THE FIELD EXPERIMENT

The main direction of the study is to assess the surveying method effectiveness using surface laser scanners to determine the area and volume of the heap leaching dump at the Belaya Gorka Site of the Rodnikovoye Field.

For a comparative analysis of the surface laser scanning capability and verification of the results obtained, the same range of works has been performed using an electronic total station. The correctness of comparing the results of the tacheometric survey and surface laser scanning is achieved by choosing the devices of the same accuracy class (Table 1).

Table 1. Comparative analysis of measurement methods using an electronic total station and surface laser scanning

Standard of comparison	Types of measurements	
	Tacheometric survey (Total Station SmartStation-1205)	Laser scanning (Leica ScanStation P40)
Accuracy of measurement, m	In plan 0.250 throughout the height 0.020	In plan 0.030 throughout the height 0.020
Period of performance, 10 ha/day	3 – 4	1
Period of cameral works performance, day	3 – 5	1 – 2
Performers, person	2 – 3	1 – 2
Range capability, m	1000/3500	300/600
Measuring rate (density on a scale 1:500), m^2	Single measurements (1 point per each 5 meters)	1000000 measurements/sec (density 3 – 5 points and more per 1 m^2)
Efficiency	Mean	Very high
Result	Drawing up a topographic map 1:500	Drawing up a topographic map 1:500 (3D model, virtual surveying plan)

Laser scanning begins with the choice of station locations relative to the scanned object (Fig. 3). The user specifies the required density of the point cloud (resolution) and the surveying area (Fig. 4).

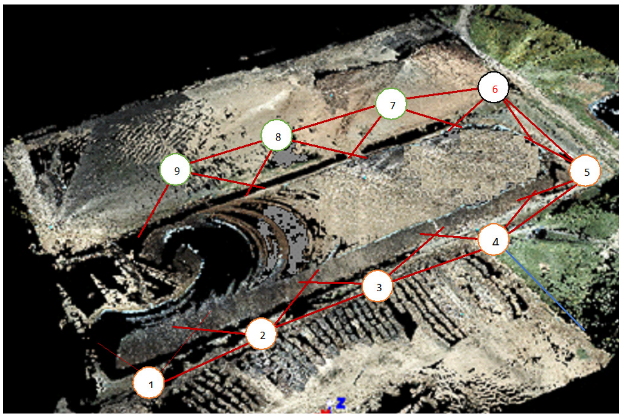

Figure 3. Location of the laser scanning station at the surveying site

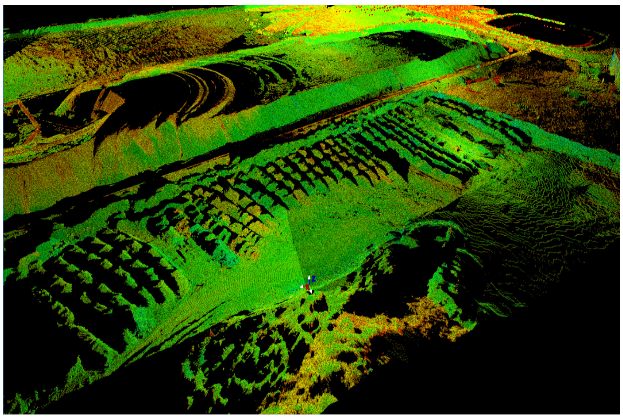

Figure 4. Point cloud

With that, it is necessary to consider the following factors affecting the scans accuracy (Voroshilov & Karachentsev, 2009):

– accuracy characteristics of scanning and subsequent determining the spatial coordinates of points;

– removal of stations from objects to be surveyed;

– dimensions of the zones to be scanned horizontally and vertically;

– providing for the zones overlapping the adjacent scans;

– visibility and accessibility for scanning, no interference for the scanning laser beam.

Accounting of these factors depends on the location of the area surveyed, the level of its loading by the scanned object heights details and the scanner accuracy characteristics.

Referencing to the local coordinate system is carried out according to two benchmarks set with the use of the electronic total station function available in the scanner.

The scanning was performed with a Leica ScanStation P40 scanner along the dump perimeter from 9 geodetic points with a resolution density of 5 – 10 mm.

With all the obvious advantages of surface laser scanning, the scans obtained have disadvantages, since they do not contain the necessary information about the location of transport routes, conveyors, industrial site, warehouses and the dumps. The task can be solved using the ScanStation P40 scanner function, which supports the scanned object with the digital video and photosurveying to obtain high-quality HDR images. The result of the virtual surveying by the scanner is shown in Figure 5.

5. RESULTS AND DISCUSSION

Based on the results of surface laser scanning of the heap leaching dump, a topographic surface and a smoothed digital surface model have been obtained (Fig. 6). Using digital model of a surface, the heap leach dump volume has been determined, which amounts to 58324.0 m^3.

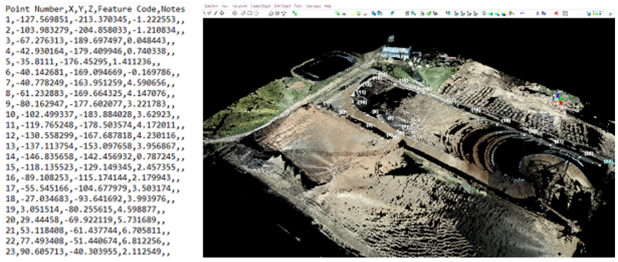

Figure 5. Virtual snapshot made by Leica ScanStation P40 scanner

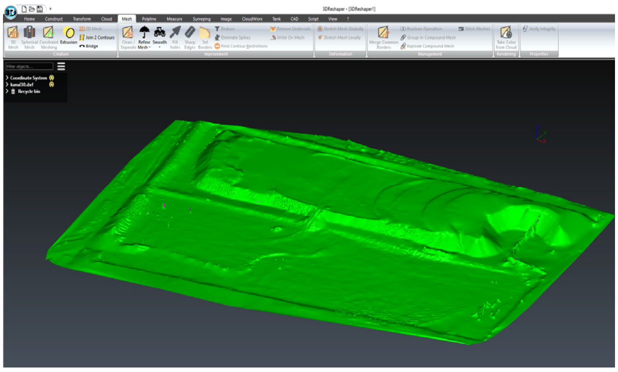

Figure 6. Smoothed digital surface model

For a tacheometric survey, this is a distance between the set pickets, which is determined by its surveying scale. The volume of the same dump according to the results of the tacheometric survey on a scale of 1:500 is 55536 m^3 (Fig. 7).

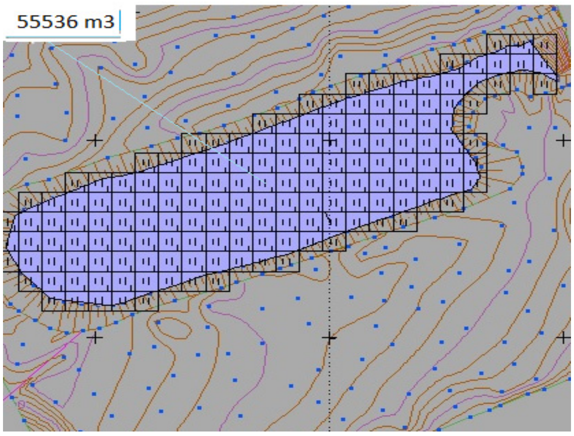

Figure 7. Determining the dump volume by the tacheometric survey results on a scale of 1:500

The difference is explained by the fact that with the selected scale of tacheometric survey, at which the distance between the pickets is about 10 meters, the contour bends and the surface shape of the dump are not taken into account in sufficient detail. The accuracy of determining the volume depends on the degree of detail. For a tacheometric survey, this is the distance between the set pickets.

To determine this dependence, the tacheometric survey of the same heap leaching dump site was conducted on different scales, with the distance between the pickets, 5, 10, 15 and 20 meters, respectively (Figs. 8 – 10).

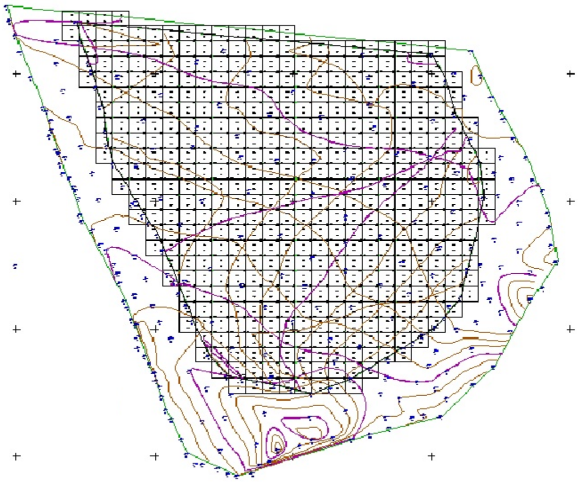

Figure 8. Determining the dump volume on a scale of 1:500; V – 18916 m^3

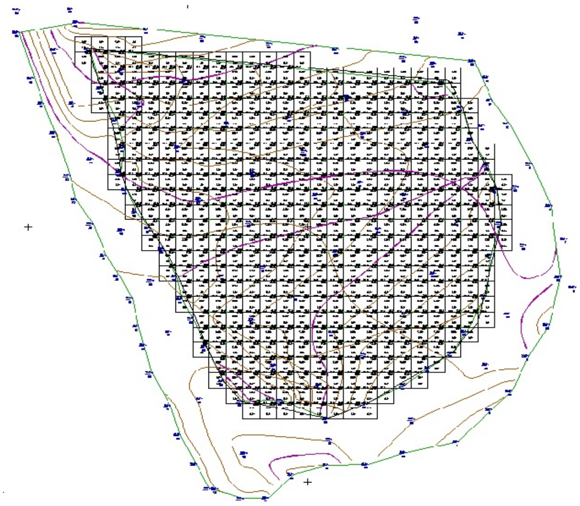

Figure 9. Determining the dump volume on a scale of 1:1000; V – 18069 m^3

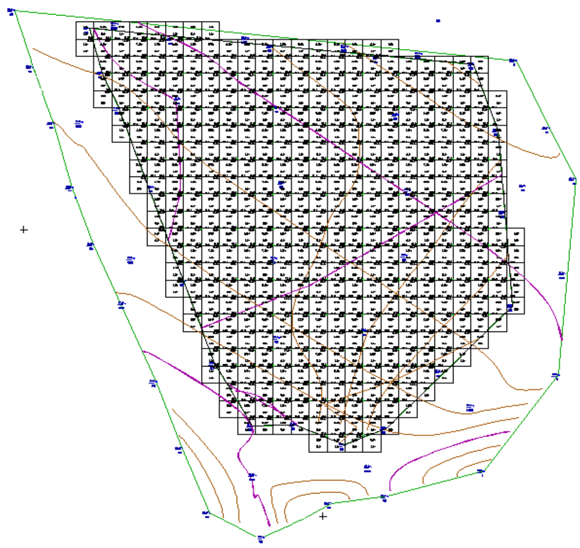

Figure 10. Determining the dump volume on a scale of 1:2000; V – 17077 m^3

The volume of the same site was determined by the surface laser scanner (Fig. 11).

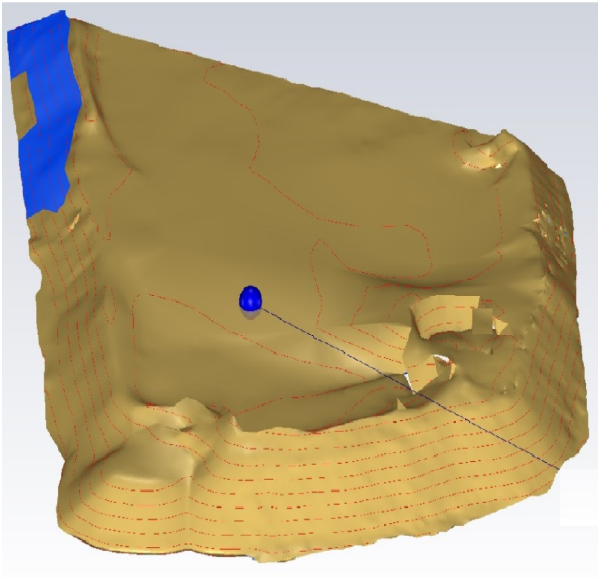

Figure 11. Determining the dump volume, where the pickets' density is 0.01 m; V – 21180 m³

The graph of dependence of the dump site volume *V*, m³ on the distance between the pickets *D*, m is presented in Figure 12.

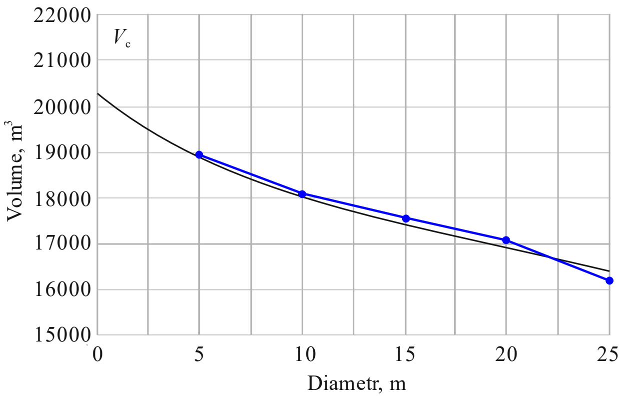

Figure 12. Dependence of determining the dump site volume on the tacheometric survey scale (where V_c – volume, obtained by laser scanning method)

It can be seen from the graph that with an increase in the surveying scale the volume value increases. This is explained by the increasing degree of surveying detail. At the same time, even with a scale of 1:500, the result of a tacheometric survey is different from a surface laser scanning by 2264 m³. Thus, the accuracy of the surface laser scanning results in comparison with the tacheometric survey is increased by 12% due to the high density of survey points.

6. CONCLUSIONS

The proposed approach to surveying support of the disturbed lands reclamation through the use of a surface laser scanning compared to a tacheometric survey has substantiated its effectiveness by ensuring high accuracy, the degree of surveying detail and increasing its performance.

The accuracy of the results of surface laser scanning technology is achieved due to the high density of points of the object to be surveyed. The actual density when surveying with the use of the surface laser scanning methods can reach 50 – 100 thousand measurements per second (3 – 5 points per 1 m² of the earth's surface). Such a density makes it possible to obtain a natural 3D model of the object at the stage of surveying performance.

The photosurveying experiments at the Belaya Gorka Site of the Rodnikovoye Field have substantiated an increase in the accuracy of the surface laser scanning results in comparison with a tacheometric survey of the same site by 12%.

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ОСОБЛИВОСТІ ЗАСТОСУВАННЯ ТЕХНОЛОГІЇ НАЗЕМНОГО ЛАЗЕРНОГО СКАНУВАННЯ ПРИ ВИРІШЕННІ ОСНОВНИХ ЗАВДАНЬ МАРКШЕЙДЕРСЬКОГО ЗАБЕЗПЕЧЕННЯ РЕКУЛЬТИВАЦІЇ

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Мета. Дослідження ефективності методів топографічної зйомки при вирішенні основних завдань маркшейдерського забезпечення рекультивації порушених земель.

Методика. Порівняльний аналіз результатів топографічної зйомки, проведених із використанням електронного тахеометра та наземного лазерного сканера при рекультивації. Об'єктом топографічної зйомки обраний відвал купчастого вилуговування ділянки Біла Гірка родовища Родникове. Для коректності порівняння, електронний тахеометр і лазерний сканер обрані одного класу точності. Визначення точності значення площі та об'єму об'єкта при тахеометричній зйомці залежить від дискретності знімальних пікетів. На практиці щільність розміщення пікетів обмежена продуктивністю знімальної бригади, яка, як правило, становить кілька сотень пікетів у день, при цьому щільність становить дві або три знімальні точки на 100 м^2 площі об'єкта. Для визначення залежності точності вимірювання при тахеометричній зйомці від щільності пікетів, вона проводилася у чотирьох різних масштабах, з відстанню між пікетами від 5 до 25 метрів. Щільність точок (пікетів) наземного лазерного сканера, використаного в дослідженнях, становить 500 точок на 100 м^2 площі зйомки.

Результати. За результатами тахеометричної зйомки і наземного лазерного сканування відвалу купчастого вилуговування отримані два варіанти планів топографічної поверхні і згладжена її цифрова модель. Підвищена деталізація при наземному лазерному сканування у порівнянні з тахеометричною зйомкою підвищує точність топографічного плану. Підвищення точності визначення обсягу при масштабі зйомки 1:500 – 1:2000 становить 12%.

Наукова новизна. Запропоновано нову концепцію проведення топографічної зйомки при вирішенні маркшейдерських завдань рекультивації порушених земель, що заснована на методах наземного лазерного сканування.

Практична значимість. Застосування технології наземного лазерного сканування дозволяє отримати миттєву тривимірну візуалізацію території, забезпечити високу точність і ступінь деталізації зйомки, підвищити продуктивність праці та умови польових робіт при зйомці, вирішити основні завдання маркшейдерського забезпечення рекультивації порушених земель у найкоротші терміни і з необхідною якістю зйомки.

Ключові слова: *рекультивація, рельєф, відвал, лазерний сканер, зйомка, електронний тахеометр*

ОСОБЕННОСТИ ПРИМЕНЕНИЯ ТЕХНОЛОГИИ НАЗЕМНОГО ЛАЗЕРНОГО СКАНИРОВАНИЯ ПРИ РЕШЕНИИ ОСНОВНЫХ ЗАДАЧ МАРКШЕЙДЕРСКОГО ОБЕСПЕЧЕНИЯ РЕКУЛЬТИВАЦИИ

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Цель. Исследование эффективности методов топографической съемки при решении основных задач маркшейдерского обеспечения рекультивации нарушенных земель.

Методика. Сравнительный анализ результатов топографической съемки, проведенных с использованием электронного тахеометра и наземного лазерного сканера при рекультивации. Объектом топографической съемки выбран отвал кучного выщелачивания участка Белая Горка месторождения Родниковое. Для корректности сравнения, электронный тахеометр и лазерный сканер выбраны одного класса точности. Определение точности значения площади и объема объекта при тахеометрической съемке зависит от дискретности съемочных пикетов. На практике плотность расстановки пикетов ограничена производительностью съемочной бригады, которая, как правило, составляет несколько сотен пикетов в день, при этом плотность составляет две или три съемочные точки на 100 м^2 площади объекта. Для определения зависимости точности измерения при тахеометрической съемке от плотности пикетов, она проводилась в четырех различных масштабах, с расстоянием между пикетами от 5 до 25 метров. Плотность точек (пикетов) наземного лазерного сканера, использованного в исследованиях, составляет 500 точек на 100 м^2 площади съемки.

Результаты. По результатам тахеометрической съемки и наземного лазерного сканирования отвала кучного выщелачивания получены два варианта планов топографической поверхности и сглаженная ее цифровая модель. Повышенная детализация при наземном лазерном сканирования в сравнении с тахеометрической съемкой повышает точность топографического плана. Повышение точности определения объема при масштабе съемки 1:500 – 1:2000 составляет 12%.

Научная новизна. Предложена новая концепция по проведению топографической съемки при решении маркшейдерских задач рекультивации нарушенных земель, основанная на методах наземного лазерного сканирования.

Практическая значимость. Применение технологии наземного лазерного сканирования позволяет получить мгновенную трехмерную визуализацию снимаемой территории, обеспечить высокую точность и степень детализации съемки, повысить производительность труда и условия полевых работ при съемке, решить основные задачи маркшейдерского обеспечения рекультивации нарушенных земель в кратчайшие сроки и с требуемым качеством съемки.

Ключевые слова: *рекультивация, рельеф, отвал, лазерный сканер, съемка, электронный тахеометр*

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