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Use of a Jig Beneficiation Process for Obtaining Mineral Raw Materials

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Abstract. The article presents a construction and operational principle of a pulsating jig, a device for obtaining minerals in a pulsating water medium. A smart control system of the device is discussed. Examples of jig implementations for obtaining minerals from natural deposits and for a recovery of minerals from mine heaps are presented. Tests results of used equipment are provided, indicating a possibility of obtaining purified aggregate and steam coal concentrate of high quality parameters.

1. Introduction

Treatment of hard coal is an integral and extremely important part of the production process of commercial products. Its aim is to increase the quality of extracted raw material and to obtain quality and quantity parameters of final products required by recipients. The quality of coal is improved by subjecting it to a series of technological operations, including a beneficiation in specialized devices [1,2]. Among the many methods used for the material classification, the gravitational separation technologies carried out in air classifiers (e.g. shaking tables, jigs) [4,5], water classifiers (e.g. jigs, hydro-cyclones) [6] and classifiers with heavy medium suspension (e.g. HMC, HMB) [7,8] are especially important.

The KOMAG Institute of Mining Technology carries out research and development work, which results in the technical documentation of machinery and equipment as well as in the results of tests conducted in industrial conditions and in mining and laboratory facilities at its own test rigs.

An example of this activity includes KOMAG pulsating jigs for material beneficiation according to the density difference, used in many coal and other mineral raw materials processing plants. The solutions, used in them, are subject to continuous improvement processes in order to increase a separation efficiency and maintain the reliability of equipment operation [3].

Basing on a many-year experience of the KOMAG Institute of Mining Technology in the construction and technological adaptation of pulsating jigs for a beneficiation of hard coal, a jig to obtain gravel and sand with a simultaneous release of organic and mineral pollutants has been developed.

The result of this work was a pulsating classifier, an innovative solution allowing for a production of sand and gravel of the required quality and an adjustment of technological parameters of products to the market requirements [9,10].

The further modifications enabled designing the device extending the scope of using the classifiers for recovering mineral resources from mine heaps [11-15].

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Presenting the possibility of obtaining high-quality raw minerals from the plants processing the aggregates and mine heaps with the use of a pulsating classifier - a state-of-the-art device designed at the KOMAG Institute of Mining Technology, is the paper objective.

2. Construction and operational principle of pulsating classifier

A principle of a classifier operation is based on a typical process of gravitational beneficiation of minerals by stratification in pulsating water of correctly prepared feed, according to its grain composition and density of ingredients [9,16].

The basic component of the pulsating classifier is a set of working chambers. In its upper part, a sieve plate is mounted on which a movement and separation of the material under beneficiation takes place.

Another component of the device is a rotary receiver equipped with a higher density product scraper. Above the receiver there is an overflow chute for a lower density product.

The pulsating movement is caused by a pneumatic system consisting of a blower, a working air tank and pulsatory plate valves, as well as a compressor supplying pulsatory valves and a working water supply system.

The structure is supplemented by feed and product of a higher density chutes as well as a water drainage and material passing through the sieve openings, from the outflow openings, situated in the lower part of the classifier's working chambers.

A classifier is usually installed on a mobile base figure 1, with a service platform and stairs, or it is installed on a structure together with cooperating devices [17].



Figure 1. K-101 pulsating jig on a mobile base [17].

A correct operation of a classifier is ensured by an electronic control system that controls water pulsation depending on technological parameters of the feed and controls a rejection of products by means of electrical pulses provided by a float sensor [17].

KOMAG has designed a series of pulsating classifiers enabling to adapt them to the user’s required capacity. The basic parameters of KOMAG classifiers are shown in table 1.

Table 1. Main technical parameters of KOMAG classifiers [13,18].

Classifier type		K-60	K-80	K-100 K-101	K-102	K-150	K-200
Nominal capacity	(t/h)	60	80	100	100	150	200
Total work surface	(m^2)	ca. 2.0	ca. 4.0	ca. 4.0	ca. 4.0	ca. 4.0	ca. 4.0
Power demand	(kW)	22.5	30.5	30.5	42	42	42
Water demand	(m^3/h)	120-140	140-170	150-200	150-250	250-300	300-320
Water pressure	(MPa)	0.1	0.1	0.1	0.1	0.1	0.1
Weight of classifier with a mobile base	(kg)	ca. 15000	ca. 18000	ca. 19000	ca. 25500	ca. 21500	ca. 21900
Weight of classifier	(kg)	ca. 7500	ca. 9150	ca. 9950	ca. 11500	ca. 12600	ca. 13000

3. Use of a pulsating classifier for obtaining aggregates from natural resources

A prototype of the classifier was built and started its operation in 2002 in the "Dębówko" Mine of Aggregates, belonging to the Szczecińskie Kopalnie Surowców Mineralnych S.A.

The experience from the prototype tests was the basis for its implementation in various industrial plants. KOMAG classifiers were implemented in:

- KSM Sp. z o.o. in Borzęcin, belonging to CEMEX Polska (figure 2a),
- Zakład Produkcji Kruszyw i Prefabrykatów in Suwałki, owned by PPMD KRUSZBET S.A. (figure 2b),
- Gravel Pit PRInż. Surowce Sp. z o.o. in Januszkowice, then taken over by CEMEX Polska (figure 3a),
- Zakład Produkcji Betonów in Zdzieszowice, belonging to Przedsiębiorstwo Usługowo Handlowe "M " Sp. z o.o. in Kędzierzyn Koźle (figure 3b),
- Bierawa Gravel Pit, owned by CEMEX Polska (figure 4a),
- Rokitno Gravel Pit near Lublin (figure 4b).



Figure 2. K-100 pulsating classifiers in Borzęcin (a) and in Suwałki (b) [9,16].



Figure 3. K-100 classifiers in Januszkowice (a) and in Zdzieszowice (b) [9,16].



Figure 4. K-150 classifier in Bierawa (a) and K80 pulsating classifier in Lublin (b) [9,16].

Pulsating classifiers are used to extract from aggregates impurities in a wide spectrum of density: organic (particles of plants and wood, coal grains) and minerals (chalk, carbonates).

High efficiency of organic impurities separation from aggregates, exceeding 90% [19], enables to use a pulsating classifier for this process with a guarantee of obtaining satisfactory results, consistent with the user's requirements.

In the Polish aggregate manufacture plants, foreign design jigs are also used. There is, however, no available literature containing information on their effectiveness.

In order to increase the efficiency of pulsating classifiers at the KOMAG Institute of Mining Technology, a modernization and research and testing infrastructure is carried out, which enables their development [19,20-22].

An experience, gained in the result of subsequent implementations of pulsating classifiers, has shown that their efficiency in purifying aggregates depends on a number of factors.

The factors that have a significant impact on the efficiency of aggregate purification are the parameters of the material being processed. The most important of them include a type of impurities present in the raw material and the extent of the material graining.

Table 2 shows the results of laboratory tests on the impact of sand grains on the efficiency of aggregate purification.

Table 2. Specification of the results of density separation efficiency of gravel and gravel-and-sand feed [21,23].

Test		1	2	3	4	5	6
Share 3-0.5 mm in feed, (%)		0.0	0.0	25.0	25.0	50.0	50.0
Capacity, (t/h)		2.1	4.2	2.1	4.2	2.1	4.2
Unit load, (t/h m^2)		12	24	12	24	12	24
Separation efficiency%	< 1.5 (g/cm^3)	99.6	100.0	98.6	90.5	81.7	74.0
	1.5-1.8 (g/cm^3)	100.0	100.0	98.2	89.3	80.3	74.1
	2.1 (g/cm^3)	87.1	79.1	52.0	52.3	25.7	31.0

The tests confirmed that the efficiency of the jig aggregate beneficiation is reduced as the load of feed, the density of impurities and the participation of sand grains in the feed increase.

Unfavorable results of the distribution of high density particles of 2.1 g/cm^3 indicate that the purification process should be carried out in narrow grain classes and in the case of the benefication process the feed should not contain sand grains [21,23].

4. Use of a pulsating classifier for a recovery of minerals from mine heaps

A market demand and inquiries regarding a possibility of using a pulsating classifier for processing waste from mine heaps inclined for a development of a modernized version of the device at the KOMAG Institute of Mining Technology - classifier type K-102, which is shown in figure 5.

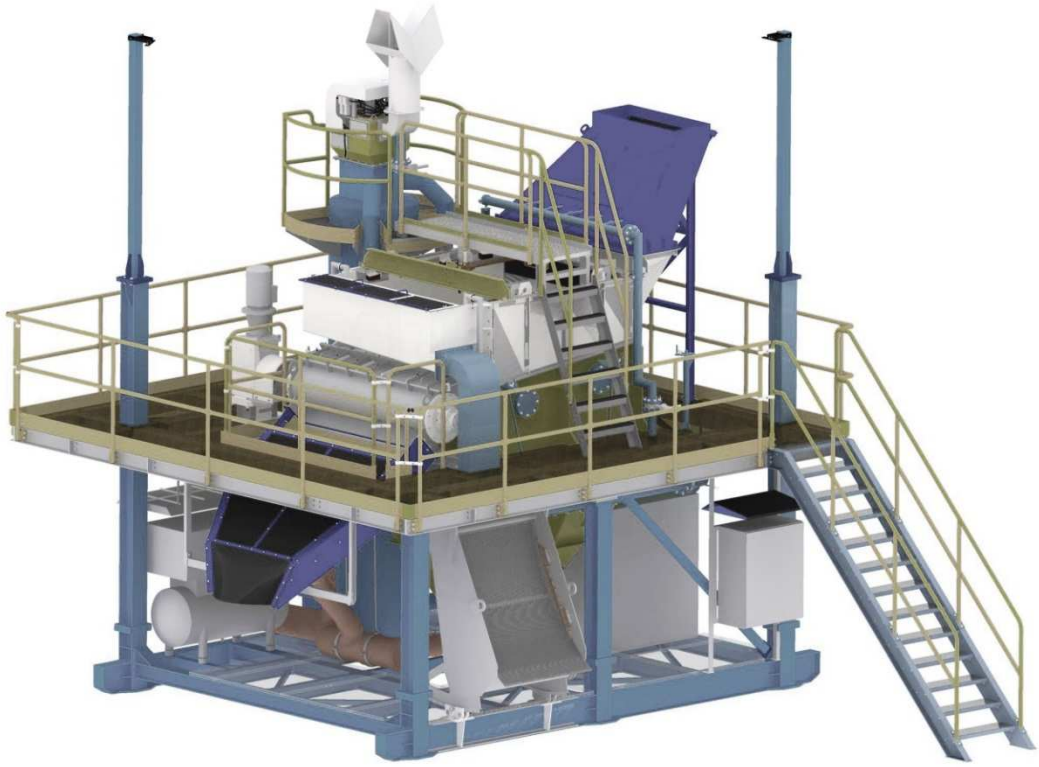


Figure 5. K-102 pulsating classifier on a mobile base for waste beneficiation from mine heaps [12,18].

In the result of hard coal production, a number of mine waste heaps have been generated, which cause many threats. These include fires, a release of gases that pollute the atmosphere, as well as leaching out of dangerous substances from heaps.

Due to a low efficiency of beneficiation processes, especially up to the mid- 20th century, a lot of coal grains were deposited on the heaps apart from the gangue [13,14,18].

In order to check the recovery efficiency of useful materials from waste heaps and for an adaptation of the K-102 classifier solutions, laboratory tests were carried out at the experimental stand [12,18].

The tests were performed on samples of waste materials from various mine heaps, which served as feed for the laboratory jig and during the technological test they were divided into two products: "light" (coal) and "heavy" (aggregate).

The samples of waste material in the 30-4 mm grain size class, taken from one of the mine waste heaps in Upper Silesia, were tested. The test results are summarized in table 3.

Table 3. Parameters of feed and beneficiation products (mine waste heap in Upper Silesia) – laboratory tests [12,18].

Fraction density, (g/cm^3)	Feed	”Light” product	”Heavy” product
	share, (%)	share, (%)	share, (%)
<1.5	5.63	76.30	0.38
1.5-1.8	5.70	16.84	4.87
>1.8	88.67	6.86	94.75
Sum	100.00	100.00	100.00
Output, (%)	100.00	6.92	93.08
Ash content, (%)	77.46	18.82	81.89
Calorific value, (MJ/kg)	4.13	25.68	2.52

In the result of the material beneficiation process, a concentrate product with an ash content of 18.82% and a calorific value of 25.68 MJ / kg as well as a 6.92% output was obtained. The waste product with 93.08% output was characterized by a small share of concentrate grains - 0.4% and an insignificant share of middlings grains - 4.9%. The ash content of the waste product was 81.89%, and its calorific value was 2.52 MJ/kg [12,18].

The test results showed that use of the gravitational beneficiation method in the K-102 pulsating classifier enables to obtain two full-value products.

A high density product, containing traces of organic matter, can be an alternative aggregate with a wide range of applications. The second product with a high calorific value and low ash content is steam coal concentrate.

The first implementation of the new K-102 classifier for a beneficiation of mine waste in the 35-3 mm grain class took place in 2015 at one of the mine heaps located in Upper Silesia.

In 2016, the second K-102 classifier was implemented. It was equipped with a state-of-the-art KOMAG control system, which allows a selection of operational parameters of the device depending on the required quantitative and qualitative parameters of the beneficiation products. Another pulsating classifier K-102 No. 3 was installed in 2017 [13,14,15].

The conducted research results show a high efficiency of the classifier, which enables to obtain beneficiation products of the quality parameters required by the user [15].

The K-102 pulsating classifiers in operation are shown in figure 6.



Figure 6. K-102 pulsating classifiers in the installations for a recultivation of mine heaps [15].

During an operation of the pulsating classifier, additional laboratory analyses of concentrate product samples were carried out, which showed very good quality parameters of this product. Selected results of tests, in operational conditions, are shown in table 4.

Table 4. Parameters of the concentrate product of a pulsating classifier [11,20].

No.	Total moisture, (%)	Ash content, (%)	Calorific value, (kJ/kg)
1	8.1	12.0	26138
2	7.8	11.3	26791
3	8.3	11.7	26651
4	9.2	10.8	26460
5	8.9	11.7	26609
6	10.8	10.3	26109

The processes of recovery of raw minerals from the mine heaps are usually based on the separation technology in cyclones with a heavy suspension fluid. Due to different technology, it is not possible to directly compare the effectiveness of the recovery processes. The technology based on heavy suspension fluid is a technology that allows for higher separation efficiency. However, it requires the use of an expensive magnetite particles. In addition, classifying in an liquid medium (water pulsating classifier) is a "pure" technology, unlike the classification in a heavy liquid due to the possibility of transferring the part of magnetite particles to the environment along with the separation products.

5. Design development of a pulsating classifier

A pulsating classifier, over the years, has been improved continually. Basing on the experience gained during the commissioning of subsequent K-100 classifiers, the K-150 classifier with increased capacity was constructed.

This capacity was obtained in the result of a reconstruction of the product's collection system - a more efficient rotary receiver with a larger capacity was used and an inclination of the collection channel was increased. In addition, the fines fraction collection system was changed by replacing four small conical nozzles with two large ones. A more efficient pulsation valve and a more powerful blower were also used [17].

Due to a need for an adaptation of the device to lower capacity, in 2012 the K-60 classifier was developed (figure 7).

In 2010 many changes were introduced in the construction of classifiers. The modernized version was named K-101. Among others a pulsation valve (figure 8) was changed, in which 4 adjustable plates were used, which allowed for an independent control of the air supply system. An auxiliary air vent was built in, enabling an additional adjustment of the working air pressure. A more effective silencer of the working air outlet was used [10].

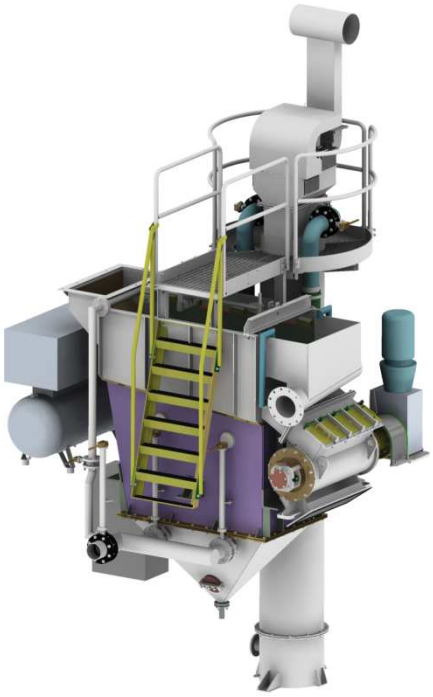


Figure 7. K-60 pulsating classifier [17].



Figure 8. ZP-4 pulsatory valve [10].

An alternative solution of the purified aggregate collection system was developed - an elastic receiver (figure 9). These changes made it possible to control an amount of the product received and to increase the maximum grain size in the feed up to 32 mm [10].

A new algorithm for a classifier operation was introduced, which enables a selection of the classifier operating modes for different types of feeds.

In addition, water and air dampers were installed to increase the range of control parameters, which make it possible to achieve higher aggregate purifying efficiency.

In the K-102 classifier installed in 2016, the KOMAG classifier control system was used for the first time (figure 10). It allowed to integrate a control of the entire beneficiation node and to obtain a number of benefits in terms of, among others:

- an optimization of the capacity of devices in the beneficiation node,
- a reduction of electricity consumption,
- an increase of service life of the discharge system under variable load conditions,
- an increase of the scope of process monitoring and a generation of a process documentation,
- a reduction of downtime,
- an access to data from one place [15].



Figure 9. Classifier elastic receiver [10].

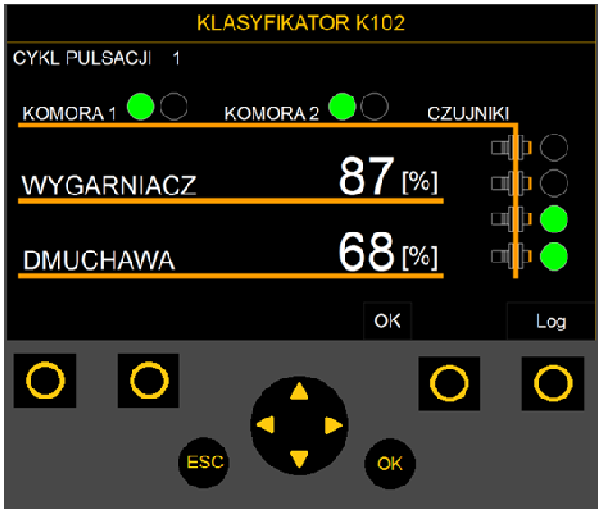


Figure 10. Main screen of K-102 No. 2 pulsating classifier control panel [15].

The classifier was also equipped with a pulsation pressure measurement system (figure 11), improving a control capabilities of the classifier and enabling to obtain higher efficiency and more favourable beneficiation indicators [15].



Figure 11. Classifier No. 3 - pressure sensor in air chambers of operational compartment [15]**.**

6. Summary

Many years of experience of the KOMAG Institute of Mining Technology in the construction and technological selection of jigs for a beneficiation of hard coal allowed for a development of a new device - a pulsating classifier, designed for a separation and purification of aggregates [2, 9].

KOMAG pulsating classifiers confirmed their advantages characterized by a reliable operation and low operational costs, at high efficiency of separating impurities from the aggregate.

The next step at the KOMAG development of equipment for a beneficiation of minerals was a use of a modernized version of the pulsating classifier for a beneficiation of mine waste.

The results of industrial tests of the mine waste beneficiation confirmed a high efficiency of the device, enabling to obtain both steam coal concentrate and so-called alternative aggregate.

The previous implementations of the pulsating classifiers showed that they are machines with a wide range of applications, and among their many advantages an ability to adapt the design to user's requirements in terms of construction conditions, expected capacity and quality of commercial products should be mentioned.

In order to increase the classifier efficiency, at the KOMAG Institute of Mining Technology, a continuous research and development work is carried out, using a laboratory jig stand. This work, through changes in technological and construction solutions, makes it possible to increase efficiency of minerals' beneficiation processes.

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