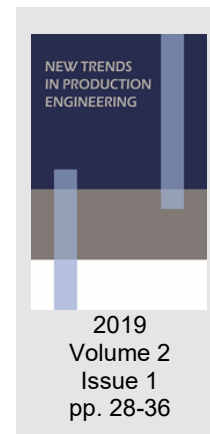


Examples of vibratory crushers applications in crushing technological lines

Marcin Mazur

AGH University of Science and Technology, **Poland**



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INTRODUCTION

Comminution is an indispensable process in many stages of mineral resource acquisition and processing (Gospodarczyk P., Kotwica K., Stopka G., 2013; Mendyka P., Kotwica K., Stopka G., Gospodarczyk P., 2016; Sidor J., Feliks J., 2015; Tomach P., 2017a; Tomach P., 2017b). Construction and operation principle of a crusher is closely related to the dominant type of load that causes the destruction of grains (Höfl K., 1985). In the jaw, cone and roll crushers the dominant load is described by its quasi-static character. In the case of impact crushers (hammer, rod, bar and centrifugal) grains of crushed material are disintegrated mainly due to dynamic impacts. Crushing processes are also performed in another group of crushers, which also use a dynamic impact of working elements on the crushed material. These machines are based on vibratory technology. The main difference between impact and vibratory crushers is frequency of working elements contacts with crushed material, which is significantly higher in vibratory crushers, and oscillates within the range of 15 to 35 Hz (Sidor J., 2008). Two main groups of this machines are cone and jaw vibratory crushers.

In recent years there has been a dynamic development of jaw and cone vibratory crushers. These machines have a number of advantages over conventional crusher designs. They are characterized by significantly higher degree of fragmentation and the ability to crush materials with very high values of compressive strength and high abrasiveness. These factors make vibratory crushers more often used to crush hard and very hard materials (Mazur M., 2010; Sidor J., 1997) with a high content of crystalline silica inclusions.

SYSTEMATICS OF VIBRATORY CRUSHERS

The first problem is to define precisely the concept of vibratory crusher. In the available technical literature there is no clear definition of this concept, therefore it is assumed that the vibratory crusher is a crushing machine which fulfills the following conditions (Sidor J., 1997):

- there is a vibratory movement of at least one working element (cone, jaw, drum),
- crushing process is performed by dynamic impact of working elements on the crushed material,
- the minimum vibration frequency of working element(s) is at least twice the maximum vibration frequency of the "classic" crushers working element(s), practically above 15 Hz.

The main systematic of vibratory crushers can be presented as follows:

- vibratory cone crushers,
- vibratory jaw crushers,
- vibratory drum crushers.

Vibratory jaw and cone crushers are most commonly used. There are four types of construction solutions for vibratory cone crushers (Sidor J., 2008):

- cone crushers with single-mass inertial vibrator mounted in the internal working cone,
- cone crushers with two-mass inertial vibrator mounted on the shaft of the inner working cone,
- cone crushers with single-mass inertial vibrator mounted on the shaft of the inner working cone,
- cone crushers with two-mass inertial vibrator driving the external working cone (with a fixed inner cone).

Much greater variation occurs with the construction of vibratory jaw crushers.

The first systematic includes the number of driven jaws (Sidor J., 1997):

- crushers with one jaw driven,
- crushers with two jaws driven.

Another systematic distinguishes the type of vibrators (Sidor J., 1997):

- crushers with one-mass inertial vibrator,
- crushers with two-mass inertial vibrator,
- crushers with kinematic vibrator,
- crushers with hydraulic vibrator.

It is also possible to distinguish vibratory jaw crushers due to the jaw suspension position (Sidor J., 2008):

- crushers with upper jaw suspension,
- crushers with lower jaw suspension,

VIBRATORY CONE CRUSHERS

Cone crushers with single-mass inertial vibrator mounted in the internal working cone

The construction solution of this type of vibratory cone crushers was first described in the literature (Andiejew S. E., Zwerebic W. W., Perow W. A., 1961). The crusher shown in Fig. 1 consist a large outer cone (2) suspended on ropes in a frame (10). Inside the outer cone, there is an inner cone (1), driven in high-frequency oscillating motion by an inertial vibrator (4) located inside the cone. In order to ensure a stable operation of the crusher, the outer cone should have a large mass, which at the same time is the main disadvantage of this type of

solution. There is currently very little information in the literature on the industrial use of vibratory cone crushers of this type.

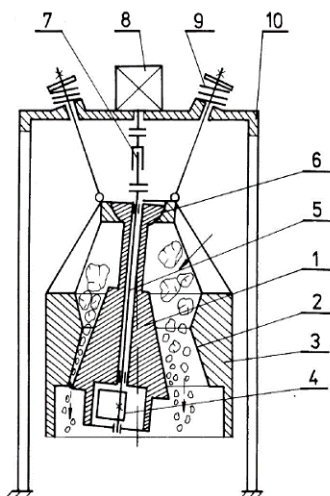


Fig. 1 Vibratory cone crusher with single-mass inertial vibrator mounted in the internal working cone:

1 – inner cone, 2 – outer cone, 3 – inertial body, 4 – vibrator, 5 – vibrator shaft, 6 – joint,
7 – cardan shaft, 8 – electric motor, 9 – rope suspension, 10 – crusher frame

Source: (Sidor J., 1997)

Cone crushers with two-mass inertial vibrator mounted on the shaft of the inner working cone

Another design solution is to place the inertia vibrators on the outside of the working cone (Fig. 2) through an additional attachment (9).

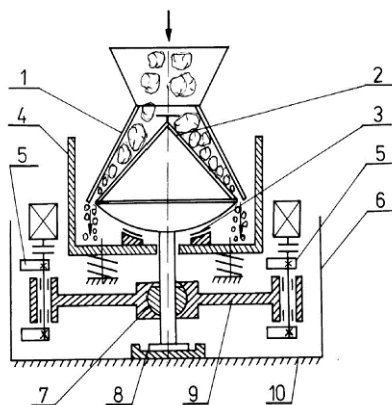


Fig. 2 Vibratory cone crusher with two-mass inertial vibrator mounted on the shaft of the inner working cone:

1 – outer cone, 2 – inner cone, 3 – cone bearing, 4 – crusher body, 5 – vibrator shaft,
6 – casing, 7 – main bearing junction, 8 – bracket, 9 – vibrators attachment, 10 – crusher base

Source: (Sidor J., 1997)

The advantage of this solution is a regular inlet opening that allows large grains of the feed to be loaded into the crusher without the risk of clogging. The drawback is the need for an additional, heavily loaded bearing junction (7), which complicates the construction and makes it more expensive to operate. Vibratory crushers of this type have not found a wider use in the industry.

Cone crushers with single-mass inertial vibrator mounted on the shaft of the inner working cone

Crushers, the structure of which is shown in Fig. 3, called "Wibrokon" mill-crushers, found the widest range of application.

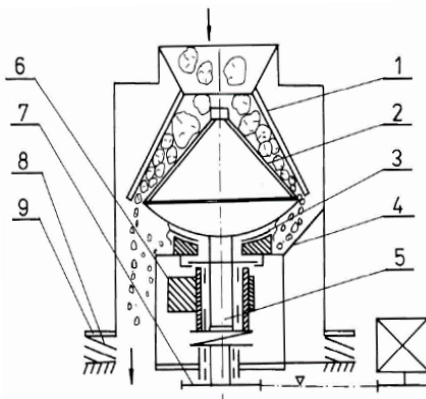


Fig. 3 Vibratory cone crusher with single-mass inertial vibrator mounted on the shaft of the inner working cone:

1 – outer cone, 2 – inner cone, 3 – inner cone support bearing, 4 – crusher frame, 5 – inner cone shaft, 6 – eccentric mass, 7 – belt transmission, 8 – support spring, 9 – spring housing

Source: (Sidor J., 1997)

The inertial vibrator (6) is located directly below the inner cone (2) and is driven from the electric motor via a flexible coupling. The inner cone rests on the support bearing (3). Due to a much simpler design than the previously described solutions, this crusher has found the widest industrial application. Fig. 4 shows a view of this type of crusher, manufactured by the Russian company Mekhanobr (Mekhanobr, 1993).

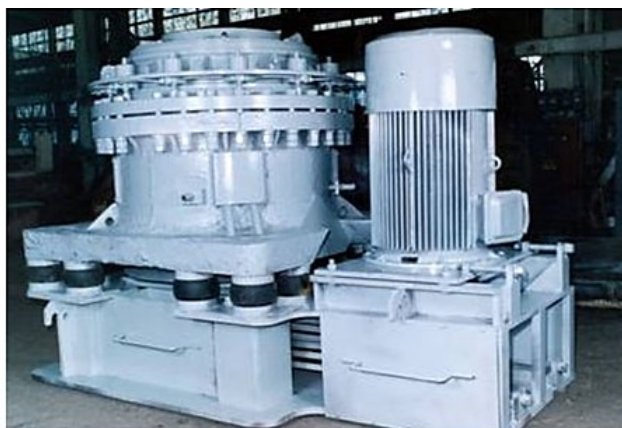


Fig. 4 Vibrating cone crusher KID series – manufactured by Mekhanobr, Russia

Source: (Mekhanobr, 1993)

Cone crushers with two-mass inertial vibrator driving the external working cone (with a fixed inner cone)

The crusher shown in Fig. 5 is a relatively new design. Unlike previous solutions, it is characterized by the inner cone being stationary and the outer cone is driven to oscillating movement.

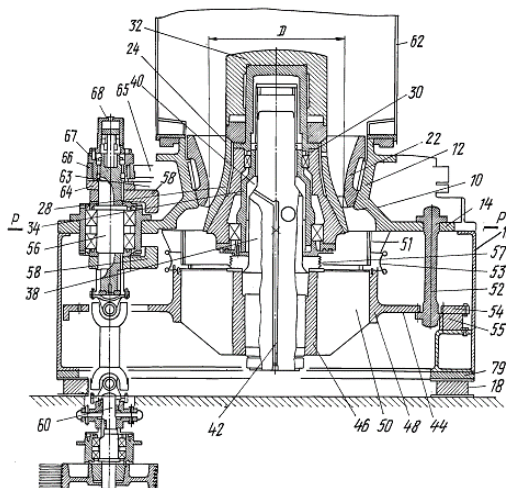


Fig. 5 Vibratory cone crusher with two-mass inertial vibrator driving the external working cone (with a fixed inner cone)

Source: (Mekhanobr, 1993)

The main advantage of this solution is the lack of internal cone support bearing, which is expensive in production and operation. The outer cone is supported on the bank of helical springs.

VIBRATORY JAW CRUSHERS

Vibratory jaw crushers with a simple jaw motion, driven by two-mass inertial vibrators

In Poland, the first designs of these crushers (Fig. 6) were developed at the AGH University of Science and Technology in Cracow, at the Institute of Mining Machinery, Processing and Automation – presently the Department of Mining, Dressing and Transport Machines.



Fig. 6 KWB-d vibratory jaw crusher with lower jaw suspension located in the AGH Department of Mining, Dressing and Transport Machines laboratory

Two types of vibratory jaw crushers, differing in the location of jaws suspension were designed. Jaws of both crushers are driven by two two-mass inertial vibrators – one vibrator per jaw (Figure 7).

Vibrators are synchronized in such a way that they provide opposed movement of the jaws, i.e., the jaws move synchronously at each moment in the "toward" or "away" direction. An important advantage of this type of construction is the elimination of typical crushers fuses against overload and feed contamination

(metal or wooden parts), which has been taken over by the function of inertia vibrators.

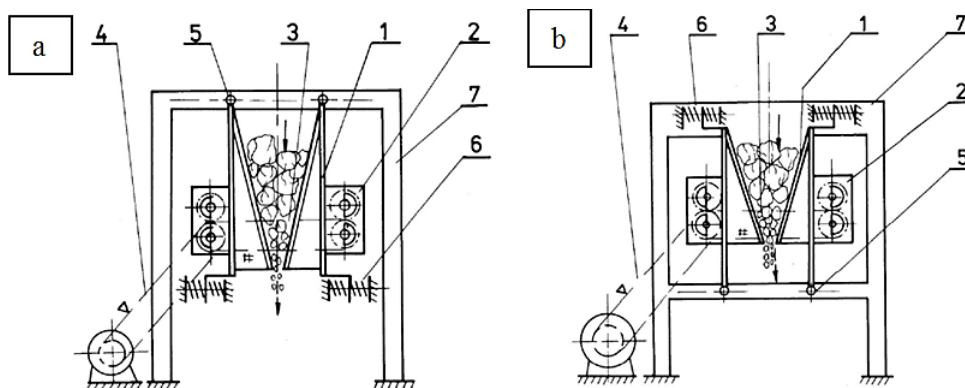


Fig. 7 Diagram of vibratory jaw crushers with upper (a) and lower (b) jaw suspension
 Source: (Sidor J., 1997)

Some disadvantages of this solution are complicated drive systems and a greater dependence of the product grain size from the grain size of the feed than in vibratory jaw crushers with kinematic actuation of the jaws.

Vibratory jaw crushers with a simple jaw motion, driven by one-mass inertial vibrators

In the works (Sidor J., 1997; Sidor J., 2006) series of currently produced vibratory jaw crushers were described. These are crushers with upper suspension of both moving jaws, each driven by a one-mass inertial vibrator connected with corresponding jaw by a spring element. The oscillating unit of the crusher, consisting two jaws (4) and vibrators (5), is suspended on a common frame (1), with spring elements (3) – Fig. 8.

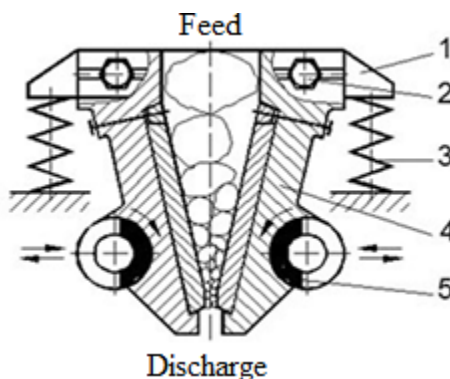


Fig. 8 Scheme of vibratory jaw crusher type VJC manufactured by Mekhanobr, Russia:
 1 – crusher body, 2 – jaw axis of rotation, 3 – spring support, 4 – jaw, 5 – inertial vibrator
 Source: (Mekhanobr, 1993)

This design solution allows the crusher working assembly to oscillate vertically, which accelerates the unloading of the crushing zone and acts as the vibration isolation. Synchronization of both vibrators was accomplished by electrical means, eliminating the mechanical transmissions in the crusher. The crushers of this type are shown in Fig. 9.

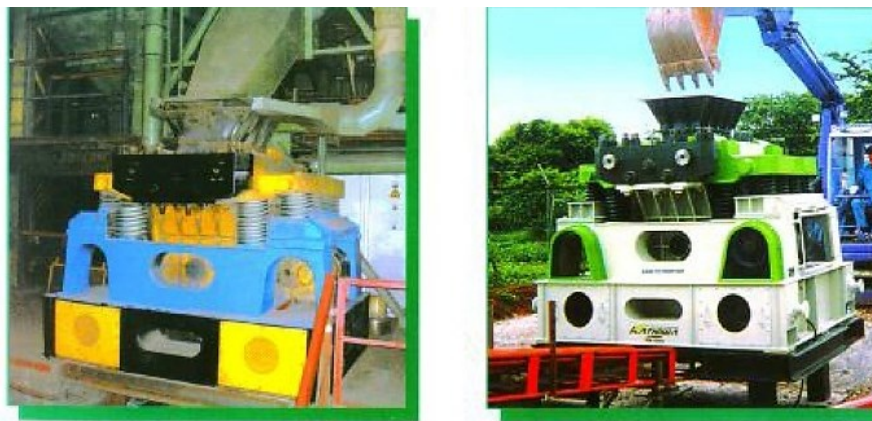


Fig. 9 View of Mekhanobr VJC vibratory jaw crushers

Source: (Mekhanobr, 1993)

Vibratory jaw crushers with a simple jaw motion, driven by kinematic vibrators

Crushers of this type were developed at the AGH University of Science and Technology in the former Institute of Metallurgical Machines and Automation, presently the Department of Manufacturing Systems. The KW 40/1 type crusher is equipped with two moving jaws (1) mounted pivotally at the bottom (Fig. 10).

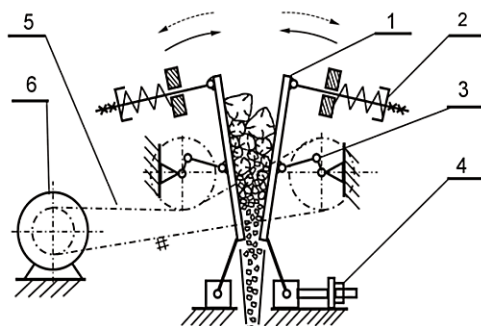


Fig. 10 Scheme of the vibratory jaw crusher type KW 40/1:

1 – jaw, 2 – recoil springs arrangement, 3 – kinematic vibrator,
4 – outlet gap adjustment mechanism, 5 – chain transmission, 6 – electric motor

Source: (Sidor J., 1997)

One of the jaws is equipped with a mechanism for adjusting the outlet gap (4). Both jaws are driven by kinematic vibrators (3) coupled and synchronized by a chain transmission (5). By this synchronization opposed movement of the jaws is ensured. The crusher has a plain, steel jaws lining, but the method of fixing it makes it possible to use a ceramic linings. The crusher has the possibility to adjust travel of both jaws.

This crushers are characterized by very little dependence of the product grain size from the grain size of the feed. This allows them to be used for very fine crushing of the hardest materials. Due to the use of kinematic vibrators it is necessary to protect the crusher from overload, which is carried out by electrical means and by very strict separation of any unwanted contamination from the feed. Fig. 11 shows the designs of this type of crushers, which have been used in Polish industrial plants.

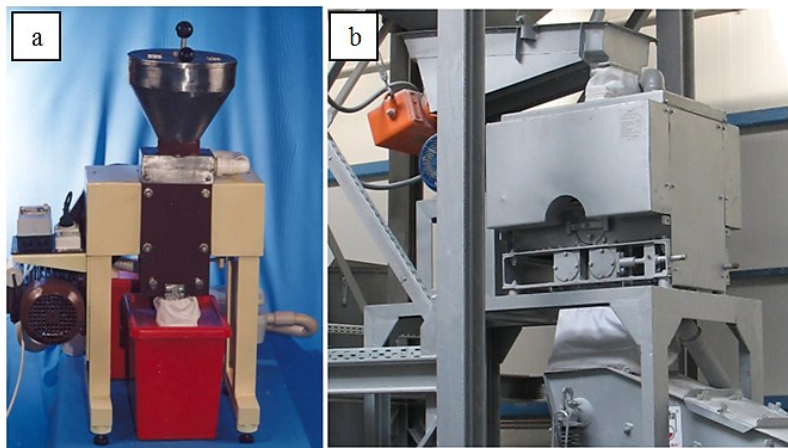


Fig. 11 Vibratory jaw crushers developed and applied in Poland:

a) KW Sj-2 for hydroxyapatite crushing in a pharmaceutical company

b) VB-C-30x8 for crushing industrial ceramic waste with feeder and screening machine

Source: (Sidor J., 2008)

CONCLUSIONS

Vibratory crushers are increasingly used industrially due to their advantages, such as:

- the ability to obtain high levels of fragmentation, even above 50 (which allows one vibratory crusher replacing several crushing stages),
- simplification of technological lines by eliminating auxiliary equipment of the crushing stages (power supply, feed and discharge, air purification);
- the possibility of almost complete dynamic balance of vibratory crushers (the possibility of using smaller foundations),
- vibratory crushers with inertial vibrators do not require any protection against overload,
- ability to comminute materials with very high compressive strength (σ_C up to 2000 MPa) e.g. ferro-alloys, special ceramics, glass.

Vibratory crushers are increasingly used for very fine crushing of hard and very hard materials, which should not be crushed in impact crushers (hammers or rod) due to the high wear of their working elements.

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Abstract.

Very fine crushing of hard and very hard materials, to product of particle size less than 2-4 mm at feed particle size of 50-200 mm, requires a very large energy inputs. This is mainly because of the need for at least three or even four degrees of crushing, containing: jaw, cone or impact crushers. One of the methods of reducing the amount of energy expended on the crushing process is reducing the number of crushers in technological line. By replacing a large number of less effective crushers with fewer machines but characterized by higher crushing efficiency we can gain considerable savings in investment and operating costs. This is possible by using crushers capable of obtaining much greater degrees of fragmentation than the aforementioned, that is vibratory crushers. The paper includes the systematic of currently used vibratory crushers, their mechanical diagrams, descriptions of the construction and operation, and basic technical parameters as well as examples of crushing technological lines utilizing vibratory crushers.

Keywords: crushing, vibratory crushing, vibratory crushers