CHAPTER 3.3

Jaw and Impact Crushers

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JAW CRUSHERS

Jaw crushers have been the mainstay of the mining and quarrying industry for more than a century and, to a great extent, this situation continues. Apart from some advances (in bearing types, manganese wear liners, frame construction, and adjustment systems), the basic frame shape and principles of operation have not changed greatly since the machines were first introduced in the mid-19th century.

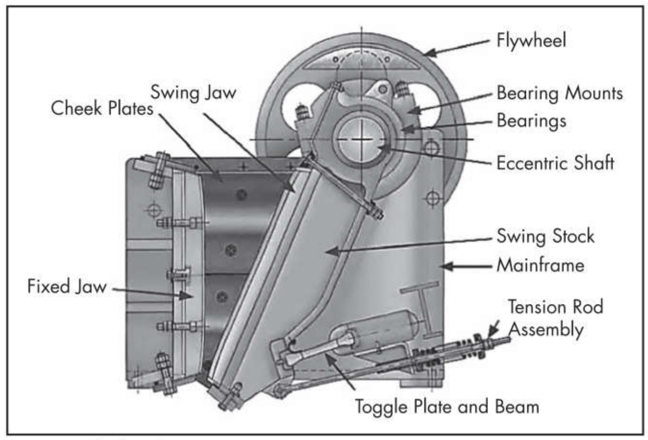
As with many types of equipment, there has been a rationalization of the number of manufacturers and the types of machines available over the last 20 years. Weiss (1985) gives a history and overview of a range of crushers, which is important context, but because of the aforementioned rationalization, this chapter only considers the more common single- and double-toggle jaw crusher types, as shown in Figures 1 and 2.

Of these two common types of jaw crusher, there has been a steady decline in the market for the more specialized, high-strength double-toggle crushers compared to the single-toggle crushers. This change in preference can be attributed to the increased strength and resilience of the newer single-toggle crushers and popularity of these machines for transportable and mobile plants.

Jaw Crusher Types

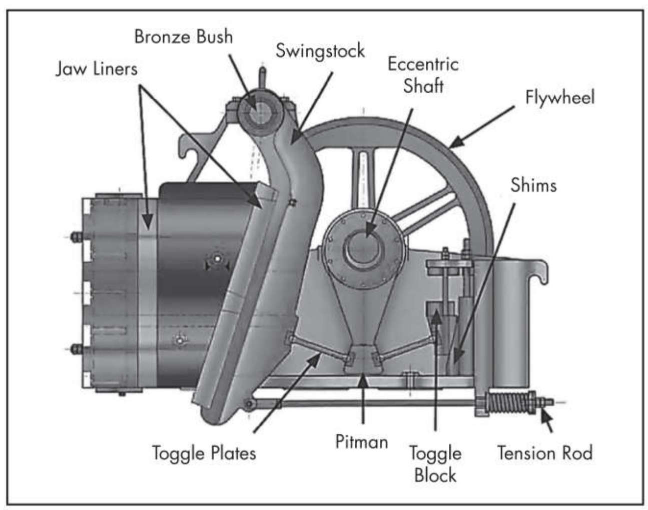
The application of energy dictates how a crusher performs, and in a jaw crusher, the energy applied is heavily dependent on the motion imparted to the swing jaw. For example, the double-toggle crusher uses a pendulum-type motion and hence, the variables in the energy application are related to the amount of eccentricity (stroke), nip angle between the jaws, and speed of the swing jaw. In single-toggle crushers, the motion of the swing jaw is controlled by additional factors including the angle of the toggle plate and the length of the toggle plate, which leads to a more complex motion.

Double-toggle crushers (also known as the Blake type) have always held a special place in mining, where they are regarded as the only machines to be used in the very hard and highly abrasive rock applications. This reputation is well founded and based on the design shown in Figure 3.



Courtesy of Telsmith

Figure 1 Single-toggle crusher



Courtesy of Telsmith

Figure 2 Double-toggle crusher

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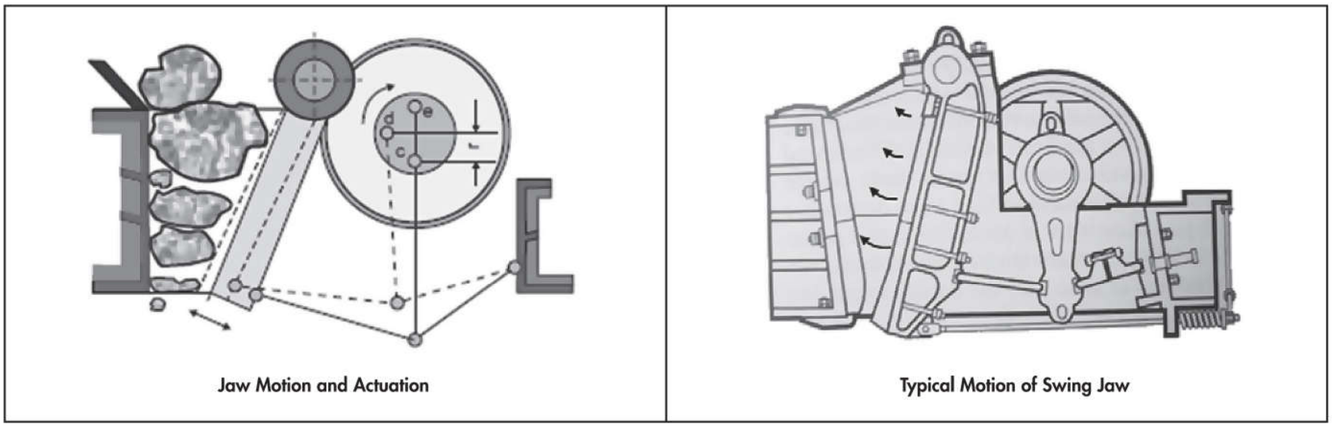


Courtesy of Metso

Figure 3 Double-toggle jaw crusher motion

It is important to note that in a double-toggle crusher, the swing jaw is pivoted around a stationary jaw shaft, and the motion of the swing jaw is imparted via a separate shaft, the pitman, and a double-toggle plate arrangement. These components provide the strength assigned to double-toggle machines, as they generate the aforementioned pendulum-like crushing action.

The action is undoubtedly appropriate for hard feed material, but the crushing action does restrict performance in other ways. The swinging, or pendulum-type motion of the swing jaw, has a major upward component to the motion, and this essentially hinders material flow through the crushing chamber, making the throughput of double-toggle crushers slightly less than that of an equivalently sized single-toggle crusher. The other main restriction is that at the feed opening of a double-toggle crusher, the jaw motion is negligible. At the pivot point, there is zero movement; however, movement increases down the length of the crushing chamber. The lack of motion (at the feed opening) does not encourage material to feed into the crusher, and in the case of larger particles, there is an increased likelihood of bridging.

The lack of motion at the feed opening also leads to the rule of thumb that the maximum particle size for a double-toggle jaw crusher should be no more than 60%–70% of the minimum feed opening dimension. In contrast, the single-toggle crusher can tolerate a maximum feed size of 80%–85% of the minimum feed opening dimension. In an effort to improve the motion of the double-toggle crusher at the feed opening, Kue-Ken developed a machine where the swing jaw pivot point was raised upward and forward. Although this *overslung* design improved the motion, it was to the detriment of the feed opening configuration, and the ingress of feed into the chamber was restricted.

When considering a double-toggle crusher, there are certain features that set it apart from the single-toggle version. As noted earlier, the double-toggle machine is used in tough applications, and this is reflected in the mass of the machine. As an example, the ThyssenKrupp double-toggle 1,500 × 2,000 mm (60 × 79 in.) machine has a total mass of 285,000 kg (628,140 lb). By way of comparison, an equivalent single-toggle machine would weigh approximately 137,000–150,000 kg (302,033–330,693 lb). Simply, this mass difference means that in terms of assembly, maintenance, and installation, the requirements for a double-toggle crusher are significantly different and must be considered.

Single-toggle jaw crushers use an overhead eccentric shaft arrangement to impart motion to the swing jaw, as seen in Figure 4. Unlike the double-toggle machine, a single shaft provides both the pivot point and the source of eccentricity.

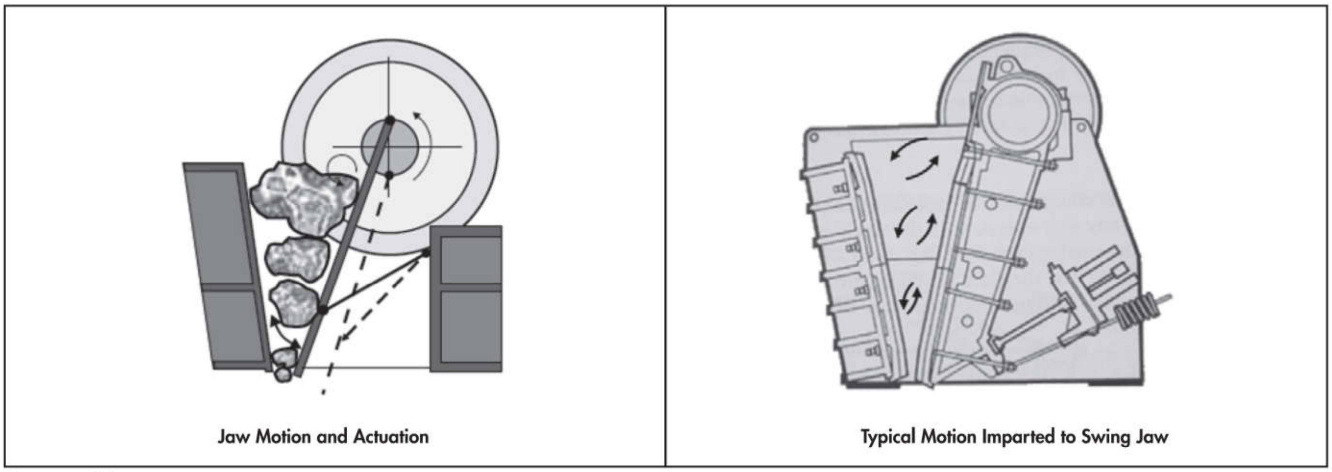
Traditionally, single-toggle machines were regarded as only suitable for soft through moderately hard rock types that display low to medium abrasion feed characteristics. Once into the hard and very hard feed types, the double-toggle became the preferred machine.

For process performance, the single-toggle crusher offers benefits in throughput and improved mobility in the feed area. These advantages come from the position of the eccentric shaft, which is at or just above the feed opening.

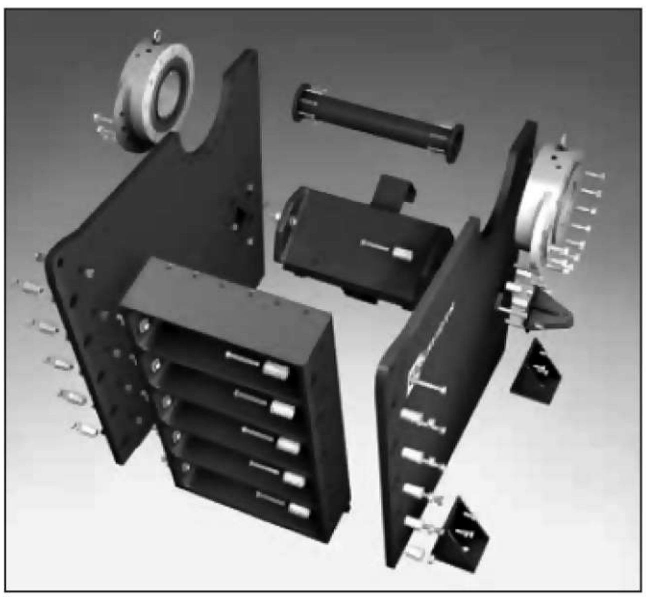
The position of the eccentric action provides maximum motion at the feed opening, and the subsequent induced motion has an elliptical form with the main axis of the ellipse having a downward inclination in the direction of the material flow. The orientation of the ellipse does change depending on the position in the crushing chamber because of the geometric relationship induced by the combination of the eccentric motion and the constraint of the toggle plate.

These ellipses provide throughput, but at the expense of crushing angle, and this is always one of the reasons why double-toggle machines have been preferred for hard feed types. Improvements in machine design now provide single-toggle crushers with a design that can handle extreme forces and at the same time have optimized the crushing motion ellipses to give a combination of throughput and angle that allow them to be highly effective in hard rock applications.

This elliptical motion, however, has a downside in that single-toggle machines generally experience two to four times the rate of wear of double-toggle machines in the same crushing conditions. Such a difference can be attributed to the scuffing action of feed material against the jaw plates brought about by the elliptical motion of the single-toggle jaw. In hard and highly abrasive feed types, liner wear rates, related costs, and downtime can become a major factor in the selection of single- versus double-toggle jaws. Applying strength and abrasivity limits to single- and double-toggle jaw crushers is difficult, as the different crusher models and manufacturers provide a variety of guidelines. In broad terms, if the strength



Courtesy of Metso
Figure 4 Single-toggle jaw crusher motion



Courtesy of FLSmidth
Figure 5 Typical bolted assembly of jaw crusher mainframe

of the feed material is regularly and consistently at or above 400 MPa compressive strength, then a double-toggle crusher is likely to be more appropriate. In terms of abrasivity, feed material with a Bond abrasion index of 0.6 or greater would cause accelerated wear in a single-toggle jaw crusher, and a double-toggle option should be considered. As with all equipment selection tasks, there are a series of trade-offs required, and therefore, all other performance considerations should be taken into account, not just strength and abrasivity.

Single-toggle machines are considerably lighter than double-toggle machines with similar feed openings. The outcome is that single-toggle machines are more suited to installation on steel structures and for use on mobile plants.

Construction and Design

Currently, both gyratory and single-toggle crushers are now routinely used to crush feed types formerly reserved for double-toggle jaw crushers. This has been driven by changes in the structural design of single-toggle machines and an improved understanding of the forces present through widespread application of finite element analysis (FEA) and validation from strain gauging. FEA is a standard design tool for any piece of mechanical equipment and has been for many years. As such, many manufacturers make reference to the use of FEA in improving design, machine mass, and strength.

Alongside this modification, a manufacturing change has taken place, with a move away from castings for the mainframes and walls of many jaw crushers. Traditionally, castings were the more trusted method for construction of crushers, but the improvements in welding processes (automated and nonautomated), better heat treatment, more consistent steel plate quality, and nondestructive testing have all combined to make fabricated frames the preferred and lower cost method of construction.

In the following paragraphs, the major mechanical and design components of jaw crushers are examined, namely:

- Mainframe
- Pitman
- Fixed and swing jaws
- Flywheels
- Main shaft
- Toggle plates
- Setting adjustment
- Overload protection
- Crusher dimensions

Bolted frames are now the standard form of construction of mainframes in jaw crushers (Figure 5), although some manufacturers still use cast steel end frames, bolted and bossed into fabricated side frames. Use of FEA techniques has allowed stiffness to be designed into the frame using web plates, ribs, and fasteners, rather than relying on heavy, one-piece cast frames. Such an approach is standard across the major manufacturers (Sandvik 2012). Welded joints are also still widely employed in the fabrication of frames, and given modern quality control and nondestructive testing employed during manufacture, there is now a much reduced likelihood of the welds introducing stress raisers and possible weak points in the frames.

Fixed jaw arrangement has varied over time and, depending on the manufacturer, the angle of the fixed jaw has varied between vertical and 80–85 degrees to the vertical plane. The angle of the fixed jaw can assist in providing improved nip angles and also for presenting rocks in relation to the type of motion ellipse that is applied.

In both types, the longer the design of the crushing chamber, the lower the included angle between fixed and swing jaw for a given feed opening and closed side setting (CSS). In very *short* or squat jaw crusher chambers, there is a risk of particle slippage upward during the compression stroke, particularly if the discharge setting used is too tight.

Replaceable crushing liners used on both the fixed and swing jaws are very similar in both single- and double-toggle crushers. In some instances, the liner plates are designed to be reversible, or they can be rotated from top to bottom in the chamber, but plates need to be designed specifically to be moved and swapped in this manner. Because of the impact environment in a jaw crusher chamber, the liner material of choice is manganese steel, which work hardens at the liner surface because of deformation caused by the rock-on-liner interaction. The main design features for the liners is the number and profile of vertical corrugations used on both fixed and swing jaws. Metso (2011) provides a comprehensive description of the various profiles available for various crushing duties. Factors that drive the selection of nonstandard profiles include the following:

- Rock strength
- Feed abrasivity
- Shape of feed
- Requirement to reduce the slabbiness of the product
- Coefficient of fraction of the feed (i.e., slippery feed)
- Fines content of the feed

An example of some of the types of liner available is given in Figure 6.

In some applications, liner designs with a curved, convex surface are used, mostly on the swing jaw. Such curved liners are usually used to restrict compaction occurring in the chamber, particularly where there are larger quantities of fines in the feed.

The *pitman* arm is integral to the design of jaw crushers, but currently the term is mostly reserved for double-toggle crushers. In single-toggle jaw crushers, the word is less widely used and has in some instances been replaced by terms such as *jawstock*, *jaw holder*, or *swing jaw holder*.

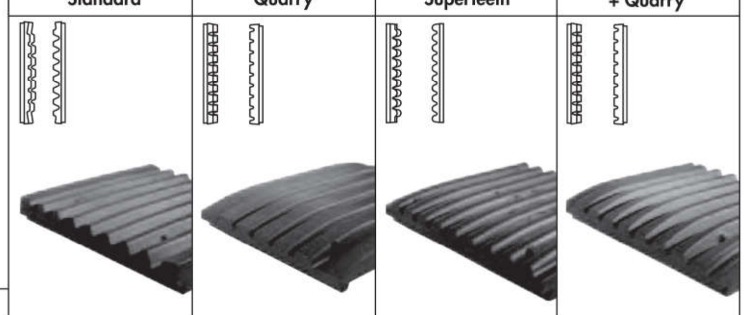
In essence, the pitman is the component that transfers the eccentric motion from the eccentric shaft to the toggle plate(s) and then into the motion of the swing jaw. In the double-toggle crusher, it is a major independent component, but in the single toggle, it is essentially the mass of the swing jaw behind the swing jaw liner plates.

In an effort to improve the process performance of jaw crushers, most manufacturers now target the use of large eccentric throws in combination with appropriate speeds and nip angles suited to the feed material and size reduction being targeted.

Flywheels are integral to the design of jaw crushers, as the embedded energy in the flywheels is required to help overcome the strength of the rock and to smooth the power draw. On each machine, two flywheels are installed, with one acting as a sheave wheel, which is driven by a series of V belts, and the other acting as a balancing unit and also providing additional inertia. The key elements of flywheels are the bearings and the balance of the flywheels. The latter element is of particular importance when the crushers are used on mobile plants. Some modern designs of single-toggle machines are so well balanced that they can be mounted on rubber isolation mounts.

Toggle plates that give their name to the crushers under discussion are integral to the operation of the crushers.

In the double-toggle crusher, a rear toggle plate forms a pivot connecting the stationary toggle block to the pitman, and the front toggle plate links the pitman to the rear of the swing jaw. Toggles are designed to be robust, but in the case of the front toggle plate, it is also designed to act like a mechanical fuse and therefore to fail if uncrushable material enters the

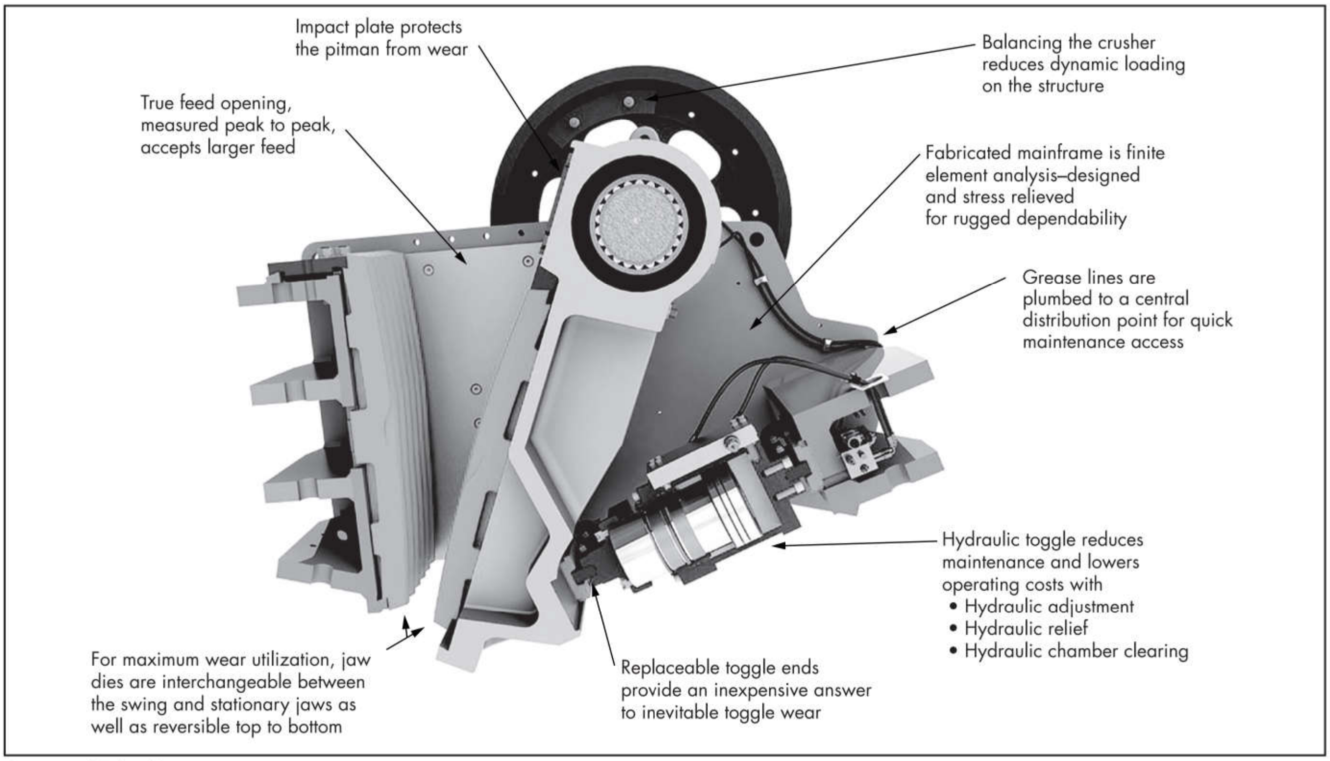


Feed Material Types:	Standard	Quarry	Superteeth	Special + Quarry
Hard Rock, UCS > 160 MPa	•	• • •	• •	• •
Soft Rock, UCS < 160 MPa	• •	• • •	• •	•
Gravel	• •	•	• • •	•
Slabby Soft Rock, UCS < 160 MPa	•			
Slippery Rocks	•	•	• •	•

Note: UCS = unconfined compressive strength. More bullets represent the better choice.

Courtesy of Metso

Figure 6 Example of some types of jaw crusher liner available



Courtesy of Telsmith

Figure 7 Hydraulic toggle arrangement

crusher. Good maintenance and lubrication of the toggle seats where the plate pivots against the toggle block seat, pitman seats, and swing jaw seat is essential. It is also required that the tension rods are properly maintained to prevent impact between the ends of the toggle plates and the pivot points. Some manufacturers employ *dry* rocking end toggles and seats that are designed for long service life and lubrication-free operation.

In single-toggle crushers, the toggle plate is free to pivot against a fixed toggle block at the rear of the crusher and also against the back of the swing jaw assembly. As with the double-toggle machine, the single-toggle plate must be free to pivot, and the correct tension needs to be applied to prevent any slack in the system. The tension rods used in single-toggle crushers are designed to be of a similar orientation to the angle of the toggle plate.

Setting adjustment in jaw crushers relies on moving the toggle plate, or rear toggle plate in double-toggle machines, which in turn moves the position of the swing jaw. Traditionally, plate metal shims were inserted to move the toggle block forward to reduce the CSS, or plates were removed to increase the CSS. This manual adjustment method is still commonly employed, but numerous attempts have been made to replace either the shimming technique or in some cases the entire metal toggle plate system with hydraulic solutions.

A common replacement for shim-based CSS adjustment is the use of counterposed wedges that can be driven into position to reduce the CSS or, alternatively, withdrawn to open the CSS. Such wedge assemblies can be either linear screw actuated or hydraulically actuated. In the Metso C series single-toggle jaw crushers, the wedge style is standard and the hydraulic version is available as an option. There are obvious advantages of having a wedge system, which include faster adjustment, reduced manual handling, and in the case of the hydraulic version, ability to remotely change the CSS from a control center.

Advancing beyond the wedge-based solution, several companies have replaced the metal toggle plate entirely with hydraulic cylinders (Figure 7). Some early attempts to deploy such a solution failed, but increasingly, such devices are finding favor. In addition to the improvements related to CSS adjustment, the hydraulic versions also offer a more effective solution to the ingress of uncrushables. Numerous patents have been lodged in the area of hydraulic adjustment and relief, including Haven et al. (2002) and Burhoff et al. (2015).

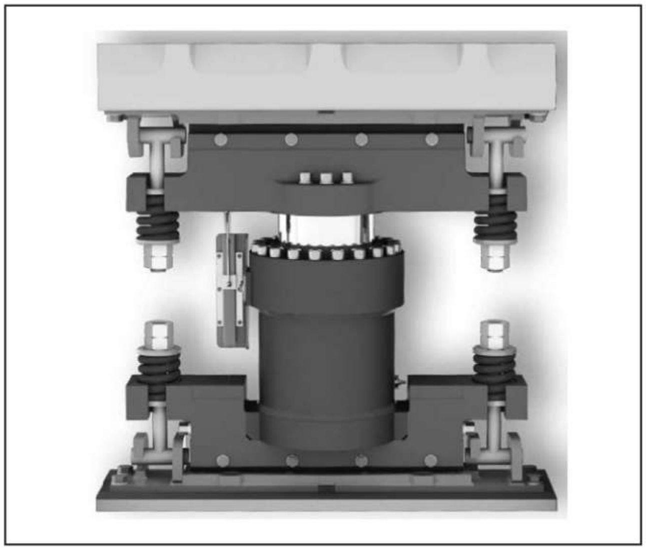
To enhance the hydraulic toggle system, the usual tension rods have also been upgraded. Figure 8 shows the toggle tensioning system deployed by Telsmith. The system uses spring assemblies to connect each end of the hydraulic toggle to the toggle seats so that there is no requirement to adjust the springs when changing the discharge setting.

In some machines, crusher overload protection has been built into the flywheels. One such device uses a torque limiting system to secure the flywheel to the shaft. In the case of uncrushable material, the device allows the flywheel to disengage and spin harmlessly on the shaft.

In some machines, the metal toggle plate is still designed to fail to protect the crusher, but in doing so, the plates must be replaced before production can resume.

If a hydraulic toggle unit is used, the rams retract to open the crusher once a pressure overload is detected; once the uncrushable material has passed, the hydraulic system resets the crusher setting back to normal. Using this approach, production can be resumed much quicker, and therefore operational interruption is greatly reduced.

One of the consequences of the difference in design between single- and double-toggle jaw crushers is the dimensions and masses of the two variants. Tables 1 and 2 show dimensions and masses for typical single- and double-toggle crushers.



Courtesy of Telsmith

Figure 8 Toggle tensioning system

Operation

Jaw crushers are most commonly used for primary crushing duties, with features such as ease of maintenance, mass, capital cost, throughput, and durability driving the selection. Jaw crushers can be seen in some limited secondary duties; however, in most instances, such applications are based on availability of equipment and not on required process performance.

Jaw crushers are similar to other compression crushers in that in operation, they oscillate from an open side setting to a CSS; however, the reciprocating action of the jaw crusher and the steep chambers are not ideal features for maximizing throughput, or for controlling flow and hence the degree of size reduction (reduction ratios in jaw crushers are normally limited to 4:1).

Jaw crushers are reasonably accepting of fines in the feed, particularly at large CSS values. In practice, a majority of jaw crusher installations are set up to remove fines prior to the crusher, mostly using a vibrating grizzly feeder or heavy-duty screen. The action of the grizzly, or screen, ahead of the crusher also performs the useful function of aligning rocks prior to the feed opening of the jaw crusher, which can reduce blockages in the feed area. The decision to bypass fines is mostly taken to increase the overall capacity of the primary crushing station or to remove troublesome, wet, and sticky fines prior to the crushing chamber.

Table 1 Metso single-toggle dimensions and masses

		C80	C100	C96	C106	C116	C3054	C110	C125	C140	C145	C160	C200
A	mm	800	1,000	930	1,060	1,150	1,380	1,100	1,250	1,400	1,400	1,600	2,000
	in.	32	40	37	42	45	54	44	50	56	56	63	79
B	mm	510	760	580	700	800	760	850	950	1,070	1,100	1,200	1,500
	in.	21	30	23	28	32	30	34	38	43	44	48	60
C	mm	1,526	2,420	1,755	2,030	2,400	2,640	2,385	2,800	3,010	3,110	3,700	4,040
	in.	61	96	70	80	95	104	94	111	119	123	146	160
D	mm	2,577	3,670	2,880	3,320	3,600	3,540	3,770	4,100	4,400	4,600	5,900	6,700
	in.	102	145	114	131	144	140	149	162	174	182	233	264
E	mm	1,990	2,890	1,610	2,075	2,675	2,470	2,890	3,440	3,950	4,100	4,580	4,950
	in.	79	114	64	82	105	98	114	136	156	162	181	195
F	mm	1,750	2,490	1,460	2,005	2,730	2,470	2,750	2,980	3,140	3,410	3,750	4,465
	in.	69	99	58	79	107	98	109	118	124	135	148	176
G	mm	1,200	1,700	755	1,135	1,790	1,080	1,940	2,100	2,260	2,430	2,650	2,800
	in.	48	67	30	45	71	43	77	83	89	96	105	111
H	mm	2,100	2,965	2,500	2,630	2,885	2,950	2,820	3,470	3,755	3,855	4,280	4,870
	in.	83	117	99	104	114	117	112	137	148	152	169	192
I	mm	625	775	465	700	1,255	690	580	980	1,050	1,050	1,300	1,400
	in.	25	31	19	28	50	28	23	39	42	42	52	56
Basic crusher weight*	kg	7,670	20,060	9,759	14,350	18,600	25,900	25,800	37,970	47,120	54,540	71,330	121,510
	lb	16,900	44,240	21,520	31,650	40,920	57,100	56,880	83,730	103,900	120,260	157,280	267,930
Fully equipped crusher weight†	kg	9,520	23,300	11,870	17,050	21,500	30,300	29,500	43,910	54,010	63,190	83,300	137,160
	lb	21,000	51,390	26,170	37,590	47,300	66,800	65,050	96,830	119,100	139,330	183,680	302,440

Courtesy of Metso

Note: Certified general arrangement, foundation, and service space requirement drawings are available from Metso.

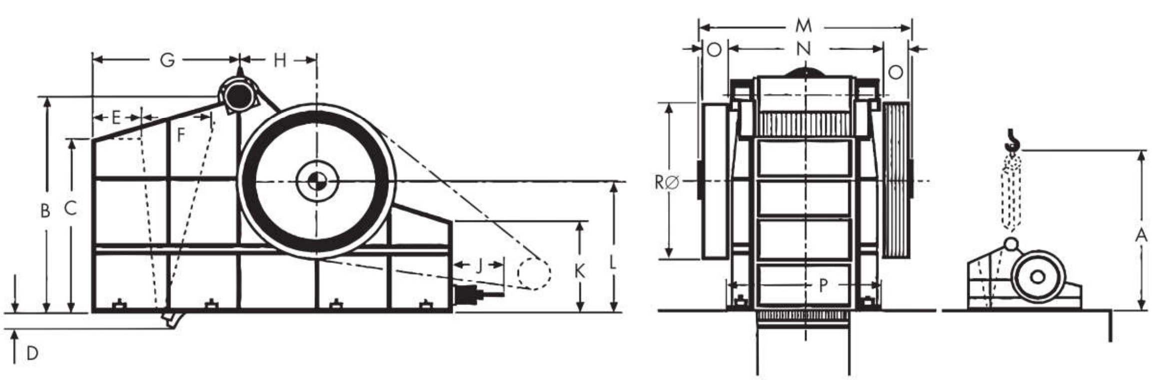
*Crusher without options.

†Crusher, hydraulic setting adjustment, flywheel guards, integral motor support, feed chute, automatic grease lubrication system, and typical electric motor.

Table 2 Double-toggle crusher dimensions and masses

Crusher Type	Largest Component	Heaviest Component	Dimensions of Largest Component, m × m × m (ft × ft × ft)	Weight Heaviest Component, kg (lb)	Maximum Weight of Crushing Jaw, kg/unit (lb/unit)
DB 6-4,2	Housing	Housing	2.60 × 1.67 × 1.08 (8.53 × 5.48 × 3.54)	4,590 (10,116)	425 (937)
DB 8-5,7	Housing	Housing	3.00 × 2.00 × 1.30 (9.84 × 6.56 × 4.27)	8,360 (18,425)	700 (1,543)
DB 10-8	Housing	Housing	3.90 × 2.65 × 1.57 (12.80 × 8.69 × 5.15)	17,600 (38,790)	1,600 (3,527)
DB 12,5-9	Housing	Housing	4.05 × 2.80 × 1.93 (13.29 × 9.19 × 6.33)	24,200 (53,337)	2,080 (4,584)
DB 15-12	Housing	Housing	5.60 × 3.90 × 2.40 (18.37 × 12.80 × 7.87)	59,070 (130,190)	4,290 (9,455)
DB 18-14	Side wall	Swing jaw	6.65 × 3.10 × 1.00 (21.82 × 10.17 × 3.28)	23,950 (52,786)	6,260 (13,797)
DB 21-16	Swing jaw	Swing jaw	5.40 × 3.10 × 1.50 (17.72 × 10.20 × 4.92)	28,710 (63,277)	8,030 (17,698)
DB 25-18	Swing jaw	Swing jaw	5.80 × 3.55 × 1.80 (19.03 × 11.65 × 5.91)	39,380 (86,794)	10,780 (23,759)

Crusher Type	A, mm (in.)	B, mm (in.)	C, mm (in.)	D, mm (in.)	E, mm (in.)	F, mm (in.)	G, mm (in.)	H, mm (in.)	J, mm (in.)	K, mm (in.)	L, mm (in.)	M, mm (in.)	N, mm (in.)	O, mm (in.)	P, mm (in.)	RØ, mm (in.)
DB 6-4,2	3,500 (138)	1,420 (55)	1,060 (42)	150 (6)	345 (14)	425 (17)	950 (37)	595 (23)	200 (8)	615 (24)	880 (35)	1,570 (62)	995 (39)	220 (9)	1,080 (43)	1,200 (48)
DB 8-5,7	4,200 (165)	1,780 (70)	1,350 (53)	150 (6)	350 (14)	570 (22)	1,040 (41)	780 (31)	200 (8)	700 (28)	1,010 (40)	2,020 (80)	1,280 (50)	320 (13)	1,300 (51)	1,650 (65)
DB 10-8	5,400 (213)	2,400 (95)	1,850 (73)	150 (6)	510 (20)	800 (32)	1,450 (57)	960 (38)	200 (8)	950 (37)	1,250 (49)	2,180 (86)	1,540 (61)	320 (13)	1,570 (62)	1,820 (72)
DB 12,5-9	5,700 (224)	2,510 (99)	2,000 (79)	200 (8)	480 (19)	900 (35)	1,635 (64)	880 (35)	250 (10)	1,050 (41)	1,380 (54)	2,730 (107)	1,930 (76)	400 (16)	1,930 (76)	2,100 (83)
DB 15-12	7,400 (291)	3,475 (137)	2,780 (109)	300 (12)	750 (30)	1,200 (48)	2,250 (88)	1,210 (48)	660 (26)	1,700 (67)	2,090 (82)	3,220 (127)	2,340 (92)	400 (16)	2,400 (95)	2,500 (98)
DB 18-14	8,700 (343)	4,200 (165)	3,200 (126)	250 (10)	865 (34)	1,400 (55)	2,750 (108)	1,280 (50)	135 (5)	2,020 (80)	2,490 (98)	3,830 (151)	2,830 (111)	500 (20)	2,960 (117)	3,000 (118)
DB 21-16	9,300 (366)	4,200 (165)	3,450 (136)	420 (17)	890 (35)	1,600 (63)	2,960 (117)	1,390 (55)	950 (37)	2,300 (91)	2,800 (110)	4,320 (170)	3,320 (131)	500 (20)	3,360 (132)	3,000 (118)
DB 25-18	10,250 (404)	4,860 (191)	3,900 (154)	420 (17)	1,080 (43)	1,800 (71)	3,460 (136)	1,500 (59)	1,100 (43)	2,250 (88)	3,060 (121)	4,960 (195)	3,860 (152)	600 (24)	3,820 (150)	3,500 (138)



Courtesy of ThyssenKrupp Industrial Solutions

One of the more common feed approaches for jaw crushers is to have a run-of-mine (ROM) hopper receiving direct tips from haul trucks, with an apron feeder pulling material from the hopper onto a vibrating grizzly screen or feeder. As part of such an arrangement, it is also common to include a hydraulic rock breaker with sufficient reach to access oversize on the feed equipment and in the feed opening of the jaw crusher.

In jaw crushers, the size designation is usually quoted as *gape × width*, for example, 914 × 1,219 mm (36 × 48 in.), or 914-mm (36-in.) gape between the fixed and swing jaw plates at the top of the chamber by 1,219-mm (48-in.) wide, where the width of the opening is the dimension of the opening between the cheek plates. Some manufacturers reverse the designation, but regardless of the manner that the model is stated, the higher number is the width of the feed opening between the cheek plates.

In practice, the width determines the throughput of the crusher at any given CSS, and the gape controls the maximum feed size. Currently, jaw crusher sizes range up to 1,500 × 2,000 mm (60 × 80 in.) for single-toggle jaw crushers and up to 1,676 × 2,133 mm (66 × 84 in.) for double-toggle crushers. The installed power for both the largest single-toggle and double-toggle machines is approximately 400 kW (536 hp).

Throughputs for jaw crushers are quoted as the amount of material passing through the jaws. In reality, the throughput of a jaw crusher should always take into consideration the total throughput for the whole station, that is, the amount of material through the jaws and the amount of fines bypassing via the scalping grizzly or screen. The additional throughput from the scalping process often makes jaw crusher throughput and unit cost more comparable to gyratory operating costs.

Throughput rates for single- and double-toggle jaw crushers are shown in Table 3 and Figure 9. Product size distribution data for single- and double-toggle crushers is provided in Figures 10 and 11.

Application

In the vast majority of fixed plant and mobile plant applications up to 1,000–1,200 t/h (1,102–1,322 stph), jaw crushers are still the preferred primary crushing tool. In the larger open pit environment, there is a continuing debate about jaw versus gyratory crusher. The main differences between the two are in the processing rate achievable and the complexity of the feed arrangements.

The feed arrangement for a jaw crusher was discussed earlier: ROM hopper, apron feeder, grizzly screen or feeder, associated chute work, and a rock breaker. In comparison, the minimal arrangement for a gyratory crusher consists of direct tip into the crusher from haul trucks. In cases where jaw crushers can still meet the throughput requirements, the relative complexity of the installation should not be the only consideration. To gain a fair comparison of jaw versus gyratory application, the following should be considered:

- Capital cost
- Operating cost
- Maintenance
- Liner life and change-out
- Machine dimensions and mass
- Physical location

Capital cost difference varies considerably according to the type of installation, geographic location, topography, and the required crusher duty. As such, there is no single answer to which machine is best, but rather it must be determined on a case-by-case basis. Factors that influence the operating cost of a crusher station need to be considered, such as ancillary and feeding equipment, hopper and chute liner wear costs, associated labor, and power.

Jaw crushers are relatively simple and robust machines to maintain, with less complexity than gyratory crushers. As such, the amount of maintenance required and the duration of major maintenance activities is often much shorter for jaw crusher installations.

Probably one of the main examples is the difference in crusher liner change-outs. On gyratory crushers, a full change of the mantle and concave plates can take up to three days, whereas changing the fixed and swing jaw plates is an activity that can be comfortably completed inside one shift. In most jaw crushers, there is also the option of rotating and/or switching the jaw plates to give extended life. In gyratory crushers, this is not an option, but in some instances, the shells (including concave plates) can be turned through 180 degrees. This option only really applies if one-half of the crushing chamber is being worn at an accelerated rate compared to the other side.

A major difference between jaw and gyratory crushers are the dimensions of the crushers and the related masses. As already stated, double-toggle jaw crushers are much heavier than single-toggle jaw crushers, and for an equivalent feed opening gyratory, the mass is close to that of a double-toggle crusher.

In most instances, in an open pit environment, the physical mass differences can be handled by the installation of gantry cranes and other specialized lifting equipment, but a bigger factor in the discussion usually relates to the height of the machines.

For underground mines, height is a significant factor, as it drives the dimensions of the chamber and the need for large excavations (Nixon and Weston 2005). In many instances, the excavations are required for the entire mine life, and this presents geotechnical and cost issues, particularly in areas where the in situ stress state is poor. Minimizing the primary crusher chamber and/or cavern dimension often drives the decision to select a jaw crusher, but where high throughput is required, this causes a mismatch of machine and capability. Various mine sites have taken different views of such issues, ranging from multiple jaw crusher installations to single large (1,524–2,260 mm [60–89 in.]) size gyratory crushers. Once again, the choice is highly site dependent.

Mobile crushing plants have exploded in popularity since the early 1990s, with single-toggle jaw crushers providing the mainstay of these plants' primary crushing duties. For a vast majority of primary mobile applications, single-toggle jaw crushers have no real competition; however, in certain instances, smaller gyratory crushers can be used, but because of height considerations, these can hinder mobility.

The jaw crushers used on mobile plants, which can be track-, wheel-, or skid-mounted, are the normal units used in static applications. In some instances, modifications are made to lower the height of the crushers, but this is the only significant change to the crusher itself. Regarding the mobile plant itself, a range of innovations have been developed to deal with problems of locating and operating equipment within a constrained space. Latimer (2012) reports on the largest mobile jaw application using a Metso C200 jaw crusher.

Table 3 Estimated throughputs for Metso C series single-toggle jaw crushers

Capacities and Technical Specifications		C110	C125	C140	C145	C160	C200
Feed opening width, mm (in.)		1,000 (44)	1,250 (49)	1,400 (55)	1,400 (55)	1,600 (63)	2,000 (79)
Feed opening depth, mm (in.)		850 (34)	950 (37)	1,070 (42)	1,100 (43)	1,200 (47)	1,500 (59)
Power kW (hp)		160 (200)	160 (200)	200 (250)	200 (300)	250 (350)	400 (500)
Speed, rpm		230	220	220	220	220	200
Product size, mm (in.)	**Closed side setting, mm (in.)**	**t/h (stph)**	**t/h (stph)**	**t/h (stph)**	**t/h (stph)**	**t/h (stph)**	**t/h (stph)**
0–60 (0–2⅜)	40 (1⅝)						
0–75 (0–3)	50 (2)						
0–90 (0–3½)	60 (2⅜)						
0–105 (0–4⅛)	70 (2¾)	160–220 (175–240)					
0–120 (0–4¾)	80 (3⅛)	175–245 (195–270)					
0–135 (0–5⅜)	90 (3½)	190–275 (215–300)					
0–150 (0–6)	100 (4)	215–295 (235–325)	245–335 (270–370)				
0–185 (0–7)	125 (5)	260–360 (285–395)	295–405 (325–445)	325–445 (355–490)	335–465 (370–510)		
0–225 (0–9)	150 (6)	310–430 (340–470)	345–475 (380–525)	380–530 (420–580)	395–545 (435–600)	430–610 (475–670)	
0–260 (0–10)	175 (7)	350–490 (390–540)	395–545 (435–600)	435–605 (480–665)	455–625 (500–690)	495–695 (545–765)	630–890 (695–980)
0–300 (0–12)	200 (8)	405–555 (445–610)	445–615 (490–675)	495–685 (545–750)	510–710 (565–780)	560–790 (615–870)	710–1,000 (780–1,100)
0–340 (0–13)	225 (9)		495–685 (545–750)	550–760 (605–835)	570–790 (630–870)	625–880 (685–965)	785–1,105 (860–1,215)
0–375 (0–15)	250 (10)		545–755 (600–830)	610–840 (670–925)	630–870 (695–960)	685–965 (755–1,060)	865–1,215 (950–1,340)
0–410 (0–16)	275 (11)				690–950 (760–1,045)	745–1,055 (820–1,160)	940–1,320 (1,030–1,455)
0–450 (0–18)	300 (12)					815–1,145 (895–1,260)	1,015–1,435 (1,120–1,575)

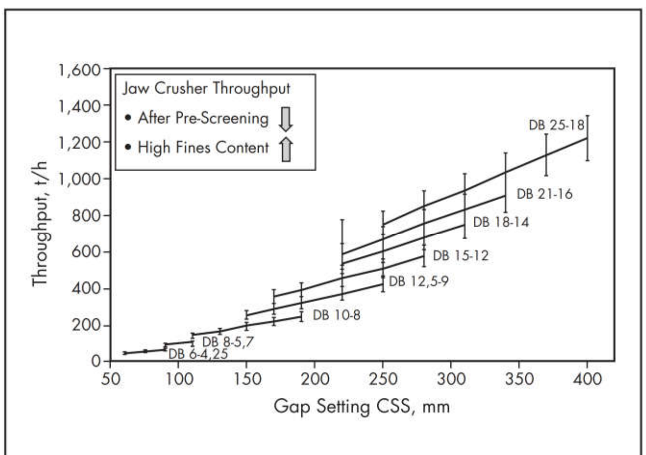
Courtesy of Metso

In low-abrasion, medium-strength applications, such as limestone and low-strength ores, horizontal shaft impactors (HSIs) and twin-shaft sizers present other options for both fixed and mobile primary crushing. These two machine types are relatively lightweight, compact, and have high throughput capacities for their overall size.

For overall primary crusher selection, the reader is directed to Utley (2002) and Chapter 3.6, "Crusher Selection and Performance Optimization," where selection charts are given for various types of crushers and applications. For context, see Tables 4–5 in which recent installations by the major suppliers are provided.

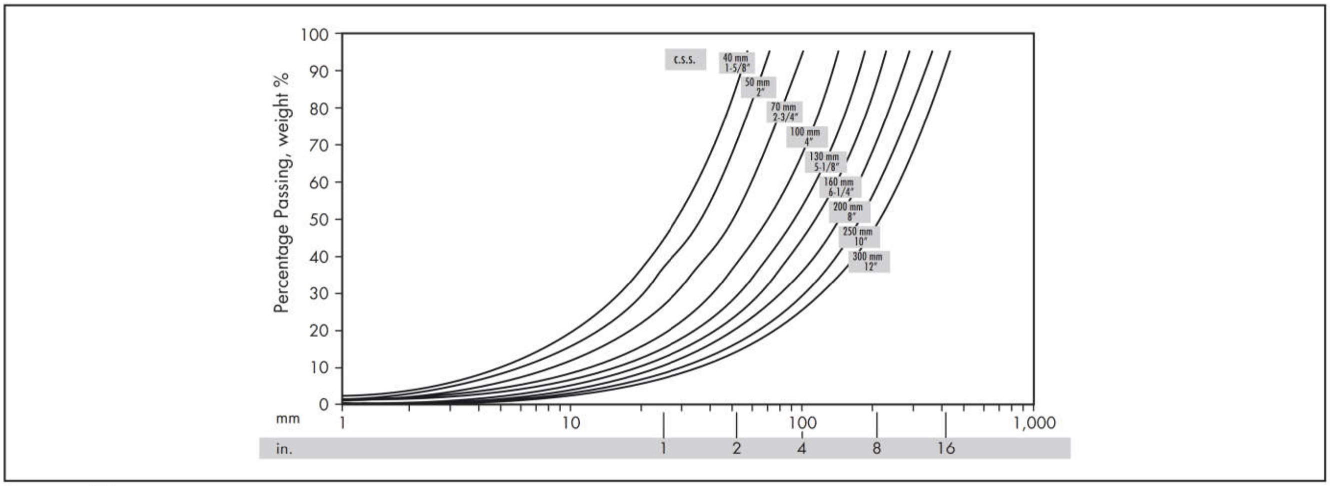
IMPACT CRUSHERS

The family of impact crushers all rely on applying a high-speed impact to a falling stream of material and accelerating falling material to a high velocity, therefore causing either particle-on-particle or particle-on-metal breakage. The breakage of the particles is unconstrained and this imparts specific performance characteristics to this type of machine.



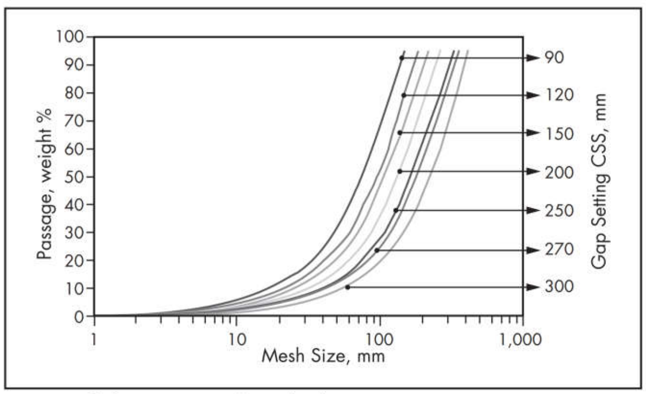
Courtesy of ThyssenKrupp Industrial Solutions

Figure 9 Estimated throughputs for ThyssenKrupp double-toggle jaw crushers



Courtesy of Metso

Figure 10 Typical product size distribution from single-toggle jaw crushers



Courtesy of ThyssenKrupp Industrial Solutions

Figure 11 Typical product size distribution from double-toggle jaw crushers

The *SME Mineral Processing Handbook* (Weiss 1985) included a major section on hammer mills, which generally used free-swinging hammers to break by impact and then crush between the path of the hammers and a discharge grate. Such machines have mostly been replaced by fine crushing impact crushers or high-pressure grinding roll machines. Because of the decline in hammer mill use, the reader is directed to Eacret and Klein (1985) for a comprehensive review of the hammer mill, and its variants and applications. The current focus for impact crushers is confined to HSIs and vertical shaft impactors (VSIs).

Principles and Terminology

The HSI has a long history and has been widely applied in a variety of applications including primary, secondary, and tertiary duties. Feed size varies with the stage of application, but in primary duties, the top size of feed can reach 1,400–1,500 mm (55–60 in.) at throughput rates of up to 3,000 t/h (3,307 stph). In finer duties, feed size can be as low as 30–40 mm (1.2–1.6 in.) at throughput rates of 70–100 t/h (77–110 stph). The machines are best suited to treating soft, friable material of low to moderate abrasivity.

In the HSI, hammers rotate around a central horizontal shaft and engage the falling feed stream. The issue of wear has always been the limiting condition for impact crushers, as the high velocity of the rotor and therefore the significant speed differential between the rotor and the feed stream leads to accelerated wear. In HSI crushers, as the hammer surfaces and fixed impact surfaces become worn, the crushing performance of the machine gradually declines.

Guidelines have been given over the years in relation to the maximum abrasivity of the feed, mostly stated in terms of silica content (<8%) or standard abrasion index measures such as the Bond abrasion index. Regardless of the type of abrasion test used, impact crushers mostly do not find economic application above an abrasion level of *low-medium* abrasivity. If applications of impact crushers are examined around the world, it becomes obvious that they are occasionally used in certain applications with very high wear rates caused by abrasive feed. In such applications, the high wear and operating costs are considered acceptable, as the impact crusher offers some other advantage(s) to the user, which are not available with alternative styles of crusher. Examples include the following:

- Ability to better shape the product
- Ability of impactors to handle damp, somewhat sticky feed
- Excellent size reduction without the generation of fines and ultra-fines
- Overall simplicity, which can be a factor where availability of service and maintenance facilities are limited

The base design of the HSI is simply a fabricated rotor with replaceable hammers fitted to a heavy shaft that runs in external roller bearings. Figure 12 shows a typical HSI cross section and the general flow of material through an HSI.

The rotor assembly is mounted within a heavy split casing with a belt and pulley drive system that spins a rotor at the desired speed. The replaceable hammers are also known as *blow bars* or *impact bars*.

The main differences in the design of HSI machines are usually found in the following:

- Steepness of feed entry
- Type of fixing used to secure the hammer
- Number of hammers

Table 4 ThyssenKrupp large single-toggle (ST) and double-toggle (DT) jaw crusher installations since 2010

Type	Feed Opening, width × gape, mm (in.)	Number of Units	Client	Country	Feed Material	Year
ST	1,100 × 800 (45 × 33)	1	Silverstone Crushers and Minerals Private Ltd., Haryana	India	Granite	2017
ST	900 × 700 (37 × 29)	1	Oasis Dale Aggregate Products, Kerala	India	Granite	2016
ST	1,200 × 1,000 (49 × 41)	2	Yamama Saudi Cement Co., Riyadh	Saudi Arabia	Iron ore	2016
ST	1,100 × 800 (45 × 33)	1	Granulats Du Cameroun, Yaoundé	Cameroon	Granite	2015
ST	2,000 × 1,500 (82 × 61)	1	McInnis Cement Co., Quebec	Canada	Limestone	2014
ST	1,600 × 1,200 (66 × 49)	1	China Nonferrous Metal Industry	China	Iron ore	2013
ST	1,400 × 1,100 (57 × 45)	1	China Nonferrous Metal Industry	China	Iron ore	2013
ST	2,000 × 1,500 (82 × 61)	3	Vale—Serra Sul, Serra Sul	Brazil	Iron ore	2012
ST	2,000 × 1,500 (82 × 61)	1	CODELCO (Corporación Nacional del Cobre de Chile)—División El Teniente, Rancagua	Chile	Copper ore	2011
ST	1,600 × 1,200 (66 × 49)	2	Angang Group, Anshan	China	Iron ore	2011
DT	1,500 × 1,200 (61 × 49)	1	Comspain S.A., Youssoufia	Morocco	Phosphate	2011
ST	1,400 × 1,100 (57 × 45)	1	China CAMC Engineering Co., Ltd. (CAMCE), Gol-E-Gohar Iron Ore Co.	Iran	Iron ore	2010
ST	1,600 × 1,200 (66 × 49)	1	China Nonferrous Metal Mining Co., Ltd. (NFC), Jalalabad	Iran	Iron ore	2010

Courtesy of ThyssenKrupp Industrial Solutions

Table 5 FLSmidth large single-toggle jaw crusher installations since 2004

Model	Size, mm (in.)	Crushers Supplied	Client	Location	Commodity	Feed Arrangements	Throughput per t/h (stph)	Installed Motor Power, kW (hp)	Year
TST1200	1,219 × 914 (48 × 36)	1	Uranium Corporation of India Limited (UCIL)	India	Uranium ore	Run-of-mine (ROM) grizzly feeder	200 (220)	150 (201)	2004
TST1550	1,549 × 1,270 (61 × 50)	2	Konkola copper mine	Zambia	Copper ore	ROM grizzly feeder	435 (480)	260 (349)	2007
TST1200	1,219 × 914 (48 × 36)	1	Bozymchak	Kazakhstan	Gold ore	ROM grizzly feeder	190 (210)	150 (201)	2009
TST1400	1,397 × 1,168 (55 × 46)	1	Administración Nacional de Combustibles, Alcoholes y Portland (ANCAP)	Uruguay	Limestone	ROM grizzly feeder	226 (250)	225 (302)	2011
TST1200	1,219 × 914 (48 × 36)	1	Uranium Corporation of India (UCIL)	India	Uranium ore	ROM grizzly feeder	200 (220)	150 (201)	2012
TST1550	1,549 × 1,270 (61 × 50)	1	Akoga	East Guinea	Limestone	ROM grizzly feeder	500 (550)	260 (349)	2013
TST1400	1,397 × 1,168 (55 × 46)	1	Edo Limestone	Nigeria	Limestone	ROM grizzly feeder	435 (480)	225 (302)	2013
TST1900	1,905 × 1,600 (75 × 63)	2	D.G. Khan	Pakistan	Limestone	ROM grizzly feeder	699 (770)	375 (503)	2014

Courtesy of FLSmidth

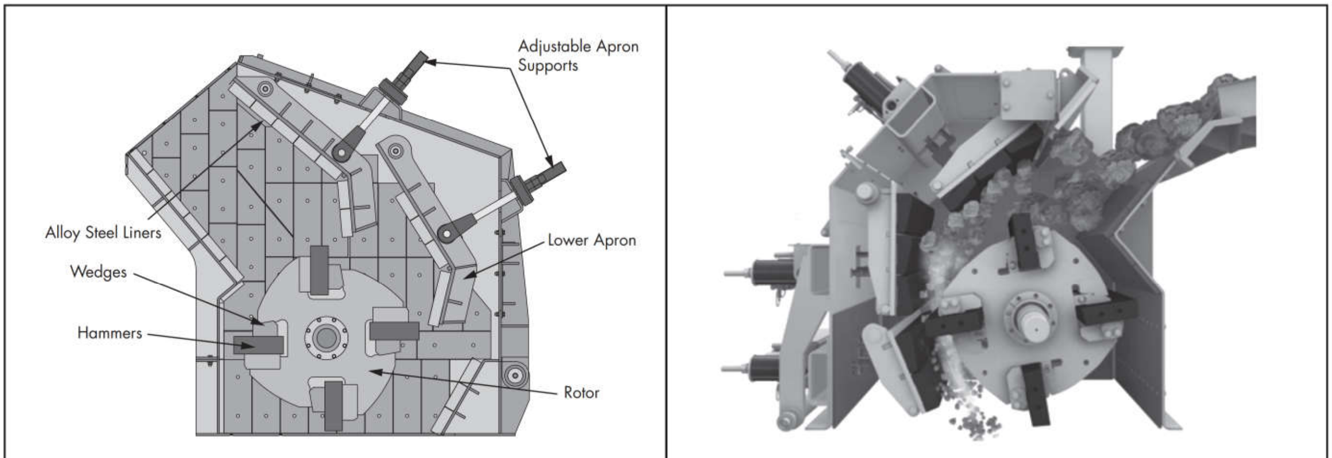
- Ability to reverse the direction of the rotor
- Presence of more than one rotor
- Presence of a grinding path
- Presence of an adjustable breaker or breakers (used with some fixed grinding path machines)
- Rotational speed control and adjustment through electric or hydraulic variable-speed drives

Model designation with HSI machines varies between manufacturers, but in many instances, nomenclature such as 13/16/4 is used, which means that this machine has a 1,300 × 1,600 mm (51 × 63 in.) feed opening with four blow bars. Additional numbers and letters are added to indicate the presence of a grinding path (i.e., an area where additional breaker bars are positioned to provide finer crushing and improved product size control). Examples of HSI machines, with and without grinding paths, are given in Figure 13.

In the most extreme version of the grinding path concept, HSI machines start to mimic the functionality of a hammer mill. Figure 14 shows an HSI designed for fine crushing; this machine is also reversible, so the rotor can be operated in both directions to get maximum usage from the wear of the stationary blow bars. This design essentially has a continuous grinding path, with the chamber ending with the blow bars and liners in close proximity to give the finest product size possible.

The VSI has a much shorter history. The first machine to market was the Barmac VSI, which started to make a market impact in the late 1970s. The machine was developed in New Zealand by Bryan Bartley and Jim McDonald (McCarthy and Campbell-Hunt 2000), with the original version sold as the Rotopactor.

In the original design, feed was introduced into the top of the machine and the feed then entered through the center of a



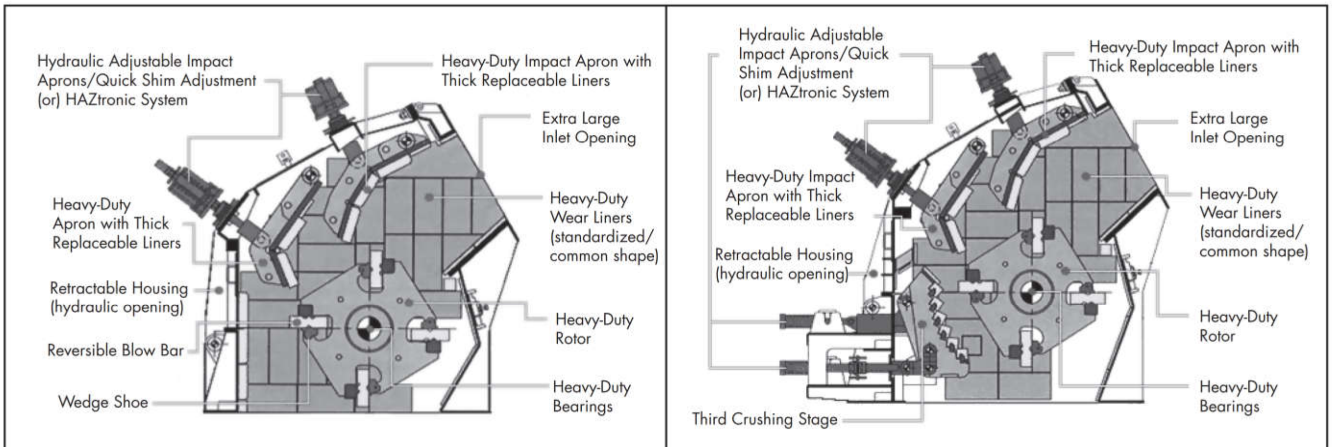
A. Cross section of a typical horizontal shaft impactor

B. Flow of material through an NP model horizontal shaft impactor

Courtesy of Telsmith

Courtesy of Metso

Figure 12 Arrangement and material flow in horizontal shaft impactors



A. Hazemag APS series secondary impactor without third crushing stage

B. Hazemag APS series secondary impactor with third crushing stage, also known as a grinding path

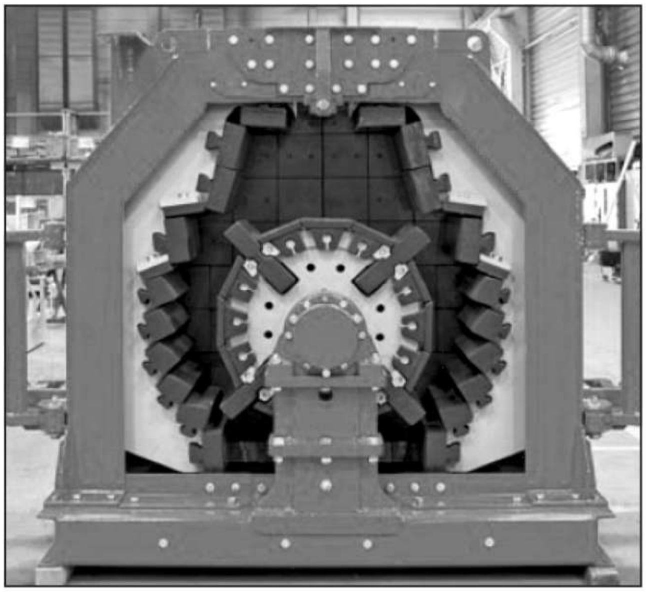
Courtesy of Hazemag USA Inc.

Figure 13 Horizontal shaft impactors with varying configurations of two secondary machines

rotor spinning about a vertical shaft. The rocks were accelerated outward from the rotor and hit beds of material formed on ledges around the chamber. This *rock-on-rock* or autogenous principle (Hamer 1990) was the main target, as this reduced wear on the shell of the machine while allowing particles to break freely. These machines were found to be proficient in improving the shape of misshapen aggregate products, and the particles generated were found to be free of the internal damage often seen as a result of breakage in compression crushers. The size reduction capability of these early VSIs was limited, however, and the energy consumed to achieve that reduction was relatively high. In addition, as the top size of the feed was pushed higher, the effectiveness of the original design declined in that the majority of the larger material would survive the crushing action.

In an effort to improve the crushing action, the Duopactor was developed. In this design, larger rocks are forced to fall in an annular curtain; rocks in the annular curtain are in turn impacted by the high-velocity material exiting the spinning rotor. The action provides the opportunity for the larger rocks to be randomly broken without applying any additional energy to the machine. Shortly after this development, the concept of cascade feed was introduced, whereby rather than channeling coarse feed just to the outside, it is introduced both through the rotor and also around the periphery.

Since the early days, the Barmac machine has been through several ownership changes and arrangements where machines were manufactured under license by distributors in a range of countries. Currently the Barmac VSI technology is supplied through Metso, following their takeover of Svedala. In essence, the B series Barmac VSI operates very much in the same way as the Duopactor, and cascade feed can be used to fine-tune the performance of the machine. The general arrangement of the current Barmac machine is shown in Figure 15. As



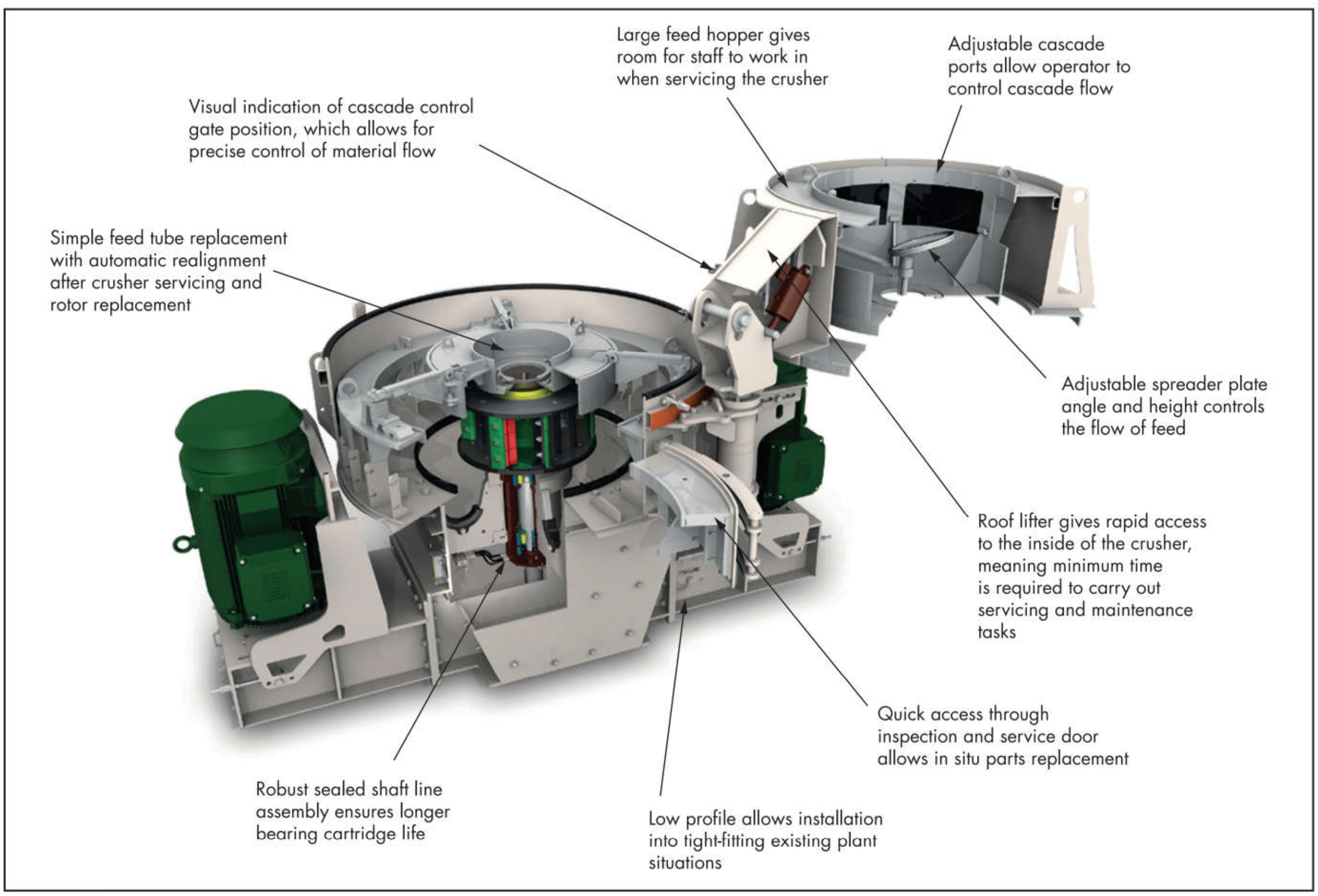
Courtesy of SBM Mineral Processing GmbH

Figure 14 Example of a reversible, fine crushing horizontal shaft impactor

can be seen, the Barmac shows a pivoting upper section for ease of access and maintenance and an overall design that has been optimized for safety, simplicity, and speed.

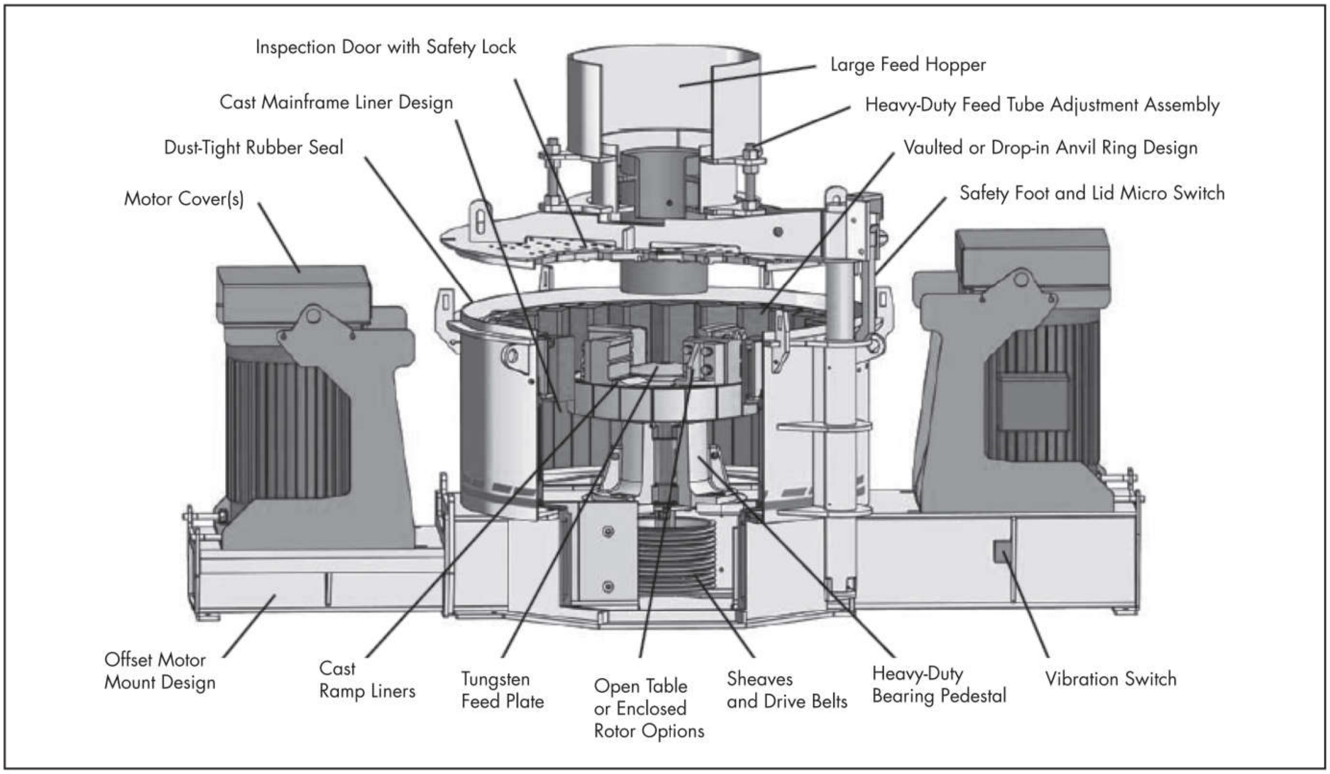
The Barmac VSI is now marketed as a machine for tertiary or quaternary crushing duties, and this extends into the region of manufactured sand for the quarrying business. Crushing in the quarrying sector often needs to consider the shape, or cubicity, of the particles. This is also true of the size ranges found in manufactured sand. The Barmac VSI has found a major niche in this area with its ability to generate improved cubicity because of the rock-on-rock breakage principle. It has had a major impact in the manufactured sand sector (Gonçalves et al. 2007) because of its ability to generate fines but control particle shape.

In the VSI market, there have been many variants and versions developed, but the only other type considered here, in addition to the Barmac, is the type characterized by the Canica VSI, patented in Canada in 1992 by the now defunct Canica Crushers Inc. In the Canica design, a rotor spins around a vertical shaft, with the rotor being either of an open or enclosed design. In the open design, feed drops into the center of the spinning rotor; in the enclosed design, the top plate has a central feed entry point and the enclosed rotor ensures that material is directed outward to provide optimal impact on a



Courtesy of Metso

Figure 15 Current Metso Barmac B series vertical shaft impactor



Courtesy of Terex Corporation

Figure 16 General arrangement of a Canica vertical shaft impactor

series of anvils surrounding the rotor or against rock material retained on ledges.

A general arrangement of a Canica-style VSI is shown in Figure 16. As in the Barmac design, there is a commitment to provide the operator with safe and easy access to key maintenance areas.

The notable difference between the autogenous Barmac-style VSI and the stone-on-steel Canica style is that the stone-on-steel machines employ an arrangement of breaking surfaces (anvils) around the inside of the circular casing. The surfaces are arranged to maximize the impact energies and therefore the size reduction achieved.

As a general rule, the stone-on-steel type VSIs achieve much higher particle reduction and at a much lower overall energy input than the autogenous Barmac-style VSIs. These gains, however, have to be traded against higher wear costs when compared with autogenous-style VSIs. As protection against wear in the Canica VSI, ledges can be used to retain rock particles.

When fitted with an open rotor, the stone-on-steel type VSIs can be successfully operated in secondary crushing roles, accepting particles up to 305 mm (12 in.) in maximum size in some applications.

Like the autogenous machines, stone-on-steel VSIs produce good particle shape, even when underfed.

As mentioned, early variants of VSI crushers, both of the Barmac and Canica types, used stone on steel, which led to high wear rates. The developments flagged previously, where crushing can now be provided via semiautogenous or autogenous means, has lifted the ability to crush abrasive feed. In general, stone-on-steel VSI action is still not suited to highly abrasive feed, and although opinions vary, apparently a limit of 8%–15% of abrasive content is commonly accepted. These abrasivity limits do not apply to VSI machines where particle-on-particle crushing predominates, as is demonstrated in the aforementioned prevalence of VSI application for manufactured sand. It is also known that VSI machines generate product with properties that differ from compression crushers (Bengtsson and Evertsson 2006). The free breakage environment tends to lead to intergranular breakage, which reduces microscale damage and generates more competent particles (Briggs and Bearman 1996). At the same time, the product shape generated tends to be more cubic and the attrition products from the shaping process contribute significantly to the increased fines seen in VSI products.

Construction and Design

The construction of HSI crushers is relatively straightforward and consists of an outer housing, stationary breaker plates (or aprons), and a rotor that carries the hammers or impact bars. The outer housing is essentially a steel box that contains the crushing area and provides structural support. The main issue for the housing is to resist flow and high-impact abrasive contacts from the flow of feed material and particles from the breakage process. To deal with the wear issue, most housings are lined with heavy-duty wear plates in areas away from the direct breakage zone. As these zones are generally not the highest wear areas and the wear is mainly flow-based, these can be made of relatively brittle material. In such a duty, materials such as white cast iron can be deployed. Also attached to the housing are the breaker plates, which are situated directly opposite the spinning rotor. These stationary plates are positioned and designed to be the anvil against which rocks can be further broken following impact by the spinning rotor and hammers or impact bars. To withstand this duty, the breaker plates are mostly made of 13%–18% manganese steel, and they are usually designed to be turned to allow extension of the overall wear life. Depending on the manufacturer, the size and arrangement of the breaker bars can vary. Some suppliers prefer to use large single castings, which are often designated as *aprons*, whereas others have designs where multiple smaller plates are used. In considering the right solution for a particular situation, safety, masses, lifting, and maneuverability should all be assessed.

One of the main design features of the HSI relates to the use of a grinding path. Coarse impact crushers tend to simply have breaker bars high in the chamber. Once breakage has occurred in this area, the particles pass through the crusher without any further interactions. If a grinding path is used, secondary breakage occurs toward the exit point of the crushing chamber. The length of the grinding path dictates the amount of fine size reduction delivered. Claims are also made that the length of the path improves the cubicity of the final product. In Figure 17, the final arrangement of liners is shown: In (A), the rotor and the last three blow bars are in close proximity, and in (B), extra length is added to the grinding path by having five liners prior to the discharge point.

In HSI machines, adjustment for wear and therefore control of product size is achieved via adjustment of the static breaker bars or aprons. In the preceding figure, the breaker bars can be seen with a hydraulic device; in some designs, a spring-loaded adjustment mechanism is located on the outside of the crusher body. Using such a system, the position of the breaker bars can be adjusted via the hydraulic, or spring, assemblies. The system relies on each section of breaker bars being pivoted at a point and the adjustment system being connected to a point toward the center of the breaker bars.

In the VSI design of impact crusher, both the Barmac- and Canica-style machines employ the same general approach of dropping feed onto a spinning rotor that then accelerates the material outward for crushing. Crushing energy in VSI machines is imparted through the kinetic energy generated by the acceleration of the particles by the spinning rotor (Nikolov 2002):

$$\text{crushing energy} = \tfrac{1}{2} mv^2$$

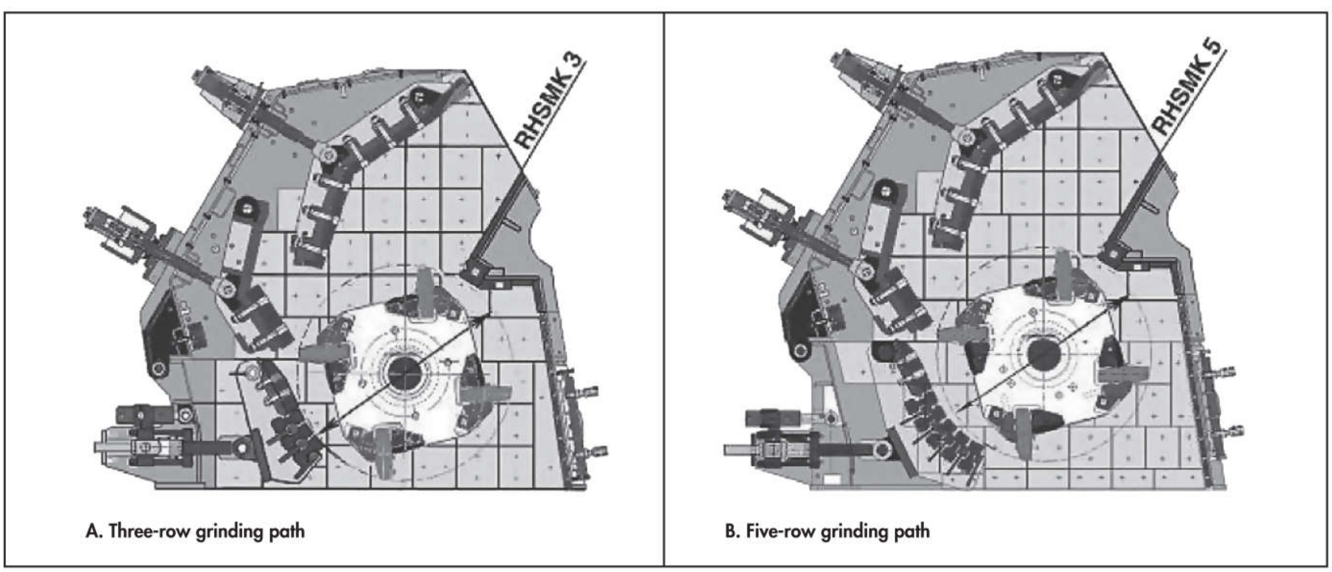
where

m = particle mass
v = particle velocity, m/s

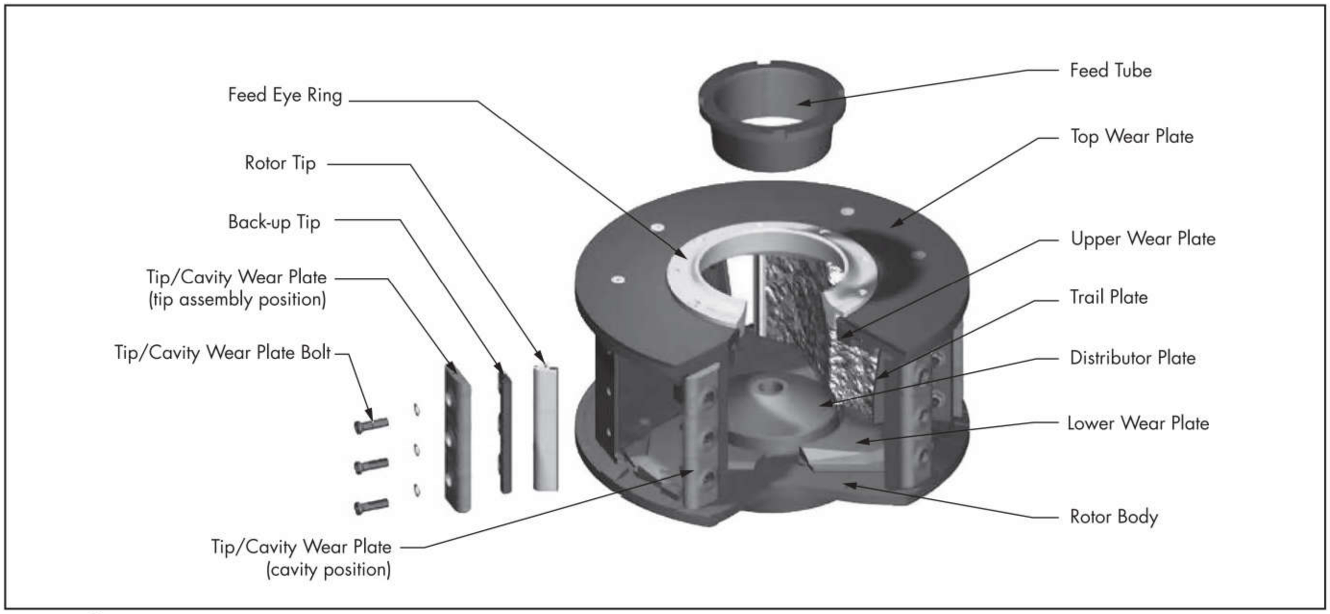
The Barmac exclusively uses the enclosed rotor design where feed enters through an orifice in the top of the rotor and then exits through the body of the rotor. Metso uses what it terms the *deep rotor technology* design, which offers advantages in throughput and also the ability to allow buildup inside the rotor to reduce wear at this critical point in the crusher design. As with all types of impact crusher, wear is the constant enemy, and therefore manufacturers put a tremendous effort into minimizing wear through design and materials selection. The Barmac rotor as shown in Figure 18, shows the overall design of the deep rotor.

The rotor tip and associated holder assembly can be configured in many ways depending on the model (size) of machine, the required duty, and the type of feed. Metso provides a detailed summary of their proprietary rotor tips and holders, which is reproduced in Figure 19. The rotor tips are color coded, available in a range of tungsten carbide grades, and can be fitted to a range of hangers. The range of tips, materials, and hangers allows an appropriate selection to be made for a specific crushing duty.

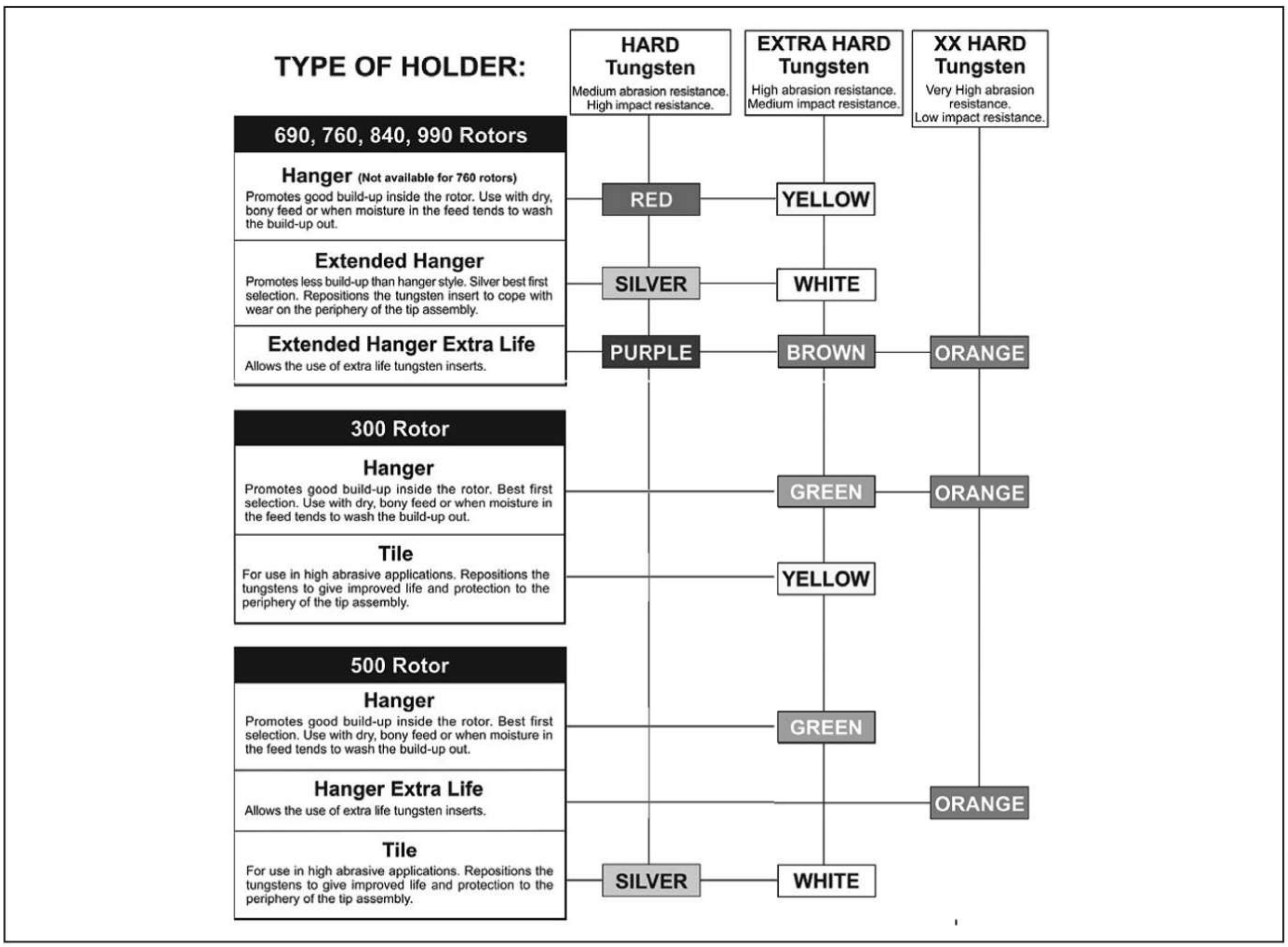
A feature of the Barmac design is the cascade feed arrangement, whereby a feed stream is also directed down the periphery of the crushing chamber to amplify the rock-on-rock crushing action of the machine. In terms of efficiency, it is generally considered that the proportion of feed used in the cascade should not exceed 60% of the feed to the rotor, except where recommended by the manufacturer. The cascade is particularly effective, as the falling stream is impacted by material exiting the rotor at speeds in the order of 80 m/s (262 ft/s). The rock-on-rock area therefore offers a range of



Courtesy of SBM Mineral Processing GmbH
Figure 17 Different types of grinding path

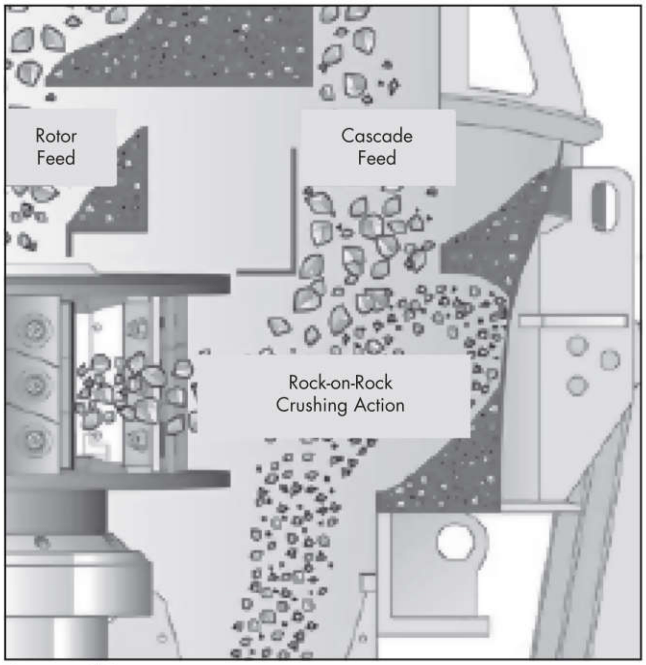


Courtesy of Metso
Figure 18 Exploded section of Metso Barmac rotor assembly



Courtesy of Metso
Figure 19 Rotor tips and holders available for the Metso Barmac

benefits including higher throughput, improved size reduction, and the ability to improve the product cubicity for quarrying applications. The action of rock-on-rock crushing is shown in Figure 20.



Courtesy of Metso

Figure 20 Rock-on-rock crushing action using the cascade feed arrangement in a Barmac vertical shaft impactor

The crushing action in the rock-on-rock area of the chamber is a combination of impact, abrasion, and attrition. The density of particles in this area is critical to the effectiveness of the breakage, as higher densities promote extra particle-on-particle crushing through the increase in turbulence and residence time (Cunha et al. 2013) in the zone.

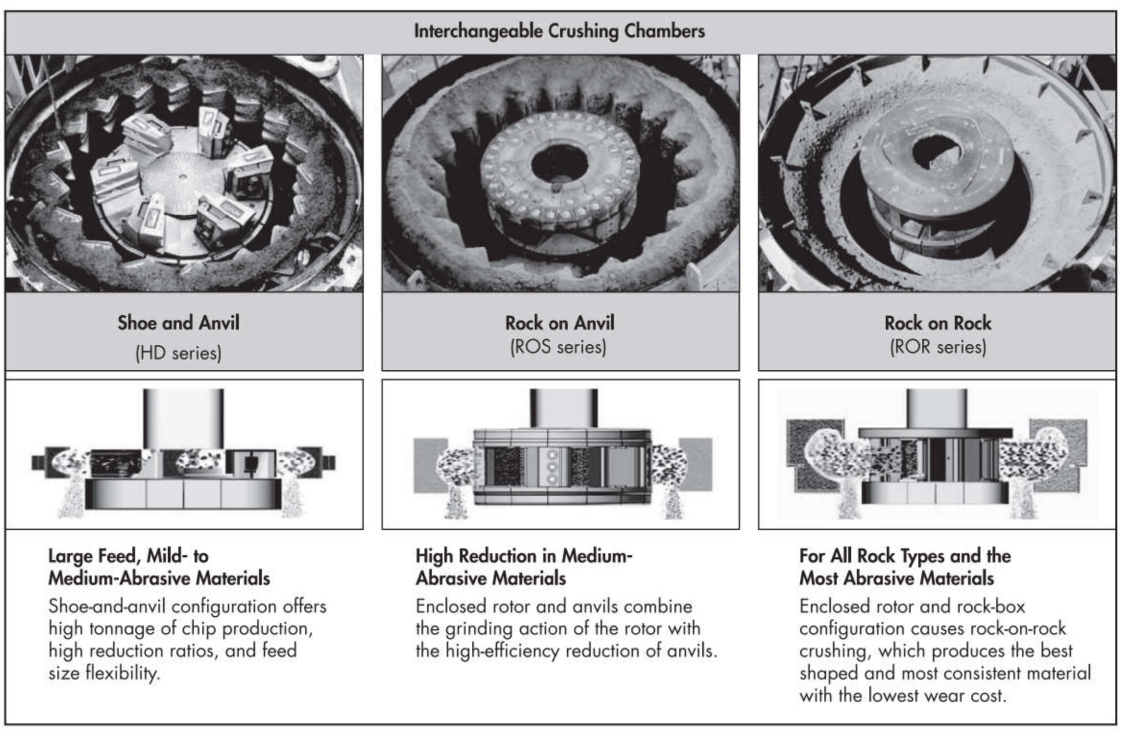
The Canica VSI design relies on feed entering the rotor in a central area, but the rotors used can be either open or closed. In addition, the Canica does not have a cascade feed feature and therefore relies on different chamber arrangements to generate either rock-on-anvil or rock-on-rock breakage. Figure 21 shows three typical arrangements for a Canica machine. The shoe-and-anvil arrangement with the open rotor is designed to take much larger feed, with the largest version stated to accept feed with a longest dimension of 305 mm (12 in.). The rock-on-anvil design is more focused on smaller feed size and greater size reduction, and the rock-on-rock design uses a rock pocket (or shelf) arrangement so material accelerated from the rotor impacts a bed of material at the wall.

Application and Operation

As mentioned, HSI machines can be deployed in a wide variety of roles from primary through to fine crushing, depending on the arrangement of the machine. The selection of a specific HSI machine follows the same principles as with any other crusher, which is feed size, reduction ratio, product size, and ability to handle feed characteristics. As an illustration of the main features of the various stages of impactor, a selection from the SBM range is given in Figure 22.

In terms of throughput, the machine variables controlling the capacity are

- Size of feed opening,
- Angle of feed entry,



Courtesy of Terex Corporation

Figure 21 Various rotor and anvil configurations for a Canica-style vertical shaft impactor

- Entry velocity of feed,
- Rotor diameter,
- Rotor speed,
- Number of blow bars, and
- Presence of a grinding path.

In terms of the product size distribution, the main factors controlling output are

- Crushing gap, including presence of grinding path;
- Rotor circumferential speed; and
- Number of blow bars.

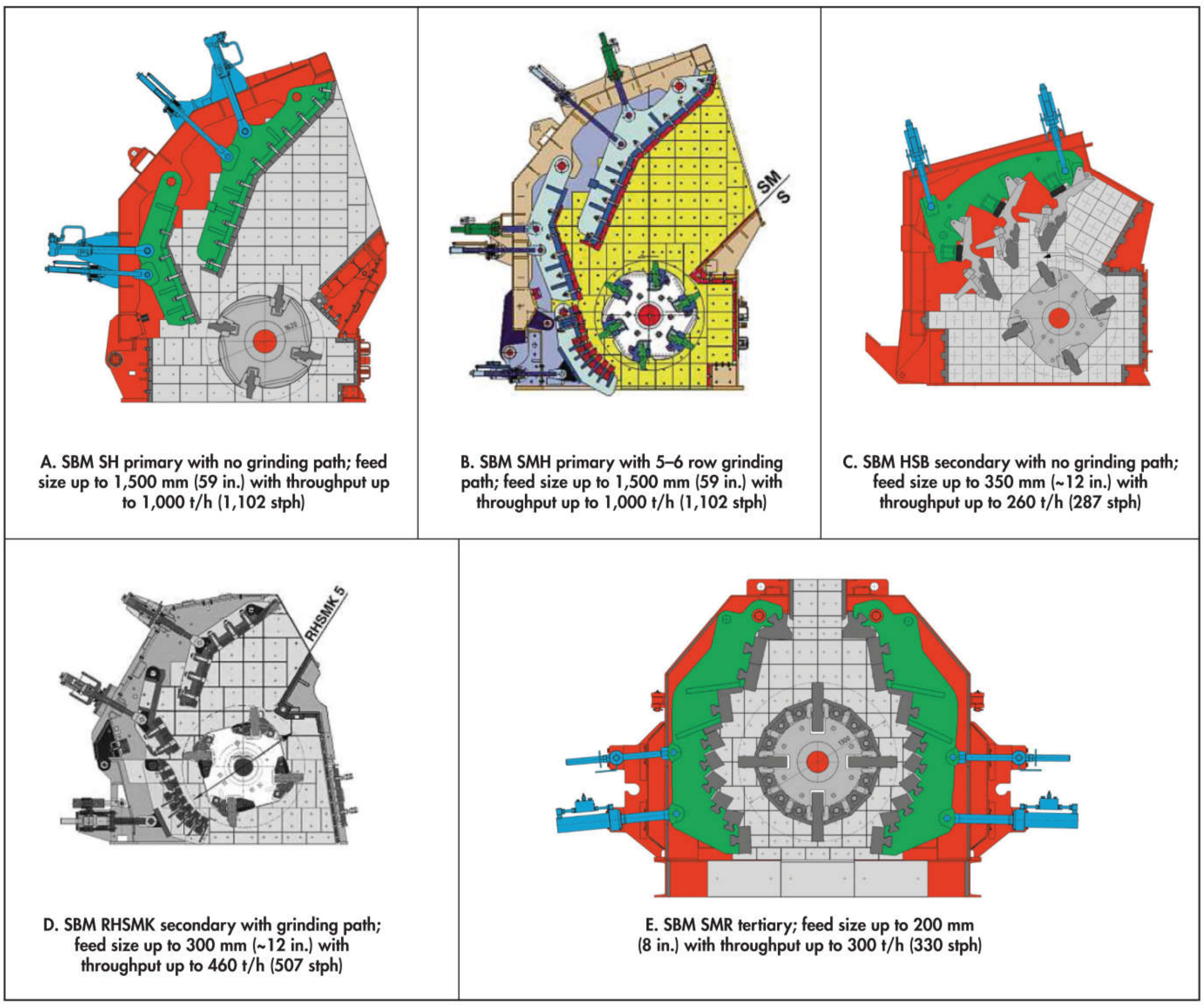
In the world of HSI crushers, manufacturers offer a great deal of customization to provide a machine suited to the specific duty required. As such, it is difficult to give a full summary of the options. Many manufacturers exist, including Hazemag, Metso, SBM, BJD, and Terex Corporation. It is not within the scope of this chapter to provide manufacturer performance estimates for all suppliers, so examples have been chosen to illustrate the range of applications.

Table 6 shows data relating to large primary HSI specifications, whereas Table 7 and Figure 23 show throughputs and product size distributions for secondary impact crushers. For completeness, Table 8 and Figure 24 shows data relating to tertiary crushing using an SBM HSI machine.

In terms of the VSI machines, the Barmac has come to be well accepted with feed sizes mostly in the –50 mm region, with a strong focus on manufactured sand generation and the ability to provide cubical product shape. This provides a point of difference to the Canica-style VSI crushers, which in the rock-on-rock configuration have similar capabilities but are also positioned to crush much coarser feed.

The application data for the Barmac B series VSI is summarized in Table 9. Metso also provides general guidance on how feed properties and operating parameters influence the key output parameters. This general guidance is shown in Figure 25.

Canica process performance guidelines are provided in Table 10, where the maximum figures are based on the *heavy-duty* version with the open rotor and anvils. Performance



A. SBM SH primary with no grinding path; feed size up to 1,500 mm (59 in.) with throughput up to 1,000 t/h (1,102 stph)

B. SBM SMH primary with 5–6 row grinding path; feed size up to 1,500 mm (59 in.) with throughput up to 1,000 t/h (1,102 stph)

C. SBM HSB secondary with no grinding path; feed size up to 350 mm (~12 in.) with throughput up to 260 t/h (287 stph)

D. SBM RHSMK secondary with grinding path; feed size up to 300 mm (~12 in.) with throughput up to 460 t/h (507 stph)

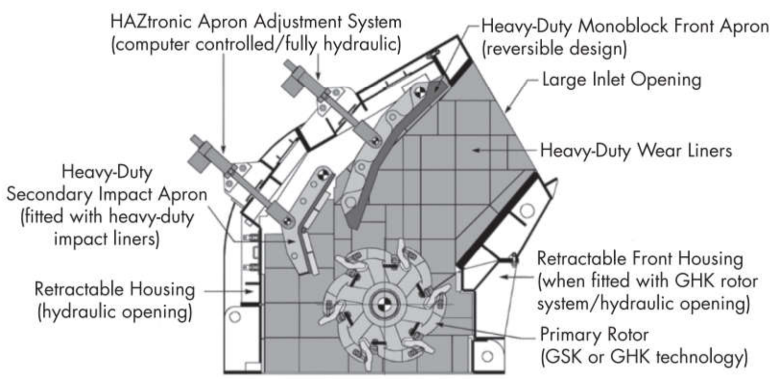
E. SBM SMR tertiary; feed size up to 200 mm (8 in.) with throughput up to 300 t/h (330 stph)

Courtesy of SBM Mineral Processing GmbH

Figure 22 SBM horizontal shaft impactors for varying stages of size reduction

Table 6 Large primary horizontal shaft impactors*

Model†	Capacity, t/h (stph)	Power Requirements, kW (hp)	Inlet Size, h × w, mm (in.)	Maximum Feed Size, mm (in.)	Rotor Size, d × w, mm (in.)	Weight, kg (lb)
APP-1513	220 (250)	160 (250)	900 × 1,360 (35 × 54)	760 (–30)	1,500 × 1,340 (60 × 53)	21,700 (47,800)
APP-1615	350 (400)	250 (350)	1,290 × 1,520 (51 × 60)	1,000 (–40)	1,600 × 1,500 (63 × 59)	39,500 (86,900)
APP-1622	600 (700)	450 (600)	1,290 × 2,270 (51 × 89)	1,000 (–40)	1,600 × 2,250 (63 × 88)	58,500 (128,700)
APP-1822	800 (900)	750 (1,000)	1,600 × 2,270 (63 × 89)	1,200 (–48)	1,800 × 2,250 (70 × 88)	69,000 (151,800)
APP-2022	1,000 (1,100)	900 (1,200)	1,830 × 2,270 (72 × 89)	1,500 (–60)	2,000 × 2,250 (79 × 88)	88,000 (193,600)
APP-2025	1,090 (1,200)	1,125 (1,500)	1,830 × 2,520 (72 × 99)	1,500 (–60)	2,000 × 2,500 (79 × 98)	108,150 (237,900)
APP-2030	1,500 (1,650)	1,350 (1,800)	1,290 × 3,020 (51 × 118)	1,500 (–60)	2,000 × 3,020 (79 × 118)	110,000 (242,000)
APP-2522	1,360 (1,500)	1,200 (1,600)	2,125 × 2,270 (84 × 89)	1,500 (–60)	2,500 × 2,250 (98 × 88)	135,000 (297,000)
APP-2525	1,800 (2,000)	1,350 (1,800)	2,125 × 2,520 (84 ×99)	1,500 (–60)	2,500 × 2,500 (98 × 98)	151,000 (332,000)
APP-2530	2,300 (2,500)	1,800 (2,500)	2,125 × 3,020 (84 × 118)	1,500 (–60)	2,500 × 3,020 (98 × 118)	180,000 (396,000)



Courtesy of Hazemag USA Inc.
*Performance details relate to medium-hard limestone.
†The naming convention used for crusher sizes and duties is "APP-rotor diameter, inlet width," e.g., APP-1513 means a crusher with a 1,500-mm (60-in.) rotor diameter and a 1,360-mm (54-in.) inlet width.

varies for other types of rotor, and thus guidance needs to be obtained from the supplier.

It is important to note that throughput and feed size effects with impact crushers are highly material specific. In compression crushers—jaw, gyratory, and cone—the progression through the crushing chambers is controlled by the geometry of the chamber and the mechanical features that control the movement of material (eccentric throw, pivot point, and speed). In impact crushers, the throughput limit is primarily controlled by the speed, feed size, and the number of blow bars. Because of these parameters, there is a certain volumetric space between each row of blow bars as the shaft rotates. The space is fixed; thus the other factor is the ability of material to enter the space. Such geometric and flow considerations can lead to situations whereby running with two blow-bar rows is more beneficial than using a higher number.

Another feature of impact crushers is the sensitivity to feed size. In impact machines, the size reduction is dependent on the ability to strike and shatter particles. If the feed size is too fine, it becomes difficult to impart sufficient energy to the smaller particles, and therefore the size reduction is much less effective. Because of the different crushing configuration between the Barmac- and Canica-style VSI machines, it is important to note that the Barmac feed size is usually limited to 50 mm (2 in.) (see Table 9), whereas the Canica style can accommodate feed up to 305 mm (12 in.). Obviously, this variation in feed size is dependent on the duty required; therefore when selecting a type of VSI, a direct comparison of duty and performance is required.

Because of the variability inherent in the crushing process in an impact crusher, it is essential that the manufacturers are consulted, and in many cases, test work is required to confirm the most suitable machine for a given duty.

Regarding the operation of impact crushers, the two styles—HSI and VSI—have differing feed arrangement requirements. In the HSI, it is critical to ensure that the feed is

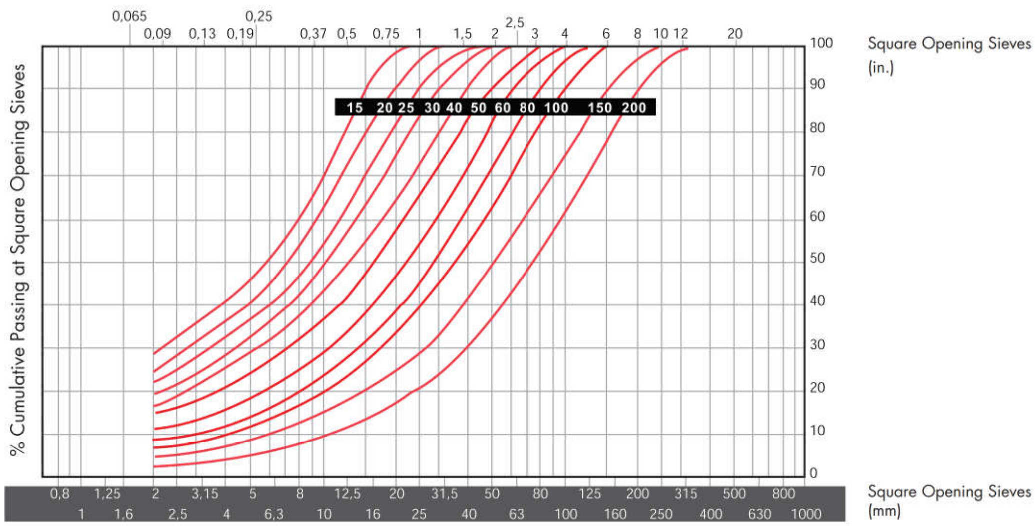
Table 7 Typical secondary HSI throughput and product size guidance*†

NP Model		Top Feed Size, 400 mm (16 in.) End Product, 60 mm (2½ in.) t/h (stph)	Top Feed Size, 400 mm (16 in.) End Product, 40 mm (1½ in.) t/h (stph)	Top Feed Size, 200 mm (8 in.) End Product, 40 mm (1½ in.) t/h (stph)	Top Feed Size, 200 mm (8 in.) End Product 20 mm (¾ in.) t/h (stph)
Secondary range	NP1110	190 (210)	150 (170)	210 (230)	130 (140)
	NP1213	250 (280)	200 (220)	280 (310)	180 (200)
	NP1315	315 (350)	250 (280)	350 (390)	225 (250)
	NP1520	500 (560)	400 (450)	560 (630)	360 (400)

Courtesy of Metso

*NP secondary crusher of the type shown in Figure 12B.

†Represents capacity through crusher based on instantaneous product sample. Impact crusher capacity charts are developed for use as an application tool to properly use the NP crusher's capabilities. The capacity figures apply to material weighing 1,600 kg/m³ (100 lb/ft³). The crusher is one component of the total circuit. As such, its performance is also dependent on the proper selections and operation of feeders, conveyors, screens supporting structure, electric motors, drive components, and surge bins.



Note: The gradation and capacities shown are dependent on feed gradation, material density, and crushability.

Courtesy of Metso

Figure 23 Typical secondary horizontal shaft impactor product distribution curves

uniformly distributed across the width of the feed opening and that there is no segregation of fines or coarse material to one particular area. Any bias in the feed leads to accelerated wear in localized areas and this leads to a loss in product size control and also the need to prematurely remove the wear components. For the most efficient operation, the feed material should have sufficient velocity to fall deep into the crushing chamber, so that the blow bars can fully engage the feed. Entry velocity is simply a function of the fall height under gravity.

As with cone crushers, it is also useful to remove fines from the feed. In HSI and VSI machines, the fines do not have a detrimental impact in terms of mechanical operation, but the presence of fines simply occupies space, therefore reducing the effective throughput of material requiring crushing. One other potential impact of fines is that with the high velocities, the fines can adhere to surfaces within the chamber, which again may compromise throughput. In terms of the product from the HSI machines, particles can exit the crushing chamber at high velocity, and therefore consideration must be given to wear protection and, if appropriate, the use of rock boxes.

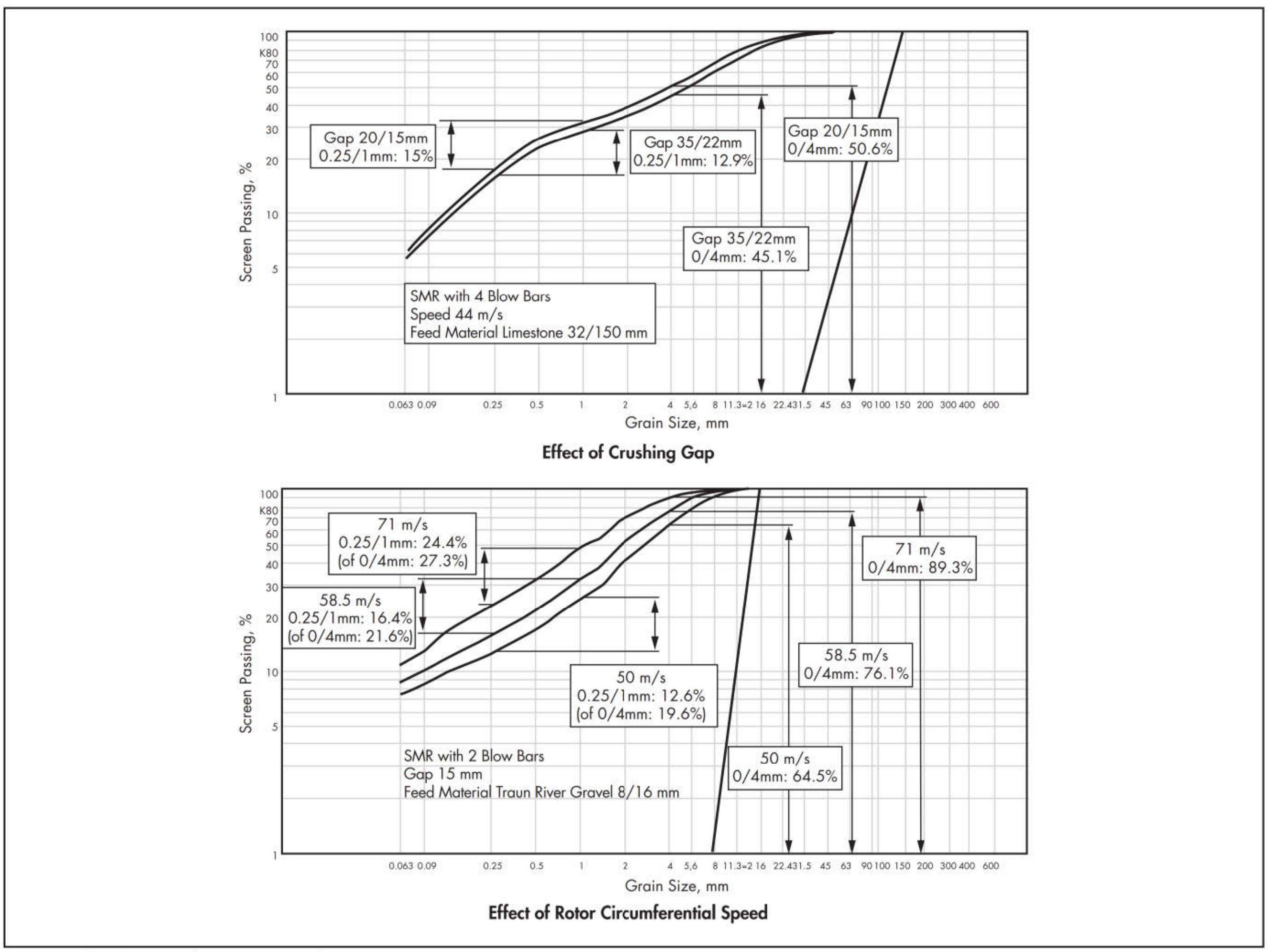
For VSI machines where the feed enters into the center of the spinning rotor, feed distribution is less of an issue. A greater concern is that the top size of the feed is controlled. If it is not, then this can lead to wear issues, and there may be a mismatch between the larger particles and the pathways within the rotor. In the Barmac-style VSI where the cascade feed arrangement is used, it is best to ensure that the feed size distribution is uniformly spread around the periphery of the machine. This should be achieved using feed control via a suitable feeder.

Installed motor power varies widely in HSI machines. The motor selection is usually based on the mechanics of being able to accelerate the rotor to the desired speeds and the added energy required to cause breakage of the rocks. To determine the required breakage energy, most suppliers use the Bond abrasion index approach. In VSI machines, the installed power is more uniform and this relates to the analogy

Table 8 Typical tertiary horizontal shaft impactor data*

Machine Type	Feeding Size Up to, mm (in.)	For Rotor Circumferential Speed, m/s (ft/s)	Throughput, t/h (stph)	Driving Power, kW	Examples of Achieved End Product Over K80 at Delivered Particle Size	Machine Weight, kg (lb)
10/05/2 SMR	80 (3¼)	50–75 (164–246)	80 (73)	75–160	v = 71 m/s; river gravel; K80:0/2.8 mm for feed 8/16 mm	7,900 (17,412)
10/05/4 SMR	150 (6)	30–60 (98–197)	130 (118)	75–160	v = 44 m/s; river gravel; K80:0/14 mm for feed 32/80 mm	8,100 (17,852)
10/10/2 SMR	80 (3¼)	50–75 (164–246)	150 (136)	110–250	v = 50 m/s; river gravel; K80:0/5.6 mm for feed 8/16 mm	12,000 (26,448)
10/10/4 SMR	150 (6)	30–60 (98–197)	200 (181)	110–250	v = 37 m/s; river gravel; K80:0/11 mm for feed 32/150 mm	12,400 (27,330)
13/7/4 SMR	200 (7⅞)	30–60	200 (181)	90–200	—	~14,600 (32,178)
13/10/4 SMR	200 (7⅞)	30–60	250 (226)	110–250	—	~22,300 (49,149)
13/13/4 SMR	200 (7⅞)	30–60	300 (272)	132–315	—	~28,900 (63,696)

Courtesy of SBM Mineral Processing GmbH
*SMR tertiary crusher of the type shown in Figure 22E.

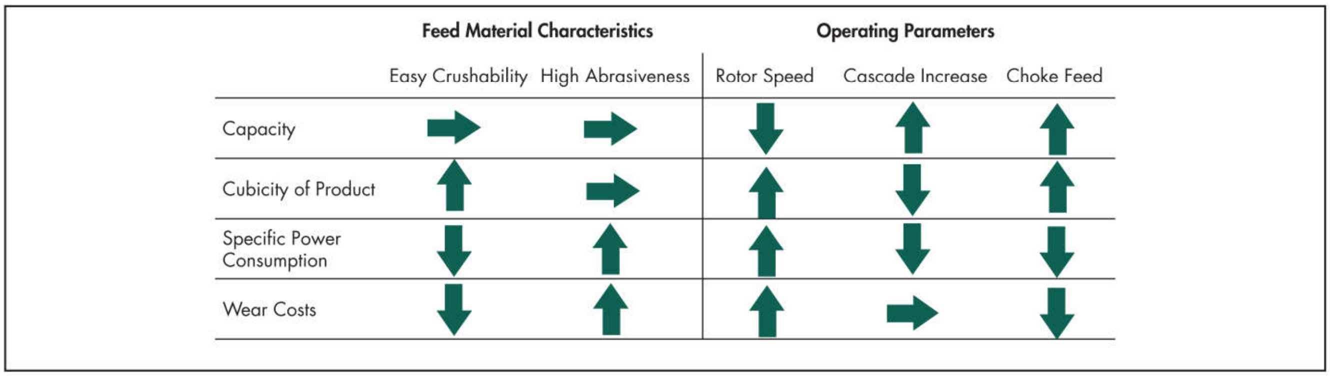


Courtesy of SBM Mineral Processing GmbH
Figure 24 Effect of the crushing gap and circumferential rotor speed on size reduction

Table 9 General operating range for Metso Barmac B series vertical shaft impactor

Barmac Model	Maximum Feed Size, Square Mesh, mm (in.)	Speed Range, m/s (rpm)	Power Range, kW (hp)	Throughput, t/h (stph)
B5100SE	30 (1¼)	45–75 (2,000–3,400)	37–55 (50–70)	15–60 (14–54)
B6150SE	37 (1½)	45–75 (1,500–2,500)	75–150 (100–200)	60–200 (54–181)
B7150SE	45 (1¾)	45–75 (1,250–2,100)	185–220 (250–300) Single drive 260–300 (350–400) Dual drive	110–420 (100–381)
B9100SE	50 (2)	840 Rotor: 45–65 (1,250–1,800) 990 Rotor: 45–75 (1,250–1,700)	370–600 (500–800) Dual drive	180–700 (163–635)

Courtesy of Metso



Courtesy of Metso

Figure 25 Guide to the impact of feed on key performance parameters and Barmac operation

Table 10 Canica vertical shaft impactor general performance data

Description*	Canica Model 1200	1400	2000SD	2000DD	2050	100	2300	105	2350	2500	3000
Motor drive	Single	Single	Single	Dual	Dual	Dual	Dual	Dual	Dual	Dual	Dual
Maximum feed size (longest dimension) HD configuration, mm (in.)	33 (1.5)	51 (2)	102 (4)	102 (4)	102 (4)	127 (5)	127 (5)	152 (6)	203 (8)	254 (10)	305 (12)
Maximum throughput capacity HD configuration, t/h (stph)	64 (70)	113 (125)	227 (250)	317 (350)	363 (400)	363 (400)	454 (500)	454 (500)	544 (600)	726 (800)	907 (1,000)
Power requirement for maximum throughput, kW (hp)	37–112 (50–150)	75–186 (100–250)	149–298 (200–400)	298–522 (400–700)	298–522 (400–700)	298–522 (400–700)	298–522 (400–700)	373–594 (500–800)	373–594 (500–800)	447–746 (600–1,000)	522–895 (700–1,200)
Internal configurations available†	HD, HDS	HD, HDS, ROS, ROR	HD, HDS, ROS high-speed, ROR high-speed, ROS HD, ROR HD	HD, HDS, ROS high-speed, ROR high-speed, ROS HD, ROR HD	HD, HDS, ROS high-speed, ROR high-speed, ROS HD, ROR HD	HD, HDS, ROS high-speed, ROR high-speed, ROS HD, ROR HD	HD, HDS, ROS high-speed, ROR high-speed, ROS HD, ROR HD	HD, HDS, ROS high-speed, ROR high-speed, ROS HD, ROR HD	HD, HDS	HD, HDS	HD, HDS

Courtesy of Terex Corporation

*Important: The maximum feed size, throughput, and power requirement are dependent on the internal configuration used. The internal configuration depends on the actual feed material, discharge requirements, and the material abrasive and strength properties.

†HD = heavy-duty (open table/anvils); HDS = heavy-duty sand (open table/anvils); ROR = rock on rock (enclosed rotor/rockshelf); ROS = rock on steel (enclosed rotor/anvils).

between a VSI and a *rock pump*. Essentially, the VSI has an *impeller*, which is the rotor. The throughput and the required power are more related to allowing material to pass and be accelerated by the rotor. In the case of both the Barmac and the Canica versions, it is common to have dual motor drives in the larger variants.

Regarding limits in VSI performance, the action of the rotor and the impact breakage mechanism employed mean that the main limiting factor is purely volumetric flow, providing sufficient power is available to the rotor to keep the charge moving and crushing. The volumetric constraint is purely a flow issue and not a *packing* issue, as seen in compression crushers.

Because of the nature of the crushing action in a VSI, the rotor simply has to impart sufficient energy to the particles to cause them to fracture either on impact with other particles or the walls or anvils. Motor power and rotor speed are therefore critical to impart the required energy and therefore generate the product size (Sinnott and Cleary 2015). However, they do not represent a limit in the same way as would be seen in a compression crusher, where input power is applied in a much more direct manner. A comparison of the energy considerations in cone and VSI crushers is specified by Lindqvist (2008).

Given that the VSI is analogous to a rock pump, measures of rock strength are still indicative of the ability to generate size reduction and therefore net product, but the effect of strength on gross throughput is much less than is seen in compression crushers. VSI machines essentially employ unconstrained, or free, breakage, either from impacting particles on a steel surface or through interparticle impacts. These mechanisms provide many of the benefits seen in VSI machines, including that all particles are exposed to breakage (unlike compression crushers), fines generation exceeds that seen in compression crushers, and the ability to treat abrasive feed via the particle-on-particle system. As always, the same features that provide benefits also constrain performance, with the main constraint seen in VSI crushers being the trade-off between feed size, reduction ratio (at the P80 level), feed abrasivity, and wear. In this regard, VSIs are a good example of the importance of understanding the fundamental basis underlying the action of any crusher. Such an understanding ensures that the equipment is applied in the appropriate duty and delivers the best overall benefit to the wider circuit.

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