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Achim Meinel (1935) studierte Maschinenbau an der Technischen Universität Magdeburg. Ab 1959 arbeitete er zunächst in der Industrie und wechselte 1965 als wissenschaftlicher Mitarbeiter an das Institut für Mechanische Verfahrens- und Aufbereitungstechnik der Bergakademie Freiberg/Sachsen, wo er 1973 promovierte. 1974 bis 1989 war er Abteilungsleiter für Technische Applikationsforschung und stellvertretender Institutsdirektor im Forschungszentrum Zwota/Sachsen, und 1990-1993 Geschäftsführer im Institut für Musikinstrumentenbau GmbH Zwota. 1994 gründete er das Ingenieur-Büro für Verfahrenstechnik und arbeitet seitdem als Consulting-Ingenieur. Dr. Meinel veröffentlichte mehr als 30 Publikationen über die Siebklassierung und angrenzende Fachgebiete.

Fine and very fine screening

Throw screening from the beginning of the 20th century to the present demonstrated by the example of directly excited throw screening machines

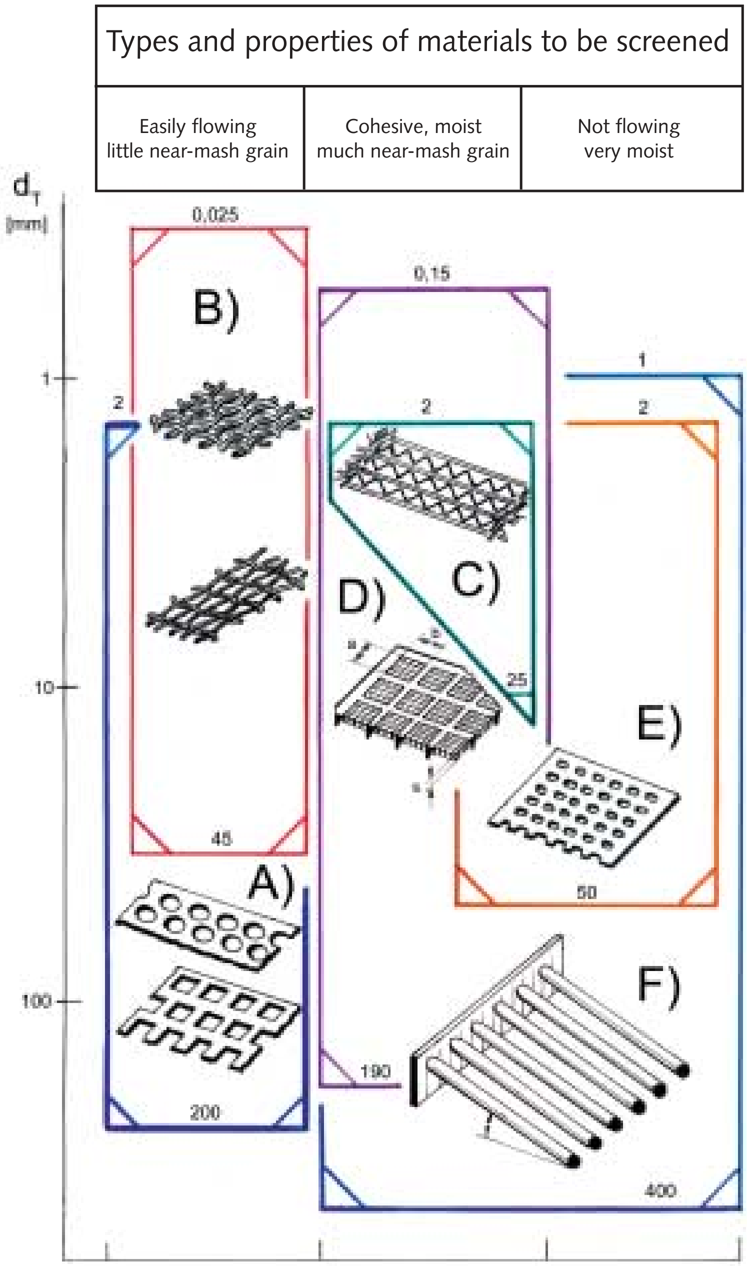
Summary: As the screening practice reached the range of fine and very fine classification in the 20th century, also comprising difficult-to-screen materials, such as in ore or salt processing and recycling as well, increased screening forces and screen deck accelerations were required. Thus, the aeration of the material to be screened should be increased and obstructing or clogging of the screen deck be reduced on the one hand, and larger specific throughputs be achieved on the other hand [6]. The technical inventions described in the following for the direct excitation of the screen deck by means of bumper, impactor bar, flip-flop or even ultrasound excitation met the new process requirements to a great extent [9, 11, 12].

1. Throw screening machines directly excited by means of bumpers or impactor bars

The development of bumper-type screens [1], which had begun in America at the beginning of the 20th century, was continued with some efficient new developments mainly in Germany from the middle of the 20th century. These screens were used for mean and fine sizing, in some cases even for very fine sizing. The knowledge acquired in the basic research of special processes proved to be an advantage for this development [2, 3, 13, 14].

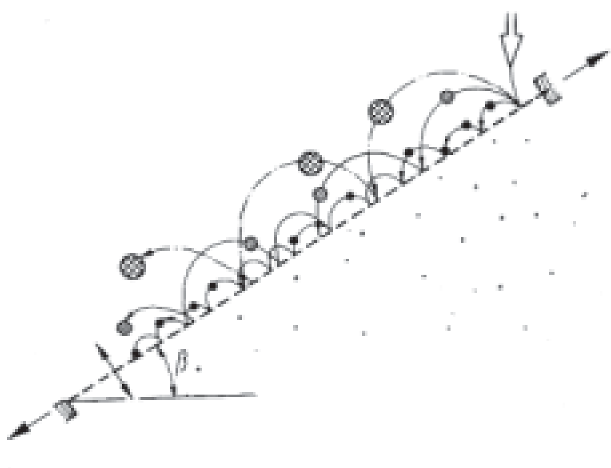
The heavily inclined bumper-type screens (the inclination of the screening surface is somewhat higher than the angle of friction of the material to be screened) classify according the principle of thin-layer screening. The motion of the material to be screened on bumper-type screens **(Fig. 1)** shows the typical granulometric segregation above the screening surface depending on the rebound coefficient [3, 4, 15]. The larger particles move in more distant layers, the finer ones, which segregate relatively quickly in the direction of the parting surface openings, move near the screening surface.

The above modern bumper-type screens mainly differ from each other by their excitation principles of the screen deck [9, 16]. From the 1950ies of the 20th century, in particular,

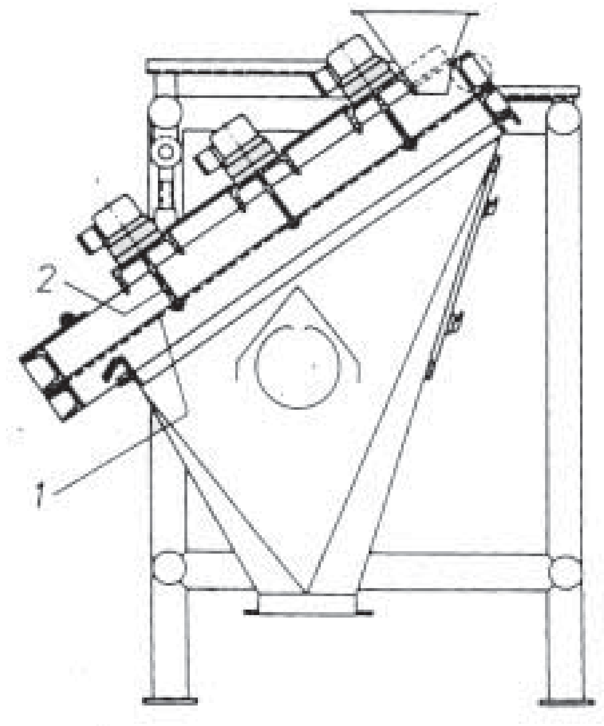


Survey of selected screen decks or surfaces, respectively, for various properties of the material to be screened as well as cut sizes (d_T): A) screen deck of steel plates, B) screen cloth, C) harp-type screen deck, D) screen deck of rubber or polyurethane fibre plates, E) screen mats of rubber or polyurethane fibre, F) cantilever beam/rod screen deck

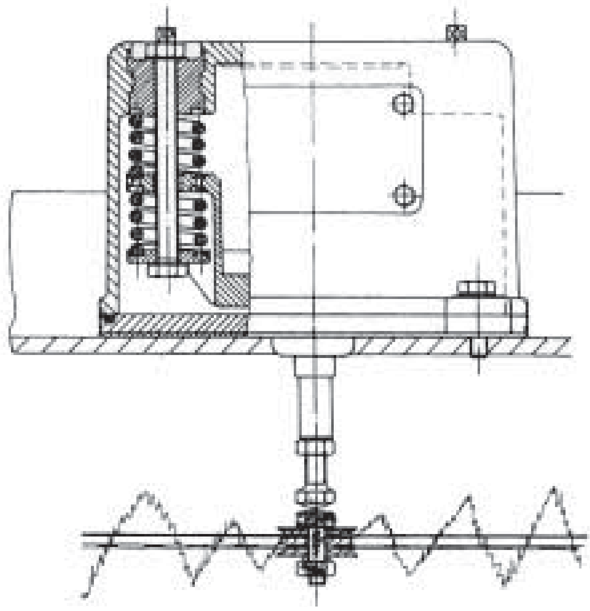
electromagnetically, punctually excited drives positively coupled to the screen deck from Rhewum (Fig. 2) were predominant [7, 17]. The screen, type Finessa, from HAVER & BOECKER (Fig. 3), which is electromagnetically excited by means of the mains frequency and positively coupled to the screen deck via impacting bumpers, also belongs to this period [18, 19]. Amongst other things, this period is characterized by the electromagnetically, positively excited screen via vibrating strips, type WA, from Rhewum (Fig. 4) with screen deck accelerations of more than 15 g (due to harmonics of up to max. 400 g) [9, 16, 21] and the Sizer 2000 from Mogensen with positive impactor bar excited by balancing weights (Fig. 5) with screen deck accelerations of 10 to 30 g [4, 9] as well as the positively excited screening machine via driving cross bars moved by balancing weights, type Fine-Line, from HAVER & BOECKER (Fig. 6) [9, 20].



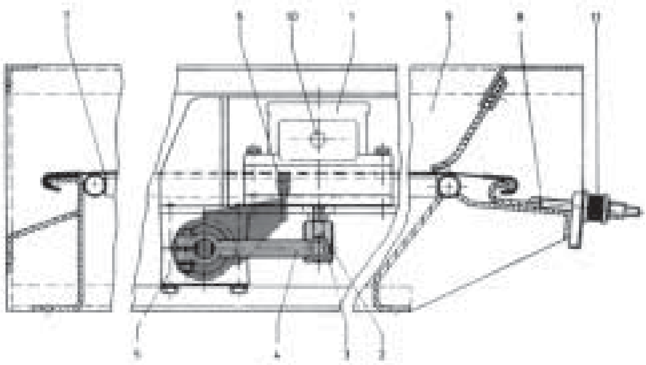
1 Schematic representation of the material motion during thin-layer screening, here with bumper-type screens



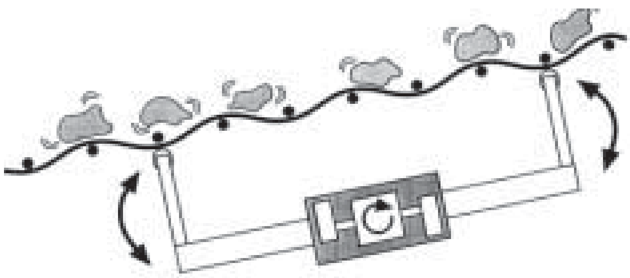
2 Diagram of an electromagnetically, positively excited bumper-type screening machine from Rhewum



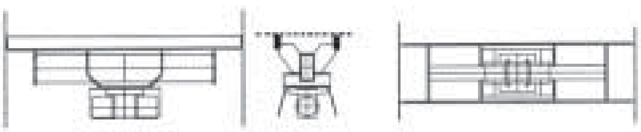
3 Diagram of an electromagnetically, positively excited screen cloth via bumpers, type Finessa from HAVER & BOECKER



4 Diagram of an electromagnetic, positive drive via vibrating strip, type WA, from Rhewum



5 Diagram of an impactor bar excited by balancing weights of the SIZER 2000 from Mogensen



6 Diagram of a drive traverse excited by balancing weights of the screening machine, type Fine-Line, from HAVER & BOECKER

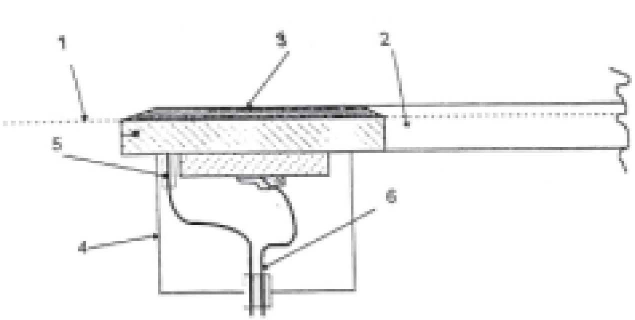
Throw screening reached the range of very fine classification of less 0.030 mm by means of ultrasonic screening, which will be described in the next section.

2. Ultrasonic screening

The oldest patent covering ultrasonic screening dates back to 1963 [22]. It is related to screens with magnetostrictive direct exciter of the screen cloth – a usual method of ultrasonic generation at that time. At present, predominantly piezoelectric ultrasonic generators are used. Piezoelectric materials have the property to change their dimensions or shape, respectively, in an electric field. The piezoelectric disc glued to the screen deck is coupled with a rod-shaped or ring-shaped flexural resonator **(Fig. 7)**. Frequencies of 20 kHz and 40 kHz, respectively, as well as maximum accelerations of up to 50 000 g are generated with this system [23]. Ultrasonic screening should only be used for protective screening. These vibration generators are frequently used as screening aids for flat screens due to their high acceleration of the screen cloth and their screen cloth cleaning properties. Thus, the throughput could be increased tenfold for some products [11, 12].

3. Flip-flop screening machines and their forerunners

Indirectly excited screening machines were not able to cope with the permanently increasing requirements as regards throughput and precision of separation of difficult-to-screen materials, e.g. in the coal and growing recycling industries. Difficult-to-screen materials frequently obstruct or clog the screen openings leading to considerably reduced throughputs and precision of separation. For a while it seemed that the



7 Schematic representation of an ultrasonic screen: 1 screen cloth, 2 resonator, 3 adhesive, 4 cover, 5 mechanical damping, 6 voltage supply

invention of directly excited screen decks with mechanically moved steel elements could solve this problem. Thus, the forerunners of the flip-flop technology came into being.

3.1 Forerunners of the flip-flop technology

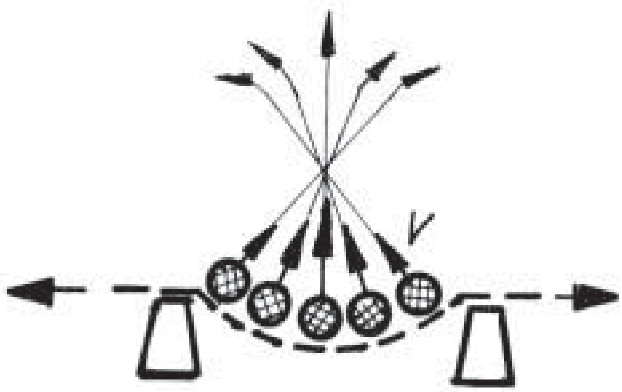
In 1951 A. Wehner applied for a patent covering the DUO grizzly [24]. The grizzly consists of a stationary base frame with clamped screening wires and a second screen tray supported in the base frame by buffers. The second screen tray is also equipped with screening wires and is able to vibrate in the first one. The wires mentioned may additionally carry out harmonics. Adjacent screen deck elements carry out differential motions on the screen surface that are to prevent blinding [11, 12, 25, 26].

At the end of the 1950ies A. Wehner applied for a patent covering the UMBRA screen, which he developed up to the production stage. With this screening machine two interlocking screen frames equipped with grate bars oscillate in opposite directions to each other. They are driven by synchronized eccentric shafts. The above inventor called this screening principle two-way sizing because of the two screening paths each of neighbouring screen deck elements. The original UMBRA screen developed for fine sizing failed in practice due to the high costs for the screen surface and the low throughput.

In the period following, screen decks of conventional design, i. e. of metal cloth or plastics, replaced the expensive grate bar screen decks. This resulted in the so-called impact screening. The screen deck of the impacting machine carried out a semicircular motion cause by impact strips, which were connected with a second screening system. The UMBREX screening machine thus created was operated with screening coefficients K from 2.5 to 4.5. Computed throw accelerations of up to 40 g were determined in the range of reversal, i.e. in the so-called impact points of the drive elements [12, 27, 28, 29]. Despite screening advantages, e.g. in the case of difficult-to-screen materials or due to the relatively cheap screen decks, this development also had only a short lifespan due to the high wear of the drive elements [29].

3.2 Directly excited flip-flop screening machines

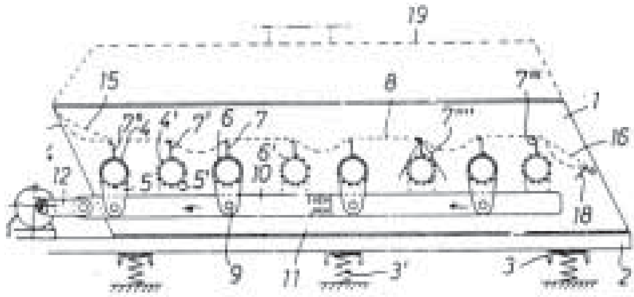
The flip-flop screening machines with their tensioning and relaxing flexible screening mats of rubber or polyurethane fibre [5, 9] can be used for screen aperture widths > 2 mm.



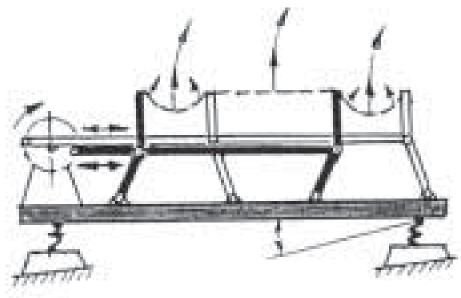
8 Schematic representation of the speed vectors v during particle motion on the flip-flop screen deck

This extremely innovative screening system is distinguished by the following particularities: The particles of the material being screened that are moving on the screening mat have different speed and acceleration vectors **(Fig. 8)** [4]. Intensive loosening and mixing processes develop in the screen bed. At the same time, the undersize motion through the screen openings and throwing the oversize off the parting surface, respectively, are extremely favoured by expansion and differential motions of the screen deck elements as well as by high acceleration values (up to 50 g) [4, 8, 25, 30, 31].

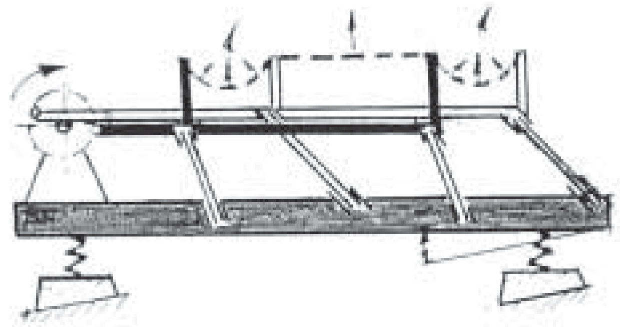
The first screening machines of this kind, the types TORWELL and LIWELL, were developed by the company Hein, Lehman at the end of the 1960ies and had a certain inclination for reasons of conveying. In the meantime flip-flop screening for the most difficult-to-screen materials has come out at top. The type LIWELL, for instance, has increasingly gained importance in the coal, ore and recycling industries. As regards the TORWELL screening machine based on a patent of A. Wehner **(Fig. 9)** [32], the tilting levers including their cross bar are excited to opposite-sense pendulum motions (with an angular displacement of 180°) by an eccentric shaft located on the vibration-isolated base frame via two separately acting push rods. The screening mates alternately arranged on the two tray weights between the cross bars are tensioned and unstressed in turn **(Fig. 10)** [29, 33, 34]. The LIWELL screening machines are distinguished by two screen trays fitted into each other and supported by guiding springs. The trays are excited by an eccentric shaft to opposite-sense motions. The cross bars installed in the screen



9 Diagram of the TORWELL screening machine according to the patent of A. Wehner, 1967



10 Diagram of the flip-flop screening machine, type TORWELL, from the company Hein, Lehmann



11 Diagram of the flip-flop screening machine, type LIWELL, from the company Hein, Lehmann

trays approach and drift apart in the rhythm of the tray oscillation. Thus, the screening mats arranged between the cross bars are tensioned like a trampoline and unstressed again **(Fig. 11)** [29, 34].

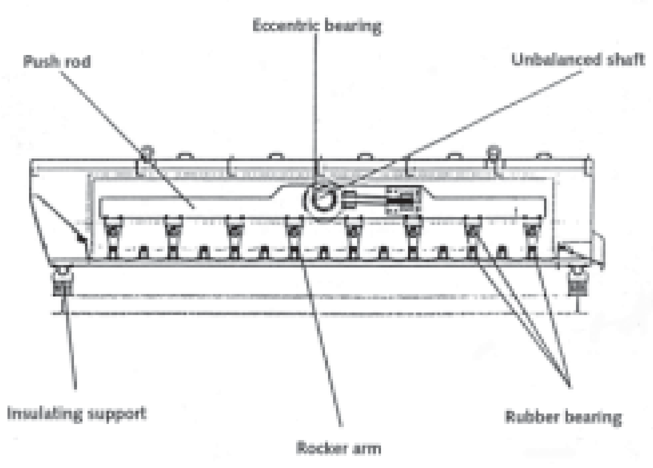
The principle of the exclusive direct excitation of the screen deck via flip-flop elements had its limits inherent in the system, i.e. in part they only achieved average precision of separation and throughputs [9]. Consequently, various screen manufacturers tried to find new solutions and arrived at the directly/indirectly excited flip-flop screening machines.

3.3 Directly/indirectly excited flip-flop screening machines

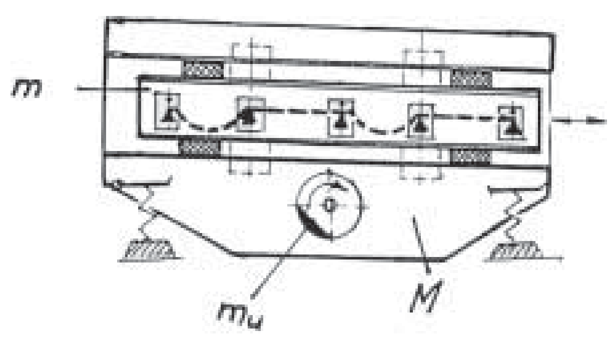
The goal of the directly/indirectly excited flip-flop screening machines is to achieve an increased undersize screening in the first section of the screening surface after feeding the material to be screened and to ensure screening of the near-mesh grains in the following sections, on the one hand, and to increase the specific throughput on the other hand. Elliptical motions of the deforming screening mats are achieved by a superposition of circular and linear vibrations on the drive or exciter end, respectively. For example, the company Hein, Lehmann superposed the pure, direct flip-flop excitation of their type LIWELL KT by a stroke-limited, eccentrically driven circular tray motion. Thus, the precision of separation as well as the conveying speed even of particularly difficult-to-screen materials were improved **(Fig. 12)** [4, 9].

The screening machine, type BIVITEC, developed by Binder & Co. at the beginning of the 1980ies is a combination between the conventional circular and linear vibration screens as well as the flip-flop screen. The screen tray mass M excited by the weight m_u carries out circular vibrations and is clearly adjusted supercritically **(Fig. 13)**. The K_v values vary between 2 and 3. The rail m, connected with the screen tray via thrust rubber springs, vibrates with a linear motion just below the natural frequency [35]. The screen mat elements are clamped on cross bars between the screen tray mass M circularly moved with machine coefficients of approx. 2 to 3 and the resonance mass m. Every second cross bar, seen from outside, carries out a circular motion. The beams in between carry out elliptical vibrations. Due to the relative motions between the screen tray mass M and the resonance mass m, the screen mat is alternately tensioned (maximum K_v values of 30 to 50) with their frequency and then unstressed. It is possible to screen the most difficult-to-screen materials, e.g. slag from refuse incineration plants, mixed building waste, peat etc., with this machine under the improved conveying conditions due to the above circular vibrations [4, 36, 37].

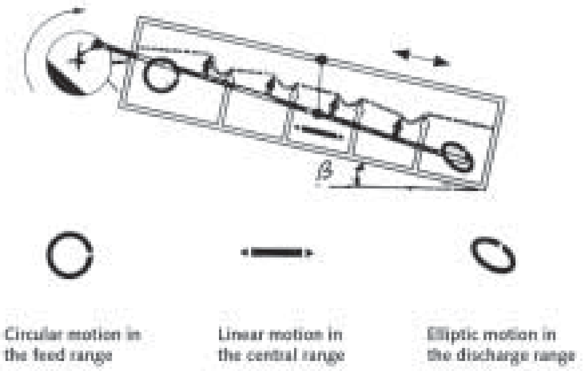
The flip-flop motion due to the eccentrically driven screen frame of the flip-flop screen, type TRISOMAT **(Fig. 14)**, developed by the company IFE in the 1990ies, is superposed



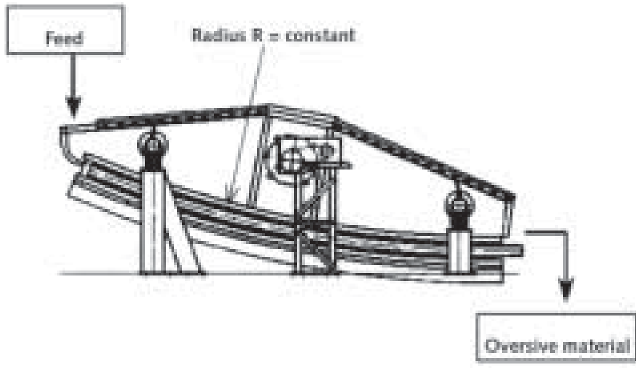
12 Diagram of the directly/indirectly excited flip-flop screening machine, type KT, from the company Hein, Lehmann



13 Diagram of the directly/indirectly excited flip-flop screening machine, type Bivitec, from the company Binder + Co



14 Diagram of the directly/indirectly excited flip-flop screening machine, type TRISOMAT, from the company IFE



15 Diagram of the directly/indirectly excited flip-flop screening machine, type banana Bivitec, from the company Binder + Co

by circular vibrations in the feeding range of the material to be screened and by elliptical vibrations in the material throw range. These vibrations favourably influence the sizing process, e.g. of difficult-to-screen shredded material and compost. The maximum dimensions of the screen surface amount to 3 x 9 m with single-deck screens and up to 2 x 8.4 m with double-deck screens [4, 11, 12, 38, 29].

Since around the beginning of the 21st century, the further developed Bivitec screen from BINDER & Co., the so-called banana Bivitec, has been successfully used for medium and fine sizing of difficult-to-screen materials, such as building waste, compost, clay and the like **(Fig. 15)**. This is a hybrid solution between the troughed or banana vibrating screen and the Bivitec principle used so far. A particularity of the banana Bivitec is the circular or cylindrical guide way of the resonance rail of the vibration mass 2 (with the radius R) oscillating in the screen tray mass 1 excited by the balancing weight. The undersize is screened in the steep surface range with a high conveying speed or large specific throughput, respectively. In the less inclined screen surface sections near-mesh grains are separated. The somewhat increasing screen bed height in the ranges of lower inclination and conveying speed contributes to the fact that the near-mesh grain is not thrown into the screen overflow. The banana Bivitec screen is particularly distinguished by high specific throughputs and precision of separation [9, 40].

4. Screen decks or cloth

Until about the first half of the 20th century, metal screen surfaces prevailed [5]. Then surfaces of rubber, polyurethane fibre and other plastic materials followed [5, 10, 41, 42], which have become more and more dominant. The Dresden-based company L. Hermann should be mentioned as the representative of the German screen cloth manufacturers with their special harp-type screen deck, which was a world's first in 1938. Today, numerous renowned German, European and in part also American manufacturers of screen decks work on the production of screening surfaces of metal, rubber and plastic materials [5, 10].

In screening classification the screen deck is responsible for the separation of the material to be screened according to size ranges on the one hand, and, for conveying the different size fractions on sizers equipped with special screen decks on the other hand [5]. When separating the material into size fractions, the undersize particles should find their way through the screen openings as far as possible without obstruction. Therefore, the openings should not be obstructed or clogged by clamping, adhesive or agglomerated particles and the like. The aforementioned separation, which takes place according to the probability laws, amongst other things, will only be possible if the undersize is passed from a certain bed height to the level of the separating area. This requires vertical conveying of the material to be screened as well as parallel to the screening surface. This is to release differential motions between the screen surface and the particles of the material to be screened and also between the material particles themselves.

The suitability of the screen deck or screen surface, respectively, for the separation of the material to be screened according to size fractions depends on the type, granulometric composition, moisture and flowability of the material to be screened. Furthermore, the classifying screen, the required cut size as well as the throughput should be taken into account. The **Lead picture**, p. 60, hows a rough survey of possible types of screen decks for different materials to be screened and cut sizes. The author has already described in detail special screen surfaces, their fields of application as well as renowned manufacturers [5, 9, 11]. Therefore, it should not be repeated here.

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