INTRODUCTION

One of the very simple devices for handling materials, known as the vibratory conveyor, has been used since the middle of the last century.(1)(2) With the capability of handling a wide variety of materials from microscopic size to large chunks, the vibratory conveyor has aroused considerable interest in almost every phase of industrial production. By appropriate selection of material or coating for the transporting deck or trough, it is possible to handle materials continuously at temperatures exceeding $1500^{\circ}F$, or to convey very abrasive or highly corrosive compounds. Output capacities can be accurately controlled in weighing or proportioning processes, and can vary within a very wide range, from a few ounces per minute to almost 1000 tons per hour. It should be realised that vibratory conveyors are easily modified for multipurpose applications such as cooling, heating, drying, screening and other processing operations.

The basic design of vibratory conveyor consists of a material transporting trough or deck, stabilizers or links for producing directional motion, and a vibratory drive system. Trapezoidal and semicircular cross-sections of conveyor trough are the most popular and offer the least resistance to material displacement. Totally enclosed troughs, usually in the form of a round tube, have been successfully used to convey bulk materials. The trough is mounted on a set of stabilizers or links on the base, and a spring system is usually incorporated. This spring system can be in the form of coil or leaf springs, torsion bars, or rubber shear springs. Vibratory action is obtained either mechanically or electrically. When produced mechanically, an eccentric, revolving element is normally used. Electrically induced motion comes from a balanced power unit which creates interrupted magnetic pulls. The length of vibratory conveyors ranges from a few feet to several hundred feet, but longer distances can be covered by connecting several individual units in series. Junctions at any angle and division into many branches are easily accomplished.(3) As a rule, vibratory conveyors are designed to convey materials at a fixed rate, horizontally, but they can operate with an upward slope of up to 15 deg.(4) They can be arranged in steps or helices to reach any height that may be required.

To convey material, it is necessary only to vibrate the trough. The adherence force of the material to the trough will have to be adequate to carry the material along with the trough during its forward stroke, and inadequate to draw the material back with the trough during its return stroke. Therefore vibratory conveyors can be divided into two groups, according to the effect of the adherence force. In the first group, the adherence force, which depends on the weight of the material and the coefficient of friction between the material and the surface of the trough, remains constant. The material slides along the trough by accelerating and decelerating the trough in accordance with a definite kinematic law. In practice, conveyors of this type are shaking conveyors, and operate at relatively low frequencies, i.e. from 30 to 100 oscillations per minute. Their displacement amplitudes are rather large, the average being from 6 to 9 inches. In the second group, a vertical component of motion is added to the reciprocating trough motion in such a way that the adherence force of the material to the trough is reduced during the return stroke, while the forward and return strokes of the trough are kinematically similar. When the trough vibrates, the material handled is thrown upwards in the direction of feed and travels in a series of small jumps towards the discharge end of the trough. In this case, the trough will be arranged to move along the straight line perpendicular to the links or leaf springs. In practice, the value of the inclination angle of the trough path ranges between 10 and 30 degrees. Generally, there are two classifications of conveyors of this type according to the drive mechanism, i.e. those in which the drive is direct-positive and those in which the drive is indirect. Positive drive mechanism consists of an eccentric driving shaft with bearings and connecting-rod assembly. Rotation of the eccentric imparts a reciprocating motion directly to the trough. In direct drives without springs, the trough inertia forces at each end of the stroke are imposed on all the connections and eccentric bearings. On the other hand, the direct drive applied to a spring-trough system operates with low thrust forces but develops extremely high bearing loads and drive stresses during starts and stops as well as high starting torques and horsepower requirements. In indirect drives, which allow the trough a certain degree of freedom of movement, the trough oscillations are created by out-of-balance weights on two counter-rotating shafts, or by electromagnets, incorporated with a spring system. The indirect drive mechanism entails lower starting stresses and minimum horsepower requirements. Mechanical losses due to linkage as well as maintenance problems are eliminated with this type of drive. Some conveyors have been designed (5) with a connecting-rod having a certain degree of flexibility in an attempt to gain the advantages of both types of conveyor. Vibratory conveyors with variable adherence force, particularly equipped with indirect drive, operate at relatively high frequencies, i.e. normally between 400 and 6000 oscillations per minute. The upper limit of amplitude of vibrations for the lower frequencies is about ½ in., and for the higher frequencies 0.06 in., with a minimum at 0.02 in.

As mentioned, the material in the trough moves forward through a series of hopping actions in consequence of the reciprocating motion of the trough. So it may be said that the frequency and amplitude of oscillation are the main factors in determining the ability of a vibratory conveyor to transport material. For the conveyor with variable adherence force, the direction of the trough motion also affects the travelling speed of the material. Furthermore, with a certain oscillation frequency, the material may be thrown away from the surface of the trough, continuing its travel along a short ballistic trajectory. In practice, vibratory conveyors mostly handle bulk materials, and their output is not governed only by the above three parameters, but by many others such as the nature of the material, the temperature, the shape of the trough, the depth of material in the trough, and so on. It is possible that some of these influences can be estimated by using hydrodynamic theory.