This equation can be integrated to give

$$\epsilon = \frac{\sigma}{E_2}\left[1 - \exp\left(-\frac{E_2}{\lambda_2} . t\right)\right] \quad . \quad . \quad (A.10)$$

In this case λ_2/E_2 is called the retardation time τ_2, and the equation can be re-written

$$\epsilon = \frac{\sigma}{E_2}\left[1 - \exp\left(-\frac{t}{\tau_2}\right)\right] \quad . \quad . \quad . \quad (A.11)$$

In this case at constant stress the strain increases from zero at zero time to an asymptotic value of σ/E_2 after an infinite time. If the stress is reduced to zero at some value of strain given by ϵ_0 then the strain relaxes to zero at a rate given by

$$\dot{\epsilon} = -\frac{E_2}{\lambda_2} . \epsilon = -\frac{\epsilon}{\tau_2} \quad . \quad . \quad . \quad . \quad (A.12)$$

and the strain at any time t is given by

$$\epsilon = \epsilon_0 . \exp\left(-\frac{t}{\tau_2}\right) \quad . \quad . \quad . \quad . \quad (A.13)$$

It can be seen that this model will represent transient creep (delayed elasticity) and the elastic after-effect.

A model which can represent the whole of the creep curve other than the accelerating part of the creep (DE in Fig. 2) is one suggested by Burgers, which consists of a Maxwell model linked to a Kelvin-Voigt model (Fig. 18). In this case the stress strain relationship at constant stress is given by

$$\epsilon = \frac{\sigma}{E_1}\left[1 + \frac{t}{\tau_1}\right] + \frac{\sigma}{E_2}\left[1 - \exp\left(-\frac{t}{\tau_2}\right)\right] \qquad (A.14)$$

The coefficients λ_1 and λ_2 which appear in τ_1 and τ_2 are sometimes directly identified as coefficients of viscosity of the viscous elements in the Maxwell and Kelvin-Voigt models, but this is unsatisfactory since the viscous elements that have been considered have been strained in extension and not shear. Coefficients like λ_1 and λ_2 were called coefficients of viscous traction by Trouton, and by considering the extension of a rod of highly viscous material he was able to show that the relationship between these coefficients and the viscosity coefficients (η) as usually defined is

$$\lambda = 3\eta \quad . \quad . \quad . \quad . \quad . \quad (A.15)$$

These models are based on the conception of creep as a form of viscous flow. However, a comparison of Maxwell's eq. A.8 with eq. 26 of the text shows that the 'viscosity coefficient' of a crystalline solid, far from being constant, depends markedly on stress, so that in practice the models are of little use for such solids.

Investigation and Development of Some Laboratory Wet Gravity Mineral Concentrators*

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SYNOPSIS

The two basic processes which cause the separation of minerals in shaking gravity concentrators, vertical stratification and lateral separation, are primarily derived from the longitudinal motion of the concentrator deck. A study of this motion for some laboratory panning devices and shaking tables was carried out using an electrical measuring technique. Analysis of the test results led to the design of a new panner drive mechanism which was shown to give an improved performance.

Further to assist the vertical stratification of particles, a porous concentrator deck was constructed and a cyclic pulse of water applied to it during panning. This development combined the advantages of jigging and tabling and enabled the principal features of both these methods of concentration to be simultaneously applied to the treatment of granular materials. Tests on a panner incorporating the 'pulsed deck' principle showed a substantial improvement in performance over a plain-decked model.

THE SEPARATION OF MINERAL PARTICLES on the deck of a shaking table or panner can be divided into two main processes[1]: vertical stratification within the particulate bed and lateral separation of the stratified layers. The former results from the longitudinal motion of the concentrator deck acting in conjunction with the flow of fluid and particles over the deck surface and riffles, if present; the latter also results from this deck motion although, in the case of panners, it is assisted by film sizing effects in the longitudinal direction. Since the longitudinal motion contributes substantially to both components of the separation process it is a very important feature in concentrator design and it is necessary to ensure that a suitable form of motion is produced if high machine performance is to be achieved.

The degree of stratification of minerals on shaking tables and panners of current design is not amenable, however, to precise control owing to the complexity of the system and interaction between the many variables. This is supported by the results of some recent work by Kirchberg and Berger[2] who examined the effect of longitudinal motion on the stratification of particles on a shaking device and showed, qualitatively, the effects of different variables on the system.

The present paper reports the results of a study of the longitudinal motion on certain gravity concentrators and of the effect of introducing the jigging principle into table concentrator design in order to ascertain whether

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[1] etc. See list of references at the end of the paper.

an improvement in separation efficiency would result. It can be appreciated that the principle of jigging provides a highly effective and controllable means of achieving rapid vertical stratification in a particulate bed. The concentrators examined with respect to longitudinal motion included the micropanner,[3] the Haultain superpanner,[4] a half-size and a laboratory-size Wilfley table. In the case of the two last concentrators the motion was not expected to differ greatly from that derived from the analysis of the mechanics of their head motion, but it was considered of interest to confirm this experimentally.

In analysing the longitudinal motion of these concentrators, the transverse movements of the panners were eliminated and their effects were not considered in relation to lateral separation of the particles. Similarly, transverse effects on shaking tables due to riffing, water and particle flow were not included in the analyses. While all these transverse motions contribute to vertical stratification of particles they are not considered important in relation to lateral separation once a particle bed is dilated.

The effect of imposing the jigging principle on that of tabling has been examined empirically using a panner fitted with a porous deck which permitted the passage of water pulses to the particle bed, a pump being used to generate the required pulses.

CONCENTRATOR MOTIONS

Requirements for Longitudinal Deck Motion

The longitudinal motion required for maximum efficiency of lateral separation on a shaking table is a uniform acceleration followed by uniform retardation. The rate of reversal of the deck at the end of the forward* stroke must also be more rapid than at the end of the return stroke, thus imparting a movement to the particles relative to the deck. This form of motion has been illustrated by Taggart[1] and long-term usage has led to its general acceptance as representing an ideal form.

The micropanner, superpanner and other devices which utilize a stop to arrest the deck at the end of the return stroke require a similar motion which is modified by replacement of the smooth reversal of the table by the sudden stop. It may be noted that this stop imparts an additional motion of lateral separation to the particles which is not obtained on a table. In these devices the acceleration during the early part of the forward stroke must be as rapid as possible so as to impart a 'snatch' effect to the deck relative to the particles; during the latter part of the stroke, acceleration decreases to give a smooth reversal into the return stroke. This stroke starts with low acceleration to enable the particles to adhere to the deck by friction; the acceleration subsequently increases and the deck finally travels at constant velocity until it strikes the stop. The particles are thus thrown towards the head of the deck, the heaviest, owing to their greater momentum, travelling furthest in this direction. It is thus desirable that no secondary oscillations should be produced by the sudden arrest of the deck. At the same time this

*Throughout this paper the forward stroke is defined as the direction of travel away from the head motion.

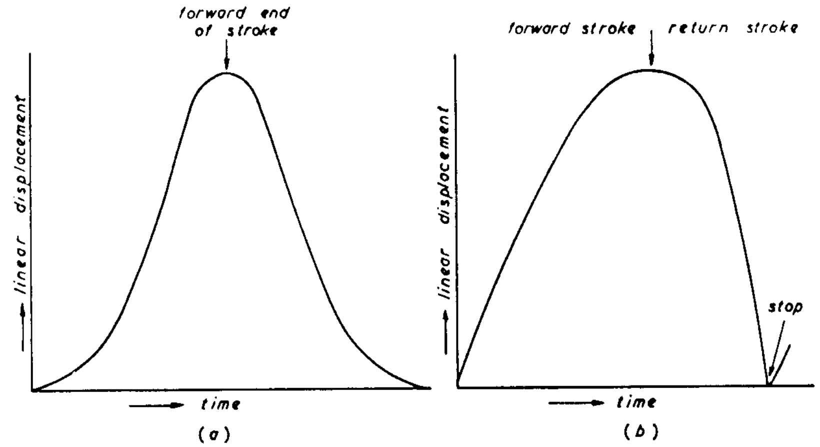


Fig. 1.—Optimum displacement/time diagrams for shaking mechanisms.
(a) shaking table; (b) panner mechanism with 'stop'.

sudden arrest encourages some stratification within the bed of particles on the deck, probably resulting from a form of jigging (consolidation trickling). Time/displacement diagrams for the ideal longitudinal motion of the shaking table (based on Taggart[1]) and, by analogy, for the panner type of separator, are shown in Fig. 1.

Investigational Technique

The method used to investigate the deck motions of the various concentrators was based on the generation of an electrical potential proportional to the linear displacement of the deck from a reference point. This potential was applied to an oscilloscope in conjunction with a time base. It was thus possible to obtain a diagram, showing deck displacement with time, which could be recorded photographically. The technique is here described in some detail as it has received little attention as a tool for mineral dressing research and it might well be used to advantage for the study of other systems, such as the mechanical performance of crushers.

The transducer used to detect displacements of the micropanner deck was a small differential transformer with a ferrite rod core. The transformer consisted of two windings on a cylindrical former which was fixed to the base plate of the micropanner. The primary winding was energized by a 20-kc alternating current from a signal generator; the potential across the primary winding was approximately 4V. The secondary winding was connected to an oscilloscope through a germanium diode half-wave rectifier and smoothing circuit. The transformer core was located inside the cylindrical former and was attached to the micropanner deck by a brass rod. With the micropanner in motion, the core oscillated inside the transformer and varied the voltage induced in the secondary winding as the core position changed. The varying d.c. voltage thus produced was separated from the a.c. voltage, also induced, by means of the rectifier, and used to deflect the trace on the oscilloscope. The differential transformer was calibrated before use by attaching the core to a micrometer and measuring the voltage induced in the secondary winding at varying known core positions inside the former using a valve voltmeter. It was found that the output voltage was proportional to core position over a range of 0·25 in. This type of transducer was suitable for the measurement of small displacements, such as those encountered on the micropanner, where the maximum throw was about 0·1 in. It also had the advantage that, since there was no mechanical contact between the measuring system and the motion being studied, mechanical losses were eliminated from the system. The equipment used is shown in Fig. 2, Plate I, and Fig. 3.

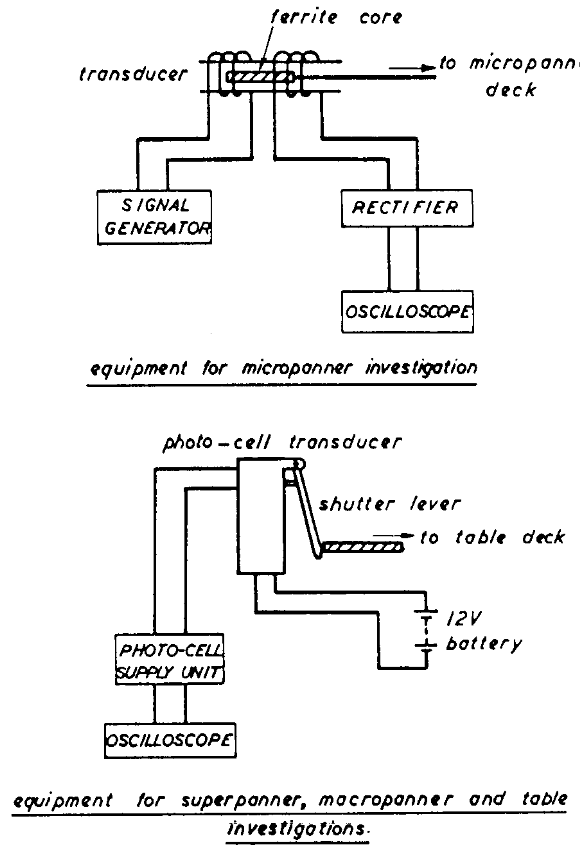
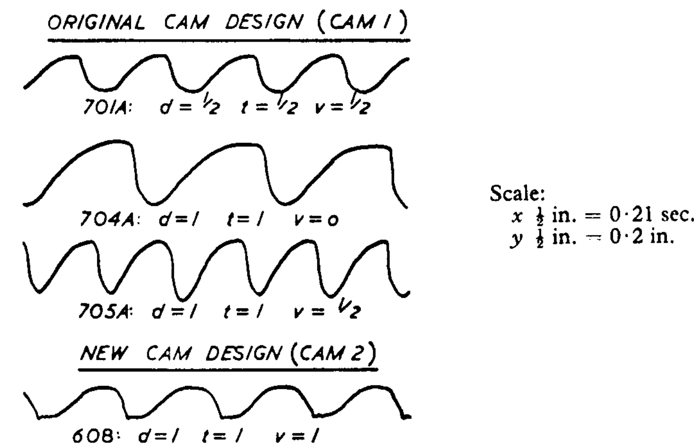


Fig. 3.—Schematic diagram showing equipment used for investigations.

As shaking tables and other shaking concentrators often throw in excess of 0·25 in. it was necessary to use another transducer for investigations of the superpanner and Wilfley tables. An attempt was made to construct a differential transformer with a greater linear response range; this being unsatisfactory, a commercial photo-cell transducer was used. This device operated on the principle that the output voltage of an energized photo-electric cell varies in proportion to the amount of light falling on it. The unit consisted of a photo-cell shielded from a light source by a mechanically operated shutter; displacement of a lever which operated the shutter varied the output voltage. A small amount of work was required to operate the shutter but the unit was found to be suitable for the investigation of the motions of the larger shaking mechanisms since its linear response range could be adjusted by changing the shutter lever length.

The Micropanner

The construction and operating variables of the micropanner have been described elsewhere.[3] The panner deck is mounted on a spring-loaded reciprocating shaft which engages with the teeth of a ratchet wheel. The length of the stroke is altered by variation of the degree of engagement of the shaft end with the ratchet teeth. Three operating variables—spring tension, motor speed and length of stroke—were investigated with the transverse motion eliminated. Selected oscilloscope traces showing displacement/time diagrams for the micropanner deck at various settings of the three variables are shown in Fig. 4, d being length of stroke, t spring tension and v motor speed. Arbitrary settings were selected for each variable: the value '1' being given to the highest setting which could be used in practice, '½' to an intermediate setting and '0' to the lowest.



Scale:
x ⅓ in. = 0·21 sec.
y ½ in. = 0·2 in.

Fig. 4.—Displacement/time diagrams for micropanner.

The traces shown in Fig. 4* indicate that the motion of the micropanner conformed closely with the ideal longitudinal motion over the forward

*The traces shown in this figure (and in Figs. 6, 7 and 9) are reproduced in the same sense as those of Fig. 1, thus the forward and return strokes of each cycle shown in the traces are in the same direction as in Fig. 1.

stroke of the deck. The trace for the return stroke, which is entirely spring-controlled, showed a major departure from the ideal form in that the acceleration was extremely high at the beginning of the return stroke, thus probably imposing an unwanted 'snatch' effect to the particles on the deck. This effect is present irrespective of the settings actually used for the panner variables. When a full length of stroke and normal deck speed is used, as in 705A, the reversal of the deck after impact is smooth and rapid. With a very low speed (704A) this reversal is slightly modified as the deck is now able to remain fractionally at rest after impact and before the next ratchet-wheel tooth contacts the end of the reciprocating shaft. This dead period is emphasized in 701A where the length of the stroke has been halved by allowing only partial engagement of the shaft with the ratchet-wheel teeth. Diagram 705A also showed that there was some variation in stroke length during operation which was not apparent at low driving speeds (704A). This is probably due to the failure of the end of the shaft to reach the roots of the ratchet-wheel teeth during every cycle under these operating conditions.

Although the longitudinal motion of the micropanner approximated to the ideal, there was some room for improvement in the return half of the

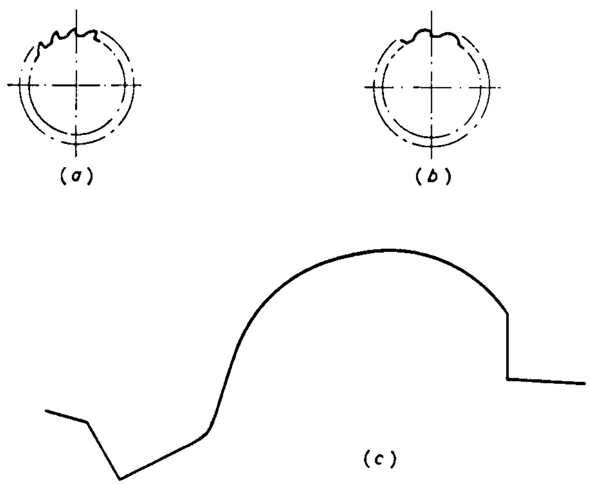


Fig. 5.—Micropanner cam designs.
(a) original design (cam 1).
(b) new design (cam 2).
(c) enlarged new profile.

cycle. The ratchet wheel, or driving cam, was therefore re-designed in order to provide a closer approach to the ideal motion; the new design is shown in Fig. 5. One such cam was constructed and gave a good approximation to the required motion (Fig. 4, 608), although a small 'dead-period' was found to exist. Since identical motion diagrams would not be observed

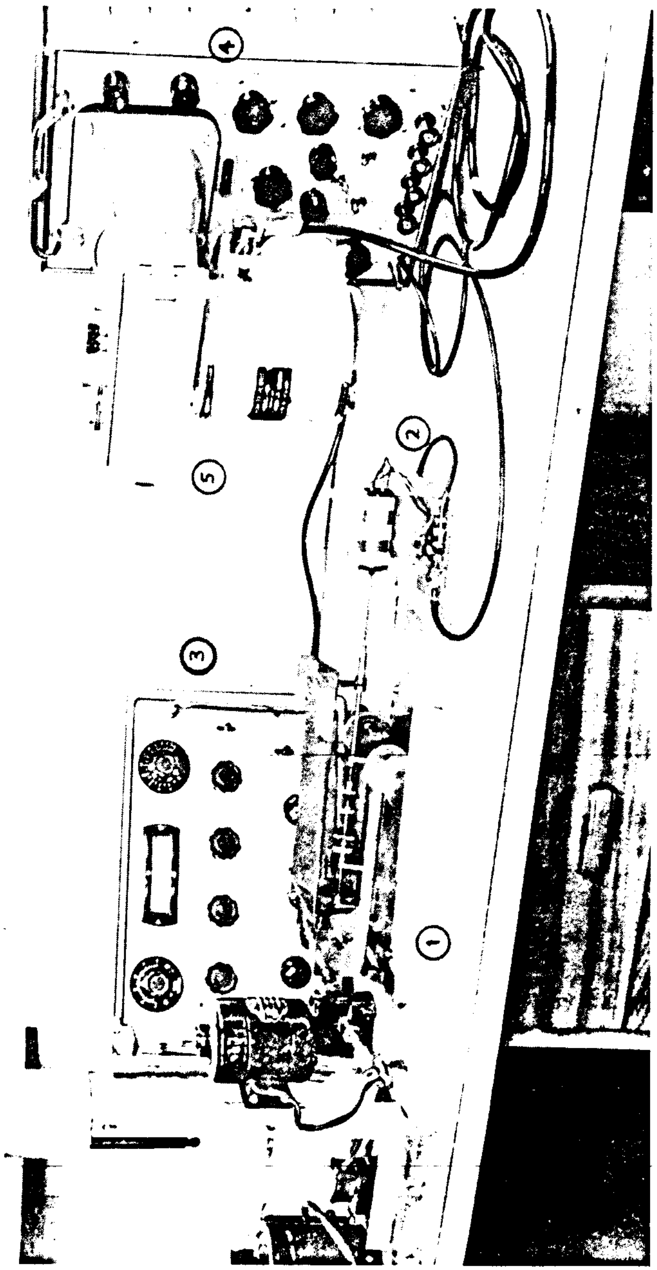


Fig. 2.—Equipment used for investigation of micropanner motion.
1. Micropanner
2. Transducer
3. Signal generator
4. Oscilloscope
5. Camera

L. D. MULLER and J. H. POWNALL: *Investigation and Development of Some Laboratory Wet Gravity Mineral Concentrators.* Plate II.

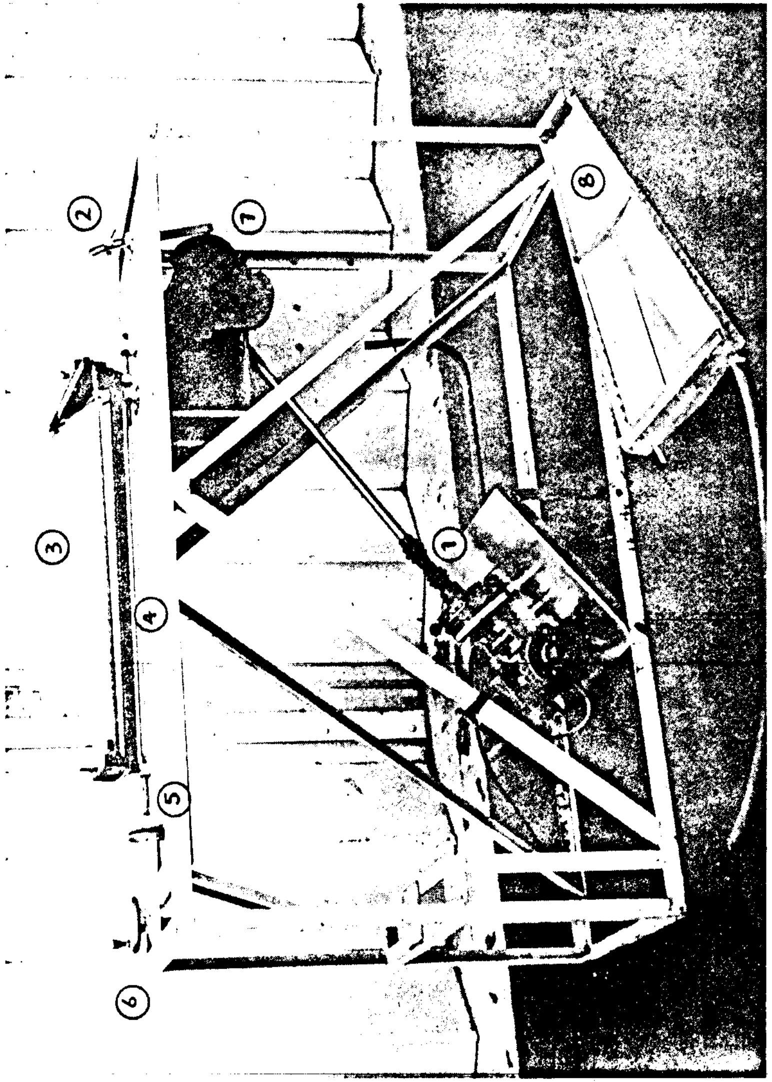


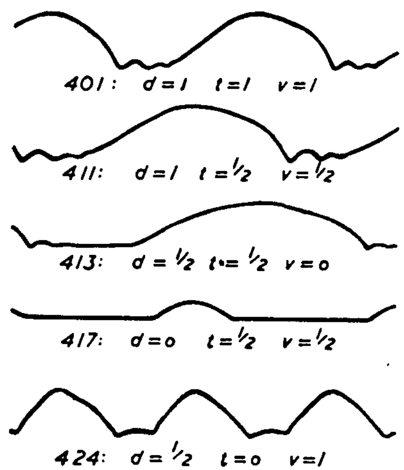
Fig. 8.—Macropanner: general arrangement.

1. *Main drive with variable speed gear*
2. *Stroke length adjustment linkage*
3. *Deck*
4. *Deck mounting rod*
5. *Return spring and handwheel*
6. *Deck tilting handwheel*
7. *Driving cam*
8. *Pulsed deck*

if the reciprocating shaft were partially withdrawn from the cam to obtain a range of stroke lengths, it would either be necessary to use a number of cams of similar form but different diameter or to incorporate an adjustable reduction linkage between the shaft and cam in order to control the length of stroke. However, because of the complex form of the cam, the small size of the micropanner, and consequent manufacturing difficulties, such modifications would prove uneconomic.

The Superpanner

Displacement/time diagrams (Fig. 6) similar to those for the micropanner have also been obtained for the superpanner and the same three variables—spring tension, motor speed and stroke length—were investigated, the same notation being used to describe the variables.



Scale:
x ½ in. = 0·21 sec.
y ½ in. = 1 in.

Fig. 6.—Displacement/time diagrams for superpanner.

A diagram for the deck motion with intermediate settings of spring tension and speed is shown in Fig. 6 (411). The forward stroke of the superpanner began with relatively large oscillations owing to rebound of the deck carriage from the stop cam. These oscillations are undesirable, since a smooth and rapid reversal of the deck is required at this juncture if high separation efficiency is to be obtained. These secondary oscillations were reduced at low speed (413) and with short stroke lengths (417), these conditions reducing inertia of the deck. These two diagrams also indicated the presence of a dead-period when the stroke amplitude was reduced. The general shape of the forward stroke diagram suggested constant velocity followed by a smooth deceleration and reversal. The deck velocity during the forward stroke was generally low, in contrast to the requirement of the ideal motion that it should be rapid during the early part of the stroke. The return stroke could be divided into two phases, the first being the return under the action of the spring but subject to restraint by the driving cam.

About half-way through the return stroke there was a change of slope in the diagram which marked the beginning of the second phase, that is, the motion of the deck due to the spring alone until the carriage struck the stop cam. During this half of the cycle the motion was very similar to the ideal requirement. Change in slope of the return stroke diagram was marked except where low spring tension (424) or short stroke length (417) was used. In general the motion during the return stroke was near the ideal form at high settings of the variables (401 and 411); the motion was then quite stable and its characteristics most pronounced.

As in the case of the micropanner, the motion of the superpanner could be improved by re-designing the driving mechanism particularly as it affected the secondary oscillation after the 'bump' and also to achieve smoother accelerations during the forward stroke. The design of the 'macropanner', a proposed successor to the superpanner, incorporating these and other improvements, is described in detail in the next part of the paper.

A Laboratory Shaking Table

The motions of Wilfley-type laboratory shaking tables of half-size and of 40-in by 18-in were investigated to check whether the motions were as near the ideal form as could be expected from the mechanical design of the head motion. The displacement/time diagrams given in Fig. 7 for the laboratory-size table show that, although the motion was close to the ideal it was slightly asymmetrical; this was more noticeable at low speeds (503).

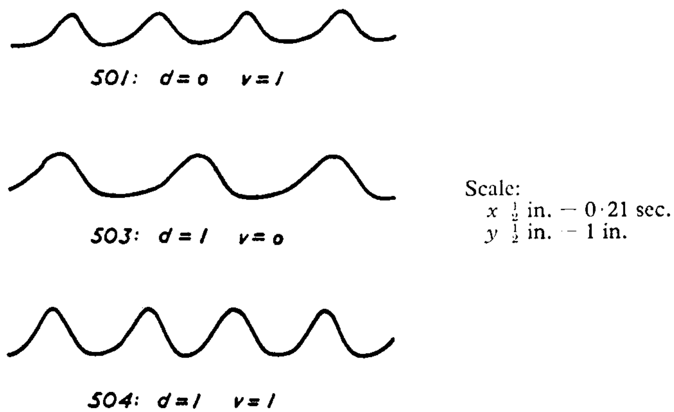


Fig. 7.—Displacement/time diagrams for laboratory shaking table.

Reduction in the stroke length (501) did not appear to affect the character of the motion. The asymmetry in the motion, which was repeated by the larger table, was thought to be due to the imbalance of loading on the driving motor because of compression and release of the return spring. The form of the table motion diagram suggested that re-design of the mechanism was not likely to increase the efficiency of the machine as a concentrator.

THE MACROPANNER

Design

Consideration of the longitudinal motion of the superpanner led to the conclusion that an improved driving mechanism could be designed which would provide a closer approximation to the ideal form of longitudinal motion. The drawing of the modified cam for the micropanner, which gave the desired result, was used as the basis for the new macropanner design. The cam, a larger version of the improved micropanner type (Fig. 5), has three lobes cut on its circumference, which cause the panner to go through three complete motion cycles for each revolution of the cam. A roller cam follower was mounted on a lever and the roller was kept in contact with the cam face so that the lever end oscillated parallel to the major axis of the panner as the cam rotated. The lever was connected to the panner deck through an adjustable linkage which permitted variation in the length of stroke of the panner, although the cam, its follower and the lever always moved through the same distance. This design ensured that the deck always followed the same displacement/time diagram although the amplitude of oscillation could be varied. There was no evidence to suggest that Haultain's design for the deck of the superpanner could be improved upon, so this was retained. The deck was mounted on a rod running parallel to the major axis and immediately beneath it, the rod being supported by three bearings. This rod also carried the spring which drove the deck through its return stroke and, acting through the driving linkage and lever, maintained the follower in contact with the cam. Transverse motion was effected by means of a variable-throw rocking mechanism, similar to that used in the micropanner, which permitted the deck to rock sideways about the main mounting rod. A photograph of the assembly with a key to the main features is reproduced in Fig. 8 (Plate II).

The principal mechanical controls of the panner were:

(*a*) stroke length: by the adjustable driving linkage;

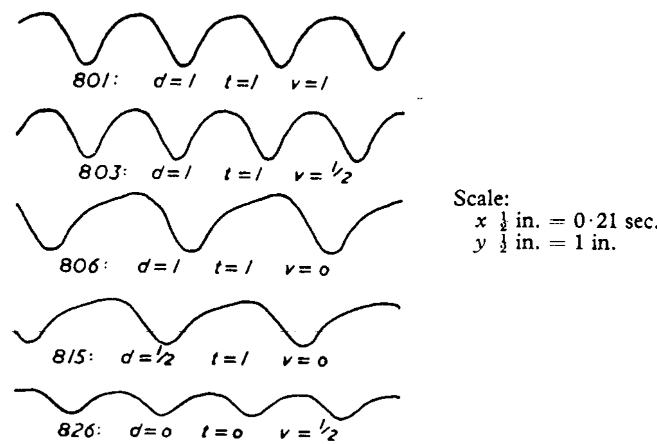


Fig. 9.—Displacement/time diagrams for macropanner.

(*b*) deck return rate: by handwheel control of return spring tension;
(*c*) degree of transverse motion: by variable throw eccentric;
(*d*) deck slope: by lead screw tilting mechanism;
(*e*) deck speed: by variable speed gearbox on the main drive shaft.

The longitudinal motion of the new design was investigated by the same technique as that applied to the superpanner; the displacement/time diagrams obtained are shown in Fig. 9. A near-ideal motion was maintained with both moderate and high settings of driving speed and spring tension (801 and 803). The general form of the diagram was maintained at reduced stroke lengths (815) although at low driving speed with high spring tension there was a noticeable increase in the time taken to complete the forward stroke (806 and 815). At very low spring tension (826) the panner motion closely resembled that of the shaking table.

Testing

The performance of the macropanner was assessed from a series of comparative tests in which samples of the same materials were treated on the superpanner and macropanner. Each test sample was obtained from the bulk of material using a rotary sampler. Strict comparability between the two machines was maintained by using the same deck for both test series. Comparative tests were also carried out on the laboratory shaking table mentioned previously.

The two test materials used were an artificial mixture of quartz and riebeckite containing 3·8 per cent riebeckite by weight, sized in the range −60 +100 mesh B.S.S., and a pyrochlore-bearing carbonatite rock, sized −60 +200 mesh B.S.S.

The quartz/riebeckite mixture was selected as a suitable test material since the minerals had measured specific gravities of 2·64 and 3·41 respectively, thus giving a concentration criterion[5] of 1·47 in water. This was regarded as being near the practicable limit for gravity separation in the size range selected. Also the material was known to be fully liberated and test products could be rapidly and conveniently analysed using a high-intensity laboratory magnetic separator. There was a small difference in shape factor between the two minerals, the riebeckite being slightly more acicular than the quartz.

The carbonatite rock consisted essentially of calcite and dolomite with minor amounts of pyrite, pyrochlore and silicates; the major silicate was a fibrous soda amphibole (arfvedsonite). The mean density of the pyrochlore was found to be 4·14, but individual grains could be expected to show some variation from this figure as the mineral contained varying amounts of the amphibole as inclusions. The pyrochlore assayed 53·3 per cent Nb_2O_5 and the sized head fractions used in the tests assayed about 1·1 per cent Nb_2O_5. For the separation of pyrochlore from calcite in water the concentration criterion is 1·83. Recovery of pyrochlore from this material was considered to present a gravity concentration problem similar to those found in practice. Pyrite can be recovered by gravity concentration much more readily than pyrochlore so that a procedure for test-product analysis was adopted which discounted the behaviour of the pyrite. Each product was analysed for its sulphur content by a chemical method, and spectro-

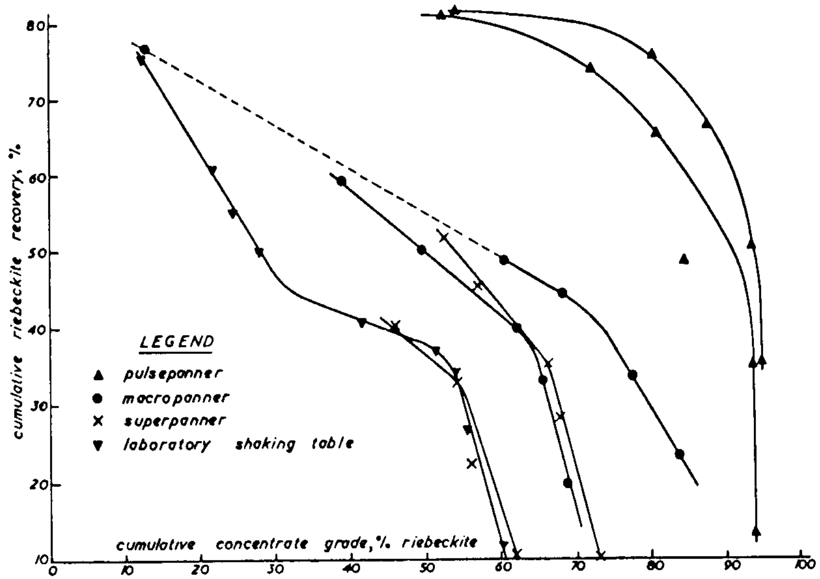


Fig. 10.—Recovery of riebeckite from a mixture with quartz.

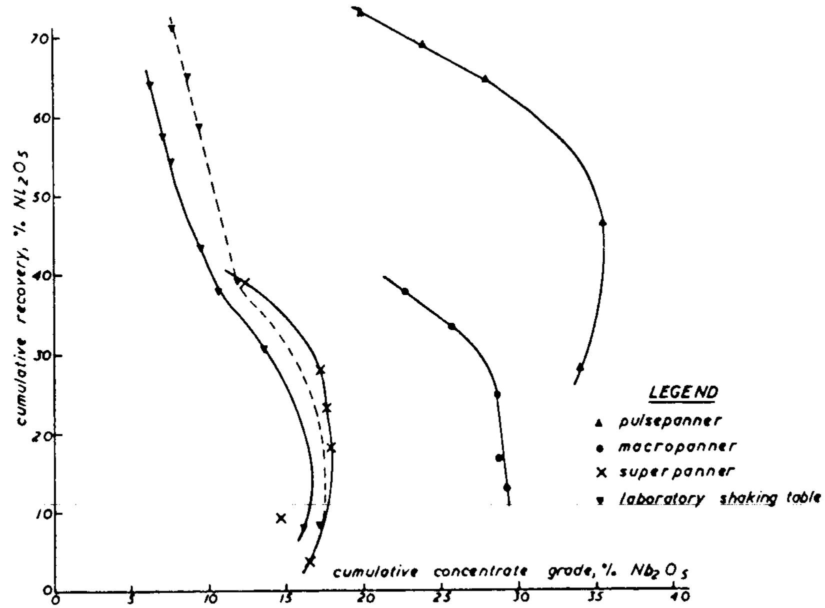


Fig. 11. Recovery of niobium values from carbonatite rock.

graphically for niobium. The pyrite content of the product was calculated from the sulphur assay, assuming the theoretical sulphur content of pyrite (53·4 per cent S), and the weight of pyrite subtracted from the product weight. A new value for the niobium content of the product was then calculated using the determined weight of the pyrite-free product. Test performance was assessed on the basis of these calculated product weights and niobium assays.

A number of tests was carried out on the two panners. In each test a quantity of feed material (30 g) was placed upon the deck and panned until it was judged that the cleanest obtainable concentrate had been reached. This concentrate was then removed and panning continued, with adjustment of operating conditions as necessary, until the next cleanest tip had been prepared; this was then removed. The various concentrates were weighed and analysed separately and, from the results obtained, the cumulative grades and recoveries of riebeckite and pyrochlore in the successive concentrates were calculated. The cumulative recovery was plotted as a function of cumulative grade. Cumulative plots were selected as a basis for comparison between tests as they enabled the factor of the operator's judgement as to the correct moment to remove a particular concentrate to be eliminated from the comparison. The operator's individual skill in manipulating the panner controls to achieve the 'best' result was important as it affected test performance. To allow for variation in operator performance a number of repeat tests was carried out on each machine and the 'best' and 'worst' results have been presented for quartz/riebeckite separations. The carbonatite/pyrochlore separation was found to be rather more reproducible so single tests results have been reported, except for the shaking table. In this instance the results of an additional test have been included to give a better indication of the shape of the cumulative grade/recovery plot. The test results are presented in Figs. 10 and 11.

The results of tests using the same materials and carried out on a laboratory shaking table are also included in Figs. 10 and 11. With this device it was not possible to maintain a single sample of material on a table deck throughout a complete test so that procedure of the panner tests was simulated by means of a closed-circuit operation. Table products were pumped to a 3-in hydrocyclone which was adjusted to eliminate wash water added to the table and return the solids to the deck for re-treatment. A sample of about 1·2 kg was fed to the table and the circulating system was allowed to settle down to steady operating conditions with a clear cyclone overflow. When the table controls had been adjusted to give the best observable separation of minerals the clean concentrate material was removed from the system until there appeared to be some decline in concentrate grade. The table was then readjusted and a second concentrate removed. This procedure was continued in the manner used for the panners and the products were analysed as before.

THE PULSEPANNER

To study the effect of imposing a jigging pulse on a shaking-deck concentrator the macropanner was modified by replacing the linoleum deck by one covered with porous polyethylene, which was connected, by a flexible hose, to a ½-in variable-stroke diaphragm pump, the outlet valve of which was removed. The inlet valve was connected to a main-water line through a stop-cock. The modified deck was driven by the macropanner mechanism and the assembly was given the name 'pulsepanner'. On opening the stop-cock, the pump, connecting line and tank were filled until the water level stood about ⅛ in. above the porous deck and all the air had been expelled from the system. The cock was then closed and the pump started up, causing a water pulse through the porous deck which varied the fluid level above the deck by about $\frac{1}{16}$ in. Material was then placed on the deck and panned in the normal manner, the water pulse height being used as an additional control to achieve good separation of the minerals. It was found by experiment that it was not possible to pulse the full area of the deck using the pump available and better results could be achieved when two blanking plates were fitted to the deck. These left exposed a triangular area of porous surface in the middle of the lower end of the deck, about 3 in. wide at the tailings end and 15 in. long, with a gap ¼ in. wide between the plates at the upper end through which the concentrate could be panned. The restricted deck area satisfactorily handled a 50-g feed sample, compared with the 30 g normally treated on the panner. A series of tests similar to those on the superpanner and macropanner were carried out on the pulsepanner and the results obtained are also shown in Figs. 10 and 11.

DISCUSSION OF TEST RESULTS

The validity of the test results presented depend upon the acceptance that the operator was successful in producing the best possible separation of minerals on the concentrator deck. The number of operating controls available on the panners studied and the high degree of interaction between them made definition of the precise effect of each variable too complex to be worth attempting, so it was necessary to rely on the operator's skill in reaching the best combinations of settings. Ideally, comparison of machine performances should be carried out by a large number of tests the results of which could be subjected to statistical analysis. However, it was possible to gain a more limited assessment of relative performance without incurring the expense of a long test programme. Within the limited number of tests carried out, the 'best' and 'worst' results obtained for quartz/riebeckite separations have been reported, while single test results have been reported for the shaking table and for the carbonatite/pyrochlore separations; these were all 'best' results. An indication of the operator's consistency may be seen from the cumulative grade/recovery plots. The best results obtainable for a fairly uniform mixture, containing only one mineral to be recovered, follow a smooth function. Should the operator have failed to produce the best obtainable concentrate at any time the resultant point on the plot would fall nearer to the origin than indicated by the form of the function. One example of such failure may be seen in Fig. 10 for a pulsepanner test. In general the points followed fairly smooth functions and the consistency of the operator may be accepted.

Obviously the best result which could be attained is 100 per cent recovery at 100 per cent grade and this would be represented by a rectangular plot, parallel to the axes and changing slope at the point (100, 100). Performance inferior to this ultimate of efficiency is indicated by some function, generally convex in character, which may be judged by its slopes and the proximity of its nearest point to (100, 100). The relative positions of the curves indicate that, for the quartz/riebeckite separations, the general order of concentrator efficiency was: pulsepanner, macropanner, superpanner, laboratory shaking table. The pulsepanner clearly gave much more effective separations than the other machines. The macropanner showed some superiority over the superpanner, its worst test result being equivalent to the best given by the superpanner. The shaking table's performance was similar to the superpanner's worst. This trend is repeated in the results for the carbonatite/pyrochlore separations. The slight tendency for decrease in cumulative pyrochlore concentrate grade at low recoveries is probably due to the error involved in the assumption that all the pyrite in the ore was of theoretical composition.

CONCLUSIONS

The analysis of longitudinal motions of concentrator decks followed by comparative performance tests has shown that some improvement in panner performance could be effected by the use of the ideal design motion. The laboratory shaking table was not found to be as efficient a concentrator of the materials tested as either the superpanner or macropanner, although it conformed closely with the ideal table design motion.

The introduction of the pulsed deck principle into panner design, however, resulted in a great improvement in performance. As a result of this, development work is now being carried out on continuous plant-scale pulsed deck concentrators, which, if the promise of the reported test work is fulfilled, should play a useful part in the commercial recovery of minerals.

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DISCUSSIONS AND CONTRIBUTIONS

Solubility of Lead in Molten Silicates

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Report of discussion at February, 1962, General Meeting (Chairman: Mr. A. R. O. Williams, President). Paper published in January, 1962, pp. 201–14

Professor F. D. Richardson introduced the paper briefly, illustrating his remarks with slides.

Mr. P. A. Wright said that the authors' experimental technique was so well established and so simple that it would be dangerous to challenge it; further, the authors had given a good account of their likely errors and had not strained the results to the limits of accuracy in order to make them fit the model they presented. Having discussed their results they gave a simple method to predict the solubilities of other metals and in that connection he would like to make sure that FeO should be regarded as the equivalent of CaO in the slag.

As he understood it, lead was more soluble in the slag than would be expected on the simple model presented. The authors had stated that the lead must be present as separate atoms, but was it not possible that in the environment of the silicate network some measure of ionization of the Pb atom could take place, since there was ample opportunity for the spreading out of the charge?

The speaker said he would like to know the effect of van der Waals forces. Could they now be computed? He did not know whether that could affect the entropy of solution.

Dr. J. Lumsden* said that the point that puzzled him particularly was the very large value of the entropy of solution of the lead. The work of Blander and others on argon, to which the authors had referred, had given what seemed a reasonable result and Professor Richardson's previous work with copper had also given a reasonable entropy of solution; it seemed, however, that the partial entropy of the lead was larger than that of lead vapour. Since, obviously, the lead atom itself could not have a location randomness larger than in a vapour, it apparently meant that in some very large volume around each lead atom there must have been a tremendous loosening of the silicate bonds, which completely spoiled the analogy with the copper and the inert gases in a salt melt. That led him to wonder whether there was any possible doubt in the interpretation of the results and he would like to ask Professor Richardson exactly what he thought the oxygen potential was. The authors had said (p. 207) that 'the fact that

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