CENTRIFUGAL MACHINES

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Introduction.

Those of us who have had the opportunity to compare the performance of electrically and water-driven 30 × 18 ins. centrifugals, both curing the same C massecuite, will have observed that the capacity of the electrical ones was at least 50 per cent. more than that of the water-driven centrifugals. Since we knew that the electrically-driven 30 ins. baskets run at 1460 r.p.m. and the water-driven ones at only 1100-1200 r.p.m. (dependent on the available water pressure at any given moment), the difference in the capacity of the two was understandable. When, however, we had to compare baskets of different dimensions running at different speeds, the question became more intricate. Nowadays, tables showing the gravity factors adjusted to speed and diameter of the baskets obviate the calculations we had to do in the old days when we wanted to compare baskets of different diameters running at different speeds. Moreover, referring to the gravity factor gives us a better insight into the question, since the gravity factor indicates:

(*a*) the centrifugal force in pounds, exerted on one pound in weight when placed at the circumference of the spinning basket; or

(*b*) how many times the centrifugal force at the circumference of the basket is greater than the force of gravity.

The gravity factor can be calculated by the formula:

GRAVITY FACTOR =

$$14.2 \text{ (Basket diam. in ins.)} \times (\text{r.p.m.}/1000)^2.$$

Note.—A table adjusting the gravity factors according to diameters and speeds (r.p.m.) of the baskets is shown in the appendix.

The range of gravity or "g" factors used in different industries is considerable, depending on the material handled. For example, when dealing with large sulphate of ammonia crystals a factor of no more than 80 gives satisfactory dryness; in the sugar industry, however, factors ranging from 400 to 2000 are used.

In the table shown in the appendix those factors which are underlined refer to the conventional belt and water-driven centrifugals with basket diameters of 30, 36 and 42 ins. The table shows that the lowest factor is attained by the 42 ins. basket running at 850 r.p.m., and the highest by the 30 ins. basket running at 1200 r.p.m. However, the electrically driven 30 ins. basket also belongs in the "old-fashioned" category as well as the 42 ins. basket running at 960 r.p.m. when driven by a six-pole AC motor. The centrifugal force of the 30 ins. E.D. basket running at 1460 r.p.m. is 908 times "g" or 50 per cent. more than that of the other ordinary or standard centrifugals. Since 908 times "g" is the highest value attained by conventional centrifugals we will call all centrifugals exerting higher gravity factors than 1000 "*High Gravity Factor Centrifugals*" and all centrifugals exerting centrifugal forces between 500 and 1000 times "g" "*Medium Gravity Factor Centrifugals.*" This means that all conventional centrifugals are to be classed as medium gravity factor centrifugals, with the exception of the 42 ins. basket when running less than 915 r.p.m. A 42 ins. basket running 800, 850 or even 900 r.p.m. exerting less than 500 times "g" is to be classed as a low gravity factor centrifugal. We give special stress to this question because in Natal belt or water-driven 42 ins. baskets are often used to cure C massecuites, while 30 ins. baskets exerting higher centrifugal force are confined to the lighter jobs.

It will be noticed that the popular name "high speed centrifugals" as a descriptive noun for both kinds of modern centrifugals has not been used up to the present. To be frank it has been purposely avoided because the use of this word has led to much misunderstanding. To prevent confusion it is recommended that the words "*High Duty Centrifugals*" be used to describe machines whose chief characteristic is the great number of cycles performed per hour; and to use the name "*High Gravity Factor Centrifugals*" when the main characteristic is the high centrifugal force exerted at full speed.

When ordering conventional types of centrifugals the choice between the different types of centrifugal was relatively easy. When electrically driven units were considered and the supply was 50-cycle AC, only two basket sizes came into consideration, viz. the 30 ins. and the 42 ins. basket; the former running 1460 r.p.m. for low grade, the latter running 960 r.p.m. for high grade sugars. When 36 ins. baskets were preferred a frequency changer, increasing the number of cycles from 50 to 57½ per second, was required in order that the 36 ins. baskets should run at 1100 r.p.m. (619 times "g"). When water or belt-driven conventional machines were considered, much the same can be said as has been said about electrically-driven centrifugals.

With modern centrifugals, however, besides having to choose between four types of drive, we have also to consider such requirements as acceleration rate, top speed, charging speed, etc. It is this question, i.e. the specifications in the case of modern centrifugals, that we want to discuss.

Operating Conditions of Modern Centrifugal Machines.

The operations of modern centrifugal machines are characterized by three speeds:

(*a*) the spinning speed;
(*b*) the charging speed;
(*c*) the discharging speed.

The spinning speed is dictated by the rated speed of the motor in the case of individual electrical drive; by the water pressure and the diameter of the Pelton drive in the case of water-driven centrifugals, etc. To obtain the two other speeds, viz. the charging and discharging speeds, special measures have to be taken. For example, the speed of the basket must be prevented from exceeding the speed limit of 60 r.p.m. when discharging so that the operator handling the mechanical plough will run no risk. During the charging period the basket speed must be kept between certain limits to assure the building-up of a sugar cake of uniform thickness; these limits range from 75–150 r.p.m., for easily purging massecuites, to 250-350 r.p.m. for less easily purging ones.

In regard to the discharging speed: a positive discharging speed can be obtained with direct coupled motors by connecting them to a low frequency supply. For example, a eight-pole motor connected to a 5-cycle/sec. AC supply (with a corresponding reduced voltage) will turn the basket when idling at a speed of about 70 r.p.m. which speed will slow down to 50–60 r.p.m. when the plough starts cutting into the sugar cake. It is obvious that centrifugals with different numbers of poles require different frequency changers; consequently a battery of machines with two-speed motors of 725/1460 r.p.m. demands a frequency changer different from that required by motors with a speed range of 465/960 r.p.m.

In the case of water-driven centrifugals a positive discharging speed can be arranged by means of an auxiliary shaft to which the basket spindle is coupled during ploughing operations.

In the case of fluid clutch drive combined with torque control the latter prevents a too high torque when the nose of the plough digs too deep into the sugar cake.

With the new Fluid Duplex Drive Coupling (an English patent) which can operate alternately to provide an acceleration and a deceleration torque, the torque can be manually or automatically controlled when ploughing.

With the "Turntork" arrangement small auxiliary electric motors can be connected by means of a clutch and V-belt drive to the basket spindles achieving positive discharging speed (in reverse with respect to the spinning rotation) in the case of electrically, water, belt and gear-driven centrifugals.

Finally, ploughing speed can also be maintained by inching; inching being necessary in all those cases where no special measures are taken to provide a special ploughing speed or a limited ploughing torque.

Returning to the demand of a limited speed range for charging, before the Second World War a Continental firm manufacturing centrifugals driven by pole-changing motors allowing basket speed of about 290 (or 320) r.p.m. during charging and speeds of 1460 (or 960) r.p.m. during spinning. Since a motor connected to a 50-cycle supply requires 20 (or 18) poles in order to run at 290 (or 320) r.p.m. the motor concerned was of too complicated a design for its capacity. Moreover, a pole-changing motor with a speed ratio of 1 : 5 (or 1 : 3) requires more energy when accelerating than one with the more common ratio of 1 : 2 and the regenerative braking is less effective too than in the case of 1 : 2 ratio motor.

Note.—For effective super-synchronous braking from full speed to slow speed, full speed may not exceed twice the speed at low speed windings.

With variable speed motors with sufficiently wide ranges of speeds—which for example can be accomplished with Schrage type motors—it is possible to maintain a positive charging speed, just as in the case mentioned where two-speed motors are wound for 290 (or 320) and 1460 (or 960) r.p.m. The charging is, however, usually performed during the acceleration period when the correct moment to open the feed valve is based on the estimated basket speed by visual observation. When badly timed, when the feed valve is clogged or when the massecuite flow is retarded due to too low a level of massecuite in the mixer, the machine has to be coasted to prevent it from exceeding the proper charging speed. It is obvious that coasting will be more frequently necessary the less attentive the operators are, and the higher the rate of acceleration is. Since coasting puts a severe strain on the switches it must be prevented as much as possible.

At the end of the spinning period the machines must be rapidly decelerated and even where conventional types of centrifugals with straight mechanical braking are concerned, brake linings are subject to great wear, and will contaminate the sugar charge and machine by the dust developed. Moreover, the brake linings have to be renewed rather frequently, causing service interruptions as well as expenses. With modern, heavy duty and high gravity factor machines the strain put on the brakes is far more severe, and though it is conceivable to adhere to straight mechanical braking by using amply dimensioned and water-cooled brake linings the application of electrical braking avoids the drawbacks mentioned. Moreover, when electrical braking is performed by means of super-synchronous braking, part of the kinetic energy stored in the rotating parts will be restored to the AC supply.

The above serves only to provide an insight into the range of operating conditions of modern sugar centrifugals. We will continue by saying something about the required top speed and acceleration rate when handling different massecuites.

The top speed or the gravity factor should not be greater than is necessary to obtain the required result in the most economical manner, because, with higher gravity factors (*a*) initial capital expenditure is greater, (*b*) maintenance is more expensive and (*c*) energy requirements are greater. Since fine-grained massecuites of low purity demand a high centrifugal force for the proper separation of the mother liquor from the crystals, it is the C massecuite which requires in the first place high gravity factor centrifugals and more particularly the foreworkers of the C massecuite. On the other hand less finely grained massecuites and higher purity massecuites which purge more easily, for example A massecuites, do not demand high gravity factor centrifugals, but high duty centrifugals. High duty machines are machines capable of performing a high number of cycles per hour—for example 20 or even 25 and more cycles per hour. A high acceleration rate is essential for such high duty machines in order to reduce the time required for a cycle. However, to obtain a high top speed combined with a short cycle is most difficult, since such a combination demands very powerful electric motors which produce excessive power surges when starting.

The high acceleration rate inherent in the short cycle machines is beneficial for the curing process of A massecuites as well, because the mother liquor will leave the massecuite before the temperature has dropped and before the sugar layer has dried out by the fanning action of the spinning basket. When the machines accelerate slowly, the molasses coating around the crystals cools down and dries out, before the centrifugal force is high enough to spin it off; and in addition the increased viscosity of the coating will result in difficulty in washing of the sugar crystals.

Since (well boiled) A massecuites are easily purged, heavy duty machines with short cycles, high acceleration and medium gravity factor are particularly suited for handling A massecuites.

In the above we have discussed some of the specifications concerning centrifugals purging A and C massecuites. There are, however, more specifications, since there are more massecuites than only those two mentioned. Very enlightening in this respect is the article published by P. F. Grove, Chief Electrical Engineer of Messrs. John Miles & Partners (London) summarizing an investigation on behalf of Messrs. Tate & Lyle Ltd. of London. This investigation was made to determine the most suitable kind of electric motor for driving sugar centrifugals for a complete range of processes such as would be required for modernization of Plaiston Wharf Refinery (Int. Sug. Journ., vol. 51; 1949; 247). In a scheme which we reproduce below the different and varying requirements demanded for the handling of each type of massecuite encountered in a refinery are specified. It concerns 58 centrifugals of 40 × 24 ins. required to handle the massecuites of a refinery melting 84 short tons of raw sugar per hour.

Sugar Centrifugal Data—For a Melt of 75 Long Tons Per Hour

	White	Affination	1st Crop	2nd Crop	3rd Crop
Number of machines	15	24	5	4	10
Wall thickness (inches)	6	6	6	6	4
Weight of dried sugar (lb.)	490	490	500	500	425
Full speed (revs. per min.)	1250	1250	1500	1500	1700
Gravity factor	888	888	1278	1278	1642
Charging speed (revs. per min.)	75–150	100–250	100–400	100–400	Standing Charge
Ploughing speed (revs. per min.)	0–75	0–75	0–75	0–75	0–75
Cycle time (secs.):					
Charging	4	10	15	20	30
Accelerating	34–40	35–50	50–100	60–180	60–180
Spinning	0–90	60–270	0–240	30–720	240–1360
Decelerating	30	30	40	40	50
Ploughing...	20	20	20	40	60–120
Possible limits of cycle time (min.)	1½–3	2½–6	3–6	5–15	10–25

We want to draw attention in particular to the difference in specifications concerning the charging operations of the white and of the other massecuites. The White centrifugals are charged by lower speeds than the Affination or the first and second crop centrifugals to prevent the sugar cake from piling up at the lower end of the basket. To build up a cake of approximately uniform thickness at the top and at the bottom, it is essential that the basket be run very slowly (at 75–150 r.p.m.) when charging with easily purging massecuites such as refinery white massecuites. The acceleration time of the white centrifugals is, moreover, the shortest of all (35–40 sec.), in order not only to attain a short cycle but also to prevent cooling off and drying out of the sugar cake during acceleration. Both requirements, *viz.* slow charging speed and high acceleration rate are essential for efficient washing operations for a type of massecuite such as the refinery white massecuite.

Not only is a slow acceleration rate (acceleration is from one to three minutes in accordance with the prevailing circumstances) prescribed for the C massecuite but also a standing charge, in accordance with the above scheme. A slow acceleration, however, is not only confined to refinery low grade practice; it is as essential for proper purging of C massecuites of sugar factories as well. In the case of C massecuite foreworkers (in addition to slow acceleration) it is recommended that after charging the baskets be run first for some minutes at half speed, before changing over to full speed in order to spin off the bulk of the molasses before the sugar cake packs too tightly. However, such an additional procedure is only possible in the case of two-speed and variable-speed motors.

The Different Means of Driving Sugar Centrifugals.

Since it is the drive which has to fulfil all speed and acceleration requirements (and often the deceleration requirements as well), the different means of driving will be discussed first:
The centrifugals can be driven—

(*a*) by belts and pulleys from a mutual shaft (belt-driven centrifugals);
(*b*) by bevel gears and clutches from a mutual shaft running over the top of the centrifugals (gear-driven centrifugals);
(*c*) by Pelton turbines driven by water under pressure (water-driven centrifugals);
(*d*) by individual electric motors (electrically-driven centrifugals).

While there are probably still more belt and water-driven centrifugals than electrically-driven machines in the world's sugar industry, most modern installations have a direct electric drive. We will therefore particularly consider (*d*).

Electrically-driven centrifugals can be sub-divided into two categories: (i) according to the way in which the motor torque is transmitted to the basket; and (ii) according to the type of motor used.

(i) Electrically-driven Centrifuges, subdivided according to torque transmission.

Firstly, the simplest way of transmitting the torque is by using the basket spindle as rotor shaft; or by having the rotor shaft connected to the basket spindle by means of a flexible coupling.

Secondly, a system which has become obsolete, is the transmission of the torque by means of friction exerted when hard wooden blocks or strips of belting are pressed by centrifugal force against the inside surface of a drum which is fastened to the basket spindle. In this instance the motor reaches full speed one to two seconds after starting and gradually spins the basket with it.

Thirdly, the motor torque can be transmitted by means of a fluid clutch drive. In this case the motor does not stop for every charge, but is always running at full speed; the coupling between motor and basket being made by filling the fluid clutch with, or emptying it of oil. Recently an English-patented Duplex fluid clutch drive came onto the market. This drive can also provide a reverse torque for deceleration.

(ii) Depending on the type of motor used the following distinctions can be made.

Firstly, the ordinary DC motor which, however, has become obsolete because direct current motors are not adapted to use in a sugar factory.

Secondly, the slipring AC motor which was rather popular with some Continental firms as a centrifugal drive before the introduction of the modern centrifugals but which has at present nearly completely lost its place to the squirrel cage motor.

Thirdly, the squirrel cage motor, the simplicity and mechanical robustness of which gives it an advantage over any slipring, commutator or DC motor for sugar factory conditions. By using a two-speed, rather than a single-speed, winding, the losses inherent in squirrel cage motors are halved, and braking from full to half speed can be done electrically with some recovery of energy and a reduction of wear on the mechanical brakes. (Mechanical braking from full speed to rest gives the brake the duty of braking *four* times more than braking from half speed to rest.)

Fourthly, the AC commutator motor; the rotor-fed as well as the stator-fed—the rotor-fed (brush shift or Schrage type) which has more advantages for centrifugal drive.

Fifthly, the DC motor in combination with the Ward-Leonard system and with the Constant Current system.

A development to be watched is the application of AC commutator motors to centrifugal drives, since this materially reduces the energy consumption. In the report of the investigation quoted earlier in this paper it was the Schrage type AC commutator motor which was finally recommended because it shows the lowest overall energy consumption. With the exception of the two-speed squirrel cage motor the Schrage type motor also shows the lowest price, since it does not require convertors as do the Ward-Leonard and Constant Current systems. Neither does it require frequency changers for ploughing operations as do the stator-fed AC and the squirrel cage motors. Last but not least the Schrage type motor would enable Tate & Lyle Ltd. to change to one type of centrifugal motor since 58 identical Schrage type motors can meet all the varying requirements of the different types of massecuites to be handled.

While AC commutator motors may eventually prove themselves preferable for special occasions, squirrel cage motors will probably continue to be standard driving units for some years, and more particularly changing-pole squirrel cage motors with 1 : 2 speed ratio.

To bear out the reasons for the preference of the two-speed motor over (*a*) the single-speed motor (*b*) the belt-driven, (*c*) the gear-driven, and (*d*) the water-driven centrifugals, we have to go back to the energy requirements for accelerating and decelerating centrifugals.

Let us assume that a centrifugal basket is connected to a steam engine in such a way that both start accelerating simultaneously and equally, and that we neglect all energy losses due to friction. Only in such a case as this is the energy required to accelerate the basket from rest to "n" revolutions per minute equal to the kinetic energy "Z" stored in the rotating basket at the end of the acceleration period.

If, however, the engine is already running at "n" revolutions, and the basket is subsequently connected to the engine by means of a clutch so that the engine gradually spins the basket to its own speed "2Z" will be required to accelerate the basket, since "1Z" in excess will be converted into heat.

The second example represents the case when baskets are (*a*) belt-driven, (*b*) gear-driven, (*c*) water-driven, (*d*) driven by direct-coupled single-speed motors, or (*e*) driven by single-speed motors by means of fluid drive or mechanical clutch. In each of these methods of driving the basket, "2Z" is required, to store "1Z" in the form of the kinetic energy of the basket, and the "1Z" which is in excess will be dissipated in the form of heat in the transmission. This is the reason why modern centrifugals have water-cooled belt pulleys; and why the oil used in the clutch of fluid drive centrifugals has to be water-cooled. In the case of directly coupled single-speed motors "1Z" will be converted into heat in the rotors, or in the case of slipring motors into heat in the separate, external resistances. In the case of water-driven centrifugals the "1Z" in excess will cause the temperature of the water used to rise. In this connection all cases mentioned show the same efficiency, viz. they all require "2Z" to gain "1Z" in the form of kinetic energy; the "1Z" in excess being converted into heat (and wear).

A centrifugal driven by a two-speed motor, however, requires only "1½Z" when accelerating in the proper manner, viz. at first connected to the half-speed winding accelerating to half speed; and secondly from half to full speed with the aid of the full speed winding. In this case "½Z" only will be wasted by conversion into heat in the rotor. (See Appendix III.)

Not only during the acceleration period does the two-speed motor show a lower energy consumption, but also by means of *super-synchronous regenerative* braking, part of the kinetic energy can be regained during the braking period. In contrast single-speed motors, belt-driven, water-driven and gear-driven centrifugals lose the whole kinetic energy as it dissipates in the form of heat (and wear) of the brake linings, which consequently have to be water-cooled and of ample dimensions.

This is not the case when electrical braking can be applied. It is now intended to discuss this. There are three distinct ways in which electrical braking can be put to use in the case of squirrel cage motors:

(*a*) DC braking;
(*b*) plugging (or braking by reversal of the current); and
(*c*) regenerative braking under super-synchronous conditions.

In the case of DC braking, one phase of the stator winding is fed from a DC supply, thus creating a stationary field which sets up current in the rotor circuit until all kinetic energy has been converted into heat in the rotor.

In the case of plugging, the direction of the rotating field of the stator is reversed to obtain the braking effect; the braking period being of the same duration as the starting period. Since the heat developed in the rotor during braking will be three times as great as that developed during starting, braking by current reversal can only be used in the case of slipring motors, because these motors have separate, external rotor resistances.

Where super-sychronous, regenerative braking with pole-changing motors, having pole numbers in the ratio 1 : 2, is concerned, the full speed running motor is suddenly changed over from the low-pole to the high-pole winding and thus braked electrically to half speed. The direction of the rotating field, however, is not reversed. When the ohmic losses are neglected, one half of the kinetic energy "Z" is recovered in this way; one-quarter of "Z" is dissipated as heat in the rotor and one-quarter of "Z" is still available at the end of the regenerative braking period since the centrifugal is still running at half speed.

Braking from half speed to rest can now be accomplished (*a*) by DC injection, (*b*) by connecting the high-pole winding to the low frequency supply for ploughing, or (*c*) by straight mechanical braking.

In the case of the Duplex fluid coupling of English make, which has already been mentioned, the Duplex can also be used for braking, since it embodies two separate oil circuits; one for acceleration and the other for deceleration. The electric or hydraulic motor (after it has been started) can be kept running at full speed all the time the battery of centrifugals is operating, just as in the case of the "fluid drive clutch" of American origin. The acceleration and the braking each occur within a fixed time predetermined by the designs of the acceleration and the deceleration circuits of the Duplex respectively. When the scoop controlling the flow of oil to the acceleration circuit is moved to the three-quarter "in" position, a ploughing torque of about 150 lbs. ft. is developed at a speed of 50–70 r.p.m. By operating a diverting valve the braking circuit can be filled with oil and a braking torque will be exerted by the Duplex. When braking from full speed to rest the entire kinetic energy "Z" will be converted into heat in the oil. In addition to this, energy has to be supplied to the motor driving the Duplex in order to create a contra torque for the braking. However, wear of brake linings is completely eliminated.

When accelerating by means of a fluid drive most of the energy wasted ("1Z") will be used in raising the temperature of the oil of the fluid drive, but part will be converted into heat in the rotor of the motor.

Basket Dimensions.

The conventional machines used to have baskets of the following sizes: 30 × 18 ins.; 36 × 18 ins.; 42 × 20 ins. and 42 × 24 ins.; (48 × 24 ins. baskets were used occasionally). The modern machines have predominantly 42 × 24 ins. baskets.

America, however, has always specialized in 40 ins. diameter baskets and also adheres to them in the case of modern machines. Recently, however, an automatic batch type centrifugal has arrived on the market with a 48 ins. diameter basket.

Since a motor connected to a 60-cycle AC supply will run 1.20 times faster than a motor with the same number of poles connected to a 50-cycle AC supply, American centrifugals will exert 1.2^2 or 1.44 times the centrifugal force with baskets of the same diameter as the European centrifugals. Although the American baskets are only 40 ins. instead of 42 ins. the gravity factor will still be 1.37 times greater. Even should the European manufacturers change to 48 ins. diameter baskets, the American 40 ins. baskets driven by 60-cycle AC supply would still be in the lead as the following scheme shows:

Gravity factors	40 ins. basket	42 ins. basket	48 ins. basket
Four-pole motor:			
60-cycle AC supply	1745	—	—
50-cycle AC supply	—	1273	1453
Six-pole motor:			
60-cycle AC supply	753	—	—
50-cycle AC supply	—	550	628

We see from this how the 50-cycle AC supply is really a handicap when higher gravity factors are demanded and the gravity factors of our 42 ins. machines running 1460 and 960 r.p.m. are both fairly low for the work for which they are used. The C massecuite machine would be better if it could exert a centrifugal force higher than 1273 times "g." The same can be said about our A massecuite machine which exerts only 550 times "g." Changing over to 48 ins. machines would split in half the difference in "g" factor. Bigger baskets, however, have a lower payload than smaller baskets. In a paper read at the Third Technical Conference of the British Sugar Corporation Limited (1950), J. Broadbent showed that the stored kinetic energy in a 40 ins. basket exerting 885 times "g" is 1,255 lbs. ft. per pound of sugar against 1,690 lbs. ft. in the case of a 48 ins. basket exerting the same "g." The kinetic energies per pound of sugar in these cases are therefore approximately in the proportion of 3 to 4.

If we should want higher gravity factors than those which can be obtained by the rated speeds of our motors, in my personal opinion the best thing to do is to step up the frequency just as is done in the case of electrically-driven 36 ins. baskets where the frequency is stepped up to 57½ to obtain the required "g." The same motors could even be used when only the voltage of the supply is stepped up in proportion to the step-up in frequency.

A table is added as an appendix showing the volume and the weight of massecuite with which differently dimensioned baskets can be charged. It is adjusted for the apparent thickness of the layer of massecuite. The term "apparent thickness" is used here, because owing to the fact that immediately a basket is charged with massecuite part of the mother liquor is expelled. It is thus possible to charge a basket with a rim or lip width of only 6 ins., with a layer of massecuite of "apparent thickness" of 7 ins.

Since it is routine in come countries to refer to the centrifugal capacities as square feet screen area per ton of cane crushed per hour, the number of square feet screen area of the different baskets is shown as well.

Power Factor and Electrically-Driven Centrifugals.

During the period of acceleration the motors of electrically-driven centrifugals are fully loaded and consequently their power factors will be high, i.e. in the neighbourhood of 0.9. During the time the baskets are running at full speed, however, the motors are only opposed by the friction torque of the centrifugals, which incidentally is chiefly composed of the resistance of the basket to air, and since the load at that time is only a fraction of the full load the power factor drops to 0.5 or lower. It is a fact that at the end of the acceleration period the power *consumption* drops to an even greater extent than the power *factor* does, but the influence of these low individual power factors will still be noticeable at the AC supply.

In this connection it can be mentioned that automatic coasting of the machines immediately when they have achieved their top speed or some minutes before the brakes will be applied, will reduce the influence of the low power factors originating from partly-loaded motors.

When the necessity to improve the low power factor resulting from the centrifugal motors becomes imperative (as a low power factor reduces the working capacity of the generating plant and mains, and lowers the efficiency of the system) nowadays static condensors or capacitors assigned to each individual centrifugal motor are installed to improve the power factor on the spot. Static condensors afford one of the simplest and most efficient solutions of the problem indeed, as they require no attendance and cause very little loss of energy. Moreover, as these condensors counteract the wattless currents at the spots where they originate, they not only improve the power factor at the generator, but also in the mains, thus reducing the losses due to wattless currents running through the mains at the same time.

Static condensors are therefore to be preferred to special synchronous motors when improving the power factor is concerned. The leading current generated by over-excitation of a synchronous motor is nearly always generated at a place located far from the spot where the low power factor originates; consequently the losses in the mains will not be reduced by synchronous motors.

Continuously-Operating Centrifugal Machines

The centrifugal machine was introduced into the sugar industry more than a century ago and since then its design has been continually improved. It is at present a highly efficient machine, even capable of performing automatically all required functions except charging. However, it still works in batches as it did a hundred years ago, and not continuously.

In the chemical industry continuously operating centrifugals have proved their merits for more than twenty years; the introduction of a continuous centrifugal into the sugar industry, however, was delayed till about three years ago due to the difficulties encountered by trying to make the continuous machine adaptable to sugar manufacturing conditions.

Advantages of continuously-operating centrifugals are: (*a*) saving of labour, (*b*) saving of maintenance costs, and (*c*) lower and more uniform power consumption than that of the batch centrifugals. It is these advantages which incited designers of centrifugal machines to try to design continuously-operating machines as early as fifty years ago.

The continuously-operating centrifugals can be divided into two categories, according to the means used to discharge the cured product from the baskets:

(i) continuous machines which discharge the cured product by means of a slowly rotating helice, or screw conveyor;

(ii) continuous machines which periodically push the cured product to the discharge side of the basket by means of a disc.

Both categories have a characteristic in common, in that the basket rotates on a horizontal axis. A horizontal position of the basket lends itself better to the operation of continuous discharge than does a vertical position, such as in the batch type centrifugal.

In the so-called push type machine a hydraulic pusher in the form of a fairly tightly fitting disc, periodically pushes the layer of product forward until it is expelled by centrifugal force at the discharge end.

It is the push type of continuous centrifugal suggested by Eckstein in 1908 that has been developed

GRAVITY FACTORS FOR CENTRIFUGAL MACHINES

Diameter of Basket	Number of Revolutions per Minute																
	800	850	900	**960***	1000	1050	1100	1150	1200	1250	1300	1350	1400	**1460***	1500	1600	1800	2000
30 ins.	—	—	345	393	426	470	*516*	*563*	**614‡**	*666*	*720*	*777*	*835*	**908†**	*959*	1091	1380	1704
36 ins.	—	369	414	471	*513*	**564‡**	*619*	*676*	*736*	*799*	*864*	*932*	1002	1090	1150	1309	1657	2045
40 ins.	364	410	460	*524*	*570*	*626*	*687*	*751*	*818*	*888*	*960*	1035	1113	1211	1278	1454	1841	2272
42 ins.	382	**431‡**	483	**550†**	*598*	*658*	*722*	*789*	*859*	*932*	1008	1087	1169	**1272†**	1342	1527	1933	2386
48 ins.	436	492	*552*	*628*	*684*	*751*	*825*	*902*	*982*	1065	1152	1242	1336	1453	1534	1745	—	—
	Low Gravity Factor Machines		Medium Gravity Factor Machines							High Gravity Factor Machines								

NOTES

* These speeds (960 and 1460 r.p.m.) are the rated speeds of induction motors equipped with six and four poles respectively when connected to a 50-cycle AC supply.

† These gravity factors (550, 908 and 1272) are the factors obtained at those rated speeds in the case of baskets of 30 and 42 ins. in diameter.

‡ These gravity factors (431, 564 and 614) are the factors generally obtained with water or belt-driven 30, 36 and 42 ins. baskets of conventional design, the 42 ins. basket having the lowest factor. In the case of electrically-driven machines the 30 ins. basket running 1460 r.p.m. attains a factor of 908 or 50 per cent. higher than that of the other machines; the 42 ins. E.D. improves to a factor of 550 when running 960 r.p.m.

In the case of high gravity factor machines the electrically-driven 42 ins. basket runs at 1460 r.p.m. and attains a centrifugal force of 1272 times "g."

by Escher Wyss into a practical, usable continuous machine for the chemical industry; since 1950 a machine has been developed which can be used for easily purging sugar massecuites and magmas.

The difficulty encountered in making the continuous machine adaptable for curing sugar factory products is the relatively high centrifugal force required. We have already mentioned that for drying ammonia sulphate crystals a gravity factor of 80 is sufficient; sugar factory products, however, require "g's" from 400 to 2000.

Let us assume a continuous centrifugal rotating at such a speed that the basket exerts a centrifugal force of 500 times "g" and let the basket wall be covered by a sugar layer of one inch in thickness. This one inch sugar layer will be pressed against the perforated plate covering the basket wall with a force such as would be exerted if 500 inches of sugar cake were resting upon it. Consequently the disc which has to push the sugar cake along the basket wall has to exert a force such as would be necessary if 500 inches or 42 feet of sugar cake were resting on the perforated covering. Moreover, the pusher has to move the sugar layer gently in order not to crush (too many) crystals. These were the difficulties resulting from the higher gravity factors required for curing sugar factory products, when it was attempted to extend continuous operation from the chemical industry to the sugar industry.

In the beet sugar factory and refinery in Aarberg in Switzerland there are now however two push-type machines designed by Escher Wyss, which cured the whole raw sugar crop of 1951-52. Aarberg has a daily output of 400 tons raws. The power consumption of these continuous centrifugals is only 1½–2½ h.p. hours per ton of sugar discharged, depending on the qualities of massecuites and sugar which are cured. One machine will cure 8–10 tons of B sugar per hour. At the end of 1952 an identical machine came into operation at the beet sugar factory Uelzen in Germany.

APPENDIX II

Volumes in Cu. ft. and Weights in Lbs. of Massecuites (weighing 90 lbs. per cu. ft.) Adjusted to the APPARENT Thickness of the Layer of Massecuite when Charging

Dimensions and Screen Area of the Basket		Apparent thickness of the massecuite layer when charging							
Ins. × Ins.	Sq. ft.	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	
30×18	11.78	1.83 165	2.65 240	3.40 300	4.09 370				Cu. ft. Lbs.
36×18	14.14	2.22 200	3.24 290	4.19 375	5.07 455				Cu. ft. Lbs.
40×20	17.45	2.76 250	4.04 360	5.24 470	6.36 570	7.42 670			Cu. ft. Lbs.
40×24	20.94	3.32 300	4.84 435	6.28 565	7.64 690	8.90 800			Cu. ft. Lbs.
42×20	18.33		4.25 385	5.53 500	6.73 600	7.85 700	8.91 800	9.90 890	Cu. ft Lbs.
42×24	21.99		5.10 460	6.63 600	8.07 725	9.42 850	10.69 960	11.85 1065	Cu. ft. Lbs.
48×24	25.13			7.68 690	9.38 840	11.00 1000	12.63 1140	13.96 1250	Cu. ft. Lbs.
48×30	31.41			9.60 865	11.73 1055	13.74 1235	15.79 1420	17.45 1570	Cu. ft. Lbs.

APPENDIX III

A.—Single-Speed Motors Accelerating and Decelerating

Diagrams I to IV included concern the acceleration and deceleration processes of a centrifugal driven by a single-speed electric motor. Diagram I concerns the energy consumption when a squirrel cage motor directly coupled to the basket spindle, accelerates. Diagram II depicts the same when a slipring motor accelerates. Diagram III represents the energy consumption when a single-speed squirrel cage motor accelerates; the motor transmitting its torque, however, by means of a centrifugal slip coupling. Diagram IV concerns the decelerating period of a single-speed motor.

Diagram I.—If it is assumed that the torque developed by the motor has a constant value which is independent of the speed, the basket speed of the centrifugal will increase linealy with the time. The power transmitted from the motor in a certain unit of time is proportionate to the torque and the speed (r.p.m.) during the given unit of time. Consequently the power also increases lineally with the time as indicated by the line AB in the diagram. The energy supplied to accelerate the mass of the basket during the entire starting process will be proportionate to the time and the power supplied per unit of time; thus it can be represented by the area of the triangle ABC which also represents "Z," the kinetic energy stored in the basket at the end of the period of time AC. Since the same quantity of energy will be converted into heat in the rotor the rectangle ADBC represents the entire quantity of energy to be supplied from outside, since the area of triangle ADB is equal to that of ABC.

Diagram II.—In this instance most of the excess energy (AEB) is transformed into heat in the slipring resistance (DEB), while part is converted into heat in the rotor (ADB).

Diagram III.—The rectangle ADBC represents the entire quantity of energy supplied to the motor during the acceleration time AC, of which the area of the triangle ABC depicts the quantity usefully consumed and the triangle ADB the quantity wasted. In this case, however, the wasted energy has to be divided into AEF, the energy converted into heat by slipping of the coupling, and EDBF—the heat in the rotor (in this instance F indicates the point where the coupling stops slipping and the basket continues accelerating—now stiffly coupled to the motor).

Diagram IV.—The content of triangle ABC again represents the stored kinetic energy "Z" in the basket; however, in this case AC indicates the deceleration time. Since the entire kinetic energy has to be dissipated by mechanical braking, ABC also depicts the energy converted into heat in the brake linings.

B.—Two-Speed Motor Accelerating and Decelerating

Diagram V concerns the accelration, and *Diagram VI* the ceceleration process of a centrifugal driven by a two-speed motor.

Diagram V.—In Diagram V ADEG represents the energy supplied in the time AG when the basket is accelerating from rest to half speed; AEG being the stored kinetic energy, and ADE the wasted energy which heated the rotor of the motor.

The rectangle GFBC represents the energy supplied in the time GC when the basket accelerates from half to full speed.

The area of ADEFBC indicates the entire energy supply; ABC again represents the kinetic energy "Z" of the basket at full speed and the area of the two triangles ADE and EFB depict the energy converted into heat in the rotor. The diagram shows that in this case the area of the blank quadrangle DHFE or "$\frac{1}{2}$Z" less energy has to be supplied than in the case of the single-speed motor.

Diagram VI.—When declerating from full to half-speed by super-synchronous braking the energy represented by the rectangle ADEF or "$\frac{1}{2}$Z" will be converted into electrical energy and returned to the AC supply, while DBE will be lost as heat in the rotor. When braking mechanically from half speed to rest EFC will be converted into heat in the brake linings. Since the latter quantity is only "$\frac{1}{4}$Z" the duty imposed on the brake linings will be only one quarter of that imposed in the case of mechanical braking from full speed to rest, which is equal to "1Z" according to Diagram IV.

Mr. Farquharson complimented Mr. Perk on his paper and said he agreed with most of what he had said but there were one or two points which he would like to amplify. He was glad to see that Mr. Perk had drawn attention to the difference between "High Duty" and "High Gravity Factor Centrifugals" and the desirability of charging the baskets at low speed, but he warned against charging at, or just below, the critical speed of the machine. In his experience, with native labour operating 2 speed AC motor driven machines, he found it impossible to get a consistent charging routine and, after a few days, he would find one basket being charged at a very low speed and another at half speed. Strange to say, there did not appear to be a great deal of difference in the final product.

He agreed with Mr. Perk regarding the severe strain put on the switchgear due to "coasting" and stated that for the same reason he was not in favour of "inching" as a means of obtaining a ploughing speed. With regard to brake wear, he thought it might be of interest to note that at

APPENDIX III

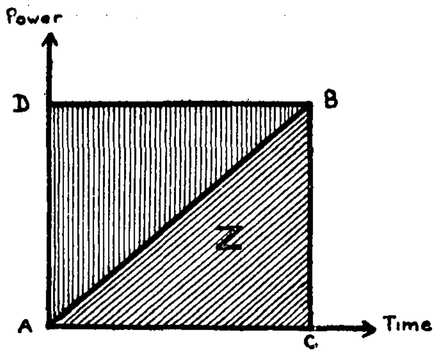

Diagram I

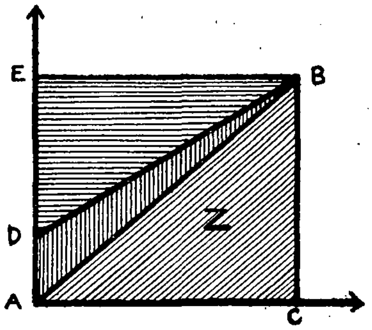

Diagram II

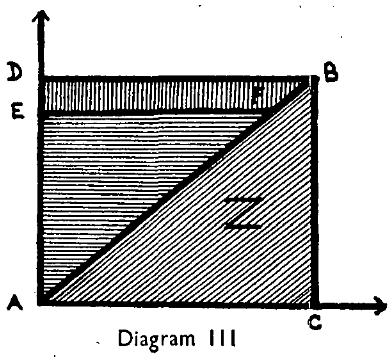

Diagram III

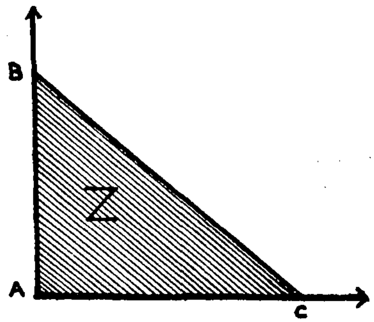

Diagram IV

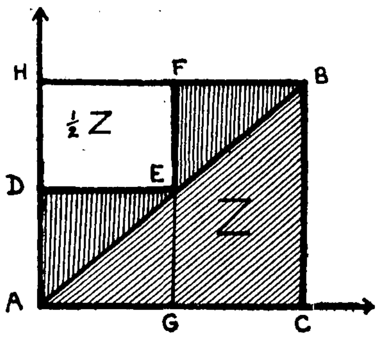

Diagram V

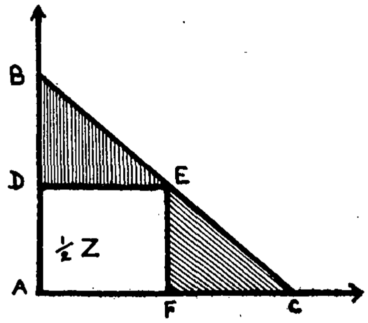

Diagram VI

Maidstone their 40 in. × 24 in. AC 2 speed 730/1460 r.p.m. centrifugals, installed in 1946, were still running with their original linings; and at Z.S.M. & P. six similar machines, but with constant current motors, had only required 4 linings altogether during the past 10 years.

He found the table of figures for a melt of 75 tons an hour most interesting, and thought it would prove very useful. Most centrifugal manufacturers endeavoured to submit accurate duty cycle times for their machines, but with the conditions peculiar to the Natal Sugar Belt this was most difficult. The massecuite varied from pan to pan and crystalliser to crystalliser. At Maidstone, for example, the extreme cases had been times when the C massecuite could be cured with a spinning time as short as 60 seconds, and when spinning for 25 minutes failed to cure it, a sticky substance rather like bird lime being formed on the inside of the sugar wall. With difficult massecuites, spinning at half speed for some time had helped, but the most successful results were obtained by charging the baskets to only half their capacity and running a normal cycle. Bad massecuites did not always plough clean and it was necessary to plough a second time or even run the machines empty and steam or wash the baskets every now and again to keep the screens clean. He did not think a higher "gravity factor" would be any benefit under these circumstances, and mentioned that Z.S.M. & P. had actually reduced the speed of their C massecuite foreworkers from 1800 r.p.m. to 1600 r.p.m., i.e. "g" from 1841 to 1454, some years ago. He explained that the spinning speed could be readily altered within specified limits on constant current machines, also the rate of acceleration on the later designs.

He was not happy about Mr. Perk's recommendation to step up the frequency to increase "g". The motors, he thought, would stand the higher electrical and mechanical loading, but what of the baskets and spindles? He doubted whether any centrifugal manufacturer would agree to running the centrifugals at higher speeds without some strengthening.

Referring to the different types of motor used, he thought a further sub-division into (*a*) fixed speed motors and (*b*) variable speed motors, might be helpful. Squirrel cage and slip ring motors came under (*a*), constant current and to some extent AC commutator motors under (*b*). Under (*a*) the operating speeds and acceleration were fixed by the design of the machine and could not be altered except by altering the frequency and voltage. The horse power required was large to cover the losses as shown in the diagrams, Appendix III, and the power supply must have ample current capacity to cope with the heavy demands when starting, bearing in mind that the current of a 2-speed motor during this period was approximately four times full load, otherwise the supply voltage would drop badly. He thought the power factor of 0.9 mentioned by Mr. Perk during acceleration rather high and felt that 0.6 would be more correct. The motors under (*b*) could be set to suit whatever working conditions were required and acted like the steam engine starting from rest, so that the total accelerating power required was "IZ". This was borne out in practice by the fact that the constant current motors at Z.S.M. & P. were only 60 h.p. as against the 2-speed AC motors at Maidstone which were 120 h.p. The baskets were identical and the duty cycle almost the same; further, owing to improved regeneration, the power demand from the supply was low and practically constant, so that the motor-generator set operated at high power factor continuously.

Regarding braking by plugging, Mr. Farquharson said he thought this method was obsolete. Apart from the great heat which had to be dissipated by the rotors or their resistances, there was not only no regeneration whatever but actually heavy power demands from the supply to stop the machines. It certainly was not a method that he would recommend.

Mr. Main expressed his interest in the subject and paid tribute to the work Mr. Perk had done.

Dr. Douwes Dekker asked whether he had understood correctly that the spinning time of certain C massecuites at Maidstone was only one minute.

Mr. Farquharson replied that the actual running time of spinning was one minute.

Dr. Douwes Dekker said that the aim of C strikes was to crystallise as much sucrose as possible, i.e. the purity of the final molasses should be as low as possible. To exhaust properly the molasses of C massecuite, it was necessary to concentrate the massecuite to a high density and unfortunately a high brix and a low purity inevitably meant a high viscosity of the final molasses. The plant, and in particular the centrifuges, should be capable of processing a C massecuite containing a final molasses of high viscosity and even with powerful centrifuges a spinning time of 10—15 minutes was not excessive. In Hawaii much longer spinning times were considered normal. The fact that it had been possible at Maidstone to spin C massecuites in one minute indicated that the viscosity of the final molasses had been low, for there was a linear proportionality between the time required to obtain a certain separation effect and the viscosity of the molasses of the cuite. A final molasses of such low viscosity could only mean that the molasses had not been properly exhausted. A spinning time of one minute could be achieved at any factory by raising the density and the purity of the molasses, but this did not prove that the factory was operating successfully.

Mr. Walsh said that Mr. Perk had done his best to present a paper which set forth many of the changes that had recently come into being. He could only wish, however, that Mr. Perk had summarised it or tried to give some recommendations. The centrifugal manufacturer was faced with a wide variety of conditions which varied from factory to factory and from country to country, and therefore could not design a standard machine applicable to all conditions. This was where difficulty was being experienced in developing high gravity factor machines. He hoped Mr. Perk would continue his present investigations and present recommendations which he thought would be of great advantage to manufacturers.

Mr. Rault said it would be very desirable to have a record of the present centrifugal practice of all South African factories. He felt sure that very few of them had enough machines and could afford the time to spin their third massecuite for as long as 15 minutes or over in the centrifugals, and the object of replacing the obsolete machines with high speed ones was to limit the curing time to between 4 and 6 minutes and use half the number of centrifugals to perform the same duty. He did not agree that very high viscosity and difficulty at curing the last grade was a desirable feature and a criterion of good boiling house work and low molasses loss, enforcing the use of a large number of centrifugals. A massecuite that did not purge its molasses completely in 5 minutes was a sign of a badly cooked one or a bad relationship of crystals to molasses and the triplicating of the number of machines for extracting barely the last 10 per cent of the molasses still left uncured did not seem to be an economical solution of the problem of increased recovery and low molasses loss.

In the examples quoted by Mr. Perk on the result of South African factory work for 1952, he would prefer to cure a last massecuite yielding 40 per cent crystal, throwing out a molasses of 39 purity, rather than a massecuite of lower purity with only 35 per cent crystal and the same molasses purity. The high yielding massecuite would give a cleaner brown sugar, more easily washed to the high polarisation of a Grade 2, or a refinery raw, with less recirculation of viscous low molasses returned to process.

Mr. Perk, replying to the discussion, said in regard to the question of high duty and high gravity factor machines, that both were names commonly used in literature. The use of the name "high speed machines" for 42 ins. machines running 960 r.p.m., but performing 20 charges per hour could only create confusion, since the gravity force exerted by these machines was just the same as that exerted by the old-fashioned electrically driven 42 ins. machines which could only perform 8 to 10 charges per hour. To be correctly named, the former had to be called "high duty" and not "high speed" machines. Since it was not always mentioned where the high gravity factor machines started and the medium gravity factor machines end, an indication of the border line was necessary. In his paper he had assumed that all machines exerting a centrifugal force higher than the old-fashioned ones, the electrically driven 30 ins. machine included, were to be called high gravity factor machines, in this way choosing 1000 times "g" as the border line between high and medium gravity factor machines.

In regard to the Constant Current Drive, he referred to the original paper by Grove about the investigations made on behalf of Messrs. Tate & Lyle, the result of which investigations showed that the Constant Current Drive was advantageous only in cases of very short cycle, i.e. up to three minutes when compared with the Schrage type motor. The Constant Current DC system with the other DC system, the Ward Leonard system, belonged to the most expensive ones.

In reply to the opinion of Mr. Farquharson, that the speed of centrifugals could not be increased without change of construction, Mr. Perk said that with the consent of the manufacturers an increase of 10 per cent in r.p.m. had sometimes been allowed. In the case of 42 × 24 ins. E.D. machines the speed was increased from 960 to 1056 r.p.m., simultaneously raising the voltage by 10 per cent. Such an increase raised the gravity factor from 550 to 650 times "g". In general, manufacturers had also consented to increase the speed of the 30 × 18 ins. B.D. from 1200 to 1350 r.p.m. when requested.

In reply to Mr. Walsh, Mr. Perk suggested that the chart concerning performances of centrifugals shown in his paper was virtually the description provided by Tate & Lyle to the manufacturers with regard to the requisite characteristics of the 58 machines required. His paper on centrifugals was written for the purpose of drawing particular attention to the fact that when ordering machines a proper description of the required performance characteristics had to be given to the manufacturers.

In regard to the curing time for C massecuites, he said that the concentration and the purity of the C massecuites must be such that the C massecuite centrifugals were kept busy the whole day. Low grade centrifugals ought to be in operation 24 hours per day, and when they operated only 20 hours per day it implied that a lower purity of final molasses could be achieved with the available equipment. Conversely, the more C massecuite centrifugals were available, the lower the purity of the final molasses could be.

Mr. Dymond said he thought this was the first paper presented on centrifugal machines and he hoped that next year it would be possible to follow this up. He hoped within that time other engineers could provide papers which would carry forward what Mr. Perk was doing. He asked the meeting to accord a vote of thanks to Mr. Perk.