

# COMPARISON OF VARIOUS ELECTRICAL DRIVES SUITABLE FOR CANE-CRUSHING MILLS

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A number of electrical power systems applicable to Cane Crushing Mill Drives are discussed. Operational characteristics and economical comparisons are shown and commented upon.

The following electrical systems are dealt with:

- AC Slip Ring Motor
- AC Squirrel Cage Motor with Torque Converter
- AC Commutator Motor with Series Characteristic
- AC Commutator Motor with Shunt Characteristic
- DC System with Mercury Arc Rectifiers
- DC System with Silicon Rectifiers
- AC-DC Cascade System
- AC-DC-AC Cascade System
- DC Ward Leonard System

A schematic diagram, an efficiency speed diagram and a speed torque diagram for each system under discussion are shown at the end of this paper. All systems are designed for a speed range of 50-100 per cent.

## AC Slip Ring Motor

The speed of this motor can be easily varied. The stator windings are connected to the supply while the rotor winding leads are brought out to a variable resistor. Whenever this resistance is increased, the motor speed decreases proportionally. The reason for this is that the voltage drop across the resistors must be additionally generated within the rotor, requiring an increase of slip and consequently a decrease of speed.

As may be observed from Curve 1 of the speed-torque diagram, the torque behaviour of a slip ring motor with resistors short circuited, corresponds to that of a normal squirrel cage motor. On starting up, the torque is well above rated value and inclines steeply to a maximum, from where it drops to adapt itself to operational requirements. There is only a small fall of speed with increase in load when the resistors are short circuited. The greater the resistance of the rotor circuit, however, the more a variation of torque influences the variation of speed. In other words, small load variations cause considerable speed variations when the rotor resistance is large.

Curves 2, 3 and 4 show the speed torque behaviour at different resistor settings, curve 4 representing the characteristic with the greatest resistance.

When varying the speed of a slip ring motor under constant torque conditions by introducing resistance into the rotor circuit, the efficiency varies in proportion to the speed. The reason for this is that the power required remains practically constant at all speeds but is divided up between the power delivered to the motor shaft and the power used up in the resistances. Resistance speed regulation is very uneconomical and, therefore, limited in its application.

A slip ring motor can be reversed by merely interchanging two phases.

## AC Squirrel Cage Motor with Torque Converter

This method employs a squirrel cage motor which runs at constant speed and drives a torque converter. A torque converter operates according to the same principle as a fluid coupling. Fluid is forced into circular motion by the impeller (input), and the runner (output) accepts the imparted energy through the guide blading and converts it into torque. The fluid circulates in a closed circuit and there is no mechanical connection between the impeller, the runner or the guide blading.

Peak torque is developed at standstill (starting up) and decreases with increasing speed. The driven speed smoothly adapts itself to the load resistance (series characteristic). The driven machine could be stalled or even turned in the opposite direction without causing harm. Required torques and speeds are set by adjusting the angles of guide blading.

The speed torque diagram shows the torque behaviour at different guide blade angles. The required driving h.p. is practically constant at every angle of guide blades. This is the reason why inexpensive squirrel cage motors can be utilised.

The total efficiency is derived by multiplying the motor efficiency by the torque converter efficiency. This product is within 0.74—0.785 at full speed and 0.67 at half speed, depending upon the size of the drive.

As it is not possible to reverse the mill with this type of drive, a separate electric motor-operated reversing gear is required.

## AC Commutator Motor with Series Characteristic

The stator of this motor has a three phase winding as in normal induction motors. One side of the winding is connected to the supply (low or high tension), while the other side is connected to the commutator brushes through an intermediate transformer. This transformer is required in order to step down the voltage to a level suitable for the commutator. At the same time, it stabilises the speed behaviour and therefore improves on conditions at speed changes.

The speed of an AC commutator motor can be steplessly adjusted without losses by varying the brushes either manually or remotely by means of a servomotor. The commutator brushes are adjustable within a wide range thereby changing the phase position between stator and rotor currents and consequently the torque speed characteristic.

The speed torque diagram shows the behaviour at different brush positions. As may be observed, the

standstill or starting torque can be increased to a considerable extent by moving the brushes accordingly.

The efficiency (and power factor) is very good at full speed and at full load and decreases accordingly at partial load and with dropping speed.

AC commutator motors may be reversed by interchanging two phases and moving their brushgear to the alternative position.

**AC Commutator Motor with Shunt Characteristic**

This type of motor is either stator or rotor fed but both designs work on the same principle. In general, motors up to approximately 100 kw. are of the rotor fed type (Schrage) while larger ones are usually of the stator fed design.

A stator-fed motor can be connected to the high voltage supply. It also has better commutation properties especially within the synchronous speed range. Therefore this type of motor is preferred for most applications. The stator, which has a three phase winding as in normal induction motors, is connected to the supply. The rotor has a DC winding and its commutator brushes are connected to the mains through a variable transformer which adjusts the voltage and the phase position.

As the speed torque diagram shows, the motor has a shunt characteristic where an increase in load results in a small fall of speed only. By moving the brushes manually or automatically, the speed can be altered upwards or downwards as required, at constant torque conditions.

The outstanding feature of a variable speed commutator motor with shunt characteristic is the loss-free control. The losses are fed back into the supply mains through the commutator. Therefore, the efficiency remains nearly constant within a wide speed range.

The direction of rotation may be changed by interchanging two phases and moving the brushgear to the alternative position.

**DC-System with Mercury Arc Rectifiers**

The DC voltage supplied by mercury arc rectifiers can be continuously altered within a wide range by means of grid control. The speed of all motors connected is thereby varied (group control). In addition individual speed control is possible by means of field resistance adjustment. The speed torque characteristic of this system is similar to that of a Ward Leonard Set.

In order to calculate the total efficiency of a DC system with mercury arc rectifiers where power is drawn from an AC supply, the efficiencies of the transformer, rectifier and the motor must be multiplied together.

The efficiency is within 0.86 and 0.80 between full speed and half speed. A great disadvantage with grid control, however, is the unfavourable behaviour of the power factor of the supply side which drops

practically proportional from 0.92 at full speed to 0.50 at 50 per cent speed.

The DC motors of the system described can be reversed either by changing the polarity of the armatures or reversing the direction of current supply to the field windings. The latter mentioned procedure proves more practical as the field current is very small compared with the armature current and therefore can be controlled much easier.

**DC System with Silicon Rectifiers**

Within a certain range, one rectifier plant suffices to feed a group of motors. Beyond this, however, each motor requires a separate rectifier.

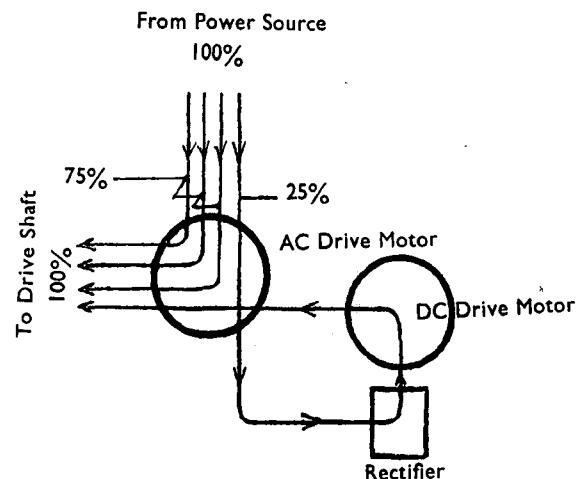
The DC voltage is altered by adjustment of the variable transformer, the size of which is defined by the voltage (speed) range required. Regarding speed alterations, torque speed characteristics and reversing, the same applies as for DC systems with grid-controlled mercury arc rectifiers described in the previous item.

The total efficiency is given by the product of the efficiencies of the transformers, the silicon rectifier and the motor. As may be observed, the total efficiency of the silicon rectifier system is better than the efficiency of a mercury arc system. In addition, the Power Factor remains approximately 0.9 throughout the speed range 50 per cent to 100 per cent.

**AC-DC Cascade System**

This system employing a Slip Ring Motor and DC motor, both driving one shaft, is also known as "Kraemer Cascade" or "Rectiflow Drive". The Slip Ring Motor is connected to the AC supply and its rectified rotor current feeds the DC motor. In the early stages, rectification was done by means of rotary converters; later mercury arc rectifiers were used but have now become almost universally replaced by silicon rectifiers.

The energy flow of the system is illustrated below:



**POWER FLOW OF AC-DC CASCADE**

At a slippage of 25 per cent the Slip Ring Motor runs at 75 per cent of its rated speed and consequently delivers 75 per cent of its load to the shaft. The remaining 25 per cent is delivered from the rotor through the rectifier to the DC motor where it is also put to work on the shaft. The AC-DC cascade is, therefore, a constant power drive within its speed range.

The efficiency of the AC-DC cascade is within 0.9 to 0.85 from full speed to 50% speed.

Reversal of direction is possible by altering the electrical connections of both the Slip Ring Motor and the DC Motor. A simpler method is to employ motor-operated reversing gear for this purpose.

#### AC-DC-AC Cascade System

This system is also known as "Scherbius Cascade" and is similar to the "Kraemer" AC-DC cascade, the difference being that the rotor energy is not mechanically but electrically recovered. The rotor current is rectified and feeds a DC motor which is coupled to an alternator. The power generated in the latter is then fed back into the supply main.

Speed is altered by adjusting the excitation of the DC motor. The torque is constant at all speeds so that the power is proportional to the speed.

The efficiency behaviour is similar to that of an AC-DC cascade. For reversal of direction, the same applies as for an AC-DC cascade although an electric motor-operated reversing gear is most practical in this case as well.

#### DC Ward Leonard System

The Ward Leonard System is very commonly used for applications where continuous variations of speed are desired on drives which are large enough to justify the expense. A DC drive motor with constant excitation is fed by a DC generator which is driven by an AC squirrel cage motor running at constant speed. The exciter for both the DC generator and the DC motor is also driven by the squirrel cage motor.

The voltage of the generator can be varied from a maximum in one direction through zero to a maximum in the other direction. As the excitation of the drive motor is constant, the speed varies in proportion to the voltage supplied by the generator. Therefore, the speed can be varied from a maximum in one direction through zero to a maximum in the other direction.

The efficiency of a Ward Leonard Set for about 500 Kw., which is made up of the efficiencies of all the components involved, is between 0.78 and 0.795 at a speed range of 50 per cent to 100 per cent.

#### Comparison of Torques

The torque characteristic of a drive is most important when judging its possible field of application. For some applications a shunt characteristic, where an increase of load only results in a small decrease of speed, is required. For other applications, a series characteristic where an increase of load results in a considerable speed drop, is preferable.

The torque behaviour of Slip Ring Motors with resistance regulation, squirrel cage motors with torque converters and, in some cases, variable speed commutator motors with series characteristics appear unsuitable for cane mill drives, as their speed-torque curves incline very steeply. In other words, small load variations cause undesirably large speed variations. Variable speed commutator motors with series characteristics have, however, been successfully used for applications with varying torques, with the help of speed regulators.

The torque behaviour of the other drives described in this paper, appear suitable for cane mill drives.

#### Comparison of Capital Costs

The price-Kw. diagram shows the relationship between the costs of the various drives under discussion and are based on the following:

- (a) 5 cane mill drives are assumed
- (b) Electric motors are of the 4-pole protected type
- (c) Speed Range 50 per cent to 100 per cent
- (d) Constant torque conditions
- (e) High voltage 3.3 kv., 50 cps.

The Slip Ring Motor drive is most favourable in price followed by the squirrel cage motor with torque converter. The price of the DC system with mercury arc rectifiers is very high and the largest available speed range of this system is not required for sugar cane mill drives.

The price of the DC system with silicon rectifiers is also high for larger ratings. Up to 500 Kw, per drive, one rectifier plant suffices to supply 5 mills but beyond that each drive must have a separate rectifier plant.

The sequence of drives in the increasing order of their prices for different powers is:-

- 250 Kw: Commutator Motor with series characteristic, commutator motor with shunt characteristic, Ward Leonard Set, DC-motor with silicon rectifier, AC-DC cascade, AC-DC-AC cascade.
- 500 Kw.: Commutator motor with series characteristic, Ward Leonard Set, Commutator Motor with shunt characteristic, DC-motor with silicon rectifier, AC-DC cascade, AC-DC-AC cascade.
- 800 Kw.: AC-DC cascade, AC-DC-AC cascade, commutator motor with series characteristic, commutator motor with shunt characteristic, Ward Leonard Set.

For smaller powers the drives with single motors are least expensive but for larger powers the drives with a number of motors become more attractive in price.

#### Comparison of Efficiencies

The economy of a drive does not only depend on the price but also on the running charges. It is also of great importance that the losses do not vary con-

siderably within the range of speed the drive is designed for.

It may be seen from the foregoing that the slip ring motor operates most uneconomically at lower speeds as the losses of the resistors have to be covered. The squirrel cage motor with torque converter also has a poor efficiency which becomes worse with decreasing speed. The remaining drives discussed all have efficiencies within 0.8—0.9 throughout their entire speed ranges. Only the Ward Leonard Set, whose efficiency is nearly constant throughout the range of speed, is somewhat below the mentioned figure.

### **Conclusion**

The slip ring motor although inexpensive appears unsuitable for cane mill drives due to its poor efficiency and torque behaviour at reduced speed. Con-

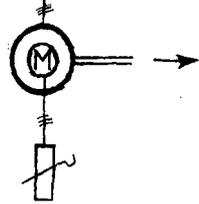
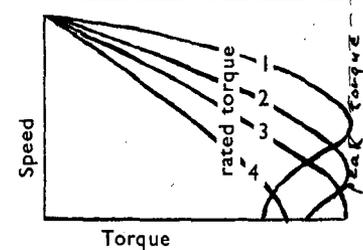
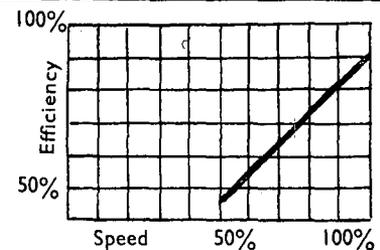
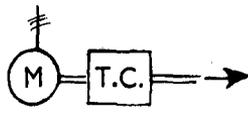
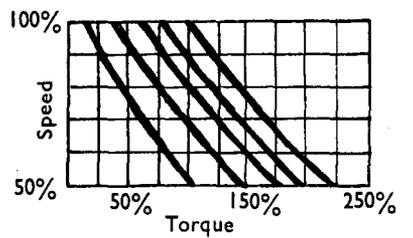
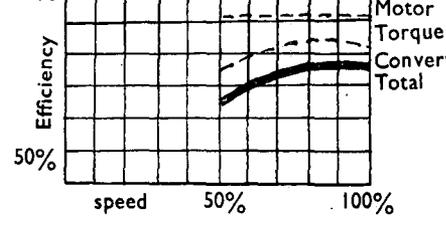
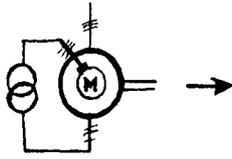
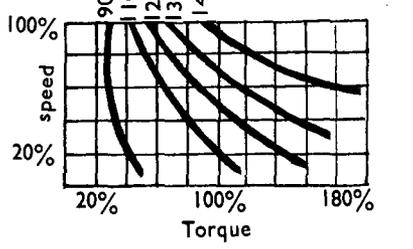
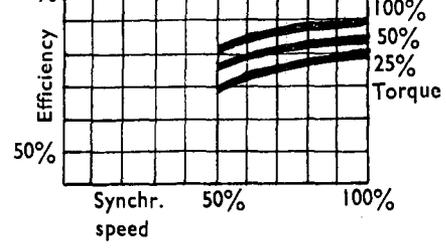
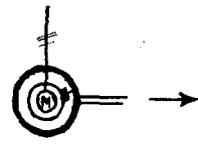
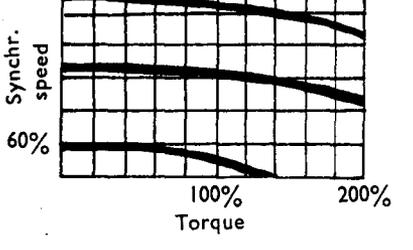
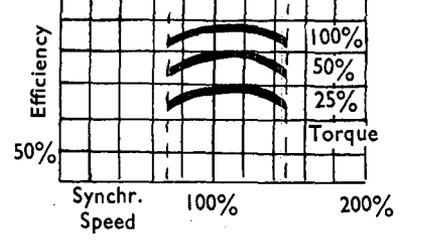
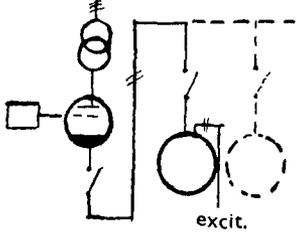
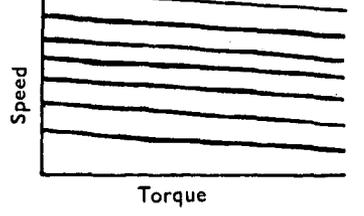
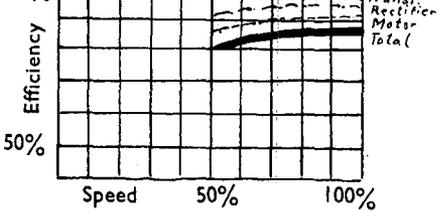
ditions are similar with the squirrel cage motor with torque converter.

Variable speed commutator motors with shunt and series characteristic show very favourable efficiencies. Their prices are also reasonable within the lower HP ranges. For higher h.p. ranges, however, the prices are very high in comparison with other drives.

The DC drive with mercury arc rectifiers also appears too high in price to be considered, although its operation is very economical.

The remaining types of drives, i.e. AC-DC cascade, AC-DC-AC cascade, Ward Leonard Set and DC motor with silicon rectifier (up to 500 kw.) may be considered most suitable for cane mill drives. For cane mills requiring large motors (within a range of 800 kw.) the cascade drives have the most interesting features.

# DIAGRAMS

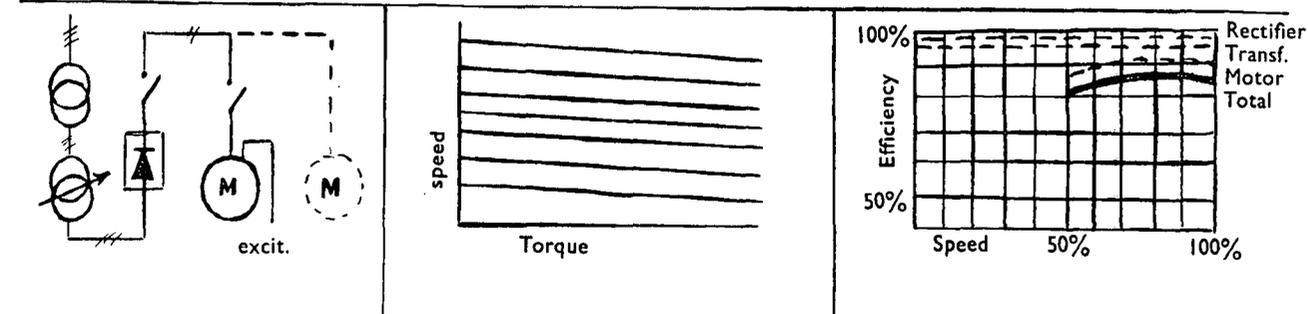
SCHEMATIC	SPEED-TORQUE	EFFICIENCY-SPEED
		
<b>AC SLIPRING MOTOR</b>		
		
<b>AC SQUIRREL CAGE MOTOR WITH TORQUE CONVERTER</b>		
		
<b>AC COMMUTATOR MOTOR WITH SERIES CHARACTERISTIC</b>		
		
<b>AC COMMUTATOR MOTOR WITH SHUNT CHARACTERISTIC</b>		
		
<b>DC SYSTEM WITH MERCURY ARC RECTIFIERS</b>		

# DIAGRAMS

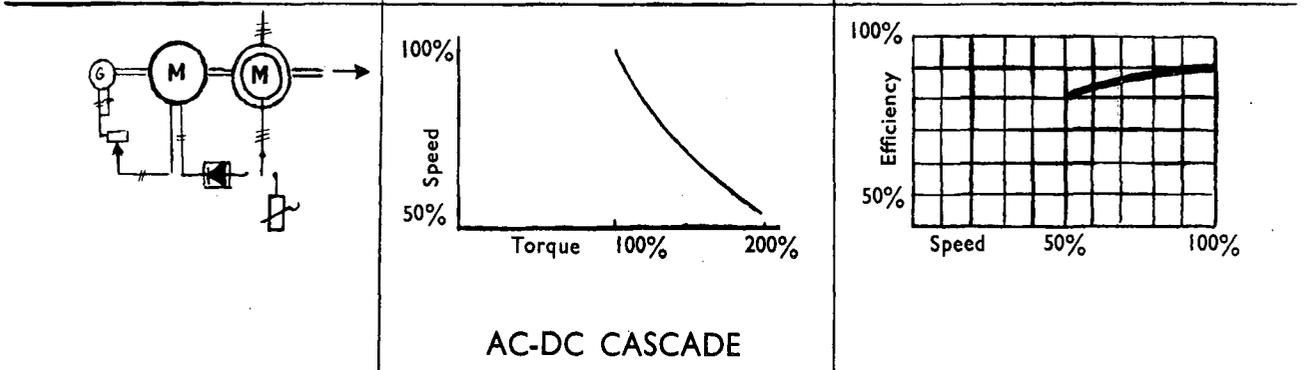
**SCHEMATIC**

**SPEED-TORQUE**

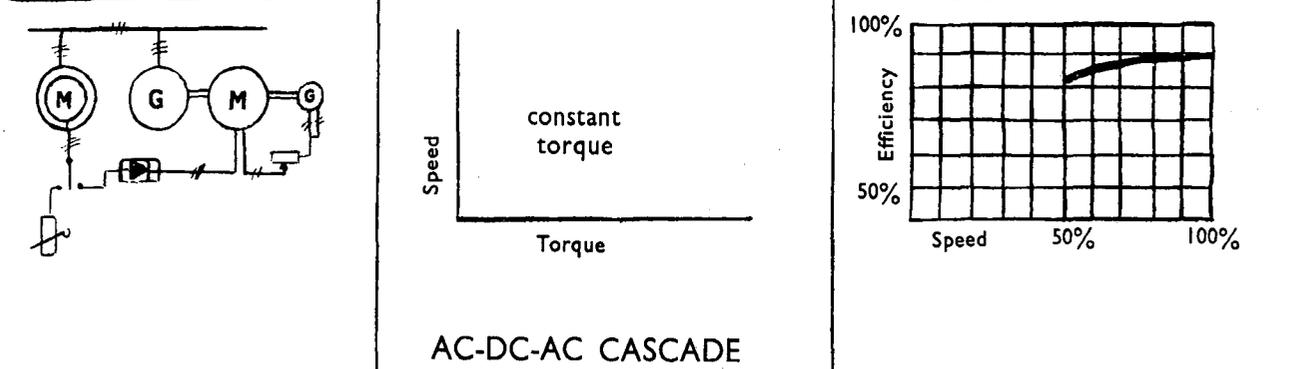
**EFFICIENCY-SPEED**



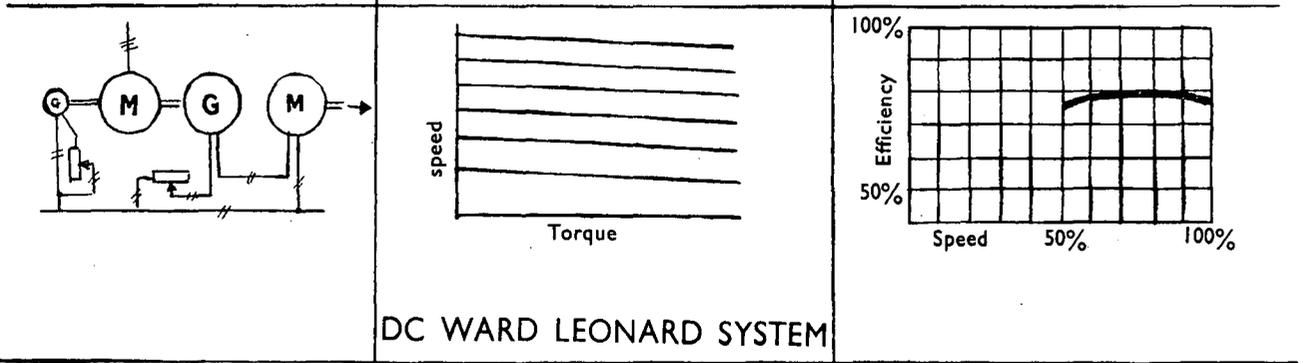
## DC SYSTEM WITH SILICON RECTIFIERS



**AC-DC CASCADE**

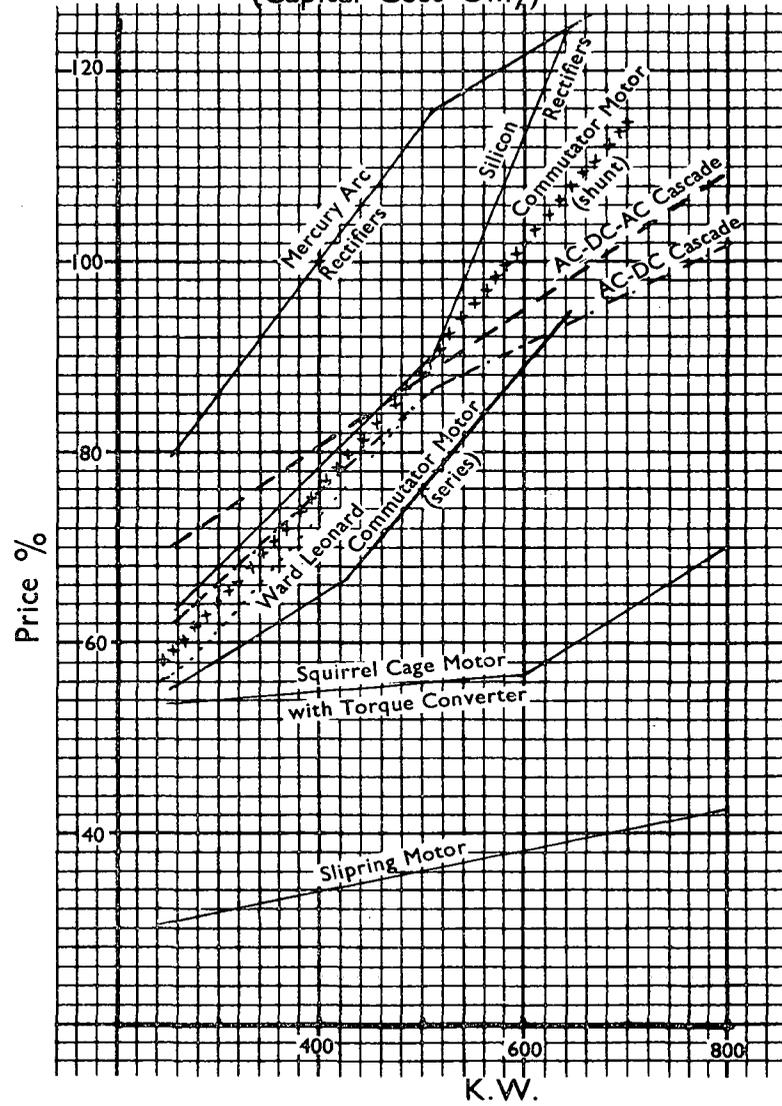


**AC-DC-AC CASCADE**

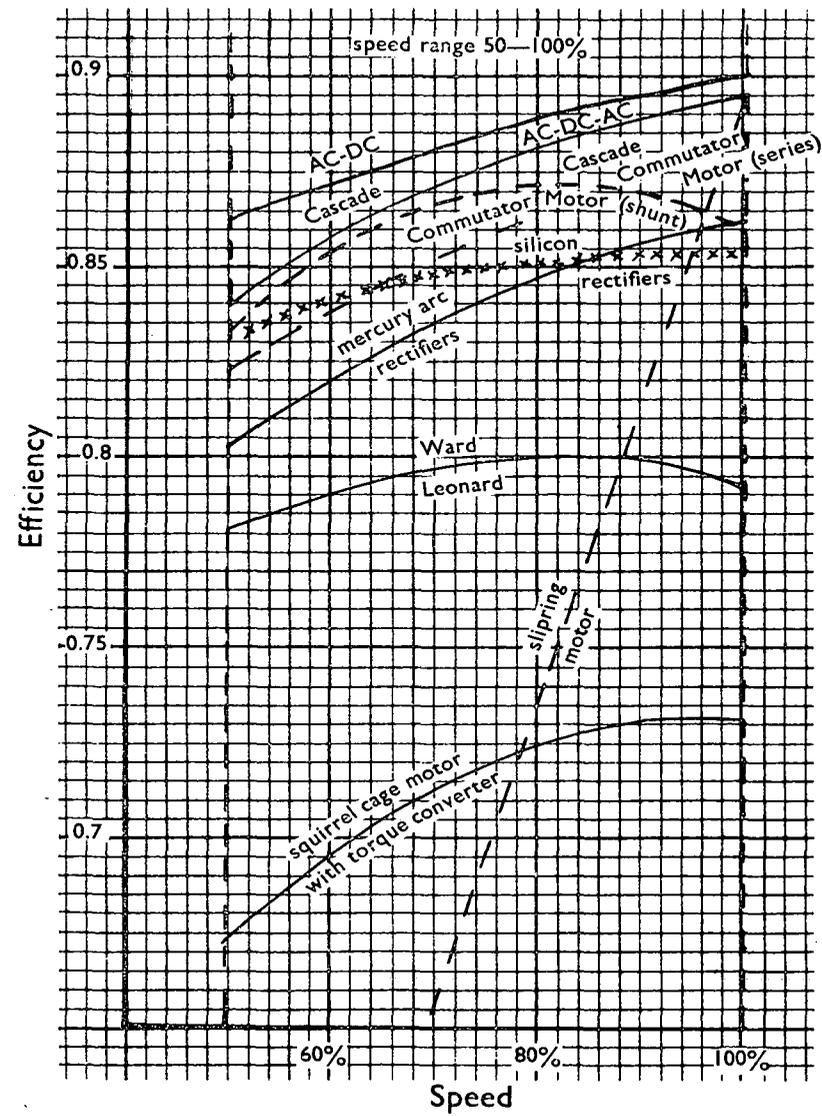


**DC WARD LEONARD SYSTEM**

**PRICE RELATIONS**  
(Capital Cost Only)



**EFFICIENCIES**



**Mr. Bentley** (in the chair): I am not against electric drives, and I appreciate their advantages and efficiency, but nearly all recent installations throughout the sugar world have been steam turbine drives. There are one or two isolated instances where electric drives have been introduced. They are fine if they can be isolated from the rest of the mill, rather as is done in steel mills, so that the electrics are kept entirely separate from bagasse, bagacillo and all the other things found in a sugar mill. Nevertheless, most new installations have been steam drives and what I consider to be the reason is that the capital cost seems to be somewhat lower for a steam drive, and assuming that a steam drive is correctly tailored the steam is first doing a job driving the mills, and is then being used for process work. Mr. Hughes mentioned the installed cost of an electric drive, "excluding increased alternator capacity". But possibly that is the whole crux of the matter, that the additional alternator capacity very much outweighs the cost of an exhaust steam range. I hope that there is someone here from Natal Estates who can tell us why they, who were the first people to go in for all-electric drives, recently installed a steam turbine.

**Mr. van Hengel:** On a recent visit to Europe I investigated electric mill drives and installations such as have been described in these papers.

In Germany there was an AC-DC Cascade System driving the gas exhauster from the coke furnaces of a steel works. The system was governed automatically by the pressure in the oven, or in the gas line to the consumer.

In a Belgian steel roller mill the drive was also by AC-DC Cascade motor, and the speed was regulated according to the different type of product being made. When the steel rollers were running empty it was possible to see the load of the Cascade System going from one extreme to the other, zero to full load, a couple of hundred times an hour. The System should well stand up to the varying loads under varying conditions of speed experienced in a sugar mill.

Electric drives are efficient and clean and are eminently suitable for mill drives.

**Mr. Farquharson:** The initial capital costs of electric drives are very heavy.

The Constant Current System should be suitable for sugar mill drives although I am not aware of it having been used for the purpose. It is useful where variable speeds and reversing speeds are required and its application includes opening and shutting dock gates and pulling ships into dry dock. It would require very high horse power for a sugar mill drive. The centrifugals at Z.S.M. sugar mill are run on this system.

**Mr. Hughes:** The Constant Current System is ideal where there are a lot of motors wound together, and one can help another all in the one system. A mill drive, however, has individual units and once a ton-

nage is set it would be rather awkward to control such a system where the machines are running at constant speed.

If the system is designed with a realistic approach to the h.p. required, full use can be made of the overload capacity.

**Mr. Farquharson:** In a constant current system the current is not varied because it is maintained constant automatically by the generator. Regarding individual control of each mill in a tandem, the system is designed for this and requires no special control for it.

**Mr. Hughes:** In the time at our disposal it is difficult to evaluate the use of a constant current system in a sugar mill. Apart from its high initial cost I think the biggest drawback is that mills normally run at constant speeds.

**Mr. Gradener:** The speed regulation of the AC-DC system is very simple and by varying the field of the DC motor the speed of the set is changed. Therefore with a very small input, say 100 to 500 watts, the speed of the main drive can be influenced. The regulation can be done by hand or by remote control.

**Mr. Hughes:** In favour of the Cascade drive is the fact that if the weakest link in the system, the DC motor and its associated gear, becomes inoperative the mill does not stop as the AC motor carries on at full speed. Also, DC motors are easy to maintain, even in the steel industry, where operating conditions are worse than in the sugar industry.

New mill drives must be compared with existing drives and in this respect the characteristics of the AC Cascade set compare favourably with a steam turbine with regard to increase in torque with decrease in speed.

**Mr. Gunn:** I fear that one of the problems we have at the moment is going to become even more difficult. Milling machinery manufacturers have advised us never to run our turbines slowly in order to avoid overloading the gears. We are now asked to use very robust drives which when run slowly will place a terrific overload on the gears which might have to be replaced every two years.

**Mr. Hughes:** The cost comparisons of these drives have been based purely on the turbine as against the electrics. But suitable gears must be installed for whatever system is used.

**Mr. Saville:** How does speed regulation apply in this system?

**Mr. Hughes:** It is similar to that of the DC shunt motor because the Cascade system is virtually a shunt drive. Instead of losing slip power or creating a voltage across the resistor and losing that power through the resistor on the slip-ring motor you increase the voltage from the DC machine by varying the field. So of the whole drive, whether 2 kW or 500 kW, all that you control is the shunt field, exactly as would be done on a DC shunt drive.