FLUID COUPLINGS IN HIGHER POWER BELT CONVEYOR DRIVEHEADS

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Conveyor drives incorporating fluid couplings can employ simple direct-on started squirrel cage motors as the prime movers. The fluid coupling allows the maximum torque capability of the motor to be made available, the torque applied to the belt can be limited throughout the starting cycles, whilst load balancing under steady running conditions between multiple driveheads can be achieved.

The torque/slip characteristics of the fluid coupling are altered by changing the contained fluid volume. Of the two basic design types the fixed filling coupling requires the drive to be stopped to adjust filling; such adjustment can be made with the variable filling in operation, and on a continuous basis if need be.

Development of increasingly sophisticated yet reliable control to operate with variable filling fluid couplings have extended their application possibilities to include regulation of regenerative load conditions.

SUMMARY

Fluid Couplings are hydro-dynamic power transmissions, following in their operation the principles of centrifugal machines such as fans and pumps. Interposed between the driving motor and the gearbox in a conveyor drive application, the coupling can, depending on its design, allow the motor either an off-load, or completely no-load start, and also limit the torque transmitted to the conveyor belt during its run-up to full speed.

There is no direct mechanical connection between input and output of the fluid coupling, all power being transmtted by a toroidally shaped vortex of fluid circulating continuously between an impeller driven by the motor and a runner driving the gearbox. The characteristics are altered by changing the amount of fluid in the toroidal vortex. In the case of a fixed filling design, the drive must be stopped to effect the change, in the controllable fill type the variation can be made, continuously if need be whilst in Operation.

The fixed fill units are constructed in both carden shaft and shaft mounted configurations, steel cased or cast aluminium outer members, and operate on a variety of working fluids, including water. The various impeller/runner combinations can include a delayed filling chamber rotating with either the primary or secondary parts.

The controllable filling designs most usually employed are the scoop control and scoop trim families. The former has the advantage of being self-contained, requiring only the addition of a cooler where necessary, but the latter caters inherently for the more demanding applications, both in power rating and operational needs.

Variable filling couplings can be combined with a range of controls, from simple open loop time based versions, to highly sophisticated micro-processor based schemes which combine the coupling with modulated disc brakes to achieve "same-time-start" and "same-time-stop", even under regenerative conditions.

The choice between fixed fill and controllable fill fluid couplings is often not straightforward, particularly on multi drive head conveyors, and-care is needed to ensure that the economic advantage of the fixed fill coupling may safely be exploited. A direct-on start squirrel cage motor with a fluid coupling provides a simple low cost high efficiency drive to meet the needs of current and future belt conveyor technology.

2. Introduction

Amongst the first orders secured for industrial use of fluid couplings was one for the mining industry in Southern Africa. In 1930, two 1,000 hp units were purchased for the Roan Antelope copper mine, to act as hydraulic slip regulators on flywheel generating sets.

These installations, rated up to 2,500 hp, were used in many countries, in conjunction with mine cage winding gears, where the electrical grid transmission system could not cope with the peak power demands of the winding cycle. They represented ideal applications for fluid couplings in that a large flywheel had to be accelerated to full running speed over an extended period, without overloading the drive motor, which was rated only for the average power demands of the cycle. Hence the requirements of this application were very similar to those of the trunk belt conveyor drivehead, where in many instances the site is remote, the electrical supplies weak, whilst the provision of a controlled start-up is essential in this instance to minimise the number of belt plies thereby achievng lowest cost, both in initial procurement and subsequent replacement.

3. Operating Principles

Fluid couplings are 2-element hydro-dynamic transmissions. In the simplest form, a semi-toroidal shaped impeller, having straight radial vanes, so that the driving effect is bi-rotational, is driven by the prime mover. A similar secondary member, the runner, is connected to the driven machinery, with a rotating shell casing fixed at the periphery to one member in order to enclose the other. Within this enclosed volume, the operating fluid circulates in a continuous vortex between impeller and runner thereby transmitting the torque, as shown in Fig. 1 and also in Fig.3.

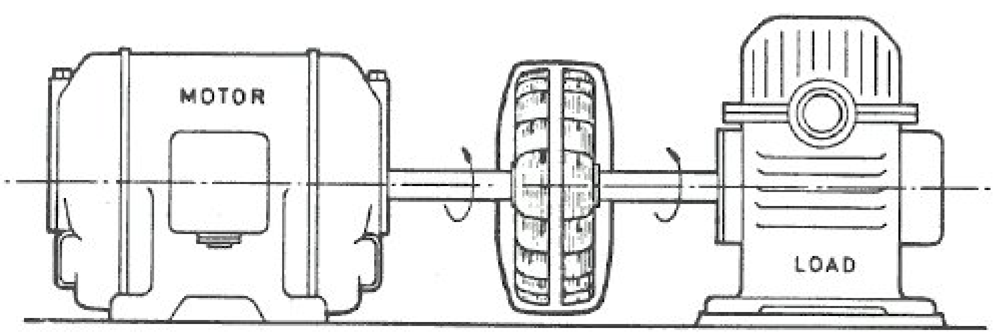


Fig.1

The combination of impeller and runner is known as the "working circuit" and the measurement across the outer diameter of the vaned toroid space known as the "profile diameter" of the fluid coupling.

There is no mechanical driving inter-connection between the fluid coupling impeller and runner, all power being transmitted by the vortex ring of fluid. Shock and impact loads cannot therefore be transmitted, whilst the inertia effect of the motor rotor is isolated from the remainder of the transmittion. It is known by many equipment makers that such isolation leads to a measurable increase in the life of gearboxes and associated equipment.

The torque transmitted by the coupling is proportional to the difference in moment of momentum of the fluid as it enters and leaves each member. The speed difference or "slip", creates the nett difference in opposing centrifugal heads of impeller and runner to circulate the fluid against the friction and shock losses within the vaned spaces, and hence it follows that the member acting as the impeller must always rotate at the highest speed. The torque imposed on the prime mover by the impeller will, under all conditions of operation and fluid filling, be equal to that being demanded from the runner by the driven machine. Thus the slip difference between the impeller and runner speeds will directly define the hydraulic efficiency.

Percentage slip difference is defined as (Input rpm - Output rpm / Input rmp) x 100

Since the torque being transmitted and the resultant slip are completely interdependent, fluid couplings are often referred to as "slip regulators". They may also be regarded as the hydraulic analogue of the AC squirrel cage induction motor, with which they are closely allied in the conveyor drive application, in that the motor torque is developed by interaction between the magnetic field rotating at synchronous speed created by the stator current, and the field created by the current it generates in the rotor cage, which turns at a slightly lower speed equivalent to the slip.

Since fluid couplings are centrifugal machines, the laws of geometric similarity apply; hence, for the same percent slip and filling of the working circuit, the horsepower transmitted is proportional to (1) the fifth power of the working circuit profile diameter, (2) the cube of the input speed, and (3) the density of the working fluid.

A great deal of theoretical work has been carried out over the years to try and predict fluid coupling performance, two of the more recent studies being listed as Reference Nos. (1) and (2). However, none of these treatments yet yield results wholly vindicated in operation, particularly when the fluid coupling is operating transiently with a partially filled working circuit, as will occur during operation at reduced output speed, or during a load acceleration sequence.

It therefore continues to be the practice to obtain testbed performance data on one frame size at a speed within the testing facility capacity and then apply such results to other fluid coupling frame sizes and input speeds, using the above relationship.

It is also found that when using different fluids, e.g. mineral oil or phosphate ester, a simple consideration of density is not sufficient, and other effects, particularly the viscosity at the operating temperature, are more significant.

Thin mineral oil is usually employed as the working fluid, unless there are site restrictions on its use. The principal reasons for such choice are:

a. Universally available
b. Relatively low in cost
c. Lubricates the fluid coupling internals when running, and protects them when stationary.
d. Non-toxic, requiring only simple precautions in use.
e. No erosion or cavitation problems arise within the working circuit.

For a given frame size and input speed, the torque/slip characteristics are altered by changing the fluid filling of the coupling. On a fixed fill design, this entails stopping the coupling, and making adjustments through the filling plug; on the controllable, or variable filling unit; the filling can be continuously and infinitely varied with the coupling running.

4. Fixed Filling Fluid Couplings

4. 1 Mounting Arrangements - "Carden Shaft" and "Shaft Mounted" Designs

Fig. 2 illustrates the two basic mounting principles used on most fixed filling designs.

Fig. 2

In the first, the fluid coupling is carried between the motor and load machine shafts, with the fluid coupling weight distributed between them in the appropriate ratio of 2 1, semi-flexible couplings are then employed for connection at input and output. With economic pressures causing manufacturers to produce ever lighter and more cost effective designs of motor and gearbox, this sharing of total coupling weight can become important. It is also possible, with this design, to very easily remove the fluid coupling for maintenance purposes on motor, coupling or load machine. A reasonable degree of foundation settlement can be tolerated after commissioning without undue loads on the drive line shafts and bearings.

In the alternative design, the fluid coupling is hollow shafted and mounted on the load machine shaft with a fully flexible connection coupling required at the input. This arrangement can of course be inverted, with the fluid coupling carried on the motor shaft.

Whilst more economical in overall length, difficulty can be experienced after extended service in withdrawing the fluid coupling from the shaft on which it has been mounted, and the selection of the fully flexible coupling is critical in achieving long and reliable service.

4.2 <u>Constructional Details and Characteristics</u>

4.2.1 <u>Construction Details</u>

The fixed filling coupling is usually available in three basic working circuit configurations:

a. Multi Vane Circuit with Baffle and Reservoir Volume
b. Stepped Circuit with Antechamber
c. Modified Stepped Circuit with delayed filling chamber.

The multi vane circuit and stepped circuit with antechamber constructions are more common in the form of carden shaft designs, but in special cases exist as shaft mounted units, one example of which will be illustrated. The stepped circuit with delayed filling chamber is more usually produced as a shaft mounted construction, but is sometimes adapted into a carden shaft arrangement, to make available the benefits of the latter, as previously reviewed.

The individual configurations can now be reviewed as follows:

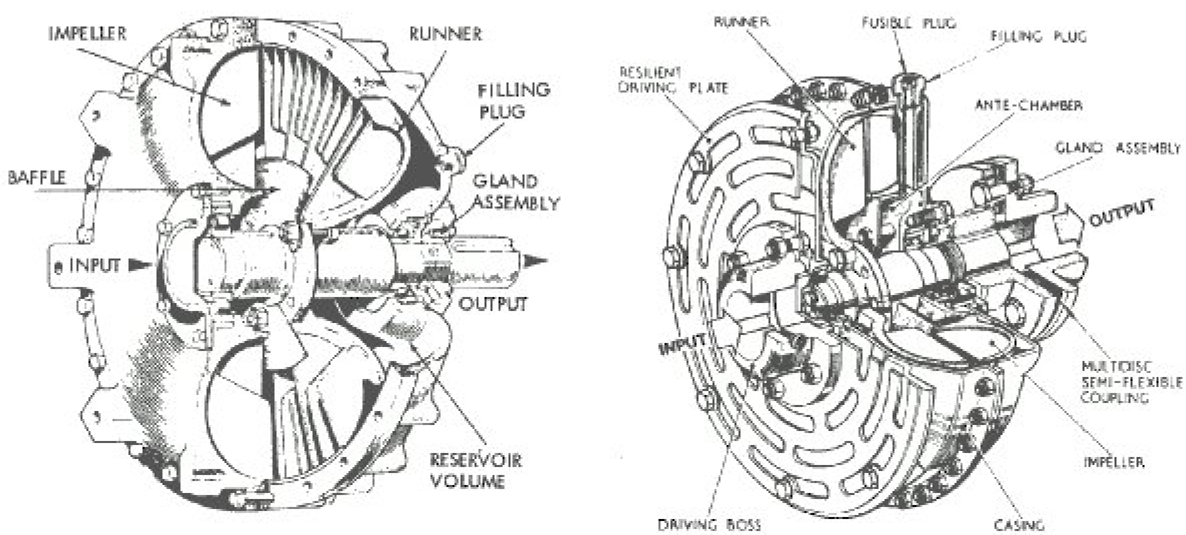


Fig. 3

a. Multi Vane Circuit with Baffle and Reservoir Volume

The left hand isometric of Fig.3 shows the basic module without mounting arrangements, with the toroidal, similar shaped, multi-vane impeller and runner, together with the disc shaped baffle on the hub of the runner. The torque/ourput speed characteristics are varied by selecting one appropriate size of baffle disc and adjusting the fluid filling accordingly.

The ability to make a significant change to the characteristics simply by changing the baffle can be a powerful benefit in resolving problems in the field during commissioning.

This design has been traditionally produced in aluminium alloy castings to achieve the most economical overall costs. In general, aluminium casings can easily incorporate fins and other protruberances to improve the thermal self dissipation.

b. Stepped Circuit with Antechamber

A unit complete with input and output semi-flexible connections is shown in the right hand isometric of Fig.3. The differing profile of impeller and runner is to be noted together with the location of an antechamber volume within the inner profile step of the impeller.

This design has since inception been produced in the form of aluminium cast impeller and runner within fabricated casings of deep drawn steel, and was originally intended for the diesel engine market. Previous practice of bolting all-aluminium castings to the steel flywheel of the engine had given problems due to differential expansion. In the event, the all steel construction has found its principal use in flame proof motor driven face and gate conveyors in underground coal mines, sublect to the presence of firedamp, where the use of exposed aluminium is forbidden.

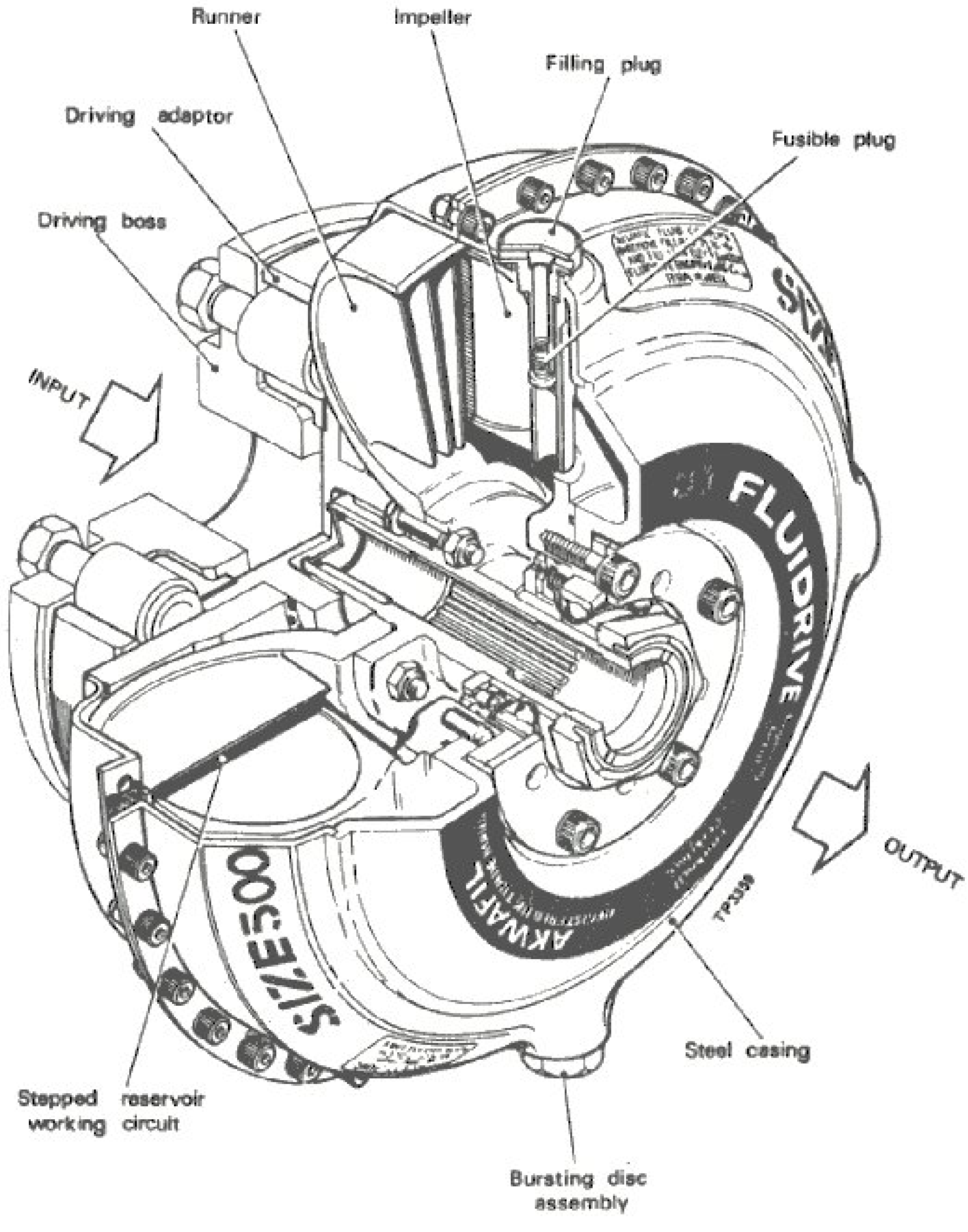


Fig. 4

Fig.4 shows a special splined shaft mounted version of this generic design suitable for operation on water. The latter feature has been regarded as essential by the UK Mines Safety Inspectorate. It is a specified requirement that when trying to start up a heavily overloaded conveyor, involving repeated starts and a high degree of heat generation within the fluid coupling, then if the conveyor does not begin to accelerate up to speed at the first attempt, a time period of some 30 - 40 seconds must elapse before operation of safety features which allow the water to be released and the drive effectively disconnected. To withstand the consequent internal pressure increase, the casings are of substantial section to prevent axial dilation in service.

Operator safety is ensured at all times by the provision of three overload protection features operating in sequence, namely a fusible plug, responsive to fluid temperature, a bursting disc which will rupture at a pressure corresponding to a slightly higher internal temperature, whilst finally the floating ring type shaft gland will lift if both fusible plug and bursting disc have been thwarted. Operation of any one of the features leads to very rapid evacuation of the water filling of the coupling. There are some 8 - 10,000 units of this basic design, of varying frame sizes in use with one prominent UK operation.

It should finally be noted that the splined male shaft of the gearbox, upon which the fluid coupling is mounted, is of special material and design so that; its outside diameter can be kept to a minimum. In this way, the outside diameter of the hollow runner shaft, which passes through the centre of the fluid coupling volume, is no greater than that of the carden shaft design shown in the right hand illustration of Fig.3. The significance of this feature is explained later.

c. Modified Stepped Circuit with delayed filling chamber

The results of a CAD (Computer Aided Design) design study to produce a drawn steel cased shaft mounted version having cast iron antechamber and aluminium impeller and runner are shown in Fig.5

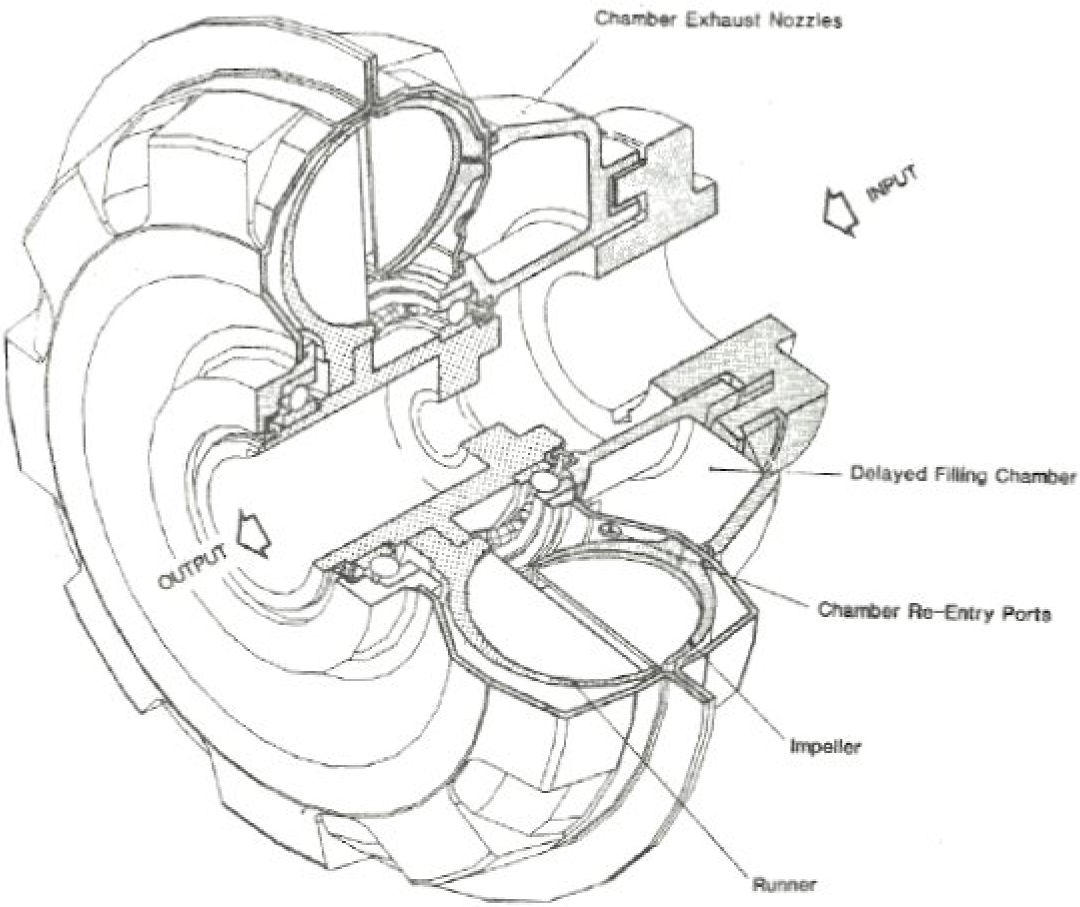


Fig. 5

Since this is a project drawing, details such as the casing peripheral joint clamping bolts are not shown. The drawing shows that the fluid coupling can be mounted on a supporting shaft (of motor or gearbox) of substantial diameter.

This in turn means that the runner shaft occupies a very much greater volume in the centre of the fluid coupling than is the case of the earlier described designs. This has an important effect on the nature of the operating characteristics, as covered in the next major paragraph.

In the version shown, the delayed filling chamber rotates with the primary ports and is located directly behind the impeller. By conducting special test to view in a stroboscopic light the fluid escape through the nozzles into the working circuit at motor start-up, and its re-entry into the chamber through the appropriate ports, either under severe overload conditions or shutdown, this was found to be a preferable location to one in which the chamber, whilst rotating with the primary parts, was located behind the runner.

A significant amount of work has also been undertaken to assess the effectiveness of a delayed filling chamber attached to the runner rather than the impeller. Some potential has been indicated from the tests, but an extended work programme will be required to bring this project to fruition.

4.2.2 - Operating Characteristics

The operation of any fluid coupling can be viewed in three distinct phases motor start-up, load acceleration, and steady running, as examined in Fig.6, which relates to the operation on mineral oil for a fluid coupling of 475 mms. profile diameter and the alternative motor speeds of 1480 and 740 rpm.

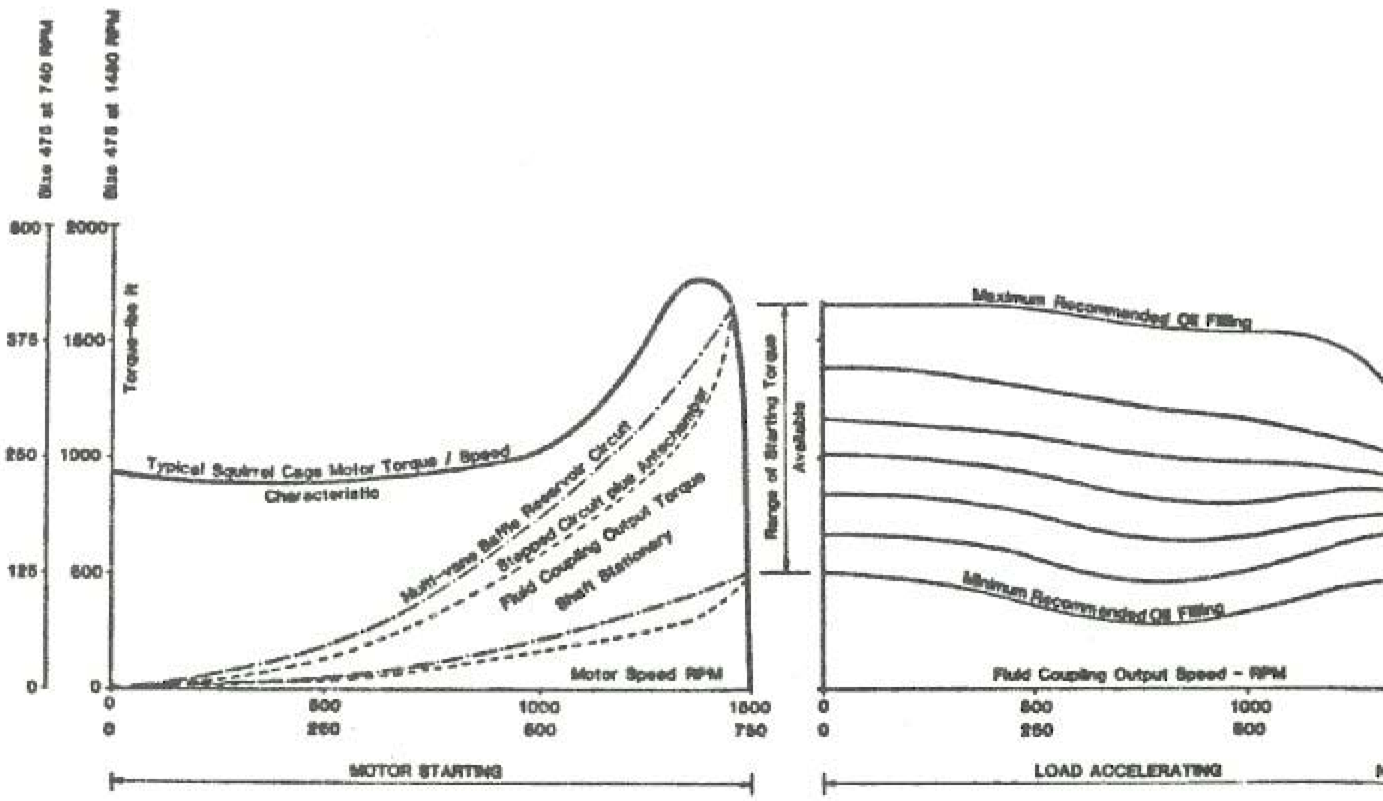


Fig. 6

At motor switch-on, with the coupling output shaft held stationary by the load, the torque generated builds up progressively from zero, allowing the motor to use a significant part of its torque capability to accelerate itself quickly up to speed, limiting the current demand on the line, other than for a brief peak at the instant of switch-on.

According to the filling chosen, the torque transmitted also limited to a pre-selected level, and it is assumed for the purposes of the presentation that the load breaks away at the instant of the motor reaching full speed. The coupling is designed so that a wide range of acceleration torque levels are available, whilst the transient torque/output speed curves are sensibly flat, giving a smooth progressive increase in driven machine speed.

Finally the normal running range of the fluid coupling is reached, where the average running slip will be between 2 - 4%. Whilst ideally the running slip should be a minimum for a given torque level, in multi drivehead conveyor applications, the ability to slightly adjust the coupling slip without major change in maximum torque transmission if possible is helpful to achieve load balancing and distribution between the individual drives.

The characteristics of the individual designs may be reviewed as follows

a. Multi Vane - Baffle - Reservoir Circuit

The curves of torque build-up with rising motor speed at starting with output stationary are square law relationships as shown in Fig.6. The coupling has the benefit of being the very simplest construction and yields its performance independently of the rate at which the motor and load accelerate.

By adjustment of both baffle and fluid filling a stalling torque range from 120% to 250% FLT can be achieved with a running slip of maximum 4½ - 4¾%, on other than the smallest frame sizes.

b. Stepped Circuit with Antechamber

During the rapid acceleration of the motor up to full speed, some fluid is held within the antechamber and does not immediately have full effect in torque transmission. In the critical part of the motor run up, where very often its characteristic curve exhibits a "saddle" of some magnitude, it is therefore briefly relieved of load immediately prior to accelerating to full speed.

The step circuit coupling does not have an equivalent advantage to the multi-vane - baffle - reservoir version of easily changing the runner baffle size to achieve a particular optimum operating zone. Nevertheless, by employing a limited number of different impeller configurations, it can achieve the same spread of acceleration torque levels, with usually a rather lower top speed slip in comparison.

c. Modified Stepped Circuit with delayed filling chamber

As illustrated in Fig.5, and reviewed in paragraph 4.2.1. c) above, a chamber whose volume is usually between 20% and 60% of the toroidal volume of the working circuit is located behind, and rotates with, the impeller. When the coupling is stationary the chamber fills with fluid to an extent governed by the fluid filling. During motor start-up, the fluid escapes through the exhaust nozzles into the working circuit.

Hence, in the mid-filling regions of the coupling a motor unloading effect more pronounced than that with an antechamber can be achieved. As may be expected, with very low and very high fillings, there is virtually no change in the nett fluid coupling of the working circuit, and thus an additional softening effect is not obtained.

In the course of the testing referred to earlier, to observe the fluid interchange between chamber and working circuit, it was noted that the most powerful effect determining the rate at which the chamber emptied was in fact the slip across the coupling.

Once the load had broken away, and output shaft had commenced to turn, the evacuation of the chamber was completed very quickly, and changing the size of the exhaust nozzles had surprisingly little effect.

If can therefore be appreciated that, where conveyor overall starting times are relatively rapid, then perfrmances equivalent to those reviewed are achievable without changing other components within the fluid coupling, but such favourable performance is significantly affected by the natural behaviour of the conveyor being driven.

However, probably the most important contribution of all made by the delayed filling chamber, is to enable the good characteristics conferred by the designs having runner shafts of diameter proportioned only to their duties of torque transmission and load carrying also to be available on the hollow shaft mounted versions. The latter have substantially greater shaft diameters to accommodate the large hollow bores necessary to receive the gearbox (or motor) shaft. Tests show that the space in the centre of the toroid plays an important part in achieving low top speed slips in combination with low acceleration torque levels. Where space is of necessity obstructed or filled by a large diameter runner shaft, then it is found that the provision of a delayed filling chamber volume rotating with the primary parts has a compensatory effect.

As a concluding illustration to this section, Fig 7 shows a two-motor drivehead of the Dowty Meco "Chieftain" conveyor.

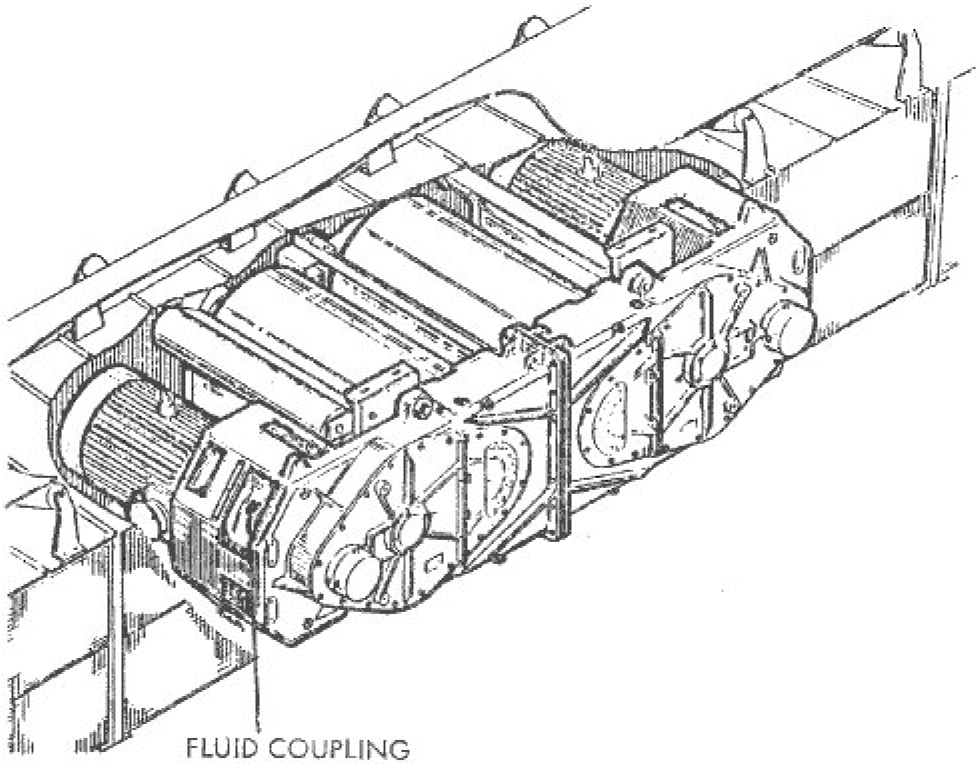


Fig. 7

Each motor is rated at either 225 or 300 kW at 1480 rpm, and drives through a steel cased fluid coupling of the types previously described. The motors, and the fluid couplings in their enclosing housings, are tucked beneath the belt run, in a compact arrangement.

5. <u>Controllable Filling Fluid Couplings</u>

Two types of controllable-fill fluid couplings are in common use today, the scoop control and the scoop trim fluid coupling. The operational phases, and overall torque transmitting characteristics are generally similar to those of the fixed filling range illustrated in Fig.6 but with major additional benefits as to be described.

Taking each in turn:

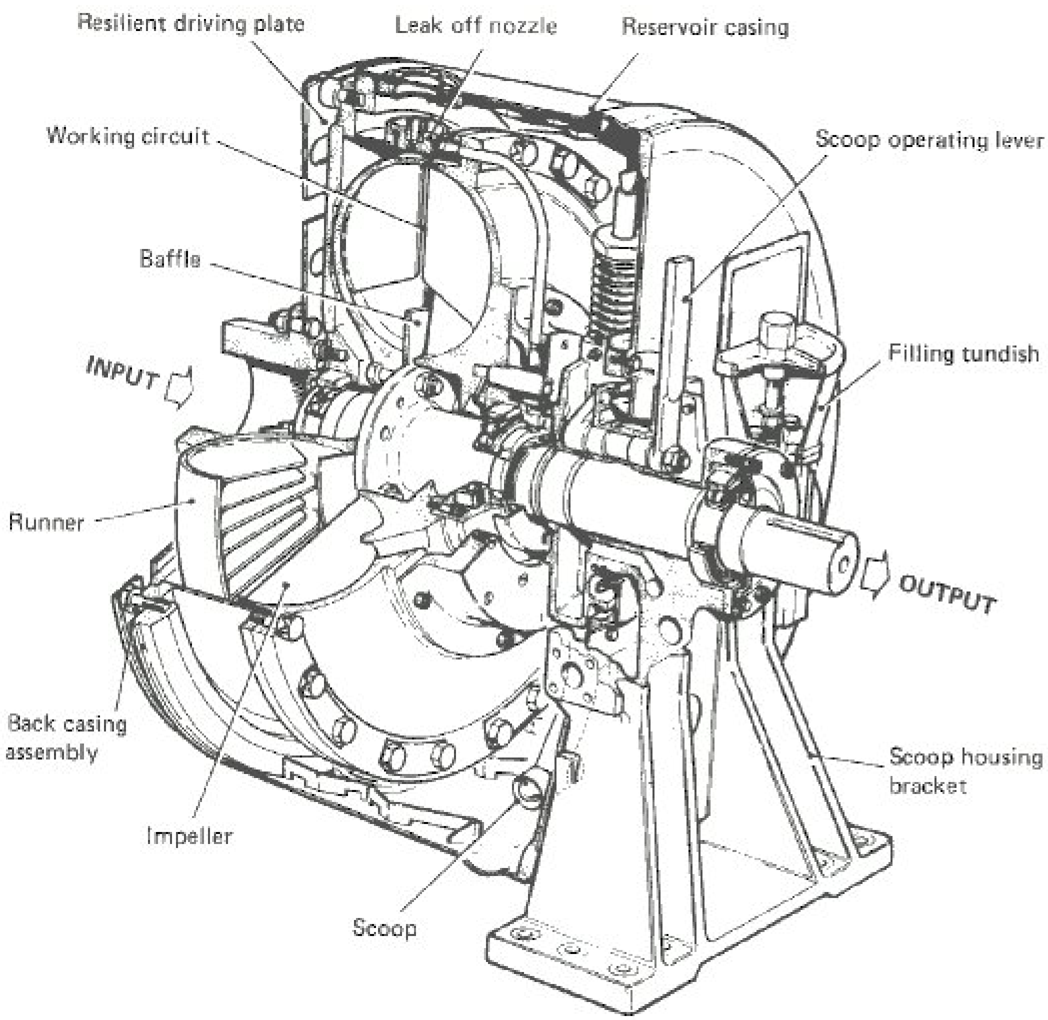


Fig. 8

5.1 Scoop Control Fluid Couplings

Fig.8 is an isometric section. The working circuit is contained within an inner casing which, with the surrounding reservoir casing, rotates at motor speed. A sliding scoop tube with open mouth facing into the motor rotation is carried within the rotating reservoir casing from a stationary bracket assembly bolted to the drivehead framework. Calibrated nozzles at the periphery of the inner casing allow a continuous controlled escape flow from the working circuit space in the reservoir casing.

Movement of the sliding scoop tube by an external pivotted lever to which a suitable actuator can be connected, will control the amount of fluid remaining within the reservoir casing and not returned to the working circuit. Hence, scoop lever position determines the nett filling of the working circuit at any time, and the dynamic head generates as the scoop tip circulates the fluid (through an external cooler if need be) back into the working circuit. The scoop tube is double ended to cater for both directions of motor rotation. The calibrated nozzles (three in number) are each drilled into a plug screwed into a threaded seating in the inner casing. When the application so requires, these plugs can be replaced, in the field if need be, by input speed sensitive centrifugal valves, or diaphragm quick emptying valves designated CQEV's, or DQEV's respectively.

5.2. Scoop Trim Fluid Couplings

This type differs from the scoop control design in the function of its scoop tube; and in having a separate pump for delivering fluid from a sump tank through the cooler into the working circuit.

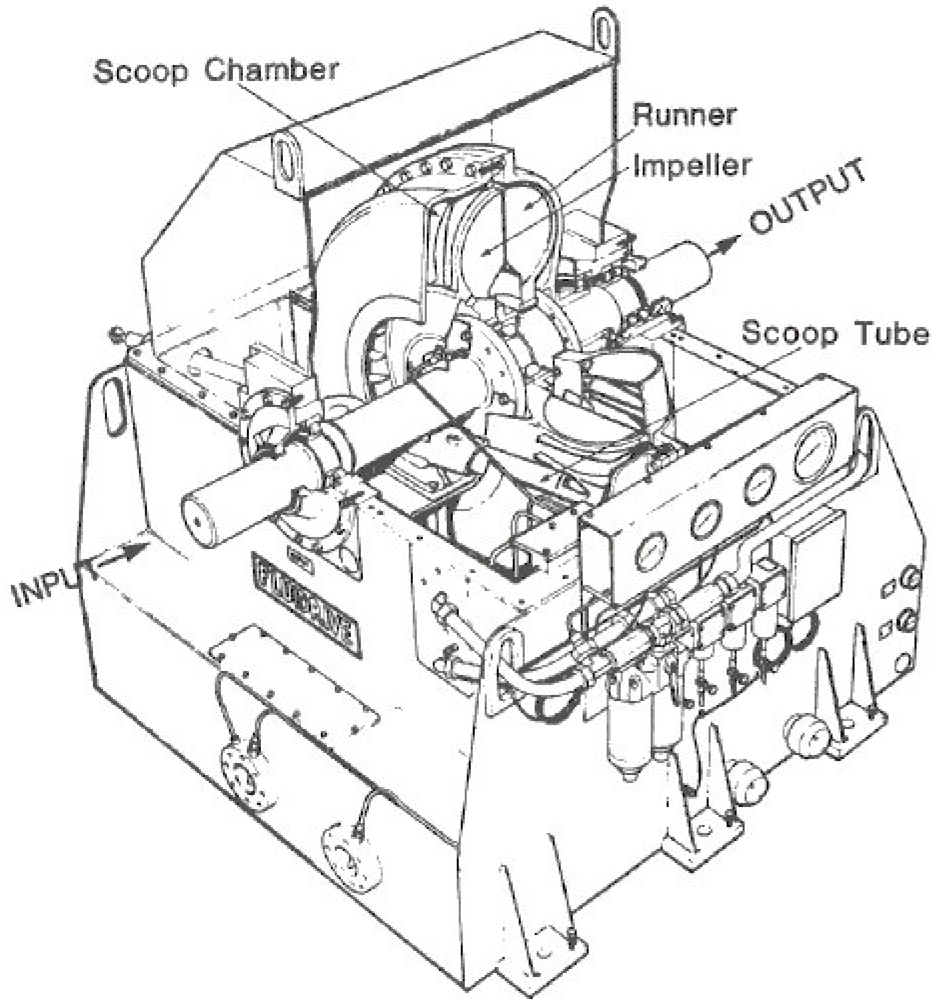


Fig. 9

Fig.9 shows that a sliding scoop tube, carried by the input bearing housing, penetrates into a scoop chamber on the back of the impeller, which is in full communication with the working circuit. An actuator mounted outside the stationary casing can move the scoop along its axis, so that it can "trim" off the fluid level in the rotating casings, and thereby control the degree of filling in the working circuit. This design gives a fast and precise control of the torque transmitted, since the position of the scoop tube directly controls the filling of the wotking circuit.

The circulation pump, which may either be driven directly from the input shaft of the fluid coupling, or electric motor driven as a separate free-standing unit as with Fig.9, can be sized to provide sufficient flow to ensure that the peak temperature of the working fluid is kept within acceptable limits.

Hence this type of fluid coupling is very relevant to drives involving considerable degrees of internal heating, such as conveyors having protracted start times, conveyor drives at 4-pole, and at the higher powers, even 6-pole motor speeds, and where especially accurate control of torque or speed is required.

For both types of variable fill fluid coupling, with the scoop tube positioned at the no-.drive setting, then at motor switch-on, any fluid within the impeller/runner space will escape during the run-up and will not be replaced. The motor is afforded a completely no-load start, and hence not only may a squirrel cage type be employed, but it can be of a "high efficiency" design, which often has rather low starting torque.

Furthermore, even with this special motor design, severe line voltage drops at the instant of motor switch-on can be accommodated.

6. <u>Fluid Couplings with Control Gear (Scoop Control SCR)</u>

6. 1 SCR Fluid Coupling with Acceleration Torque Limiting Control ATLC

A major Canadian heavy iron ore conveyor handling facility in the early 1950's was probably the first large project on which the belting manufacturer specifically pointed out that the major stresses occur during starting and that, if these stresses could be kept below 140% FLT, then for the belts available at that time an optimum economic balance would be struckbetween reduced capital cost, (effected by a reduction in the number of belt plies), and the life of the belt.

The first efforts to meet this requirement with the fluid coupling utilised a special balanced flow design of input speed sensitive centrifugal valves, located in the scoop control inner casing. The intention was that as the squirrel cage motor speed fell with increasing load, the valves would open at the speed corresponding to 140% FLT, and limit the torque capacity of the coupling.

In fact, it was found that the normal variations in site supply voltage and frequency could produce wider variations in motor speed than those due to load variation. These proposals were abandoned, and to meet the requirements of these conveyors, which had starting times up to 40 - 50 seconds, a simple self-contained, and fully automatic control was developed, designated the accelerating torque limiting control (ATLC). The fluid coupling requires no external impulses, or control power supplies, but the main motor must be switched at each start-up.

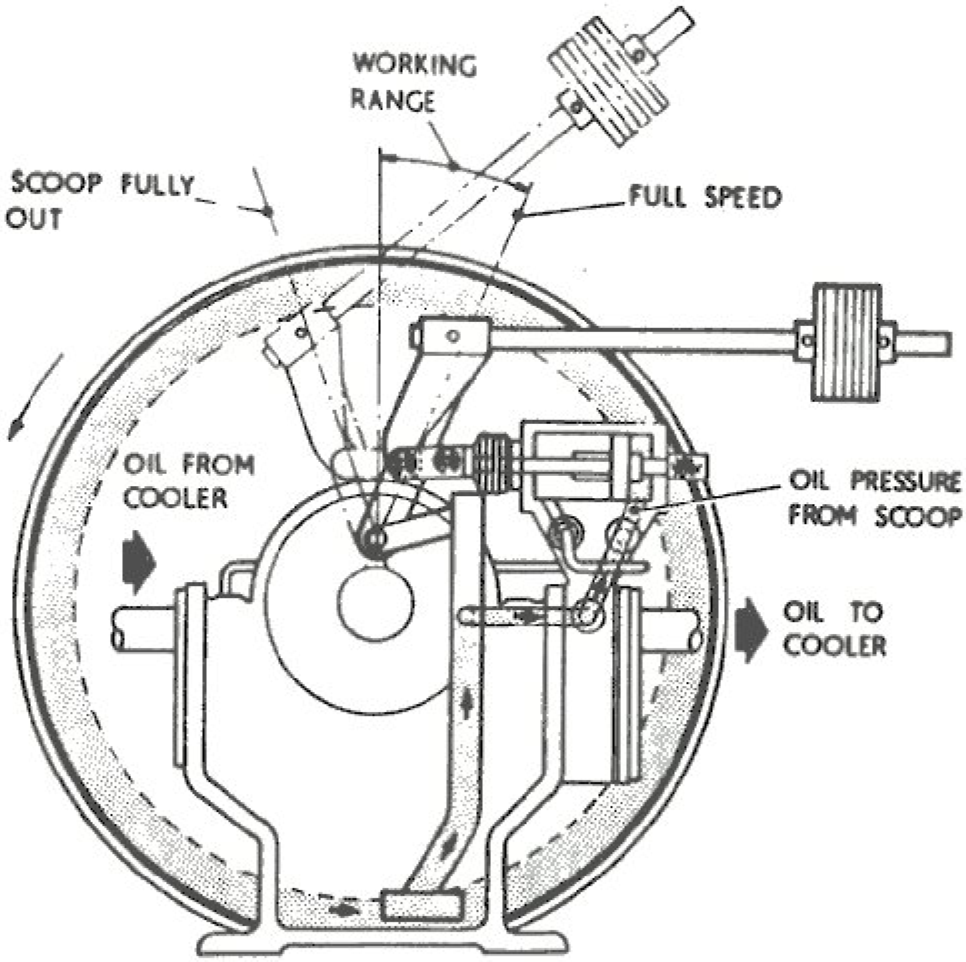


Fig. 10

From Fig. 10 diagrammatic arrangement, the control consists of a servo-piston linked to the scoop lever, working in opposition to a counterweight. On start-up, the fluid coupling scoop already being at "full", a transiently higher scoop pressure will exist for a while after switch-on.: Using this pressure, the servo piston drives the scoop lever, against the effect of its counterweight, to a pre-determined starting position. At this partally filled condition, the fluid

coupling limits the acceleration torque applied to the conveyor drivehead. As conditions stabilise, and the belt accelerates to full speed, the scoop returns to the "full" position.
Should the conveyor not move off with the reduced torque applied, then as the scoop pressure begins to decline, the scoop lever is urged by the counterweight towards the "circuit full" position. Thus, the torque applied to the belt is smoothly and progressively increased, until either the break-away point is reached, or the setting of the main motor current trips to prevent an unduly high value of the belt tension being attained. This characteristic is of value to start a heavily overloaded or frozen-up conveyor, in which the torque applied has to rise above the preferred level, to achieve break-away.
Fig. 11 depicts a nest of transient acceleration characteristics obtained on the testbed by appropriate adjustment of the mass of the counterweight and its position on the supporting rod.

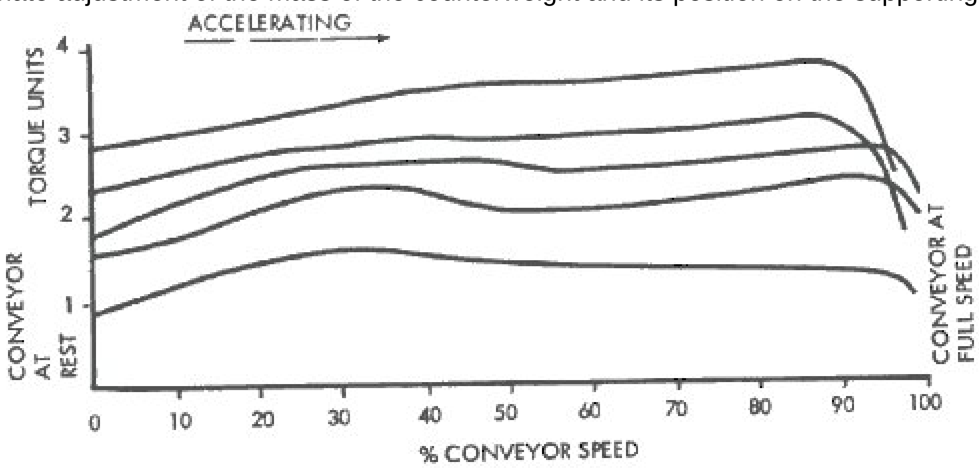
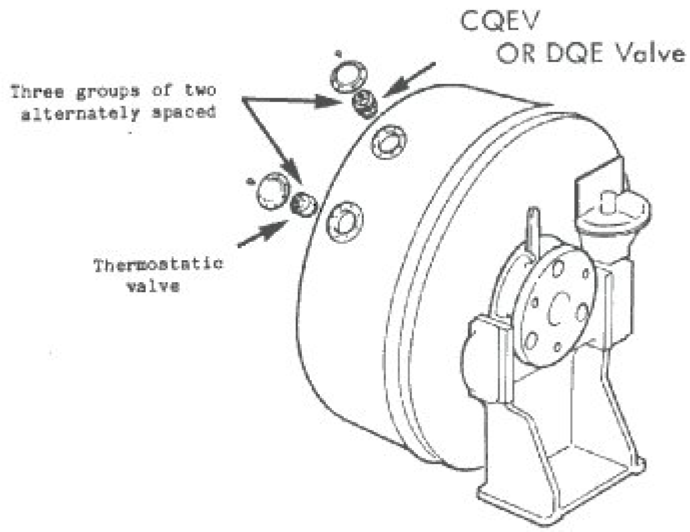


Fig. 11

The first maior installation in Southern Africa came in the late 1950's with the N'Changa Open Cast Pit conveyors, employing 27 scoop controlled couplings with ATLC at the modest rating by current standards of around 250 hp @ 990 rpm.
Some conveyors has multiple driveheads totalling 630 hp. As a contribution to a paper delivered in Johannesburg after commissioning (Reference 3) the user confirmed the success of these couplings with ATLC controls.

6.2 <u>SCR Couplings with ATLC, and also Thermostatic Valves to achieve Belt InspeCtion Speed Facility</u>

A requirement of increasing significance is the need to run an empty conveyor at reduced speeds for belt training, cleaning or inspection. This speed is usually around one-quarter to one-third of normal full speed value. Even though the conveyor at the time with either be completely empty, or the remnants of the load material being run off at the commencement of the low speed cycle, the procedure will generate a significant degree of heating within the fluid coupling.
With the scoop control couplings, a problem can arise in that with the working circuit partially empty, to achieve the requisite low conveyor speed, the oil flow through the circuit leak-off nozzles will in consequence also be reduced. With the less oil flow the size of the cooler becomes uneconomically increased, or in extreme cases, the slip heat generated cannot be removed within an acceptable temperature for the oil.
A design of thermostatically operated valves responsive to the oil temperature leaving the working circuit has therefore been evolved, and arranged for screwing into threaded bosses on the fluid coupling inner casing, as with conventional leak-off nozzles, CQEVs or DQEVs. When the temperature sensed by the valves reached a pre-determined limit, they automatically open to increase the effective nozzle escape area, and thereby the oil flow through the oil cooler.
Fig. 12 illustrates that under full speed operating conditions, the effects of centrifugal force will maintain the ball in the valve shut position. A small amount of oil will circulate through the working circuit and cooler via the leak-off path indicated.



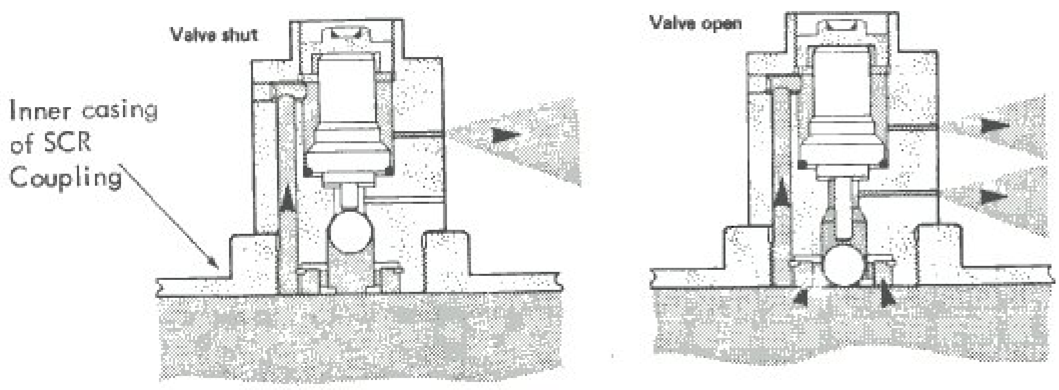


Fig. 12

Rise in the oil temperature will cause the plunger of the thermostatic element to extend, move the ball off its seat and increase the flow of oil circulating through the cooler. The valve will automatically shut when the circulating oil has cooled to normal operating temperature.

Usually these valves will be used in conjunction with normal centrifugal or diaphragm emptying valves, as illustrated, and therefore the fluid coupling inner and reservoir casings are modified to accommodate both sets of valves.

One of the most recently commissioned major coal handling facilities has been the Stockyard Conveyors at, the South African power station of Lethabo, on which 38 Scoop Control Couplings, all fitted with the ATLC are employed, at motor ratings up to 600 kW @ 1480 rpm. On seven of the double drivehead conveyors, there is a requirement to achieve a 25% full speed for belt inspection purposes, and hence the primary drive couplings are fitted with thermostatic valves, and a special latch type stop on the ATLC mechanism so that the scoop lever can be manually moved to the slow speed setting. A limit switch is incorporated to signal that belt inspection is in progress, and to prevent inadvertent starting of the secondary drive motor.

6.3 <u>SCR Couplings with "Power Memory Unit" Control</u>

Advances in conveyor technology, including the introduction of the steel-cored belt, have imposed further limitations of the starting torques, and today 125% FLT is a normal requirement. On the other hand, it has been accepted that a blockage on a long belt conveyor inevitably leads to belt damage, and overload torque protection is no longer sought. It is, however, usual to set the motor

current trips to a level related to that required during the acceleration phase, which confers protection against steadily applied overload during normal running.
Furthermore it is acknowledged that, where a conveyor brake is fitted, the timing of the brake release during the starting phase is a vital factor in attaining a smooth breakaway followed by a soft initial acceleration. While this aspect is of particular importance on inclined belts, a badly set brake release can still adversely affect the fluid coupling performance on a horizontal installation. Fig. 13 illustrates the situation for a twin drivehead conveyor where the coupling scoops are moved continuously through their full travel by a simple single rate actuator with full account yet to be taken of brake release and rate of coupling filling. By careful site adjustment on a trial and error basis, the situation can be improved as shown in Fig. 13b., but still not to the desired degree of precision.

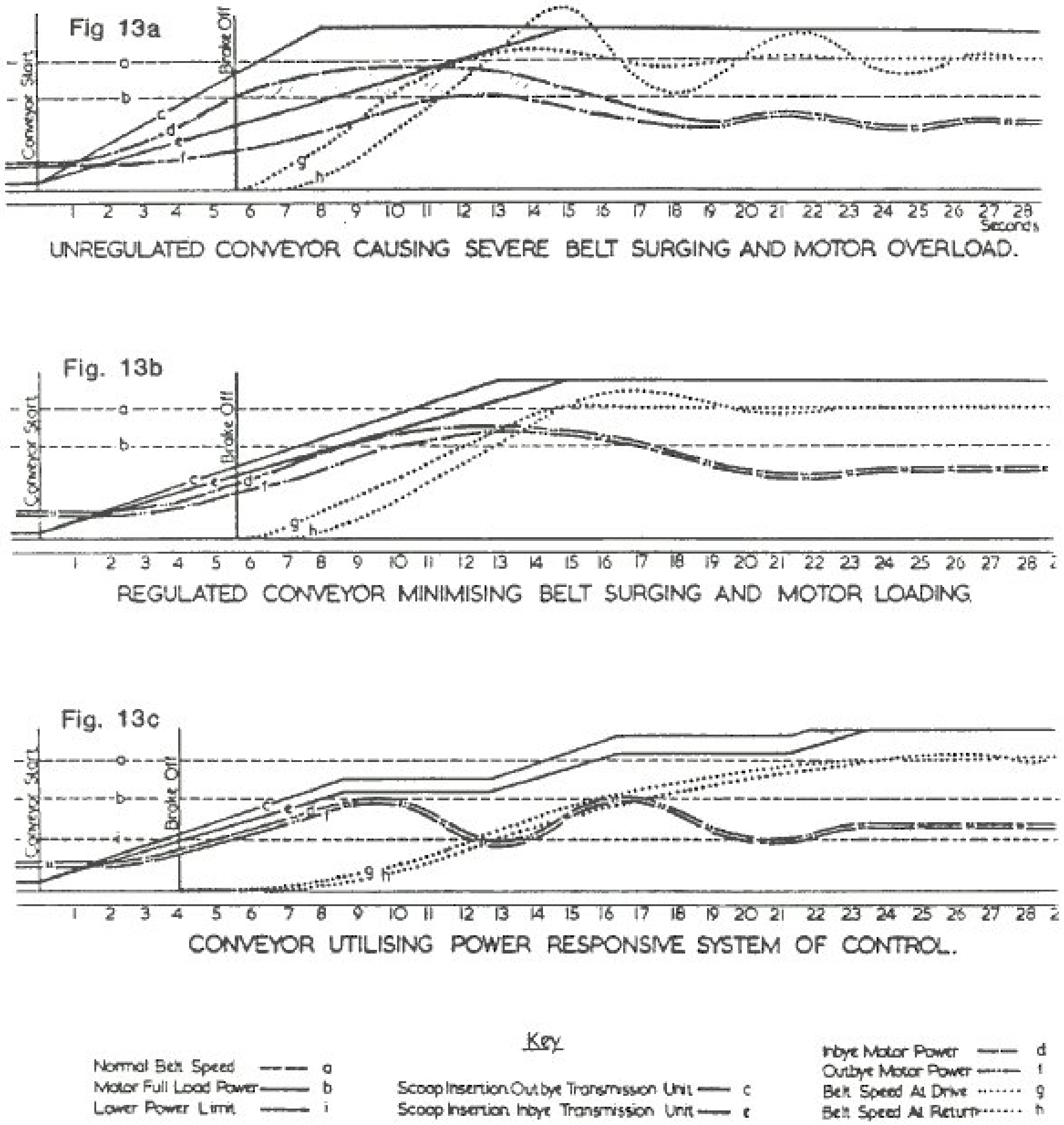


Fig. 13

To achieve low starting torques of the order of 125% FLT and to release and re-apply the brakes at the correct points in the starting and braking cycles, one on the UK conveyor makers has evolved an electro-hydraulic scoop actuator, whose control module incorporates a computer with memory capability for controlling the release of the conveyor brake. During normal running the memory is regularly updated on the prevailing motor load. On shutdown the brake is applied when the conveyor has fallen in speed to a pre-selected level, as detected by a conventional pick-up probe, or after a pre-determined time from switching off the motor.

At the re-start the microprocessor triggers the scoop movement towards "Coupling Full" at the appropriate rate, and the computer monitors the increasing load imposed on the motor. When the motor load reaches the level obtaining before shutdown, or some pre-computed proportion, the brake is released, and a smooth breakaway ensues.

If at any time during the starting phase the motor load rises beyond the set level, then the coupling scoops are locked until the transient overload has been relieved. Fig. 13c) records the site results of such on start-up. Reference 4 describes the site testing and commissioning of this main drift conveyor in greater detail.

7. <u>Scoop Trimming Fluid Couplings applied to Higher Duty Conveyor Drives</u>

7.1 <u>Inherent Characteristics</u>

This type of fluid coupling is particularly relevant to conveyors requiring very protracted start-up times (several minutes or longer), having high drivehead horsepowers (1MW or more), requiring extremely close control of the starting torque (110% FLT or lower).

The provision of a separate sump constitutes a valuable "heat sink" whose thermal capacity can be used to help absorb the heat generated during start-up. In fact, even if a cooler is fitted, its major contribution at least during the initial start may be the additional thermal inertia it brings to the system. For subsequent re-starts, with the fluid coupling already at working temperature, then the dissipation capability of the cooler becomes significant.

As part of an on-going product development programme, and using a simple open-loop, time based actuator, a new design or working circuit was evolved.

The inherent characteristics of this special working circuit are graphed in Fig. 14 which shows the flatness of the traces for fixed scoop positions.

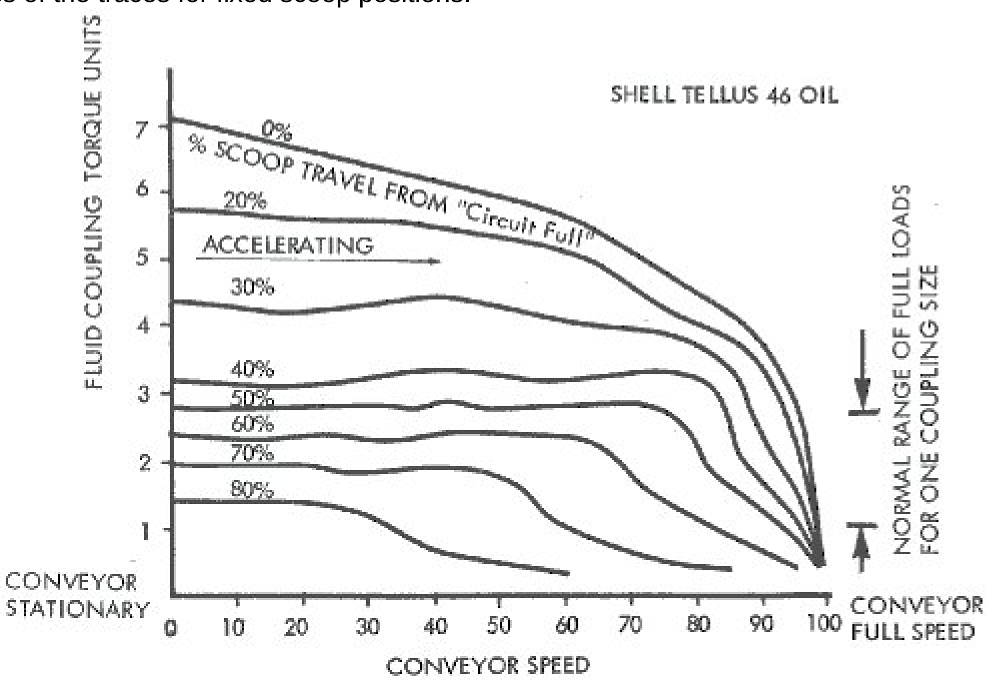


Fig. 14

A number of scoop trim couplings fitted with this circuit are in successful operation on main colliery drift conveyor duties in the UK, and in Australia. In every case, operation is with N.T.P.E. fluid, motor powers are up to 750 kW (1000 hp) at 1480 rev/mm, and in most instances the conveyor has twin driveheads with the fluid coupling scoop tubes mechanically ganged together, and controlled by a simple single rate actuator moving the scoops continuously towards "coupling full".

7.2 Scoop Trimming Couplings combined with Fully Modulated Actuator and Microprocessor Based Closed Loop Control

With increasing complexity of conveyor installations it is no longer sufficient simply to hold the applied torque to some pre-determined percentage of the motor rated value. With such simple controls, then on a lightly loaded conveyor, the acceleration becomes much more rapid than under full load conditions. Whilst excessive stresses may not be induced in the belt plies, there could certainly be a danger of the load material being spilled, or with the belt lifting off the idlers at transitions between horizontal and vertically inclined sections.

In the same way, a requirement can arise for controlled braking sequences, sometimes to limit belt stress and risk of belt bunching or changes in profile from horizontal to inclined runs, and vice versa. Additionally, in the case of complex multiple installations in which individual conveyors receive the discharge from a preceding conveyor and discharge on to a succeeding conveyor, there could be a need for all the conveyors to stop in the same time period regardless of individual load and other parameters. In this way a loss in production time can be avoided that is otherwise absorbed in running-off conveyors in sequence prior to shutdown, and running the material back on to each conveyor again on start-up.

There is therefore a need for a control that can give a pre-selected relationship between conveyor and speed and time from motor switch-on or switch-off at any instant during accelerating or decelerating sequence. In other words, these speed/time profiles can be selected at will. In a rather more simple approach to the problem, a system of "same time starting" and "same time stopping" can be used. Since, however, there will usually be a need to limit the motor current drawn during start-up to some desired level, as described earlier, then clearly the operation of this parameter limit has an overall effect on the time taken to start or stop the conveyor.

A scheme has therefore been evolved (Reference 5) as shown on Fig. 15 which is based on an underground installation where a full measure of flameproofing would be required, but in a normal industrial or above-ground mining environment, these additional measures would not be relevant.

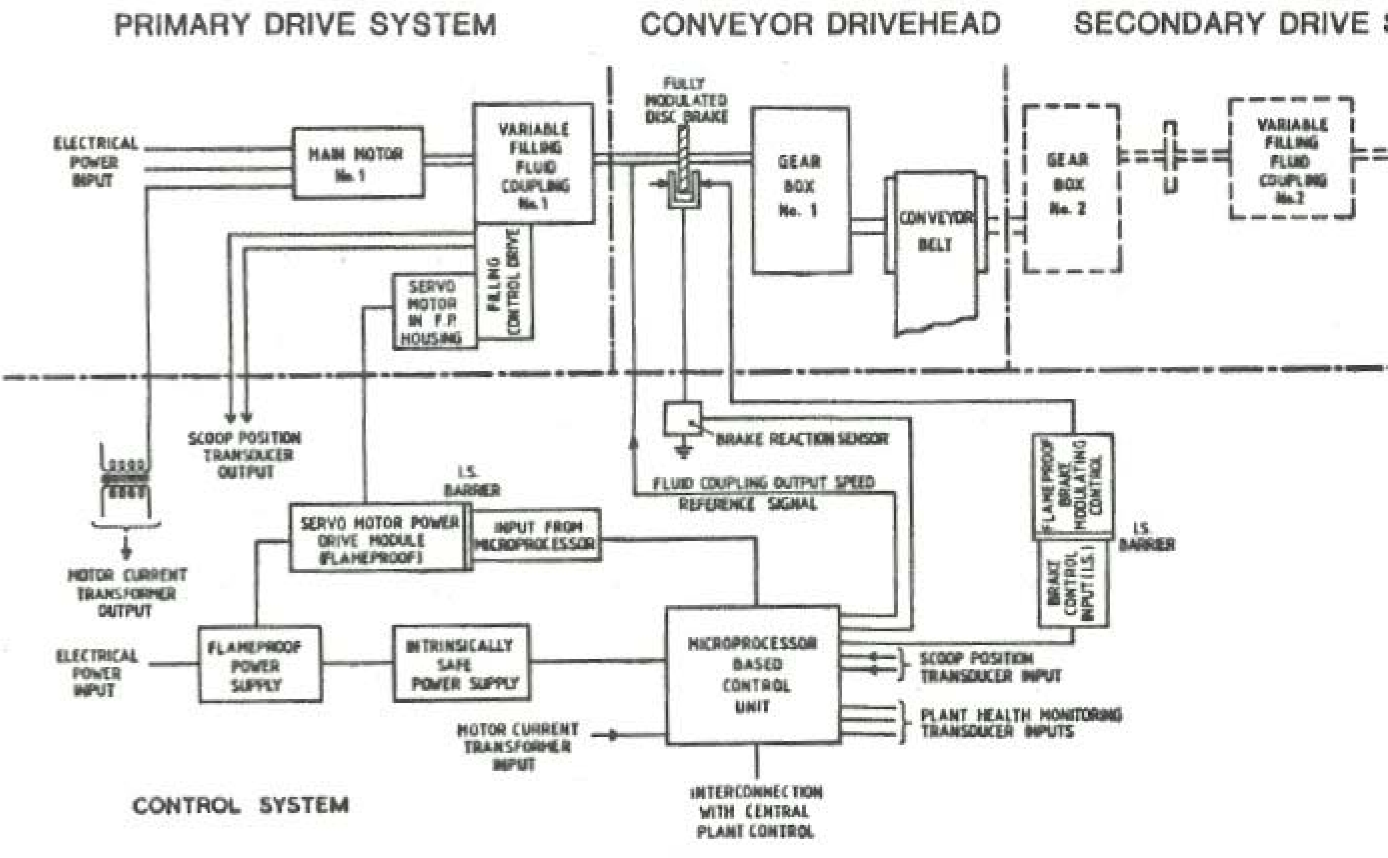


Fig. 15

At start-up, the disc brake on the fluid coupling output shaft would be applied with the variable filling fluid coupling in the "empty" condition. When the necessary plant health and other pre-start checks had been satisfactorily completed, the main motor would be energised, and the servo motor would power the scoop control drive such that torque resisted by the brake ultimately was just into the same rotation as that for conveyor forward movement.
The brake sensor would then signal that conveyor breakaway level had been attained.
The brake sensor could either be a strain gauge on the brake framework or, alternatively, a torque sensitive brake.
At this stage the brake would be released and thereafter the conveyor accelerated to speed following the relationship between time and speed at any instant as required, using the fluid coupling output speed reference signal as the measuring parameter. If in fact at any stage in this start-up sequence the driving load became regenerative, then the rate at which the conveyor gathered speed could be checked, as appropriate, by the brake. Under these conditions, the filling of the fluid coupling could be limited so that an excessive torque was not handled by the brake.
For a shut-down sequence the emptying of the fluid coupling and application of the brake would again be effected in such a way through the appropriate controls to achieve the required deceleration time ramp. Here again, the control could equally well cater for a regenerative condition.
8. The Choice between Fixed Filling and Controllable Filling Designs
This choice may sometimes become commercially contentious. However, three simple initial observations are:

a. The fewer components used in the construction of the fixed fill coupling will make it less in first cost than the controllable fill unit.
b. The only low and medium power circumstances in which, there could indisputably be no case for using a fixed fill unit would be those in which the conveyor needed to be started and stopped more frequently than could be permitted by just switching the motor on and off. Common limitations on the latter are those of electrical supply capacity and motor thermal rating.
c. All leading present day fluid coupling manufacturers will regularly offer their fixed fillunits for conveyor drive applications at 4-pole motor speed ratings up to 4/500 kW, the upper limit sometimes being fixed by the capability of the largest frame size in the particular range.

However, an assessment based only on the nominal nameplate rating of the drive ignores the many aspects that have to be satisfactorily resolved, before advantage may safely be taken of the lower capital cost of the fixed fill coupling.
In selecting a fluid coupling for a given duty there are always three criteria to be satisfied.

a. The mechanical capabilities, such as torque ratings of shafts and fastenngs, and the ability of enclosing casings to withstand centrifugal loadings. Resolution of these aspects is a mechanical design exercise, and is not a problem in the present context.
b. The hydraulic performance of the working circuit. In this instance the coupling must limit the acceleration torque appropriately and return an acceptably low top speed slip. In the case of a single drivehead conveyor, this is in itself usually sufficient. However, on multiple drivehead installations, not only must the torque be held within acceptable hints, but the slip must also be a prescribed value, to achieve load balancing. Often this can only be achieved using a controllable fill fluid coupling, particularly if for commercial reasons, the drum diameters cannot be held within very close tolerances. Variation in conveyor demand at different loadings over a period and with changes in ambient conditions can make the more sophisticated design essential to achieve sufficiently low belt stressing at start, and sometimes during stopping as well.
c. Removal of the slip heat generated, both during starting and running, without undue temperature rise. With a controllable filling design, adequately rated cooling equipment

can be relatively easily provided. With a fixed filling unit this can only be achieved by self dissipation, which may be inhibited by installation of the coupling within a bell housing for safety reasons, high ambient temperatures, and the fact that, if the conveyor is not running, then the dissipation is of very low order.

Again, as with the hydraulic performance considerations, these aspects are relatively easy of evaluation with a single drivehead. With multiple drlveheads, sequential starting of motors to limit the maximum line current drawn is a common requirement, which could mean that fixed filling couplings on the motors started first reach very high temperatures before the conveyor attains full speed under the combined effect of all the drives.

Specifications may also include a minimum number of re-starts per hour, and in order that a fixed fill coupling can sufficiently clear the heating from one start before commencing the next cycle, it could need the drive to have run for some time after achieving each successful start. Where the requirement is for a number of abortive attempts to be made in succession, then either the frequency has to be relatively limited, or the coupling has to be allowed to reach a high temperature, which may shorten the fluid charge life. Should the coupling reach an unacceptably high temperature for any reason, even if this is detected by a non-contacting thermal trip feature and without the loss of fluid due to the operation of a fusible plug, then there could be a delay of say half an hour or more whilst the stationary coupling gradually cools down to normal temperature level.

The controllable filling coupling therefore confers great flexibility on the transmission, particularly in combination with a suitable control, these benefits becoming even more pronounced at the higher power ratings.

9. Conclusion

The fluid coupling, available in a number of standard design forms, can be combined with a direct on started squirrel cage motor to provide a simple low cost, totally reliable drive for a belt conveyor. In the more demanding applications, the fluid coupling can operate in conjunction with a control of appropriate sophistication, and if need be, a modulated brake, to meet currently known requirements of belt conveyor transmission technology.

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LIST OF ILLUSTRATIONS