BELTCON 1

BELT CONVEYORS - DESIGN, OPERATION AND OPTIMIZATION

PAPER A7

HYDRODYNAMIC COUPLINGS USED AS CONVEYOR STARTING EQUIPMENT

A. Roberson
Surtees and Son (Pty) Ltd

University of the Witwatersrand
S.A. Institute of Materials Handling
S.A. Institution of Mechanical Engineers

C O N T E N T S

1. SUMMARY

This paper discusses the general design and operation of the hydrodynamic coupling used as conveyor starting equipment.

We will briefly touch on the theory behind the hydrodynamic coupling and elaborate on the interaction between electric motor and hydrodynamic coupling as well as hydrodynamic coupling and conveyor via a gearbox.

Also we will elaborate on the difference between traction, "delay filled" and "scoop" couplings.

2.1 GENERAL DESIGN AND OPERATION OF THE HYDRODYNAMIC COUPLING

In the schematic diagram of a hydrodynamic coupling (fig. 1) the driving engine is at the left and the propeller of the driven ship at the right. Interposed between these two components are the basic elements of a hydrodynamic power transmission: a centrifugal pump and a Francis turbine with guide vanes, the two components being connected by piping and an oil reservoir which contains the operating fluid. The pump absorbs the mechanical energy supplied by the engine and produces kinetic energy which is absorbed by the turbine and then converted back into mechanical energy.

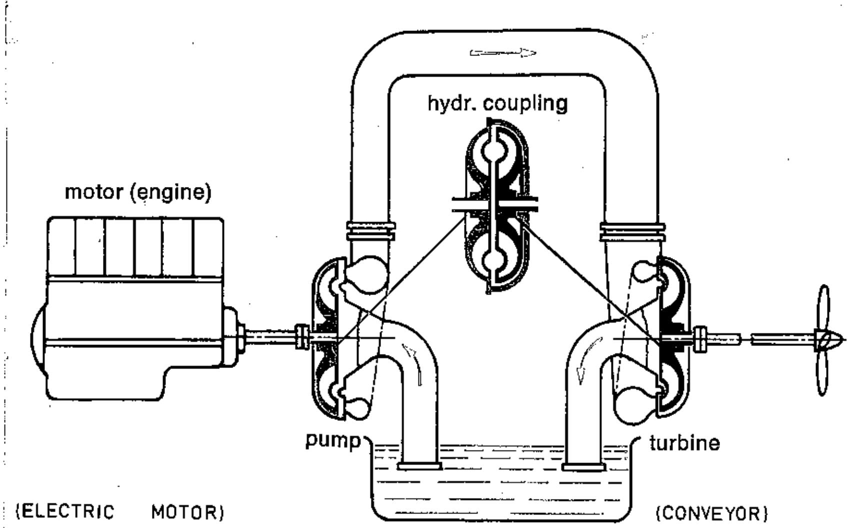


Fig. 1 Operating principle of a hydrodynamic coupling

It was Foettinger's idea to eliminate all avoidable sources of loss, such as draft tubes, spiral casing and the piping itself, and this resulted in a compact hydrodynamic coupling shown in fig. 2.

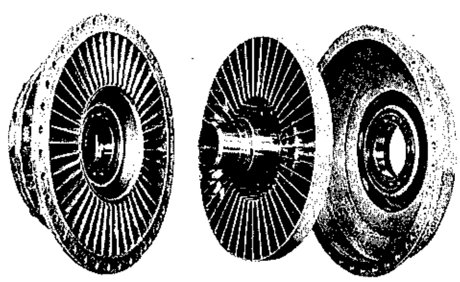


Fig. 2 Main components of a hydrodynamic coupling

The operating fluid circulates between the impeller and the turbine wheel over a minimum distance and transmits the energy exclusively by dynamic forces, if the negligible friction in the bearings and seals is disregarded. Since a hydrodynamic coupling incorporates no reaction member, 'actio' is equivalent to a 'reactio'. The input and output torques must be equal, and so the hydrodynamic coupling is a genuine coupling. The modern day hydrodynamic coupling is still being built according to this concept (fig. 2). From left to right: the pump impeller or primary wheel, the turbine wheel or secondary wheel and the shell, together form the coupling. Impeller and turbine wheel are concentrically supported in respect of each other: in the shell a rotating seal is fitted where the shaft passes through the shell. The blades are radically arranged and are parallel to the axis; they form the ducts for the operating fluid. The coupling is filled with mineral oil (usual filling between 50% and 80%) if used in the simplest form as shown. Water and other fluids can be used with minor constructional changes in the coupling.

The slip losses which cause the operating oil to heat up must be transmitted to the ambient air by convection through the shell of the coupling. Only in special cases continuous circulation and cooling of the operating oil are necessary.

The approximate torque characteristics of a hydrodynamic coupling as described above are shown in fig. 3 (torque as a function of the output speed n_2 and of the slip 's' (opposed direction). When the slip is large, the torque which can be transmitted is substantially larger than at the so-called minimum slip of 1,5 to 3,5%, for which the rated torque is designed for continuous operation. Slippage occurs only when the coupling is overloaded. Every slip value corresponds to a torque value according to the applicable characteristics. If a certain slippage occurs (according to the ratio $\frac{\text{input speed-output speed}}{\text{input speed}}$, the coupling absorbs a corresponding slippage torque, the full value of which is transmitted. These values can be determined with great accuracy; they depend on the temperature (viscosity) of the oil.

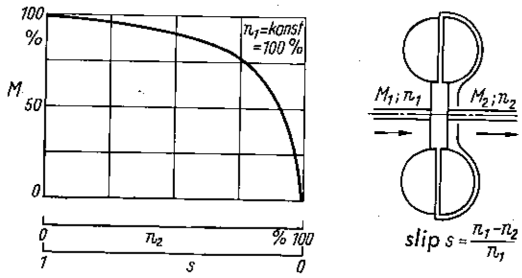


Fig. 3 Torque characteristics of a hydrodynamic coupling

The power that a hydrodynamic coupling can transmit is proportional to the cube of the input speed.

2.2 CONDITIONS JUSTIFYING THE USE OF A HYDRODYNAMIC COUPLING FOR THE START-UP OF DRIVEN MACHINES

The hydrodynamic coupling is used as starting coupling whenever the characteristics of driving engine (motor) and driven machine, as shown in fig. 4, would be incompatible.

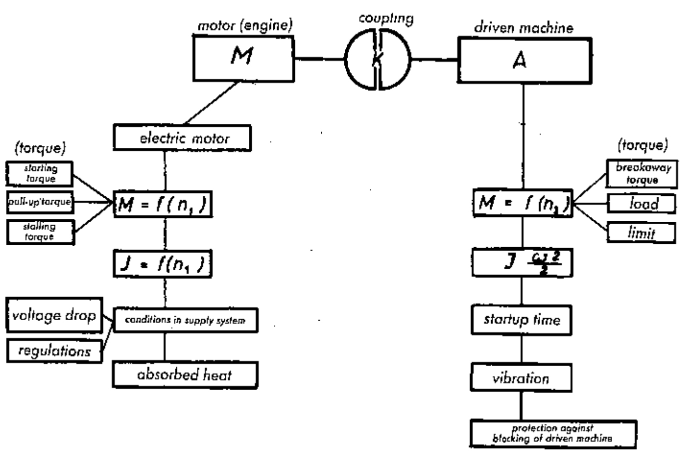


Fig. 4 Operating characteristics of motors (engines) and driven machines

As a prime mover the squirrel cage electric motor will be considered (fig. 5).

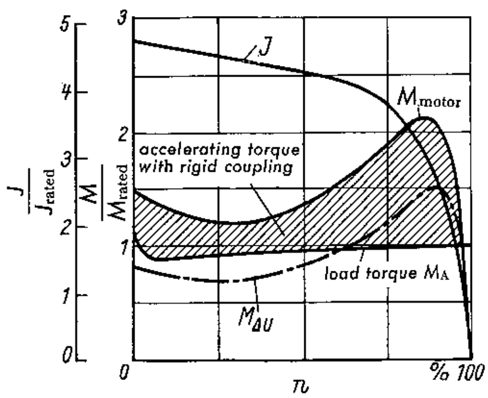


Fig. 5 Characteristics of a squirrel-cage motor

The characteristics of the electric motor are given by the torque and the current drawn by the motor as a function of the motor speed. The torque curve shows the starting torque and the stalling torque and between these values the pull-up torque. The effect which a voltage drop may have on these values must be considered. Sometimes the supply system makes it necessary to limit the maximum starting current and its duration. Furthermore, the heat which can be stored may also impose restrictions.

The driven machines of the most diverse types also have a torque curve as a function of their speed (fig. 6); this torque curve shows the breakaway torque, the friction torque and possibly also the permissible peak torque. The driven machine is further characterized by the mass amount of inertia which must be run up to a maximum speed. If this start-up is to be completed in a prescribed time, this requirement determines the necessary input power.

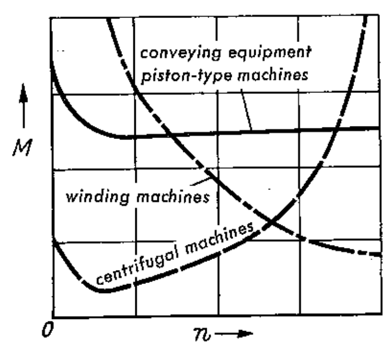


Fig. 6 Torque curves of various driven machines

Requirements which an interposing "starting" coupling should meet are illustrated below (fig. 7).

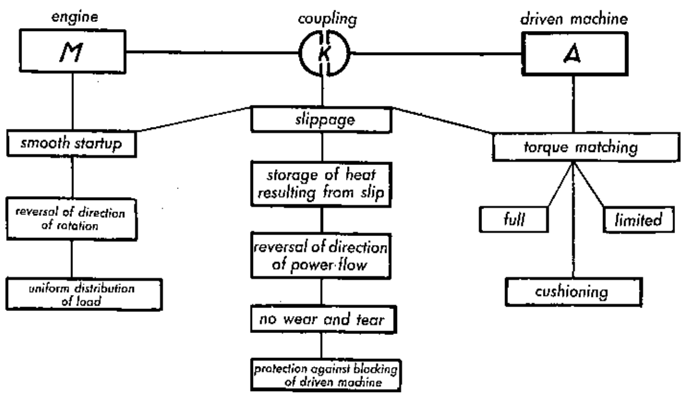


Fig. 7 Requirements which a startup coupling should meet

2.3 CHARACTERISTIC FEATURES OF THE HYDRODYNAMIC COUPLING

The hydrodynamic coupling meets the requirements in the following way:

As the transmitted torque 'M' varies as the square of the motor (engine) speed n_1, starting begins under no-load conditions, even if the output end is stalled, and running-up of the motor (engine) to speed is facilitated (fig. 8).

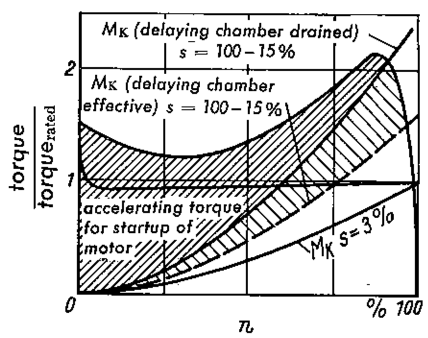


Fig. 8 Interaction between squirrel-cage motor and hydrodynamic coupling

It can be noted from this curve, which applies, by way of example, to an electric motor, that the difference between the torque curve of the motor and that of the coupling is available for the acceleration of the rotor of the motor. If desired, the torque of the coupling can be varied by variation of the oil filling. Thus, independently of the starting of the driven machine, the motor will run up to speed rapidly, passing through the range of high current consumption. This effect can be heightened by temporarily operating the coupling with reduced filling. This can be achieved with the arrangement shown in fig. 9. When the motor is started from standstill, the oil in the delaying chamber flows into the blade compartment with a certain delay (delayed filling). Three operating phases can be distinguished:

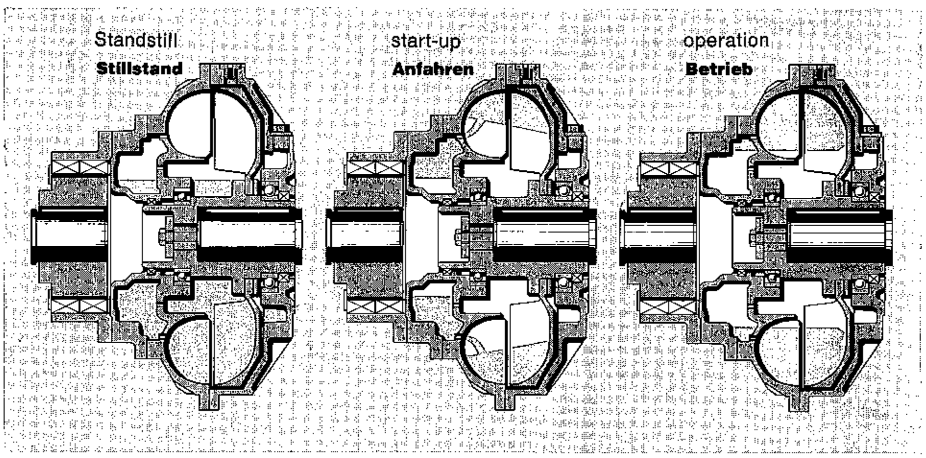


FIG. 9

1. With the coupling at standstill, the oil levels in the delaying chamber and the blade compartment are the same.
2. When the motor is running up to speed, the oil flows from the "delaying" chamber into the blade compartment through nozzles.
3. Under steady-state conditions at full speed, all the oil has been transferred to the blade compartment.

The shape of the torque curve as a function of the output speed n_2 of the coupling, as shown in fig. 10, applies to a coupling taken from the normal production. It may be noted that the rated torque lies close to the range of very low slip and can be chosen at will while the coupling is still in the design stage. Thus, in the region of higher slips, the coupling transmits a substantially larger torque which can be varied in wide limits by the filling. In this way, the torque requirements of the driven machine or of the motor (engine) can be matched. When multiple drives are used, the load can be uniformly distributed over the motors or engines, even if they are in different power categories.

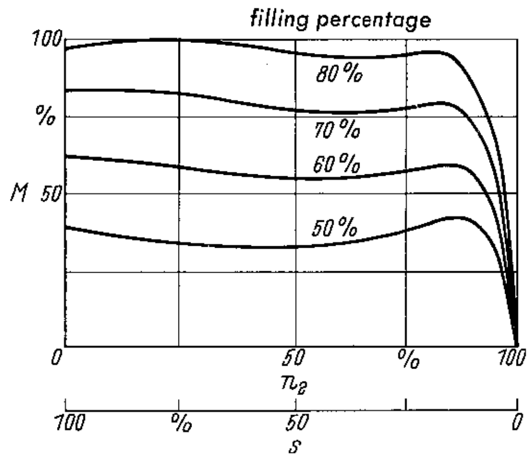


Fig. 10 Influence of the filling percentage on the characteristic

These curves, as shown in the first quadrant, can be projected so as to apply to the other quadrants, i.e. counter-braking or for the reverse direction of rotation or power flow, e.g. when using the motor braking. Thus, the requirement is met that the direction of rotation or the power flow is to be reversed. When folding the curves about the ordinate to the other side, the curves now represent the braking curves for operation in the opposite direction and, as a mirror reflection, above the point of synchronism the range of running above synchronisation, and the torque curve with the turbine wheel driving and the pump impeller driven as a function of the speed of the driven wheel. For such representations, in order to avoid confusion, the original symbols of the bladed wheels should be retained and not be interchanged when they change their function.

The above statements are correct, provided that the bladed wheels are of identical design. With minor deviations such as usually occur, corresponding deviations result in the torque curves in the corresponding quadrants.

The variable speed coupling (scoop coupling), shown in fig. 11, which is a special version of this coupling, permits variation of the filling of the rotating coupling at will. Most of these variable speed couplings are fitted with a so-called scoop tube, which continuously removes oil from the coupling and transfers it to the cooler. The coupling shown in fig. 11 is only one example of many versions.

It is to this external cooling circuit of the variable speed coupling which makes it particularly suitable for difficult start-ups, for which the standard coupling types would not meet requirements. The scoop tube controls the filling of the coupling - shown in fig. 11 - as the scoop tube compartment and blade compartment constitute a common vessel.
The edge of the radially displaceable scoop tube determines the inner diameter of the rotating oil annulus, and thus the oil filling in the interior of the coupling.

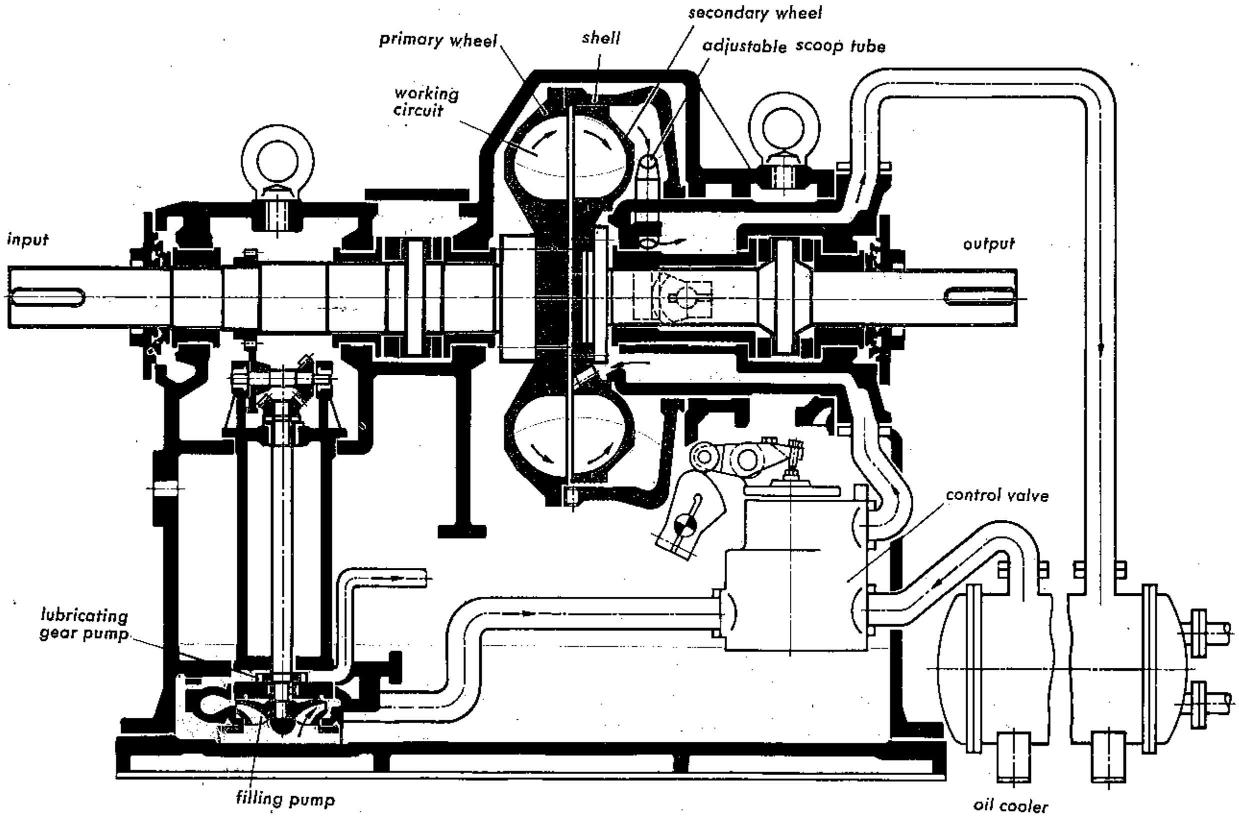


Fig. 11 General arrangement of a variable-speed hydrodynamic coupling

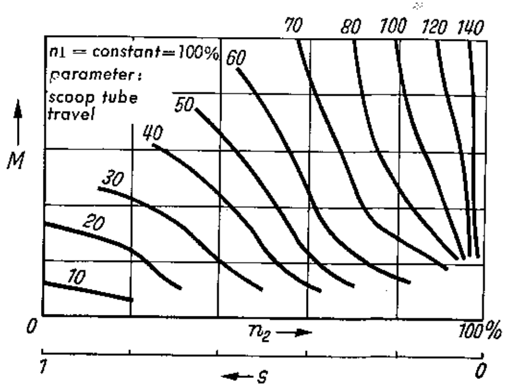


Fig.12 Characteristics of a variable-speed hydrodynamic coupling

2.3 COMPARISON BETWEEN TRACTION AND DELAY FILLED HYDRO-DYNAMIC COUPLINGS (FIG. 13)

The only constructional difference between the two types of couplings is the fact that one unit has a chamber (delay fill) in the primary wheel which holds approximately 20% of the working fluid. The emptying of this chamber can either be time or slip dependent. With the time dependent system, the chamber empties over a period of 20-25 seconds after motor start-up has been effected. The slip dependent coupling actually refills the chamber during conveyor (driven machine) start-up and only after conveyor has reached full speed does the chamber empty. Only recently has there been a development to increase the capacity of the delay fill chamber to almost double that of the standard unit.

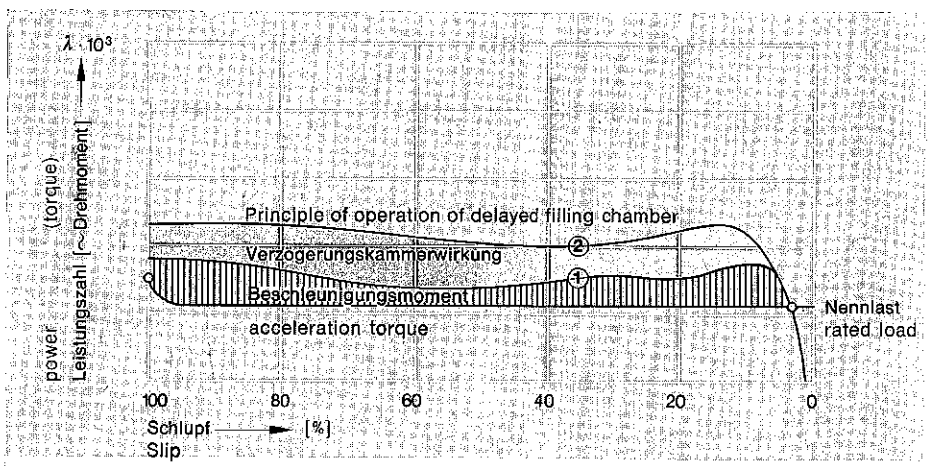


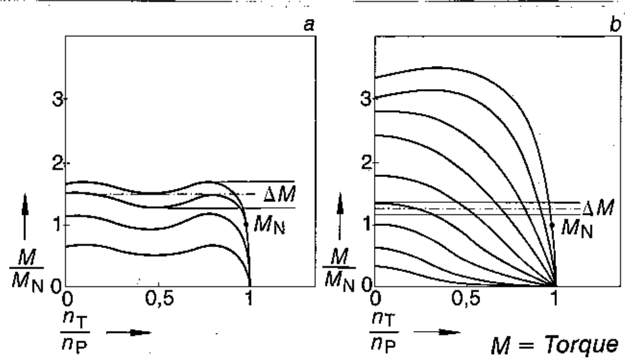
FIG. 13

Curve 2: Standard traction coupling (constant fill).

Curve 1: Delay fill coupling.

2.4 COMPARISON BETWEEN "DELAY FILL" AND SCOOP COUPLINGS

When the hydrodynamic coupling is used as a "heat sink", i.e. when very long conveyor start-up times are required, it is often advantageous to use a scoop coupling instead of a "delay fill" coupling, as the oil can be cooled externally. As can be seen from the typical characteristic curves (fig. 14), the constant filling coupling has a very "flat" typical curve whereas the scoop coupling has a "steep" curve more suited to speed regulation. However, speed regulation for bulk handling conveyors is not normally required.



M = *Torque*
N = *Rated ...*
P = *Pump*
T = *Turbine*
n = *Speed*

Fig. 14
Hydrodynamic couplings
Comparison of performance curves
a = Turbo coupling with constant filling
b = Variable-speed turbo coupling (adjustable coupling) with oil through-flow

Therefore, when using a scoop coupling to start a conveyor, it is necessary to limit the torque transmitted (i.e. the rate of scoop tube withdrawal) by an external means, i.e. either with a torque accelerating device or by electronic monitoring of the torque transmitted.

3.1 APPLICATION EXAMPLES

Delay Fill Couplings:

The highest powered conveyor to date driven by traction (delay fill) couplings is at the S.A.R. Loading Terminal at Saldanha Bay. The total installed drive power is 2 200 kW and is powered by 5 x 440 kW motors.

Sasol shaft belts have an installed power of 1 200 kW with a drive package of 2 x 600 kW.

Scoop Couplings

Anglo Power Collieries, Kriel Division (shaft belt), is a typical example of where traction couplings would not suffice due to design considerations. The starting torque of the scoop couplings is electronically controlled.

4. ACKNOWLEDGEMENT

In conclusion, I would like to thank Voith Turbo GmbH & Co. KG, Crailsheim, and their representatives, Surtees & Son (Pty) Ltd., for giving me the opportunity to present this paper.