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The SA Institute of Materials Handling
The SA Institution of Mechanical Engineering
Conveyor Manufacturers Association of SA Limited

**-DOWNHILL BELT CONVEYORS-
THE STARTING AND SPEED CONTROL THEREOF**

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The S.A. Institution of
Mechanical Engineering



Conveyor Manufacturers
Association of SA Limited



SA Institute of
Materials Handling

1. INTRODUCTION

Generally, most conveyors move material uphill, or along the surface of the earth, conveyor designers have been exposed to this type of design which has become reasonably simple. But a real challenge exists when considering downhill or regenerative conveyors.

This becomes a challenge to the designing engineers due to the conveyors natural instability under load. With increased tonnages and high negative lift conveyors and several hundred meters of drop, it has become necessary to develop an intelligent braking drive system to address their starting and stopping requirements under various load conditions.

This paper describes the critical design criteria of large regenerative conveyors and some of the advances in mechanical braking systems and drive control technology.

2. DESIGN REQUIREMENTS

Conventional uphill and overland conveyors require the design engineer to focus most of his design criteria on the starting and stopping, especially when considering horizontally curved belts to minimise the belt drift in the curve and also vertically curved belts to ensure that during starting there is no belt lift and during stopping there is minimal tension drop in the vertical curve. Downhill conveyors are even more critical due to their natural instability under load and to ensure material stability on the belt, i.e. if braking or starting is too rapid that the material does not avalanche "down the hill".

The design of such conveyors and the integration of links between the various options on brake and drive components, should be carefully considered for the best system design. One must consider all the load options and emergency braking, to produce an integrated reliable system. Then careful evaluation of the available drive, brake, and control options, should be taken into consideration.

3. DYNAMIC ANALYSIS MODELLING

One of the most powerful tools available today in design of conveyor systems is the use of computerised dynamic analysis modelling. Dynamic analysis modelling is the method which analyses a belt as an elastic system with real time dynamic response. The belt is modelled as a series of connected elastic springs with individual masses and damping properties. This technique is developed to predict the creation and propagation of tension and velocity waves in conveyors belts during transient operations. Once the static design has been completed, it is recommendable that a dynamic analysis must be done to determine the possible stop/starting problems that can occur.

As the mechanical braking system is the ultimate device to ensure that the conveyor does not run away, as in the case when using a backstop on an incline conveyor is to ensure that the conveyor does not run backwards. In both cases, these are safety devices not only to avoid damage to the conveyor but to personnel as well. Therefore it is imperative to make absolutely sure that the braking system for the downhill conveyor should be 100% secure and should be fail safe in the event of a power failure.

4. DRIVE AND BRAKE SYSTEMS SELECTION

The proper design and selection of the drive and brake systems is extremely important. This directly influences the accuracy of the starting and stopping controls, they have a direct impact on the ability to control dynamic instabilities. Speed of response, torque accuracy and repeatability, control predictability, reliability, and failure modes. These are among the parameters which have to be evaluated, combined with dynamic analysis modelling, directly influences the selection of the control program.

The drive and brake selection have to take into account the technical requirements, the cost, its reliability and its serviceability. The clients preferences must be considered with the required system maintenance, the site maintenance procedures and the expected competence of the maintenance personnel. Available support and spare parts availability are also important factors in remote locations.

An important consideration in the design of downhill conveyors is the drive's ability to deliver retarding torque below synchronous speed. All the major drive options, except for DC drives and eddy current drives, require initial brake control at very low speed to provide smooth acceleration and stopping of the belt. Inverter drives can provide retarding torque down to 8 percent speed, but usually still require brake control below this speed. Most commonly used drives cannot provide retarding torque until full speed and require brake control during the full starting sequence. This has a large impact on the design of the brake control and hardware since more energy is dissipated in the brake during starting than during stopping. This results from the increased torque required when the brake must resist both the gravity load and the motor driving torque during the start sequence.

It is very important to realise that the mechanical brake is the only means of stopping a loaded downhill conveyor in case of motor failure. This is true even when the selected drive can normally provide retarding torque. As a result, the brake system is one of the most critical components in a downhill conveyor. The brake and its control system must always be designed to safely stop the fully loaded conveyors from full speed and under any failure condition.

As is often the case in engineering design, the final choice is usually a trade off between cost, simplicity and performances. The best choice is the simplest, most reliable system which will do the job satisfactorily.

5. DRIVE OPTIONS

5.1 DC Drives

DC drives are available in any power configurations. They can provide both driving and retarding torque at any speed, and are available with quadrants control. Four quadrants control allows the drive to regenerate energy into the main electric grid.

DC drives are normally used when very precise torque and velocity controls are required, or when the conveyor needs to be run under load at low speed for extended periods of time. Their ability to regenerate power can result in substantial electrical savings for large horse power applications. Their ability to control speed down to a complete stop minimises the duty on the brake system which can be sized for emergency use only. Their major disadvantages are high cost and high maintenance requirements.

5.2 INVERTER DRIVES (VFD - Variable Frequency Drives)

Once limited to medium power applications, Variable Speed Inverter Drives are now available in high power, high voltage configurations. Most configurations can provide both driving and retarding torque at speed as low as 8 percent of full speed. Some inverter drives are available with four quadrants control.

An inverter drive can be bypassed when the conveyor reaches full speed. This increases the drive efficiency and decreases its duty.

Inverter drives are a good choice for conveyors which require accurate velocity control above 10% speed, or which need to be run under load over 50 percent speed for extended periods of time. They present similar advantages to DC drives, but require additional brake control in the very low speed range.

Their major disadvantages are high cost, high electrical noise, and sophisticated training requirements. Some types of inverter drives can generate an enormous amount of RF electrical noise, especially in the low to medium speed range, which can create problems with sensitive electronic control equipment.

5.3 WOUND ROTOR MOTORS (or slip-ring motors)

Wound rotor motors are a good choice for most large conveyors because of their low cost, predictable torque and simple maintenance requirements.

Wound rotor motors equipped with secondary step resistors can produce variable driving torque, but the timing sequence of the resistor steps must be checked for possible dynamic problems. Their major disadvantage is the inability to produce retarding torque until synchronous speed. This requires both the starting and the stopping sequences to be controlled by the brake.

5.4 FLUID COUPLINGS

Induction motors equipped with fluid couplings are also commonly used. They can be divided into two basic types: fixed oil fill or traction couplings and variable scoop or drain couplings.

Fluid couplings are a common way to provide soft acceleration control for low to high power applications. They are a good choice for conveyors because of their relatively low cost, reliability, easy load sharing capabilities and simple maintenance requirements. Scoop or drain couplings are often used where long start-up times are required, or to provide some degree of variable speed control.

6. HYDRAULIC DISC BRAKES

The "intelligent" braking system must have a controller requiring multiple feedback to a PLC, through the monitoring of the belt speed feedback, the brake torque can be controlled using a simple hydraulic valve to regulate the pressure. With this in mind, at no stage must the brake be oversized or setting to be high, as this will lead to over-tensioning the belt and possible disaster. Loop stability must be installed with control relating to valve response time, time delay in brake application and maximum rate of change in drive torque.

Hydraulic disc brake systems are available in all sizes and in many different configurations. They can be of the high speed or low speed type. They can be hydraulically applied or spring applied and hydraulically released. They are available with a variety of hydraulic power units, single solenoid valve control proportional valve control, with the latter being very expensive.

High speed disk brakes are located on the high speed side of the reducer and are usually small due to the lower torque required on the motor side of the reducer. Their main advantages are low cost and accurate torque control. An added advantage in some designs is the natural flywheel effect of their discs which reduces the dynamic sensitivity of the conveyor. Their main disadvantages are small heat capacity and increased duty on the reducer. They also offer decreased safety compared to low speed brakes, as a reducer or low speed coupling failure results in the complete loss of braking capacity. High speed brakes are commonly used on uphill and flat conveyors, where their main functions are belt sequencing control to eliminate transfer chute pluggage, and tension control.

Low speed disc brakes are located on the gearbox low speed shaft or drive pulley shaft. They are much larger and more expensive for the same torque requirement. Their main advantages are increased safety, high thermal capacity due to larger disc sizes, and increased pad sweep area. Low speed brakes are a natural choice on downhill conveyors where their increased safety and large thermal capacity are essential.

Spring applied calipers are used whenever a fail-safe design is required. In these brakes, the pad pressure is supplied by sets of mechanical springs, and hydraulic pressure is used to release the pads. This ensures that the maximum braking torque is always available, even during power failure. Spring applied calipers offer down to 25 millisecond response time and good torque control. Hydraulically applied, calipers boast quicker response time, but do not offer the fail safe facility of spring applied brakes.

6.1 SOBO soft braking option system

High speed hydraulic fail safe spring applied disc brake incorporating tacho feedback linked to a PLC to control braking sequence.

[refer to fig.1 and 2]

The aim of the SOBO system is to prevent the high braking torque that is the result of normal braking with full torque applied.

The normal approach to solving this problem would often be to control the braking torque regulating the pressure in the brakes using a proportional valve. This is however quite an expensive way to do it if no very special requirements are needed.

In the SOBO system this is obtained by using a relatively simple hydraulic regulation unit, based on directional valves and throttling, and a dedicated electronic controller. During braking the actual rpm is measured and compared with an ideal sequence expressed as rpm versus time. If the speed is below that required, the brake torque is reduced, and vice versa.

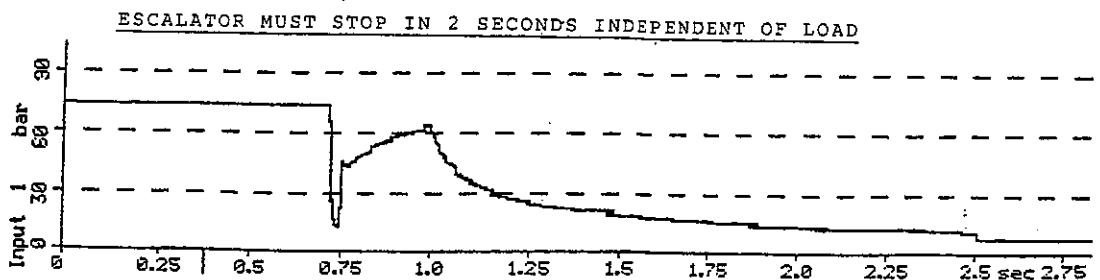
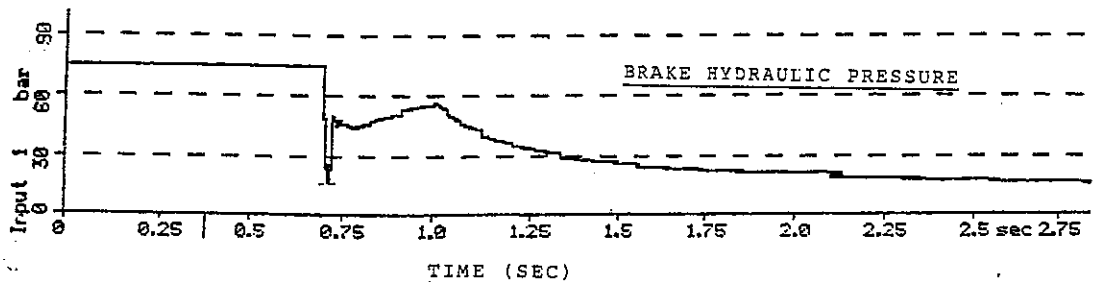
If overspeed is detected the system can be designed to react according to specifications, i.e. a conveyor could be braked down to the nominal rpm, where a wind turbine would be braked to a full stop. More rpm limits with different reaction patterns can be built into the system. For safety reasons the brake is fully engaged if an external emergency chain has been broken.

The SOBO system ensures:

- A specified braking time can be kept, almost independently of the applied load.
- The braking torque during soft braking will not reach the maximum level.
- The overshoot and oscillations at the end of the braking sequence are minimised or eliminated.

To ensure a very fast response in case of emergency braking, one of the directional valves is drained directly to the tank, bypassing any throttle and accumulator that may slow down the system.

Test done on escalator supplied by Otis in New York [Refer to test no. 1 below].



The main parts in the SOBO system

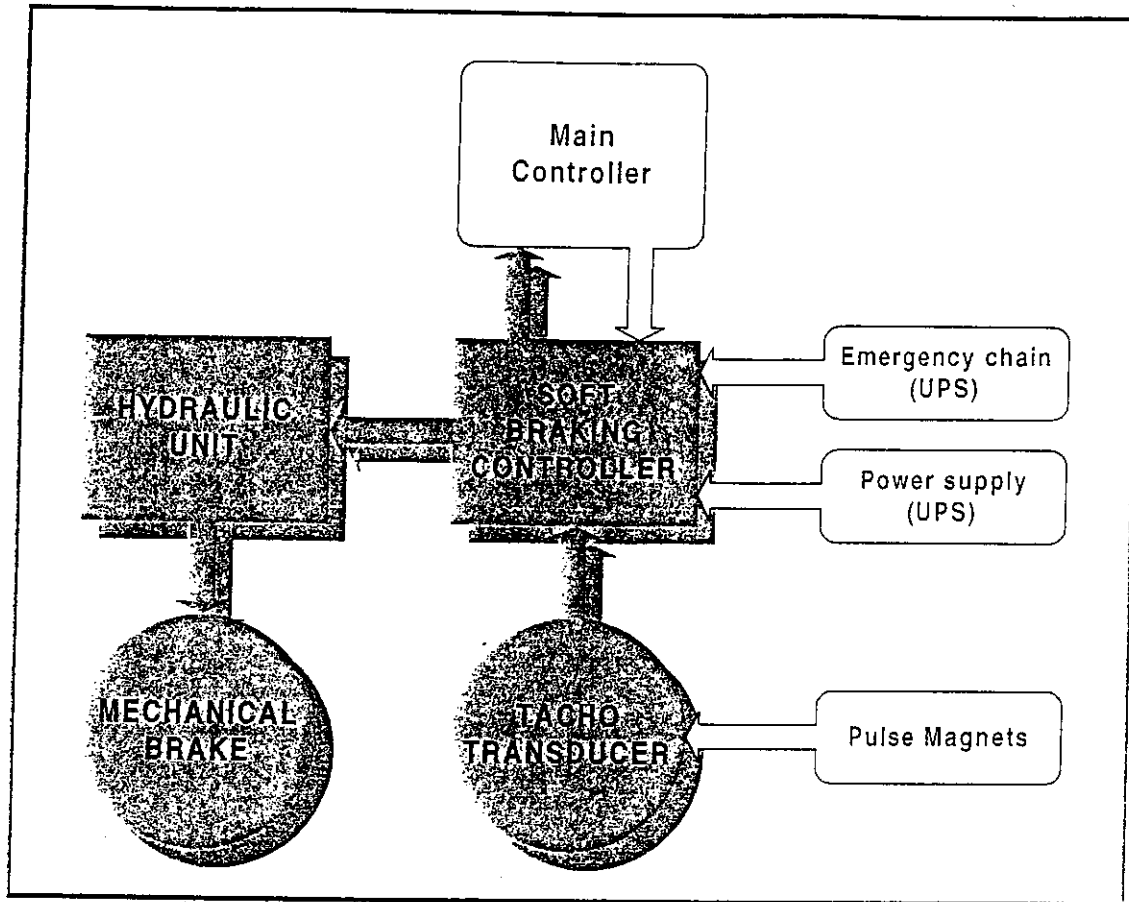


FIG. NO. 1

The Input/output connections

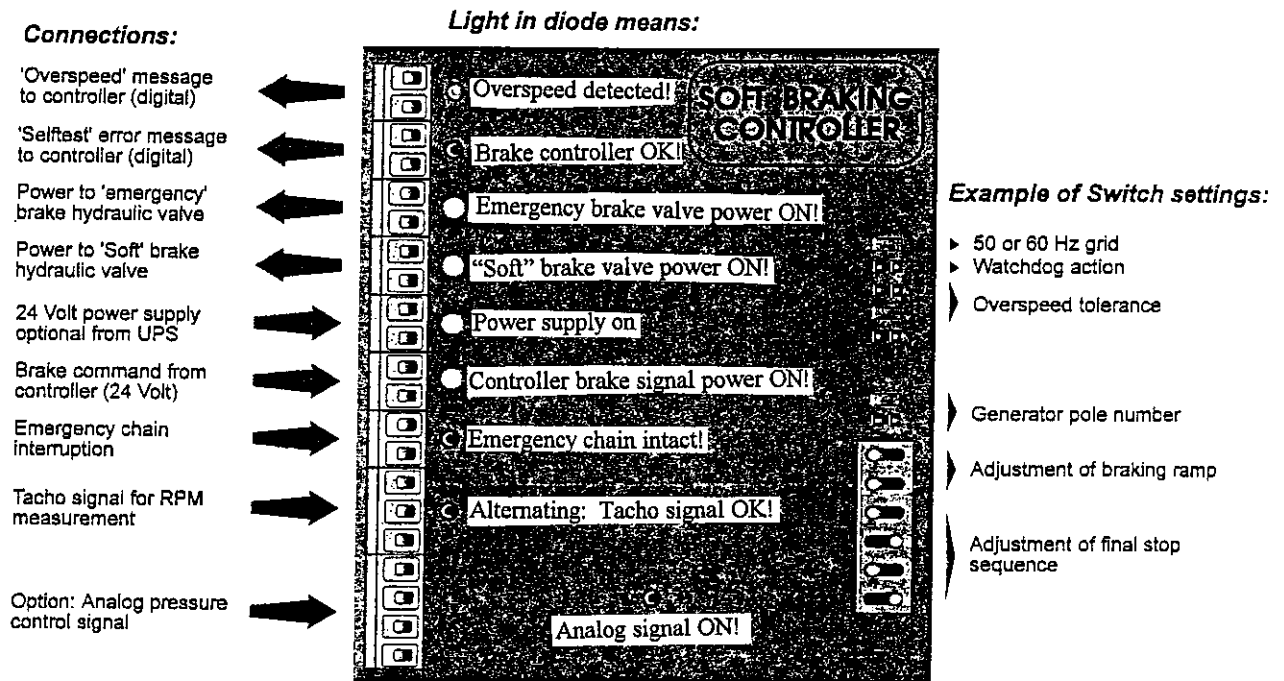


FIG. NO. 2

7. WELGEDACHT MINE DOWNHILL CONVEYOR

Welgedacht Mine is situated at Utrecht near Newcastle in Kwazulu Natal. The conveyor was designed and installed by Ingwe, using redundant components originally from Majuba mine which had been shut down. [Refer to attached Fig. No. 3 for the profile of the conveyor]. This conveyor played a vital role for in mine's life and was built and commissioned within 6 months. The drive selected was 185 kW, combined with a fluid coupling (Voith 562 TSS) through a helical parallel gearbox on a single drive pulley at the tail of the conveyor.

MATERIAL SPECIFICATIONS

1. Material conveyed	Coal
2. Design tonnage	1200 t/h
3. Bulk density	950 kg/m ³
4. Surcharge angle	20 kg
5. Lump size and percentage	300 mm x 20.00 %
6. Lump shape factor	1.40
7. Chute drop distance	2.00 m
8. Abrasive index	VERY
9. Environmental condition. (cema index)	DIRTY
10. Maintenance condition... (cema index)	POOR
11. Hours in service per day	24

FULL EVENLY LOADED

BELT SPECIFICATION

1. Width	1200 mm (1123.5 /LUMPS)
2. Speed	2.5 m/s
3. Type of belt carcass	STEEL
4. Breaking strength	2200 N/mm
5. Weight	56 kg/m
6. Cover thickness	6 X 6 mm
7. Elasticity	149731.4 N X 1000
8. Sag allowable on carry side, %	500 %
9. Edge distance / bed depth	120.608 / 221.893 mm
10. Impact force from lumps	368.778 N-m

IDLER AND ANCILLARY SPECIFICATIONS

	CARRY		RETURN
	SPECIAL		SPECIAL
1. Idler series			
a. Idler angle	35 DEG.	5	DEG.
b. Diameter	127 mm	127	mm
c. Load rating	19700 N	19700	N
d. Adjusted load capacity	14184 N	15288	N
e. Applied load at max. spacing	2228 N	1673	N
f. Rotating height	30 kg	28	kg
g. Number of rollers	3	2	

MOTOR / REDUCER / BRAKE SPECIFICATIONS

1. Motor nameplate Kilowatts	185
2. Motor synchronous rpm	1450
Running rpm	1469
3. Breakaway torque Nm	-56.9
4. Starting torque lim. Percentage	135
5. Drive inertia at motor kgm ²	6.1
6. Drive efficiency	0.950
7. Drive friction factor, running	0.250
acel/dec	0.400
8. Gearbox ratio	38.459
9. Brake torque low-speed (Nm)	39771
10. Brake energy absorbed (kW - secs)	3182
11. Acceleration Time	3.655 sec. Take-up Travel 7.2m
12. Braking Time	40 sec. Take-up Travel 4.3m

FLITE NO.	LENGTH (m)	HEIGHT (m)	IDLER SPG (m)	SAG TEN (N)
1 CARRY	30.00	0.00	0.45	6963.
2	597.00	-90.00	1.20	18567.
3	50.00	16.00	1.20	18567.
4 RETURN	-1.00	-1.00	3.05	18567.
5	-50.00	-16.00	3.00	18567.
6	1.20	1.00	0.00	7297.
7	-597.00	90.00	3.00	7297.
8	-30.00	0.00	3.00	7297.
9	-1.00	0.00	0.00	7297.
10	-1.20	1.00	0.00	0.

STATION TENSION SPECIFICATIONS

PT.	ITEM	RUNNING (N)	EMPTY (N)	ACCEL. (N)	BRAKE (N)
1	TAIL	182376	101700.	78167.	191898.
2	CONVEX R	184454	103076.	85494.	193496.
3	CONCAV E R	45583	67751.	35066.	46543.
4	HEAD P	77764.	77764.	74938.	78023.
5	CONCAV E R	77416.	77416.	75072.	77630.
6.	TAKE-UP	70000.	70000.	70000.	70000.
7.	CONVEX R	70928.	70928.	71108.	70912.
8.	CONVEX R	128868.	128868.	156007.	126388.
9.	DRIVE	129291.	129291.	157769.	126689.
10.	TAIL DR.	181183.	100508.	76279.	127134.

INPUT TAKE-UP TENSION 70000. N

DECLINE ONLY - LOADED

Running Kilowatts	-181.1	0.0
Breakaway Torque	-87.2	0.0
Break torque low-speed (Nm)		53572.
Brake energy absorbed (kW-Secs)		4286.

STATION TENSION SPECIFICATIONS

PT.	ITEM	RUNNING (N)	EMPTY (N)	ACCEL. (N)	BRAKE (N)
1	TAIL	204535.	101700.	86621.	213620.
2	CONVEX R	206614.	103076.	94925.	215219.
3	CONCAV E R	67752.	67751.	60954.	68276.
4	HEAD P	77764.	77764.	74413.	78023.
5	CONCAV E R	77416.	77416.	74636	77630.
6.	TAKE-UP	70000.	70000.	70000.	70000.
7.	CONVEX R	70928.	70928.	71141.	70912.
8.	CONVEX R.	128868.	128868.	161053.	126388.
9.	DRIVE	129291.	129291.	163065.	126689.
10.	TAIL DR2	203342.	100508.	84563.	126778.

The above calculations show that with the belt fully loaded evenly, the regenerative power is approximately 125 kW. In the worst condition, with the decline loaded only, the regenerative power calculated was 181 kW, therefore a 185 kW motor was installed. Brake torque required was set at 47 kNm for the worst condition.

Two brake calipers were selected and joined with one hydraulic power pack, to reduce the axle loads on the low speed pulley. A 1300mm diameter (35mm thick) disk was supplied which was fitted via a rigid flange coupling to the shaft on the non-drive side of the drive pulley. [Ref. To Fig. No.4].

The SOBO system was supplied including a optical pick-up for speed or tacho generation feedback to the PLC (fitted to low speed side for safety). A uninterrupted power supply (UPS) was also supplied in case of a power failure.

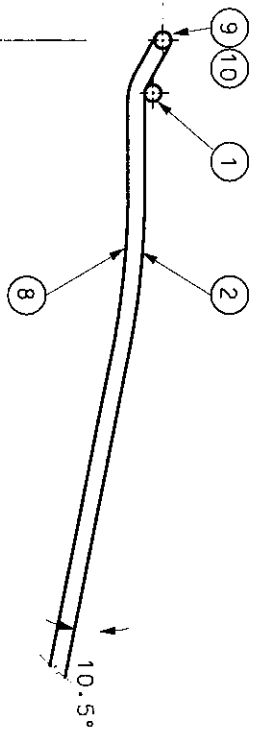
Disk brake material strength and heat generation calculation/checks

Material data for brake disc:			Steel
Length expansion	(1/grad)	=	1.20E-05
Conductivity	(W/m & grad)	=	50.0
Specific heat	(Ws/kg & grad)	=	500.0
Density	(kg/m ³)	=	7850.0
Elastic modulus	(N/mm ²)	=	205000.0
Poisson number	(-)	=	.300
Disc brake data:			
Braking torque total	(Nm)	=	47000
Disc diameter outer	(m)	=	1.300
Disc thickness	(m)	=	.035
Disc speed, start	(rpm)	=	38.0
Braking time	(sec)	=	40.0

Result: with one stop

Disc temperature surface	(grad)	=	116.4
Disc temperature maximum	(grad)	=	135.5 (350 max.)
Disc tension.....maximum	(N/mm ²)	=	164.4 (500 max.)

TAIL DRIVE
WITH BRAKE FITTED



WELGEDACHT DOWNHILL CONVEYOR

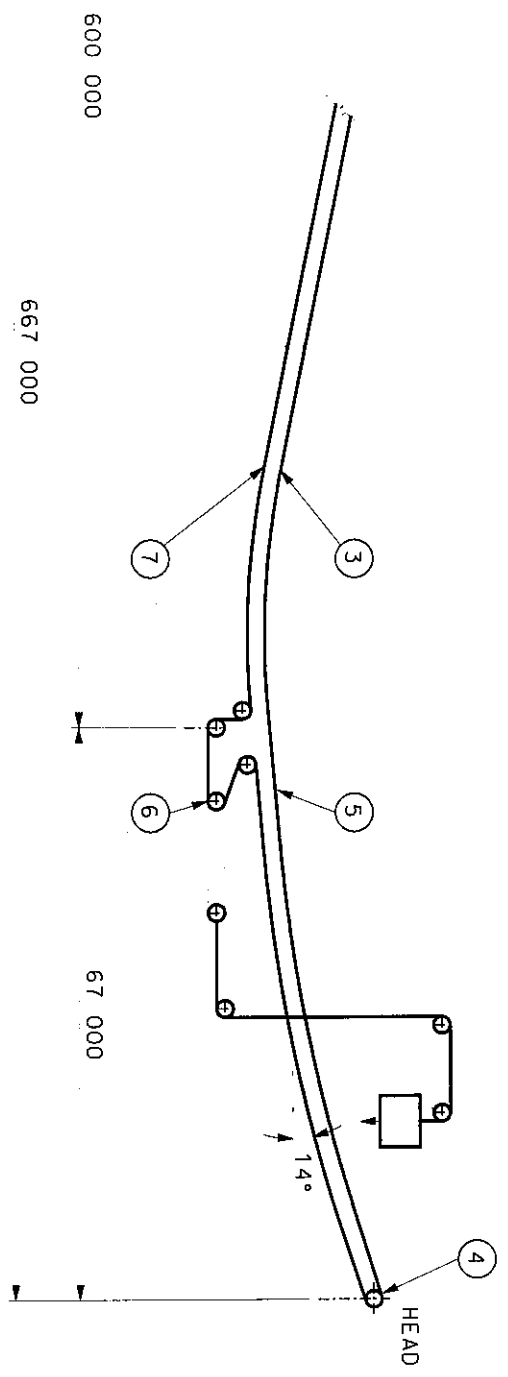


FIG. NO. 3

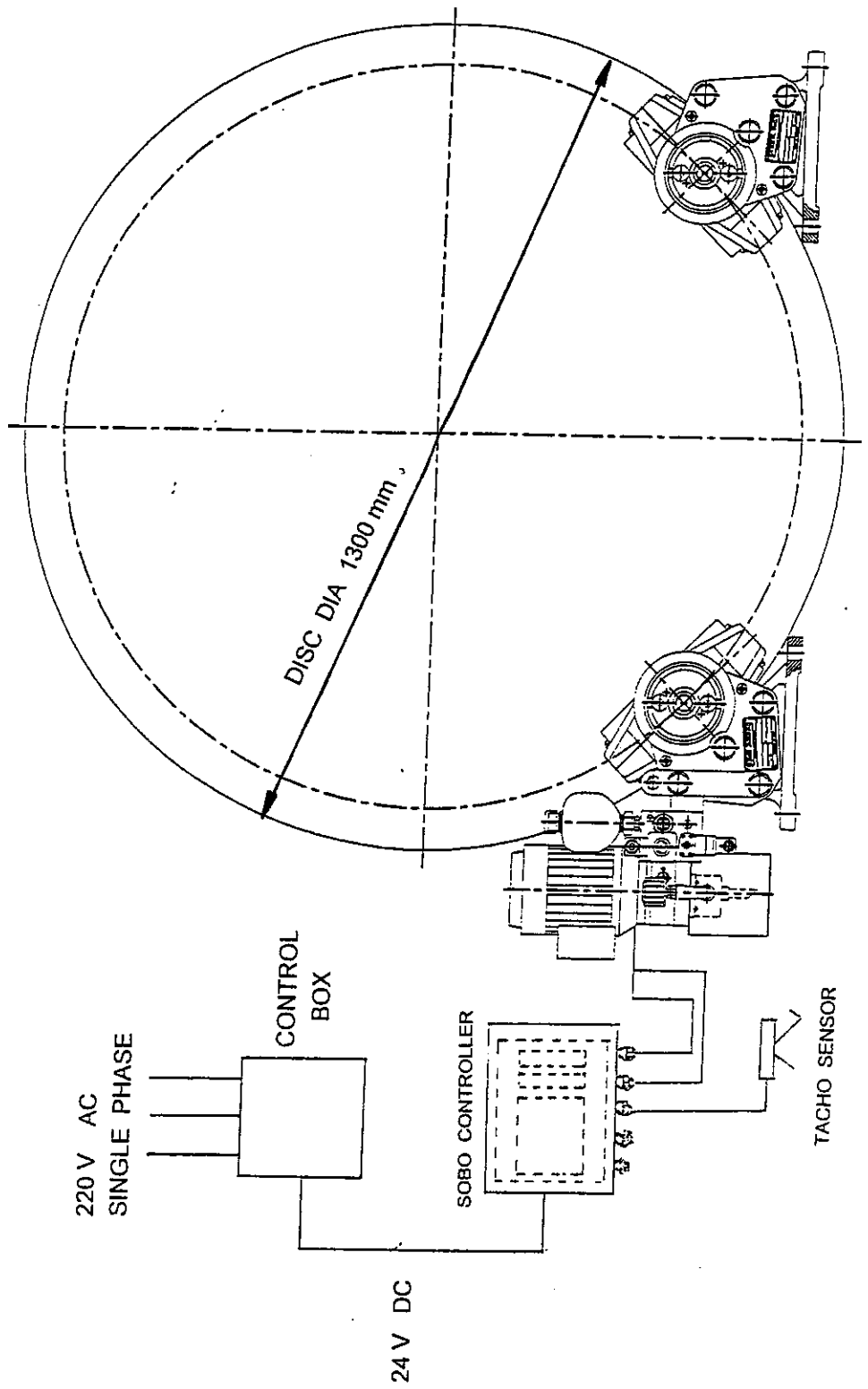


FIG. NO. 4

8. DYNAMIC SIMULATION [Refer to flow chart - Fig. No. 5]

From the static calculations, a dynamic simulation was done. It was concluded that the drives should have been at the tail and that the take-up should be as near to the head as possible lowest-tension. Static calculations $T_2 = \pm 33 \text{ kN}$, as the belt was totally oversized, the T_2 was increased to 70 kN to ensure reduced sag in the concave curve. It was also concluded that at starting fully loaded, the acceleration must not be less than 5 seconds. Therefore a Turbo Soft Start Fluid Coupling was used with an extra accumulator installed in the hydraulic brake circuit, which would feed through a non-return valve, to allow a 5 second delay in mechanical brake release, after 5 seconds after starting, under all conditions. This pressure is released to the tank when the conveyor is shut down, in order to allow delayed mechanical release again on start up.

During running, the tacho would control the brake pressure, if in the event of an overspeed the hydraulic pressure would be reduced to apply the disc brake to attempt to reduce the overspeed back to normal speed. If so - the brake will be released again. If in the event of not being corrected to normal speed after five attempts, the SOBO PLC will shut down the conveyor using soft braking. A watchdog is continuously checking the PLC, if the tacho signal is lost, then the conveyor will shut down. On stopping, the dynamic simulation showed that a very slow deceleration was required and that the stopping time independent of load should be approximately 40 seconds at full load and 12,5 seconds with an empty belt.

Calculations also showed that in a full load condition, the belt could accelerate from normal belt speed of 2,5 m/second to 5 m/second in approximately 10 seconds, whereupon major catastrophes could occur.

9. HYDRAULIC CIRCUIT [Refer to Fig. No. 6]

The hydraulic circuit is shown with :
electrical driven pump, pressure controlled

Three accumulators:

- a) enough oil for braking sequence
- b) make the controlled oil volume larger
- c) delayed brake release

Two - two-way solenoid valves.

- A) emergency brake valve
- B) brake pressure control valve

The above components providing the heart of the soft braking system.

10. EMPTY BELT [Refer to Fig. No. 7]

Site measurements were conducted - the motor current, brake pressure and belt speed were monitored.

This is an empty belt start and stop. When the motor starts up, the hydraulic pressure released over a 5 second ramp time period, and on motor shutdown the hydraulic pressure is controlled to give a very steady deceleration ramp time of 11 seconds. The empty belt does not provide enough regenerative inertia to facilitate the use of the full 40 second ramp-down time.

11. **PARTIALLY LOADED** [Refer to Fig. No. 8]

This test was done with partially loaded belt - The starting sequence was very similar to the empty belt start, we unfortunately could not test the belt under full load condition as the production of the mine was not at full capacity at that stage.

The motor is shut down, whereupon the brake monitors the speed of the belt, using the PLC to ramp the speed down, by controlling the pressure. The stopping time measured was 36,5 seconds with a very steady slow stopping ramp-down deceleration. Unfortunately the brakes are designed for full tonnage, a steady deceleration rate was not achieved, but will be easily achieved when the belt is fully loaded.

12. **CONCLUSION**

In designing a downhill conveyor it will take a lot of time to consider every aspect of loading, the drive configuration and most importantly - the brake. Always ensure a soft start and that the soft braking is sufficient. Increase the T2 take-up tension to its maximum, for an allowable T1 that the belt class can withstand with appropriate safety margins.

Ensure triple safety and pay the extra expense for a dynamic simulation.

13. **ACKNOWLEDGEMENTS**

- To Ingwe Coal and Welgedacht Mine, for their assistance and valuable information.
- To every person that helped along with the production of this paper.

14. **REFERENCES**

- [1] Dr. Jean Luc Cornet Requirements and stringent specifications for braking systems on regenerative conveyors Bulk Solid Handling Trans Tech Publication

INGWE

FLOW CHART SOFT BRAKING HYDRAULIC DISC BRAKE

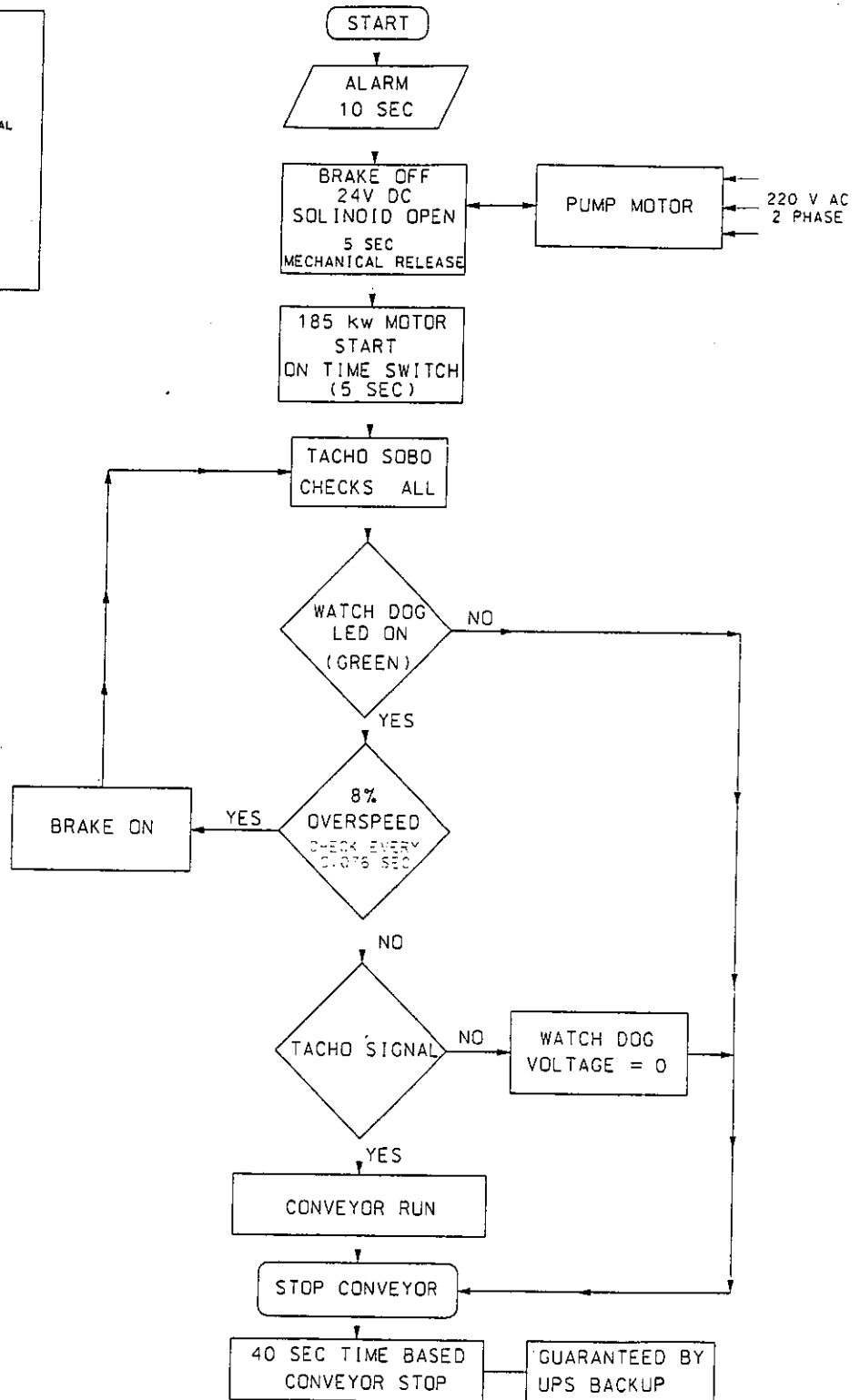
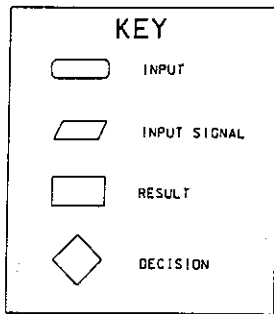


FIG. NO. 5

HYDRAULIC CIRCUIT

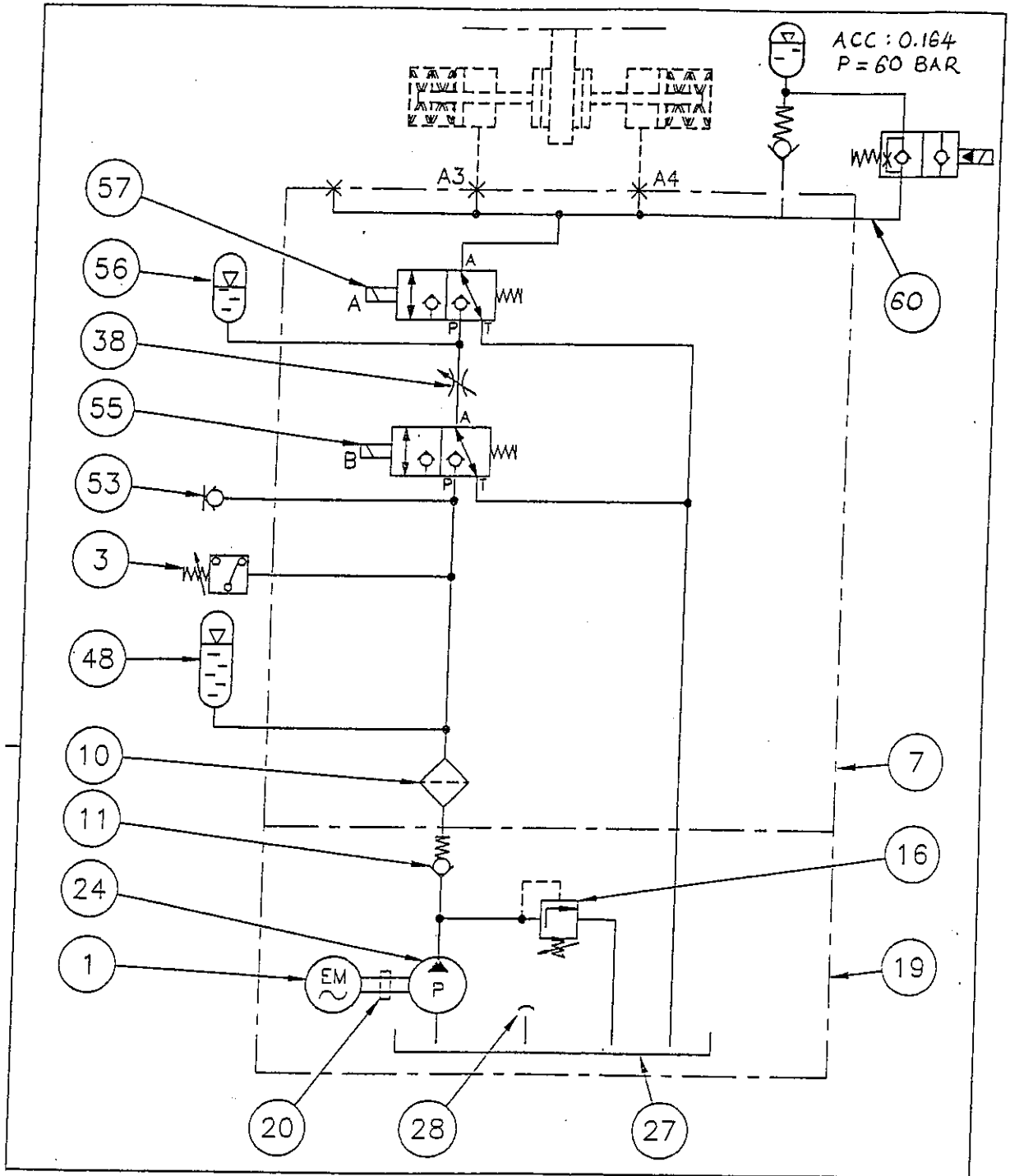


FIG. NO. 6

WELGEDACHT DOWNHILL CONVEYOR

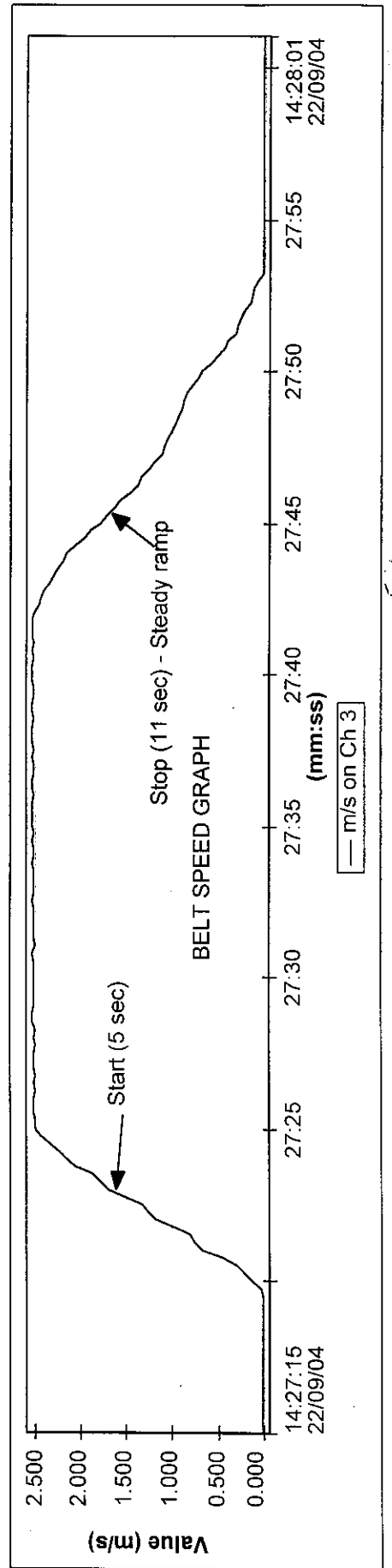
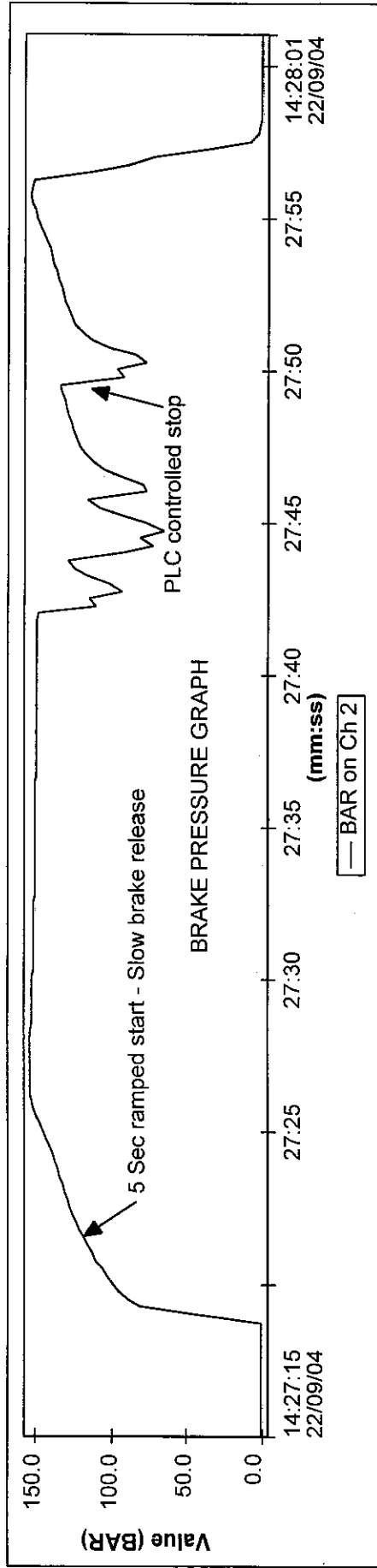
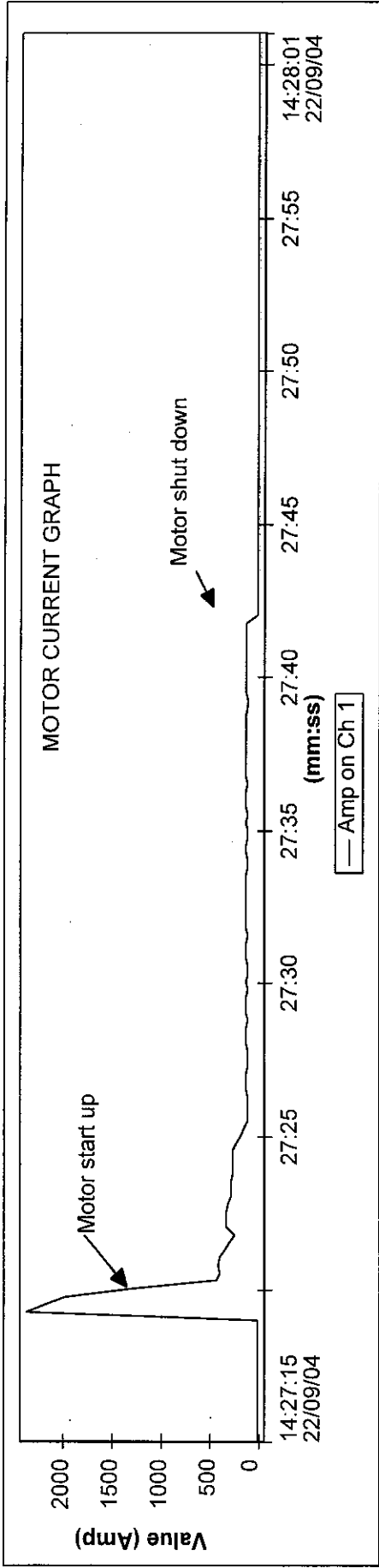


FIG 7

EMPTY START/STOP

WELGEDACHT DOWNHILL CONVIOLOR

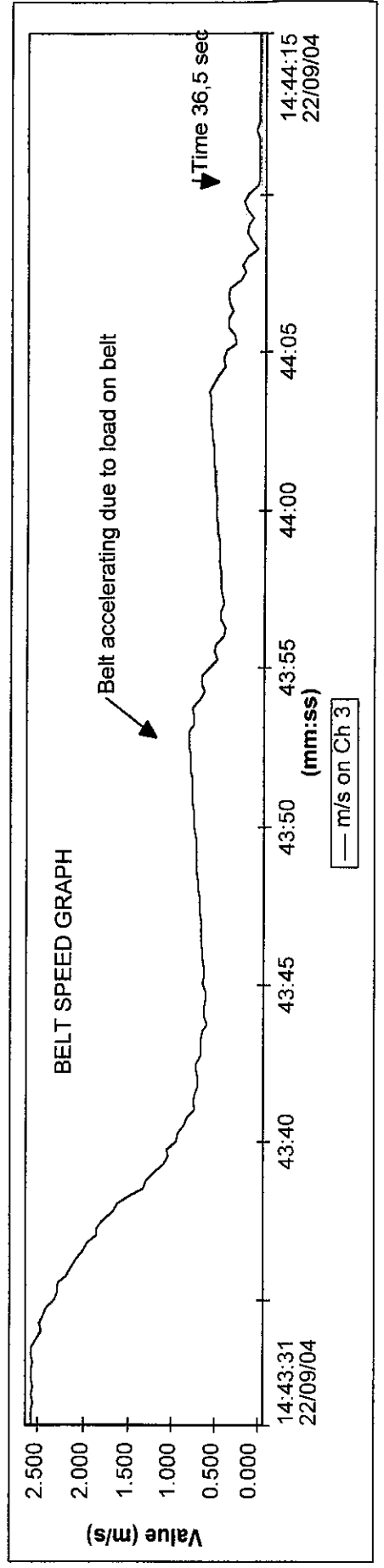
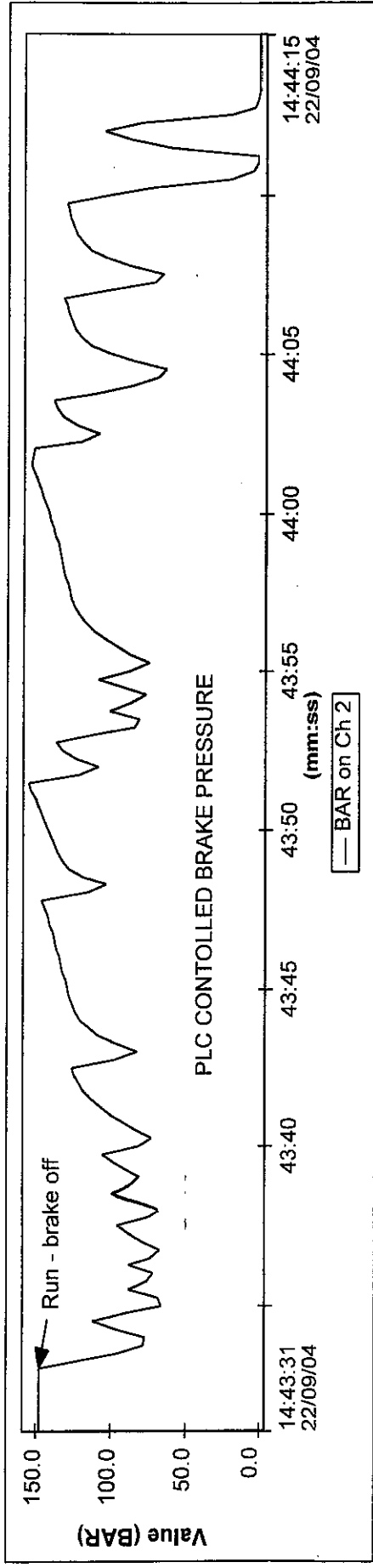
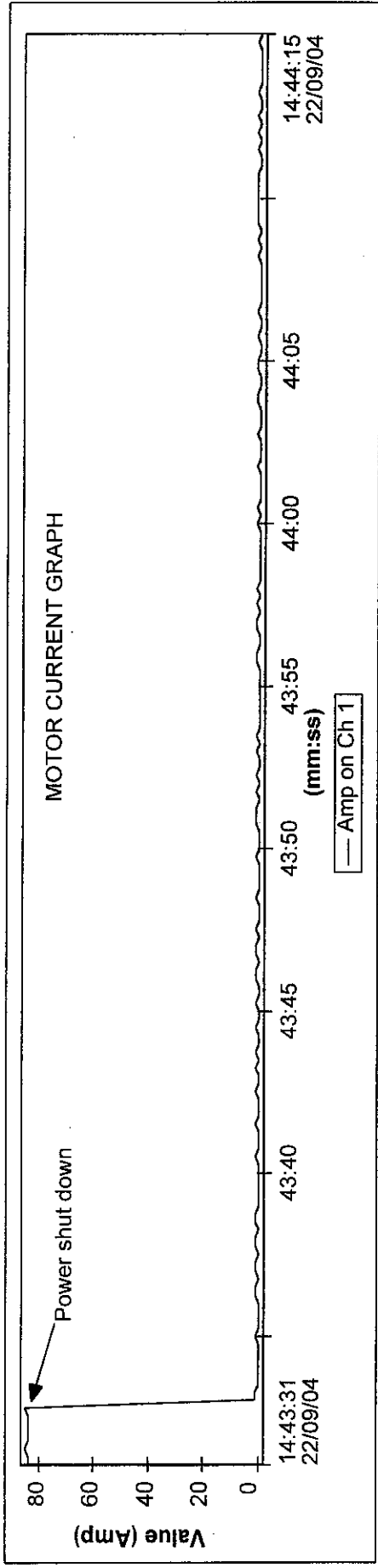


FIG 8

PARTIALLY LOADED STOP

NATAL PORTLAND CEMENT-PORT SHEPSTONE (NATAL)
 900 WIDE DOWNHILL CONVEYOR

CONVEYOR DATA

DESIGNED BY PWH WESSERHUTTE 1992
 MOTOR POWER 3x55kW(4p)
 BELT SPEED 1.8m/s
 BELT WIDTH 900mm ST1000
 FLUID COUPLINGS ORIGINALLY FITTED
 AND REMOVED
 -10° ANGLE
 MATERIAL LIMESTONE -28mm
 CAPACITY 400 tph
 LOW SPEED BRAKE 2x DISCS + 1 CALIPER
 (HAGGLAND SPRING APPLIED)
 SQUARE -D DC INJECTION INTO AC
 SQUIRREL CAGE MOTOR FOR INITIAL
 BRAKING.

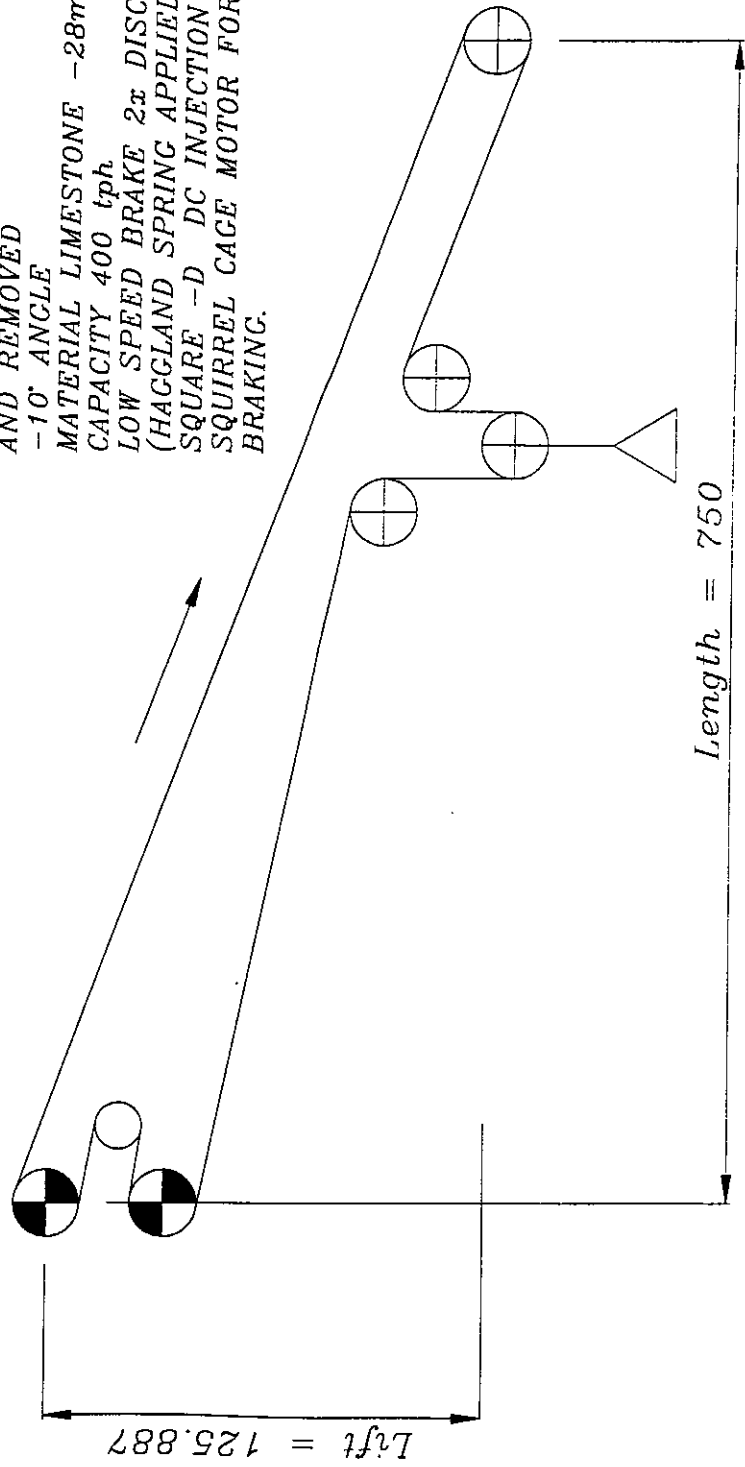


FIG. NO. 9

12. CONCLUSION

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Ensure triple safety and pay the extra expense for a dynamic simulation.

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14. REFERENCES

- [1] Dr. Jean Luc Cornet Requirements and stringent specifications for braking systems on regenerative conveyors
Bulk Solid Handling Trans Tech Publication

PARTICULARS OF AUTHOR

Full name: Graham Anthony Surtees

Position: Managing Director of Surtees Power Transmission (Pty) Ltd

Main activity of the company: Manufacture and supply of transmission products

Education: Matric, King Edwards, 1978;
Mechanical Engineering higher national diploma, Wits. Technical College, 1984.
Marketing & sales Management Diploma, Damelin, 1986.

First Job: Sales Representative, M.A.G. Brakes, 1978

First job with present company: Sales representative

Number of people under leadership: 60